Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls

Prepared for

Paula Maccabee
Attorney for WaterLegacy
1961 Selby Avenue
St. Paul, MN 55104

By

J.D. Lehr
Professional Geologist
P.O. Box 217
Lutsen, MN 55612

I hereby certify that this plan, document, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Geologist under the laws of the state of Minnesota.

J.D. Lehr
Reg. No. 30063

Date: January 4, 2022

TABLE OF CONTENTS

1.0 QUALIFICATIONS

I have included at the end of this report Curriculum Vitae that summarize my academic and professional experience and list my credentials as a geologist (Appendix C). My academic and professional experience has direct connections to the geology of the PolyMet tailings basin.

My graduate thesis research was focused on the surficial geology of an area north of the eastern Mesabi Range.[1] The PolyMet tailings basin property was within my thesis study area and part of my research involved geologic field work on the tailings basin site.

My first full-time geology job was with the South Dakota Geological Survey mapping surficial geology in the glaciated eastern part of the state and carrying out investigations of subsurface geology via drilling. After two years I returned to Minnesota to take a position with the Minnesota Department of Natural Resources (DNR) where my primary responsibility was to map surficial geology for aggregate resource assessment purposes. During 10 years working on the DNR's aggregate mapping program I gained thousands of hours of experience mapping surficial geology and also published on the subjects of glacial geology, mapping and mineral resources (Appendix C).

While working with DNR I and an associate from the Minnesota Geological Survey convened a 2-day field conference on the surficial geology of a portion of northeastern Minnesota. At the conference, I presented a large group of geoscientists from around the country (and Canada) with information about glacial sediments that I had studied and led critical discussions about my interpretations. This field conference resulted in the publication of a Minnesota Geological Survey Guidebook,[2] serving as peer-review and validation of the mapping techniques and research results that included critical portions of the PolyMet tailings basin site.

I then worked for an international construction materials company that was one of the largest producers of sand and gravel in the nation. I used my experience mapping surficial geology to identify new deposits and to assist them in understanding the geometry of those deposits being mined. I continue to provide advice as a consulting geologist on part-time basis. The techniques I developed to map surficial geology (including detailed analysis of subsurface data) have been validated by my success in identifying valuable construction aggregate deposits.

During my semi-retirement, I have continued to map surficial geology of northeastern Minnesota as a hobby interest, for some teaching, and to advise WaterLegacy on matters relating to geology and the PolyMet project.

---

[1] Lehr, J.D., 2000, Pleistocene geology of the Embarrass area, St. Louis County, Minnesota: M.S. Thesis, University of Minnesota, 157 p., scale 1:48,000.

[2] Lehr, J.D. and Hobbs, H.C., 1992, Field trip guidebook for the glacial geology of the Laurentian divide area, St. Louis and Lake counties, Minnesota: Minnesota Geological Survey Guidebook Series No. 18, 73 p., 1 plate, scale 1:250,000.

2.0 EXECUTIVE SUMMARY

One of PolyMet's key assumptions in support of their plans to control water pollution at the tailings basin is that below the upper 10 feet of bedrock a "no-flow boundary" or an "impermeable" zone exists within the bedrock at the tailings basin. This assumption is unfounded. PolyMet assumed for the purposes of modeling the efficacy of the proposed seepage capture system that groundwater flow through this zone is negligible. An objective presentation of the bedrock drilling information and derived RQD and packer test data presented in the Geotechnical Report shows that: 1) sampling bias was involved in arriving at PolyMet's fundamental conclusion regarding groundwater seepage, therefore invalidating those assumptions about groundwater flow through bedrock, and 2) even the selective data available do not support a "no-flow boundary" below the upper 10 feet of bedrock. The seepage capture system design approved by DNR and the concept that the efficacy of bentonite application to the tailings basin can be measured by the volume of seepage collected by this system are both based on this assumption.

An objective examination of PolyMet's subsurface dataset reveals significant gaps in the drilling data claimed to identify competent bedrock into which the tailings basin seepage collection system must be "keyed." Additionally, several of the holes drilled yielded low-confidence results, suggesting that they may have terminated in large boulders, not bedrock. These shortcomings are most prevalent along the northern perimeter of the tailings basin. Finally, when read closely, PolyMet's Geotechnical Report demonstrates the presence artesian groundwater conditions everywhere along the perimeter of the tailings basin, evidenced by widespread wintertime open water conditions and artesian water levels measured in all monitoring wells installed. Flowing artesian conditions were also noted during drilling along the northern perimeter of the tailings basin.

Open water conditions caused by artesian groundwater flow prevented access with drilling equipment and prohibited collection of subsurface information in many areas, especially along the northern perimeter of the tailings basin. This results in underrepresentation of areas at the perimeter of the seepage collection system where the most extensively fractured bedrock exists.

Extensively fractured bedrock at the tailings basin will increase the likelihood of contaminant transport off the site through fractured bedrock beneath the tailings basin, the seepage capture area, or the slurry wall rather than containment by the slurry wall. Assumptions of nearly complete capture used in PolyMet's modeling are based on an incomplete and biased subsurface dataset and are not supported.

PolyMet claims that subsurface conditions at the tailings basin will allow a bentonite-rich slurry wall to be constructed without interruption along the west, north and portions of the east perimeter of the existing tailings basin. The assumptions relied upon to predict successfully capturing tailings seepage depend on a bentonite slurry wall that can be constructed so that it is effectively "*keyed to competent bedrock*" as specified by DNR. However, PolyMet's drilling and testing have failed to demonstrate that the slurry wall can be keyed into solid granite bedrock given: 1) the great (and still uncertain) depths to competent bedrock, 2) the boulder-rich nature of the glacial sediments, 3) the commonplace occurrence of very large boulders, and 4) the widespread occurrence of artesian groundwater conditions at the PolyMet seepage capture perimeter.

There is no basis to conclude that subsurface conditions at the PolyMet tailings basin would allow construction of an effective slurry wall: 1) PolyMet has not defined depth to competent bedrock in critical areas along the northern perimeter of the tailings basin. 2) Only a low degree of confidence exists regarding represented depths to competent bedrock in other areas. 3) PolyMet's biased and incomplete picture of the subsurface further calls into question the location of competent bedrock into which the slurry wall must be "keyed". 4) Widespread artesian groundwater flow conditions at the seepage capture system perimeter are entirely unaccounted for in PolyMet's plans to construct the seepage capture system. Slurry wall construction under these artesian groundwater conditions is likely to be impossible for the same reasons drilling was not possible over large areas along the northern perimeter of the tailings basin.

Despite PolyMet's continuing assumptions that tailings basin bedrock acts as a "no flow boundary",[3, 4] their drilling and testing data show this assumption is inaccurate. PolyMet has not demonstrated the feasibility of "keying" the slurry wall to "competent bedrock" given the cumulative sum of adverse subsurface geologic conditions known to exist.

The cumulative adverse subsurface geologic conditions at the tailings basin and the lack of a robust subsurface dataset will result in PolyMet's failure to achieve the levels of water pollution control predicted in their models. In addition, due to the likely release of uncaptured seepage to the environment, monitoring the seepage capture system will be ineffective to assess the efficacy of bentonite application to the tailings basin pond in reducing seepage volume.

3.0 BACKGROUND

3.1 Description of the existing tailings basin

PolyMet Mining ("PolyMet") proposes to permanently store 20 years of sulfide-bearing copper-nickel mine waste (tailings) on top of an existing iron ore[5] tailings impoundment known historically as the Erie/LTV tailings basin.[6] Construction of the tailings basin was begun by Erie Mining Company in the mid-1950's by building dams out of a combination of mining waste rock and locally occurring glacial sediments and then simply pumping taconite tailings onto the ground behind these dams.[7, 8] The patchwork of glacial sediments, post-glacial peat and forest soils onto which the first tailings were discharged would become the tailings basin's foundation. Notice on Figure 1 three naturally occurring

[3] Permit to Mine Application, p. 349.
[4] Geotechnical Report, p. 71.
[5] The iron ore mined in Minnesota is also known as taconite.
[6] This tailings basin is also referred to as the LTVSMC tailings basin.
[7] NorthMet Mining Project and Land Exchange Final Environmental Impact Statement, November 2015 ("Final EIS"), p. 772.
[8] The progressive inundation of the forest with taconite tailings is apparent on historic aerial photographs covering the site. For example air photo slc_045_049.jpg from 1972 and air photo stl_016_089.jpg from 1981. These aerial photos were accessed at https://www.dnr.state.mn.us/maps/landview/index.html.

streams and extensive wetlands that are now covered by tailings. No low-permeability liner has ever been installed beneath the taconite tailings; in fact, the tailings basin was initially designed so that precipitation and water used to pump the tailings would percolate through the tailings and infiltrate the natural glacial sediments and bedrock below, leaving the pile of tailings less structurally vulnerable.

An additional factor that led Erie Mining to choose this location for their tailings basin is that a series of natural bedrock hills (shown on U.S. Geological Survey maps as the Embarrass Mountains) would form most of the southern and eastern margins of the tailings basin (Figure 1 and Figure 2). Tailings storage capacity was increased over the years by expanding the initial footprint and by building additional, higher waste-rock dams offset in the upstream direction – that is, in the direction from which tailings were being pumped. The upstream method used to construct the tailings dams has resulted in the stair-stepped appearance most obvious along the southwestern, western and northern perimeter of the tailings basin (Figure 2).

The Erie/LTV/PolyMet tailings basin is notable in comparison to other taconite tailings basins in Minnesota for two reasons. It is the oldest taconite tailings basin in the State and also the tallest, currently rising on its west side to greater than 250 feet above the land immediately to the north.[9] The tailings basin and plant site have remained un-reclaimed and dormant since LTV ceased mining and taconite processing operations in 2001.

How the tailings dams were built and how taconite tailings were disposed of is related to the efficacy of PolyMet's proposed water pollution controls because both taconite tailings and native geologic materials underlie the entire portion of the existing tailings basin that PolyMet's proposes to use as a permanent location to dispose of their copper-nickel tailings. No liners have been installed beneath the existing tailings basin, nor is any type of liner proposed beneath PolyMet's tailings (Figure 2).

3.2 PolyMet's proposed water pollution controls in relation to subsurface geologic conditions

PolyMet proposes to utilize the eastern half of the existing tailings basin for disposal of their tailings over a 20 year timescale[10] (Figure 2). The topography of the higher western half of the existing tailings basin will remain largely unchanged and will not be covered with bentonite or a low-permeability cover.[11] For the remainder of this report the eastern half of the existing tailings basin where PolyMet plans to dispose of tailings will be referred to as the "FTB**"** (PolyMet's "Flotation Tailings Basin").[12]

---

[9] This measurement was made using the 2012 LiDAR topographic data available for the tailings basin site.

[10] The annual volume of tailings production is a point of dispute. The Final EIS was prepared based on an assumed daily plant throughput of +/-30,000 tons. PolyMet has represented to investors that they intend to triple plant output thereby increasing tailings volume three-fold. The feasibility and effects of supporting this increased tailings volume has not been addressed by a public review process.

[11] Bentonite application to the pond, beaches, and dam slopes only pertains to the eastern side of the tailings basin where copper-nickel tailings will be stored (the "FTB").

[12] The terms "FTB" and "tailings basin" are sometimes used interchangeably where it makes no difference in the meaning of a statement. Likewise, "FTB site" and "tailings basin site" are also sometimes used interchangeably in this report.

In addition to taconite tailings, the foundation of the FTB would be formed by the natural geologic materials that occur beneath that land surface onto which the first taconite tailings were discharged. PolyMet's Permit to Mine Application and supporting documents explains proposed engineered solutions to control water pollution at the FTB. PolyMet characterizes existing geologic conditions of the site as allowing for the installation and operation of these engineered water pollution controls as effectively as predicted and for the timescales predicted. The analysis below will focus on the nature and distribution of the natural geologic materials that underlie the tailings basin and the proposed seepage capture system, including how this information has been portrayed in PolyMet's permitting documents and how site geology relates to seepage through bedrock, slurry wall construction, and long-term efficacy of the seepage capture system at the FTB.

The efficacy of engineered solutions to control water pollution at the FTB is dependent upon an accurate understanding of bedrock geology, surficial geology, and groundwater hydrogeology. Derived geologic and hydrologic variables and assumptions are plugged into computer models to design and then predict the efficacy of engineered water pollution control structures. Successful implementation of complex projects requires accurate understanding of site geology. Geologic site conditions misunderstood or misrepresented will result in actual geologic conditions encountered during construction that are different than predicted; increasing the likelihood engineered structures will fail.

This report demonstrates how PolyMet's own data when examined objectively do not support the most fundamental assumptions that were used in modelling the efficacy of water pollution control at the tailings basin. Since actual geologic conditions at the PolyMet tailings site are different than the conditions assumed during computer modelling and conceptual design of pollution control structures, the efficacy of PolyMet's engineered solutions will be compromised and seepage control will not achieve predicted efficacy in seepage capture.

3.3 General discussion of RQD

A brief introduction to Rock Quality Designation (RQD) is presented in this section. When extracting drill core from bedrock, sometimes (rarely) the sample comes out of the sampling tube as one continuous cylinder of solid rock. Sometimes it comes out of the sampling tube so fractured it looks like pieces of gravel mixed with sand. Most often the rock from a given cored interval will come out of the sampling tube naturally broken into at least a few pieces. The planes or discontinuities separating these pieces of drill core represent natural fractures in the bedrock.[13]

RQD is a simple and effective way to measure where along the spectrum from extremely fractured to nearly entirely competent a given interval of bedrock is. The RQD procedure calls for measuring the length of each piece of sound[14] drill core re**c**overed that is greater than 4 inches long. Then the sum of those measurements is divided by the total length of the coring run, and the percentage is reported. The

[13] Sometimes drill core becomes artificially fractured during the drilling process. An experienced core logger can distinguish natural fractures from those induced by drilling. The RQD procedure calls for ignoring drill-induced fractures.

[14] Weathered pieces of drill core "not hard and sound" are excluded from the RQD calculation. (Deere, D.U., 1989, Rock Quality Designation (RQD) After 20 Years, U.S. Army Corps of Engineers Contract Report GL-89-1, 100 p.)

RQD procedure specifies the "actual drill run lengths"[15] as the basis for the denominator in the formula (Figure 3). By consistently using the total length of each coring run as the denominator, the procedure eliminates potential bias that could otherwise be introduced by arbitrarily or intentionally selecting which intervals are used to calculate RQD. The RQD formula and an illustrated example of how RQD is calculated are shown on Figure 3. Notice the RQD method also provides a means to translate numeric RQD values into descriptive rock quality terms.

Natural breaks in the drill core shown in Figure 3 aren't restricted to only the diameter of the drill hole. They extend well beyond the diameter of the borehole forming an interconnected network that often transmits groundwater. The direct relationship between RQD values and bedrock fracture density is summarized in Figure 4. This graph shows the lower the RQD value, the greater the density of fractures present. Higher RQD values (90 to 100) indicate fewer fractures, but (importantly) never indicate zero fractures. Lower RQD values (less than 75) indicate highly weathered or fractured rock.

It is significant to note that a given cored interval of bedrock can result in an RQD of 100 and still exhibit a number of fractures as long as each individual piece of naturally broken, sound core recovered is longer than 4 inches. For example, a 4-foot-long coring run resulting in eight 6-inch-long pieces of sound drill core separated by naturally occurring fracture planes would yield an RQD of 100. This means the RQD metric works best to define where fractured rock exists and is of lesser value to define with any confidence where un-fractured rock exists. Specific RQD results for the FTB site related to the occurrence of bedrock fractures, other testing carried out, and predicted water pollution control efficacies at the FTB are discussed in Section 5 below.

4.0 POLYMET'S PRESENTATION OF ISSUES IN THE PERMIT TO MINE APPLICATION

This section summarizes aspects of PolyMet's portrayal of geology at the FTB that will cause its proposed water pollution controls to be less effective than predicted. Specific disagreements with PolyMet's portrayals will be explained fully in Section 5 below.

4.1 Proposed seepage capture system

One of the most important elements of PolyMet's plan to control water pollution is the design and construction of a seepage collection system in the subsurface around portions of the existing tailings basin. The purpose of this infrastructure is to intercept process-contaminated groundwater and surface water from the surface of and from beneath the FTB for re-use in the processing plant or treatment and discharge. The Permit to Mine Application states that "the FTB Seepage Containment System is expected to have a capture efficiency of 100%".[16] PolyMet has, thus, predicted its seepage containment system will be 100% effective in capturing contaminated water seeping from the FTB, and has allowed for a no margin of error in their predictions.

[15] Ibid., p. 45.
[16] Permit to Mine Application, p. 1527.

