BARR

Hydrogeology of Fractured Bedrock in the Vicinity of the NorthMet Project

Prepared for
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Contents

List of Tables

List of Figures

List of Large Figures

List of Appendices

1.0 Introduction

The NorthMet Project (Project) is located adjacent to the Mesabi Iron Range, which has been mined for iron since the discovery of rich deposits in 1890 (Reference (1)). The Project includes the Mine Site and the Plant Site, which includes the Tailings Basin and processing plant structures formerly operated by LTV Steel Mining Company (LTVSMC). The bedrock geology in the vicinity of the Project consists of granites and associated lithologies overlain by metamorphosed sedimentary (meta-sedimentary) rocks that host the northeast trending Biwabik Iron Formation (BIF), and the intruded igneous Duluth Complex, which is the source of the ore to be mined by the Project. This report was prepared to summarize work conducted to date that results in the current understanding of bedrock structure and hydrogeology at the Mine Site and the Plant Site and describe the regional and local bedrock geology and hydrogeology, including the nature of fractured bedrock.

Numerous bedrock geology and hydrogeology studies, ranging in scale from regional to Project-specific, have been completed in the Project area (Table 1-1). Based on these studies, the Project Supplemental Draft Environmental Impact Statement (SDEIS) (Reference (2)) describes the bedrock at the Mine Site and Plant Site as being fractured. Fractures are breaks in rocks such as faults or joints. A fault is a fracture or fracture zone along which there has been displacement parallel to the fracture (or offset) of geologic units relative to one another. Faults are variably shown on regional and local geologic maps of the Project area (Large Figure 1) and brecciated fault zones, slickensides and gouge mineralization sometimes feet thick have all been identified through core logging at NorthMet (Reference (3); Reference (4)). Faults tend to be more laterally and vertically extensive than joints and can extend to great depths. A joint, on the other hand, is a fracture or parting without displacement, which can be caused by many different types of stresses, including cooling of magma, tectonic deformation, and/or erosional loading/unloading. In crystalline rocks, joints can be abundant, particularly near the surface, although they generally are of limited extent. Where abundant, they can form a three-dimensional network of conduits in the near-surface bedrock. Deeper, more extensive joints also can occur due to regional tectonic stresses, but are typically much less common.

During the environmental review process, concerns were raised regarding the potential for impacted water to preferentially migrate through fractured bedrock and the adequacy of the hydrogeologic characterization of the fractured bedrock. The SDEIS language specifically discussing these concerns is located on SDEIS page 5-33, and is included for reference here:

> *"Concerns have been raised that fractures or faults may exist at the Mine Site that could function as high-permeability conduits for groundwater over long distances through the bedrock. Such features have been identified elsewhere on the Canadian Shield. Most of these features, however, have been associated with tectonic events occurring more than 1.6 billion years ago. These events would not be relevant to the Duluth Complex as they predate its emplacement, which occurred during the Mid-Continent Rift approximately 1.1 billion years ago. A few studies have identified the presence of fracturing and faults in the Duluth Complex, but these features were believed to have formed during emplacement of the Duluth Complex and are unlikely to transmit water and, where fractures were*

found, they were largely filled with gouge (Foose and Cooper 1979; 1981), or relate to an unusual cleavage pattern known to occur in one location west of Duluth, about 70 miles from the Mine Site (Foster and Huddelston 1986).

Although the presence of fractures at the Mine Site cannot be completely ruled out, site specific data, such as boring logs, indicate the bedrock appears competent, only rarely encountered deep fractures near the surface, and hydrogeologic investigations have indicated that the bulk hydraulic conductivity of bedrock at the Mine Site is very low."

In the bedrock units in Northeastern Minnesota, the bulk hydraulic conductivity of the bedrock reflects fracture flow. Intrusive igneous rock, for example, has little, if any, primary porosity (Reference (5)), indicating that water moves almost *entirely* through fractures and secondary porosity features. In order for groundwater flow to occur, there must be fractures, such as joints and open faults, the characteristics of which can be highly variable within the rock body. Factors associated with groundwater flow in fractured rock include effective stress and pore water pressures, fracture aperture and surface area, temperature, and fracture geometry (roughness and waviness). Fractures can also control groundwater movement by acting as barriers to flow due to the presence of clay gouge or competent igneous rock such as diabase that has been intruded along structural features. This variability in the hydrogeologic behavior of fractured rock is borne out by variable well yields experienced by thousands of domestic drinking water well owners whose water source is from bedrock units in Northeastern Minnesota (Reference (6)).

Fractures in water-bearing rocks can be the result of compression and/or tension caused by regional tectonic stresses, shrinking during cooling of igneous rock masses, pressure relief due to erosion of overburden rock (erosional 'unroofing'), and crustal loading and unloading during periods of glaciation. The fractures resulting from these "stress" events are evident in the regional and local geologic record, which has been studied extensively because of economic mineralization in the rock bodies (iron and taconite in the BIF, and copper, nickel, palladium, platinum and gold (Cu/Ni ± PGE) in the base of the Duluth Complex). Local and regional bedrock hydrogeology has been studied for various purposes including groundwater supply, potential for storage of radioactive wastes, and potential for environmental impact due to mining.

This report was prepared at the request of the Co-lead Agencies and includes four sections including this introduction: Section 2.0 presents a summary of the geologic and hydrogeologic work that has been conducted, and Section 3.0 presents the results of these investigations and a description of the bedrock geology and hydrogeology at the NorthMet Site. Section 4 presents implications for impact assessment and project planning.

Table 1-1 Local and Regional Bedrock Hydrogeologic Studies

Study Title	Author/ Commissioner	Date	Synopsis	Bedrock hydraulic conductivity estimates (in cm/s), if available
Surficial geology and ground-water geology of the Babbitt-Kawishiwi area, northeastern Minnesota, with planning implications	Stark, J.R. (Reference (7)	1977	Examined local-scale groundwater hydrogeology. Conducted 5 bedrock permeability tests in exploratory drillholes. Small data set, but transmissivity appeared to be inversely related to distance from a mapped lineament.	Duluth Complex = Range: 1.4×10^{-7} to 1.5×10^{-4}; Geometric Mean: 4.4×10^{-6}
Water Resources for the Possible Minnimax Mining Facility	AMAX/ E.A. Hickock and Associates (Reference (8))	1977	Water management information during development of a mine shaft in Duluth Complex bedrock. Annual average pumping from the shaft was 9 to 14 gpm. Individual fractures were grouted during shaft development, so this reflects pumping with engineering controls in place.	--
Hydrology and Water Quality of the Copper-Nickel Study Region, Northeastern Minnesota	Siegel, D.I., and Ericson, D.W./USGS (Reference (9)	1980	Study ran from 1974 to 1978. Tested specific capacity in 2 wells in the upper portions of the Duluth Complex, 1 well in the upper portion of the Giants Range granite, and 4 wells in the BIF (various depths). Found that water occurs in fractures that frequently occur in the upper surface of the bedrock. They estimate that groundwater inflow to open pits in the Duluth Complex would be on the order of 0.4 to 1 gpm/acre of pit. K values estimated from specific capacity data.	Upper Duluth Complex = 5.6×10^{-6}, and 9.9×10^{-7}; Upper GR granite = 9.1×10^{-6}; BIF = Range: 5.2×10^{-5} to 5.7×10^{-3}; Geometric Mean: 3.5×10^{-4}
Geology, Hydrology, and Mineral Resources of Crystalline Rock Areas of the Lake Superior Region, United States	Harrison et al., 1983 (Reference (10))	1983	Compilation of bedrock stress history, seismic potential, structural information, hydrology, and hydrogeologic properties for the Giants Range granite and the Duluth Complex. No original testing, but compilation of granite and related crystalline rock hydrogeologic properties.	Granite = 10^{-8} (mean of compiled values)

Study Title	Author/ Commissioner	Date	Synopsis	Bedrock hydraulic conductivity estimates (in cm/s), if available
Preliminary Assessment/Site Investigation: Former Finland Air Force Station, Lake County, Minnesota	U.S. Army Corps of Engineers	1999	Field investigation into frequency and occurrence of fractures in three drillholes in the granitic bedrock underlying Lookout Mountain, where contaminated groundwater was encountered. Fourteen hydrogeologic tests were performed in the bedrock.	Beaver Bay Complex = Range: 2.4×10^{-7} to 2.0×10^{-4} Geometric Mean: 6.9×10^{-6}
East Range Hydrology Project	Adams, et al./MDNR (Reference (11))	2004	Field investigation and hydrology modeling study to predict overflows from taconite mine pits. Describes dominance of groundwater flow in surficial deposits over bedrock inflows. Provides estimates of groundwater inflow into open pits.	--
Hydrogeologic Investigation - Phase I, PolyMet NorthMet Mine Site, RS-02 Draft-02	Barr/ PolyMet (Reference (12))	2006	Ten hydrogeologic tests were performed in exploratory drillholes in the Duluth Complex at the Mine Site.	Duluth Complex = Range: 9.2×10^{-8} to 1.4×10^{-5}; Geometric Mean: 8.0×10^{-7}
Hydrogeologic Investigation- Phase II, PolyMet NorthMet Mine Site, RS-10 Draft-02	Barr/ PolyMet (Reference (13))	2006	Hydrogeologic characterization of the Virginia Formation. Installation of 4 pumping wells and 6 observation wells. Three 36-hour pumping tests and one 96-hour pumping test were performed.	Virginia Formation = Range: 8.5×10^{-7} to 2.4×10^{-4}; Geometric Mean: 6.0×10^{-5}
Phase III Hydrogeologic Investigation, RS10A Draft-01	Barr/ PolyMet (Reference (14))	2007	One 30-day pumping test was performed in the Virginia Formation to characterize response in wetland. In addition, two specific capacity tests were conducted in the upper portion of the Virginia Formation.	Upper Virginia Formation = 2.2×10^{-4} and 2.5×10^{-4}
Geotechnical Investigation - Tailings Basin	Barr/ PolyMet (Appendix A)	2014	Investigation along potential alignment of FTB Containment System. Ten permeability tests in upper portion of Giants Range granite.	Upper GR granite = Range: ~0 to 7.2×10^{-4}; Geometric Mean: 1.9×10^{-5}

2.0 Summary of Geologic and Hydrogeologic Work

2.1 Geologic Information

The geologic history of the rocks at the Mine Site and Plant Site forms the basis of our understanding of where and how fractures may be present. The rocks have various depositional or igneous intrusive histories, and have undergone variable tectonic (or "stress") histories, which lead to the formation of fractures of various orientation or scales. The regional and local geology are well known, due to extensive exploration and mapping of iron ore and Cu/Ni ±PGE mineralization (see summary in Reference (15)). In addition, the Archean granite and Duluth Complex were studied for their potential to host a repository for high-level radioactive waste (Reference (10)). The Archean granitic rocks are frequently investigated to determine the chronology of Archean terrane accretion (Reference (16); Reference (17); Reference (18)). The following provides a summary of the geologic and mineral exploration work.

Early exploration of the BIF dates back to the mid-1800s, when iron ore was actively being mined on the Vermilion Range, located north of the Mesabi Iron Range. Discovery of rich iron ore in Mountain Iron heralded the extensive natural ore (leached and oxidized taconite) and taconite mining on the Mesabi Iron Range that continues today. Scores of mine company and university research geologists have studied the geology, mineralogy, deformation, rock mechanics, and thermal metamorphism of the taconite on the Mesabi Iron Range (see Reference (19)) for a summary and references specifically for the eastern Mesabi Iron Range).

Initial geologic mapping of the adjacent Duluth Complex (Complex) took place from 1852 through 1911. These initial surveys were completed by state and federal agencies that identified general rock types and their extent. From 1911 through 1961 more extensive field mapping of the region was conducted by F. F. Grout and G. M. Schwartz. Grout was also the first individual to conduct an aeromagnetic survey of the Complex which led to identifying the sulfide and oxide minerals in the southern and central portions of the intrusive body (Reference (20)). United States Steel Corporation (USS) was the first entity to conduct extensive exploratory drilling of the Complex in 1970, and copper and nickel ore was identified at the base of the Duluth Complex. This area was initially called the Dunka Road deposit, but is now referred to as NorthMet. USS drilled 112 holes comprising 133,716 feet of intercept over a five-year period (Reference (21)). Amid interest in mining the Cu/Ni ± PGE deposits, Cooper (Reference (22)) and Foose and Cooper (Reference (23)) mapped potential structural features within the Duluth Complex to determine whether those features control mineralization. They delineated the presence of joints and faults in the Duluth Complex by mapping aeromagnetic anomalies, joint density data gathered from outcrops in the surrounding region (Reference (24)), topographic lineations, and truncations of mineralogic horizons within the intrusive rocks.

From 1961-1982, more detailed quadrangle mapping by the Minnesota Geological Survey (MGS) was completed. The Natural Resources Research Institute (NRRI) re-logged the USS drill holes and correlated stratigraphic units between drill holes to create a geologic map of the igneous structure of the Complex from 1988 to 1991. In 1995, when there was more interest in mining the deposits, NRRI staff returned to the NorthMet deposit and spent two months mapping outcrops, examining drillcore, and mapping the basal contact and igneous stratigraphy (Reference (3)).

The focus of mapping in the area since the time of the MGS quadrangle maps has been on using higher resolution and more extensive aeromagnetic surveys (0.25-mile flight lines flown 1979-1982). The aeromagnetic data, combined with available outcrop and drillhole data at the time, was used to produce the first maps that focused on the structural features that might host mineralization within the Duluth Complex. The aeromagnetic data led to additional shallow drilling in the central Complex from 1989 to 1991. These drillhole data, combined with the aeromagnetic data, were used to produce the MGS map of the Duluth Complex (M-119; Reference (15)). Extensive exploratory drilling at the NorthMet deposit has since been performed by Poly Met Mining, Inc. (PolyMet) (formerly Fleck Resources), and has increased the understanding of Duluth Complex stratigraphy (Reference (25); Reference (26)). Specifically, for the Duluth Complex in this area, there are over 1,100 drillholes and nearly 1,000,000 feet of core have been logged or re-logged in the past 15 years by a small group of company and university research geologists (Reference (27), and references therein).

2.2 Hydrogeologic Information

2.2.1 Information from Groundwater Use and Management

Bedrock in the shallow subsurface (where surficial deposits are limited in thickness) is used regionally as a source for domestic drinking water supplies. Water well records, including driller's logs and variable amounts of well-yield data, are available from the Minnesota Department of Health County Well Index (CWI). The U.S. Geological Survey (USGS), in response to anticipated population growth on the Iron Range, specifically studied the hydrogeology and water resource potential of the surficial deposits and bedrock of the eastern Mesabi Iron Range in the 1960s (Reference (28); Reference (29)).

Management of groundwater that flows into mine pits and underground mine structures in the region has occurred for over a century, and some projects have accessible records documenting the nature of groundwater encountered (including notes on fracture flow, quantity, and quality). Many iron ore reserves were mined out through underground mining (i.e., Soudan Underground Mine). In the 1970s, amid interest in mining the Cu/Ni ± PGE deposits located along the Duluth Complex, a 14-foot diameter exploration shaft was sunk to 1,728 feet in Duluth Complex rock; an additional 3,760 feet of drift were developed at the 1,700-foot level (the AMAX or MinnAMAX Project; Reference (30)).

2.2.2 Hydrogeologic Studies

In the 1970s, the State of Minnesota commissioned a multi-disciplinary study (Copper-Nickel Study), aimed at understanding the potential environmental impacts of mining the copper-nickel deposits. The Copper-Nickel Study work related to hydrogeology was described by Siegel and Ericson (Reference (9)), who conducted specific capacity testing in surficial deposits, the BIF, the Giants Range granite, and the Duluth Complex. During this period, bedrock permeability data related to potential Duluth Complex copper-nickel prospects were also collected by J.R. Stark (Reference (7)). His thesis work included conducting aquifer tests in exploration drillholes within the Duluth Complex and conducting permeability tests on overlying surficial materials; he specifically estimated potential groundwater flow into hypothetical open-pit Cu/Ni ± PGE mines.

The late 1970s and early 1980s also marked a period of increased hydrogeological work in the region at the federal level. The USGS series of hydrologic atlases for the Rainy Lake and St. Louis River watersheds were published in 1976 and 1979, respectively. Well yields and water quality data from bedrock units used for industrial, municipal (including the BIF at Aurora, Biwabik, Hibbing, McKinley, Mountain Iron and Virginia, and the Virginia Formation at Iron Junction) and domestic supply were summarized (Reference (31)). The Department of Energy (DOE), recognizing the very low permeability of the crystalline rocks in the Lake Superior region (Archean granite and Duluth Complex gabbro,) assessed their potential to host a repository for high-level radioactive waste (Reference (10)). The DOE compendium of information includes extensive discussion of regional tectonic history and stress regimes, and the regional occurrence and density of joints and faults in the bedrock. In addition, the hydrogeology of the crystalline rock units (Archean granite and Duluth Complex) is extensively covered as part of that assessment.

The US Army Corp of Engineers (USACE) investigated the hydrogeology of fractured granitic Beaver Bay Complex rock (which is genetically related to the Duluth Complex) as part of site assessment at the Former Finland Air Force Station in Finland, Minnesota in the late 1990s (Reference (32)). The study was initiated after chlorinated solvents were discovered in a newly- installed community water supply well.

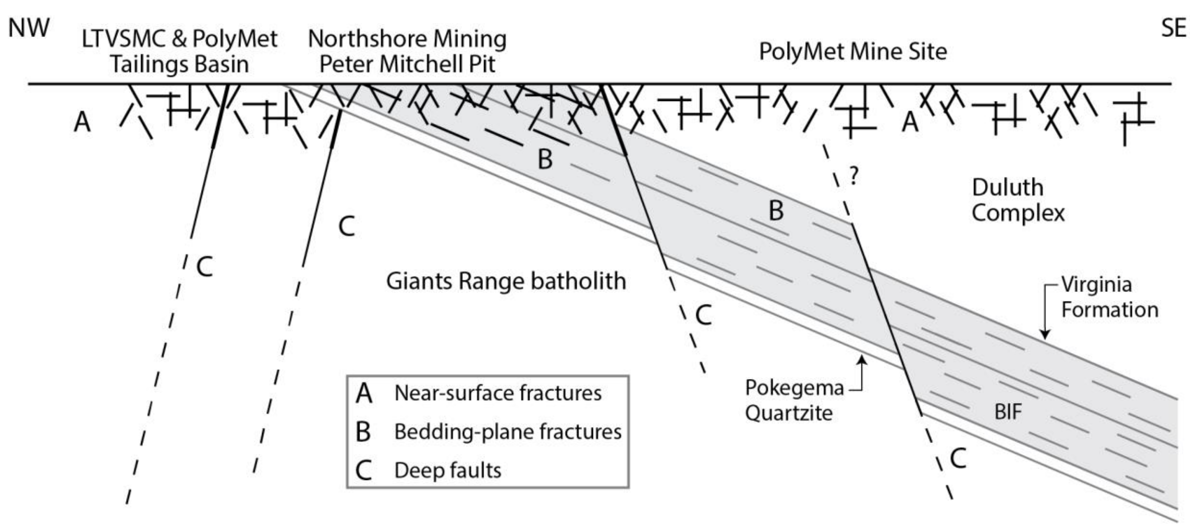
The Minnesota Department of Natural Resources studied the hydrology of the eastern Mesabi Range during the early 2000s after mining was discontinued in several taconite pits (Reference (11)). They calculated water balances for several mine pits, including groundwater contribution, in order to estimate eventual pit outfall quantities and locations.

Engineering plans and environmental permitting requirements resulted in additional hydrogeologic and geotechnical investigation at NorthMet in the early 2000s (Reference (12); Reference (13); Reference (14)). This work included studies specifically aimed at understanding the bulk hydrogeologic characteristics of the Duluth Complex and the Virginia Formation, and the connection between surface water/shallow groundwater and deeper groundwater at the Mine Site. Rock quality designation (RQD) was determined for the Duluth Complex, Virginia Formation, and BIF using tens of thousands of feet of exploratory drillcore to determine if there is a structural control on ore grade (Reference (27)). RQD is a measure of the amount of breaks (fractures) in rock drillcore, where 100% indicates no breaks and 0% indicates that all pieces of core within a core run are less than 10 cm long. In 2014, testing of individual locations within the uppermost Giant’s Range Granite underlying the Plant Site was carried out to support design of the proposed FTB Containment System.

3.0 Bedrock Geology and Hydrogeology Description

The rock record in the vicinity of the Project reflects several events that have resulted in structural features that affect the permeability of the rock units. Figure 3-1 conceptually illustrates these structural features.

- The most recent event (and likely the most important with respect to the water-bearing characteristics of the rock) was glacial loading and unloading during the Pleistocene (past 2.5 million years). The fractures and joints that were activated during that time are likely near the surface, and include reactivation of existing planes of weakness (affecting the upper portions of "deep faults"). These features are referred to as "near-surface fractures".
- Bedding plane fractures and variably-oriented faults within meta-sedimentary footwall rocks (Pokegama Quartzite, BIF, and Virginia Formation) all act to enhance the permeability of those units relative to both the underlying granitic rocks and the overlying Duluth Complex.
- Structures related to Archean deformation are found in the Giants Range granite. Younger structural features related to crustal shortening during the Penokean Orogeny or to extension during the Keweenawan rifting are also prevalent in the Animikean footwall rocks, and may include reactivation of Archean faults in the granitic rocks. Because major fault zones cannot be correlated within the igneous stratigraphy of the Duluth Complex, many of the deep faults within the granitic terrane and footwall rocks likely do not extend into the intrusive rock (Reference (4)).



(Approximate locations of mine features are located with respect to the geologic section. Not to scale.)

Figure 3-1 Conceptual Illustration of Structural Features that Affect the Hydraulic Conductivity of Rock Units at NorthMet

At NorthMet, the meta-sedimentary footwall rocks can be conceptualized as a tilted package of more transmissive bedrock units sandwiched between two massive and less transmissive igneous units, the Giants Range granite below, and the Duluth Complex gabbro above. At the surface, however, all bedrock units are affected by fracturing (i.e., near-surface fractures). The following sections describe the geology (Section 3.1) and bedrock hydrogeology (Section 3.2) that form the basis of this conceptual model.

3.1 Geologic History

This section summarizes the geologic history of the region as a framework for understanding the occurrence and types of secondary permeability features. A summary of the geologic events responsible for (1) assemblage of the rock (stratigraphic) record and (2) development of key structural features in the rock record is presented (Figure 3-2).

The rock record at the Project site reflects three large-scale tectonic events: (1) Collisional tectonics during the Neoarchean, approximately 2690-2670 Ma (million years ago), and emplacement of intrusive rocks; (2) Paleoproterozoic (1880-1860 Ma) arc accretion, back-arc spreading and sedimentation, followed by continent-continent collision, crustal shortening, and additional sedimentation during the Penokean orogeny (1840-1770 Ma); and, most recently, (3) Mesoproterozoic (1110-1050 Ma) crustal extension, voluminous volcanism and emplacement of intrusive rocks (Duluth Complex), and sedimentation (Keweenawan rifting and development of the Midcontinent Rift System). The Archean rocks created through collisional tectonics in the Neoarchean underlie the Plant site. At the Mine Site, the Precambrian rocks that were deposited or emplaced on the Archean terrane dip to the south-southeast at 10 to 30° (Figure 3-3). Walking a transect from north to south at the Mine Site is thus equivalent to moving 'up-section' into progressively younger (Precambrian) rocks. A widespread veneer of late-Pleistocene glaciogenic sediments ('drift') covers the bedrock, limiting bedrock exposure and making geologic mapping strongly dependent on geophysical techniques and inference (e.g., in general, faults mapped within the area are inferred from lineaments, such as elongated wetland areas, and have not been independently confirmed by observation of displaced geologic units either at the surface or in drill core).

3.1.1 Neoarchean (2690-2670 Ma)

The rocks of the Neoarchean Giants Range Granitic Complex (informally termed the Giants Range batholith) were emplaced within older crust, including the Archean schists located near the Plant Site (Large Figure 1; Reference (18)), which, together with a complex collection of lithospheric plates and accreted terranes, form the core of the North American craton. These rocks are referred to collectively as the Canadian Shield. Three phases of compression (crustal shortening) affected the region during the Neoarchean Minnesotan orogeny (~2680 Ma) and produced local structural features including regional deformation that resulted in folding of the Soudan Iron Formation, and northwest- to northeast-striking faults and associated compressional structures (Reference (33); Reference (18); and Reference (34)). These compressional events gave rise to many of the deep-seated faults that are mapped within the Giants Range batholith, such as the Camp Rivard, Waasa, Vermilion, and Wolf Lake faults.

3.1.2 Paleoproterozoic (1880-1860 Ma)

Unconformably overlying the Giants Range Granitic Complex is the Animikie Group (Figure 3-3), which, in ascending order, consists of the Pokegema Quartzite, BIF, and the Virginia Formation. Strata of the group have a combined representative thickness of over 1000 feet. The Pokegema Quartzite is relatively thin to absent in the area, and consists of a coarsening-upward collection of argillite, siltstone, and sandstone deposited in a shallow-marine setting with significant tidal influence (e.g., Reference (35)). The BIF conformably overlies the Pokegema Quartzite and is a ferrigenous chemical sedimentary rock unit with an average thickness of about 700 feet. The strata of the BIF are dominated by two facies, the 'cherty' and 'slaty' facies (Reference (36)). Mineralogically, both facies consist of chert and iron oxides, iron silicates, and iron carbonates. Overlying the BIF is the clastic sedimentary Virginia Formation (informally termed the Virginia Slate), which is a succession of turbiditic shale (argillite), siltstone, and sandstone (greywacke) deposited in a deep-water setting. Collectively, at the NorthMet site, the rocks of the Animikie Group are termed the 'footwall rocks' although only the Virginia Formation will actually be encountered in the footwall of the NorthMet mine pits (Figure 3-3).

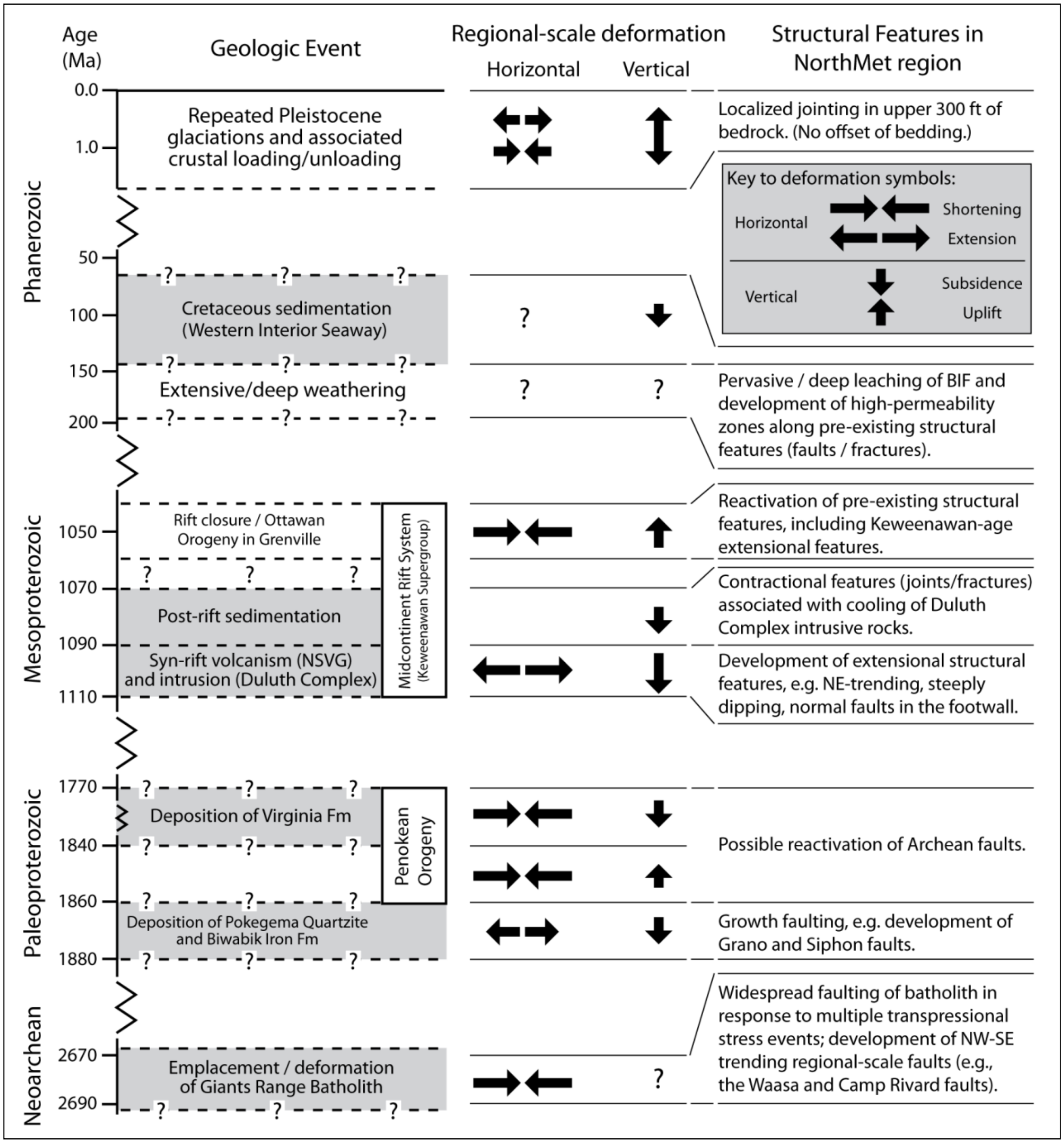
Recent work by Schulz and Cannon (Reference (37)) and Cannon et al. (Reference (38)) provides a clear interpretation of the complex tectono-stratigraphic evolution of the Animikie Basin (the basin in which Animikie Group rocks were deposited) in the context of Paleoproterzoic development of the southern margin of the North American craton. The turbiditic sediments of the Virginia Formation accumulated in the Animike basin between about 1850 and 1780 Ma. The Virginia Formation and the underlying BIF and Pokegema Quartzite (and their regional correlative equivalents) were subsequently deformed by compressive stresses of the Penokean Orogeny which occurred to the south and east of the Project area during the late Paleoproterozoic. The degree of Penokean deformation decreases northward with distance from the fold-and-thrust belt: deformation is greatest in the Gogebic iron range of northern Michigan and significantly less on the Mesabi iron range. Crustal shortening during the Penokean orogeny was accommodated in part by reactivation of older (Archean) faults.

There are two major north–south trending fault zones located to the west and east of the Project which may have formed during Animike Basin development. They are the Siphon Fault and the Grano Fault respectively (Large Figure 1; Reference (15)). The faults are interpreted to be growth faults (and are thus Animikean in age) because of changes in thickness of the Animike sediments across the faults. The Duluth Complex igneous stratigraphy may also be offset on these faults due to later re-activation; however, the faults do not directly intersect the Duluth Complex at the NorthMet deposit. The Grano Fault is located to the east of the Project area. The Siphon Fault is located approximately halfway between the Mine Site and the Plant Site, and underlies the former Spring Mine (AKA Silverton or Siphon Mine; now Spring Mine Lake). The Siphon Fault is offset 100 to 230 feet and is hypothesized to be a growth fault due to the thickness change of the Iron Formation across the structure (Reference (39)). There is some indication of sulfide mineralization within the Duluth Complex underlying and along the trend of the Siphon Fault.

3.1.3 Mesoproterozoic (1110-1050 Ma)

The Paleoproterozoic Penokean orogeny was followed by over 700 million years of relative tectonic quiescence, which ended with a continental-scale Mesoproterozoic rifting event and the development of the Midcontinent Rift System (MRS). Between approximately 1110 and 1040 Ma (Reference (40); Reference (41); Reference (42)), lithospheric extension, thinning and crustal subsidence was accompanied by the eruption of plateau lavas and the emplacement of immense volumes of intrusive igneous rocks. As active rifting waned, continued thermal subsidence led to the deposition of a thick package of clastic sedimentary rocks. Collectively, the volcanic/plutonic and sedimentary rock assemblage is termed the

Keweenawan Supergroup. Cannon (Reference (43)) attributed failure of the MRS to collisional tectonics in the Grenville Orogeny and associated northwest-directed compression.



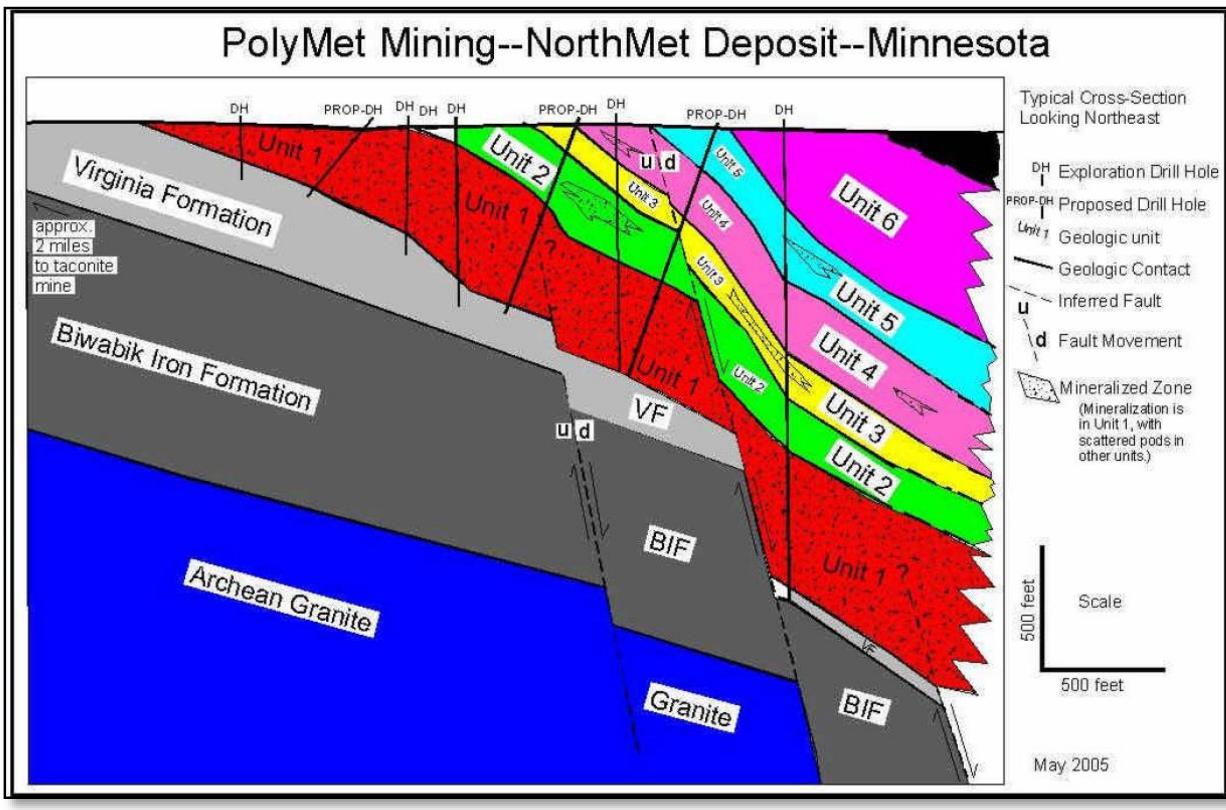
Origin of the rock units are shaded gray. Timing of events is approximate and based on compilations of ages in the literature. Timescale is non-linear. Refer to text for details.

Figure 3-2 Timeline of Geologic Events, Local and Regional Stress History, and Resultant Structural Features Evident in the Vicinity of the Project

During rifting, magmas of the Duluth Complex and the Beaver Bay Complex were emplaced at several kilometers depth between overlying Keweenawan volcanics of the North Shore Volcanic Group and

Paleoproterozoic Animikie Group sedimentary rocks (Large Figure 1). Subsequent uplift and erosion have removed the overlying Keweenawan volcanic rocks, leaving Duluth Complex rocks in subcrop.

The Duluth Complex is a mafic layered igneous intrusion with a bulk gabbroic composition. It is one of the largest such intrusions on earth, with a maximum thickness exceeding 15 km. In detail, the Duluth Complex consists of numerous intrusive bodies with a complicated history of emplacement; of these, the Partridge River Intrusion and South Kawishiwi Intrusion are located along the western edge of the complex in close proximity to the Project site (Reference (15)). The NorthMet deposit is located at the base of the Partridge River Intrusion at its contact with the underlying Virginia formation, which is present in subcrop along the northwest edge of the Project mine pits. The Partridge River Intrusion has been subdivided into eight different igneous units based on its internal igneous stratigraphy (several of which are shown on Figure 3-3).