A key component of PolyMet's proposed seepage capture system is the installation of a continuous bentonite-rich slurry wall[17] (Figure 5) 12-inches-thick along the perimeter of the western, northern and portions of the eastern margins of the existing tailings basin from the land surface keyed into solid bedrock. PolyMet assumes that if installed as described, the bentonite slurry wall will sufficiently prevent the migration of seepage so that all contaminated groundwater as well as surface water can be captured by drain pipes, sumps and pumps installed inside the slurry wall (Figure 5). The efficacy of this seepage capture network will then depend on the ability to maintain inward flowing groundwater pressure necessary for flow to be directed towards the seepage capture portion of the system.

The Permit to Mine Findings of Fact specify PolyMet must construct this bentonite-rich slurry wall and seepage capture system so that it is "keyed to competent bedrock, maintain[s] an inward head[18] difference, and meet[s] designated performance standards".[19] The "keyed to competent bedrock" requirement for bentonite slurry wall construction and the effects of subsurface geology on PolyMet's claims for efficacy are analyzed in Section 5 below.

4.2 Representations of geology at the FTB Site

PolyMet's characterization of the geology beneath the tailings basin and at the seepage capture system perimeter contained in the Permit to Mine Application and related documents is based primarily on drilling and testing programs carried out by Barr Engineering[20] during 2014. Results from the 2014 drilling programs are available only along the western, northern, and partial eastern margins of the proposed FTB seepage capture system (Figure 6).

While seepage collection is proposed in the swale leading to Spring Mine Lake midway along the eastern side of the FTB and in the vicinity of the swale leading to Second Creek along the south side of the FTB,[21] no detailed subsurface information exists for these areas because no deep drilling was carried out there (Figure 6). Likewise, no direct information exists for the bedrock beneath the tailings basin because no deep drilling was carried out there either. Without subsurface information from these areas, the feasibility and overall effectiveness of seepage containment strategies in these areas cannot be assumed.

PolyMet's Permit to Mine Application reports that along the alignment of the proposed seepage capture system there exists a variable thickness of unconsolidated glacial sediments consisting of silty sand 0 to

---

[17] Slurry walls are also sometimes referred to as cutoff walls or soil-bentonite slurry walls (SBSW).

[18] Head is a term used in hydrology to refer to groundwater pressure relative to some point of reference. So "inward head difference" used here means an inward flowing (relative to the slurry wall) groundwater pressure maintained by PolyMet's pumping network.

[19] Minnesota DNR, NorthMet project – Permit to mine, Findings of fact, conclusions and order of Commissioner, November 1, 2018 ("Permit to Mine Findings of Fact"), p. 131.

[20] Barr Engineering of Minneapolis has been PolyMet's primary consultant for engineering, geology, hydrology and other natural resource expertise throughout the NorthMet project environmental review and permitting process.

[21] Permit to Mine Application, p. 1818.

6 feet thick overlying glacial till[22] that ranges from 5 to 36.5 feet thick. Cobbles and boulders ranging from <1 to 4 feet in diameter are reportedly interspersed within the till. This sequence of glacial sediments[23] overlies a very irregular granite bedrock surface with depths to bedrock reportedly ranging from 2 to 47 feet below the land surface. Some intervals within the granite bedrock are described as weathered or fractured, others as sound. In places along the alignment, the glacial sediments are overlain by taconite tailings up to 17 feet thick and in some places by post-glacial peat up to 20 feet thick. Groundwater levels are reportedly "at or just below the ground surface"[24] around the perimeter of the tailings basin.

PolyMet relied heavily on the results of the 2014 drilling and testing programs to conclude that "soils suitable for installation of a seepage cutoff wall exist along the proposed system alignment",[25] but added the caveat that "when selecting construction methods, the containment system construction contractor will need to consider the presence of cobbles and boulders in the till".[26] The relevance of this cautionary remark regarding "cobbles and boulders in the till" will be explained in Section 5 below.

The Geotechnical Report contained in the Permit to Mine Application arrives at the conclusion that only the upper 10 feet of bedrock contains a fracture density significant to groundwater flow and that below that zone bedrock fractures are so insignificant to groundwater flow that "*the bedrock* [beneath and surrounding the tailings basin] *acts as a no-flow boundary*" (Figure 5).[27, 28] As explained in more detail in Section 5, testing data derived from the 2014 drilling programs at the tailings basin do not support PolyMet's assumed "impermeable" and groundwater "no-flow" attributes of the bedrock at the tailings basin.

4.3 Testing results used to characterize groundwater flow

Barr Engineering carried out testing for PolyMet within selected boreholes in the field and in the lab using samples collected during two 2014 drilling programs. Barr used these testing programs to quantify groundwater flow for modeling in support of the Permit to Mine Application. Barr's testing for potential groundwater flow through the bedrock and RQD data are briefly discussed below.

In order to quantify groundwater flow through the bedrock, packer testing was carried out within certain intervals of drill holes where bedrock core was collected at the FTB site. In simple terms a packer test involves using flexible bladders or similar devices to block off the top and bottom of any selected interval within a borehole so that fluids can be analyzed within the isolated interval. Hydrologic testing can be carried out on any specific interval within the borehole chosen to be isolated by packers.

[22] Glacial till is a type of sediment deposited by or from glacial ice with little or no sorting by water resulting in a homogeneous mixture of clay, silt, sand, gravel and larger rocks of various sizes.
[23] These sediments are collectively referred to as "soils" by engineers and will be referred to in this report as glacial sediments.
[24] Geotechnical Report, p. 21.
[25] Ibid.
[26] Ibid., p. 22.
[27] Geotechnical Report, p. 71.
[28] Permit to Mine Application, p. 349.

Barr reported that "ten (10) 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*".[29] Packer testing methods and results are discussed in Section 5.

5.0 ANALYSIS OF GEOLOGY AS RELATED TO PROPOSED SEEPAGE CAPTURE SYSTEM

PolyMet's portrayal of the subsurface geologic conditions along the alignment of the proposed seepage capture system at the tailings basin is neither accurate nor objective. PolyMet's unsupported assumptions lead to overestimates of the efficacy of proposed engineered water pollution controls at the tailings basin. Available data do not support PolyMet's modeling of 100% seepage capture. Tailings basin seepage through bedrock fractures and around or below areas of the proposed slurry wall in excess of PolyMet's predictions is virtually certain.

Shortcomings and biases in PolyMet's portrayal of subsurface geologic conditions at the FTB site are reviewed in this section as follows:

1) Data do not support PolyMet's claims about bedrock fractures and a "no-flow boundary"
2) Packer testing used by PolyMet to support a "no-flow boundary" was biased
3) PolyMet has not demonstrated depth to competent bedrock for its slurry wall.
4) There is a low degree of confidence where depth to competent bedrock is reported
5) PolyMet has not shown how its slurry wall could be effectively keyed into granite bedrock
6) Surficial geology indicates increased seepage along northern perimeter of FTB
7) Artesian groundwater flow conditions may preclude proposed slurry wall
8) Cumulative subsurface conditions do not support the proposed design

Any one of these individual shortcomings and biases in PolyMet's portrayal of the subsurface conditions at the FTB has the potential to cause the seepage capture system as currently conceived to fail. Looking at the cumulative data in a spatially meaningful way, troubling patterns show conditions at the FTB that are likely to prevent control of water pollution to the degree predicted in the Permit to Mine Application. The Permit to Mine is likely to require substantial revisions due to the lack of a complete and reliable understanding of and objective portrayal of subsurface geologic conditions at the FTB site.

All data used in the following analysis were taken directly and presented in their entirety from drilling records and from Table 3-2 (Rock Quality Designation Summary) contained in the Geotechnical Report[30] (Figures 7 and 8). Pertinent data extracted from these drilling records discussed in this report are summarized in Tables 1 to 4. Drilling records shown in these tables are reproduced without change from the Geotechnical Report except where noted and where calculations are made from them by simple

---

[29] Geotechnical Report, p. 47. Emphasis added.
[30] The drilling logs are found on pages 780-802 (Rotasonic) and pages 831-844 (SPT/Coring), Table 3-2 on pages 745 and 746 of the Geotechnical Report.

arithmetic. [31, 32] Figure 6 shows the locations of the 2014 drill holes that are the basis for the Geotechnical Report as well as this report. Additional holes were drilled at the tailings basin but they were either not drilled deep enough or in the right locations to encounter bedrock. The drill holes discussed below (Tables 1 to 4) were drilled close to the proposed alignment of the tailings basin seepage capture system making them most relevant to discussing the relationship between the efficacy of the proposed seepage capture system and subsurface geology.

5.1 Data do not support PolyMet claims about bedrock fractures and a "no-flow boundary"

The efficacy of the PolyMet tailings basin seepage capture system depends on a "no flow" or "impermeable" boundary - namely the absence of bedrock fractures extending in any direction or to any depth below the tailings basin or the seepage collection system.

A fundamental understanding of geology predicts the occurrence of deeper bedrock fractures at the tailings basin. In addition, PolyMet's RQD data demonstrate fractured bedrock and therefore permeable bedrock along the tailings basin perimeter. There are no data in the record that would allow PolyMet or DNR to assume that bedrock beneath the tailings basin and across the FTB seepage collection site is "impermeable."

5.1.1 Bedrock characteristics and fractures

Bedrock in northeastern Minnesota isn't a monolithic mass of solid impermeable rock; this bedrock is widely understood to contain deep fractures. The multiple advance-retreat cycles of continental-scale glaciers during the Ice Ages noticeably displaced the Earth's mantle, substantially flexing the overlying crust, resulting in an extensive network of fractures imparted deeply into glaciated bedrock. The voluminous literature resulting from the search for underground locations to store high-level nuclear waste in the 1970's and 80's proved that monolithic un-fractured rock does not exist anywhere on the Canadian Shield. It is well-known that the granitic bedrock in northeastern Minnesota is significantly fractured to depths far greater than 10 feet, and that these fractures are often interconnected, thereby providing pathways for groundwater to flow.

The Permit to Mine Application and supporting documents provide no direct information about the nature of competent bedrock deeper than 16 feet because that was as deep as PolyMet chose to drill.[33] PolyMet does however present general information to support deep fractures existing beneath the

---

[31] For example, PolyMet's Geotechnical Report does not present artesian head values. However these can be derived mathematically given information found on the drilling logs.

[32] RQD values shown in Tables 2 and 4 are weighted averages based on results reported in Table 3-2 of the Geotechnical Report. Elsewhere in this report RQD's were adjusted to account for intervals with zero core recovery and reported weathered zones that were included.

[33] Drill hole B14-52 reported 15.8 feet of competent granite (Table 1). This drill hole represents the deepest penetration of competent granite during any drilling program carried out at the tailings basin.

tailings basin.[34] The faults shown on this geologic map represent major fracture zones within the bedrock, at least some of which convey significant amounts of groundwater.

Evidence for significant groundwater flow through widespread interconnected bedrock fractures is provided by the thousands of residents of rural northeastern Minnesota that have drinking water in their homes. Figure 9 shows the locations of wells from the County Well Index[35] in the vicinity of the tailings basin completed in Giants Range Granite – the same bedrock unit that underlies glacial sediments at the tailings basin. The depths of wells completed in the Giants Range Granite vary from 20 to 640 feet deep (Figure 9). Fractures conveying enough water for domestic use were intersected at depths hundreds of feet into the bedrock within the Giants Range Granite in the vicinity of the tailings basin. Contrary to PolyMet's claim, the local hydrogeology of the Giant Range Granite makes it highly likely that hydrologically significant fractures exist deeper than 10 feet into the bedrock at the FTB tailings site.

No evidence based on drilling or testing is presented in the Permit to Mine Application to contradict the claim that deep fractures like those revealed by the County Well Index database are also present to similar depths within the Giants Range Granite beneath the tailings basin. If there are connections to deeper fractures anywhere beneath the 3,000 acre tailings basin or the seepage capture perimeter, they could transport contaminated seepage. Well-established concepts supported by subsurface data provide lines of evidence that contradict a central assumption made by PolyMet that the bedrock beneath the tailings basin *"acts as a no-flow boundary".* [36, 37] PolyMet has provided no evidence that would verify its improbable claim that deeply fractured bedrock either does not exist or would not transport FTB tailings seepage.

5.1.2 RQD results at the tailings basin perimeter

PolyMet did not drill into bedrock beneath the tailings basin and therefore has not provided any direct information on the hydrogeologic properties of bedrock beneath the tailings basin. The Geotechnical Report provides selective RQD and packer test results from the FTB tailings site perimeter. These data do not support PolyMet's assertions that only the upper 10 feet of bedrock is significantly fractured or that below 10 feet bedrock fractures are so insignificant that they can be ignored for the purposes of groundwater modelling.

1. PolyMet reports its calculations of RQD in ways that underrepresent the extent of fractured and weathered bedrock at the FTB.
2. The majority of PolyMet's subsurface data present evidence for a significant number of fractures extending as deeply into the granite bedrock as they decided to drill.
3. Gaps in drilling data undermine PolyMet's assumptions regarding bedrock hydrogeology.

[34] Hydrogeology of Fractured Bedrock in the Vicinity of the NorthMet Project: Prepared for PolyMet Mining Inc., December 2014 (112 pages) ("Hydrogeology Report"), p. 42.
[35] Source: County Well Index: Minnesota Department of Health database.
[36] Geotechnical Report, p. 71.
[37] Permit to Mine Application, p. 349.

Underreported fractured and weathered bedrock. PolyMet's RQD data derived from drill core collected at the FTB site are reproduced in Figures 7 and 8 and along with some averages in Tables 5 and 6. Intervals highlighted in pink on Tables 5 and 6 are places where PolyMet inadequately characterized RQD values. In many instances, RQD data are not reported by PolyMet where no samples were recovered.[38] In other instances[39] weathered samples were counted as though they were sound and unweathered. RQD's for these intervals should be characterized as 0 or "very poor quality". According to the procedure, rock not meeting the soundness requirements[40] and zones of no core recovery should not be included in the numerator, but the thickness of those intervals drilled must be included in the denominator of the RQD formula (Figure 3). By not stating that these intervals within bedrock have RQD's of zero, PolyMet has distorted the portrayal of RQD and therefore the fracture density of the bedrock.

Drill hole B14-52 provides a particularly clear example of underreporting fractured and weathered bedrock and deviation from PolyMet's assumptions. For the two intervals 47 to 50 feet and 61.5 to 63.5 feet, PolyMet reports no RQD results (Figure 8 and Table 5). Close examination of the drilling log for B14-52[41] shows that no core was recovered from these intervals; therefore the RQD values for these intervals should be reported as 0. Also in this hole, the interval 44 to 47 has a reported RQD of 100 (Figure 8 and Table 5), but this interval is described on the drilling logs as "highly weathered", causing the correct RQD to be 0. By inadequately charactering these intervals with zero RQD's, PolyMet has underrepresented the degree of bedrock fracturing and weathering at the tailings basin site.

Tables 5 and 6 include adjusted RQD values that account for the zero-core-recovery intervals and weathered zones inadequately characterized by PolyMet. Adjusted RQD values are also mapped on Figures 10 and 11. These values more accurately represent bedrock conditions encountered during the two 2014 drilling programs.

Evidence of Fractures. PolyMet's claimed "no-flow boundary" within the bedrock must be supported by widespread areas and thick intervals where RQD results indicate "excellent quality" bedrock – RQD's greater than 90. PolyMet's RQD data show a single drill hole at the southwest corner of the tailings basin that yielded an average RQD of 77 (Figure 10). However, this drill hole is not in direct alignment with seepage flow paths originating from the FTB so it is less useful to the discussion of bedrock fractures and contaminant transport from the FTB. The most relevant RQD data exist along the north side of the tailings basin and in particular, the north side of the FTB because groundwater flow direction is generally north-northwest across the site making these areas down-gradient from contaminated seepage emanating from the FTB.

---

[38] See Tables 5 and 6, drill holes B14-40, 48, 52, 55, 65, 72, 80 and drilling logs on pages 832 to 844 in the Geotechnical Report.

[39] See Tables 5 and 6, drill holes B14-44, 52, 62 and 69 and drilling logs on pages 832 to 844 in the Geotechnical Report.

[40] Rock that is "not hard and sound" is not counted. Deere, D.U., 1989, Rock Quality Designation (RQD) After 20 Years, U.S. Army Corps of Engineers Contract Report GL-89-1, 100 p.

[41] Geotechnical Report, p. 836-837.

Average RQD's for the remainder of the tailings basin perimeter range from 67 to zero! But most significant is the occurrence of highly fractured and weathered bedrock evidenced by two drill holes with average RQD's of zero, ("very poor quality" rock) exactly coincident with the northern perimeter of the FTB. The overall average RQD results demonstrate three important points: 1) bedrock everywhere along the perimeter of the tailings basin contains fractures, 2) there is a wide range in the degree of bedrock fracturing evidenced by average RQD's ranging from 0 to 77, and 3) extremely fractured bedrock exists along large areas of the northern perimeter of the FTB (Figure 10).