Note: Not shown at the base of the BIF is the relatively thin Pokegema Quartzite.)

Figure 3-3 Cross-Section Depicting the Stratigraphy of the Partridge River Intrusion and Footwall Rocks at the Site

The nature and extent of faulting during emplacement of the Duluth Complex has been the topic of considerable discussion and debate (e.g., Reference (44); Reference (45); Reference (46)). The extensional stress field generated during the rifting phase of Midcontinent Rift System (MRS) evolution would favor the development of northeast-trending, southeast-dipping normal faults (Reference (44)); northwest-directed compressional stresses during rift failure could generate northeast-trending reverse faults and/or reactive former normal faults. These faults would be most apparent in the footwall rocks. Significant crustal extension during volcanism was accommodated on the Keweenaw Fault located along the south limb of the MRS; during rift failure, this normal fault was reactivated as a reverse fault and accommodated significant crustal shortening (e.g., Reference (47)). In contrast, on the north limb of the MRS in northeastern Minnesota, evidence of similar large-scale faulting is largely absent (Reference (46)), and the mechanisms for accommodating strain during MRS evolution are uncertain.

At NorthMet, the extent of faulting in both the Paleoproterzoic footwall rocks and the Duluth Complex itself is poorly constrained. At the former LTVSMC property, where the BIF is exposed at the surface, numerous faults—with highly variable orientations—have been mapped. Examples of these are the Donora Fault, the Fowler Fault, the Mesabi Lake Fault (Large Figure 1), and the Boundary Fault at the Dunka Mine. The extent to which these faults are Animikean in age, similar to the Siphon structure and the Virginia Horn, or reflect later motion during MRS development is unclear (e.g., Reference (46)). The structures pervasive in the BIF are interpreted by Holst et al. (Reference (46)) to be a result of essentially brittle or semi-brittle deformation of indurated sediments that overlie a strong base (the Giant's Range batholith) and became fractured and warped in response to fairly low stresses.

The extensive faulting mapped in the BIF in mine pits in the area suggests that the footwall rocks (at least the BIF) below the Duluth Complex may be extensively faulted. However, significant displacement of geologic units within the Duluth Complex itself is rare and individual faults and/or fault zones cannot be correlated from drillhole to drillhole despite extensive exploration (Reference (4)). Due to its immense volume, the Duluth Complex is thought to have had a long cooling history, which may have kept the intrusive body relatively ductile, thus limiting the development of large-scale faults within it (Reference (46)), even as footwall rocks became faulted. Some evidence of normal-faulting of footwall rocks during rifting is provided by drillhole data: Severson and Zanko (Reference (3)) described two parallel N 60^{o} E trending faults identified by offset of the top of the BIF in the footwall (Figure 3-3). They also identified northwest trending faults by changes in the top of the BIF as well as changes in the thickness (76 to 623 feet) in one of the units of the Partridge River intrusion. The potential extension of footwall faults into the overlying Duluth Complex (Reference (3)) suggests a complicated history of movement and reactivation along the faults during emplacement of the Duluth Complex. However, the faults have not been positively identified in drillcore that correspond with the stratigraphic displacement.

In addition to footwall fault development, Duluth Complex emplacement may have resulted in local incipient displacement within the intrusive body as it cooled and contracted. These contraction joints are not marked by significant offsets in geologic units, and cannot be correlated between drill cores at NorthMet (Reference (4)). Cooper (Reference (22)) and Foose and Cooper (Reference (23)) described extensive NE and NW trending faulting and fracturing in the Duluth Complex. However, they inferred the presence of faults via truncations of plagioclase-rich anorthositic horizons in the Duluth Complex. This technique is problematic because plagioclase-rich blocks are commonly determined to be inclusions of older anorthositic series rocks that formed at the top of the magma and then sank into the magma chamber before the rest of the magma fully solidified (Reference (20); Reference (21)). In addition, topographic linear features can also be attributed to glacial scour, rather that the presence of underlying bedrock structure.

3.1.4 Phanerozoic (540 Ma to Present)

The Phanerozoic is characterized by three geologic events that influence the hydrogeologic characteristics of the bedrock at NorthMet site (Figure 3-2). The first of these events is the widespread leaching of silica from iron formation and genesis of 'soft' (AKA 'natural') ores within the Animikie Basin iron formations. The volume loss associated with silica leaching generated fractures; some of these fractures (and possibly older fractures and faults) appear to have become permeable conduits for flow during the leaching process. In places, leaching and soft ore formation extended to great depth (in excess of 4,500 feet below current land surface). While the causal mechanism for (and age of) the leaching process remains somewhat equivocal, a general consensus supports the idea of a long-lived, deep, and widespread weathering event. Erosional unloading ('unroofing') and/or crustal uplift during this weathering event may have affected the stress field in the upper crust. Within the footwall rocks at NorthMet, and locally in outcrop within the neighboring Peter Mitchell Pit, no evidence for the presence of leached BIF or natural ore has been encountered, perhaps due to the presence of the adjacent Duluth Complex (Reference (48)). This relationship suggests that leaching post-dates emplacement of the Duluth Complex.

The second geologic event of the Phanerozoic is crustal subsidence and associated sedimentation during the Cretaceous. Phanerozoic rocks are absent at the NorthMet site. However, crustal subsidence associated with this event may have affected reactivated deep-seated faults in the region.

The third and final geologic event is Pleistocene (2.5 Ma to recent) glaciation. A veneer of late-Wisconsinan glaciogenic sediments associated with the last advance of the Rainy Lobe of the Laurentide Ice Sheet covers the entire region. At the NorthMet Mine site, the unconsolidated sediments range in thickness from zero (absent) to 60 feet, with an average value of about 15 feet (Reference (49)).

While Pleistocene-age deposits form a volumetrically insignificant component of the stratigraphic record in the vicinity of the Project, repeated glaciations throughout the Pleistocene likely played a significant role in the development and/or reactivation of near-surface bedrock structures (fractures/ faults). Repeated loading and unloading of the lithosphere—and its associated isostatic adjustment—during ice-sheet growth/advance and collapse/retreat, respectively, affected the stress field in the upper crust. The result of glacial loading/unloading may have enhanced the permeability of the upper portions of bedrock by repeated reactivation of fractures (Reference (50)).

3.1.5 Summary

In summary, the geologic record indicates that fracturing in bedrock can be generally classified into three major groups (Figure 3-1):

- *Near-surface fractures*: These are pressure-release joints that formed due to glacial loading/unloading. They are the most likely to form interconnected networks of fractures capable of transmitting water, and likely affect only the upper portions of the bedrock.
- *Bedding plane fractures and variably-oriented faults affecting the meta-sedimentary bedrock units*: These structures act to enhance the permeability of those units relative to both the underlying granitic Giants Range rocks and the overlying Duluth Complex.

- *Deep-seated faults*: These are mappable structures generally related to tectonic events. Archean structures are found in the Giants Range granite, while younger structural features related to tectonic events are also prevalent in the Animikean footwall rocks. Deep faults within the granitic terrane and footwall rocks may not extend into the Duluth Complex. However, exploratory drilling has intersected apparent fault zones in the Duluth Complex, and although they cannot be correlated from drillhole to drillhole, these suggest at least the local presence of what may be deep-seated faults.

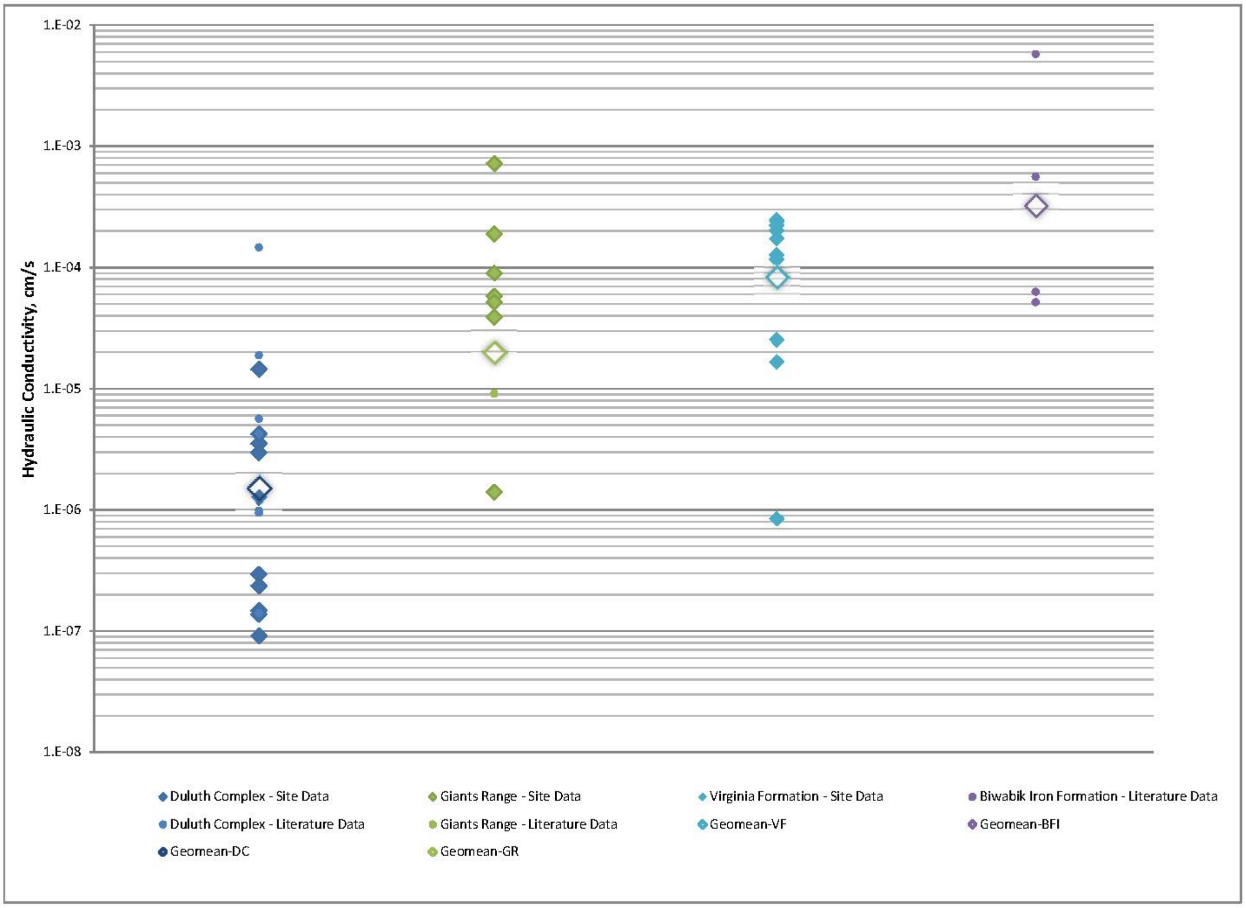
3.2 Bedrock Hydrogeology

Site-specific and regional data indicate that the hydraulic conductivity of bedrock in the NorthMet area is generally low. Given the age of the bedrock units and their long histories of deformation and (low-grade) metamorphism (as discussed in Section 3.1), it is likely that most of the primary permeability of these rocks has been overprinted through geologic time. Today, the hydrogeologic characteristics of the bedrock reflect the structural features of the rock, i.e., the secondary permeability associated with joints, fractures, and faults (Figure 3-1).

The low hydraulic conductivity of the crystalline rock units in the region was recognized by the USGS during siting of a geologic repository for long-term storage of high-level radioactive waste (Reference (7)). Hydraulic conductivity generally decreases with depth in bedrock. Literature values describing the depth of pressure-release fractures resulting from crustal loading and unloading during glaciation suggest that enhanced permeability due to these features is limited to the upper approximately 300 feet of rock (Reference (9); Reference (10)). These fractures have little to no offset of geologic units, but indicate that the lower portions of the affected rock masses will be less permeable than the upper portions (Reference (9)). The frequency of occurrence, aperture width, and effective connectivity of these features appears to diminish rapidly with depth as a result of the increased confining pressure from overlying rocks; as such, pressure-release fractures appear to have little effect on groundwater conditions at depths greater than 500 to 650 feet (Reference (10)). Anecdotally, the enhanced permeability of the upper portions of the bedrock is the basis for regional well drillers' expectation that domestic supplies of water in crystalline rocks will only be encountered in the upper 300 feet of rock drilling.

Fractures in crystalline bedrock in northeastern Minnesota were specifically identified and characterized in three drillholes in the granitic rocks near Finland, MN (Reference (32)). The bedrock in this area is granite of the Finland granophyre of the Beaver Bay Complex. The Finland granophyre represents an intrusive granitic complex that perhaps pre-dated the intrusion of the more mafic gabbros and associated rocks that underlie it stratigraphically (Reference (51)). The granophyre is analogous to crystalline rocks at NorthMet: compositionally, it is similar to the Giants Range granite; structurally, it has undergone a similar stress history as the Duluth Complex. The geologic and hydrogeologic studies carried out in the area focused on characterization of groundwater flow in the fractured bedrock. Specifically, fracturing was found to be concentrated in the uppermost 100 feet of rock. The granophyre is more massive (less fractured) with depth, and with distance from major fault zones and geologic contacts. The investigators also identified a strong correlation between fractures and RQD. No significant zones of unusually high hydraulic conductivity were identified. Hydraulic conductivity measurements from single well tests for this fractured rock ranged from 2.4 x 10^{-7} to 2.0 x 10^{-4} cm/s (geometric mean of 6.9 x 10^{-6} cm/s) and were within the expected range for this type of rock based on literature.

Groundwater flow in bedrock at NorthMet occurs in fractures within three relevant bedrock units: the Duluth Complex, the Virginia Formation that makes up the 'footwall' rocks, and the underlying granite of the Giants Range batholith (which forms the uppermost unit at the Plant Site) (Figure 3-3). The hydrogeology of the BIF is also discussed below as it is present at depth below the mine pits, and it is exposed at the surface in nearby mine pits. A compilation of field-based hydraulic conductivity measurements for these bedrock units is presented in Figure 3-4 and Table 3-1. Figure 3-4 includes site-specific data for the Duluth Complex and Virginia Formation collected during the hydrogeologic investigations of the Mine Site (Reference (12), Reference (13), Reference (14)), site-specific data for the Giants Range Granite collected during the geotechnical investigation of the Tailings Basin (Appendix A), and literature data from studies within close proximity of the project area (Reference (9), Reference (7)). Additionally, site-specific hydraulic conductivity data are shown in plan view in Large Figure 2. In general, the Duluth Complex has the lowest permeability, due to its relatively massive nature (i.e., it has fewer fractures, compared to the other geologic units) and relatively young stress history, followed by the upper portions of the Virginia Formation and Giant's Range batholith, with the more faulted and fractured BIF having the highest permeability (Reference (49)).



Geometric mean indicated by large diamond.

Figure 3-4 Field Hydraulic Conductivity (K) Measurements for Bedrock Units

Table 3-1 Field Hydraulic Conductivity (K) Measurements for Bedrock Units

Study Title	Source Author	Date	Location (with depth interval, in feet)	Bedrock K Estimate, cm/sec	Bedrock K Estimate, ft/day
Duluth Complex					
Surficial geology and ground-water geology of the Babbitt-Kawishiwi area, northeastern Minnesota, with planning implications	Stark	1977	INCO #32786 (12-371)	1.5E-04	4.1E-01
Surficial geology and ground-water geology of the Babbitt-Kawishiwi area, northeastern Minnesota, with planning implications	Stark	1977	HANNA #K-20 (0-250)	1.9E-05	5.3E-02
Surficial geology and ground-water geology of the Babbitt-Kawishiwi area, northeastern Minnesota, with planning implications	Stark	1977	INCO #40913 (10-2795)	1.4E-07	4.0E-04
Surficial geology and ground-water geology of the Babbitt-Kawishiwi area, northeastern Minnesota, with planning implications	Stark	1977	INCO #11533 (19-1319)	4.2E-06	1.2E-02
Surficial geology and ground-water geology of the Babbitt-Kawishiwi area, northeastern Minnesota, with planning implications	Stark	1977	INCO #32758 (0-1250)	9.4E-07	2.7E-03
Hydrology and Water Quality of the Copper-Nickel Study Region, Northeastern Minnesota	Siegel, D.I., and Ericson, D.W./USGS	1980	61-11-19bdc (well depth of 125 ft)	5.6E-06	1.6E-02
Hydrology and Water Quality of the Copper-Nickel Study Region, Northeastern Minnesota	Siegel, D.I., and Ericson, D.W./USGS	1980	61-11-34bbc (well depth of 225 ft)	9.9E-07	2.8E-03
Hydrogeologic Investigation - Phase I, PolyMet NorthMet Mine Site, RS-02 Draft-02	Barr	2006	05-401M (0-349)	1.3E-06	3.6E-03
Hydrogeologic Investigation - Phase I, PolyMet NorthMet Mine Site, RS-02 Draft-02	Barr	2006	05-404M (0-328)	3.5E-06	1.0E-02
Hydrogeologic Investigation - Phase I, PolyMet NorthMet Mine Site, RS-02 Draft-02	Barr	2006	05-407M (8-354)	3.0E-06	8.4E-03

Study Title	Source Author	Date	Location (with depth interval, in feet)	Bedrock K Estimate, cm/sec	Bedrock K Estimate, ft/day
Hydrogeologic Investigation - Phase I, PolyMet NorthMet Mine Site, RS-02 Draft-02	Barr	2006	05-411M (13-639)	3.0E-07	8.4E-04
Hydrogeologic Investigation - Phase I, PolyMet NorthMet Mine Site, RS-02 Draft-02	Barr	2006	05-405C (31-723)	2.4E-07	6.7E-04
Hydrogeologic Investigation - Phase I, PolyMet NorthMet Mine Site, RS-02 Draft-02	Barr	2006	05-406C (6-686)	9.2E-08	2.6E-04
Hydrogeologic Investigation - Phase I, PolyMet NorthMet Mine Site, RS-02 Draft-02	Barr	2006	05-409C (16-442)	1.4E-05	4.1E-02
Hydrogeologic Investigation - Phase I, PolyMet NorthMet Mine Site, RS-02 Draft-02	Barr	2006	05-410C (7-668)	1.5E-07	4.2E-04
Hydrogeologic Investigation - Phase I, PolyMet NorthMet Mine Site, RS-02 Draft-02	Barr	2006	05-413C (12-336)	4.2E-06	1.2E-02
Hydrogeologic Investigation - Phase I, PolyMet NorthMet Mine Site, RS-02 Draft-02	Barr	2006	05-414C (0-1303)	1.4E-07	3.9E-04
Virginia Formation					
Hydrogeologic Investigation- Phase II, PolyMet NorthMet Mine Site, RS-10 Draft-02	Barr	2006	P-1 (27-610)	8.5E-07	2.4E-03
Hydrogeologic Investigation- Phase II, PolyMet NorthMet Mine Site, RS-10 Draft-02	Barr	2006	P-2 (27-610)	2.5E-05	7.2E-02
Hydrogeologic Investigation- Phase II, PolyMet NorthMet Mine Site, RS-10 Draft-02	Barr	2006	P-3 (27-610)	2.0E-04	5.7E-01
Hydrogeologic Investigation- Phase II, PolyMet NorthMet Mine Site, RS-10 Draft-02	Barr	2006	Ob-3 (21-100)	2.4E-04	6.8E-01
Hydrogeologic Investigation- Phase II, PolyMet NorthMet Mine Site, RS-10 Draft-02	Barr	2006	Ob-3a (17-50)	1.7E-04	4.9E-01
Hydrogeologic Investigation- Phase II, PolyMet NorthMet Mine Site, RS-10 Draft-02	Barr	2006	717971 (19-260)	1.3E-04	3.6E-01
Hydrogeologic Investigation- Phase II, PolyMet NorthMet Mine Site, RS-10 Draft-02	Barr	2006	P-4 (46-485)	1.2E-04	3.3E-01

Study Title	Source Author	Date	Location (with depth interval, in feet)	Bedrock K Estimate, cm/sec	Bedrock K Estimate, ft/day
Phase III Hydrogeologic Investigation, RS10A Draft-01	Barr	2007	Ob-2 (18-100)	1.7E-05	4.7E-02
Phase III Hydrogeologic Investigation, RS10A Draft-02	Barr	2007	P-3 (27-300)	2.2E-04	6.3E-01
Phase III Hydrogeologic Investigation, RS10A Draft-03	Barr	2007	P-4 (46-200)	2.5E-04	7.0E-01
Giants Range Granite					
Hydrology and Water Quality of the Copper-Nickel Study Region, Northeastern Minnesota	Siegel, D.I., and Ericson, D.W./USGS	1980	59-14-2adc (well depth of 197 ft)	9.1E-06	2.6E-02
Geotechnical Investigation - Tailings Basin	Barr	2014	B14-36 (14-18.5)	<1.4E-06[1]	<1.4E-06[1]
Geotechnical Investigation - Tailings Basin	Barr	2014	B14-36 (20.5-26.5)	1.4E-06	4.0E-03
Geotechnical Investigation - Tailings Basin	Barr	2014	B14-55 (37-41.5)	7.2E-04	2.0E+00
Geotechnical Investigation - Tailings Basin	Barr	2014	B14-55 (41.5-46.5)	<1.4E-06[1]	<1.4E-06[1]
Geotechnical Investigation - Tailings Basin	Barr	2014	B14-55 (46-50.5)	<1.4E-06[1]	<1.4E-06[1]
Geotechnical Investigation - Tailings Basin	Barr	2014	B14-44 (34-42)	3.9E-05	1.1E-01
Geotechnical Investigation - Tailings Basin	Barr	2014	B14-44 (42-46)	5.8E-05	1.6E-01
Geotechnical Investigation - Tailings Basin	Barr	2014	B14-65 (24-30)	5.2E-05	1.5E-01
Geotechnical Investigation - Tailings Basin	Barr	2014	B14-65 (27.5-33.5)	1.9E-04	5.4E-01
Geotechnical Investigation - Tailings Basin	Barr	2014	B14-76 (37-42)	9.0E-05	2.6E-01
Specific Capacity Analysis from Well and Boring Record for Residential Well 620123	MDH - CWI	1999	620123 (18-65)	1.2E-03	4.2E+01

[1] These tests did not produce water, suggesting that the permeability of the interval is less than the lowest value observed using the measurement technique (1.4E-06 cm/sec).

Study Title	Source Author	Date	Location (with depth interval, in feet)	Bedrock K Estimate, cm/sec	Bedrock K Estimate, ft/day
Biwabik Iron Formation					
Hydrology and Water Quality of the Copper-Nickel Study Region, Northeastern Minnesota	Siegel, D.I., and Ericson, D.W./USGS	1980	58-15-3cca2 (well depth of 455 ft)	5.6E-04	1.6E+00
Hydrology and Water Quality of the Copper-Nickel Study Region, Northeastern Minnesota	Siegel, D.I., and Ericson, D.W./USGS	1980	59-15-26dbc (well depth of 299 ft)	6.3E-05	1.8E-01
Hydrology and Water Quality of the Copper-Nickel Study Region, Northeastern Minnesota	Siegel, D.I., and Ericson, D.W./USGS	1980	59-15-26dbc (well depth of 398 ft)	5.2E-05	1.5E-01
Hydrology and Water Quality of the Copper-Nickel Study Region, Northeastern Minnesota	Siegel, D.I., and Ericson, D.W./USGS	1980	60-12-17aad (well depth of 110 ft)	5.7E-03	1.6E+01

3.2.1 Giants Range Granite and Archean Schists

Granite of the Giants Range batholith (granite) and associated Archean schists underlie the Plant Site. At the Tailings Basin, 'mounding' of the water table within the tailings pile, which is generally constructed on a groundwater divide, drives groundwater flow into the underlying surficial deposits and potentially into the upper portions of the underlying granitic bedrock.

Harrison et al. (Reference (10)) recognized that the type of crystalline rock (i.e., Duluth Complex versus Archean granite) is less important than site-specific conditions (e.g., stress history, type of stress, and fracture geometry) in controlling the overall permeability of the bedrock in the region. In general this means that crystalline rock units behave similarly under the glacial loading/unloading regime, and the upper portions of all rock units are more likely than rock at depth to contain a fracture network capable of transmitting water.

RQD data support the presence of fracturing in the upper portions of bedrock. RQD data from the bedrock that underlies the area to the north and west of the Plant Site (Appendix A) indicate the influence of the upper fractured bedrock: average RQD increases from about 60% to 85% from the bedrock surface to 20 feet below the top of bedrock. Figure 3-5 presents these RQD data converted to number of fractures per foot of core, using a relationship between RQD and number of fractures per length of core (fracture index, Fi) developed by Priest and Hudson, (Reference (52)). The number of fractures per foot of core decreases by more than half within the first 20 feet of bedrock.

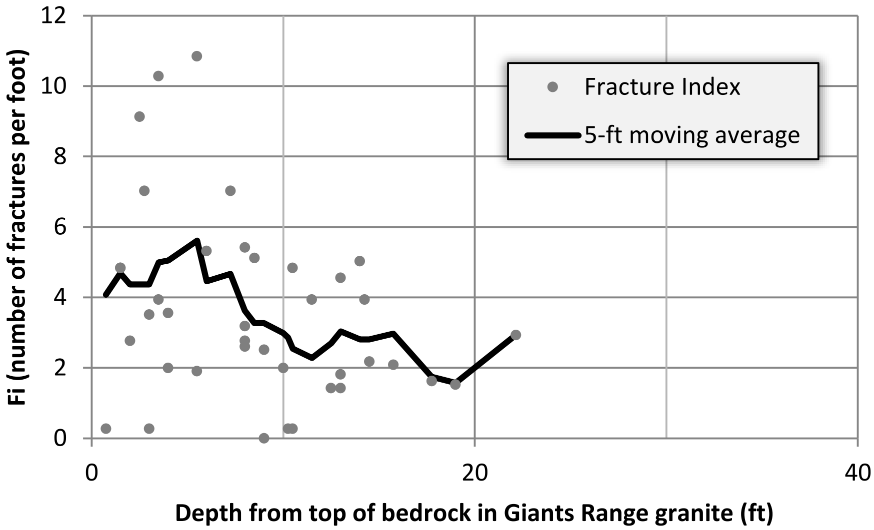


Figure 3-5 Number of Fractures per Foot (Fracture Index) with Depth in the Giants Range Granite

The literature-based assessment of the upper fractured zone suggests that groundwater flow in the Giants Range granite likely occurs mostly in the upper 300 feet of the bedrock; however, the site-specific fracture data indicate that the amount of fracturing decreases significantly in the upper 20 feet of the bedrock surface (Figure 3-5).

The hydraulic conductivity of uppermost portions of the Giants Range granite (<20 feet) was tested during a 2014 geotechnical investigation. The results of this investigation are attached to this report (Appendix A). Hydraulic conductivity values for the upper portion of the Giant's Range granite surrounding the Plant Site range from effectively zero (e.g., no water was produced in three of the packer test intervals) to 7.2 x 10^{-4} cm/s, with a geometric mean of 1.9 x 10^{-5} cm/s (Table 1-1 and Large Figure 2). (For the purposes of calculating a geometric mean, the lowest hydraulic conductivity value measured during the investigation was used for the three intervals that did not produce water). Artesian groundwater conditions were encountered in several piezometers and drillholes during investigation, including one drillhole (R14-20) that encountered approximately 10-12 gallons per minute (gpm) of flow within the upper foot of the granite, which the drillers attribute to groundwater flow at the top of bedrock.

The hydraulic conductivity measurements from this investigation reflect heterogeneity with respect to hydraulic properties of the upper 20 feet of bedrock. Regional measurements in the Giants Range granite also indicate variability: Siegel and Ericson (Reference (9)) measured specific capacity in one well in the upper 200 feet of the Giants Range, and found hydraulic conductivity was 9.1 x 10^{-6} cm/s, while specific capacity data from a well record for a residential well located to the north of the Plant Site suggests that the hydraulic conductivity of the upper 65 feet of the granite is 1.5 x 10^{-2} cm/s. Based on a compilation of field- and lab-based hydraulic conductivity values for granites in North America, Harrison et al. (Reference (10)) estimated a mean conductivity value of 10^{-8} cm/s for granite in the Lake Superior region.

The various hydraulic conductivity values from literature and site test work are shown on Large Figure 2 and in Table 1-1.

Fracturing due to glacial loading/unloading in the Giants Range is limited to the upper portions of bedrock. At depth, fractures become less frequent (Figure 3-5), and more closed. The contrast between the bulk hydraulic conductivity of the upper 20 feet of Giant's Range granite and that of other granites in the Lake Superior region (Table 1-1) generally suggests that deep-seated faults or other fractures may be discontinuous or filled at depth.

3.2.2 Duluth Complex

The Duluth Complex rock at NorthMet is massive, with very few fractures except within the upper approximately 40 feet (Figure 3-6). RQD data are collected during ongoing exploration and PolyMet's assay database is continually updated with information from drillcore logging and re-logging efforts. To date, there are over 14,000 RQD measurements for the Duluth Complex within PolyMet's database (Reference (4)). RQD data from exploratory drilling indicate that rock quality in the Duluth Complex is generally excellent (>90%). Average RQD increases from 73% at the top of bedrock to 94% within 40 feet below the top of bedrock. Figure 3-6 presents these RQD data from top of bedrock to 500 feet below top of bedrock within the Duluth Complex. The RQD data are converted to number of fractures per foot of core, using the fracture index (Fi) developed by Priest and Hudson, (Reference (52)). The average number of fractures per foot of core decreases from almost 3 to less than 1 within the first 20 feet of bedrock.

Blasting and mining (unloading) of the Duluth Complex rock may act to open joints or fractures, but the extent of this "damaged" rock will be localized within the area of the pit shells (Reference (53)). The potential increase in bedrock permeability due to damaged rock will not affect the larger-scale flow paths that deliver groundwater into and out of the mine. Regardless of the potential presence of a "damaged rock zone", the long-term average groundwater inflow rates into and out of the open pits (which are subject to seasonal and long-term climatic variations) will stabilize due to the limited capacity (low transmissivity) of the surrounding unaffected bedrock.

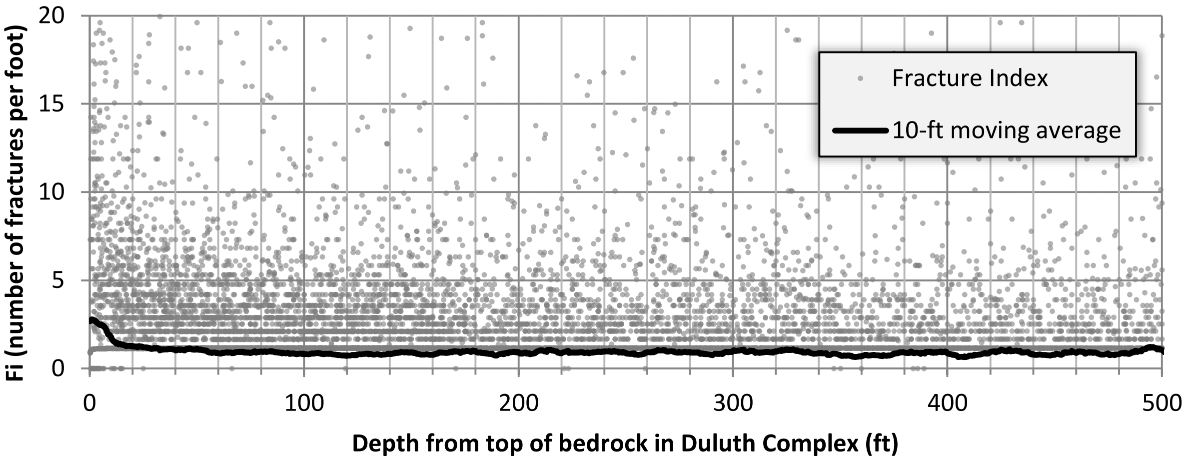


Figure 3-6 Number of Fractures per Foot (Fracture Index) with Depth in the Duluth Complex

Siegel and Ericson (Reference (9)) collected specific capacity information from two exploratory drillholes located between 10 and 20 miles northeast of the Mine Site in the Duluth Complex. These data were converted to hydraulic conductivities of 5.6 x 10^{-6} and 9.9 x 10^{-7} cm/s. They report that the Duluth Complex rocks yield 5 to 15 gpm in the upper portion of the bedrock unit, where joints and fractures resulting from glacial loading/unloading are transmissive. Stark (Reference (7)) estimated that the hydraulic conductivity of the Duluth Complex ranged from 1.4 x 10^{-7} to 1.5 x 10^{-4} cm/s, with a geometric mean of 4.4 x 10^{-6} cm/s based on aquifer tests. He also found that transmissivity is greater closer to mapped lineaments, though the data to support this conclusion are not extensive. At depth within the Duluth Complex, i.e., below approximately 300 feet, fracturing is limited to larger structural features (if present) of relatively low transmissivity.

Barr (Reference (12)) conducted 10 aquifer performance tests in exploratory drillholes that ranged in depth from 328 to 1303 feet. Hydraulic conductivity values for the Duluth Complex at the Mine Site ranged from 9.2 x 10^{-8} to 1.4 x 10^{-5} cm/s, with a geometric mean of 8.0 x 10^{-7} cm/s (Table 1-1). The spatial distribution of the hydraulic conductivity estimates is shown on Large Figure 2. The five hydraulic conductivity estimates derived from single-well pumping tests conducted on drillholes within about 1000 feet of the Virginia Formation/Duluth Complex contact (10^{-5} to 10^{-6} cm/s) are generally about an order of magnitude higher than those derived from more distally-located drillholes (10^{-7} to 10^{-8} cm/s).

Hydraulic conductivity results were further analyzed to assess variability related to depth. Assuming the hydraulic conductivity values estimated from the Duluth Complex aquifer tests represent both the effective, thickness-weighted average of the hydraulic conductivities of the upper, more permeable portion and the lower, less permeable portion of the Duluth Complex (an appropriate assumption for tests conducted in boreholes with distinct intervals of contrasting permeability (Reference (54 p. 252)), hydraulic conductivity was calculated under two assumed values for thickness of the bedrock contributing flow during the tests: 50 feet and 100 feet. Hydraulic conductivity values were calculated assuming no groundwater inflow occurred within the borehole beneath these two depths (Table 3-2). As shown in Table 3-2, the hydraulic conductivity values calculated for the assumed upper, fractured portion of bedrock are generally 3 to 30 times greater than the effective, measured hydraulic conductivity values from the aquifer tests. For example, for the five boreholes located more than 1,000 feet south of the Virginia Formation/Duluth Complex contact, the geometric mean hydraulic conductivity is 1.7×10^{-7} cm/s if based on the entire test interval thickness (approximate open borehole interval) of each borehole, 1.3×10^{-6} cm/s if the effective water-producing interval is 100 feet, and 2.5×10^{-6} cm/s if the effective water-producing interval is 50 feet. The hydraulic conductivity values from the five single-well pumping tests conducted near the Virginia Formation/Duluth Complex contact remain higher than the values from drillholes located further from the contact after normalization to the two assumptions of flow-contributing bedrock thickness.

Estimates of inflow to underground structures in the area provide context for how much of this groundwater might be derived from bedrock. Underground mine facilities in the region (i.e., AMAX, Soudan Underground Mine) typically construct engineering controls (e.g., fracture grouting) to manage the quantities of water that are encountered. During the development of a 1700-foot deep exploratory mine shaft at AMAX, four individual fractures that produced water were encountered (Reference (8)). These reflect seepage from the Duluth Complex, and were encountered at 60 feet, 147 feet, approximately 1,050 to 1,080 feet (record is unclear), and 1,194 feet below ground surface. Inflow along these individual fractures ranged from 2.7 to approximately 25 gpm. After the fractures were grouted, inflow ranged from 0.8 to 4.0 gpm for the individual fractures. Average pumping rates from the AMAX shaft after engineering controls were in place were approximately 9 to 14 gpm during its operation (Reference (8)).

Table 3-2 Duluth Complex Hydraulic Conductivity Estimates under Different Assumed Aquifer Thicknesses

Source Author	Date	Location	Approximate Open Borehole Interval, ft	Bedrock K Estimate, cm/sec	Bedrock K Estimate, ft/day	Effective Bedrock K assuming Flow in Upper 50 feet of Bedrock, cm/sec	Effective Bedrock K assuming Flow in Upper 100 feet of Bedrock, cm/sec
Boreholes within 1000 feet of the Duluth Complex/Virginia Formation contact subcrop							
Barr	2006 (Phase I Hydro Investigation)	05-401M	0 - 349	1.3E-06	0.0036	8.9E-06	4.4E-06
Barr	2006 (Phase I Hydro Investigation)	05-404M	0 - 328	3.5E-06	0.01	2.3E-05	1.2E-05
Barr	2006 (Phase I Hydro Investigation)	05-407M	8 - 354	3.0E-06	0.0084	2.1E-05	1.0E-05
Barr	2006 (Phase I Hydro Investigation)	05-409C	16 - 442	1.4E-05	0.041	1.2E-04	6.4E-05
Barr	2006 (Phase I Hydro Investigation)	05-413C	12 - 336	4.2E-06	0.012	2.7E-05	1.4E-05
Boreholes in southern portion of the West Pit, > 1000 feet from the Duluth Complex/Virginia Formation contact subcrop							
Barr	2006 (Phase I Hydro Investigation)	05-411M	13 - 639	3.0E-07	0.00084	3.7E-06	1.9E-06
Barr	2006 (Phase I Hydro Investigation)	05-405C	31 - 723	2.4E-07	0.00067	3.3E-06	1.7E-06
Barr	2006 (Phase I Hydro Investigation)	05-406C	6 - 686	9.2E-08	0.00026	1.2E-06	6.3E-07
Barr	2006 (Phase I Hydro Investigation)	05-410C	7 - 668	1.5E-07	0.00042	2.0E-06	9.9E-07
Barr	2006 (Phase I Hydro Investigation)	05-414C	0 - 1303	1.4E-07	0.00039	3.6E-06	1.8E-06
Barr	2006 (Phase I Hydro Investigation)	Geometric Mean	--	8.0E-07	0.0023	8.3E-06	4.2E-06

3.2.3 Virginia Formation

The Virginia Formation is the first rock below the mineralized zone within the Duluth Complex (Figure 3-3), and will be exposed in some areas within the northern mine pit walls, as the Duluth Complex is mined along its dip-slope (Figure 3-3). The Virginia Formation is also present in subcrop below features of the Mine Site, such as the Category 1 Waste Rock Stockpile.

The hydraulic conductivity of the Virginia Formation has been affected by joints and fractures from glacial loading/unloading (where present in sub-crop), bedding plane fractures, and faults and joints related to tectonic stresses. Groundwater movement in the Virginia Formation occurs mostly in the upper portions of the bedrock affected by glacial loading and unloading (i.e., the near-surface fractures). This may be due to the aperture width of fractures, and, by extension, the hydraulic conductivity, decreasing with depth as confining pressure from the overlying rock increases.

At the Mine Site, five pumping tests (three 36-hour tests, one 96-hour test, and one 30-day test) were conducted in four wells completed within the Virginia Formation, near the contact with the Duluth Complex. Pumping test data suggest the bulk hydraulic conductivity of the upper approximately 600 feet of the Virginia Formation has hydraulic conductivity of 8.5×10^{-7} to 2.4×10^{-4} cm/s. The geometric mean of the hydraulic conductivity estimates from each of the pumping wells is 6.0×10^{-5} cm/s.

Specific capacity testing was conducted in two of the Virginia Formation wells in order to assess the relative permeability of the upper (0-300 ft) versus lower (300-600 ft) portions of the formation. This work found the upper portion of the Virginia formation to be approximately three to five times more permeable than the lower portion (Reference (14)).

3.2.4 Biwabik Iron Formation (BIF)

The BIF, which comprises the footwall at depth below the Virginia Formation at the Mine Site, represents the most hydraulically conductive of the bedrock units at NorthMet. Where the BIF is present in sub-crop, it is recognized as a regional water resource; weathered and leached BIF can supply 1000 gal/min to wells that supply villages on the Mesabi Iron Range (Reference (28)). When it is exposed near the surface (i.e., Peter Mitchell Pit to the north of the Mine Site), fractures are widespread and include bedding-plane fractures, joints and variably oriented large- and small-offset faults (i.e., Siphon Fault, Donora Fault). Although most groundwater discharge to local taconite mine pits comes from the interface between the surficial deposits and the bedrock (Reference (11)), groundwater discharging from joints within the BIF are common in dewatered pits (Reference (55)). Siegel and Ericson (Reference (9)) measured specific capacity in four wells screened in the BIF. These data suggest that hydraulic conductivity of the BIF ranges from 5.2×10^{-5} to 5.7×10^{-3} cm/s (with a geometric mean of 3.5×10^{-4} cm/s).

The hydraulic conductivity of the BIF at depth below the NorthMet mine pits likely will be less than where it is exposed in subcrop, due to the decreased aperture width resulting from the confining stress exerted by the overlying Virginia Formation and Duluth Complex. In addition, because the Virginia Formation, and not the BIF, will be exposed at the base of the mine pits, seepage from the BIF is not anticipated.

3.2.5 Summary

The bedrock hydrogeology at the Mine Site and Plant Site is characterized by near-surface fracture flow that is likely limited almost entirely to the uppermost portions of bedrock. Despite literature-based values indicating that the depth of this upper zone of higher permeability may be approximately 300 feet, RQD data for the Duluth Complex, beneath the Mine Site, suggests that the bedrock fracture network capable of transmitting significant quantities of water is limited to the upper approximately 40 feet. The meta-sedimentary rock units of the Virginia Formation that make up the footwall at the Mine Site have somewhat higher hydraulic conductivity than the more massive igneous rocks of the Duluth Complex, given the presence of bedding-plane fractures. Experience from advancing the exploration shaft at AMAX indicates that deep-seated fractures within the bedrock can contribute water to excavations at depth. These features are localized and likely discontinuous and are not able to be mapped from drillhole to drillhole in the Duluth Complex at the Mine Site.

4.0 Implications for Impact Analysis

The assessment of potential environmental impacts from the Project considers the presence of fractures capable of transmitting water and the permeability of the bedrock units (collectively referred to as bedrock hydrogeology). The groundwater components of the impact analysis were simulated using an assumption of equivalent porous media for groundwater flow through bedrock, which means that flow in individual fractures is not considered, but flow through a network of connected fractures is considered; the resulting modeled hydraulic conductivity is directly comparable to the site-specific field-based bulk hydraulic conductivity measurements from drillholes that are open to significant thicknesses of bedrock. Additional details on the modeling of flow through bedrock at the Mine Site and Plant Site are discussed further below.

4.1 Mine Site

Duluth Complex rock will be blasted and mined in the course of mine progression. During mining, the Duluth Complex and some Virginia Formation will be exposed at the surface along the sides and bottom of the open pits and will contribute groundwater flow to the open pits. The open pits will act as a sink for groundwater during operations, i.e., dewatering will induce groundwater discharge to the pit; a significant fraction of the groundwater discharging to the pits is expected to be from surficial deposits, given the higher hydraulic conductivity of this material. Localized flow from the bedrock is expected, most likely from the near-surface fractures. After pit flooding in closure, there will be continued groundwater inflow to the pits from the north via Duluth Complex (what remains following mining) and the Virginia Formation. In closure, most water leaving the pit will be through pumping to the waste-water treatment facility, with minimal flow to groundwater in the surficial deposits. Very little, if any, flow is expected to leave the pit via fractures in bedrock given the low gradient and permeability of the rock (less than 1 gpm on average). Any groundwater outflow will be through the Duluth Complex to the south.

The bedrock hydrogeology at the Mine Site is a factor in the assessment of water quality impacts as part of the SDEIS. In addition, bedrock hydrogeology is used in the development of the overall project water balance, which affects volumes of water that need to be managed. Specifically, bedrock hydrogeology is used in addressing the following questions:

- How much groundwater inflow will there be to the mine pits during operations and pit flooding?
- Will there be water quality impacts from groundwater outflow from the mine pits after they are reflooded during reclamation and long-term closure?
- Will there be water quality impacts associated with leakage/seepage from stockpiles and other surficial mine features?

Each of these questions, and the analysis conducted to date to address the questions, is presented further below in light of the geologic and hydrogeologic discussion presented in this document.

4.1.1 Groundwater Inflow to Pits

The quantity of groundwater inflow to the mine pits during operations and pit flooding is estimated using MODFLOW (Attachment C of Reference (49)). This modeling uses, among other inputs, the bulk hydraulic conductivity of the bedrock units, treating them as equivalent porous media. The bulk hydraulic properties of the bedrock, representative of the collective near-surface fractures, are considered, rather than the hydraulic conductivity of individual fractures, because the prediction of interest is the spatially-averaged groundwater inflow into the pits. Flow from individual factures is not needed, and adding the level of mathematical complexity necessary to make this sort of prediction would be unwarranted. The Virginia Formation is the primary unit transmitting water to the pits due to the higher hydraulic conductivity of this unit compared to the Duluth Complex (Table 1-1 and Large Figure 2). Differences in hydraulic properties in the upper versus lower Virginia Formation are addressed in the groundwater model by assigning separate zones of differing hydraulic conductivity to the upper and lower portions of the Virginia Formation. In the MODFLOW model, the hydraulic conductivity values are allowed to vary during the calibration process. Specifically, bedrock hydraulic conductivity values derived from site-specific test work were considered in defining the range of allowable hydraulic conductivity adjustments during calibration.

The Mine Site GoldSim model uses the MODFLOW estimated groundwater inflow rates to establish the overall project water balance. For this assessment, uncertainty in the groundwater inflow rates, which in part reflects uncertainties in bedrock hydraulic conductivities, are represented with a probabilistic distribution that scales the MODFLOW estimated inflow values. A log-normal distribution is defined such that the mean groundwater inflow rate is the MODFLOW estimated value and the 95% confidence interval extends from approximately 0.75 to 2.0. This assumption was discussed as part of the Impact Assessment Process (IAP process) and is based on professional judgment.

4.1.2 Groundwater Impacts from Mine Pit Outflow

The estimate of water quality impacts from groundwater outflow from the mine pits considered the hydrogeology of both surficial deposits and bedrock at the Mine Site. Given the predicted gradients following pit flooding, any groundwater outflow from the pits will be to the south through the surficial deposits and the Duluth Complex. Given the fact that the hydraulic conductivity of the surficial deposits is much higher than the Duluth Complex, the majority of outflow will be through the surficial deposits. However, transport through bedrock is still considered in the GoldSim modeling of potential water quality impacts.

In the GoldSim model, bedrock is assumed to behave as an equivalent porous media with a hydraulic conductivity equal to the optimized value from the MODFLOW model calibration. Uncertainty in hydraulic conductivity of one log-cycle is considered. There is a practical inability to predict the locations of (and therefore to characterize) transmissive open fracture or fault zones in bedrock via drillholes prior to operations given the lack of continuity of features. However, any zones that could transmit significant quantities of water away from the pits following flooding would be zones that contribute groundwater inflow during dewatering and will be visible as seeps. During operations, if and when individual fracture zones are encountered that contribute abundant water to the pit, that water will be managed, and mitigation steps will be taken to minimize flow from those zones. Management steps taken during mine pit progression may include grouting of the fracture zone to prevent local flow. Mitigation steps taken during mine pit progression that prevent in-flow from deep-seated faults (i.e., individual fracture zones that intersect the pit at depth) will also minimize out-flow (and any associated water quality impacts) from groundwater from the flooded pit through bedrock.

4.1.3 Groundwater Impacts from Stockpile Seepage or Leakage

The estimates of water quality impacts associated with leakage or seepage from stockpiles and other surficial mine features do not consider the potential for transport through bedrock. These features will primarily be constructed on top of the surficial deposits, and as a result of engineering controls constructed to collect leakage and seepage, there will be very little head driving any seepage or leakage from these features into bedrock. This, combined with the low hydraulic conductivity of the bedrock relative to the surficial deposits, results in a very low likelihood for impacts to groundwater in bedrock. Given this, the impact analysis considered the interface between the surficial deposits and bedrock to be an impermeable boundary. The effect of this assumption is that groundwater in the surficial aquifer is modeled to have faster travel times and less attenuation of constituent mass than if the model assumed groundwater flow in bedrock.

4.2 Plant Site

The bedrock hydrogeology at the Plant Site is a factor in the assessment of water quality impacts. Specifically, bedrock hydrogeology is used in addressing the following questions:

- How much seepage loss will occur through the base of the Flotation Tailings Basin?
- Will there be water quality impacts from groundwater outflow from the Tailings Basin?

Groundwater modeling was conducted to allocate seepage from the Tailings Basin to groundwater flow paths designated in the GoldSim impact analysis. The groundwater model used to estimate the quantity of seepage loss that would occur through the base of the Tailings Basin is calibrated to measured hydraulic heads within and around the Tailings Basin, to estimates of seepages losses from the Tailings Basin ponds, and to measurements of seepage to the south of the Tailings Basin. For modeling, the bedrock beneath the Tailings Basin is assumed to act as an impermeable boundary. Based on the geometric means of site-specific hydraulic conductivity data for the surficial deposits (1.7×10^{-3} cm/s; Reference (56)) and bedrock (1.9×10^{-5} cm/s; Appendix A), the hydraulic conductivity of the bedrock is nearly 100 times lower than the hydraulic conductivity of the surficial deposits. Given this disparity in hydraulic conductivity values, the majority of seepage losses from the Tailings Basin will be through the surficial deposits.

The impact analysis conducted using the GoldSim model focused on flow and transport in the surficial deposits, and not on the underlying granitic bedrock. Assuming no leakage to bedrock has the effect of decreasing travel times of constituent mass from the Tailings Basin to evaluation points in the surficial aquifer, and allowing for less attenuation of constituent mass than if the model assumed groundwater flow in bedrock. This results in mass reaching the evaluation points more quickly than would be expected in an area where the surficial aquifer and the bedrock are connected and some constituent mass could enter the bedrock. In reality, some of the groundwater flow from the Tailings Basin may be accommodated in the upper fractured granitic bedrock, although this flow is considered to be negligible compared to the amount of groundwater flow through flow paths in the surficial deposits. The groundwater flow from the Tailings Basin through the surficial aquifer will be captured by the FTB Containment System. The impact analysis, however, incorporates an assumption that reflects the potential for flow in the uppermost portions of the granite. While the FTB Containment System is designed to capture 100% of the groundwater coming from the Tailings Basin, the impact analysis assumes that some seepage (equal to 10% of the capacity of the surficial aquifer) bypasses the FTB Containment System.

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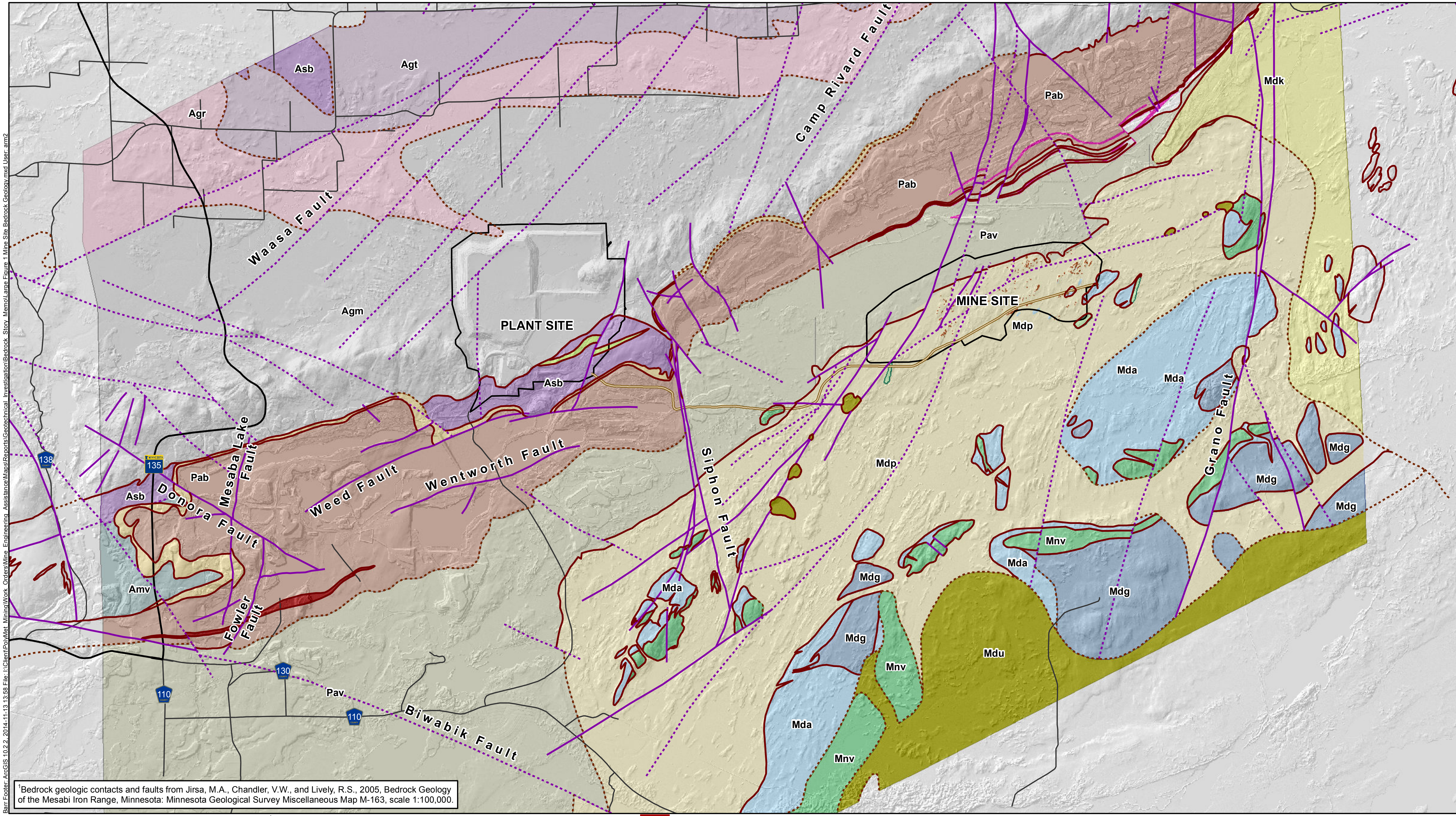
Large Figures



- Fault (approximate)
- Fault (inferred)
- Geologic Contact (approximate)
- Geologic Contact (inferred)
- Dunka Road
- Project Areas

Bedrock Geology[1]

- Agm - Quartz monzonite and monzodiorite
- Agr - Quartz monzonite, monzodiorite, and monzogranite
- Agt - Tonalite to granodiorite
- Amv - Tholeiitic to calc-alkalic volcanic rocks
- Asb - Schist of sedimentary protolith
- Asv - Schist of mafic to intermediate volcanic protlith
- Mda - Anorthositic series subsuite of the Duluth Complex
- Mdg - Gabbro
- Mdk - South Kawishiwi intrusion
- Mdp - Partridge River intrusion
- Mdu - Ultramafic, oxide-rich intrusions
- Mia - Aurora sill
- Mmi - Mafic intrusions
- Mnv - North Shore Volcanic Group
- Pab - Biwabik Iron Formation
- Paq - Pokegama Quartzite
- Pav - Virginia Formation

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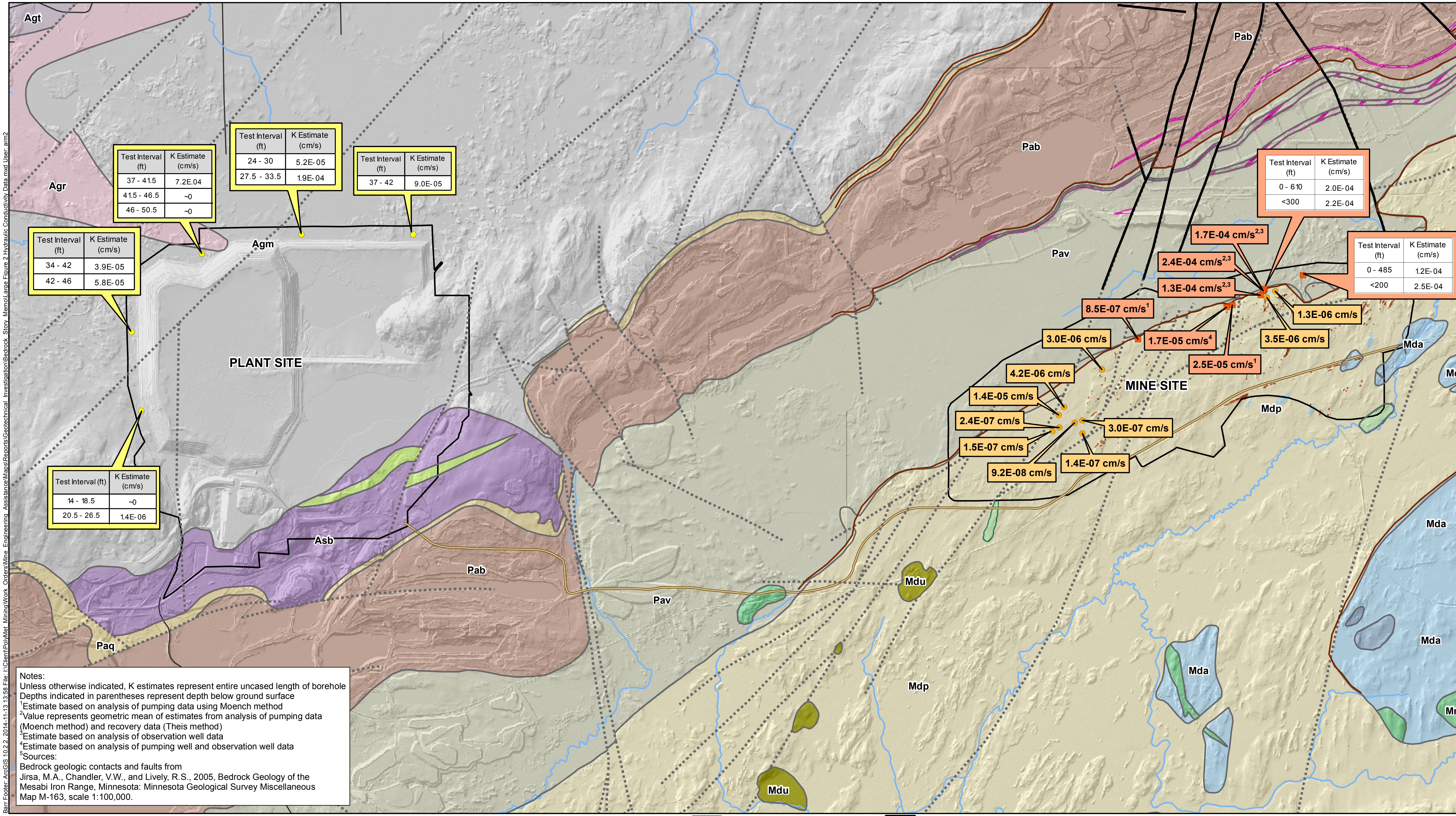
Miles

Large Figure 1
BEDROCK GEOLOGY
Minnesota Geological Survey M163
NorthMet Project
Poly Met Mining Inc.
Hoyt Lakes, MN



- Giants Range Granite
- Duluth Complex
- Virginia Formation

Bedrock Geologic Contact and Faults from PolyMet
- Geologic Contact (Approximately Located)
- Fault (Approximately Located)

Bedrock Geology[5]
- Agm - Quartz monzonite and monzodiorite
- Agr - Quartz monzonite, monzodiorite, and monzogranite
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- Pab - Biwabik Iron Formation
- Paq - Pokegama Quartzite
- Pav - Virginia Formation

- Project Areas
- Dunka Road
- Public Waters Inventory (PWI) Watercourses

0 2,000 4,000 8,000
Feet

Large Figure 2
BEDROCK HYDRAULIC CONDUCTIVITY (K) DATA
NorthMet Project
Poly Met Mining Inc.
Hoyt Lakes, MN

Appendix A

August 14, 2014 PolyMet Geotechnical Exploration - Winter 2013/2014 Memo

Memorandum

To: Project File
From: Kristin Alstadt, Tom Radue
Subject: PolyMet Geotechnical Exploration – Winter 2013/2014
Date: August 28, 2014
Project: 23/69-0C29
c:

During late winter 2013/2014 Barr Engineering Company (Barr) under authorization and contract with PolyMet Mining Company (PolyMet) completed a geotechnical exploration at the NorthMet site to characterize subsurface soil and bedrock along the alignment of the proposed Flotation Tailings Basin (FTB) Seepage Capture System (system). The geotechnical exploration consisted of two parts: 1) Rotasonic Exploration and 2) SPT Exploration. Exploration locations are shown on **Figure 1** and summarized on **Table 1**, and logs and associated test data are in **Attachments A** through **D**. More specifically, the exploration was performed to:

- Confirm depth to bedrock at numerous points along the proposed alignment of the seepage cutoff wall component of the system.
- Confirm soil types along the proposed alignment of the system.
- Confirm the presence of cobbles and boulders within the glacial till along the proposed cutoff wall alignment.
- Confirm the hydraulic conductivity of the soils and bedrock along the proposed cutoff wall alignment.

In general, the field exploration encountered a thin layer of peat in the wetlands overlying predominantly silty sand and gravel soils (glacial till). Peat was absent in upland areas. Underlying the glacial till was strong, competent bedrock. The peat ranged in thickness from 0 to 20 feet. The glacial till ranged in thickness from 0 to 42.5 feet. Bedrock was encountered at depths ranging from approximately 2 to 42.5 feet with bedrock at its deepest on the northwest side of the tailings basin. Bedrock fractures were generally in-filled. Cobbles and boulders were frequently encountered on the surface and in the till at various depths.

Rotasonic Borings

The rotasonic borings were performed to: 1) document and sample the soil stratigraphy and bedrock depth along the cutoff wall alignment, 2) collect soil and rock samples for examination, and 3) install standpipe piezometers to monitor ground water elevations and perform slug tests to measure in-situ soil hydraulic conductivity. A total of 22 rotasonic borings (R14-02, 04, 05, 06, 07, 08, 09, 10, 10a, 11, 12, 13, 15, 16, 20, 24, 25, 26, 27, 28, 29, and 30) were performed as part of the geotechnical exploration. Each location was drilled to the estimated top of bedrock and then typically extended an additional 3 to 8.5 feet to confirm that bedrock rather than a boulder was encountered. If rock was encountered shallower than anticipated, several offset borings were performed to confirm bedrock depth.

Ten (10) standpipe piezometers (R14-04, 06, 08, 12, 13, 15, 16, 26, 27, and 28) were installed in 22 of the rotasonic locations to bottom-of-screen depths ranging from 10 to 35 feet. Standpipe piezometers were constructed to monitor water levels and assist in performing slug tests. The piezometers were installed in the borehole and consist of a riser with a screened pipe interval at the bottom 5 feet. Sand pack was placed in the annulus along the screened interval and a bentonite seal was placed above the sand to isolate the pore water pressure to the screened interval. The piezometers were then backfilled with bentonite grout to prevent unwanted vertical migration of water. The screened zone was installed in glacial till at depths determined at the time of drilling and typically corresponded to zones assumed to have a higher hydraulic conductivity than the surrounding soil, usually located just above bedrock. The piezometers were bailed three times during the geotechnical exploration by Barr field staff in order to clean the piezometers and establish flow through the screens. Once water levels were stabilized, slug tests were performed.

A slug test consists of rapid displacement of the static water level in a piezometer or well by adding or removing a solid piece of PVC pipe (as performed for this exploration) or building up and releasing air pressure in the well casing. The slug testing was performed with 5-foot and 10-foot long 1-inch PVC slugs. Three sets of tests were performed in each piezometer. The first and third test was performed with the 10-foot slug and the second test was performed with the 5-foot slug to confirm repeatability. A slug test in which the displacement is initiated by rapidly lowering a slug below the water level is referred to as a slug-in or falling-head test; a slug-out or rising-head test is one in which the slug is rapidly removed. Two slug tests—slug-in and slug-out—were performed sequentially at piezometers. The resulting water-level recovery to static, pre-test conditions was monitored using a data-logging pressure transducer (InSitu – LevelTroll 700). Slug testing data is undergoing final analysis and will be reported in a future update to this memorandum.

SPT Borings

The SPT geotechnical exploration consisted of soil borings performed using mud rotary and hollow stem auger drilling methods. During the drilling, standard penetration tests (SPT), soil sampling via split spoon, bulk soil sampling, and packer testing in the bedrock were performed to: (1) determine the soil and bedrock stratigraphy, (2) collect and perform laboratory testing of undisturbed peat and disturbed till samples, (3) collect in-situ soil characteristics data such as the Standard Penetration Test (SPT) blow count (N) value, and (4) perform packer testing in the bedrock to determine in-situ hydraulic conductivity. Rock cores were collected to confirm depth to bedrock and provide qualitative information, including Rock Quality Designation (RQD) values and fracture characteristics. A total of 12 SPT borings (B14-36, 40, 44, 48, 52, 55, 62, 65, 69, 72, 76, and 80) were performed as part of the geotechnical exploration. Borings were terminated when apparent bedrock was encountered, typically indicated by standard penetration test results in excess of 50 blows for less than one-half foot of penetration, at which point coring into bedrock was performed to obtain a total core of 15-foot length to confirm that bedrock and not a boulder was encountered and to provide adequate rock borehole length for the performance of one to three packer tests per boring location.

Per the SPT borings the bedrock is strong to very strong with zones that appear to previously have been fractured. Fractures were present in most of the cored bedrock from the site and the rock cores were considered to be slightly too moderately fractured. Bedrock contained horizontal fractures, vertical fractures, and fractures ranging from 45 to 65 degrees from the horizontal. The fracture faces are slightly decomposed and fractures occasionally are in-filled with non-cohesive sediment or weathered rock. Packer testing zones containing factures had a higher average hydraulic conductivity than bedrock without fracturing. The fracturing was most prevalent in the upper 5 to 10 feet of bedrock.

Ten (10) Packer tests were performed at various elevations within five (5) of the 12 boring locations (B14-36, 44, 55, 65, 76). The packer testing interval was determined in the field with the intent to obtain the most representative data possible for measuring the hydraulic conductivity of the bedrock. The goal of the packer tests was to perform repetitive tests that would yield reliable information on how much water the rock will conduct to serve as a basis for bedrock hydraulic conductivity. Calibration of the flow meter, gages, and head loss was conducted prior packer testing. All calibration was performed according to the standard methods in United State Bureau of Reclamation publication USBR 7310-89 (United States Bureau of Reclamation, 1989).

Packer testing readings were taken by Barr personnel in accordance with USBR 7310-89. A single or double packer was selected based on best fit with the characteristics of the borehole. All packer tests were performed at the same pressure increments of 15, 30, and 45 psi for 1-minute durations at each increment. For each pressure, once a consistent water loss was recorded for at least three (3) consecutive readings, the pressure was increased or decreased. A complete test cycle was of five-minute duration at pressure readings of 15, 30, 45, and back down to 30 and 15 psi.

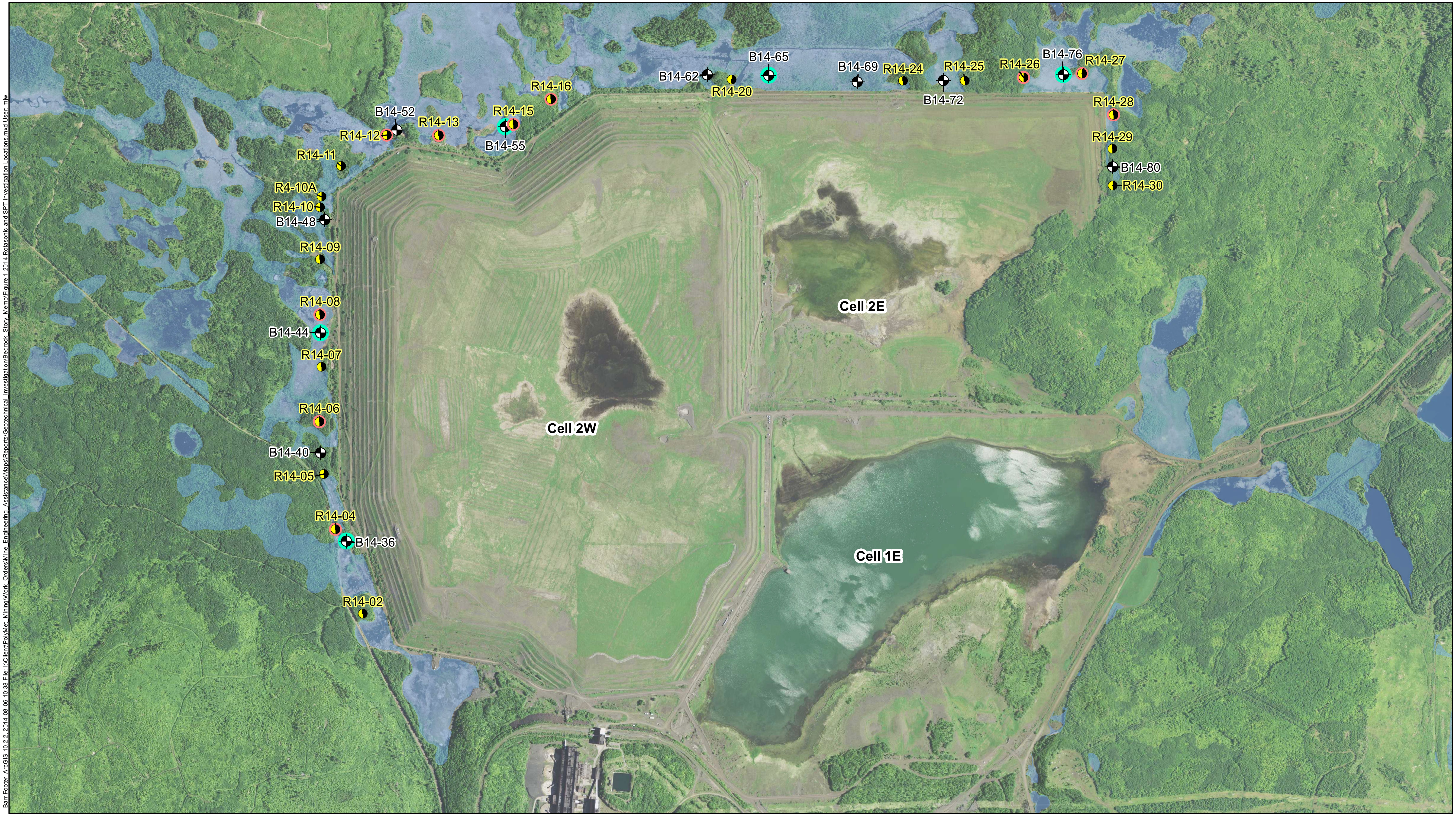
Packer tests were performed in the bedrock at depths ranging from 14 to 50.5 feet below ground surface. The testing intervals were 4.5 to 8 feet in length. The packer test data was analyzed to determine the potential seepage through fractures. The selected hydraulic conductivity from each test was based on the lowest test result from the first three pressure increments to represent the in situ conditions.

There does not appear to be a relationship between packer depth and hydraulic conductivity or RQD. Hydraulic conductivity results were fairly consistent across the site with a slightly lower hydraulic conductivity in B14-36 on the west side of the site. Three of the locations tested indicated that the formation did not take any water at these locations. From the set of packer test results from the winter geotechnical exploration the geometric mean hydraulic conductivity of the bedrock at the site is 1.9×10^{-6} ft/s (5.8×10^{-5} cm/s). For reference, a hydraulic conductivity value of 3.3×10^{-9} ft/s (1.0×10^{-7} cm/s) is considered practically impervious. For packer test results where zero inflow is observed during testing; adjusting these values by incorporating the lowest test value into the calculation of the geomean yields a value of 6.3×10^{-7} ft/s (1.9×10^{-5} cm/s) as a measurement of potential leakage through bedrock joints or fractures. The prevalence of fractures often decreased with increasing core depth and as such the overall conductivity of the bedrock may also decrease with depth.