The degree of fracturing deeper within the bedrock is key to PolyMet's claim for the interval deeper than 10 feet into bedrock to be "impermeable" or a groundwater "no-flow" zone and therefore incapable of transmitting contaminated groundwater. This deeper zone would have to be devoid of bedrock fractures (RQD = 100) for it to be impermeable. PolyMet's RQD data show extensive fractures to exist as deep into bedrock as they decided to drill. At the northern perimeter of the FTB, average RQD results for the interval deeper than 10 feet into bedrock range from 51 to 58 (Figure 11) – indicating only "fair quality" rock, or in other words bedrock that is extensively fractured. PolyMet's claim of "no-flow" of groundwater through this deeper bedrock zone is not supported.

Gaps in Drilling Data. Drill hole B14-62 was terminated before any competent bedrock was encountered (Table 6). The first three feet of bedrock (17 to 20 feet) yielded an RQD of 53 (fair quality). The next five feet (20 to 25 feet) yielded an RQD of 13 (very poor quality) and the last two feet of bedrock cored yielded an RQD of *zero*! A total of 10 feet of "highly weathered bedrock"[42] was encountered in this hole before it was decided to stop drilling. The only explanation given why drilling ceased before encountering competent bedrock was they reported "*difficult drilling*".[43] With RQD values of zero at 10 feet below the top of the bedrock, it is highly likely there is a large amount of groundwater flowing through extremely fractured bedrock here that is neither reported nor accounted for in PolyMet's assumptions.[44]

Drill hole B14-69 was also terminated prematurely after coring only the upper five feet of bedrock (Table 6). The reason given for terminating this hole was that flowing artesian groundwater conditions[45] were encountered. The occurrence of artesian groundwater conditions is likely related to the presence of highly fractured bedrock.

Two additional gaps in PolyMet's drilling dataset prevent objectively addressing the full extent of bedrock fracturing and the full extent of groundwater flow through bedrock at the tailings basin. No bedrock drilling data are provided beneath the tailings basin or along the southern perimeter. In addition, even where PolyMet has produced RQD information, no drilling extends any deeper than 16 feet into competent bedrock anywhere on the FTB site (Tables 1 to 4). There is no evidence in PolyMet's RQD dataset to support the claim that a "no-flow boundary" or an impermeable zone exists within the

[42] Drilling log for B14-62, Geotechnical Report, p. 839. Granite here is described as "highly weathered bedrock; appears to be silty gravel with up to 1 foot boulders throughout".
[43] Geotechnical Report, p. 743.
[44] Ibid.
[45] Ibid.

bedrock at the FTB site or that weathering and fractures do not exist 10, 20, or more feet below the bedrock surface at the tailings basin site.

5.2 Packer testing used by PolyMet to support a "no flow boundary" was biased

Packer testing was carried out within the bedrock on selected boreholes (Figure 12) and on selected intervals within those boreholes (Tables 7-11). The stated goal of packer testing was to objectively determine how much water moved through bedrock so that these values could then be used in groundwater modeling to predict the efficacy of proposed water pollution controls. PolyMet relied heavily on packer test results to assume that bedrock throughout the tailings basin site is virtually impermeable for modeling purposes. PolyMet claims that "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".[46]

However, PolyMet's packer testing intervals were not representative of the full extent of bedrock fracturing. Looking at the RQD results of intervals selected for packer testing, it is clear that the most fractured intervals within the bedrock - as defined by the lowest RQD values - were excluded from packer testing (Tables 7 through 11). Since granite bedrock between fracture zones is largely impermeable, this exclusion misrepresents overall hydraulic conductivity of bedrock.

Not one drilling record shows a packer testing interval that completely encompassed the most fractured (lowest RQD) zones within that selected drill hole (Tables 7 to 11). For example, as shown in Table 9, for drill hole B14-55 from 30 to 35.5 feet RQD data are missing (therefore 0), and poor quality (33) to 39 feet; packer tests of water flow were started at 37 feet, excluding from packer testing the 7 feet of fractured rock 30 to 37 feet.

A more troubling pattern in exists for drill hole B14-65 (Table 10). In this hole, packer tests were avoided not only in the shallower bedrock where rock quality was low, but there was also a gap in packer testing between 33.5 and 37 feet, coincident with a drop in RQD. By excluding the interval 33.5 to 37 in this hole from packer testing Barr overlooked an opportunity to directly measure the hydraulic conductivity of its assumed "impermeable" zone. This type of sampling bias is shown for every interval selected for packer testing (Tables 7 through Table 11). The full range of groundwater conditions present in the bedrock can't be addressed without looking at both ends the ends of the spectrum.

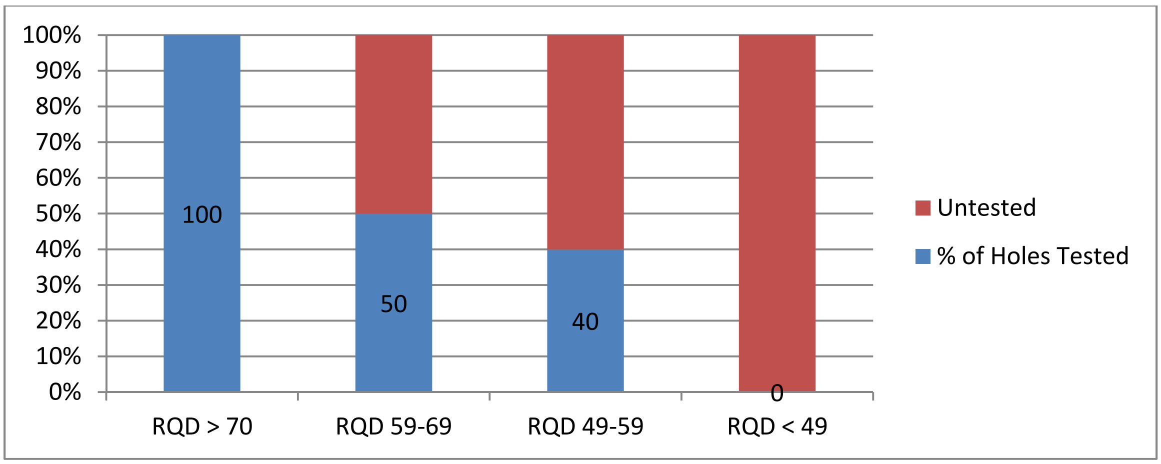
While in the field standing over boxes of variably fractured drill core just collected, Barr chose to select intervals to carry out packer testing so that the most heavily fractured zones within the bedrock were excluded. This would bias hydraulic conductivity values derived so that they would not fully measure the amount of groundwater flowing through fractured bedrock at the proposed seepage capture system perimeter.

---

[46] Geotechnical Report, p. 47.

Additional bias was introduced to the packer tests in deciding which drill holes to select for testing. Packer testing was carried out on all drill holes (100%) with weighted average RQD results[47] greater than 75 and on 2 of the 4 (50%) drill holes with RQD results in the 60's. Of the 5 drill holes with RQD results ranging from 49 to 59, only 2 (40%) were selected for packer testing and none of the drill holes with RQD's less than 49 were chosen (0%) (Figure 12). Notice that for that portion of the seepage capture system alignment immediately down-hydrologic-gradient from the FTB – the north side - packer testing was carried out in the two drill holes yielding the highest RQD results (66). Two drill holes with average RQD's of 0 and another of 53 were excluded from packer testing (Figure 12).

PACKER TESTING WAS BIASED BY NOT TESTING DRILL HOLES WITH MOST FRACTURED ROCK



Barr did not conduct packer testing within the most fractured intervals and conducted disproportionately fewer packer tests within drill holes where more fractured bedrock is present. This biased testing resulted in unrepresentative conclusions as to the amount of water that flows through bedrock at the tailings basin site. Although the Final EIS stated that the "geometric mean of hydraulic conductivity values . . . is 0.14 ft/day," this "best estimate"[48] does not reflect unbiased testing. Even though packer testing did not fully encompass intervals with the lowest RQD's and excluded from packer testing drill holes with the lowest average RQD's, individual packer test results yielded hydraulic conductivities that varied by two orders of magnitude.[49]

A close look at the drilling and testing data shows that groundwater seepage through the bedrock at the tailings basin is underestimated. Packer test results neither support an "impermeable" nor "no flow" boundary in the bedrock nor the modeled hydraulic conductivity value. If the assumed hydraulic conductivity of the bedrock is underestimated by even a small amount (less than an order of

---

[47] Weighted average is a type of average that takes into consideration the thickness of an interval. For example: the weighted average of an interval 10 feet thick with a value of 10 and a 5-foot thick interval with a value of 80 would be ((10 x 10) + (5 x 80)) divided by (10+5) = 500/15 = 33.3. Deere, 1989 (p. 45) recommends calculating weighted average RQD to assess spatial variation in rock quality (and therefore bedrock fractures).

[48] Final EIS, p. 464.

[49] Measured hydraulic conductivities resulting from packer testing ranged from 1.4×10^{6} (lower permeability) to 7.2×10^{4} cm/s (permeable) (Geotechnical Report, p. 846)

magnitude), seepage that escapes capture would greatly exceed PolyMet's predictions of nearly perfect capture.

5.3 PolyMet has not demonstrated depth to competent bedrock for its slurry wall

A bentonite slurry wall interface will be ineffective if is not "keyed to competent bedrock." Granite bedrock is considered to be "competent" where it is unweathered and relatively un-fractured. Unweathered and relatively un-fractured intervals of bedrock are supported by only the highest RQD values. Confidently determining depths to competent bedrock is essential. If the bottom of PolyMet's proposed bentonite slurry wall were built in glacial sediments, on a boulder, or in weathered or highly fractured granite, if even for a short distance, contaminated groundwater would easily seep beneath the slurry wall through porous materials. The Permit to Mine Findings of Fact specifies the bentonite-rich slurry wall must be "*keyed to competent bedrock*" (p. 131). If the tailings basin site geology does not support this condition, PolyMet's proposed seepage capture engineering controls will not be effective.

PolyMet's subsurface dataset does not adequately document the depth to competent bedrock into which the tailings collection slurry wall must be keyed. First, the weathered granite that commonly occurs on the FTB site beneath the glacial sediments and overlying competent granite bedrock is not adequately portrayed. Drilling logs for 16 of the 34 drilling logs (R14-04, 05, 06, 09, 16, 20 and B14-40, 44, 48, 52, 55, 62, 65, 69, 72 and 80) in PolyMet's dataset show evidence for weathered granite (Table 2 and Table 3), yet "weathered granite" is not used as a primary material description on the drilling logs. This obscures the actual extent of weathered bedrock at the tailings basin perimeter. Twelve of these 16 holes (R14-04, 05, 06 and 09 and B14-40, 44, 48, 52, 55, 65, 72 and 80) were drilled deep enough to have penetrated a weathered zone and PolyMet reported sound granite below. The remaining 4 of 16 drill holes (R14-16, 20, B14-62, and 69) that encountered weathered granite were clearly terminated before "competent bedrock" was reached (Figure 13, Tables 1 to 4). Two other drill holes fail to provide depth to competent granite. One hole (R14-30) reported 3 feet of "fractured granite" but does identify to what depth it extends (Table 2). Another hole (B14-72) reported granite from 10 to 25 feet but also reported it was "highly fractured" at 17.5 feet, 20-22 feet, and 23-23.5 feet. The average RQD from 10 to 25 feet is 56 in B14-72, suggesting this 15-foot-thick interval represents fractured bedrock and that competent bedrock exists at some greater, undefined depth.

PolyMet's justification for terminating drill holes before confidently reaching competent bedrock is inadequate. Drill hole B14-62 was terminated due to "*difficult drilling*"[50] and B14-69 was "*abandoned when artesian flow was encountered*".[51] No justification is provided why the other 3 holes (R14-16, 20, and 30) were prematurely abandoned, but adverse drilling conditions are inferred. Flowing artesian groundwater conditions and zones with highly fractured bedrock are not only adverse drilling conditions known to exist at the FTB site. They are also conditions that could prevent a slurry wall from being continuously keyed into competent bedrock.

[50] Geotechnical Report, p. 743. Emphasis added.
[51] Ibid. Emphasis added.

The five drill holes where no competent bedrock was encountered were drilled to depths of 27 to 35 feet (Tables 1 to 4 and Figure 13) and four of the five occur clustered together along the northern margin of the tailings basin (Figure 13). This situation results in a gap along the northern margin of the tailings basin nearly 1.5 miles long where the depth to competent granite bedrock has not been established. There is a second, shorter, segment along the east margin where depth to competent bedrock is also unknown (Figure 13).

Despite this widespread level of uncertainty about the actual depths to competent bedrock, engineering cross-sections within the Permit to Mine Application[52] and maps in the Final EIS[53] portray bedrock as if competent bedrock was actually encountered. These cross-sections and maps present a biased portrayal of the bedrock surface and do not reflect actual subsurface conditions encountered during drilling.

5.4 There is a low degree of confidence where depth to competent bedrock is reported

Another geologic variable essential to the efficacy of the proposed bentonite slurry wall is that there must be a high degree of certainty that the depth to the top of the "competent bedrock" surface has been defined everywhere along the entire alignment of the proposed slurry wall so that the bentonite materials can be successfully "keyed" into actual bedrock. There must be a high degree of confidence that every drill hole used to define depth-to-bedrock was terminated in competent bedrock. If drilling was, in fact, terminated in a large boulder and competent bedrock exists at some greater undefined depth, the resulting gap under the containment system would leave a deeper porous pathway for contaminated groundwater seepage.

The Geotechnical Report describes the glacial till on the FTB site to contain boulders up to 4 feet in diameter.[54] However, it is known from the geologic literature[55] and experience that boulders significantly larger than 4 feet in diameter commonly occur within glacial sediments in the immediate vicinity of the FTB. Figure 14 shows boulders much greater than 4 feet in diameter at the Peter Mitchell Mine site 7.5 miles to the east of the FTB. Boulders of the size shown in Figure 14 also exist at the FTB site. During my field work on the LTV property, I have seen boulders on the land surface as large as my Jeep.[56] The boulder-rich nature of the glacial sediments in the vicinity of the FTB is an extraordinary geologic condition that I rarely encountered beyond the eastern Mesabi Range and parts of the adjacent Superior National Forest.

Drilling logs contained in the Geotechnical Report provide indisputable evidence for the presence of large boulders along the alignment of the proposed seepage capture system. The drilling log for B14-

[52] These cross sections are shown on Drawings FTBCA-008, 009 and 011, pages 1040, 1041 and 1043 of the Permit to Mine Application.

[53] Figure 4.2.2-15: Depth to Bedrock at Tailings Basin Area (Final EIS, p. 456).

[54] Geotechnical Report, p. 21.

[55] Supplemental photographs published with Jennings, C.E., and Reynolds, W.K., 2005 Surficial geology of the Mesabi Iron Range: Minnesota Geological Survey Miscellaneous Map M-164, scale 1:100,000.

[56] In my files, which are unfortunately currently inaccessible, I have a 35mm slide taken while carrying out field work on the LTV property showing a boulder at the land surface as big as my Jeep (approximately 6 feet wide and 10 feet long).

52[57] shows that from 16.5 to 24 feet a boulder 7.5 feet in diameter was intersected. Then an additional 26 feet of glacial sediments and fractured and weathered bedrock were intersected below the boulder before encountering competent granite at 50 feet. An interval of 15.8 feet of sound granite was then drilled before terminating this hole at a total depth of 65.8 feet. This drilling log provides direct evidence that boulders significantly larger than 4 feet in diameter occur within the subsurface within the alignment of the proposed seepage capture system and illustrates the implications of not drilling deeper. If B14-52 were terminated after drilling 4 or 5 feet into "bedrock" a total thickness of approximately 26 feet of glacial sediments and fractured and weathered bedrock would have been overlooked, resulting in a giant hole in the seepage capture system.

To confidently and objectively define the depths to "competent bedrock" based on PolyMet's prediction of boulder size, one would be obligated to drill deeper than 4 feet into rock that is neither weathered nor heavily fractured. Based on boulder size at the Peter Mitchell Mine and on drilling log B-14-52, drilling should have continued 8 to 10 feet or more into sound rock at every location for the very modest additional drilling costs. Drilling only slightly deeper would significantly increase confidence that the drill hole was not unintentionally and prematurely terminated on a boulder rather than on actual competent bedrock.

Only 8 of the 34 holes[58] drilled intersected more than 10 feet of reportedly competent bedrock - the green markers shown on Figure 15. All of the remaining 26 drill holes – the black, red, and yellow markers on Figure 15 – intersected less than 10 feet of bedrock and therefore do not provide sufficient confidence that competent bedrock was reached during drilling at those locations.