Table 1
Flotation Tailings Basin Seepage Containment System
SPT Borehole and Rotasonic Borehole Installation Summary

Borehole	Borehole Station[1]	Piezometer Installed	Packer Testing	Depth to Weathered Bedrock (feet)	Depth to Competent Bedrock (feet)	Drilled (incl. Rock Coring) (feet)	Depth to Water[2] (feet)
SPT Borings							
B14-36	19+54		x	--	13.5	26.5	0.0
B14-40	35+25			--	15.0	30.5	4.3
B14-44	55+48		x	31.5	36.5	46.0	2.0
B14-48	74+92			9.5	15.0	25.0	3.0
B14-52	96+85			--	47.0	65.8	4.0
B14-55	115+34		x	30.0	39.0	50.5	10.0
B14-62	152+53			17.0	>27.0	27.0	12.0
B14-65	162+85		x	20.5	22.0	37.0	0.0
B14-69	178+36			29.0	>34.0	34.0	0.0
B14-72	192+86			--	10.0	25.0	1.0
B14-76	213+12		x	25.0	27.0	42.5	0.0
B14-80	235+33			--	10.0	21.0	7.0
Rotasonic Borings							
R14-02	7+15			--	7.5	11.0	--
R14-04	22+07	x		12.0	13.0	15.0	6.0
R14-05	31+64			7.0	8.5	15.0	4.0
R14-06	40+50	x		17.0	17.5	20.0	11.0
R14-07	49+76			--	5.3	12.0	3.0
R14-08	58+50	x		--	21.0	24.0	10.0
R14-09	67+90			13.0	15.0	19.0	5.0
R14-10	76+99			--	2.0	10.0	--
R14-10A	78+81			--	14.0	21.0	5.0
R14-11	85+72			--	10.0	16.0	4.0
R14-12	95+14	x		--	31.0	35.0	2.0
R14-13	103+85	x		--	39.0	45.0	5.0
R14-15	116+67	x		--	32.0	35.0	20.0
R14-16	124+31	x		--	25.5	30.0	16.0
R14-20	156+61			--	31.0	35.0	5.0
R14-24	186+08			--	5.5	14.0	--
R14-25	196+47			--	3.5	10.5	--
R14-26	206+41	x		--	21.5	28.0	4.0
R14-27	216+26	x		--	26.0	30.0	10.0
R14-28	226+60	x		--	10.5	16.5	6.0
R14-29	232+26			--	29.0	34.0	5.0
R14-30	238+49			--	26.0	29.0	10.0

Notes:
(1) Borehole station location is shown (± 25 feet). Actual station location may vary due to offsets.
(2) Depth to water is at time of drilling.



Barr Footer: ArcGIS 10.2.2, 2014-08-06 10:38 File: I:\Client\PolyMet_Mining\Work_Orders\Mine_Engineering_Assistance\Maps\Reports\Geotechnical_Investigation\Bedrock_Story_Memo\Figure 1 2014 Rotasonic and SPT Investigation Locations.mxd User: mlw

Rotasonic Location

Rotasonic Location with a Piezometer

Boring Locations

Boring Locations with Packer

Wetlands

0 1,500 3,000

Feet

Figure 1
2014 ROTASONIC AND SPT GEOTECHNICAL INVESTIGATION LOCATIONS
NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, Minnesota

Attachment A

Rotasonic Logs

Barr Engineering Company
4700 West 77th St. Suite 200
Minneapolis, MN 55435
Telephone: 952-832-2600

LOG OF BORING R14-02

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1566.4 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 734,259.7 ft E 2,858,091.9 ft	Completion Depth:	11.0 ft
Datum:	NAD83 Minnesota State Plane		

Surface Elev.: 1566.4 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION	Depth	Sample No.	% Recovery	SPT, N value or RQD %
1566.4	0	TOPSOIL (OL): dark brown; moist; with roots and leaves; top 2.5 feet frozen.				
1564.9 ft		SILTY SAND WITH GRAVEL (SM): fine to medium grained; brown to gray at 4 feet; moist; weathered granite fragments; some clay below 5 feet; [Till].	1.5ft	A, B	100	
					100	
1558.9 ft		GRANITE; mottled red, black, and white; [Bedrock].	7.5ft	C	67	
1555.4 ft		Bottom of Boring at 11.0 feet	11.0ft			

STANDARD PENETRATION TEST DATA N in blows/ft ◎ (10, 20, 30, 40)
REC% / RQD % ◆ (20, 40, 60, 80)
SHEAR STRENGTH, tsf (0, 2.5, 5)

DRAFT

Date Boring Started:	3/11/14 7:45 am
Date Boring Completed:	3/11/14 8:35 am
Logged By:	BJL2
Drilling Contractor:	Cascade
Drill Rig:	CRS-17-C

Water Levels (ft)
At Time of Drilling: Dry

Remarks:

Weather: 30F, partly cloudy

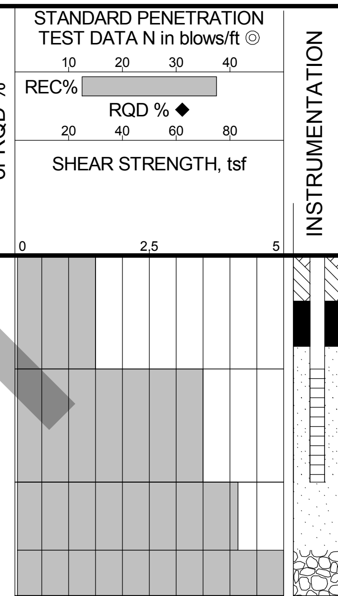
Barr Engineering Company
4700 West 77th St. Suite 200
Minneapolis, MN 55435
Telephone: 952-832-2600

LOG OF BORING R14-04

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1545.4 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 735,679.7 ft E 2,857,633.8 ft	Completion Depth:	15.0 ft
Datum:	NAD83 Minnesota State Plane		

Surface Elev.: 1545.4 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION	Sample No.	% Recovery	SPT, N value or RQD %
1545	0	PEAT (PT): dark brown; moist; sapric; woody debris; top 1.5 feet frozen. 1543.9 ft (1.5ft)	A	30	
		LEAN CLAY (CL): moist; some sand; some sapric peat. 1539.9 ft (5.5ft)			
1540	5	POORLY GRADED SAND WITH SILT (SP-SM): medium to coarse grained; wet; with clay and gravel; [Till]. 1535.9 ft (9.5ft)	B, C	70	
1535	10	POORLY GRADED GRAVEL (GM): medium grained; brown; moist; some clay; [Till]. 1533.4 ft (12.0ft)	D	83	
		GRANITE; mottled red, black, and white; highly weathered to 13 feet; competent bedrock below; [Bedrock]. 1530.4 ft (15.0ft)		100	
	15	Bottom of Boring at 15.0 feet			



Date Boring Started:	3/11/14 9:30 am
Date Boring Completed:	3/11/14 10:15 am
Logged By:	BJL2
Drilling Contractor:	Cascade
Drill Rig:	CRS-17-C

Water Levels (ft)

At Time of Drilling	6.0
After Install	1.1

Remarks:

Weather: 30F, partly cloudy

Barr Engineering Company
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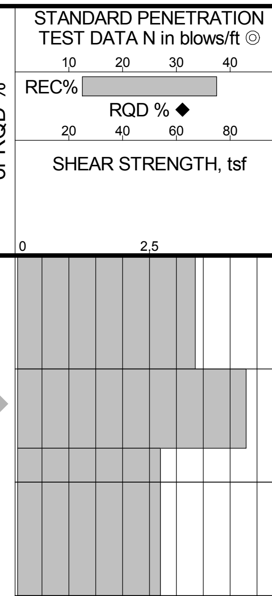
Minneapolis, MN 55435
Telephone: 952-832-2600

LOG OF BORING R14-05

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1539.3 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 736,606.1 ft E 2,857,437.1 ft	Completion Depth:	15.0 ft
Datum:	NAD83 Minnesota State Plane		

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (Surface Elev.: 1539.3 ft)		Sample No.	% Recovery	SPT, N value or RQD %
	0	TOPSOIL (OL): dark brown; roots; top 1.5 feet frozen. 1537.8 ft	1.5ft		67	
1535	5	SILTY SAND WITH GRAVEL (SM): fine to medium grained; brown; moist to wet; weathered granite fragments throughout; changes to gray at 3 feet; [Till]. 1532.3 ft	7.0ft	A	86	
1530	10	GRANITE; mottled red, black, and white; weathered to 8.5 feet, competent rock below; [Bedrock].			54	
1525	15	1524.3 ft	15.0ft			
		Bottom of Boring at 15.0 feet				



Date Boring Started:	3/11/14 12:30 pm	Water Levels (ft)	Remarks: A second boring was offset 8 feet southwest where bedrock was encountered at 8 feet and boring was terminated in bedrock at 13.5 feet.
Date Boring Completed:	3/11/14 2:00 pm	At Time of Drilling 4.0 Estimated	
Logged By:	BJL2		
Drilling Contractor:	Cascade		
Drill Rig:	CRS-17-C		Weather: 30F, partly cloudy

Barr Engineering Company
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Telephone: 952-832-2600

LOG OF BORING R14-06

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1526.4 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 737,489.5 ft E 2,857,364.4 ft	Completion Depth:	20.0 ft
Datum:	NAD83 Minnesota State Plane		

Surface Elev.: 1526.4 ft

Depth, feet	Material Description	Bottom Depth	Sample No.	% Recovery
0	SILTY SAND (SM): fine to medium grained; brown; moist; top 1.5 feet frozen; weathered granite fragments and cobbles; [Till].		A	92
				80
	1518.9 ft Granite boulder from 6.5 to 7.5 feet.	7.5ft		
	SILTY SAND (SM): fine to medium grained; gray; moist; with weathered granite fragments; [Till]. 1515.4 ft	11.0ft		
	10-15 feet: cobble clogged barrel, poor recovery.		B	30
	SANDY SILT (ML): fine grained; gray; wet; with cobbles; [Till]. 1513.9 ft	12.5ft		
	SILTY SAND WITH GRAVEL (SM): medium to coarse grained; gray; wet; [Till]. 1509.4 ft	17.0ft	C	50
	GRANITE; mottled red, black, and white; weathered granite to 17.5 feet; [Bedrock]. 1506.4 ft	20.0ft		100

Bottom of Boring at 20.0 feet

Elevation, feet: 1525, 1520, 1515, 1510. Depth, feet: 0, 5, 10, 15, 20.

STANDARD PENETRATION TEST DATA N in blows/ft (10, 20, 30, 40); REC% ; RQD % (20, 40, 60, 80); SHEAR STRENGTH, tsf (0, 2.5, 5); INSTRUMENTATION

Date Boring Started:	3/11/14 3:00 pm
Date Boring Completed:	3/11/14 4:30 pm
Logged By:	BJL2
Drilling Contractor:	Cascade
Drill Rig:	CRS-17-C

Water Levels (ft)

At Time of Drilling	11.0
After Install	6.9

Remarks:

Weather: 30F, partly cloudy

Barr Engineering Company
4700 West 77th St. Suite 200
Minneapolis, MN 55435
Telephone: 952-832-2600

LOG OF BORING R14-07

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1504.9 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 738,412.4 ft E 2,857,400.7 ft	Completion Depth:	12.0 ft
Datum:	NAD83 Minnesota State Plane		

Surface Elev.: 1504.9 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION	Sample No.	% Recovery	SPT, N value or RQD %
	0	PEAT (PT): dark brown; moist; sapric; wood debris; top 2 feet frozen.	A	80	
	3.0ft	1501.9 ft SILTY SAND (SM): fine to medium grained; brown; wet; [Till].			
1500	5.3ft	1499.7 ft GRANITE; mottled red, black, and white; [Bedrock].	B	100	
				50	
1495	10				
	12.0ft	1492.9 ft		75	

Bottom of Boring at 12.0 feet

STANDARD PENETRATION TEST DATA N in blows/ft ◎ (10, 20, 30, 40)
REC% ; RQD % ◆ (20, 40, 60, 80)
SHEAR STRENGTH, tsf (0, 2.5, 5)

DRAFT

Date Boring Started:	3/12/14 8:00 am
Date Boring Completed:	3/12/14 10:00 am
Logged By:	BJL2
Drilling Contractor:	Cascade
Drill Rig:	CRS-17-C

Water Levels (ft)
At Time of Drilling 3.0

Remarks: A second boring was offset ~8 feet west where bedrock was encountered at 7 feet and the boring was terminated in bedrock at 11 feet.

Weather: 0 to 20F, sunny

Barr Engineering Company
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Minneapolis, MN 55435
Telephone: 952-832-2600

LOG OF BORING R14-08

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1502.8 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 739,287.6 ft E 2,857,372.0 ft	Completion Depth:	24.0 ft
Datum:	NAD83 Minnesota State Plane		

Surface Elev.: 1502.8 ft

Depth, feet	MATERIAL DESCRIPTION	Sample No.	% Recovery
0	PEAT (PT): dark brown; moist; top 2 feet frozen. 1498.8 ft	A	40
4.0ft	SILTY SAND (SM): fine to medium grained; brown; moist; trace gravel; [Till]. 1492.8 ft	B	80
10.0ft	POORLY GRADED SAND WITH SILT AND GRAVEL (SP-SM): medium to coarse grained; brown; wet; with cobbles from 18 to 21 feet; [Till]. 1481.8 ft	C	23
			100
			33
21.0ft	GRANITE; mottled red, black, and white; [Bedrock]. 1478.8 ft		83
24.0ft	Bottom of Boring at 24.0 feet		

Column headings: Elevation, feet; Depth, feet; MATERIAL DESCRIPTION; Graphic Log; Samples; Sample No.; % Recovery; SPT, N value or RQD %; STANDARD PENETRATION TEST DATA N in blows/ft ◎ (10, 20, 30, 40); REC%; RQD % ◆ (20, 40, 60, 80); SHEAR STRENGTH, tsf (0, 2.5, 5); INSTRUMENTATION

Elevation scale: 1500, 1495, 1490, 1485, 1480. Depth scale: 0, 5, 10, 15, 20.

Date Boring Started:	3/12/14 11:00 am
Date Boring Completed:	3/12/14 12:45 pm
Logged By:	BJL2
Drilling Contractor:	Cascade
Drill Rig:	CRS-17-C

Water Levels (ft)

At Time of Drilling	10.0
After Install	0.6

Remarks:

Weather: 0 to 20F, sunny

Barr Engineering Company
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Telephone: 952-832-2600

LOG OF BORING R14-09

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1493.3 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 740,225.4 ft E 2,857,373.8 ft	Completion Depth:	19.0 ft
Datum:	NAD83 Minnesota State Plane		

Surface Elev.: 1493.3 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION	Sample No.	% Recovery	SPT, N value or RQD %
1493.3	0	SILTY SAND (SM): medium grained; brown; moist to wet; trace gravel; with cobbles below 5 feet; top 2 feet frozen; [Till].	A	100	
	5 (water level)	5-10 feet: poor recovery likely due to cobble in shoe.		30	
				50	
1480.3 ft	13.0ft	GRANITE; mottled red, black, and white; weathered granite from 13 to 15 feet; [Bedrock].		67	
1474.3 ft	19.0ft	Bottom of Boring at 19.0 feet			

STANDARD PENETRATION TEST DATA N in blows/ft; REC%; RQD %; SHEAR STRENGTH, tsf

Date Boring Started:	3/12/14 2:30 pm	Water Levels (ft)	Remarks:
Date Boring Completed:	3/12/14 4:00 pm	At Time of Drilling 5.0	
Logged By:	BJL2		
Drilling Contractor:	Cascade		
Drill Rig:	CRS-17-C		Weather: 10 to 20F, sunny

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Minneapolis, MN 55435
Telephone: 952-832-2600

BARR

LOG OF BORING R14-10

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1492.8 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 741,099.5 ft E 2,857,371.8 ft	Completion Depth:	10.0 ft
Datum:	NAD83 Minnesota State Plane		

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (Surface Elev.: 1492.8 ft)	Depth	Graphic Log	Samples	Sample No.	% Recovery	SPT, N value or RQD %
	0	TOPSOIL (OL): dark brown; moist; roots; top 2 feet frozen. 1492.6 ft	0.3ft					
1490		POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; brown; moist; with weathered granite fragments; organic material; [Till]. 1490.8 ft	2.0ft				100	
1485	5	GRANITE; mottled red, black, and white; [Bedrock]. 1482.8 ft					83	
	10	Bottom of Boring at 10.0 feet	10.0ft					

STANDARD PENETRATION TEST DATA N in blows/ft ◎ (10, 20, 30, 40)
REC% ▭
RQD % ◆ (20, 40, 60, 80)
SHEAR STRENGTH, tsf (0, 2.5, 5)

Date Boring Started:	3/13/14 10:00 am
Date Boring Completed:	3/13/14 11:30 am
Logged By:	BJL2
Drilling Contractor:	Cascade
Drill Rig:	CRS-17-C

Water Levels (ft)
At Time of Drilling: Dry

Remarks: A second boring was offset ~30 feet south where bedrock was encountered at 3 feet. A third boring was offset ~10 feet east of the first boring where bedrock was encountered at 1.5 feet.

Weather: 20 to 40F, overcast

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LOG OF BORING R14-10A

Sheet 1 of 1

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1493.0 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 741,279.3 ft E 2,857,400.1 ft	Completion Depth:	21.0 ft
Datum:	NAD83 Minnesota State Plane		

Surface Elev.: 1493.0 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION	Sample No.	% Recovery	SPT, N value or RQD %
1492.5 ft	0–0.5ft	TOPSOIL (OL): dark brown; moist; roots and organics; top 2 feet frozen.			
1490.5 ft	0.5–2.5ft	POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; brown; moist; with weathered granite fragments; [Till].	A	100	
1488.0 ft	2.5–5.0ft	BOULDER: mottled red, black, and white.	B	80	
1479.0 ft	5.0–14.0ft	POORLY GRADED SAND WITH SILT (SP-SM): medium to coarse grained; brown; wet; gray below 10 feet; with weathered granite fragments; [Till].		100	
1472.0 ft	14.0–21.0ft	GRANITE; mottled red, black, and white; drilling bit wore out - no recovery from 20 to 21 feet; [Bedrock].		67	
				0	

Bottom of Boring at 21.0 feet

STANDARD PENETRATION TEST DATA N in blows/ft ◎ 10 20 30 40
REC% ▨
RQD % ◆ 20 40 60 80
SHEAR STRENGTH, tsf 0 2.5 5

Date Boring Started:	3/18/14 11:30 am
Date Boring Completed:	3/18/14 12:15 pm
Logged By:	BJL2
Drilling Contractor:	Cascade
Drill Rig:	CRS-17-C

Water Levels (ft)
At Time of Drilling 5.0

Remarks:

Weather: 20F, overcast

DRAFT

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LOG OF BORING R14-11

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1483.1 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 741,794.5 ft E 2,857,729.4 ft	Completion Depth:	16.0 ft
Datum:	NAD83 Minnesota State Plane		

Surface Elev.: 1483.1 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION	Layer Depth	Sample No.	% Recovery	SPT, N value or RQD %
	0	TOPSOIL (OL): dark browm; moist; organics with roots; top 1.5 feet frozen. 1482.9 ft	0.3ft			
1480		SILTY SAND (SM): fine to medium grained; brown; moist; 6-inch clay layer at 1.5 feet; [Till]. 1479.1 ft	4.0ft	A	77	
1475	5	POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; brown; wet; [Till]. 1474.1 ft	9.0ft	B	100	
	10	POORLY GRADED SAND WITH SILT (SP-SM): medium to coarse grained; gray; wet; with cobbles and weathered granite fragments; [Till]. 1473.1 ft	10.0ft			
1470	15	GRANITE; mottled red, black, and white; [Bedrock]. 1467.1 ft	16.0ft	C	83	

Bottom of Boring at 16.0 feet

STANDARD PENETRATION TEST DATA N in blows/ft ◎ (10, 20, 30, 40)
REC%
RQD % ◆ (20, 40, 60, 80)
SHEAR STRENGTH, tsf (0, 2.5, 5)

Graphic Log | Samples

Date Boring Started:	3/13/14 8:00 am
Date Boring Completed:	3/13/14 9:10 am
Logged By:	BJL2
Drilling Contractor:	Cascade
Drill Rig:	CRS-17-C

Water Levels (ft)
At Time of Drilling 4.0

Remarks:

Weather: 20 to 40F, overcast

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LOG OF BORING R14-12

Sheet 1 of 1

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1480.3 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 742,311.8 ft E 2,858,500.4 ft	Completion Depth:	35.0 ft
Datum:	NAD83 Minnesota State Plane		

Surface Elev.: 1480.3 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION	Layer depth	Sample No.	% Recovery
	0	TOPSOIL (OL): dark brown; moist; with wood and leaf debris. 1479.8 ft	0.5ft		
		SILT (ML): brown; moist; with sand. 1478.3 ft	2.0ft	A, B	100
1475	5	POORLY GRADED SAND WITH SILT (SP-SM): fine to coarse grained; gray to brown; wet; some weathered granite fragments to 13 feet; [Till].			40
1470	10	1467.3 ft		C	100
		SILTY SAND (SM): fine grained; gray; wet; [Till]. 1465.3 ft	13.0ft		
1465	15	SILT (ML): gray; moist; with sand; little clay at 18 feet; [Till]. 1462.3 ft	15.0ft	D	80
		SILTY SAND (SM): fine to medium grained; gray; wet; [Till].	18.0ft		
1460	20				92
1455	25			E	50
		1451.3 ft			90
1450	30	POORLY GRADED GRAVEL WITH SAND (GP): gray; wet; some cobbles with weathered granite fragments; [Till]. 1449.3 ft	29.0ft		
		GRANITE; mottled red, black, and white; [Bedrock]. 1445.3 ft	31.0ft		83
	35	Bottom of Boring at 35.0 feet	35.0ft		

Column headings: Graphic Log; Samples; Sample No.; % Recovery; SPT, N value or RQD %; STANDARD PENETRATION TEST DATA N in blows/ft ◎ (10, 20, 30, 40); REC%; RQD % ◆ (20, 40, 60, 80); SHEAR STRENGTH, tsf (0, 2.5, 5); INSTRUMENTATION

DRAFT

Date Boring Started:	3/13/14 1:45 pm
Date Boring Completed:	3/13/14 3:30 pm
Logged By:	BJL2
Drilling Contractor:	Cascade
Drill Rig:	CRS-17-C

Water Levels (ft)

At Time of Drilling	2.0
After Install	-0.3

Remarks:

Weather: 20 to 40F, overcast

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LOG OF BORING R14-13

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1489.1 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 742,310.5 ft E 2,859,372.0 ft	Completion Depth:	45.0 ft
Datum:	NAD83 Minnesota State Plane		

Surface Elev.: 1489.1 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION	Depth	Sample No.	% Recovery
1488.9 ft	0	TOPSOIL (OL): dark brown; moist; roots and organics; top 1.5 feet frozen.	0.3ft	A, B	80
1486.6 ft		POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; brown; moist; with granite fragments.	2.5ft		
1484.1 ft	5	SILTY SAND (SM): fine to medium grained; brown; moist; some gravel, clay, and cobbles; [Till].	5.0ft	C	100
1474.6 ft	10	POORLY GRADED SAND WITH SILT (SP-SM): medium to coarse grained; brown; wet; with weathered granite fragments; [Till].		D	80
1473.6 ft	14.5	SILTY SAND (SM): fine to medium grained; brown; wet; [Till].	14.5ft		
1467.1 ft	15.5	POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; brown to gray; wet; weathered granite fragments; [Till].	15.5ft	E	60
				F	60
1454.6 ft	22.0	SILTY SAND (SM): fine grained; gray; wet; with 3 to 6 inch silt and sand layers from 30 to 34.5 feet; [Till].	22.0ft	G	20
					100
1450.1 ft	34.5	POORLY GRADED SAND WITH SILT (SP-SM): medium to coarse grained; gray; wet; with cobbles and weathered granite fragments; brown below 37 feet; [Till].	34.5ft		100
1444.1 ft	39.0	GRANITE; mottled red, black, and white; [Bedrock].	39.0ft		50
	45	Bottom of Boring at 45.0 feet	45.0ft		

Column headings: Graphic Log; Samples; Sample No.; % Recovery; SPT, N value or RQD %; STANDARD PENETRATION TEST DATA N in blows/ft ◎ (10, 20, 30, 40); REC%; RQD % ◆ (20, 40, 60, 80); SHEAR STRENGTH, tsf (0, 2.5, 5); INSTRUMENTATION

Elevation scale: 1485, 1480, 1475, 1470, 1465, 1460, 1455, 1450, 1445. Depth scale: 0, 5, 10, 15, 20, 25, 30, 35, 40, 45.

Date Boring Started:	3/14/14 8:00 am	Water Levels (ft)	Remarks:
Date Boring Completed:	3/14/14 12:00 pm	At Time of Drilling 5.0	
Logged By:	BJL2	After Install 1.9	
Drilling Contractor:	Cascade		
Drill Rig:	CRS-17-C		Weather: 20 to 30F, overcast

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LOG OF BORING R14-15

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1494.8 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 742,493.1 ft E 2,860,626.1 ft	Completion Depth:	35.0 ft
Datum:	NAD83 Minnesota State Plane		

Surface Elev.: 1494.8 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION	Sample No.	% Recovery
1494.3	0.5	TOPSOIL (OL): dark brown; moist; roots and sticks.		
1490.3	4.5	POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; dark brown to brown; moist; with weathered granite fragments.	A	83
1465.8	29.0	SILTY SAND WITH GRAVEL (SM): medium to coarse grained; brown; moist to wet; with cobbles from 5 to 10 feet; with weathered granite fragments; [Till]. Saturated zone at 20 feet.	B	40
				80
				100
			C	80
				80
1462.8	32.0	POORLY GRADED SAND WITH SILT (SP-SM): medium to coarse grained; brown to gray; wet; with cobbles and weathered granite fragments; [Till].		100
1459.8	35.0	GRANITE; mottled red, black, and white; [Bedrock].		75

Bottom of Boring at 35.0 feet

Column headings: Graphic Log; Samples; SPT, N value or RQD %; STANDARD PENETRATION TEST DATA N in blows/ft ◎ (10, 20, 30, 40); REC%; RQD % ◆ (20, 40, 60, 80); SHEAR STRENGTH, tsf (0, 2.5, 5); INSTRUMENTATION

Date Boring Started:	3/14/14 1:30 pm	Water Levels (ft)	Remarks:
Date Boring Completed:	3/14/14 4:00 pm	After Install 6.8	
Logged By:	BJL2		
Drilling Contractor:	Cascade		
Drill Rig:	CRS-17-C		Weather: 15 to 20F, overcast

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LOG OF BORING R14-16

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1507.6 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 742,916.4 ft E 2,861,262.2 ft	Completion Depth:	30.0 ft
Datum:	NAD83 Minnesota State Plane		

Surface Elev.: 1507.6 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION	Sample No.	% Recovery
1507.1	0.5	TOPSOIL (OL): brown; moist; organics and leaf debris.		
		SILTY SAND WITH GRAVEL (SM): fine to medium grained; brown; moist to wet; [Till].	A	100
				100
		Cobbles and granite fragments from 9 to 9.5 feet.		90
				50
1483.1	24.5		B	100
1482.1	25.5	POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; brown; wet; [Till].		100
1477.6	30.0	GRANITE; red; highly weathered; poor recovery due to drilling with water; [Bedrock].		13

Bottom of Boring at 30.0 feet

Column headings: Graphic Log; Samples; SPT, N value or RQD %; STANDARD PENETRATION TEST DATA N in blows/ft ◎ (10, 20, 30, 40); REC%; RQD % ◆ (20, 40, 60, 80); SHEAR STRENGTH, tsf (0, 2.5, 5); INSTRUMENTATION

DRAFT

Date Boring Started:	3/15/14 8:30 am
Date Boring Completed:	3/15/14 9:15 am
Logged By:	BJL2
Drilling Contractor:	Cascade
Drill Rig:	CRS-17-C

Water Levels (ft)
- At Time of Drilling: 16.0
- After Install: 16.8

Remarks:

Weather: 5 to 20F, overcast

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LOG OF BORING R14-20

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1487.3 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 743,246.7 ft E 2,864,302.4 ft	Completion Depth:	35.0 ft
Datum:	NAD83 Minnesota State Plane		

STANDARD PENETRATION TEST DATA N in blows/ft ◎ (10, 20, 30, 40); REC%; RQD % ◆ (20, 40, 60, 80); SHEAR STRENGTH, tsf (0, 2.5, 5)

Surface Elev.: 1487.3 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION	Sample No.	% Recovery	SPT, N value or RQD %
1487.3 – 1486.3 ft	0 – 1.0ft	PEAT (PT): dark brown; moist; sapric; woody debris; top 1.5 feet frozen.			
1486.3 – 1470.3 ft	1.0 – 17.0ft	SILTY SAND WITH GRAVEL (SM): fine to medium grained; brown; moist; with clay and cobbles; [Till].	A	100, 100, 100, 88	
1470.3 – 1469.3 ft	17.0 – 18.0ft	BOULDER: mottled red, black, and white.			
1469.3 – 1463.3 ft	18.0 – 24.0ft	CLAYEY SAND WITH GRAVEL (SC): fine to medium grained; brown; moist; with cobbles; boulder from 17 to 18 feet; [Till].	B	100, 100	
1463.3 – 1460.3 ft	24.0 – 27.0ft	BOULDER: mottled red, black, and white.			
1460.3 – 1456.3 ft	27.0 – 31.0ft	POORLY GRADED GRAVEL WITH SAND (GP): brown and gray; wet; medium to coarse sand; [Till].	C	67	
1456.3 – 1452.3 ft	31.0 – 35.0ft	GRANITE; mottled red, black, and white; highly weathered; [Bedrock].		100	
	35.0ft	Bottom of Boring at 35.0 feet			

Water level symbol at depth 5 ft.

Date Boring Started:	3/15/14 12:00 pm
Date Boring Completed:	3/15/14 4:00 pm
Logged By:	BJL2
Drilling Contractor:	Cascade
Drill Rig:	CRS-17-C

Water Levels (ft)
▼ At Time of Drilling 5.0

Remarks: Artesian flow of ~10-12 gpm started at 31 feet. Static water level was ~34-36 inches above ground surface.

Weather: 5 to 15F, sunny

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LOG OF BORING R14-24

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1491.1 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 743,227.5 ft E 2,867,188.8 ft	Completion Depth:	14.0 ft
Datum:	NAD83 Minnesota State Plane		

Surface Elev.: 1491.1 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION	Sample No.	% Recovery	SPT, N value or RQD %
1490.1 ft	1.0ft	TOPSOIL (OL): brown; moist; with roots and leaf debris.			
1485.6 ft	5.5ft	SILTY SAND WITH GRAVEL (SM): fine to medium grained; brown; moist; some cobbles and weathered granite fragments; [Till].	A, B	100	
				100	
				100	
				50	
1477.1 ft	14.0ft	GRANITE; mottled red, black, and white; [Bedrock].		100	

Bottom of Boring at 14.0 feet

STANDARD PENETRATION TEST DATA N in blows/ft ◎ (10, 20, 30, 40); REC% ▭; RQD % ◆ (20, 40, 60, 80); SHEAR STRENGTH, tsf (0, 2.5, 5)

Date Boring Started:	3/16/14 8:30 am
Date Boring Completed:	3/16/14 11:30 am
Logged By:	BJL2
Drilling Contractor:	Cascade
Drill Rig:	CRS-17-C

Water Levels (ft)
At Time of Drilling: Dry

Remarks:

Weather: -10 to 10F, sunny

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LOG OF BORING R14-25

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1497.2 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 743,227.7 ft E 2,868,226.9 ft	Completion Depth:	10.5 ft
Datum:	NAD83 Minnesota State Plane		

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION	Graphic Log	Samples	Sample No.	% Recovery	SPT, N value or RQD %	STANDARD PENETRATION TEST DATA N in blows/ft ◎ / REC% / RQD % ◆ / SHEAR STRENGTH, tsf
	0	Surface Elev.: 1497.2 ft						
		BOULDER: mottled red, black, and white. 1496.2 ft (1.0ft)			A	57		
1495		SILTY SAND WITH GRAVEL: fine to medium grained; brown; moist; with weathered granite fragments; [Till]. 1493.7 ft (3.5ft)						
	5	GRANITE; mottled red, black, and white; [Bedrock].				88		
1490								
	10	1486.7 ft				56		
		Bottom of Boring at 10.5 feet (10.5ft)						

Date Boring Started:	3/16/14 12:00 pm	Water Levels (ft)	Remarks:
Date Boring Completed:	3/16/14 1:40 pm	At Time of Drilling Dry	
Logged By:	BJL2		
Drilling Contractor:	Cascade		
Drill Rig:	CRS-17-C		Weather: 10 to 20F, sunny

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LOG OF BORING R14-26

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1502.5 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 743,283.6 ft E 2,869,216.9 ft	Completion Depth:	28.0 ft
Datum:	NAD83 Minnesota State Plane		

Surface Elev.: 1502.5 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION	Sample No.	% Recovery
1502.5–1501.5 ft	0–1.0 ft	PEAT (PT): dark brown; frozen; wood and leaf debris; top 1 foot frozen.		
1501.5–1481.0 ft	1.0–21.5 ft	SILTY SAND WITH GRAVEL (SM): fine to medium grained; brown; moist to wet; some cobbles; [Till].	A	60
			B	100
				100
				40
1481.0–1474.5 ft	21.5–28.0 ft	GRANITE; mottled red, black, and white; [Bedrock].		100
				100
		Bottom of Boring at 28.0 feet		

Column headings: Graphic Log; Samples; Sample No.; % Recovery; SPT, N value or RQD %; STANDARD PENETRATION TEST DATA N in blows/ft ◎ (10, 20, 30, 40); REC%; RQD % ◆ (20, 40, 60, 80); SHEAR STRENGTH, tsf (0, 2.5, 5); INSTRUMENTATION

Date Boring Started:	3/16/14 2:00 pm	Water Levels (ft)		Remarks:
Date Boring Completed:	3/16/14 4:00 pm	At Time of Drilling	4.0	
Logged By:	BJL2	After Install	1.6	
Drilling Contractor:	Cascade			
Drill Rig:	CRS-17-C			Weather: 15 to 20F, sunny

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LOG OF BORING R14-27

Sheet 1 of 1

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1502.8 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 743,350.1 ft E 2,870,201.4 ft	Completion Depth:	30.0 ft
Datum:	NAD83 Minnesota State Plane		

Elevation, feet | Depth, feet | MATERIAL DESCRIPTION | Graphic Log | Samples | Sample No. | % Recovery | SPT, N value or RQD % | STANDARD PENETRATION TEST DATA N in blows/ft ◎ (10, 20, 30, 40); REC% ; RQD % ◆ (20, 40, 60, 80); SHEAR STRENGTH, tsf (0, 2.5, 5) | INSTRUMENTATION

Surface Elev.: 1502.8 ft

PEAT (PT): dark brown; moist; with roots and sticks; frozen. 1502.3 ft — 0.5ft

POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; brown; moist to wet; with cobbles and weathered granite fragments; [Till].

Weight of barrel pushed sampler from 10 to 13 feet.

1487.8 ft — 15.0ft

POORLY GRADED SAND (SP): medium grained; brown; wet; with cobbles and weathered granite fragments; [Till].

1483.3 ft — 19.5ft

POORLY GRADED GRAVEL WITH SILT (GP): gray; wet; with cobbles and weathered granite fragments; sand layer from 23-24 feet; [Till].

1477.8 ft — 25.0ft

POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; gray; wet; [Till].

1476.8 ft — 26.0ft

GRANITE; mottled red, black, and white; fracture at 29.5 feet; [Bedrock].

1472.8 ft — 30.0ft

Bottom of Boring at 30.0 feet

Depth interval (ft)	Sample No.	% Recovery
0–5	A	80
5–10		100
10–15		30
15–20	B	30
20–25	C	80
25–26		100
26–30		75

Elevation scale: 1500, 1495, 1490, 1485, 1480, 1475. Depth scale: 0, 5, 10, 15, 20, 25, 30.

Date Boring Started:	3/17/14 8:00 am	Water Levels (ft)	Remarks:
Date Boring Completed:	3/17/14 10:00 am	At Time of Drilling 10.0	
Logged By:	BJL2	After Install 1.7	
Drilling Contractor:	Cascade		
Drill Rig:	CRS-17-C		Weather: 20F, overcast, some wind

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LOG OF BORING R14-28

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1509.5 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 742,651.3 ft E 2,870,734.5 ft	Completion Depth:	16.5 ft
Datum:	NAD83 Minnesota State Plane		

Surface Elev.: 1509.5 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION	Sample No.	% Recovery
	0	POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; brown; moist; with cobbles and weathered granite fragments; top 1 foot frozen; [Till].	A	80
1505	5			80
1500	10	1499.0 ft		100
	10.5ft	GRANITE; mottled red, black, and white; [Bedrock].		100
1495	15	1493.0 ft		
	16.5ft	Bottom of Boring at 16.5 feet		

STANDARD PENETRATION TEST DATA N in blows/ft (10, 20, 30, 40); REC%; RQD % (20, 40, 60, 80); SHEAR STRENGTH, tsf (0, 2.5, 5); INSTRUMENTATION

Graphic Log; Samples; SPT, N value or RQD %

DRAFT

Date Boring Started:	3/17/14 1:00 pm
Date Boring Completed:	3/17/14 2:00 pm
Logged By:	BJL2
Drilling Contractor:	Cascade
Drill Rig:	CRS-17-C

Water Levels (ft)

At Time of Drilling	6.0
After Install	4.3

Remarks:

Weather: 20F, overcast

LOG OF BORING R14-29

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1521.5 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 742,084.4 ft E 2,870,713.4 ft	Completion Depth:	34.0 ft
Datum:	NAD83 Minnesota State Plane		

Surface Elev.: 1521.5 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION	Sample No.	% Recovery	SPT, N value or RQD %
1521.5 – 1515.5	0 – 6.0	SILTY SAND WITH GRAVEL (SM): fine to medium grained; brown; moist; with cobbles and weathered granite fragments; [Till].	A	40	
1515.5 – 1513.5	6.0 – 8.0	BOULDER: mottled red, black, and white.		80	
1513.5 – 1502.0	8.0 – 19.5	SILTY SAND WITH GRAVEL (SM): fine to medium grained; brown; wet; with cobbles and weathered granite fragments; [Till].	B	70, 80	
1502.0 – 1492.5	19.5 – 29.0	POORLY GRADED SAND WITH SILT (SP-SM): medium to coarse grained; gray; wet; with cobbles and weathered granite fragments; [Till].		100, 75	
1492.5 – 1487.5	29.0 – 34.0	GRANITE; mottled red, black, and white; fracture at 33 feet; [Bedrock].		87	

Bottom of Boring at 34.0 feet 34.0ft

STANDARD PENETRATION TEST DATA N in blows/ft ◎ (10, 20, 30, 40)
REC% ▭ RQD % ◆ (20, 40, 60, 80)
SHEAR STRENGTH, tsf (0, 2.5, 5)

Water level symbol at 5 ft.

DRAFT

Date Boring Started:	3/17/14 3:00 pm
Date Boring Completed:	3/17/14 5:00 pm
Logged By:	BJL2
Drilling Contractor:	Cascade
Drill Rig:	CRS-17-C

Water Levels (ft)
At Time of Drilling 5.0

Remarks:

Weather: 20F, overcast

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LOG OF BORING R14-30

Project:	Winter 2013/2014 Rotasonic Investigation	Surface Elevation:	1529.2 ft
Job No.:	23690C29.13	Drilling Method:	Sonic
Location:	Hoyt Lakes, MN	Sampling Method:	Rotosonic Soil Core
Coordinates:	N 741,461.2 ft E 2,870,719.3 ft	Completion Depth:	29.0 ft
Datum:	NAD83 Minnesota State Plane		

Surface Elev.: 1529.2 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION	Sample No.	% Recovery
1529.2	0	BOULDER: gray.		
1528.7 ft	0.5ft	POORLY GRADED SAND WITH SILT (SP-SM): medium grained; reddish brown; moist; trace weathered granite fragments; [Till].	A	73
1524.2 ft	5.0ft	POORLY GRADED SAND WITH SILT (SP-SM): medium to coarse grained; brown; moist to wet; with cobbles and weathered granite fragments increasing with depth; [Till].	B	40
	10–15			50
	15–20	Pushed a rock from 15 to 20 feet.		0
	20–24			80
	24–25			100
1503.2 ft	26.0ft	GRANITE; mottled red, black, and white; fractured bedrock; no water return during drilling; [Bedrock].		83
1500.2 ft	29.0ft	Bottom of Boring at 29.0 feet		

Column headings: Elevation, feet; Depth, feet; MATERIAL DESCRIPTION; Graphic Log; Samples; Sample No.; % Recovery; SPT, N value or RQD %; STANDARD PENETRATION TEST DATA N in blows/ft ◎ (10, 20, 30, 40); REC% ; RQD % ◆ (20, 40, 60, 80); SHEAR STRENGTH, tsf (0, 2.5, 5)

Elevation scale: 1525, 1520, 1515, 1510, 1505. Depth scale: 0, 5, 10, 15, 20, 25. Water level symbol at elevation 1520 (depth 10).

Date Boring Started:	3/18/14 8:15 am	Water Levels (ft)	Remarks:
Date Boring Completed:	3/18/14 10:40 am	At Time of Drilling 10.0	
Logged By:	BJL2		
Drilling Contractor:	Cascade		
Drill Rig:	CRS-17-C		Weather: 20F, overcast

Attachment B

Piezometer Logs

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Telephone: 952-832-2600

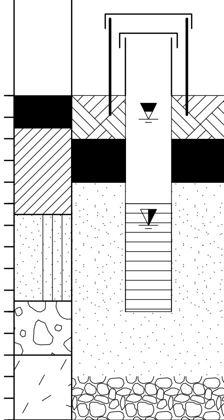
LOG OF PIEZOMETER R14-04

Project: Winter 2013/2014 Piezometers	Location: Hoyt Lakes, MN	Client: PolyMet
Barr Project Number: 23690C29.13	Surface Elevation: 1545.4 ft	Top of Casing Elevation: 1547.7

STRATA

DESCRIPTION	DEPTH, ft
PEAT (PT): dark brown; moist; sapric; woody debris; top 1.5 feet frozen. 1543.9 ft	0
LEAN CLAY (CL): moist; some sand; some sapric peat. 1539.9 ft	5
POORLY GRADED SAND WITH SILT (SP-SM): medium to coarse grained; wet; with clay and gravel; [Till]. 1535.9 ft	10
POORLY GRADED GRAVEL (GM): medium grained; brown; moist; some clay; [Till]. 1533.4 ft	15
GRANITE; mottled red, black, and white; highly weathered to 13 feet; competent bedrock below; [Bedrock]. 1530.4 ft	

Bottom of Boring at 15.0 feet



DEPTH, ft		ELEVATION, ft
-2.5	TPC	1547.9
-2.3	TRC	1547.7
0.0	GS	1545.4
2.0		1543.4
4.0	BS	1541.4
10.0	BSC	1535.4
13.0	TD	1532.4
15.0		1530.4

PIEZOMETER CONSTRUCTION DETAILS FOR STANDPIPE PIEZOMETER

PROTECTIVE CASING
Diameter: **6 inches**
Type: **Steel**
Interval: **-2.5 - 4.5**

RISER CASING
Diameter: **2 inches**
Type: **PVC**
Interval: **-2.3-5**

GROUT
Type: **Cement**
Interval: **0-2**

SEAL
Type: **Bentonite Chips**
Interval: **2-4**

SANDPACK
Type: **Silica Sand**
Interval: **4-13**

SCREEN
Diameter: **2 inches**
Type: **Continuous 0.01" slotted PVC**
Interval: **5-10**

Remarks:

Completion Depth:	15.0 ft
Date Started:	3/11/14
Date Completed:	3/11/14
Logged By:	BJL2
Drilling Contractor:	Cascade
Drilling Method:	Sonic
Datum:	NAD83 Minnesota State Plane
Coordinates:	N 735,679.7 ft E 2,857,633.8 ft

LEGEND

FILTER PACK
BENTONITE
CEMENT GROUT
CUTTINGS / BACKFILL

TPC	TOP OF PROTECTIVE CASING
TRC	TOP OF RISER CASING
BPC	BASE PROTECTIVE CASING
GS	GROUND SURFACE
BS	BENTONITE SEAL
FP	FILTER PACK
TSC	TOP OF SCREEN
BSC	BOTTOM OF SCREEN
TD	TOTAL DEPTH

WATER LEVELS(ft)

At Time of Drilling	6.0
After Install	1.1

The stratification lines represent approximate boundaries. The transition may be gradual.

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LOG OF PIEZOMETER R14-06

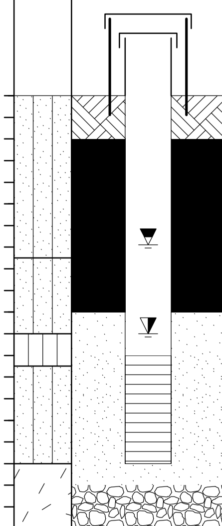
Project: Winter 2013/2014 Piezometers	Location: Hoyt Lakes, MN	Client: PolyMet
Barr Project Number: 23690C29.13	Surface Elevation: 1526.4 ft	Top of Casing Elevation: 1528.7

STRATA

DESCRIPTION	DEPTH, ft
SILTY SAND (SM): fine to medium grained; brown; moist; top 1.5 feet frozen; weathered granite fragments and cobbles; [Till]. 1518.9 ft	0
SILTY SAND (SM): fine to medium grained; gray; moist; with weathered granite fragments; [Till]. 1515.4 ft	
SANDY SILT (ML): fine grained; gray; wet; with cobbles; [Till]. 1513.9 ft	
SILTY SAND WITH GRAVEL (SM): medium to coarse grained; gray; wet; [Till]. 1509.4 ft	
GRANITE; mottled red, black, and white; weathered granite to 17.5 feet; [Bedrock]. 1506.4 ft	20

Bottom of Boring at 20.0 feet

PIEZOMETER DETAILS



DEPTH, ft		ELEVATION, ft
-2.5	TPC	**1528.9**
-2.3	TRC	**1528.7**
0.0	GS	**1526.4**
2.0		1524.4
10.0	BS	1516.4
17.0	BSC	1509.4
18.0	TD	1508.4
20.0		1506.4

PIEZOMETER CONSTRUCTION DETAILS FOR STANDPIPE PIEZOMETER

PROTECTIVE CASING
Diameter: **6 inches**
Type: **Steel**
Interval: **-2.5-4.5**

RISER CASING
Diameter: **2 inches**
Type: **PVC**
Interval: **-2.3-12**

GROUT
Type: **Cement**
Interval: **0-2**

SEAL
Type: **Bentonite Chips**
Interval: **2-10**

SANDPACK
Type: **Silica Sand**
Interval: **10-18**

SCREEN
Diameter: **2 inches**
Type: **Continuous 0.01" slotted PVC**
Interval: **12-17**

Remarks:

Completion Depth:	20.0 ft
Date Started:	3/11/14
Date Completed:	3/11/14
Logged By:	BJL2
Drilling Contractor:	Cascade
Drilling Method:	Sonic
Datum:	NAD83 Minnesota State Plane
Coordinates:	N 737,489.5 ft E 2,857,364.4 ft

LEGEND

FILTER PACK
BENTONITE
CEMENT GROUT
CUTTINGS / BACKFILL

TPC TOP OF PROTECTIVE CASING
TRC TOP OF RISER CASING
BPC BASE PROTECTIVE CASING
GS GROUND SURFACE
BS BENTONITE SEAL
FP FILTER PACK
TSC TOP OF SCREEN
BSC BOTTOM OF SCREEN
TD TOTAL DEPTH

WATER LEVELS(ft)

At Time of Drilling	11.0
After Install	6.9

The stratification lines represent approximate boundaries. The transition may be gradual.

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LOG OF PIEZOMETER R14-08

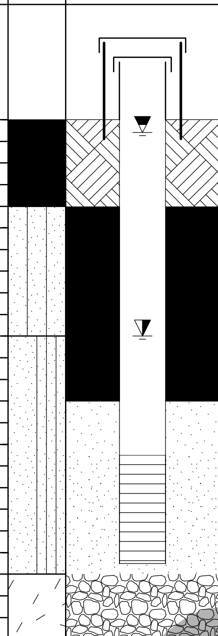
Project: Winter 2013/2014 Piezometers	Location: Hoyt Lakes, MN	Client: PolyMet
Barr Project Number: 23690C29.13	Surface Elevation: 1502.8 ft	Top of Casing Elevation: 1505.0

STRATA

DESCRIPTION	DEPTH, ft
PEAT (PT): dark brown; moist; top 2 feet frozen. 1498.8 ft	0
SILTY SAND (SM): fine to medium grained; brown; moist; trace gravel; [Till]. 1492.8 ft	5
POORLY GRADED SAND WITH SILT AND GRAVEL (SP-SM): medium to coarse grained; brown; wet; with cobbles from 18 to 21 feet; [Till]. 1481.8 ft	10, 15, 20
GRANITE; mottled red, black, and white; [Bedrock]. 1478.8 ft	

Bottom of Boring at 24.0 feet

SYMBOL / PIEZOMETER DETAILS



DEPTH, ft		ELEVATION, ft
-2.5	TPC	1505.3
-2.2	TRC	1505.0
0.0	GS	1502.8
4.0		1498.8
13.0	BS	1489.8
20.5	BSC	1482.3
21.0	TD	1481.8
24.0		1478.8

PIEZOMETER CONSTRUCTION DETAILS FOR STANDPIPE PIEZOMETER

PROTECTIVE CASING
Diameter: **6 inches**
Type: **Steel**
Interval: **-2.5-4.5**

RISER CASING
Diameter: **2 inches**
Type: **PVC**
Interval: **-2.2-15.5**

GROUT
Type: **Cement**
Interval: **0-4**

SEAL
Type: **Bentonite Chips**
Interval: **4-13**

SANDPACK
Type: **Silica Sand**
Interval: **13-21**

SCREEN
Diameter: **2 inches**
Type: **Continuous 0.01" slotted PVC**
Interval: **15.5-20.5**

Remarks:

Completion Depth:	24.0 ft
Date Started:	3/12/14
Date Completed:	3/12/14
Logged By:	BJL2
Drilling Contractor:	Cascade
Drilling Method:	Sonic
Datum:	NAD83 Minnesota State Plane
Coordinates:	N 739,287.6 ft E 2,857,372.0 ft

LEGEND

- FILTER PACK
- BENTONITE
- CEMENT GROUT
- CUTTINGS / BACKFILL

TPC	TOP OF PROTECTIVE CASING
TRC	TOP OF RISER CASING
BPC	BASE PROTECTIVE CASING
GS	GROUND SURFACE
BS	BENTONITE SEAL
FP	FILTER PACK
TSC	TOP OF SCREEN
BSC	BOTTOM OF SCREEN
TD	TOTAL DEPTH

WATER LEVELS(ft)

At Time of Drilling	10.0
After Install	0.6

The stratification lines represent approximate boundaries. The transition may be gradual.

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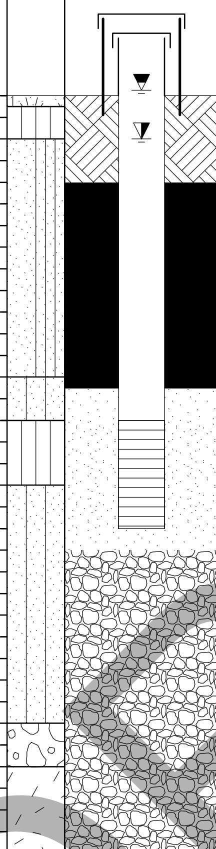
LOG OF PIEZOMETER R14-12

Project: Winter 2013/2014 Piezometers	Location: Hoyt Lakes, MN	Client: PolyMet
Barr Project Number: 23690C29.13	Surface Elevation: 1480.3 ft	Top of Casing Elevation: 1482.6

STRATA

DESCRIPTION	DEPTH, ft
TOPSOIL (OL): dark brown; moist; with wood and leaf debris. 1479.8 ft	0
SILT (ML): brown; moist; with sand. 1478.3 ft	
POORLY GRADED SAND WITH SILT (SP-SM): fine to coarse grained; gray to brown; wet; some weathered granite fragments to 13 feet; [Till]. 1467.3 ft	
SILTY SAND (SM): fine grained; gray; wet; [Till]. 1465.3 ft	
SILT (ML): gray; moist; with sand; little clay at 18 feet; [Till]. 1462.3 ft	
SILTY SAND (SM): fine to medium grained; gray; wet; [Till]. 1451.3 ft	
POORLY GRADED GRAVEL WITH SAND (GP): gray; wet; some cobbles with weathered granite fragments; [Till]. 1449.3 ft	
GRANITE; mottled red, black, and white; [Bedrock]. 1445.3 ft	35

Bottom of Boring at 35.0 feet



DEPTH, ft		ELEVATION, ft
-2.5	TPC	1482.8
-2.3	TRC	1482.6
0.0	GS	1480.3
4.0		1476.3
13.5	BS	1466.8
20.0	BSC	1460.3
21.0	TD	1459.3
35.0		1445.3

PIEZOMETER CONSTRUCTION DETAILS FOR STANDPIPE PIEZOMETER

PROTECTIVE CASING
Diameter: **6 inches**
Type: **Steel**
Interval: **-2.5-4.5**

RISER CASING
Diameter: **2 inches**
Type: **PVC**
Interval: **-2.3-15**

GROUT
Type: **Cement**
Interval: **0-4**

SEAL
Type: **Bentonite Chips**
Interval: **4-13.5**

SANDPACK
Type: **Silica Sand**
Interval: **13.5-21**

SCREEN
Diameter: **2 inches**
Type: **Continuous 0.01" slotted PVC**
Interval: **15-20**

Remarks:

Completion Depth:	35.0 ft
Date Started:	3/13/14
Date Completed:	3/13/14
Logged By:	BJL2
Drilling Contractor:	Cascade
Drilling Method:	Sonic
Datum:	NAD83 Minnesota State Plane
Coordinates:	N 742,311.8 ft E 2,858,500.4 ft

LEGEND

FILTER PACK
BENTONITE
CEMENT GROUT
CUTTINGS / BACKFILL

TPC	TOP OF PROTECTIVE CASING
TRC	TOP OF RISER CASING
BPC	BASE PROTECTIVE CASING
GS	GROUND SURFACE
BS	BENTONITE SEAL
FP	FILTER PACK
TSC	TOP OF SCREEN
BSC	BOTTOM OF SCREEN
TD	TOTAL DEPTH

WATER LEVELS(ft)

At Time of Drilling	2.0
After Install	-0.3

The stratification lines represent approximate boundaries. The transition may be gradual.

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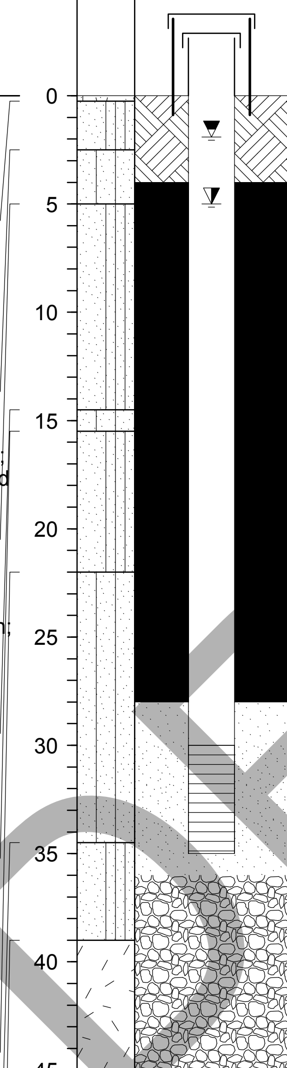
LOG OF PIEZOMETER R14-13

Project: Winter 2013/2014 Piezometers	Location: Hoyt Lakes, MN	Client: PolyMet
Barr Project Number: 23690C29.13	Surface Elevation: 1489.1 ft	Top of Casing Elevation: 1491.4

STRATA

DESCRIPTION
TOPSOIL (OL): dark brown; moist; roots and organics; top 1.5 feet frozen. 1488.9 ft
POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; brown; moist; with granite fragments. 1486.6 ft
SILTY SAND (SM): fine to medium grained; brown; moist; some gravel, clay, and cobbles; [Till]. 1484.1 ft
POORLY GRADED SAND WITH SILT (SP-SM): medium to coarse grained; brown; wet; with weathered granite fragments; [Till]. 1474.6 ft
SILTY SAND (SM): fine to medium grained; brown; wet; [Till]. 1473.6 ft
POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; brown to gray; wet; weathered granite fragments; [Till]. 1467.1 ft
SILTY SAND (SM): fine grained; gray; wet; with 3 to 6 inch silt and sand layers from 30 to 34.5 feet; [Till]. 1454.6 ft
POORLY GRADED SAND WITH SILT (SP-SM): medium to

PIEZOMETER DETAILS



DEPTH, ft		ELEVATION, ft
-2.5	TPC	1491.6
-2.3	TRC	1491.4
0.0	GS	1489.1
4.0		1485.1
28.0	BS	1461.1
35.0	BSC	1454.1
36.0	TD	1453.1
45.0		1444.1

PIEZOMETER CONSTRUCTION DETAILS FOR STANDPIPE PIEZOMETER

PROTECTIVE CASING
Diameter: **6 inches**
Type: **Steel**
Interval: **-2.5-4.5**

RISER CASING
Diameter: **2 inches**
Type: **PVC**
Interval: **-2.3-30**

GROUT
Type: **Cement**
Interval: **0-4**

SEAL
Type: **Bentonite Chips**
Interval: **4-28**

SANDPACK
Type: **Silica Sand**
Interval: **28-36**

SCREEN
Diameter: **2 inches**
Type: **Continuous 0.01" slotted PVC**
Interval: **30-35**

Remarks:

Completion Depth:	45.0 ft
Date Started:	3/14/14
Date Completed:	3/14/14
Logged By:	BJL2
Drilling Contractor:	Cascade
Drilling Method:	Sonic
Datum:	NAD83 Minnesota State Plane
Coordinates:	N 742,310.5 ft E 2,859,372.0 ft

LEGEND

- FILTER PACK
- BENTONITE
- CEMENT GROUT
- CUTTINGS / BACKFILL

TPC	TOP OF PROTECTIVE CASING
TRC	TOP OF RISER CASING
BPC	BASE PROTECTIVE CASING
GS	GROUND SURFACE
BS	BENTONITE SEAL
FP	FILTER PACK
TSC	TOP OF SCREEN
BSC	BOTTOM OF SCREEN
TD	TOTAL DEPTH

WATER LEVELS(ft)

At Time of Drilling	5.0
After Install	1.9

The stratification lines represent approximate boundaries. The transition may be gradual.

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LOG OF PIEZOMETER R14-13

Project: Winter 2013/2014 Piezometers	Location: Hoyt Lakes, MN	Client: PolyMet
Barr Project Number: 23690C29.13	Surface Elevation: 1489.1 ft	Top of Casing Elevation: 1491.4

STRATA DESCRIPTION	DEPTH, ft	SYMBOL	PIEZOMETER DETAILS	DEPTH, ft		ELEVATION, ft
coarse grained; gray; wet; with cobbles and weathered granite fragments; brown below 37 feet; [Till]. 1450.1 ft						
GRANITE; mottled red, black, and white; [Bedrock]. 1444.1 ft						
Bottom of Boring at 45.0 feet						

PIEZOMETER CONSTRUCTION DETAILS FOR STANDPIPE PIEZOMETER

PROTECTIVE CASING
Diameter: **6 inches**
Type: **Steel**
Interval: **-2.5-4.5**

RISER CASING
Diameter: **2 inches**
Type: **PVC**
Interval: **-2.3-30**

GROUT
Type: **Cement**
Interval: **0-4**

SEAL
Type: **Bentonite Chips**
Interval: **4-28**

SANDPACK
Type: **Silica Sand**
Interval: **28-36**

SCREEN
Diameter: **2 inches**
Type: **Continuous 0.01" slotted PVC**
Interval: **30-35**

Remarks:

Completion Depth:	45.0 ft
Date Started:	3/14/14
Date Completed:	3/14/14
Logged By:	BJL2
Drilling Contractor:	Cascade
Drilling Method:	Sonic
Datum:	NAD83 Minnesota State Plane
Coordinates:	N 742,310.5 ft E 2,859,372.0 ft

LEGEND

- FILTER PACK
- BENTONITE
- CEMENT GROUT
- CUTTINGS / BACKFILL

TPC	TOP OF PROTECTIVE CASING
TRC	TOP OF RISER CASING
BPC	BASE PROTECTIVE CASING
GS	GROUND SURFACE
BS	BENTONITE SEAL
FP	FILTER PACK
TSC	TOP OF SCREEN
BSC	BOTTOM OF SCREEN
TD	TOTAL DEPTH

WATER LEVELS(ft)

At Time of Drilling	5.0
After Install	1.9

The stratification lines represent approximate boundaries. The transition may be gradual.

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LOG OF PIEZOMETER R14-15

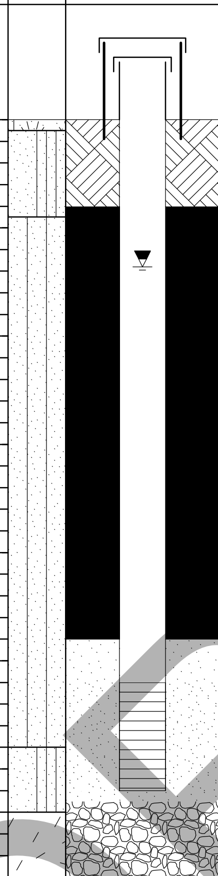
Project: Winter 2013/2014 Piezometers	Location: Hoyt Lakes, MN	Client: PolyMet
Barr Project Number: 23690C29.13	Surface Elevation: 1494.8 ft	Top of Casing Elevation: 1497.1

STRATA

DESCRIPTION	DEPTH, ft
TOPSOIL (OL): dark brown; moist; roots and sticks. 1494.3 ft	0
POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; dark brown to brown; moist; with weathered granite fragments. 1490.3 ft	5
SILTY SAND WITH GRAVEL (SM): medium to coarse grained; brown; moist to wet; with cobbles from 5 to 10 feet; with weathered granite fragments; [Till]. 1465.8 ft	15
POORLY GRADED SAND WITH SILT (SP-SM): medium to coarse grained; brown to gray; wet; with cobbles and weathered granite fragments; [Till]. 1462.8 ft	30
GRANITE; mottled red, black, and white; [Bedrock]. 1459.8 ft	35

Bottom of Boring at 35.0 feet

SYMBOL / PIEZOMETER DETAILS



DEPTH, ft		ELEVATION, ft
-2.5	TPC	1497.3
-2.3	TRC	1497.1
0.0	GS	1494.8
4.0		1490.8
24.0	BS	1470.8
31.0	BSC	1463.8
31.5	TD	1463.3
35.0		1459.8

PIEZOMETER CONSTRUCTION DETAILS FOR STANDPIPE PIEZOMETER

PROTECTIVE CASING
Diameter: **6 inches**
Type: **Steel**
Interval: **-2.5-4.5**

RISER CASING
Diameter: **2 inches**
Type: **PVC**
Interval: **-2.3-26**

GROUT
Type: **Cement**
Interval: **0-4**

SEAL
Type: **Bentonite Chips**
Interval: **4-24**

SANDPACK
Type: **Silica Sand**
Interval: **24-31.5**

SCREEN
Diameter: **2 inches**
Type: **Continuous 0.01" slotted PVC**
Interval: **26-31**

Remarks:

Completion Depth:	35.0 ft
Date Started:	3/14/14
Date Completed:	3/14/14
Logged By:	BJL2
Drilling Contractor:	Cascade
Drilling Method:	Sonic
Datum:	NAD83 Minnesota State Plane
Coordinates:	N 742,493.1 ft E 2,860,626.1 ft

LEGEND

FILTER PACK
BENTONITE
CEMENT GROUT
CUTTINGS / BACKFILL

TPC TOP OF PROTECTIVE CASING
TRC TOP OF RISER CASING
BPC BASE PROTECTIVE CASING
GS GROUND SURFACE
BS BENTONITE SEAL
FP FILTER PACK
TSC TOP OF SCREEN
BSC BOTTOM OF SCREEN
TD TOTAL DEPTH

WATER LEVELS(ft)

After Install	6.8

The stratification lines represent approximate boundaries. The transition may be gradual.

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Telephone: 952-832-2600

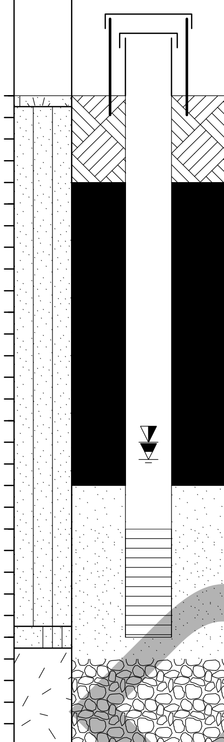
LOG OF PIEZOMETER R14-16

Project: Winter 2013/2014 Piezometers	Location: Hoyt Lakes, MN	Client: PolyMet
Barr Project Number: 23690C29.13	Surface Elevation: 1507.6 ft	Top of Casing Elevation: 1509.9

STRATA

DESCRIPTION	DEPTH, ft
TOPSOIL (OL): brown; moist; organics and leaf debris. 1507.1 ft	0
SILTY SAND WITH GRAVEL (SM): fine to medium grained; brown; moist to wet; [Till]. 1483.1 ft	5–25
POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; brown; wet; [Till]. 1482.1 ft	25
GRANITE; red; highly weathered; poor recovery due to drilling with water; [Bedrock]. 1477.6 ft	30

Bottom of Boring at 30.0 feet



DEPTH, ft		ELEVATION, ft
-2.5	TPC	**1510.1**
-2.3	TRC	**1509.9**
0.0	GS	**1507.6**
4.0		1503.6
18.0	BS	1489.6
25.0	BSC	1482.6
26.0	TD	1481.6
30.0		1477.6

PIEZOMETER CONSTRUCTION DETAILS FOR STANDPIPE PIEZOMETER

PROTECTIVE CASING
Diameter: **6 inches**
Type: **Steel**
Interval: **-2.5-4.5**

RISER CASING
Diameter: **2 inches**
Type: **PVC**
Interval: **-2.3-20**

GROUT
Type: **Cement**
Interval: **0-4**

SEAL
Type: **Bentonite Chips**
Interval: **4-18**

SANDPACK
Type: **Silica Sand**
Interval: **18-26**

SCREEN
Diameter: **2 inches**
Type: **Continuous 0.01" slotted PVC**
Interval: **20-25**

Remarks:

Completion Depth:	30.0 ft
Date Started:	3/15/14
Date Completed:	3/15/14
Logged By:	BJL2
Drilling Contractor:	Cascade
Drilling Method:	Sonic
Datum:	NAD83 Minnesota State Plane
Coordinates:	N 742,916.4 ft E 2,861,262.2 ft

LEGEND

FILTER PACK
BENTONITE
CEMENT GROUT
CUTTINGS / BACKFILL

TPC	TOP OF PROTECTIVE CASING
TRC	TOP OF RISER CASING
BPC	BASE PROTECTIVE CASING
GS	GROUND SURFACE
BS	BENTONITE SEAL
FP	FILTER PACK
TSC	TOP OF SCREEN
BSC	BOTTOM OF SCREEN
TD	TOTAL DEPTH

WATER LEVELS(ft)

At Time of Drilling	16.0
After Install	16.8

The stratification lines represent approximate boundaries. The transition may be gradual.

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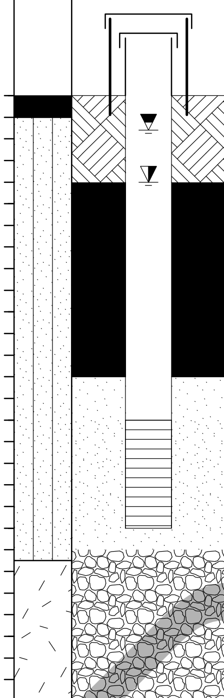
LOG OF PIEZOMETER R14-26

Project: Winter 2013/2014 Piezometers	Location: Hoyt Lakes, MN	Client: PolyMet
Barr Project Number: 23690C29.13	Surface Elevation: 1502.5 ft	Top of Casing Elevation: 1504.8

STRATA

DESCRIPTION	DEPTH, ft
PEAT (PT): dark brown; frozen; wood and leaf debris; top 1 foot frozen. 1501.5 ft	0
SILTY SAND WITH GRAVEL (SM): fine to medium grained; brown; moist to wet; some cobbles; [Till]. 1481.0 ft	5, 10, 15, 20
GRANITE; mottled red, black, and white; [Bedrock]. 1474.5 ft	25
Bottom of Boring at 28.0 feet	

SYMBOL / PIEZOMETER DETAILS



DEPTH, ft		ELEVATION, ft
-2.5	TPC	**1505.0**
-2.3	TRC	**1504.8**
0.0	GS	**1502.5**
4.0		1498.5
13.0	BS	1489.5
20.0	BSC	1482.5
21.0	TD	1481.5
28.0		1474.5

PIEZOMETER CONSTRUCTION DETAILS FOR STANDPIPE PIEZOMETER

PROTECTIVE CASING
Diameter: **6 inches**
Type: **Steel**
Interval: **-2.5-4.5**

RISER CASING
Diameter: **2 inches**
Type: **PVC**
Interval: **-2.3-15**

GROUT
Type: **Cement**
Interval: **0-4**

SEAL
Type: **Bentonite Chips**
Interval: **4-13**

SANDPACK
Type: **Silica Sand**
Interval: **13-21**

SCREEN
Diameter: **2 inches**
Type: **Continuous 0.01" slotted PVC**
Interval: **15-20**

Remarks:

Completion Depth:	28.0 ft
Date Started:	3/16/14
Date Completed:	3/16/14
Logged By:	BJL2
Drilling Contractor:	Cascade
Drilling Method:	Sonic
Datum:	NAD83 Minnesota State Plane
Coordinates:	N 743,283.6 ft E 2,869,216.9 ft

LEGEND

FILTER PACK
BENTONITE
CEMENT GROUT
CUTTINGS / BACKFILL

TPC	TOP OF PROTECTIVE CASING
TRC	TOP OF RISER CASING
BPC	BASE PROTECTIVE CASING
GS	GROUND SURFACE
BS	BENTONITE SEAL
FP	FILTER PACK
TSC	TOP OF SCREEN
BSC	BOTTOM OF SCREEN
TD	TOTAL DEPTH

WATER LEVELS(ft)

At Time of Drilling	4.0
After Install	1.6

The stratification lines represent approximate boundaries. The transition may be gradual.

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Telephone: 952-832-2600

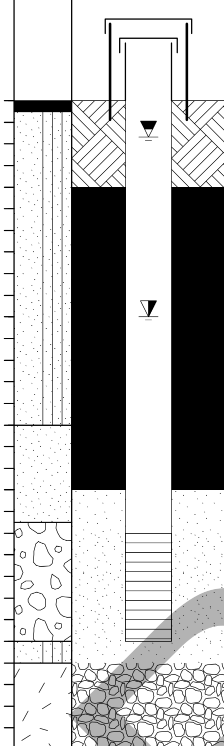
LOG OF PIEZOMETER R14-27

Project: Winter 2013/2014 Piezometers	Location: Hoyt Lakes, MN	Client: PolyMet
Barr Project Number: 23690C29.13	Surface Elevation: 1502.8 ft	Top of Casing Elevation: 1505.1

STRATA

DESCRIPTION	DEPTH, ft
PEAT (PT): dark brown; moist; with roots and sticks; frozen. 1502.3 ft	0
POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; brown; moist to wet; with cobbles and weathered granite fragments; [Till]. 1487.8 ft	5, 10, 15
POORLY GRADED SAND (SP): medium grained; brown; wet; with cobbles and weathered granite fragments; [Till]. 1483.3 ft	20
POORLY GRADED GRAVEL WITH SILT (GP): gray; wet; with cobbles and weathered granite fragments; sand layer from 23-24 feet; [Till]. 1477.8 ft	25
POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; gray; wet; [Till]. 1476.8 ft	
GRANITE; mottled red, black, and white; fracture at 29.5 feet; [Bedrock]. 1472.8 ft	30

Bottom of Boring at 30.0 feet



DEPTH, ft		ELEVATION, ft
-2.5	TPC	1505.3
-2.3	TRC	1505.1
0.0	GS	1502.8
4.0		1498.8
18.0	BS	1484.8
25.0	BSC	1477.8
26.0	TD	1476.8
30.0		1472.8

PIEZOMETER CONSTRUCTION DETAILS FOR STANDPIPE PIEZOMETER

PROTECTIVE CASING
Diameter: **6 inches**
Type: **Steel**
Interval: **-2.5-4.5**

RISER CASING
Diameter: **2 inches**
Type: **PVC**
Interval: **-2.3-20**

GROUT
Type: **Cement**
Interval: **0-4**

SEAL
Type: **Bentonite Chips**
Interval: **4-18**

SANDPACK
Type: **Silica Sand**
Interval: **18-26**

SCREEN
Diameter: **2 inches**
Type: **Continuous 0.01" slotted PVC**
Interval: **20-25**

Remarks:

Completion Depth:	30.0 ft
Date Started:	3/17/14
Date Completed:	3/17/14
Logged By:	BJL2
Drilling Contractor:	Cascade
Drilling Method:	Sonic
Datum:	NAD83 Minnesota State Plane
Coordinates:	N 743,350.1 ft E 2,870,201.4 ft

LEGEND

FILTER PACK
BENTONITE
CEMENT GROUT
CUTTINGS / BACKFILL

TPC	TOP OF PROTECTIVE CASING
TRC	TOP OF RISER CASING
BPC	BASE PROTECTIVE CASING
GS	GROUND SURFACE
BS	BENTONITE SEAL
FP	FILTER PACK
TSC	TOP OF SCREEN
BSC	BOTTOM OF SCREEN
TD	TOTAL DEPTH

WATER LEVELS(ft)

At Time of Drilling	10.0
After Install	1.7

The stratification lines represent approximate boundaries. The transition may be gradual.