In addition to the 5 drill holes where no competent granite was encountered (the black markers on Figure 15), 8 additional drill holes (the red markers on Figure 15)[59] only penetrated 2 to 4 feet of reportedly competent granite before stopping (Table 1 and Figure 15). The depths to competent bedrock reported in these areas should be considered highly suspect since the commonplace occurrence of large boulders of at least 4 feet in diameter increases the likelihood that at least some of these holes were terminated on boulders instead of competent bedrock.

An additional 9 drill holes[60] reported encountering between 5 and 7 feet of sound bedrock before being terminated. Based on the presence of boulders at least 7.5 feet in diameter along the alignment of the proposed bentonite slurry wall (B14-52), there is also inadequate confidence in the depths to bedrock in these areas.

---

[57] Geotechnical Report, p. 836.

[58] Seven holes confidently intersected > 10 feet of reportedly competent bedrock: B14-36, 40, 48, 52, 55, 65 and 76. B14-72 showed inconclusive results whether competent granite was reached. It is mapped competent on Figure 15.

[59] Eight drill holes intersected between 2 and 4 feet of reportedly competent granite: R14-02, 04, 06, 08, 09, 12, 15 and 27.

[60] Nine drill holes intersected between 5 and 7 feet of reportedly competent granite: R14-05, 07, 10A, 11, 13, 25, 26, 28 and 29.

In summary, 22 of the 34 drill holes in PolyMet's dataset (65%) either did not encounter any competent bedrock at all or only reported 7 feet or less of sound bedrock and 26 of the 34 drill holes (76%) encountered less than 10 feet of sound bedrock (Table 1, Table 2, and Figure 15). As shown in Figure 15, this results in a gap along the north boundary of the tailings basin of nearly one and a half miles where only a single drill hole[61] confidently defines the depth to competent bedrock along the proposed slurry wall alignment (Figure 15).

PolyMet's subsurface data fail to support the critical permitting assumption that the proposed seepage capture system would, in fact, be keyed into competent bedrock. Going forward with this project without a clear definition of a continuous, competent bedrock surface at the perimeter of the seepage capture system virtually guarantees that the seepage collection system will fail to control water pollution as PolyMet has predicted.

5.5 PolyMet has not shown how its slurry wall could be effectively keyed into granite bedrock

In order for the slurry wall to meet permitting conditions and claimed pollution control efficacies it must be constructed so that it is "keyed to competent bedrock." However no explanation is provided of how the bentonite slurry wall will be "keyed to competent bedrock" at great and still uncertain depths and into solid granite bedrock. This is not a detail that can be left to future "adaptive management" if difficulties are encountered during construction or the seepage collection system fails to perform. If the bentonite slurry wall is not properly keyed into bedrock (Figure 16), larger-than-predicted volumes of untreated groundwater seepage will pass beneath the slurry wall, bypassing capture by the pumping network and adversely affecting the environment.

Solid and competent granite bedrock cannot be excavated by using traditional excavating equipment or the kinds of equipment typically used to install slurry walls. The only widely used effective approach to excavating competent granite bedrock involves drilling and blasting the rock prior to excavating the broken rock. If constructing a slurry wall at the FTB involves blasting, additional concerns would arise, including creation of new fractures, dilation of existing fractures and potential impacts to tailings dam stability. The approach that would be used to key the slurry wall into bedrock at the FTB site must be specified to determine if it would be feasible.

It is widely known that boulders present within profiles excavated during slurry wall construction can preclude effective slurry wall construction.[62] Both the size and frequency of large boulders are subsurface conditions detrimental to construction of an effective slurry wall. PolyMet proposes to construct a continuous one-foot-wide slurry wall, however even their incomplete subsurface database demonstrates several instances along the slurry wall alignment where boulders significantly larger than one foot in diameter exist.

[61] Only one drill hole confidently defines depth to competent bedrock along north perimeter: B14-65.

[62] Ryan, C.R., 2021, 70 Years of soil-bentonite slurry walls: What's new? *in* GEOSTRATA Magazine: Specialty Geo-Construction Equipment Issue, v. 25, Issue 3, May/June/July 2021.

[63] Barr Technical Memorandum. Subject: Groundwater Containment System – Degree of Use in Industry. Dated December 26, 2012 (3 pages) ("Ground Water Containment Memo")

PolyMet provides no explanation how boulders several times larger than the width of the slurry wall can be excavated from a 12-inch-wide trench. PolyMet has carried out no modelling to assess the diminished efficacy that would result from the inability to remove boulders ranging from 1.5 to at least 7.5 feet in diameter from the one-foot-wide trench. If even a single boulder along the slurry wall alignment precludes keying the slurry wall into competent bedrock, PolyMet's predicted seepage capture rates will be exceeded.

DRILL HOLE	BOULDER DIAMETER (FT)
R14-10A	2.5
R14-20	3.0
R14-29	2.0
B14-44	3.0
B14-52	7.5
B14-55	1.5

Barr's 2012 Groundwater Containment Memo[63] lists several case studies where slurry walls were reportedly installed to control groundwater seepage. Unfortunately, some of the URL links to the projects offered for comparison are no longer valid so the details of these slurry wall construction projects are unavailable. From the information presented in the Groundwater Containment Memo it seems none of these case studies of slurry wall construction were successfully built under subsurface conditions similar to those at the FTB. Most notably none of them claim to have "keyed" a slurry wall into competent granite bedrock at comparable depths. Nor do any of them seem to provide examples of slurry walls constructed in boulder-rich glacial sediments or under artesian groundwater flow conditions similar to those found at the tailings basin site.

PolyMet's claim that its FTB slurry wall will achieve the rates of capture predicted is unsupported.

5.6 Surficial geology indicates increased seepage along northern perimeter of FTB

PolyMet's assumptions regarding glacial sediments lead to overly optimistic predictions regarding efficacy of the seepage capture system. For modelling purposes, the sediment beneath the tailings basin was assumed everywhere to be glacial till. However, published surficial geologic maps show the FTB site to be underlain by a variety of glacial sediments. This well-documented heterogeneity is important because areas of glacial outwash sand and gravel can increase permeability and therefore transmit higher volumes of groundwater seepage.

The distribution of surficial glacial sediments surrounding and beneath the tailings basin according to published sources is shown on Figure 17. The background mapping is from the most recent Minnesota Geological Survey compilation of surficial geology. In addition, Figure 17 shows two relevant mapping units from the geologic map contained in my thesis. This mapping shows the area along most of the northern perimeter of the tailings basin to be underlain by extensive sand and gravel.

Four separate published (and peer-reviewed) geologic maps[64, 65, 66, 67] document a glacial ice margin extending right through the FTB site during the waning stages of the ice ages (Figure 17). My thesis

---

[64] Lehr, J.D. and Hobbs, H.C., 1992, Field trip guidebook for the glacial geology of the Laurentian divide area, St. Louis and Lake counties, Minnesota: Minnesota Geological Survey Guidebook Series No. 18, 73 p., 1 plate, scale 1:250,000.

[65] Lehr, J.D., 2000, Pleistocene geology of the Embarrass area, St. Louis County, Minnesota: M.S. Thesis, University of Minnesota, 157 p., scale 1:48,000.

mapping concluded that the northeastern quadrant of the tailings basin now inundated with tailings is underlain in large part by sand and gravel deposited in association with this ice margin.

Drilling logs in the Geotechnical Report describe several occurrences of sand and silt above till at the tailings basin (Table 1 and Table 2); in one area as much as 28.5 feet thick (B14-52). These are lacustrine[68] sediments overlying the till at the tailings site. This is a common occurrence in the Embarrass area that has been overlooked in PolyMet's overly simplified assumptions regarding surficial geology and hydrogeology. However, the Geotechnical Report claims that "till" is the "existing native material comprising the thick consolidated foundation layer for the existing tailings basin" (p. 37) and does not distinguish between till and sand and gravel outwash or lacustrine sand and silt or peat.

A foundation of glacial till would be highly desirable beneath a tailings basin. Water flows very slowly through till because silt and clay occupy the pathways through which water might otherwise flow. In contrast, glacial outwash sand and gravel is orders of magnitude more permeable than glacial till and therefore has the capacity to transmit vastly larger volumes of groundwater seepage.

Sand and gravel along the northern perimeter of the tailings basin is not addressed in PolyMet's predictions of pollution control efficacy. These highly permeable sediments beneath and adjacent to the tailings basin on the northeast may increase rate and volume of groundwater seepage. These increased volumes of groundwater seepage are not accounted for in PolyMet's modelling of seepage containment system efficacy.

5.7 Artesian groundwater flow conditions may preclude proposed slurry wall

According to drilling records in the Geotechnical Report, artesian groundwater conditions are widespread along the alignment of the proposed seepage capture system. <u>Every single piezometer[69] installed show artesian groundwater conditions to be present</u> (Figure 18 and below).

Artesian groundwater conditions mean that groundwater is pressurized to the extent that water levels are observed above the screened interval in a well. Flowing artesian groundwater conditions are situations where groundwater is under such extreme pressures that water rises to levels higher than the ground surface causing it to flow onto the ground if not confined by a section of pipe rising above the ground. It is well known that wetlands have expanded along the north margin of the tailings basin due to groundwater seepage over the decades.[70] Artesian conditions at various drill holes are described as follows:

---

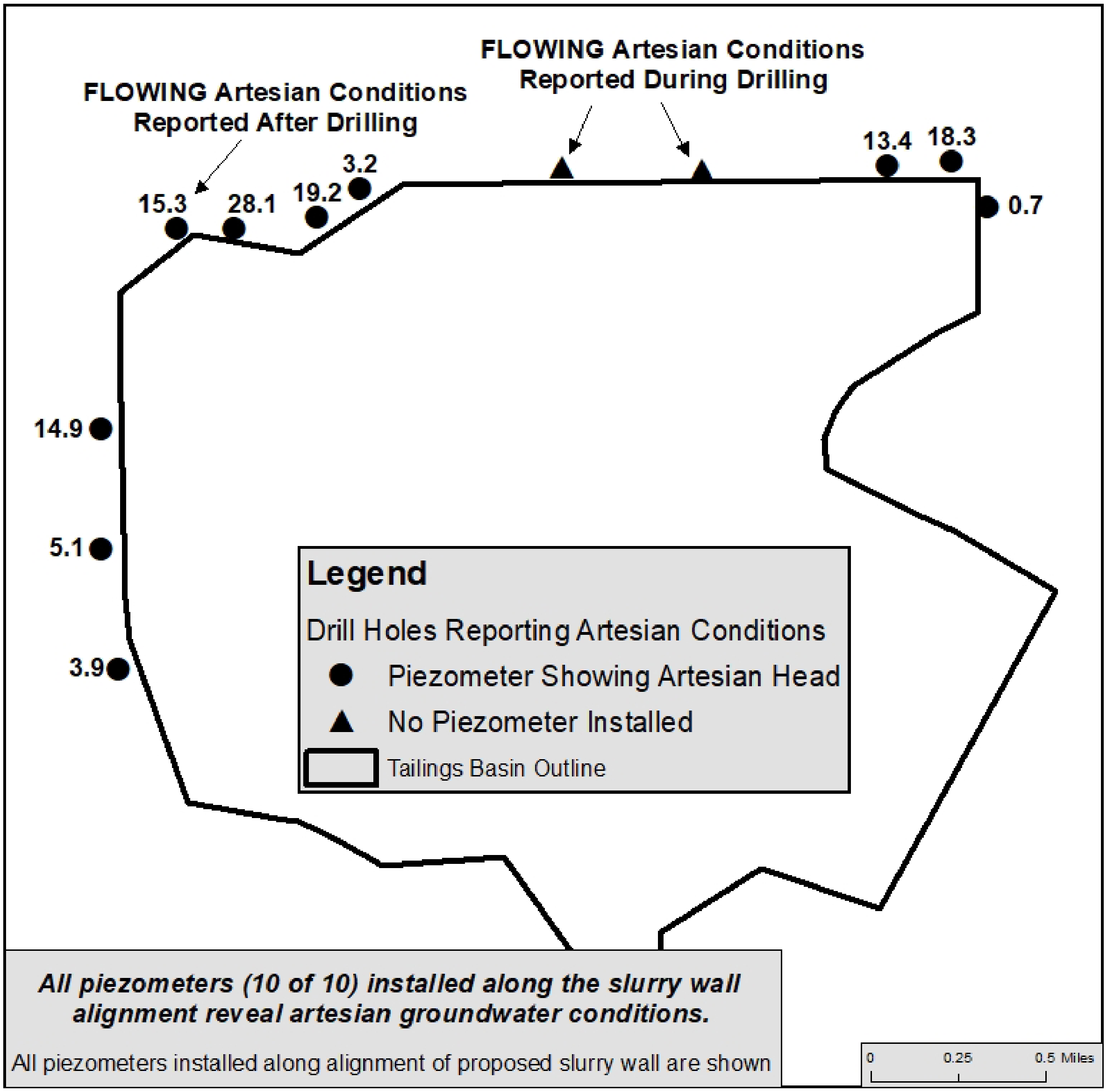
[66] Jennings, C.E., and Reynolds, W.K., 2005 Surficial geology of the Mesabi Iron Range: Minnesota Geological Survey Miscellaneous Map M-164, scale 1:100,000.

[67] Minnesota Geological Survey, 2021, Compilation of mapping to create statewide surficial geology map: Minnesota Geological Survey Database D-1.

[68] Lacustrine sediment refers to sediment deposited in a lake.

[69] A piezometer is a type of well installed to monitor groundwater levels. Piezometers were only installed in certain drill holes.

[70] Final EIS, p. 458.



SUMMARY OF FIGURE 18. ARTESIAN GROUNDWATER CONDITIONS MAY PRECLUDE PROPOSED SLURRY WALL[71]

> "Artesian groundwater conditions were encountered in several piezometers and drill holes 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." [72]

> "During the Rotasonic investigation, artesian flow was encountered in R14-20 with a head of 3 feet above ground surface. During the SPT work, localized artesian flow was encountered at B14-69, where a head of up to 1 foot above ground surface was observed."[73]

---

[71] Source: Drilling records in NorthMet Project Geotechnical Data Package, Volume 1 – Flotation Tailings Basin, Version 8. Issue Date: May 15, 2017. Also see Figure 18 in Appendix A.

[72] Hydrogeology Report, p. 25. Also see the drilling log for R14-20 on p. 795 of the Geotechnical Report.

Gaps in the distribution of drill holes along the northern margin of the tailings basin (Figure 6) are explained in the Geotechnical Report as resulting from site access constraints. Along the northern perimeter of the tailings basin a total of 7 of the proposed 30 Rotasonic drill holes[74] were not drilled because "the proposed locations were not accessible"[75] "due to open water conditions".[76]

Rotasonic drilling was carried out from March 11 to 18, 2014. This area experiences some of the coldest wintertime temperatures in Minnesota and by mid-March the only water that remains open or unfrozen in the Embarrass area is either artificially warmed for some reason (like discharges at a power plant) or rapidly flowing due to strong currents. The Geotechnical Report states that "ground conditions remained frozen and temperatures remained below freezing" (p. 738) during the Rotasonic drilling program and that "ground conditions remained frozen until approximately April 17, 2014" (p. 743). It was not abnormally warm weather that led to the "open water conditions" at the tailings basin site. The water in this wetland area along the northern perimeter of the tailings basin most likely remained unfrozen throughout the winter because of currents caused by strong artesian groundwater flow.[77]

Artesian groundwater conditions existing along the northern perimeter of the tailings basin made drilling infeasible, even in winter. The presence of artesian conditions indicates groundwater is currently flowing under extraordinary pressures from beneath the existing tailings basin.

Construction of a bentonite slurry wall in the subsurface under artesian groundwater flow conditions with such shallow depths to groundwater will be highly challenging if not impossible to accomplish. Yet, no application or permitting documents discuss the feasibility of building a slurry wall keyed to solid bedrock under artesian groundwater conditions, particularly along the north perimeter of the tailings basin.

A recent review[78] of slurry wall construction technology by an industry expert discusses limitations on soil-bentonite slurry wall construction caused by certain subsurface geologic conditions. "Rock or boulders in the profile" and groundwater levels shallower than 2 feet are known to limit successful slurry wall construction. Also specified is the requirement that the slurry wall is continuously "keyed" into impermeable materials and that the "key" must extend at least 1 to 3 feet deep for it to be effective. Perhaps most significant is the warning of "truly dangerous situations that can result in trench

---

[73] Minnesota Department of Natural Resources Public Waters/Dam Permit Application, Reference Number 2016-1380 ("Dam Safety Permit Application"), p. 1117. Also see the drilling log for B14-69 on p. 841 of the Geotechnical Report.

[74] Drill holes R14-14, 17, 18, 19, 21, 22 and 23 along the northern margin were skipped along with R14-01 and 03.

[75] Geotechnical Report, p. 738. It should be noted that, according to drilling logs, rotasonic drilling was carried out using a CRS-7-C rig, a small, all-terrain, track mounted drill designed to be highly mobile and adaptable even under difficult site access conditions.

[76] Ibid. Emphasis added.

[77] See also Dam Safety Permit Application, p. 1117, "It was also noted that even during cold winter months, there was still open water that did not freeze due to seepage at some locations, particularly along the northwest corner of the Tailings Basin."

[78] Ryan, C.R., 2021, 70 Years of soil-bentonite slurry walls: What's new? *in* GEOSTRATA Magazine: Specialty Geo-Construction Equipment Issue, v. 25, Issue 3, May/June/July 2021.

collapse, or where a SBSW [soil-bentonite slurry wall] likely won't work" if a "layer anywhere in the excavated profile with artesian head conditions" or "highly organic soil-like peat"[79] exist. Widespread artesian groundwater conditions, groundwater levels "at or just below the ground surface,"[80] (Table 3 and Table 4) commonplace occurrence of boulders significantly larger than the width of the slurry wall and thick intervals of peat along the alignment of the proposed seepage capture system are not accounted for in PolyMet's plans to contain 100% of groundwater seepage.

5.8 Cumulative subsurface conditions do not support the proposed design

To address whether PolyMet's claim that subsurface geologic conditions will allow for the construction of the seepage capture system is supported, the concerns raised in Section 5 must be reviewed spatially and cumulatively. Mapping of weighted average RQD show areas with the most fractured bedrock are disproportionally concentrated along the northwestern and northern perimeter of the tailings basin perimeter (Figures 10 and 11).

Bedrock with RQD values indicating "good quality" bedrock[81] (RQD = 77) occurs at a single location along the southwestern perimeter of the FTB (the green symbol shown on Figure 10). Note that green symbols are lacking from the entire remainder of the tailings basin perimeter. This leaves an extended segment of the alignment of the proposed seepage capture system where RQD data from every hole drilled show some degree of fractured bedrock throughout the entire interval of bedrock drilled. None of the drill holes yielded RQD results demonstrating fully competent bedrock.

An additional way to identify spatial patterns within the RQD dataset (and therefore patterns in fracture density) is to look at RQD results from only those intervals drilled deeper than 10 feet into bedrock – what PolyMet assumed was a "no-flow boundary". The weighted average RQD's for only those intervals are mapped on Figure 11. For RQD data to support PolyMet's claim of a "no-flow" zone, all of the RQD values shown on Figure 11 should approach 100.

Several RQD data points from the western (LTV) side of the tailings basin show average RQD values ranging from 88 to 100, indicating "good to excellent quality" bedrock at >10 feet, although one drill hole showed an RQD of 53 indicating only "fair quality " bedrock (Figure 11). The caveat is that these results represent literally only a few feet (3-8 feet) of bedrock in each hole. Since only a few feet of sound bedrock was drilled at so many locations; many of these reported RQD results could in fact represent boulders within glacial sediments rather than bedrock. Additionally, there are many areas where no RQD data are available from the deeper interval, resulting in limited direct information on the frequency of deeper bedrock fractures.

North of PolyMet's proposed FTB, a striking pattern is revealed. All of the available RQD data for over the entire mile-and a quarter-long stretch of the northern margin of the FTB show the deeper bedrock

[79] Ibid. Emphasis added.
[80] Geotechnical Report, p. 21.
[81] This descriptive translation of RQD is from Figure 1 contained in Deere, D.U., 1989, Rock Quality Designation (RQD) After 20 Years, U.S. Army Corps of Engineers Contract Report GL-89-1, 100 p. Reproduced in this report as Figure 3.

to contain only “fair quality” bedrock with RQD values from 51 to 58 (Figure 11). These are 3 of the 4 lowest RQD values reported anywhere from the interval more than 10 feet below the top of bedrock. They indicate extensively weathered and fractured bedrock and the potential for more groundwater to seep below the bentonite slurry wall through these areas which are not “impermeable”. Neither the Final EIS nor PolyMet’s modeling considered this seepage.[82]

The cumulative effects of adverse subsurface conditions at the tailings basin on the northern side of the FTB will ultimately render the tailings basin seepage collection engineering controls ineffective or impossible to construct. These cumulative unfavorable geologic conditions include locations: 1) with weathered/fractured bedrock, 2) lacking information on competent bedrock or claiming sound “bedrock” after drilling less than 10 feet, 3) with increased water flow through sand and gravel, and 4) with flowing artesian groundwater or artesian heads.

Figure 19 shows the alignment of areas with the most fractured bedrock (lowest RQD values), the greatest depths to reported competent bedrock, substantial amounts of sand and gravel, artesian groundwater conditions and high artesian heads (Figure 18) along the northern perimeter of the tailings basin. Coupled with the low degree of confidence where competent bedrock is located and the total lack of bedrock data from beneath the tailings basin and along critical segments elsewhere around the tailings basin perimeter, these adverse geological conditions will have synergistic negative effects on the feasibility of slurry wall construction and it’s performance, especially along the northern perimeter.

PolyMet’s prediction of capturing 100% of contaminated groundwater seepage at the FTB is based on the ability to successfully construct the seepage capture system and bentonite slurry wall as proposed, leaving no margin of error in efficacy rates. However the assumption that geologic conditions at the tailings basin will allow for the successful construction of this infrastructure is based on a biased and very incomplete subsurface dataset. This situation will cause PolyMet’s water pollution controls to be ineffective.

6.0 CONCLUSIONS

PolyMet has presented an incomplete and biased portrayal of geology at the tailings basin site resulting in the efficacy of proposed water pollution controls being lower than predicted and/or impossible to construct as proposed. Specific conclusions are:

1) Data do not support PolyMet’s claims about bedrock fractures and a “no-flow boundary”
2) Packer testing used by PolyMet to support a “no-flow boundary” was biased
3) PolyMet has not demonstrated depth to competent bedrock for its slurry wall.
4) There is a low degree of confidence where depth to competent bedrock is reported
5) PolyMet has not shown how its slurry wall could be effectively keyed into granite bedrock
6) Surficial geology indicates increased seepage along northern perimeter of FTB
7) Artesian groundwater flow conditions may preclude proposed slurry wall

[82] The Final EIS states (p. 2306) “It is acknowledged that the Plant Site MODFLOW model does not include bedrock below surficial deposits and thus does not consider flow towards the Embarrass River in bedrock.”

8) Cumulative subsurface conditions do not support the proposed design

The cumulative and synergistic effects of the shortcomings and biases listed above will cause the seepage capture system to fail to control water pollution as predicted and will prevent construction of a continuous slurry wall that is keyed into competent bedrock. The feasibility of continuous slurry wall construction at unspecified depths, within extremely boulder-rich sediments that are known to contain boulders as large as 7.5 feet in diameter and under pervasive artesian groundwater conditions is unsupported.

No data exist on bedrock fractures deeper than 16 feet and all data available for the bedrock indicate fractured bedrock exists along the entire perimeter of the tailings basin to depths as deep as PolyMet chose to drill. No modeling of seepage throughput is based on the extent of bedrock fracturing shown by PolyMet's drilling information.

PolyMet has done no modeling that would predict volumes of contaminated seepage unsuccessfully captured resulting from gaps in the proposed bentonite slurry wall perimeter. Unfavorable geologic conditions – most notably widespread artesian groundwater conditions and the frequency of large boulders - will cause continuous slurry wall construction to be very difficult if not impossible over extended portions of the proposed seepage containment perimeter. The wintertime open water conditions that prohibited lightweight, all-terrain drilling equipment from accessing large areas along the northern perimeter of the tailings basin will also prohibit access into these areas with heavier, less mobile slurry wall construction equipment causing large gaps in the seepage containment system. Artesian groundwater conditions will prove problematic, perhaps disastrous, to carrying out construction of the slurry wall as proposed.

Finally, because of the aforementioned shortcomings and biases in PolyMet's analysis of subsurface geologic and hydrologic conditions at the tailings basin, any modeling or assumptions derived from these test results are called into question and provide no basis to conclude seepage collection will be 100% or nearly 100% effective as PolyMet has repeatedly claimed.

7.0 DOCUMENTS REVIEWED

- Barr Technical Memorandum. Subject: Groundwater Containment System – Degree of Use in Industry. Dated December 26, 2012 (3 pages) ("Ground Water Containment Memo")
- Dam Safety Permit (8 pages) ("Dam Safety Permit")
- Deere, D.U., 1989, Rock Quality Designation (RQD) After 20 Years, U.S. Army Corps of Engineers Contract Report GL-89-1, 100 p.[83]
- Hydrogeology of Fractured Bedrock in the Vicinity of the NorthMet Project. Prepared for PolyMet Mining Inc., December 2014 (112 pages) ("Hydrogeology Report")

[83] Accessed December 31, 2021 at: https://www.nrc.gov/docs/ml0037/ML003749192.pdf

- Jennings, C.E., and Reynolds, W.K., 2005, Surficial geology of the Mesabi Iron Range: Minnesota Geological Survey Miscellaneous Map M-164, scale 1:100,000.[84]

- Lehr, J.D., 2000, Pleistocene geology of the Embarrass area, St. Louis County, Minnesota: M.S. Thesis, University of Minnesota, 157 p., scale 1:48,000.[85]

- Lehr, J.D. and Hobbs, H.C., 1992, Field trip guidebook for the glacial geology of the Laurentian divide area, St. Louis and Lake counties, Minnesota: Minnesota Geological Survey Guidebook Series No. 18, 73 p., 1 plate, scale 1:250,000.[86]

- Minnesota Department of Natural Resources Public Waters/Dam Permit Application, Reference Number 2016-1380 (2,008 pages) ("Dam Safety Permit Application")

- NorthMet Mining Project and Land Exchange Final Environmental Impact Statement, November 2015 (3,579 pages) ("Final EIS")

- NorthMet Project – Permit to Mine: Findings of Fact, Conclusions, and Order of Commissioner. November 1, 2018 (183 pages) ("Permit to Mine Findings of Fact")

- NorthMet Project, Geotechnical Data Package, Volume 1 – Flotation Tailings Basin, Version 8. Issue Date: May 15, 2017 (968 pages) ("Geotechnical Report")

- NorthMet Project-Dam Safety Permits: Findings of Fact, Conclusions, and Order of Commissioner, November 1, 2018 (74 pages) ("Dam Safety Permit Findings of Fact")

- Permit to Mine Application & Appendices: NorthMet Project. December 2017 (4,194 pages) ("Permit to Mine Application")

- Ryan, C.R., 2021, 70 Years of soil-bentonite slurry walls: What's new? *in* GEOSTRATA Magazine: Specialty Geo-Construction Equipment Issue, v. 25, Issue 3, May/June/July 2021.[87]

- State of Minnesota Department of Natural Resources Permit to Mine Approval: PolyMet Mining Corp. and Poly Met Mining, Inc., NorthMet Mining Project (79 pages) ("Permit to Mine Approval")

[84] Accessed December 31, 2021 at: https://hdl.handle.net/11299/58160
[85] Accessed December 31, 2021 at: https://hdl.handle.net/11299/220202
[86] Accessed December 31, 2021 at: https://hdl.handle.net/11299/59139
[87] Accessed December 31, 2021 at: https://www.readgeo.com/geostrata/may_june_july_2021/MobilePagedArticle.action?articleId=1697490#articleId1697490

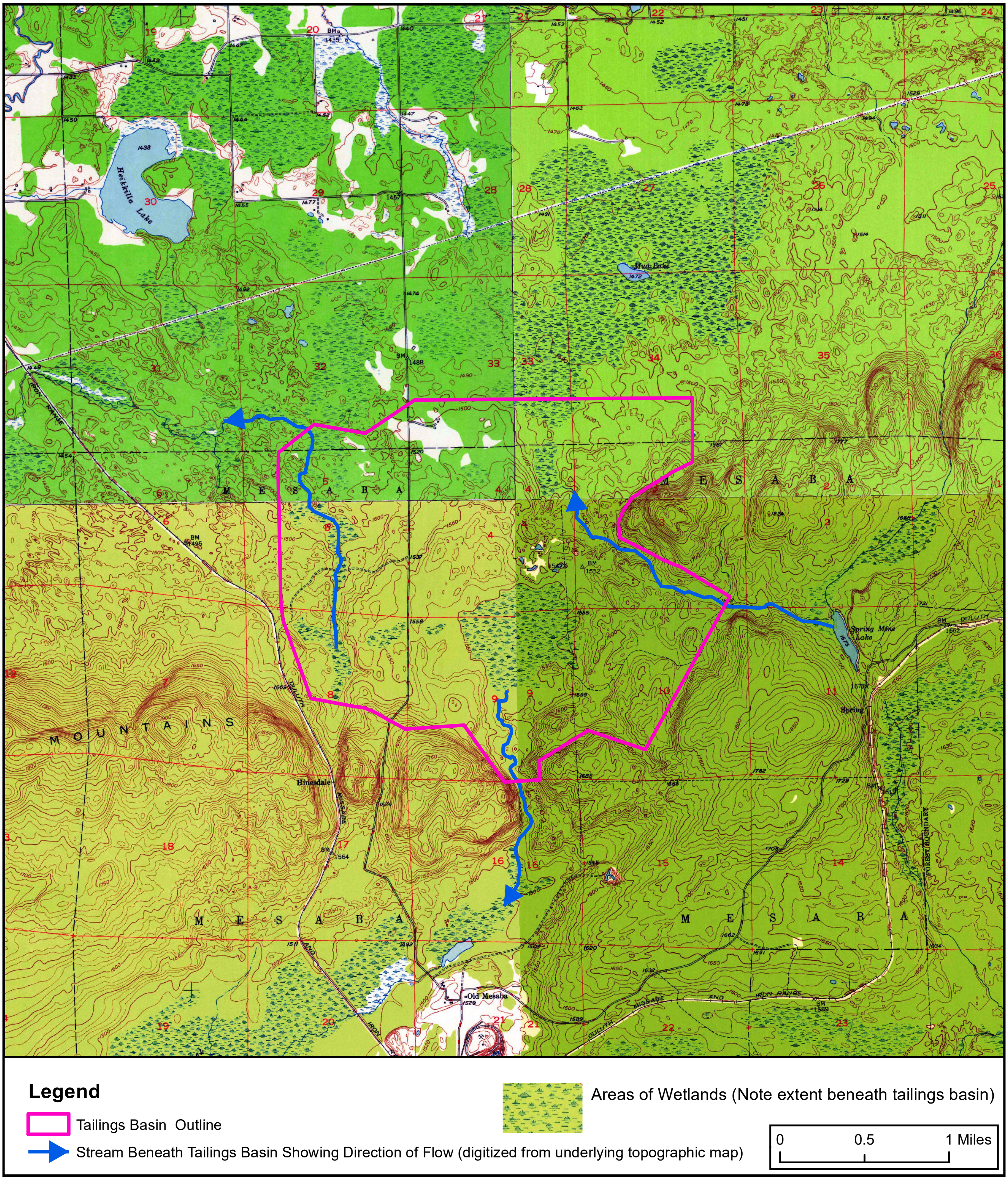


FIGURE 1. SITE CONDITIONS PRIOR TO TAILINGS BASIN CONSTRUCTION

Source: 1949 editions of the Allen, Aurora, Embarrass and Isaac Lake Quadrangles, U.S. Geological Survey 7.5 Minute Series. Quadrangle mapping based on aerial photographs taken in 1947.