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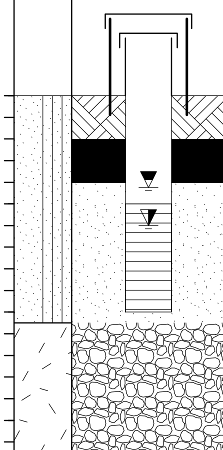
LOG OF PIEZOMETER R14-28

Project: Winter 2013/2014 Piezometers	Location: Hoyt Lakes, MN	Client: PolyMet
Barr Project Number: 23690C29.13	Surface Elevation: 1509.5 ft	Top of Casing Elevation: 1511.8

STRATA

DESCRIPTION	DEPTH, ft
POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; brown; moist; with cobbles and weathered granite fragments; top 1 foot frozen; [Till]. 1499.0 ft	0–10.5
GRANITE; mottled red, black, and white; [Bedrock]. 1493.0 ft	10.5–16.5
Bottom of Boring at 16.5 feet	



DEPTH, ft		ELEVATION, ft
-2.5	TPC	1512.0
-2.3	TRC	1511.8
0.0	GS	1509.5
2.0		1507.5
4.0	BS	1505.5
10.0	BSC	1499.5
10.5	TD	1499.0
16.5		1493.0

PIEZOMETER CONSTRUCTION DETAILS FOR STANDPIPE PIEZOMETER

PROTECTIVE CASING
Diameter: **6 inches**
Type: **Steel**
Interval: **-2.5-4.5**

RISER CASING
Diameter: **2 inches**
Type: **PVC**
Interval: **-2.3-5**

GROUT
Type: **Cement**
Interval: **0-2**

SEAL
Type: **Bentonite Chips**
Interval: **2-4**

SANDPACK
Type: **Silica Sand**
Interval: **4-10.5**

SCREEN
Diameter: **2 inches**
Type: **Continuous 0.01" slotted PVC**
Interval: **5-10**

Remarks:

Completion Depth:	16.5 ft
Date Started:	3/17/14
Date Completed:	3/17/14
Logged By:	BJL2
Drilling Contractor:	Cascade
Drilling Method:	Sonic
Datum:	NAD83 Minnesota State Plane
Coordinates:	N 742,651.3 ft E 2,870,734.5 ft

LEGEND

FILTER PACK
BENTONITE
CEMENT GROUT
CUTTINGS / BACKFILL

TPC	TOP OF PROTECTIVE CASING
TRC	TOP OF RISER CASING
BPC	BASE PROTECTIVE CASING
GS	GROUND SURFACE
BS	BENTONITE SEAL
FP	FILTER PACK
TSC	TOP OF SCREEN
BSC	BOTTOM OF SCREEN
TD	TOTAL DEPTH

WATER LEVELS(ft)

At Time of Drilling	6.0
After Install	4.3

The stratification lines represent approximate boundaries. The transition may be gradual.

Attachment C

SPT Logs

Barr Engineering Company
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Telephone: 952-832-2600

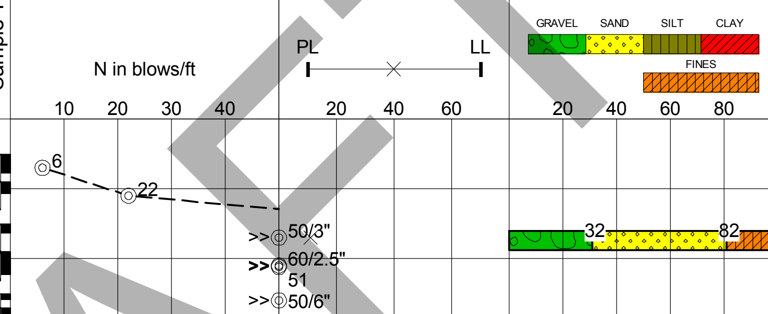
LOG OF BORING B14-36

Project: Winter 2013/2014 SPT Investigation | Location: Hoyt Lakes, MN | Client: PolyMet

Barr Project Number: 23690C29.13

Surface Elev.: 1554.7 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)	SPT N (blows/ft)	Sieve Analysis	WC %	RQD %
1554.7	0.0	FINE TAILINGS (ML): fine grained; black and gray metallic; saturated.	6; 22			
1547.7	7.0	SILTY SAND (SM): fine to coarse grained; gray; saturated; with weathered granite fragments; [Till].	>>50/3"; >>60/2.5"; 51; >>50/6"	32; 82	11	
1541.2	13.5	GRANITE; mottled black, red and white; massive; strong to very strong; slightly decomposed; slightly to moderately fractured; horizontal and 60 degree fractures; mostly healed; trace green inclusions throughout; [Bedrock].				77; 48; 100
1528.2	26.5	Bottom of Boring at 26.5 feet				



Physical Properties: WC %, γ pcf, ϕ °, Q_u tsf, Q_p tsf, Gs, RQD %

Completion Depth:	26.5
Date Boring Started:	5/8/14
Date Boring Completed:	5/13/14
Logged By:	GFS
Drilling Contractor:	Braun Intertec
Drilling Method:	HSA / Mud Rotary / NQ Coring
Ground Surface Elevation:	1554.7
Coordinates:	N 735,479.9 ft E 2,857,818.0 ft
Datum:	NAD83 Minnesota State Plane

Remarks: Modified location to avoid wetlands. 6 1/4" ID augers. Due to sealing difficulty, samples 1&2 are from the first hole, 3&4 are from the second hole and 4B&5 are from the final hole. Packer performed from 14-18.5 feet and 20.5-26.5 feet.

SAMPLE TYPES: Split Spoon; Rock Core

WATER LEVELS (ft): At Time of Drilling 0.0

LEGEND:
MC Moisture Content
γ Dry Unit Weight
ϕ Friction Angle
Q_u Unconfined Compression
Q_p Hand Penetrometer UC
Gs Specific Gravity
RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

BARR
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Minneapolis, MN 55435
Telephone: 952-832-2600

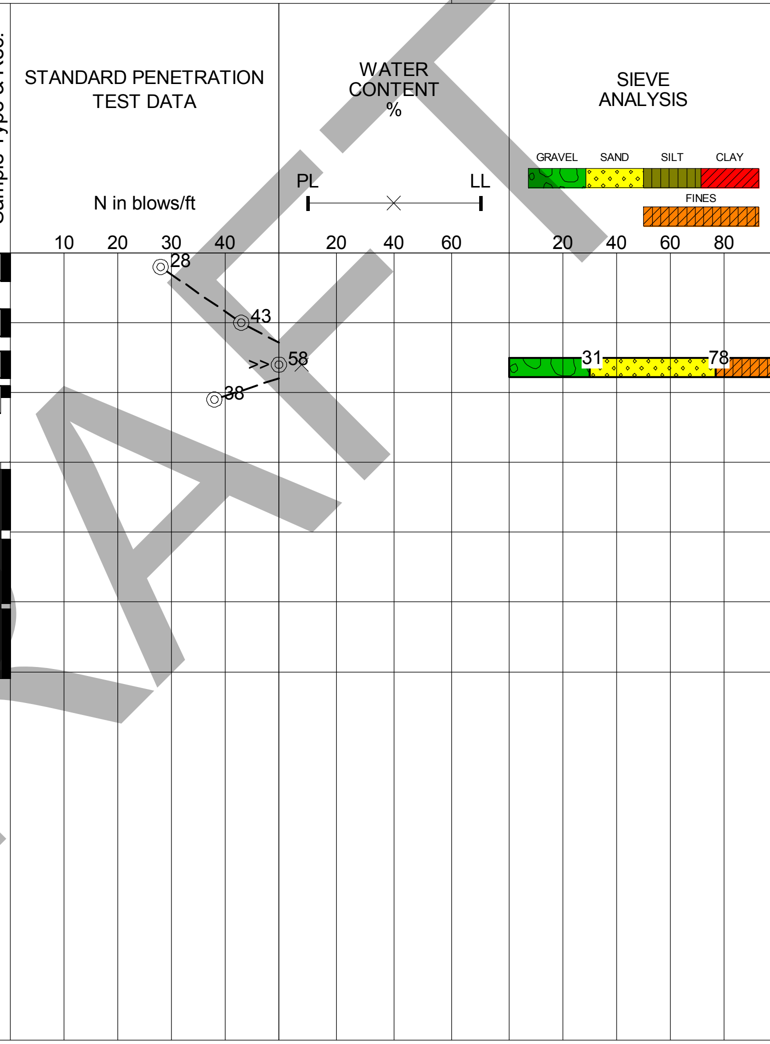
LOG OF BORING B14-40

Project: Winter 2013/2014 SPT Investigation | Location: Hoyt Lakes, MN | Client: PolyMet

Barr Project Number: 23690C29.13

Surface Elev.: 1534.0 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)	Depth	WC %	γ pcf	φ °	Qu tsf	Qp tsf	Gs	RQD %
1533.3	0–0.8	TOPSOIL (OL): dark brown; moist; large boulders (2 to 3 feet) interbedded.	0.8							
1519.0	0.8–15.0	SILTY SAND (SM): fine to medium grained; gray; very moist to saturated; with weathered granite fragments throughout increasing with depth; [Till].	15.0	8	125	47				
1503.5	15.0–30.5	GRANITE; mottled black and white with red; massive; strong to very strong; slightly decomposed; slightly to moderately fractured; 30 to 60 degrees fractures; moderately healed; 2-foot vertical fracture through sample from 22 to 24 feet; 6 inch red quartz-rich zone at 18 feet; 6 inch green zone at 28 feet; [Bedrock].	30.5							68, 47, 92
		Bottom of Boring at 30.5 feet	30.5							



Physical Properties

Completion Depth:	30.5
Date Boring Started:	5/15/14
Date Boring Completed:	5/16/14
Logged By:	GFS
Drilling Contractor:	Braun Intertec
Drilling Method:	HSA / Mud Rotary / NQ Coring
Ground Surface Elevation:	1534.0
Coordinates:	N 736,963.9 ft E 2,857,381.9 ft
Datum:	NAD83 Minnesota State Plane

Remarks: Modified location to avoid wetlands. 6 1/4" ID augers. Started mud rotary at 11.5 feet.

SAMPLE TYPES: Split Spoon; No Recovery; Rock Core

WATER LEVELS (ft): At Time of Drilling 4.3

LEGEND

- MC Moisture Content
- γ Dry Unit Weight
- φ Friction Angle
- Q_u Unconfined Compression
- Q_p Hand Penetrometer UC
- Gs Specific Gravity
- RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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Telephone: 952-832-2600

LOG OF BORING B14-44

Project: Winter 2013/2014 SPT Investigation | Location: Hoyt Lakes, MN | Client: PolyMet

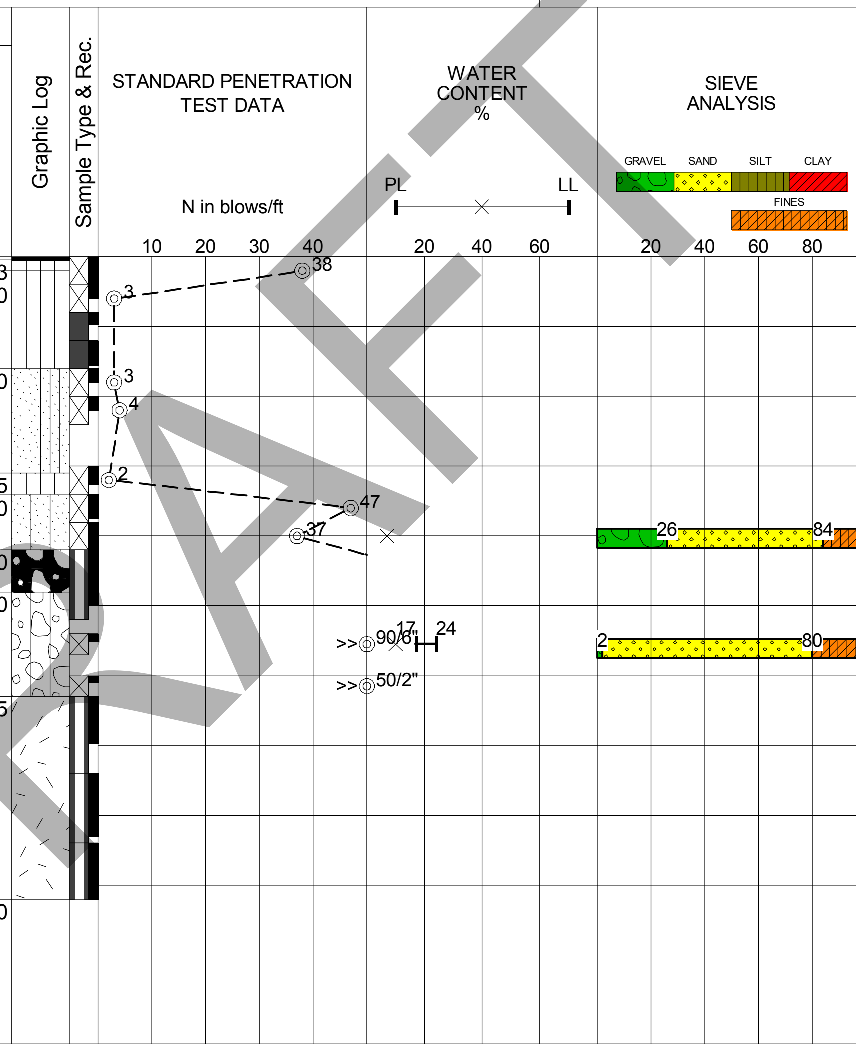
Barr Project Number: 23690C29.13

Surface Elev.: 1502.9 ft

MATERIAL DESCRIPTION (ASTM D2488)

Elevation, feet	Description	Depth, feet
1502.7	PEAT (PT): dark brown; moist; cattail roots and wood	0.3
1501.9	inclusions; stripped during clearing; top 2 feet frozen.	1.0
1494.9	FINE TAILINGS (ML): black; wet; appears to be contaminated with petroleum product; oily; slight smell; frozen.	8.0
1487.4	FINE TAILINGS (ML): very fine to fine grained; gray with black streaks; wet; soft; [magnetite tailings].	15.5
1485.9	COARSE TAILINGS (SP-SM): fine to coarse grained; dark brown; saturated; very loose; heavy.	17.0
1481.9	FINE TAILINGS (ML): very fine to fine grained; dark gray; saturated; very loose; heavy; liquefiable behavior.	21.0
1478.9	SILTY SAND (SM): fine to coarse grained; grayish brown; wet; with weathered granite fragments; interspersed with cobbles (1-2 inches); [Till].	24.0
1471.4	BOULDER; mottled black, red, and white; strong; slightly decomposed; moderately fractured; fractures occur at 60 degree angles; some fully healed locations.	31.5
1456.9	SILTY GRAVEL (GM): fine to coarse grained; grayish brown; wet; with sand; trace clay; interspersed with cobbles (1-2 inches); green and yellow staining; copper-colored inclusions; [Till].	46.0
	GRANITE; mottled black, red, and white; massive; strong to very strong; slightly decomposed; slightly to moderately fractured; first 5 feet is weathered and becomes increasingly competent with depth; color transition occurs at 40 feet where rock becomes slightly stronger; [Bedrock].	

Bottom of Boring at 46.0 feet



Physical Properties

Depth, feet	WC %	γ pcf	ϕ °	Q_u tsf	Q_p tsf	Gs	RQD %
~20	7						
~24							76
~28	10						
~35							33
~40							77
~44							92

Completion Depth:	46.0
Date Boring Started:	3/28/14
Date Boring Completed:	4/3/14
Logged By:	KNA
Drilling Contractor:	Braun Intertec
Drilling Method:	HSA / Mud Rotary / NQ Coring
Ground Surface Elevation:	1502.9
Coordinates:	N 738,984.5 ft E 2,857,382.8 ft
Datum:	NAD83 Minnesota State Plane

Remarks: 4 1/2" ID augers. Started mud rotary at 20 feet. Core performed in offset hole at : N=738977.63ft, E=2857368.8ft; Packer testing performed at 33-42 feet and 42-46 feet.

SAMPLE TYPES: Split Spoon; 3-inch Shelby Tube; Rock Core

WATER LEVELS (ft): At Time of Drilling 2.0; 24 hrs After Drilling 0.0

LEGEND: MC Moisture Content; γ Dry Unit Weight; ϕ Friction Angle; Q_u Unconfined Compression; Q_p Hand Penetrometer UC; Gs Specific Gravity; RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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Telephone: 952-832-2600

LOG OF BORING B14-48

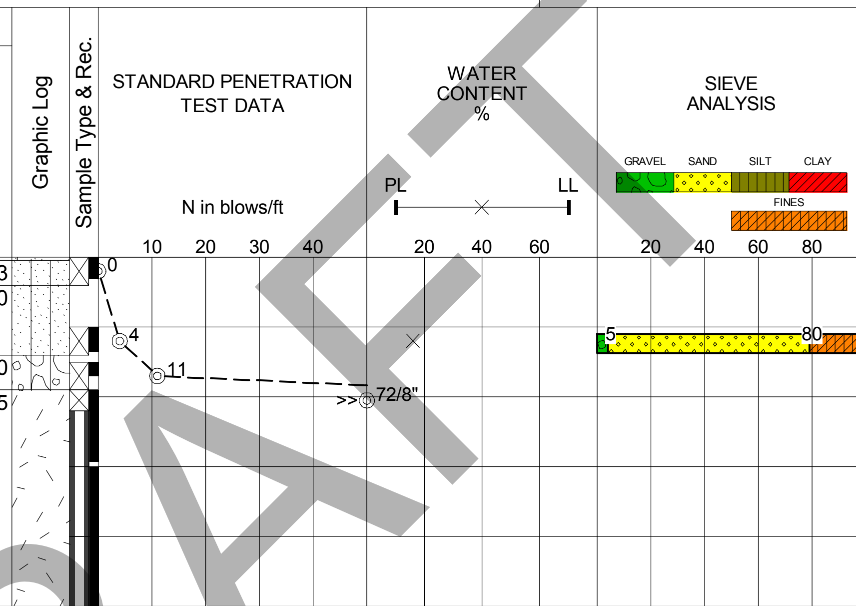
Project: Winter 2013/2014 SPT Investigation | Location: Hoyt Lakes, MN | Client: PolyMet

Barr Project Number: 23690C29.13

Surface Elev.: 1491.8 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)	Depth	SPT N (blows/ft)	Sieve Analysis	WC %	RQD %
1491.6	0.3	TOPSOIL (OL): dark brown; moist; wood and root inclusions; some clay; trace sand and gravel.	0.3	0			
1489.8	2.0	SILTY SAND (SM): fine to medium grained; brown; wet to saturated; very loose; trace roots and gravel; [Till].	2.0	4	5 / 80	16	
1484.8	7.0	SILTY SAND (SM): fine to coarse grained; gray; wet to saturated; very loose to medium dense; trace roots and clay; subangular; [Till].	7.0	11			
1482.3	9.5	SILTY GRAVEL (GM): fine to coarse grained; gray; wet; very dense; little sand; trace clay; [Till].	9.5	>>72/8"			
1466.8	25.0	GRANITE; mottled black and white with red; massive; strong to very strong; slightly decomposed; slightly to moderately fractured; vertical fracture from 12.5 to 14 feet; gray sediment in fractures; becomes increasingly competent with depth; gold-colored inclusions; [Bedrock].	25.0				15, 72, 88

Bottom of Boring at 25.0 feet



Physical Properties: WC % | γ pcf | ϕ ° | Q_u tsf | Q_p tsf | Gs | RQD %

Completion Depth:	25.0
Date Boring Started:	5/19/14
Date Boring Completed:	5/20/14
Logged By:	KNA
Drilling Contractor:	Braun Intertec
Drilling Method:	HSA / Mud Rotary / NQ Coring
Ground Surface Elevation:	1491.8
Coordinates:	N 740,886.7 ft E 2,857,452.1 ft
Datum:	NAD83 Minnesota State Plane

Remarks: Modified location to avoid wetlands. 6 1/4" ID augers. Started mud rotary at 10 feet.

SAMPLE TYPES

Split Spoon | Rock Core

WATER LEVELS (ft)

At Time of Drilling	3.0
0.5 hrs After Drilling	2.5

LEGEND

MC Moisture Content
γ Dry Unit Weight
ϕ Friction Angle
Q_u Unconfined Compression
Q_p Hand Penetrometer UC
Gs Specific Gravity
RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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Minneapolis, MN 55435
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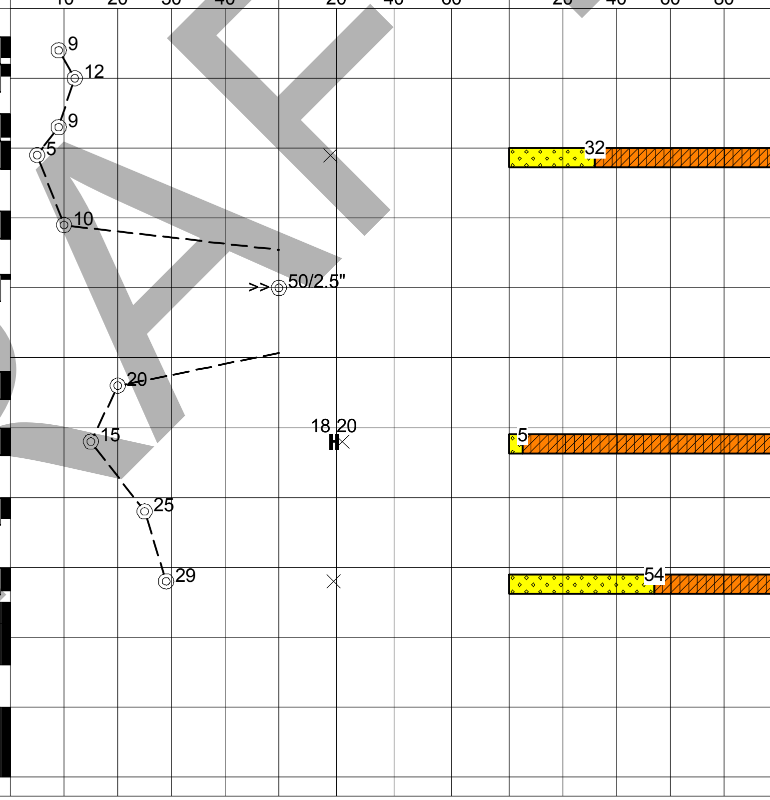
LOG OF BORING B14-52

Project: Winter 2013/2014 SPT Investigation | Location: Hoyt Lakes, MN | Client: PolyMet

Barr Project Number: 23690C29.13

Surface Elev.: 1486.0 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)	Sieve / Physical Properties WC %	RQD %
1484.0	2.0	TOPSOIL (OL): dark brown; moist; interbedded with large (2') boulders at surface.		
1480.0	6.0	CLAYEY SAND (SC): fine to coarse grained; dark tan; moist to saturated; with 2-inch diameter gravel.		
1469.5	16.5	SILTY SAND (SM): fine to medium grained; tan; saturated; small to medium gravel (weathered, rounded); silt content decreases with depth; gravel content increases with depth.	18	
1462.0	24.0	BOULDER: grayish black; crushed granite.		
1448.0	38.0	SILT (ML): gray; saturated; little to no inclusions from 26-35 feet; trace sand from 35-38 feet.	22	
1443.5	42.5	SILTY SAND (SM): fine to medium grained; gray; saturated; [Till].	19	
1442.0	44.0	GRANITE; Strong; no fractures until bottom of sample; green marbel zone at bottom 6 inches.		100
1439.0	47.0	GRANITE; highly weathered granite.		100, 86



Physical Properties: WC % | γ pcf | ϕ ° | Q_u tsf | Q_p tsf | Gs | RQD %

Continued Next Page

Completion Depth:	65.8
Date Boring Started:	5/5/14
Date Boring Completed:	5/7/14
Logged By:	GFS
Drilling Contractor:	Braun Intertec
Drilling Method:	HSA / Mud Rotary / NQ Coring
Ground Surface Elevation:	1486.0
Coordinates:	N 742,396.5 ft E 2,858,667.8 ft
Datum:	NAD83 Minnesota State Plane

Remarks: 6 1/4" ID augers. Started mud rotary at 20 feet.

SAMPLE TYPES: Split Spoon, Rock Core

WATER LEVELS (ft): At Time of Drilling 4.0

LEGEND:
- MC Moisture Content
- γ Dry Unit Weight
- ϕ Friction Angle
- Q_u Unconfined Compression
- Q_p Hand Penetrometer UC
- Gs Specific Gravity
- RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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Telephone: 952-832-2600

LOG OF BORING B14-52

Project: Winter 2013/2014 SPT Investigation | Location: Hoyt Lakes, MN | Client: PolyMet

Barr Project Number: 23690C29.13

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)	Graphic Log	Sample Type & Rec.	Standard Penetration Test Data (N in blows/ft)	Water Content %	Sieve Analysis	WC %	γ pcf	φ °	Q_u tsf	Q_p tsf	Gs	RQD %
1430, 1425	55–65.8	GRANITE; mottled red and white with black; massive; very strong; slightly decomposed; slightly to moderately fractured; fractures at horizontal and 65 degree angles; moderately healed; black/oxidized on healed joints; 6 inch quartz-rich zones; [Bedrock]. *(Continued)*		Rock Core										84, 90, 75
1420.3	65.8	Bottom of Boring at 65.8 feet												

Completion Depth: 65.8
Date Boring Started: 5/5/14
Date Boring Completed: 5/7/14
Logged By: GFS
Drilling Contractor: Braun Intertec
Drilling Method: HSA / Mud Rotary / NQ Coring
Ground Surface Elevation: 1486.0
Coordinates: N 742,396.5 ft E 2,858,667.8 ft
Datum: NAD83 Minnesota State Plane

Remarks: 6 1/4" ID augers. Started mud rotary at 20 feet.

SAMPLE TYPES: Split Spoon; Rock Core

WATER LEVELS (ft): At Time of Drilling 4.0

LEGEND:
MC Moisture Content
γ Dry Unit Weight
φ Friction Angle
Q_u Unconfined Compression
Q_p Hand Penetrometer UC
Gs Specific Gravity
RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

BARR

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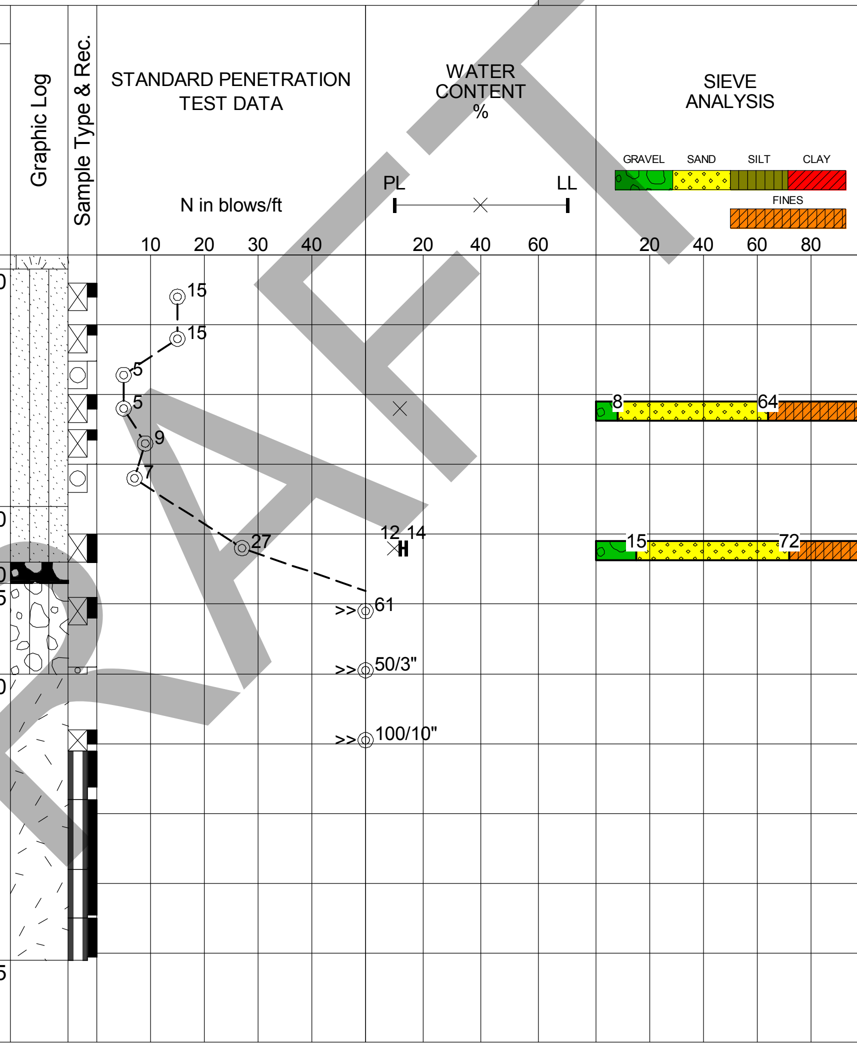
LOG OF BORING B14-55

Project: Winter 2013/2014 SPT Investigation | Location: Hoyt Lakes, MN | Client: PolyMet

Barr Project Number: 23690C29.13

Surface Elev.: 1494.8 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)	Depth to base
1493.8	0	TOPSOIL (OL): reddish brown; moist; roots; small shrubs and grass.	1.0
1476.8	1.0	SILTY SAND (SM): fine to coarse grained; brown; moist to saturated; loose to medium dense; with gravel up to 1 inch in diameter; round to angular; increasing sand content with depth; [Till].	18.0
1472.8	18.0	SILTY SAND WITH GRAVEL (SM): medium to coarse grained; gray; moist to wet; medium dense; trace clay; slightly cohesive; 1/2-inch diameter weathered granite fragments; [Till].	22.0
1471.3	22.0	BOULDER: molted red with black and white; crushed granite.	23.5
1464.8	23.5	SILTY GRAVEL (GM): fine to coarse grained; gray; saturated; very dense; green and orange oxidation staining; seams of weathered granite; [Till].	30.0
1444.3	30.0	GRANITE; mottled red with black and white; massive; very strong; slightly decomposed; slightly to moderately fractured; fractures at 45 to 80 degree angles; moderately healed; black on oxidized fractured faces and healed locations; green zone at 42.5 feet; [Bedrock].	50.5
		Bottom of Boring at 50.5 feet	50.5



Depth, feet	WC %	γ pcf	ϕ °	Q_u tsf	Q_p tsf	Gs	RQD %
~11	12						
~21	10						
~37.5							33
~41.5							63
~46							85
~49							91

Completion Depth: 50.5
Date Boring Started: 4/28/14
Date Boring Completed: 5/2/14
Logged By: KNA
Drilling Contractor: Braun Intertec
Drilling Method: HSA / Mud Rotary / NQ Coring
Ground Surface Elevation: 1494.8
Coordinates: N 742,451.6 ft E 2,860,494.0 ft
Datum: NAD83 Minnesota State Plane

Remarks: 6 1/4" ID augers. Started mud rotary at 20 feet. Packer performed from 37-41.5 feet, 41.5-46.5 feet, and 46-50.5 feet.

SAMPLE TYPES: Split Spoon; No Recovery; Rock Core

WATER LEVELS (ft): At Time of Drilling 10.0

LEGEND
- MC Moisture Content
- γ Dry Unit Weight
- ϕ Friction Angle
- Q_u Unconfined Compression
- Q_p Hand Penetrometer UC
- Gs Specific Gravity
- RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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LOG OF BORING B14-62

Project: Winter 2013/2014 SPT Investigation | Location: Hoyt Lakes, MN | Client: PolyMet

Barr Project Number: 23690C29.13

Surface Elev.: 1493.3 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)	Bottom depth	SPT N (blows/ft)	Water Content %	Sieve Analysis	WC %	γ pcf	ϕ °	Qu tsf	Qp tsf	Gs	RQD %
1493.1	0	TOPSOIL (OL): dark brown; moist; root inclusions; some sand.	0.3	0									
1491.3	0.3	SILTY SAND (SM): fine to medium grained; orangish brown; saturated; some clay; cohesive.	2.0	23, 24		Gravel 19, Sand to 74	8	125	38				
1476.3	2.0	SILTY SAND WITH GRAVEL (SM): medium to coarse grained; brownish gray to gray; moist to wet; trace clay; slightly cohesive; trace black inclusions; weathered granite fragments up to 1-inch in diameter; subangular; [Till].	17.0	>>57, >>71, >>50/4"									
1466.3	17.0	GRANITE; highly weathered bedrock; appears to be silty gravel with up to 1-foot boulders throughout; cobbles in 2-inch diameter in various colors; [Bedrock].	27.0										53, 13, 0
	27.0	Bottom of Boring at 27.0 feet											

Water level (▼) at approx. 12 ft (elev. ~1481).

Completion Depth:	27.0
Date Boring Started:	4/21/14
Date Boring Completed:	4/28/14
Logged By:	KNA
Drilling Contractor:	Braun Intertec
Drilling Method:	HSA / Mud Rotary / NQ Coring
Ground Surface Elevation:	1493.3
Coordinates:	N 743,327.3 ft E 2,863,894.1 ft
Datum:	NAD83 Minnesota State Plane

Remarks: 6 1/4" ID augers. Mud rotary started at 10 feet.

SAMPLE TYPES: Split Spoon; Rock Core

WATER LEVELS (ft): At Time of Drilling 12.0

LEGEND

- MC Moisture Content
- γ Dry Unit Weight
- ϕ Friction Angle
- Q_u Unconfined Compression
- Q_p Hand Penetrometer UC
- Gs Specific Gravity
- RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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LOG OF BORING B14-65

Project: Winter 2013/2014 SPT Investigation | Location: Hoyt Lakes, MN | Client: PolyMet

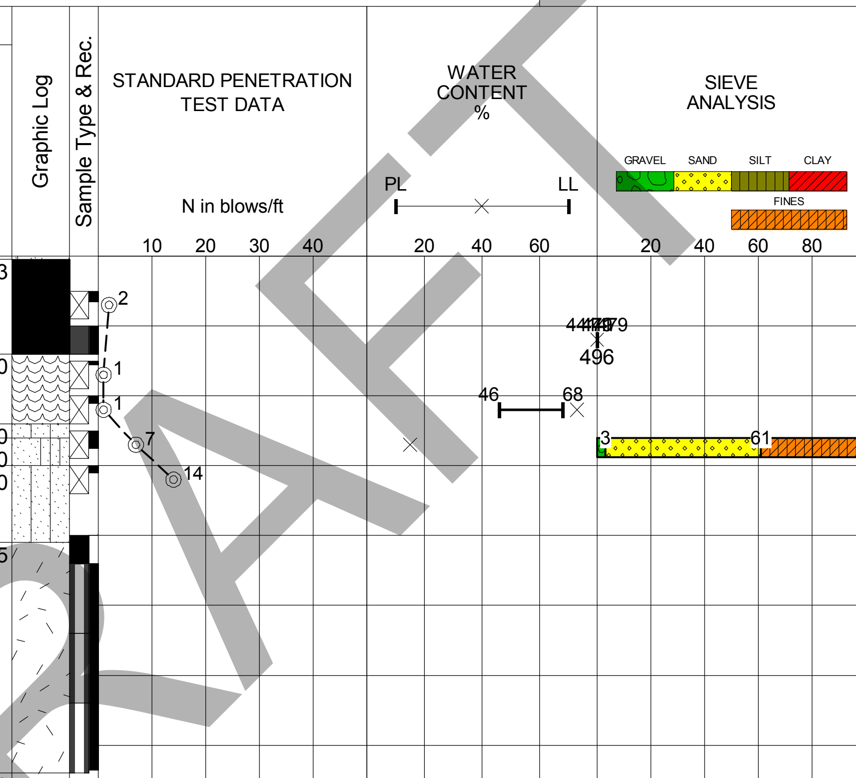
Barr Project Number: 23690C29.13

Surface Elev.: 1487.2 ft

MATERIAL DESCRIPTION (ASTM D2488)

Elevation, feet	Depth, feet	Material Description	WC %	RQD %
1487.0	0.3	TOPSOIL (ML): gray; saturated; silt; very fine; smears; top 2 feet frozen [magnetite tailings].		
1480.2	7.0	PEAT (PT): dark brown; saturated; very soft; cattail roots and wood inclusions; top 4.5 feet frozen. 1 foot of gray magnetite tailings at 5 feet.	496	
1475.2	12.0	ORGANIC SILT (OH): dark brown; saturated; very soft; wood inclusions.	73	
1474.2	13.0	SILTY SAND (SM): medium to coarse grained; gray; wet; some gravel and organics; [Till].	15	
1472.2	15.0	POORLY GRADED SAND WITH SILT (SP-SM): medium to coarse grained; orangish brown; wet; loose; subangular to angular; trace clay; [Till].		
1466.7	20.5	SILTY SAND (SM): medium to coarse grained; gray; saturated; medium dense; with weathered granite fragments; [Till].		
1450.2	37.0	GRANITE; red mottled with black and white; massive; strong to very strong; slightly decomposed; slightly to moderately fractured; fractures are at 0, 45, or 60 degree angles; appears to previously have been highly fractured but is now fully healed with green sediment; [Bedrock].		86, 80, 51

Bottom of Boring at 37.0 feet



Physical Properties: WC %, γ pcf, ϕ °, Q_u tsf, Q_p tsf, Gs, RQD %

Completion Depth:	37.0
Date Boring Started:	4/16/14
Date Boring Completed:	4/17/14
Logged By:	KNA
Drilling Contractor:	Braun Intertec
Drilling Method:	HSA / Mud Rotary / NQ Coring
Ground Surface Elevation:	1487.2
Coordinates:	N 743,316.0 ft E 2,864,926.5 ft
Datum:	NAD83 Minnesota State Plane

Remarks: 6 1/4" ID augers. Hit refusal at 10 feet, offset 10 feet East and blind-drilled to 10 feet. Started mud rotary at 15 feet. Packer performed from 24-30 feet and 27.5-33.5 feet.