From: Appendix A - Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls (J.D. Lehr, January, 2022)

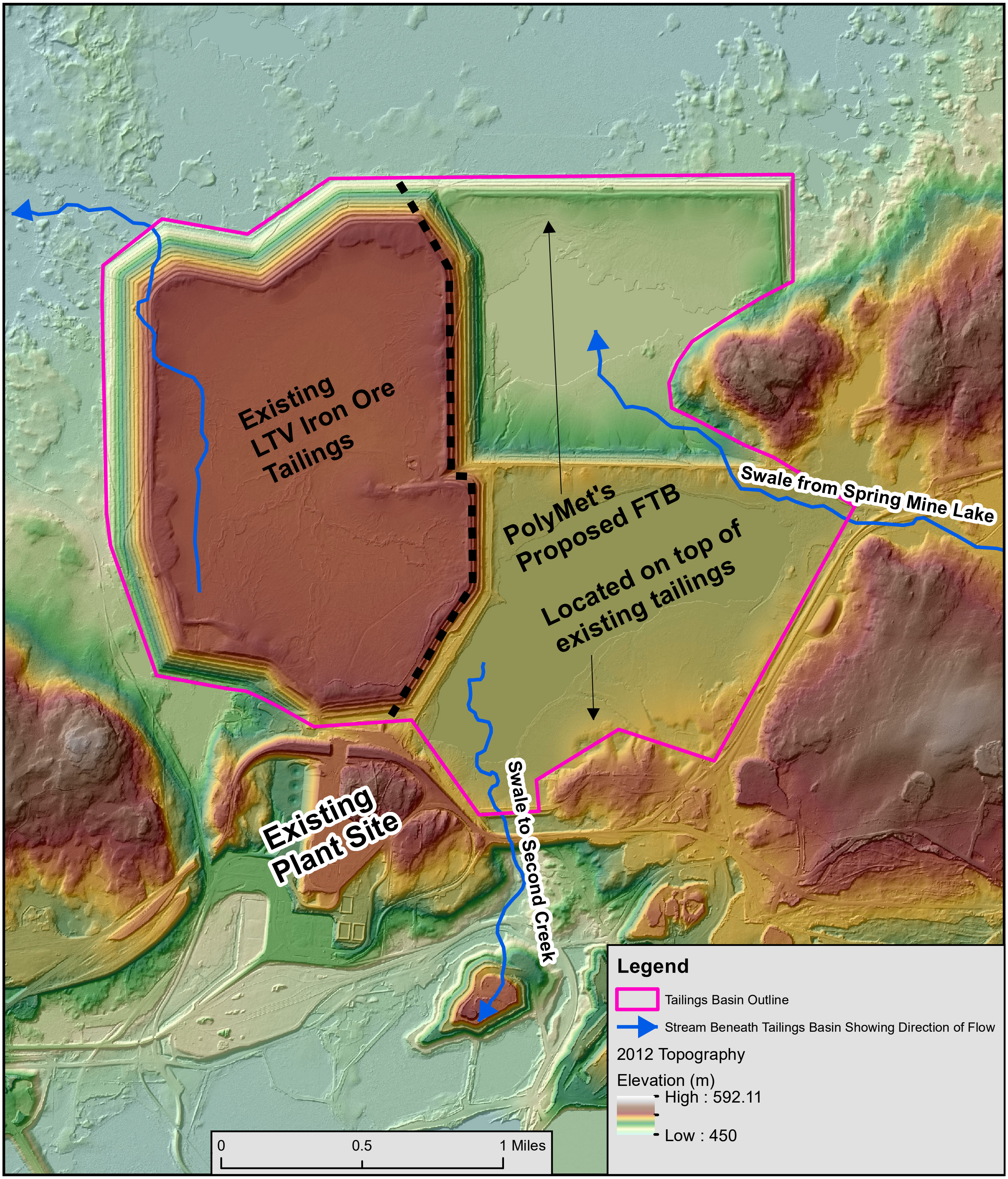


FIGURE 2. CURRENT SITE CONDITIONS AT TAILINGS BASIN

Background image of topography from LiDAR imagery acquired Spring 2012
Streams digitized from 1949 editions of the Allen, Aurora, Embarrass, and Isaac Lake quadrangles (U.S. Geological Survey 7.5 minute series)

From: Appendix A - Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls (J.D. Lehr, January, 2022)

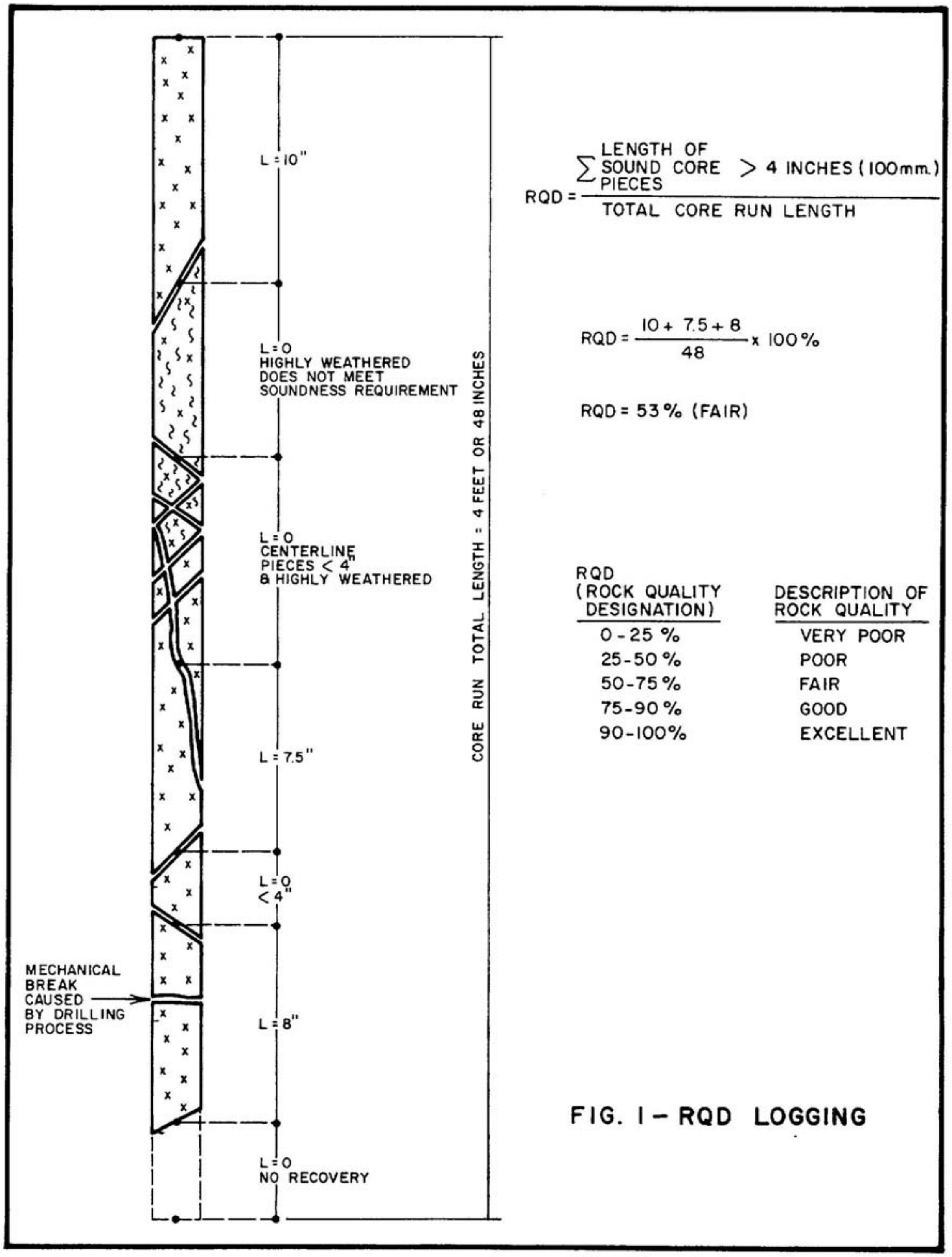


FIGURE 3. EXPLANATION OF ROCK QUALITY DESIGNATION (RQD). *Source: Deere, D.U., 1989, Rock Quality Designation (RQD) After 20 Years, U.S. Army Corps of Engineers Contract Report GL-89-1, 100 p.*

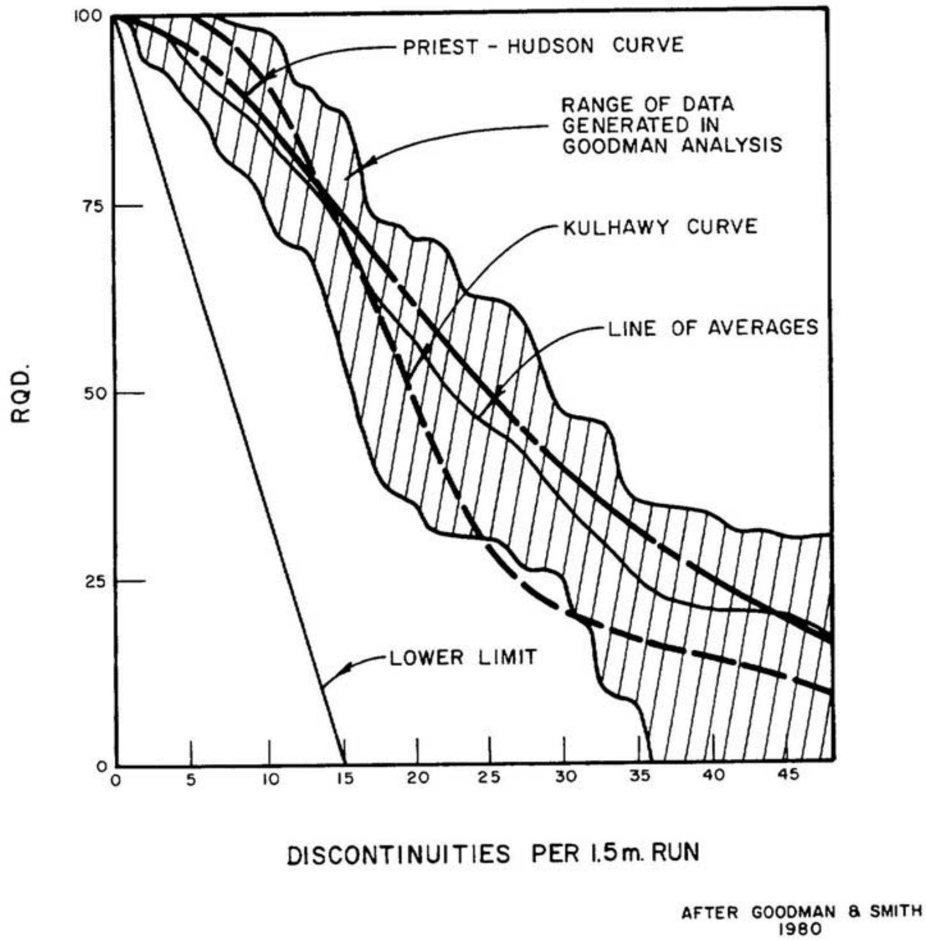


FIG. 5 – RQD. VERSUS FRACTURE FREQUENCY

FIGURE 4. RELATIONSHIP BETWEEN RQD AND FRACTURE FREQUENCY *Source: Deere, D.U., 1989, Rock Quality Designation (RQD) After 20 Years, U.S. Army Corps of Engineers Contract Report GL-89-1, 100 p.*

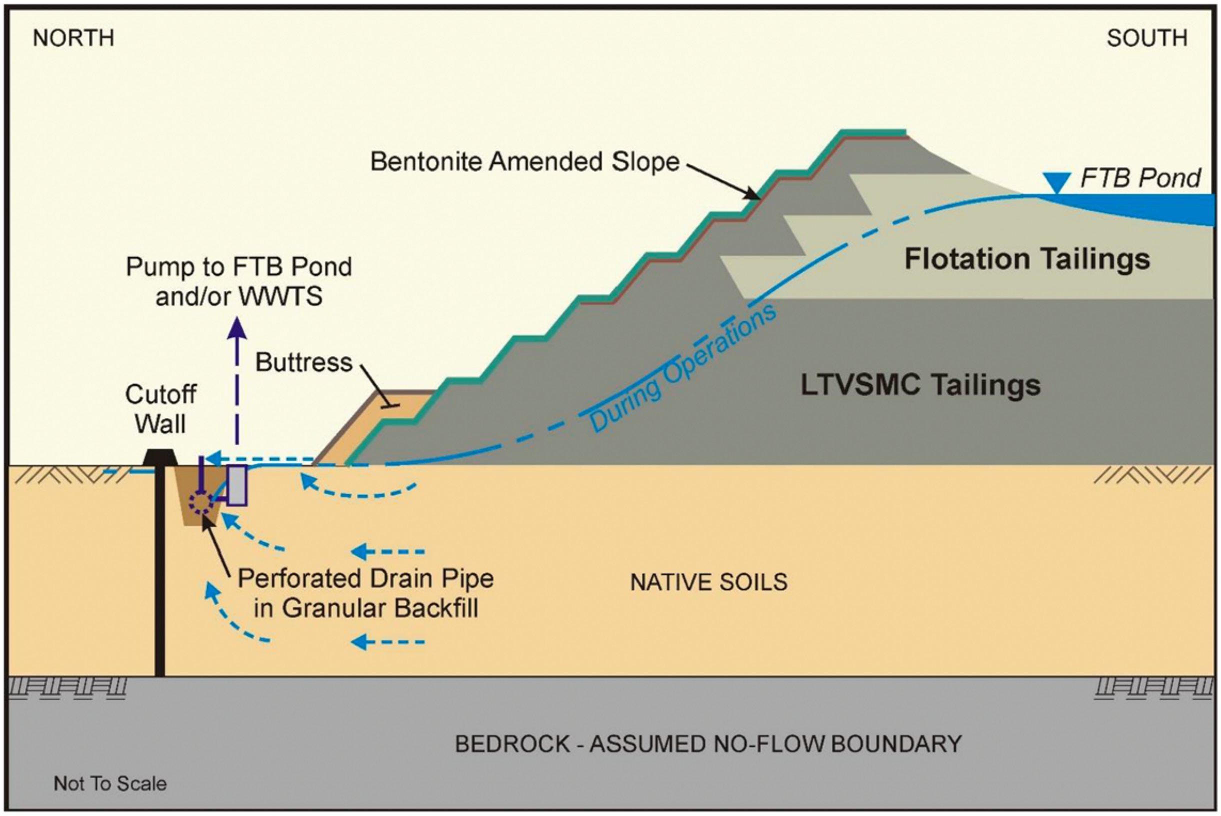


FIGURE 5. POLYMET'S SCHEMATIC DIAGRAM SHOWING ASSUMED NO-FLOW BOUNDARY WITHIN BEDROCK

Note: this figure does not show the slurry/cutoff wall "keyed" into bedrock.

SOURCE: Permit to Mine Application, p. 1524

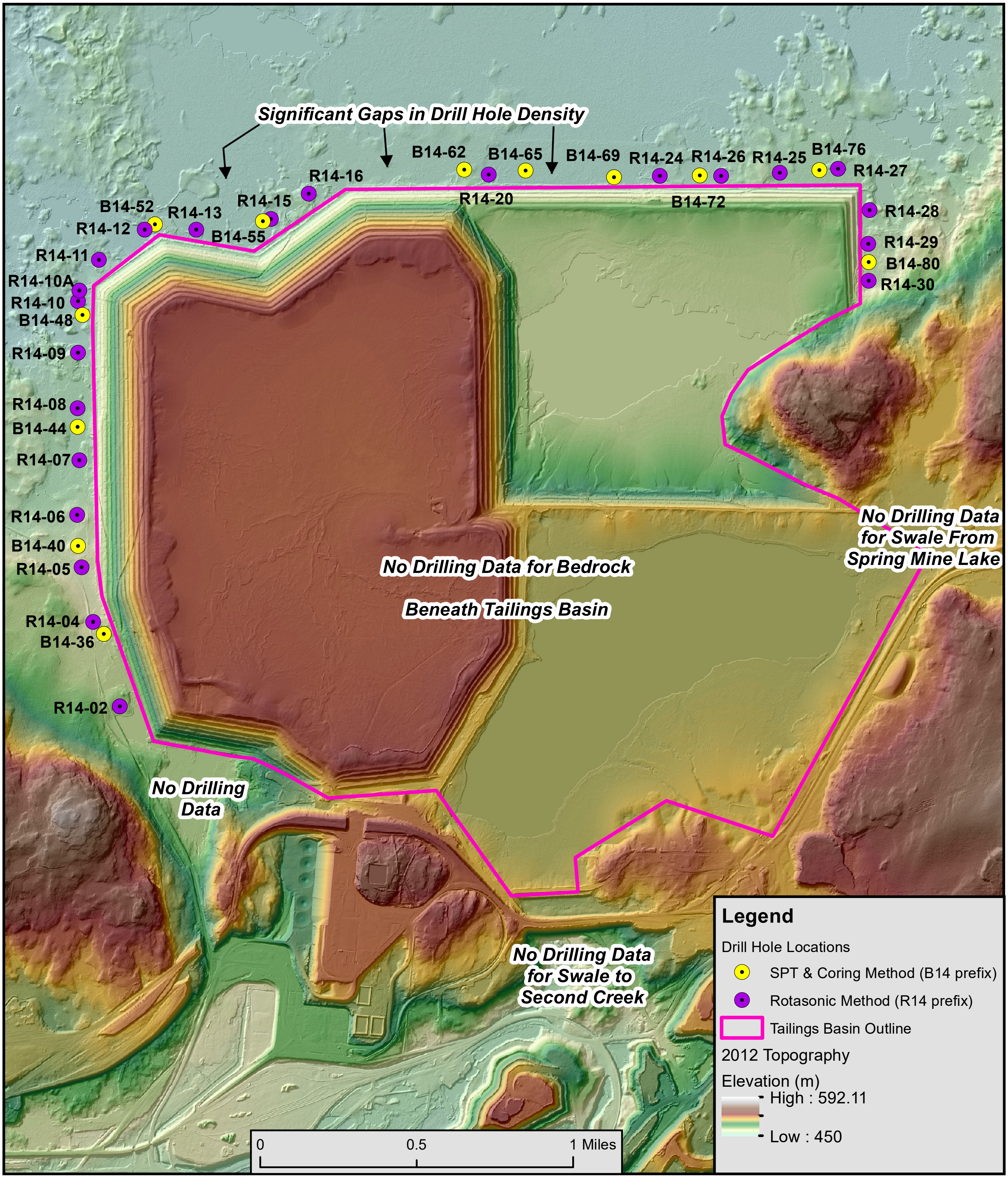


FIGURE 6. DRILL HOLE LOCATIONS

Labels correspond to numbering used on drilling logs in the Geotechnical Report and associated documents

Data Source: NorthMet Project, Geotechnical Data Package, Volume 1 – Flotation Tailings Basin, Version 8. Issue Date: May 15, 2017

Base map shows topography based on Spring 2012 LiDAR survey

From: Appendix A - Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls (J.D. Lehr, January, 2022)

Table 3-2 Rock Quality Designation Summary

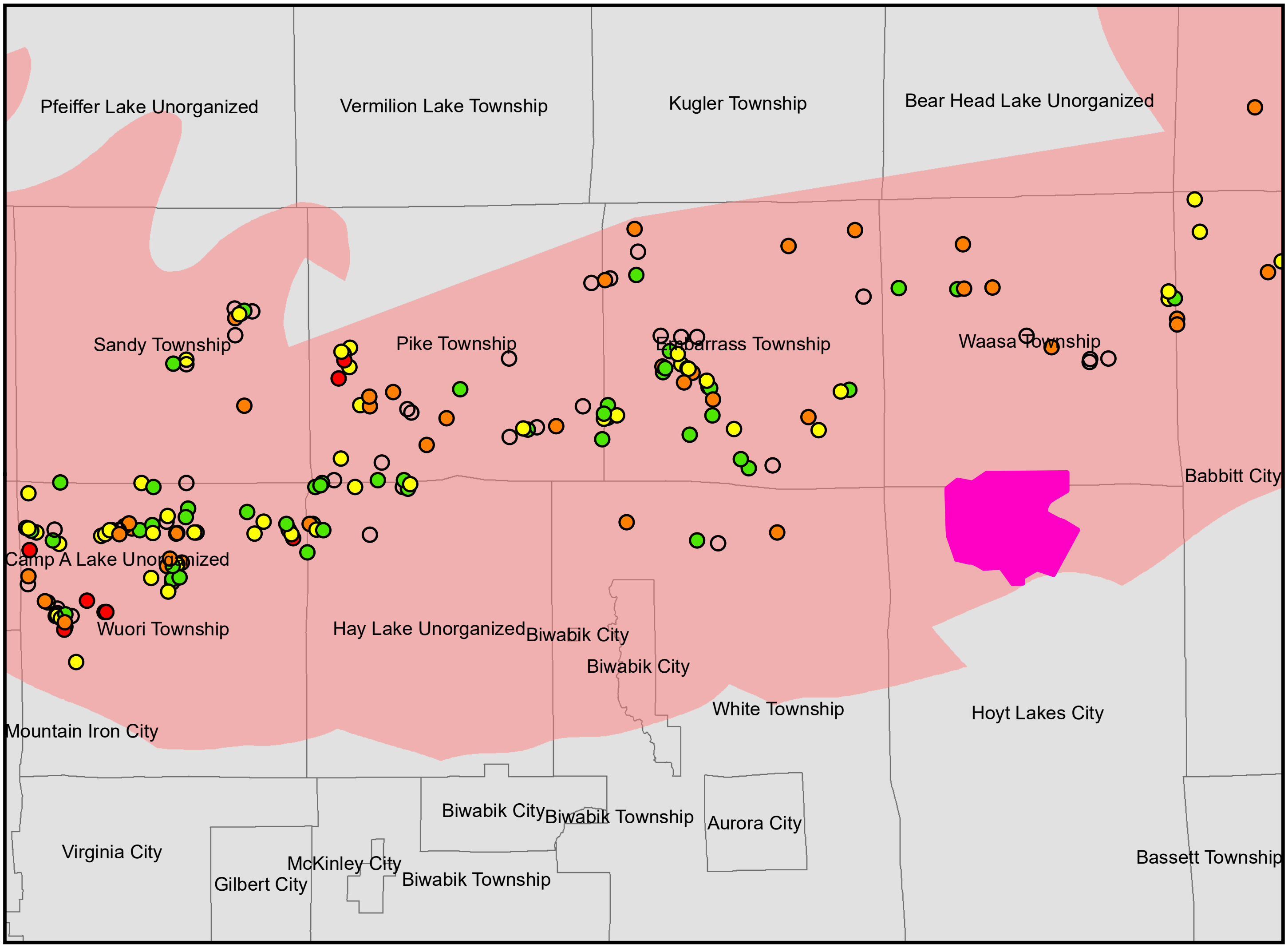
Borehole	Depth (feet)	Average Test Depth (feet)	Test Elevation (feet)	Rock Quality Designation (RQD)
B14-36	13.5-17.5	15.5	1539.2	77
	17.5-21.5	19.5	1535.2	48
	21.5-26.5	24	1530.7	100
B14-40	15.5-20.5	18	1516	68
	20.5-25.5	23	1511	47
	25.5-30.5	28	1506	92
B14-44	31.5-37	34	1468.9	33
	37-42	39.5	1463.4	77
	42-46	44	1458.9	92
B14-48	11-15	13	1478.8	15
	15-20	17.5	1474.3	72
	20-25	22.5	1469.3	88

FIGURE 7. RQD RESULTS FROM BEDROCK AT THE FTB (PART 1) *Source: Table 3-2 in the Geotechnical Report, p. 745*

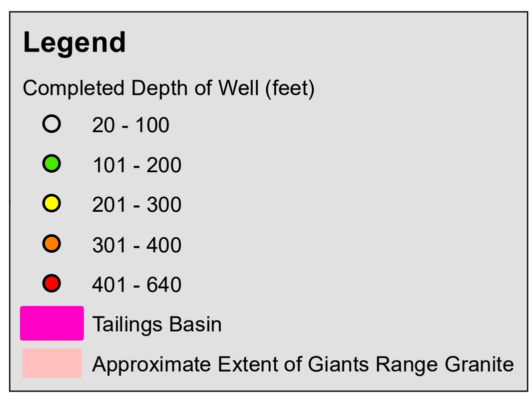
Borehole	Depth (feet)	Average Test Depth (feet)	Test Elevation (feet)	Rock Quality Designation (RQD)
B14-52	42.5-44	43	1443	100
	44-47	45.5	1440.5	100
	50-55	52.5	1433.5	86
	55-59	57	1429	84
	59-61.5	60.5	1425.5	90
	63.5-65.8	64.5	1421.5	75
B14-55	35.5-39	38.5	1456.3	33
	39-44	41.5	1453.3	63
	44-47.5	46	1448.8	85
	47.5-50.5	49	1445.8	91
B14-62	17-20	18.5	1474.8	53
	20-25	22.5	1470.8	13
	25-27	26	1467.3	0
B14-65	22-27	24.5	1462.7	86
	27-32	29.5	1457.7	80
	32-37	34.5	1452.7	51
B14-69	29-34	31.5	1453.6	20
B14-72	11-16	13.5	1479.5	63
	16-21	18.5	1474.5	50
	21-25	23	1470	56
B14-76	27-30	28.5	1472.7	53
	30-35	32.5	1468.7	87
	35-40	37.5	1463.7	53
	40-42.5	41.5	1459.7	63
B14-80	11.5-16.5	14	1509.4	67.5
	16.5-19.5	18	1505.4	79
	19.5-21	20.5	1502.9	100

FIGURE 8. RQD RESULTS FROM BEDROCK AT THE FTB (PART 2) *Source: Table 3-2 in the Geotechnical Report, p. 746*

From: Appendix A – Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls (J.D. Lehr, January, 2022)



The pattern of wells shown above results from a combination of where people live and geology. No domestic wells exist in the Giants Range Granite in close proximity to the tailings basin and towards the southwest because this is mining company property. Gaps in well density elsewhere are due either to lack of residences or sufficient water was found in glacial aquifers or homes are connected to municipal water systems. Absence of wells on the map above does not indicate lack of fractured water-bearing bedrock.



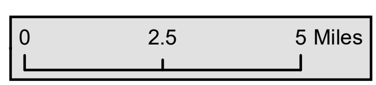


FIGURE 9. DOMESTIC WATER WELLS COMPLETED IN GIANTS RANGE GRANITE

Water well data from Minnesota Department of Health County Well Index database (CWI).
Geology generalized from: Geologic map of Minnesota, bedrock geology: Minnesota Geological Survey State Map Series S-20. March, 1995

From: Appendix A - Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls (J.D. Lehr, January, 2022)

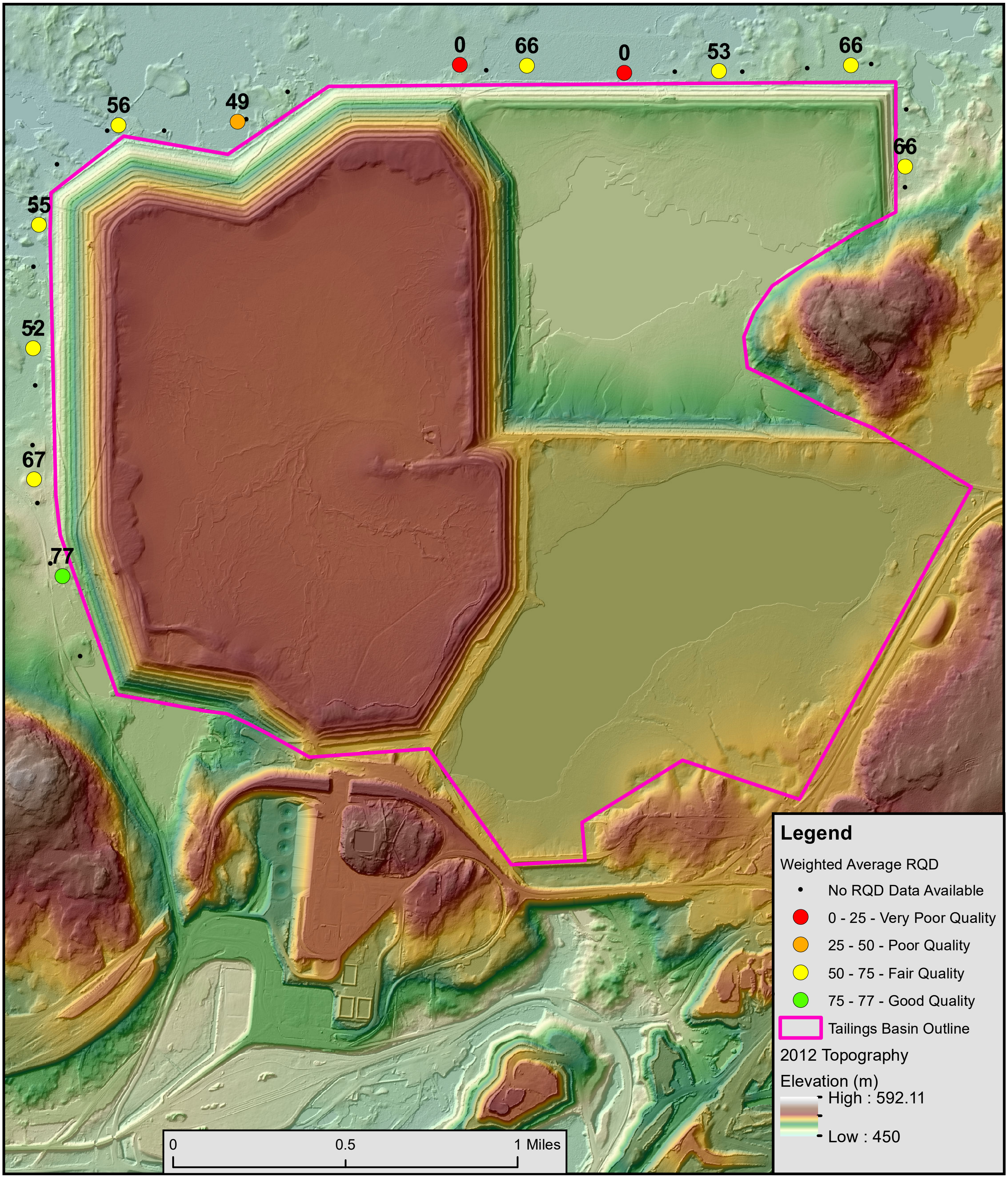


FIGURE 10. OVERALL WEIGHTED AVERAGE RQD*

Data Source: NorthMet Project, Geotechnical Data Package, Volume 1 – Flotation Tailings Basin, Version 8. Issue Date: May 15, 2017

**RQD reported here is Adjusted RQD shown in Tables 5 and 6. Adjusted after accounting for intervals with weathered rock and zero core recovery.*

Base map shows topography based on Spring 2012 LiDAR survey

From: Appendix A - Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls (J.D. Lehr, January, 2022)

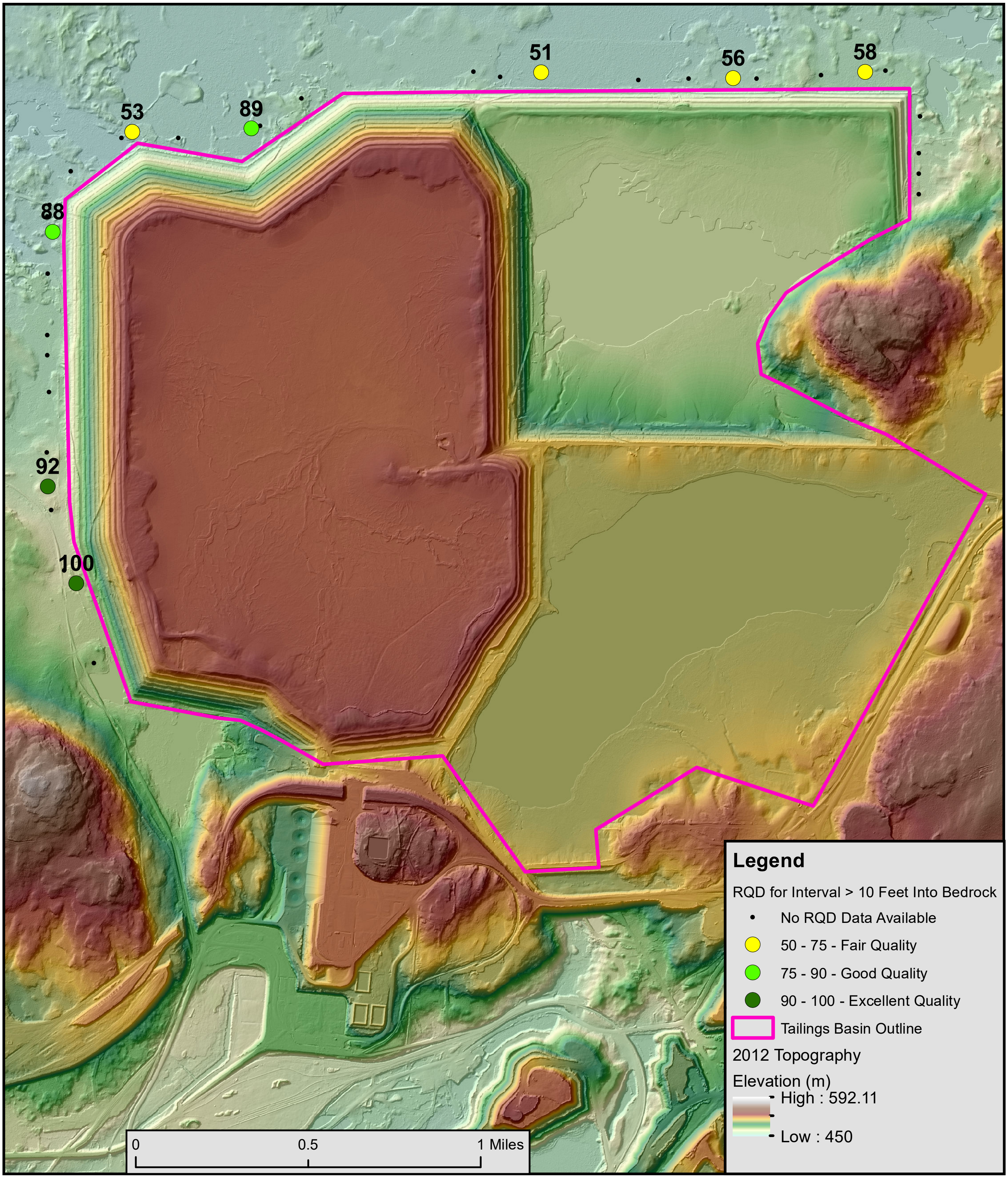


FIGURE 11. WEIGHTED AVERAGE RQD FOR INTERVAL > 10 FEET INTO BEDROCK*

Data Source: NorthMet Project, Geotechnical Data Package, Volume 1 – Flotation Tailings Basin, Version 8. Issue Date: May 15, 2017