SAMPLE TYPES: Split Spoon; 3-inch Shelby Tube; Undisturbed Sample; Rock Core

WATER LEVELS (ft): At Time of Drilling 0.0

LEGEND

MC	Moisture Content	Q_u	Unconfined Compression
γ	Dry Unit Weight	Q_p	Hand Penetrometer UC
ϕ	Friction Angle	Gs	Specific Gravity
		RQD	Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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LOG OF BORING B14-69

Sheet 1 of 1

Project: Winter 2013/2014 SPT Investigation | Location: Hoyt Lakes, MN | Client: PolyMet

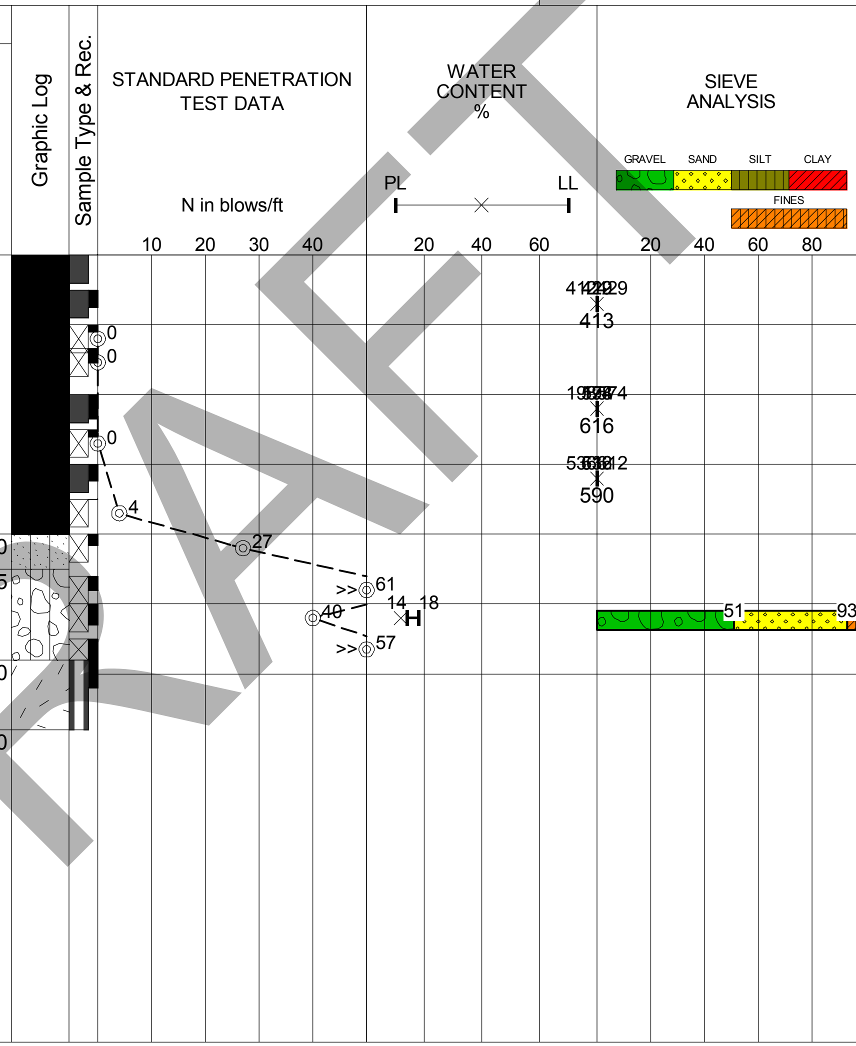
Barr Project Number: 23690C29.13

MATERIAL DESCRIPTION (ASTM D2488)

Surface Elev.: 1485.1 ft

Elevation, feet	Depth, feet	Material Description
	0	PEAT (PT): dark brown; saturated; very soft; sapric; wood interspersed throughout increasing with depth; top 1.5 feet frozen.
1465.1		Gray silt (magnetite tailings) at 17.5 feet.
1462.6	20.0 – 22.5	SILTY SAND WITH GRAVEL (SM): medium to coarse grained; dark brown; wet; medium dense; 1/2-inch cobbles and weathered granite fragments; [Till].
1456.1	22.5 – 29.0	SILTY GRAVEL (GM): gray; very dense; 1 inch weathered granite fragments; some gray clayey sand; [Till].
1451.1	29.0 – 34.0	GRANITE; mottled red and black with white; 60 degree fracture at 29-30 feet; most of core consisted of 2-inch cobbles; [Highly Weathered Bedrock].

Bottom of Boring at 34.0 feet



Physical Properties

Depth (approx.)	WC %	γ pcf	φ °	Q_u tsf	Q_p tsf	Gs	RQD %
~3.5	413	13				1.7	
~11	616						
~16	590						
~26	12						
~31							20

Completion Depth:	34.0
Date Boring Started:	4/7/14
Date Boring Completed:	4/8/14
Logged By:	KNA/GFS
Drilling Contractor:	Braun Intertec
Drilling Method:	HSA / Mud Rotary / NQ Coring
Ground Surface Elevation:	1485.1
Coordinates:	N 743,207.5 ft E 2,866,416.5 ft
Datum:	NAD83 Minnesota State Plane

Remarks: 4 1/2" ID augers. With the augers at 24 feet, artesian flow started around teh outside of the augers after sample at 23 feet was collected. Before flow started, water was 1-foot above ground surface in the augers.

SAMPLE TYPES: 3-inch Shelby Tube; Split Spoon; Rock Core

WATER LEVELS (ft)

- End of Drilling: -1.0
- At Time of Drilling: 0.0

LEGEND

- MC Moisture Content
- γ Dry Unit Weight
- φ Friction Angle
- Q_u Unconfined Compression
- Q_p Hand Penetrometer UC
- Gs Specific Gravity
- RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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LOG OF BORING B14-72

Project: Winter 2013/2014 SPT Investigation | Location: Hoyt Lakes, MN | Client: PolyMet

Barr Project Number: 23690C29.13

Surface Elev.: 1493.0 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)	Sample Type & Rec.	N in blows/ft	Water Content %	Sieve Analysis	WC %	RQD %
1492.5	0.5	PEAT (PT): dark grown; moist; frozen; sapric; roots and wood inclusions.	Split Spoon	27				
1488.0	5.0	SILT (ML): gray; wet; medium dense to dense; frozen; roots and wood inclusions; seams of coarse sand; [Tailings].	Split Spoon	38; 14	25	4 (gravel), 28	25	
1483.0	10.0	SILTY SAND WITH GRAVEL (SM): fine to coarse grained; brown; wet; medium dense to very dense; 1/8 - 1 inch weathered granite fragments; [Till].	Split Spoon	36; >>50/5"	9	30, 83	9	
1468.0	25.0	GRANITE; dark red mottled with black and white; massive; strong to very strong; slightly decomposed; moderately fractured becoming more competent with depth; highly fractured at 17.5, 20-22, and 23-23.5 feet; healed throughout; 60 degree fractures from 21 - 25 feet, otherwise horizontal or 90 degree fractures; green and brown in-filling; [Bedrock].	Rock Core					63; 50; 56

Bottom of Boring at 25.0 feet

Physical Properties columns: WC (%), γ (pcf), ϕ (°), Q_u (tsf), Q_p (tsf), Gs, RQD (%)

Completion Depth:	25.0
Date Boring Started:	4/4/14
Date Boring Completed:	4/7/14
Logged By:	KNA
Drilling Contractor:	Braun Intertec
Drilling Method:	HSA / Mud Rotary / NQ Coring
Ground Surface Elevation:	1493.0
Coordinates:	N 743,232.9 ft E 2,867,866.5 ft
Datum:	NAD83 Minnesota State Plane

Remarks: 4 1/2" ID augers. Tried Denison sample at 7.5 feet. Started mud rotary at 7.5 feet.

SAMPLE TYPES: Split Spoon; Rock Core

WATER LEVELS (ft): At Time of Drilling 1.0

LEGEND
- MC Moisture Content
- γ Dry Unit Weight
- ϕ Friction Angle
- Q_u Unconfined Compression
- Q_p Hand Penetrometer UC
- Gs Specific Gravity
- RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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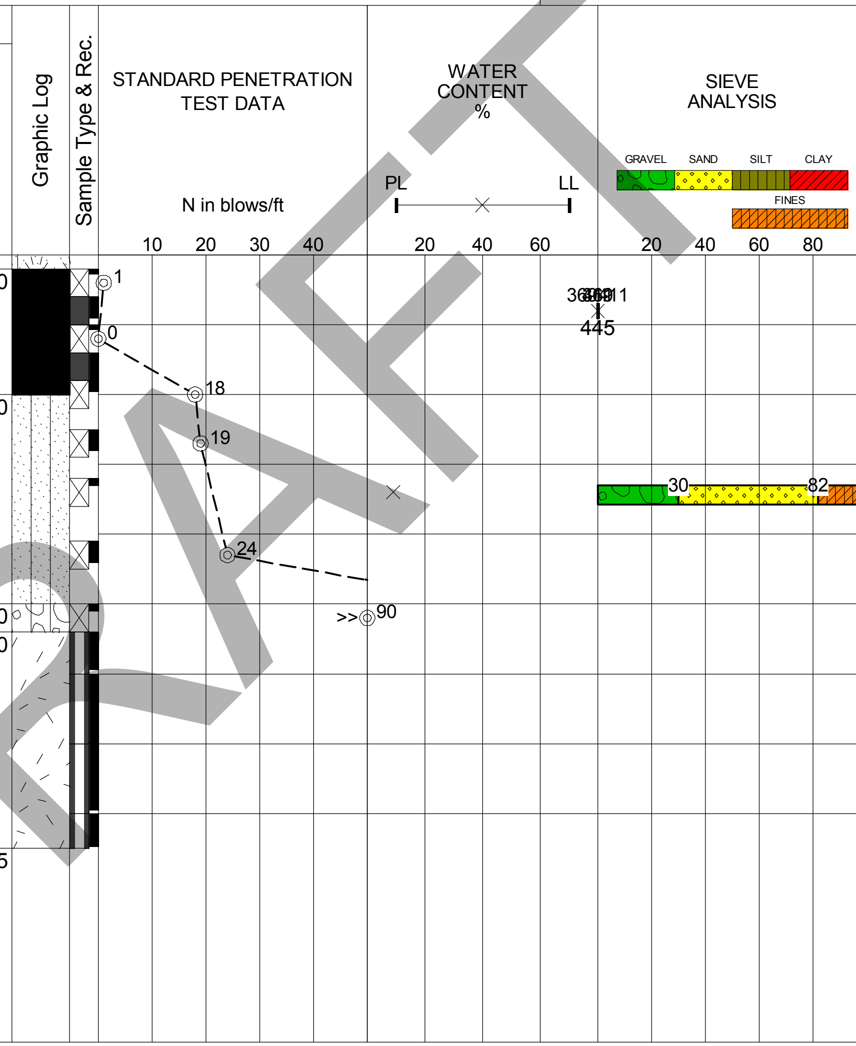
LOG OF BORING B14-76

Project: Winter 2013/2014 SPT Investigation | Location: Hoyt Lakes, MN | Client: PolyMet

Barr Project Number: 23690C29.13

Surface Elev.: 1501.2 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)	Bottom depth
1500.2	0	TOPSOIL (OL): dark brown; wet; frozen; roots; trace silt.	1.0
		PEAT (PT): dark brown; saturated; very soft; sapric; some silt and clay; trace sand and <1-inch gravel.	
1491.2		SILTY SAND (SM): gray; saturated; loose to medium dense; trace clay; sand and gravel amount increases with depth; gravel <1 inch to 4 inches in diameter; [Till].	10.0
1476.2			25.0
1474.2		SILTY GRAVEL (GM): gray and red; saturated; with weathered granite fragments; [Till].	27.0
		GRANITE; red mottled with black and white; massive; strong to very strong; slightly decomposed; moderately fractured decreasing with depth; 60 to 80 degree fractures; appears previously highly fractured but is now fully healed; green and brown in-filling; [Bedrock].	
1458.7		Bottom of Boring at 42.5 feet	42.5



Physical Properties

Elevation (ft)	WC %	γ pcf	ϕ °	Q_u tsf	Q_p tsf	Gs	RQD %
~1497	445						
~1485	9	122	45				
~1472							53
~1468							87
~1463							53
~1460							63

Completion Depth: 42.5
Date Boring Started: 4/9/14
Date Boring Completed: 4/11/14
Logged By: GFS
Drilling Contractor: Braun Intertec
Drilling Method: HSA / Mud Rotary / NQ Coring
Ground Surface Elevation: 1501.2
Coordinates: N 743,328.6 ft E 2,869,888.1 ft
Datum: NAD83 Minnesota State Plane

Remarks: 4 1/2" ID augers. Started mud rotary at 13 feet.

SAMPLE TYPES
Split Spoon | 3-inch Shelby Tube | Rock Core

WATER LEVELS (ft)
At Time of Drilling 0.0

LEGEND
MC Moisture Content
γ Dry Unit Weight
ϕ Friction Angle
Q_u Unconfined Compression
Q_p Hand Penetrometer UC
Gs Specific Gravity
RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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LOG OF BORING B14-80

Project: Winter 2013/2014 SPT Investigation | Location: Hoyt Lakes, MN | Client: PolyMet

Barr Project Number: 23690C29.13

Surface Elev.: 1523.4 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)	Sample Type & Rec.	Standard Penetration Test Data (N in blows/ft)	Water Content %	Sieve Analysis	WC %	γ pcf	ϕ °	Q_u tsf	Q_p tsf	Gs	RQD %
1523.2	0.3	TOPSOIL (SM): dark brown; moist; organics and roots; with gravel; top 2 feet frozen.											
1513.4	10.0	SILTY SAND (SM): medium to coarse grained; brown; moist to wet; medium dense to very dense; with angular to subangular weathered granite fragments; gray clay content increasing with depth; [Till].	Split Spoon	14		17 / 82	8						
			Split Spoon	>>66									
			Split Spoon	>>50/5"									
			No Recovery	>>50/1"									
1502.4	21.0	GRANITE; mottled red, black, and white; massive; very strong; slightly decomposed; slightly to moderately fractured becoming more competent with depth; fractures 45 and 60 degrees angles; totally healed with red and green sediment; [Bedrock].	Rock Core										67.5
			Rock Core										79
			Rock Core										100

Bottom of Boring at 21.0 feet

Completion Depth:	21.0
Date Boring Started:	3/26/14
Date Boring Completed:	3/27/14
Logged By:	KNA
Drilling Contractor:	Braun Intertec
Drilling Method:	HSA / Mud Rotary / NQ Coring
Ground Surface Elevation:	1523.4
Coordinates:	N 741,777.3 ft E 2,870,717.9 ft
Datum:	NAD83 Minnesota State Plane

Remarks: 4 1/2" ID augers. Drilled to 7.5 feet then offset 5 feet east and blind-drilled to 10 feet. Started mud rotary at 10 feet.

SAMPLE TYPES: Split Spoon, No Recovery, Rock Core

WATER LEVELS (ft): At Time of Drilling 7.0

LEGEND:
- MC Moisture Content
- γ Dry Unit Weight
- ϕ Friction Angle
- Q_u Unconfined Compression
- Q_p Hand Penetrometer UC
- Gs Specific Gravity
- RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

Attachment D

Packer Testing Results

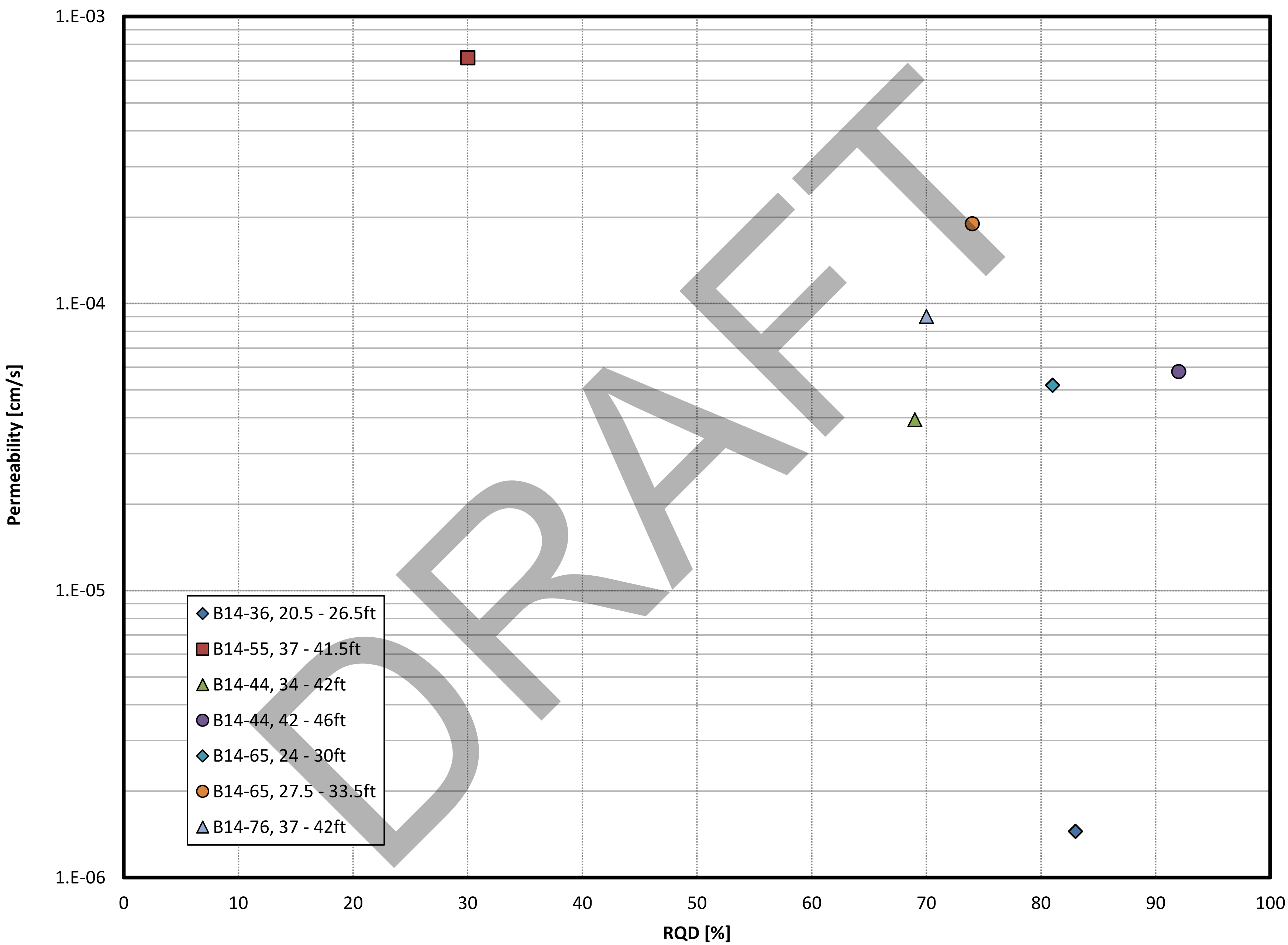
PolyMet 2014 Packer Test Data Summary - FTB Seepage Containment System Borings

Boring	Test Interval	Testing Length	Packer	RQD	Leakage Through Fractures / Bedrock Permeability			
					Test Results[1]		Test and Inferred Results[2]	
	feet	feet			cm/s	ft/s	cm/s	ft/s
B14-36	14 - 18.5	4.5	Double	93	0	0	1.4E-06	4.8E-08
B14-36	20.5 - 26.5	6	Single	83	1.4E-06	4.8E-08	1.4E-06	4.8E-08
B14-55	37 - 41.5	4.5	Single	30	7.2E-04	2.4E-05	7.2E-04	2.4E-05
B14-55	41.5 - 46.5	5	Double	100	0	0	1.4E-06	4.8E-08
B14-55	46 - 50.5	4.5	Single	48	0	0	1.4E-06	4.8E-08
B14-44	34 - 42	8	Single	69	3.9E-05	1.3E-06	3.9E-05	1.3E-06
B14-44	42 - 46	4	Double	92	5.8E-05	1.9E-06	5.8E-05	1.9E-06
B14-65	24 - 30	6	Double	81	5.2E-05	1.7E-06	5.2E-05	1.7E-06
B14-65	27.5 - 33.5	6	Double	74	1.9E-04	6.2E-06	1.9E-04	6.2E-06
B14-76	37 - 42	5	Single	70	9.0E-05	3.0E-06	9.0E-05	3.0E-06
				Geomean =	5.8E-05	1.9E-06	1.9E-05	6.3E-07

[1] *Based on the lowest permeability value resulting from the first three pressure increments as the value most likely to represent in-situ conditions. Geomean excludes values where zero inflow is observed during testing.*

[2] *For Packer Test Results where zero inflow is observed during testing, permeability values are selected based on inference from lowest packer test result obtained. Geomean includes all test intervals.*

The resulting permeability is not a true permeability since the rock is not a true porous media. Instead, the packer test provides a relative measurement of potential leakage through bedrock joints or fractures.


1.E-03
1.E-04
1.E-05
1.E-06
Permeability [cm/s]
0
10
20
30
40
50
60
70
80
90
100
RQD [%]
B14-36, 20.5 - 26.5ft
B14-55, 37 - 41.5ft
B14-44, 34 - 42ft
B14-44, 42 - 46ft
B14-65, 24 - 30ft
B14-65, 27.5 - 33.5ft
B14-76, 37 - 42ft
DRAFT

PolyMet 2014 Packer Testing

Performed: 5/13/2014

Analyzed: 5/21/2014

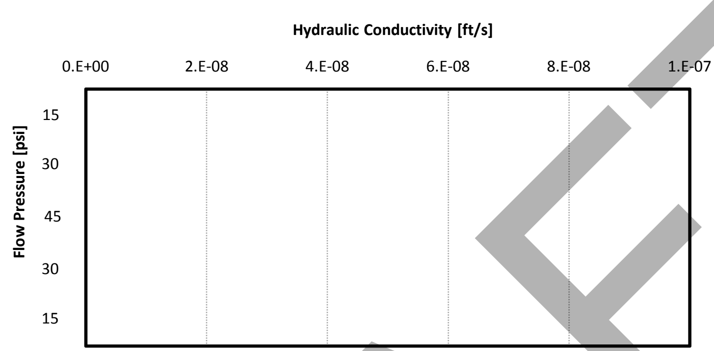
B14-36, 14 - 18.5ft

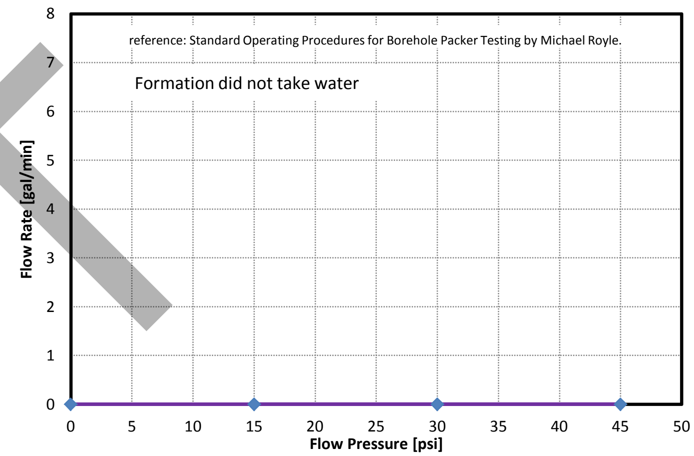
Hydraulic Conductivity =	0.00E+00	cm/s	0.00E+00	ft/s
Maximum =	0.00E+00	cm/s	0.00E+00	ft/s
Minimum =	0.00E+00	cm/s	0.00E+00	ft/s

Notes: Double Packer Test

Packer length (ft) =	2
Screened interval (ft) =	3
Total depth of boring (ft) =	26.5
Test interval top (ft) =	14
Test interval bottom (ft) =	18.5
Original GWT (ft) =	4.7
GWT before inflation (ft) =	4.7
GWT after inflation (ft) =	4.7
GWT during test (ft) =	4.7
GWT at end of test (ft) =	4.7
Height of pressure gauge (ft) =	3
Packer inflation pressure (psi) =	140
RQD for test interval (%) =	93
Borehole radius (inches) =	1.5

Total testing interval (ft) =	4.5
Length of pipe above ground (ft) =	3
Length of pipe below ground (ft) =	12
Total length for losses (ft) =	15





Flow Pressure (psi) =	15			30			45			30			15		
Time (min)	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow
0	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0
1	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0
2	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0
3	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0
4	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0
5	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0	80.64	0.0	0.0

Average Flowrate (gal/min) =	0.0	0.0	0.0	0.0	0.0
Applied pressure (psi) =	15	30	45	30	15
Friction loss/foot (psi) =	0.08	0.08	0.08	0.08	0.08
Friction loss (psi) =	1.2	1.2	1.2	1.2	1.2
Effective pressure (psi) =	13.8	28.8	43.8	28.8	13.8

USBR 7310-89 Calculation for Hydraulic Conductivity

q (constant rate of flow into the test interval), cm^3/s =	0.0	0.0	0.0	0.0	0.0
L (length of the test interval), cm =	137.2	137.2	137.2	137.2	137.2
H_g (distance from ground water to pressure gauge), cm =	234.7	234.7	234.7	234.7	234.7
H_p (linear units of water head), cm =	974.8	2030.9	3087.1	2030.9	974.8
H (total gravity and pressure differential head), cm=	1209.5	2265.6	3321.8	2265.6	1209.5
r (radius of borehole), cm =	3.8	3.8	3.8	3.8	3.8
k (hydraulic conductivity), cm/s =	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
k (hydraulic conductivity), ft/s =	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

PolyMet 2014 Packer Testing

Performed: 5/13/2014
Analyzed: 5/21/2014

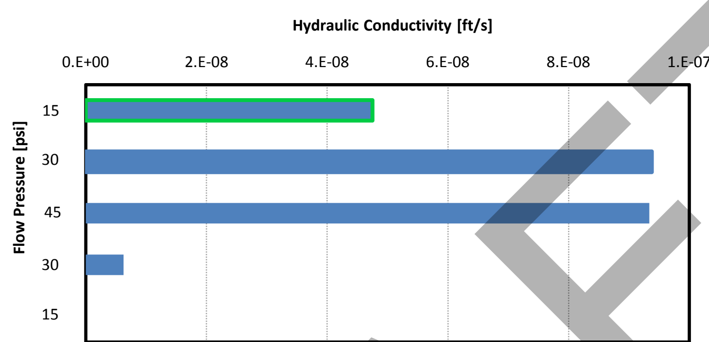
B14-36, 20.5 - 26.5ft

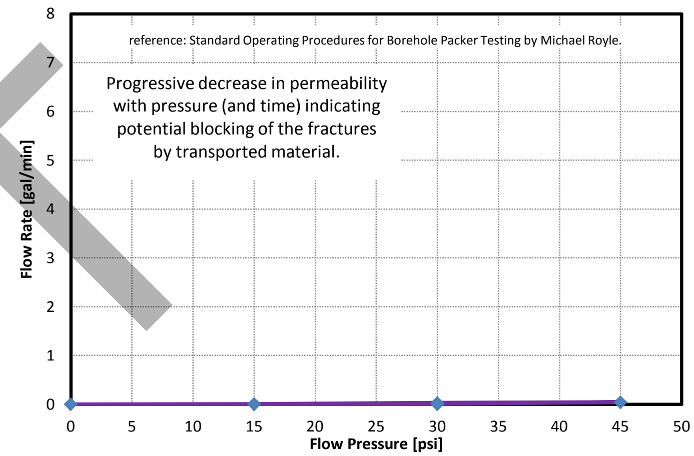
	Value	Unit	Value	Unit
Hydraulic Conductivity =	1.45E-06	cm/s	4.75E-08	ft/s
Maximum =	2.86E-06	cm/s	9.38E-08	ft/s
Minimum =	0.00E+00	cm/s	0.00E+00	ft/s

Notes: Double Packer Test

Packer length (ft) =	2
Screened interval (ft) =	
Total depth of boring (ft) =	26.5
Test interval top (ft) =	20.5
Test interval bottom (ft) =	26.5
Original GWT (ft) =	4.7
GWT before inflation (ft) =	4.7
GWT after inflation (ft) =	4.7
GWT during test (ft) =	4.7
GWT at end of test (ft) =	4.7
Height of pressure gauge (ft) =	3
Packer inflation pressure (psi) =	140
RQD for test interval (%) =	83
Borehole radius (inches) =	1.5

Total testing interval (ft) =	6
Length of pipe above ground (ft) =	3
Length of pipe below ground (ft) =	18.5
Total length for losses (ft) =	21.5





Flow Pressure (psi) =	15			30			45			30			15		
Time (min)	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow
0	80.80	0.0	0.0	80.88	0.0	0.0	81.05	0.0	0.0	81.27	0.0	0.0	81.28	0.0	0.0
1	80.81	0.0	0.0	80.92	0.0	0.0	81.11	0.1	0.1	81.28	0.0	0.0	81.28	0.0	0.0
2	80.81	0.0	0.0	80.95	0.1	0.0	81.17	0.1	0.1	81.28	0.0	0.0	81.28	0.0	0.0
3	80.82	0.0	0.0	80.98	0.1	0.0	81.21	0.2	0.0	81.28	0.0	0.0	81.28	0.0	0.0
4	80.83	0.0	0.0	81.01	0.1	0.0	81.24	0.2	0.0	81.28	0.0	0.0	81.28	0.0	0.0
5	80.84	0.0	0.0	81.03	0.2	0.0	81.27	0.2	0.0	81.28	0.0	0.0	81.28	0.0	0.0

	15 psi	30 psi	45 psi	30 psi	15 psi
Average Flowrate (gal/min) =	0.0	0.0	0.04	0.00	0.00
Applied pressure (psi) =	15	30	45	30	15
Friction loss/foot (psi) =	0.08	0.08	0.08	0.08	0.08
Friction loss (psi) =	1.7	1.7	1.7	1.7	1.7
Effective pressure (psi) =	13.3	28.3	43.3	28.3	13.3

USBR 7310-89 Calculation for Hydraulic Conductivity

	15 psi	30 psi	45 psi	30 psi	15 psi
q (constant rate of flow into the test interval), cm^3/s =	0.5	1.9	2.8	0.1	0.0
L (length of the test interval), cm =	182.9	182.9	182.9	182.9	182.9
H_g (distance from ground water to pressure gauge), cm =	234.7	234.7	234.7	234.7	234.7
H_p (linear units of water head), cm =	939.6	1995.7	3051.8	1995.7	939.6
H (total gravity and pressure differential head), cm=	1174.3	2230.4	3286.5	2230.4	1174.3
r (radius of borehole), cm =	3.8	3.8	3.8	3.8	3.8
k (hydraulic conductivity), cm/s =	1.45E-06	2.86E-06	2.85E-06	1.91E-07	0.00E+00
k (hydraulic conductivity), ft/s =	4.75E-08	9.38E-08	9.34E-08	6.25E-09	0.00E+00

PolyMet 2014 Packer Testing

Performed: 5/2/2014

Analyzed: 5/21/2014

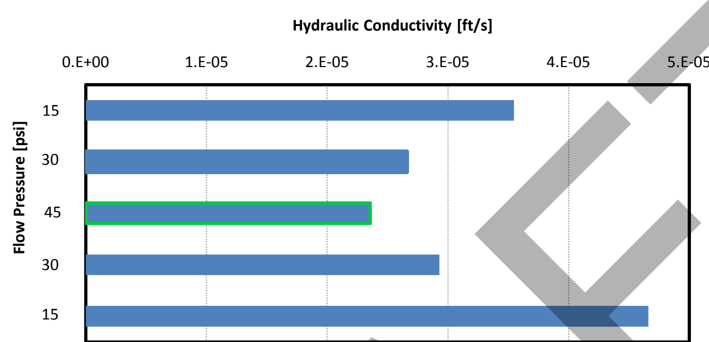
B14-55, 37 - 41.5ft

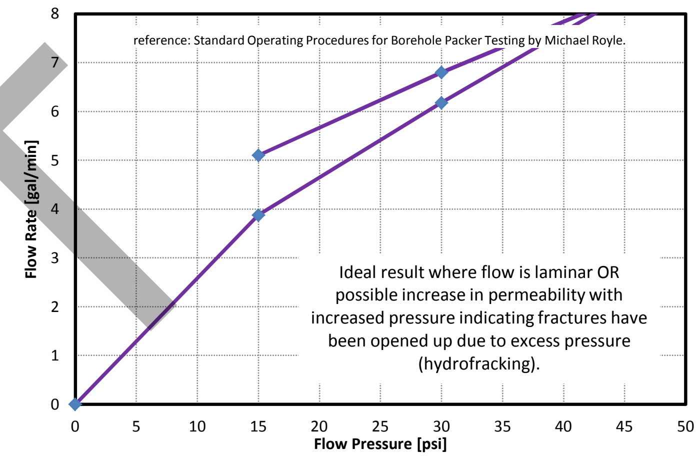
Hydraulic Conductivity =	7.18E-04	cm/s	2.36E-05	ft/s
Maximum =	1.42E-03	cm/s	4.66E-05	ft/s
Minimum =	7.18E-04	cm/s	2.36E-05	ft/s

Notes: Double Packer Test

Packer length (ft) =	2
Screened interval (ft) =	3
Total depth of boring (ft) =	50.5
Test interval top (ft) =	37
Test interval bottom (ft) =	41.5
Original GWT (ft) =	0
GWT before inflation (ft) =	0
GWT after inflation (ft) =	0
GWT during test (ft) =	0
GWT at end of test (ft) =	0
Height of pressure gauge (ft) =	3
Packer inflation pressure (psi) =	140
RQD for test interval (%) =	30
Borehole radius (inches) =	1.5

Total testing interval (ft) =	4.5
Length of pipe above ground (ft) =	3
Length of pipe below ground (ft) =	35
Total length for losses (ft) =	38





Flow Pressure (psi) =	15			30			45			30			15		
Time (min)	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow
0	0.40	0.0	0.0	2.50	0.0	0.0	5.20	0.0	0.0	9.70	0.0	0.0	5.70	0.0	0.0
1	4.50	4.1	4.1	8.50	6.0	6.0	13.40	8.2	8.2	16.30	6.6	6.6	10.80	5.1	5.1
2	8.20	7.8	3.7	14.60	12.1	6.1	21.90	16.7	8.5	23.20	13.5	6.9	15.90	10.2	5.1
3	12.00	11.6	3.8	20.90	18.4	6.3	30.30	25.1	8.4	30.00	20.3	6.8	21.00	15.3	5.1
4	15.50	15.1	3.5	27.00	24.5	6.1	38.50	33.3	8.2	36.90	27.2	6.9	26.20	20.5	5.2
5	19.80	19.4	4.3	33.40	30.9	6.4	47.00	41.8	8.5	43.70	34.0	6.8	31.20	25.5	5.0

	15 psi	30 psi	45 psi	30 psi	15 psi
Average Flowrate (gal/min) =	3.88	6.18	8.36	6.80	5.10
Applied pressure (psi) =	15	30	45	30	15
Friction loss/foot (psi) =	0.08	0.08	0.08	0.08	0.08
Friction loss (psi) =	2.9	2.9	2.9	2.9	2.9
Effective pressure (psi) =	12.1	27.1	42.1	27.1	12.1

USBR 7310-89 Calculation for Hydraulic Conductivity

q (constant rate of flow into the test interval), cm^3/s =	244.8	389.9	527.4	429.0	321.8
L (length of the test interval), cm =	137.2	137.2	137.2	137.2	137.2
H_g (distance from ground water to pressure gauge), cm =	91.4	91.4	91.4	91.4	91.4
H_p (linear units of water head), cm =	850.1	1906.2	2962.4	1906.2	850.1
H (total gravity and pressure differential head), cm=	941.6	1997.7	3053.8	1997.7	941.6
r (radius of borehole), cm =	3.8	3.8	3.8	3.8	3.8
k (hydraulic conductivity), cm/s =	1.08E-03	8.12E-04	7.18E-04	8.93E-04	1.42E-03
k (hydraulic conductivity), ft/s =	3.55E-05	2.66E-05	2.36E-05	2.93E-05	4.66E-05

PolyMet 2014 Packer Testing

Performed: 5/2/2014

Analyzed: 5/21/2014

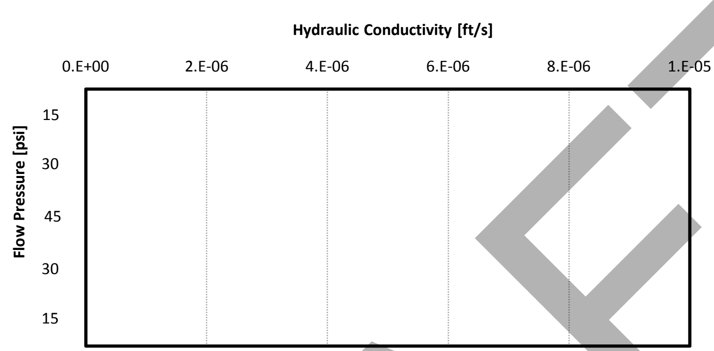
Notes: Double Packer Test

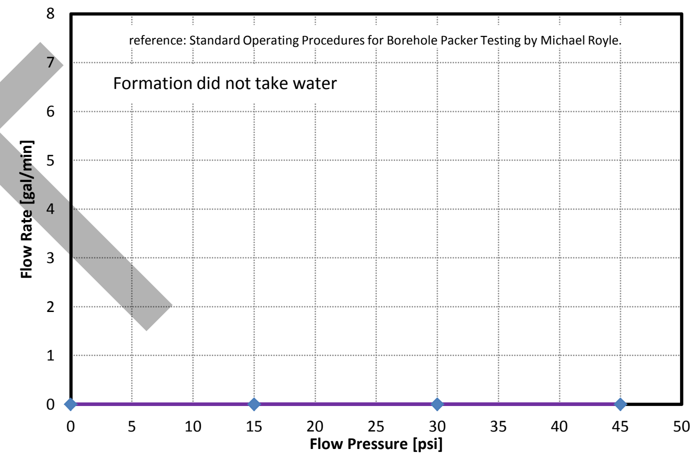
B14-55, 41.5 - 46.5ft

Hydraulic Conductivity =	0.00E+00 cm/s	0.00E+00 ft/s
Maximum =	0.00E+00 cm/s	0.00E+00 ft/s
Minimum =	0.00E+00 cm/s	0.00E+00 ft/s

Packer length (ft) =	2
Screened interval (ft) =	3
Total depth of boring (ft) =	50.5
Test interval top (ft) =	41.5
Test interval bottom (ft) =	46
Original GWT (ft) =	0
GWT before inflation (ft) =	0
GWT after inflation (ft) =	0
GWT during test (ft) =	0
GWT at end of test (ft) =	0
Height of pressure gauge (ft) =	3
Packer inflation pressure (psi) =	140
RQD for test interval (%) =	100
Borehole radius (inches) =	1.5

Total testing interval (ft) =	4.5
Length of pipe above ground (ft) =	3
Length of pipe below ground (ft) =	39.5
Total length for losses (ft) =	42.5





Flow Pressure (psi) =	15			30			45			30			15		
Time (min)	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow
0	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0
1	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0
2	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0
3	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0
4	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0
5	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0	5.50	0.0	0.0

Average Flowrate (gal/min) =	0.0	0.0	0.0	0.0	0.0
Applied pressure (psi) =	15	30	45	30	15
Friction loss/foot (psi) =	0.08	0.08	0.08	0.08	0.08
Friction loss (psi) =	3.3	3.3	3.3	3.3	3.3
Effective pressure (psi) =	11.7	26.7	41.7	26.7	11.7

USBR 7310-89 Calculation for Hydraulic Conductivity

q (constant rate of flow into the test interval), cm^3/s =	0.0	0.0	0.0	0.0	0.0
L (length of the test interval), cm =	137.2	137.2	137.2	137.2	137.2
H_g (distance from ground water to pressure gauge), cm =	91.4	91.4	91.4	91.4	91.4
H_p (linear units of water head), cm =	825.7	1881.9	2938.0	1881.9	825.7
H (total gravity and pressure differential head), cm=	917.2	1973.3	3029.4	1973.3	917.2
r (radius of borehole), cm =	3.8	3.8	3.8	3.8	3.8
k (hydraulic conductivity), cm/s =	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
k (hydraulic conductivity), ft/s =	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

PolyMet 2014 Packer Testing

Performed: 5/2/2014
Analyzed: 5/21/2014

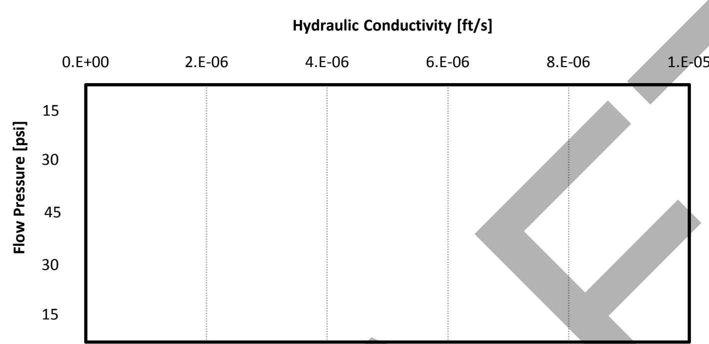
B14-55, 46 - 50.5ft

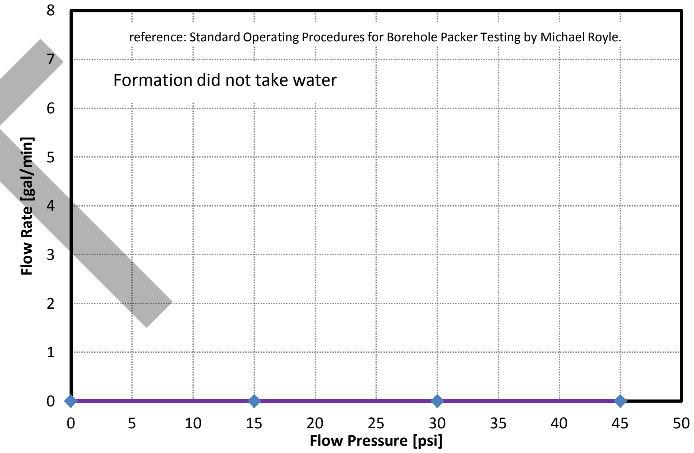
Hydraulic Conductivity =	0.00E+00	cm/s	0.00E+00	ft/s
Maximum =	0.00E+00	cm/s	0.00E+00	ft/s
Minimum =	0.00E+00	cm/s	0.00E+00	ft/s

Notes: Single Packer Test

Packer length (ft) =	2
Screened interval (ft) =	
Total depth of boring (ft) =	50.5
Test interval top (ft) =	46
Test interval bottom (ft) =	50.5
Original GWT (ft) =	0
GWT before inflation (ft) =	0
GWT after inflation (ft) =	0
GWT during test (ft) =	0
GWT at end of test (ft) =	0
Height of pressure gauge (ft) =	3
Packer inflation pressure (psi) =	140
RQD for test interval (%) =	48
Borehole radius (inches) =	1.5

Total testing interval (ft) =	4.5
Length of pipe above ground (ft) =	3
Length of pipe below ground (ft) =	44
Total length for losses (ft) =	47





Flow Pressure (psi) =	15			30			45			30			15		
Time (min)	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow
0	1.20	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0
1	1.20	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0
2	1.20	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0
3	1.20	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0
4	1.20	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0
5	1.20	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0	1.30	0.0	0.0

Average Flowrate (gal/min) =	0.0	0.0	0.0	0.0	0.0
Applied pressure (psi) =	15	30	45	30	15
Friction loss/foot (psi) =	0.08	0.08	0.08	0.08	0.08
Friction loss (psi) =	3.6	3.6	3.6	3.6	3.6
Effective pressure (psi) =	11.4	26.4	41.4	26.4	11.4

USBR 7310-89 Calculation for Hydraulic Conductivity

q (constant rate of flow into the test interval), cm^3/s =	0.0	0.0	0.0	0.0	0.0
L (length of the test interval), cm =	137.2	137.2	137.2	137.2	137.2
H_g (distance from ground water to pressure gauge), cm =	91.4	91.4	91.4	91.4	91.4
H_p (linear units of water head), cm =	801.3	1857.5	2913.6	1857.5	801.3
H (total gravity and pressure differential head), cm=	892.8	1948.9	3005.0	1948.9	892.8
r (radius of borehole), cm =	3.8	3.8	3.8	3.8	3.8
k (hydraulic conductivity), cm/s =	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
k (hydraulic conductivity), ft/s =	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

PolyMet 2014 Packer Testing

Performed: 4/3/2014

Analyzed: 5/21/2014

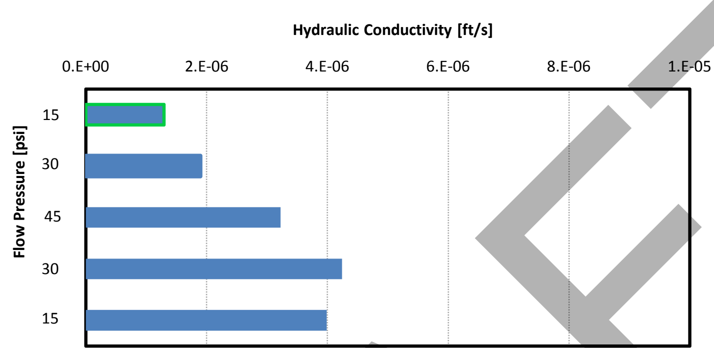
B14-44, 34 - 42ft

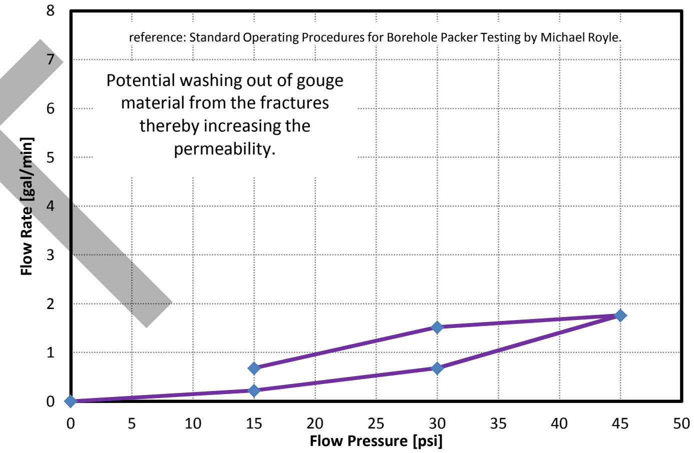
Hydraulic Conductivity =	3.93E-05	cm/s		1.29E-06	ft/s
Maximum =	1.29E-04	cm/s		4.24E-06	ft/s
Minimum =	3.93E-05	cm/s		1.29E-06	ft/s

Notes: Single Packer Test

Packer length (ft) =	2
Screened interval (ft) =	
Total depth of boring (ft) =	42
Test interval top (ft) =	34
Test interval bottom (ft) =	42
Original GWT (ft) =	0
GWT before inflation (ft) =	0
GWT after inflation (ft) =	0
GWT during test (ft) =	0
GWT at end of test (ft) =	0
Height of pressure gauge (ft) =	3
Packer inflation pressure (psi) =	140
RQD for test interval (%) =	69
Borehole radius (inches) =	1.5

Total testing interval (ft) =	8
Length of pipe above ground (ft) =	3
Length of pipe below ground (ft) =	32
Total length for losses (ft) =	35





Flow Pressure (psi) =	15			30			45			30			15		
Time (min)	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow
0	7.0	0.0	0.0	8.5	0.0	0.0	2.6	0.0	0.0	2.7	0.0	0.0	0.5	0.0	0.0
1	7.1	0.1	0.1	9.2	0.7	0.7	3.9	1.3	1.3	4.0	1.3	1.3	1.1	0.6	0.6
2	7.4	0.4	0.3	9.9	1.4	0.7	5.8	3.2	1.9	5.6	2.9	1.6	1.8	1.3	0.7
3	7.7	0.7	0.3	10.5	2.0	0.6	6.7	4.1	0.9	7.1	4.4	1.5	2.6	2.1	0.8
4	7.9	0.9	0.2	11.2	2.7	0.7	8.3	5.7	1.6	8.7	6.0	1.6	3.3	2.8	0.7
5	8.1	1.1	0.2	11.9	3.4	0.7	11.4	8.8	3.1	10.3	7.6	1.6	3.9	3.4	0.6

	15 psi	30 psi	45 psi	30 psi	15 psi
Average Flowrate (gal/min) =	0.2	0.7	1.8	1.5	0.7
Applied pressure (psi) =	15	30	45	30	15
Friction loss/foot (psi) =	0.08	0.08	0.08	0.08	0.08
Friction loss (psi) =	2.7	2.7	2.7	2.7	2.7
Effective pressure (psi) =	12.3	27.3	42.3	27.3	12.3

USBR 7310-89 Calculation for Hydraulic Conductivity

	15 psi	30 psi	45 psi	30 psi	15 psi
q (constant rate of flow into the test interval), cm^3/s =	13.9	42.9	111.0	95.9	42.9
L (length of the test interval), cm =	243.8	243.8	243.8	243.8	243.8
H_g (distance from ground water to pressure gauge), cm =	91.4	91.4	91.4	91.4	91.4
H_p (linear units of water head), cm =	866.4	1922.5	2978.6	1922.5	866.4
H (total gravity and pressure differential head), cm=	957.8	2014.0	3070.1	2014.0	957.8
r (radius of borehole), cm =	3.8	3.8	3.8	3.8	3.8
k (hydraulic conductivity), cm/s =	3.93E-05	5.78E-05	9.82E-05	1.29E-04	1.22E-04
k (hydraulic conductivity), ft/s =	1.29E-06	1.90E-06	3.22E-06	4.24E-06	3.99E-06

PolyMet 2014 Packer Testing

Performed: 4/3/2014

Analyzed: 5/21/2014

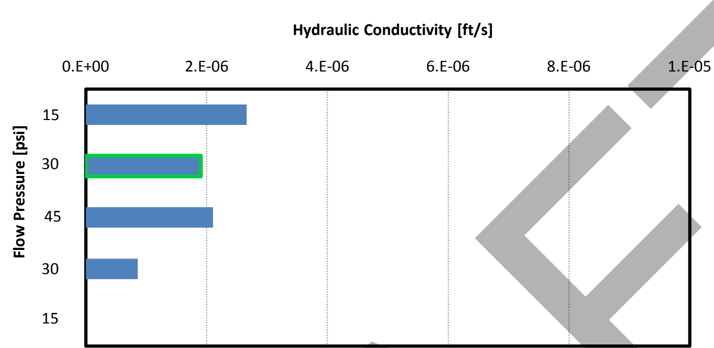
B14-44, 42 - 46ft

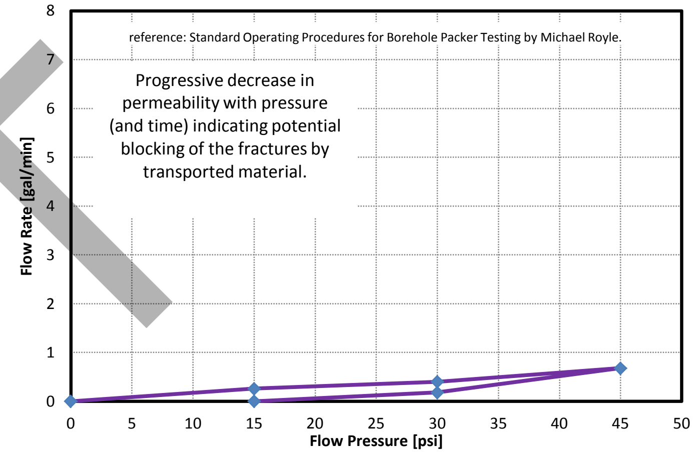
Hydraulic Conductivity =	5.79E-05	cm/s	1.90E-06	ft/s
Maximum =	8.12E-05	cm/s	2.66E-06	ft/s
Minimum =	0.00E+00	cm/s	0.00E+00	ft/s

Notes: Double Packer Test

Packer length (ft) =	2
Screened interval (ft) =	3
Total depth of boring (ft) =	46
Test interval top (ft) =	42
Test interval bottom (ft) =	46
Original GWT (ft) =	0
GWT before inflation (ft) =	0
GWT after inflation (ft) =	0
GWT during test (ft) =	0
GWT at end of test (ft) =	0
Height of pressure gauge (ft) =	3
Packer inflation pressure (psi) =	140
RQD for test interval (%) =	92
Borehole radius (inches) =	1.5

Total testing interval (ft) =	4
Length of pipe above ground (ft) =	3
Length of pipe below ground (ft) =	40
Total length for losses (ft) =	43





Flow Pressure (psi) =	15			30			45			30			15		
Time (min)	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow
0	4.6	0.0	0.0	6.3	0.0	0.0	9.2	0.0	0.0	2.9	0.0	0.0	3.8	0.0	0.0
1	4.9	0.3	0.3	6.8	0.5	0.5	9.9	0.7	0.7	3.1	0.2	0.2	3.8	0.0	0.0
2	5.2	0.6	0.3	7.1	0.8	0.3	10.6	1.4	0.7	3.3	0.4	0.2	3.8	0.0	0.0
3	5.5	0.9	0.3	7.5	1.2	0.4	11.2	2.0	0.6	3.3	0.4	0.0	3.8	0.0	0.0
4	5.7	1.1	0.2	7.9	1.6	0.4	11.9	2.7	0.7	3.4	0.5	0.1	3.8	0.0	0.0
5	5.9	1.3	0.2	8.3	2.0	0.4	12.6	3.4	0.7	3.8	0.9	0.4	3.8	0.0	0.0

Average Flowrate (gal/min) =	0.3	0.4	0.7	0.2	0.0
Applied pressure (psi) =	15	30	45	30	15
Friction loss/foot (psi) =	0.08	0.08	0.08	0.08	0.08
Friction loss (psi) =	3.3	3.3	3.3	3.3	3.3
Effective pressure (psi) =	11.7	26.7	41.7	26.7	11.7

USBR 7310-89 Calculation for Hydraulic Conductivity

q (constant rate of flow into the test interval), cm^3/s =	16.4	25.2	42.9	11.4	0.0
L (length of the test interval), cm =	121.9	121.9	121.9	121.9	121.9
H_g (distance from ground water to pressure gauge), cm =	91.4	91.4	91.4	91.4	91.4
H_p (linear units of water head), cm =	823.0	1879.1	2935.3	1879.1	823.0
H (total gravity and pressure differential head), cm=	914.4	1970.6	3026.7	1970.6	914.4
r (radius of borehole), cm =	3.8	3.8	3.8	3.8	3.8
k (hydraulic conductivity), cm/s =	8.12E-05	5.79E-05	6.41E-05	2.61E-05	0.00E+00
k (hydraulic conductivity), ft/s =	2.66E-06	1.90E-06	2.10E-06	8.55E-07	0.00E+00

PolyMet 2014 Packer Testing

Performed: 4/18/2014

Analyzed: 5/21/2014

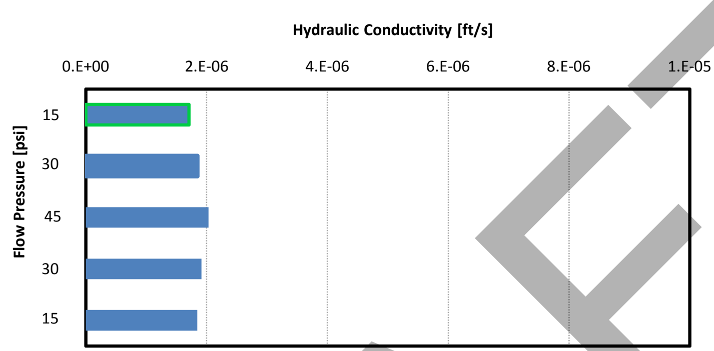
B14-65, 24 - 30ft

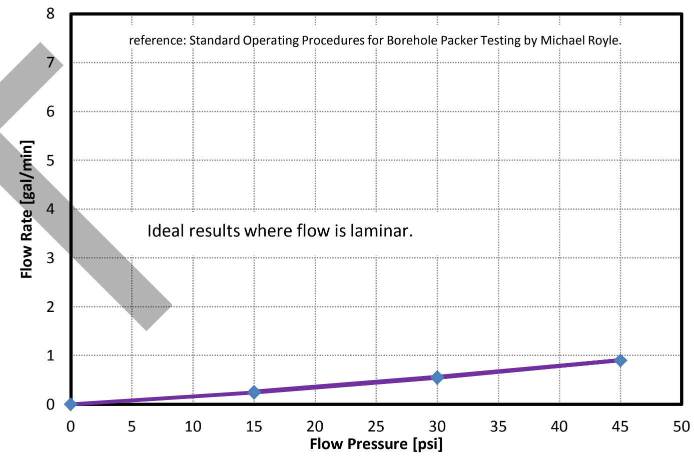
Hydraulic Conductivity =	5.19E-05	cm/s	1.70E-06	ft/s
Maximum =	6.18E-05	cm/s	2.03E-06	ft/s
Minimum =	5.19E-05	cm/s	1.70E-06	ft/s

Notes: Double Packer Test

Packer length (ft) =	2
Screened interval (ft) =	5
Total depth of boring (ft) =	37
Test interval top (ft) =	24
Test interval bottom (ft) =	30
Original GWT (ft) =	0
GWT before inflation (ft) =	0
GWT after inflation (ft) =	0
GWT during test (ft) =	0
GWT at end of test (ft) =	0
Height of pressure gauge (ft) =	3
Packer inflation pressure (psi) =	140
RQD for test interval (%) =	81
Borehole radius (inches) =	1.5

Total testing interval (ft) =	6
Length of pipe above ground (ft) =	8.5
Length of pipe below ground (ft) =	22
Total length for losses (ft) =	30.5





Flow Pressure (psi) =	15			30			45			30			15		
Time (min)	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow
0	4.5	0.0	0.0	6.1	0.0	0.0	9.7	0.0	0.0	4.5	0.0	0.0	7.3	0.0	0.0
1	4.7	0.2	0.2	6.6	0.5	0.5	10.6	0.9	0.9	5.0	0.5	0.5	7.5	0.2	0.2
2	4.9	0.4	0.2	7.2	1.1	0.6	11.5	1.8	0.9	5.6	1.1	0.6	7.8	0.5	0.3
3	5.2	0.7	0.3	7.7	1.6	0.5	12.3	2.6	0.8	6.2	1.7	0.6	8.0	0.7	0.2
4	5.5	1.0	0.3	8.3	2.2	0.6	13.3	3.6	1.0	6.7	2.2	0.5	8.3	1.0	0.3
5	5.7	1.2	0.2	8.8	2.7	0.5	14.2	4.5	0.9	7.3	2.8	0.6	8.6	1.3	0.3

Average Flowrate (gal/min) =	0.2	0.5	0.9	0.6	0.3
Applied pressure (psi) =	15	30	45	30	15
Friction loss/foot (psi) =	0.08	0.08	0.08	0.08	0.08
Friction loss (psi) =	2.3	2.3	2.3	2.3	2.3
Effective pressure (psi) =	12.7	27.7	42.7	27.7	12.7

USBR 7310-89 Calculation for Hydraulic Conductivity

q (constant rate of flow into the test interval), cm^3/s =	15.1	34.1	56.8	35.3	16.4
L (length of the test interval), cm =	182.9	182.9	182.9	182.9	182.9
H_g (distance from ground water to pressure gauge), cm =	91.4	91.4	91.4	91.4	91.4
H_p (linear units of water head), cm =	890.8	1946.9	3003.0	1946.9	890.8
H (total gravity and pressure differential head), cm=	982.2	2038.3	3094.5	2038.3	982.2
r (radius of borehole), cm =	3.8	3.8	3.8	3.8	3.8
k (hydraulic conductivity), cm/s =	5.19E-05	5.63E-05	6.18E-05	5.84E-05	5.63E-05
k (hydraulic conductivity), ft/s =	1.70E-06	1.85E-06	2.03E-06	1.92E-06	1.85E-06

PolyMet 2014 Packer Testing

Performed: 4/18/2014

Analyzed: 5/21/2014

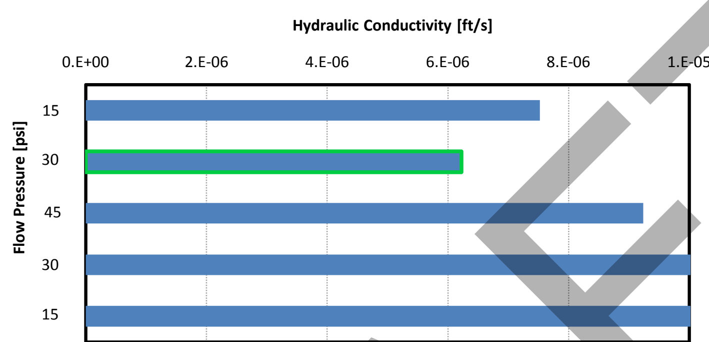
B14-65, 27.5 - 33.5ft

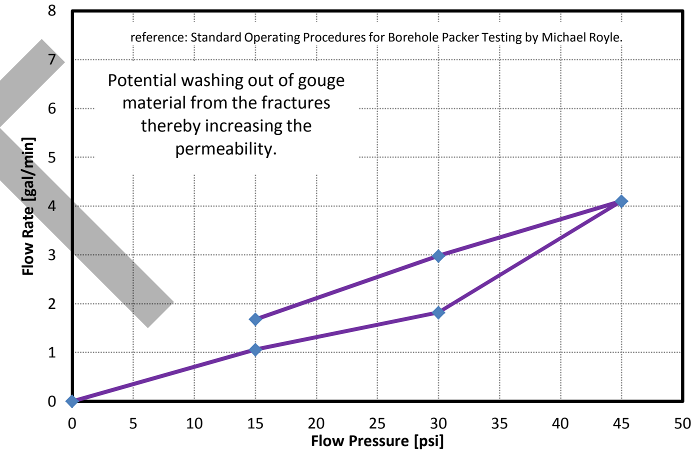
Hydraulic Conductivity =	1.90E-04	**cm/s**	6.23E-06	**ft/s**
Maximum =	3.64E-04	**cm/s**	1.19E-05	**ft/s**
Minimum =	1.90E-04	**cm/s**	6.23E-06	**ft/s**

Notes: Double Packer Test

Packer length (ft) =	2
Screened interval (ft) =	5
Total depth of boring (ft) =	37
Test interval top (ft) =	27.5
Test interval bottom (ft) =	33.5
Original GWT (ft) =	0
GWT before inflation (ft) =	0
GWT after inflation (ft) =	0
GWT during test (ft) =	0
GWT at end of test (ft) =	0
Height of pressure gauge (ft) =	3
Packer inflation pressure (psi) =	140
RQD for test interval (%) =	74
Borehole radius (inches) =	1.5

Total testing interval (ft) =	6
Length of pipe above ground (ft) =	5
Length of pipe below ground (ft) =	25.5
Total length for losses (ft) =	30.5





Flow Pressure (psi) =	15			30			45			30			15		
Time (min)	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow
0	0.0	0.0	0.0	6.5	0.0	0.0	7.5	0.0	0.0	9.1	0.0	0.0	4.3	0.0	0.0
1	1.1	1.1	1.1	8.5	2.0	2.0	10.7	3.2	3.2	12.0	2.9	2.9	5.9	1.6	1.6
2	2.1	2.1	1.0	10.3	3.8	1.8	14.5	7.0	3.8	15.0	5.9	3.0	7.6	3.3	1.7
3	3.2	3.2	1.1	12.1	5.6	1.8	18.8	11.3	4.3	17.9	8.8	2.9	9.2	4.9	1.6
4	4.1	4.1	0.9	13.9	7.4	1.8	23.5	16.0	4.7	21.0	11.9	3.1	11.0	6.7	1.8
5	5.3	5.3	1.2	15.6	9.1	1.7	28.0	20.5	4.5	24.0	14.9	3.0	12.7	8.4	1.7

	15 psi	30 psi	45 psi	30 psi	15 psi
Average Flowrate (gal/min) =	1.1	1.8	4.1	3.0	1.7
Applied pressure (psi) =	15	30	45	30	15
Friction loss/foot (psi) =	0.08	0.08	0.08	0.08	0.08
Friction loss (psi) =	2.3	2.3	2.3	2.3	2.3
Effective pressure (psi) =	12.7	27.7	42.7	27.7	12.7

USBR 7310-89 Calculation for Hydraulic Conductivity

q (constant rate of flow into the test interval), cm^3/s =	66.9	114.8	258.7	188.0	106.0
L (length of the test interval), cm =	182.9	182.9	182.9	182.9	182.9
H_g (distance from ground water to pressure gauge), cm =	91.4	91.4	91.4	91.4	91.4
H_p (linear units of water head), cm =	890.8	1946.9	3003.0	1946.9	890.8
H (total gravity and pressure differential head), cm=	982.2	2038.3	3094.5	2038.3	982.2
r (radius of borehole), cm =	3.8	3.8	3.8	3.8	3.8
k (hydraulic conductivity), cm/s =	2.29E-04	1.90E-04	2.82E-04	3.11E-04	3.64E-04
k (hydraulic conductivity), ft/s =	7.53E-06	6.23E-06	9.24E-06	1.02E-05	1.19E-05

PolyMet 2014 Packer Testing

Performed: 4/3/2014

Analyzed: 5/21/2014

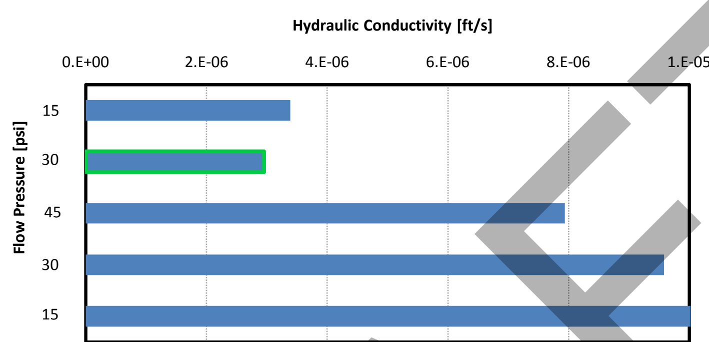
B14-76, 37 - 42ft

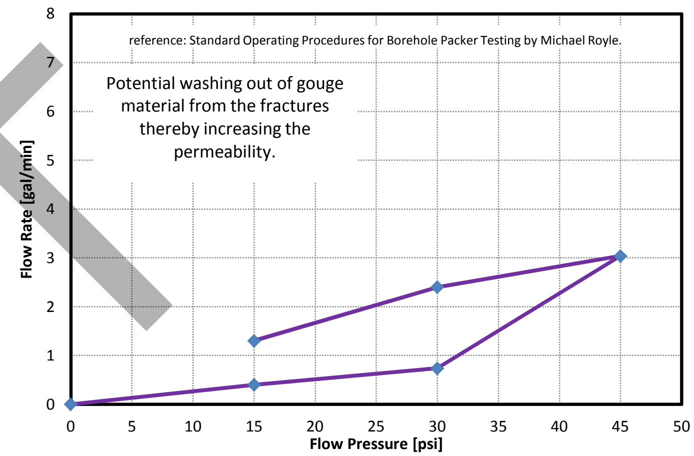
Notes: Single Packer Test

Packer length (ft) =	2
Screened interval (ft) =	5
Total depth of boring (ft) =	42
Test interval top (ft) =	37
Test interval bottom (ft) =	42
Original GWT (ft) =	0
GWT before inflation (ft) =	0
GWT after inflation (ft) =	0
GWT during test (ft) =	0
GWT at end of test (ft) =	0
Height of pressure gauge (ft) =	3
Packer inflation pressure (psi) =	140
RQD for test interval (%) =	70
Borehole radius (inches) =	1.5

Total testing interval (ft) =	5
Length of pipe above ground (ft) =	3
Length of pipe below ground (ft) =	35
Total length for losses (ft) =	38

Hydraulic Conductivity =	9.00E-05	cm/s	2.95E-06	ft/s
Maximum =	3.36E-04	cm/s	1.10E-05	ft/s
Minimum =	9.00E-05	cm/s	2.95E-06	ft/s





Flow Pressure (psi) =	15			30			45			30			15		
Time (min)	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow	Flow (gal)	Cumulative	Partial Flow
0	9.5	0.0	0.0	2.5	0.0	0.0	8.0	0.0	0.0	4.0	0.0	0.0	8.4	0.0	0.0
1	10.0	0.5	0.5	3.2	0.7	0.7	10.8	2.8	2.8	6.7	2.7	2.7	9.7	1.3	1.3
2	10.5	1.0	0.5	3.9	1.4	0.7	14.0	6.0	3.2	9.1	5.1	2.4	11.1	2.7	1.4
3	10.5	1.0	0.0	4.7	2.2	0.8	17.0	9.0	3.0	11.5	7.5	2.4	12.4	4.0	1.3
4	11.0	1.5	0.5	5.5	3.0	0.8	20.1	12.1	3.1	13.9	9.9	2.4	13.6	5.2	1.2
5	11.5	2.0	0.5	6.2	3.7	0.7	23.2	15.2	3.1	16.0	12.0	2.1	14.9	6.5	1.3

Average Flowrate (gal/min) =	0.4	0.7	3.0	2.4	1.3
Applied pressure (psi) =	15	30	45	30	15
Friction loss/foot (psi) =	0.08	0.08	0.08	0.08	0.08
Friction loss (psi) =	2.9	2.9	2.9	2.9	2.9
Effective pressure (psi) =	12.1	27.1	42.1	27.1	12.1

USBR 7310-89 Calculation for Hydraulic Conductivity

q (constant rate of flow into the test interval), cm^3/s =	25.2	46.7	191.8	151.4	82.0
L (length of the test interval), cm =	152.4	152.4	152.4	152.4	152.4
H_g (distance from ground water to pressure gauge), cm =	91.4	91.4	91.4	91.4	91.4
H_p (linear units of water head), cm =	850.1	1906.2	2962.4	1906.2	850.1
H (total gravity and pressure differential head), cm=	941.6	1997.7	3053.8	1997.7	941.6
r (radius of borehole), cm =	3.8	3.8	3.8	3.8	3.8
k (hydraulic conductivity), cm/s =	1.03E-04	9.00E-05	2.42E-04	2.92E-04	3.36E-04
k (hydraulic conductivity), ft/s =	3.39E-06	2.95E-06	7.94E-06	9.58E-06	1.10E-05