**RQD reported here is Adjusted RQD shown in Tables 5 and 6. Adjusted after accounting for intervals with weathered rock or zero core recovery.*

Base map shows topography based on Spring 2012 LiDAR survey

From: Appendix A - Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls (J.D. Lehr, January, 2022)

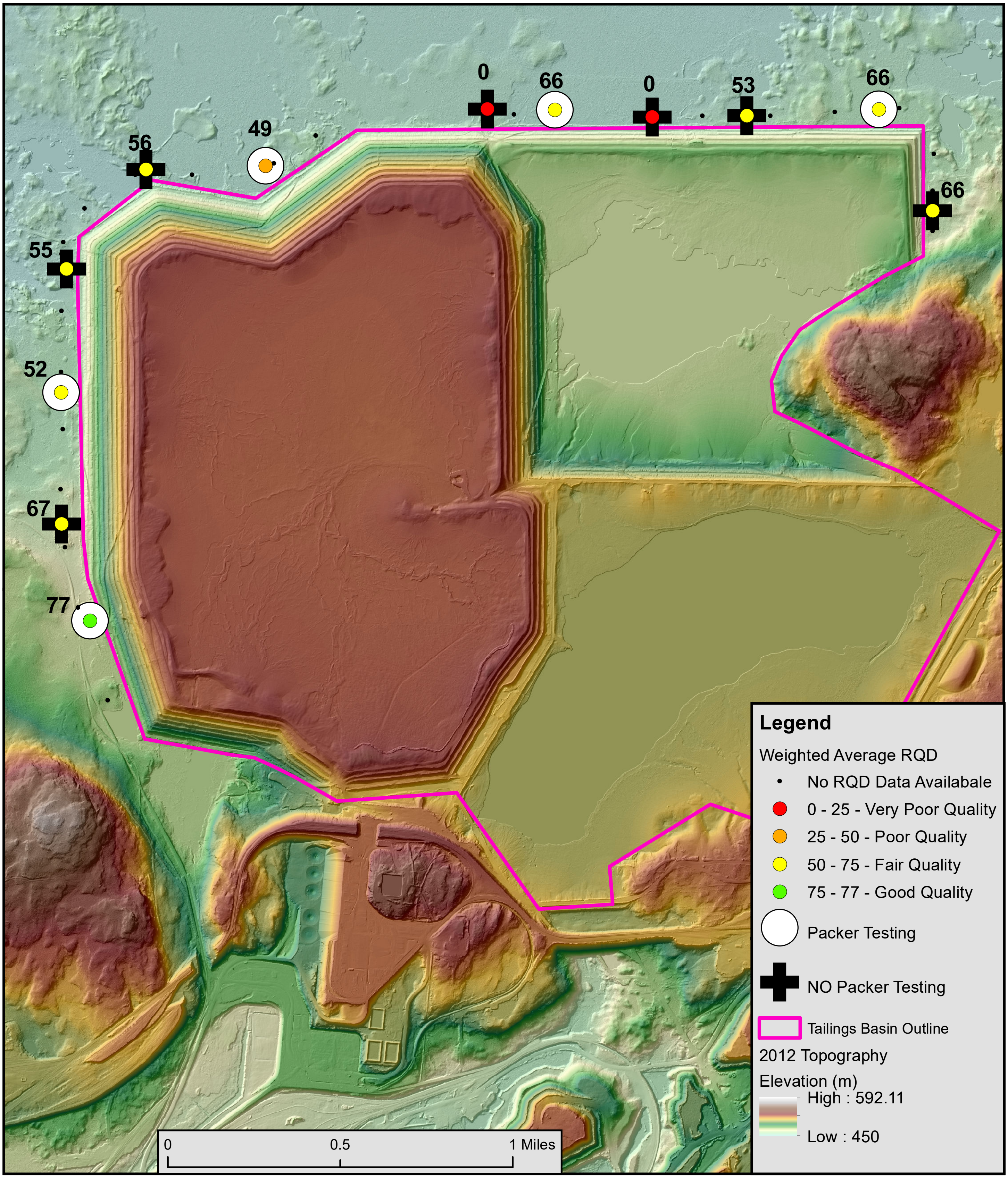


FIGURE 12. DRILL HOLES SELECTED FOR PACKER TESTING

Data Source: NorthMet Project, Geotechnical Data Package, Volume 1 – Flotation Tailings Basin, Version 8. Issue Date: May 15, 2017

Base map shows topography based on Spring 2012 LiDAR survey

From: Appendix A - Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls (J.D. Lehr, January, 2022)

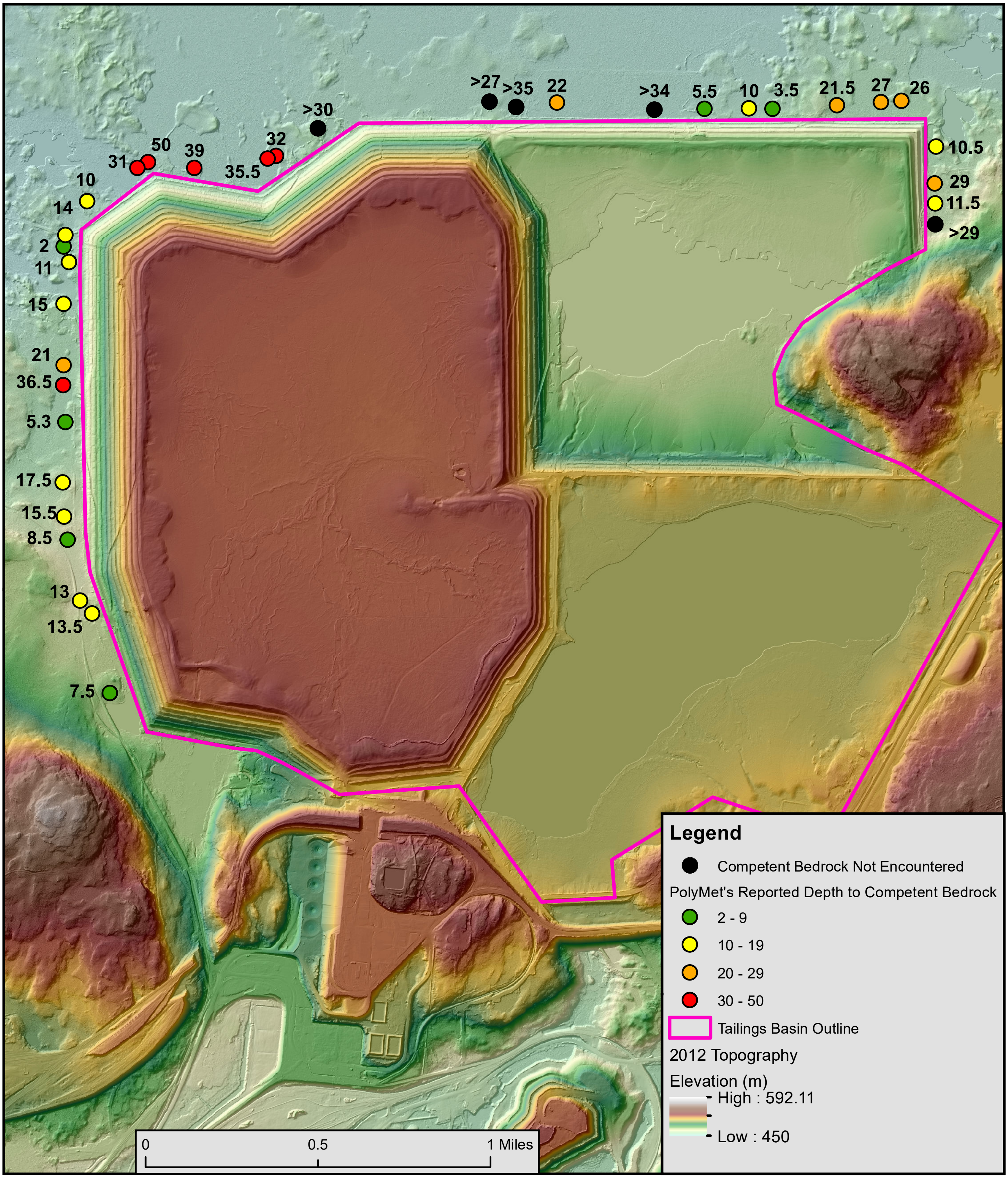


FIGURE 13. POLYMET'S REPORTED DEPTH TO COMPETENT BEDROCK

Data Source: NorthMet Project, Geotechnical Data Package, Volume 1 – Flotation Tailings Basin, Version 8. Issue Date: May 15, 2017

Base map shows topography based on Spring 2012 LiDAR survey

From: Appendix A - Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls (J.D. Lehr, January, 2022)

FIGURE 14. LARGE BOULDERS AT PETER MITCHELL MINE. Note pickup truck at top of bank for scale in second photo. *Source: Supplemental materials contained in Jennings, C.E., and Reynolds, W.K., 2005 Surficial geology of the Mesabi Iron Range: Minnesota Geological Survey Miscellaneous Map M-164, scale 1:100,000.*

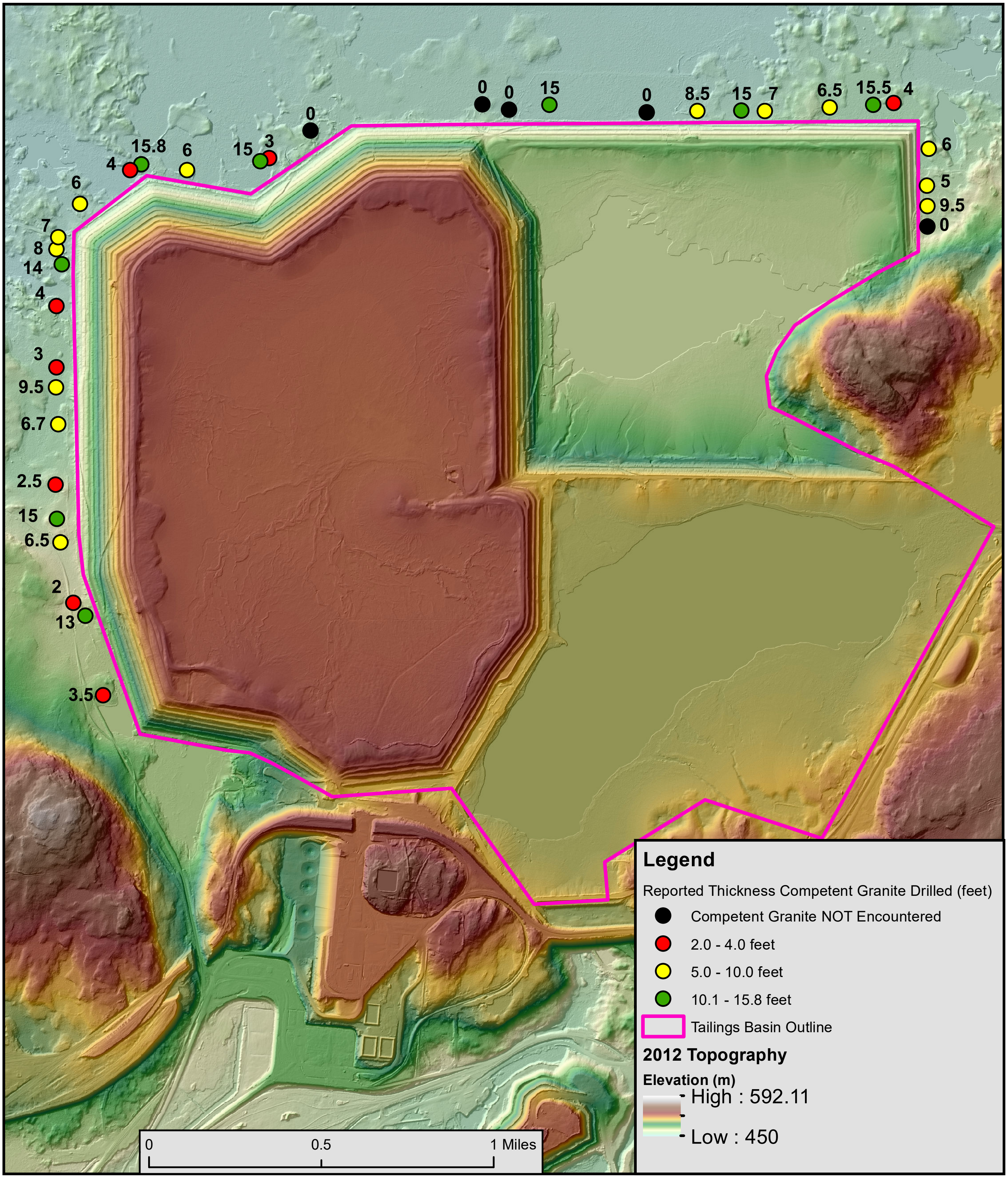


FIGURE 15. POLYMET'S REPORTED THICKNESS OF COMPETENT GRANITE DRILLED

Data Source: NorthMet Project, Geotechnical Data Package, Volume 1 – Flotation Tailings Basin, Version 8. Issue Date: May 15, 2017

Base map shows topography based on Spring 2012 LiDAR survey

From: Appendix A - Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls (J.D. Lehr, January, 2022)

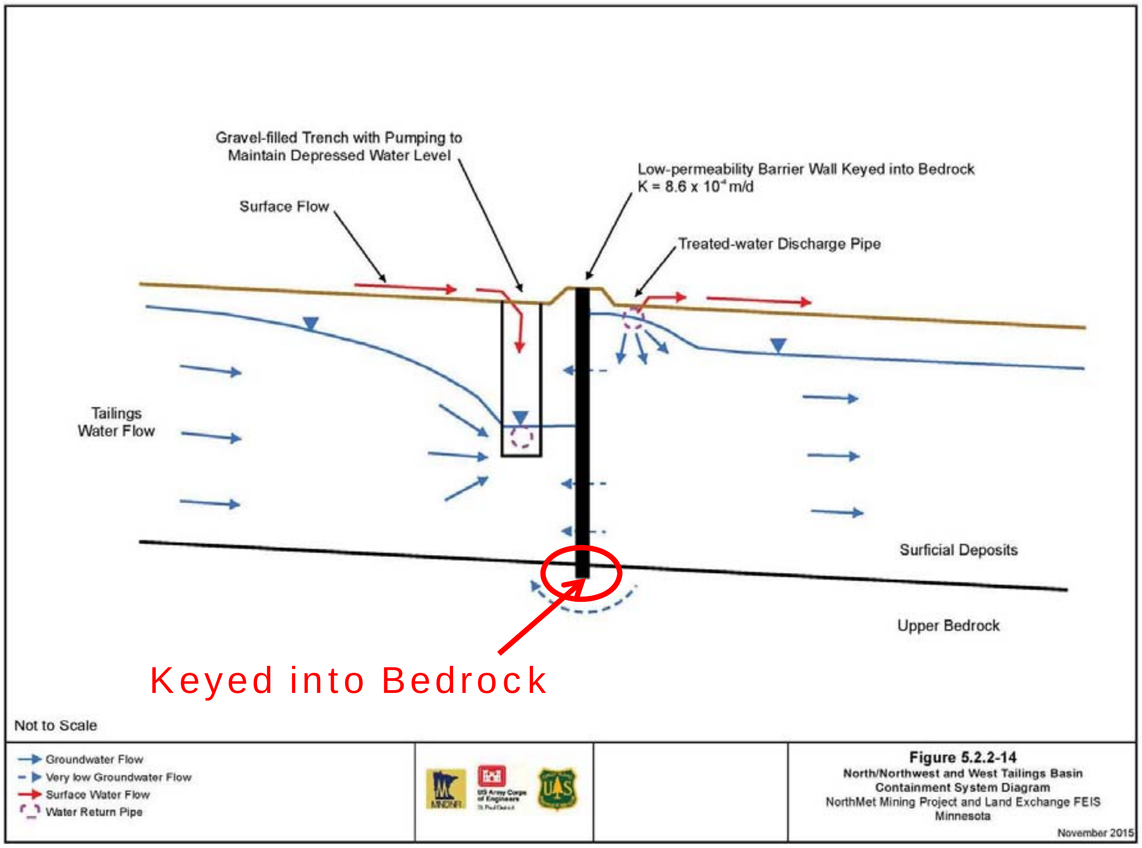


FIGURE 16. DRAWING SHOWING SLURRY WALL "KEYED TO COMPETENT BEDROCK" *Source: Final EIS, p. 1068. Note: the original drawing from the Final EIS has been modified here by adding in red the explanation of the "keyed into bedrock" relationship that the original drawing shows but does not label.*

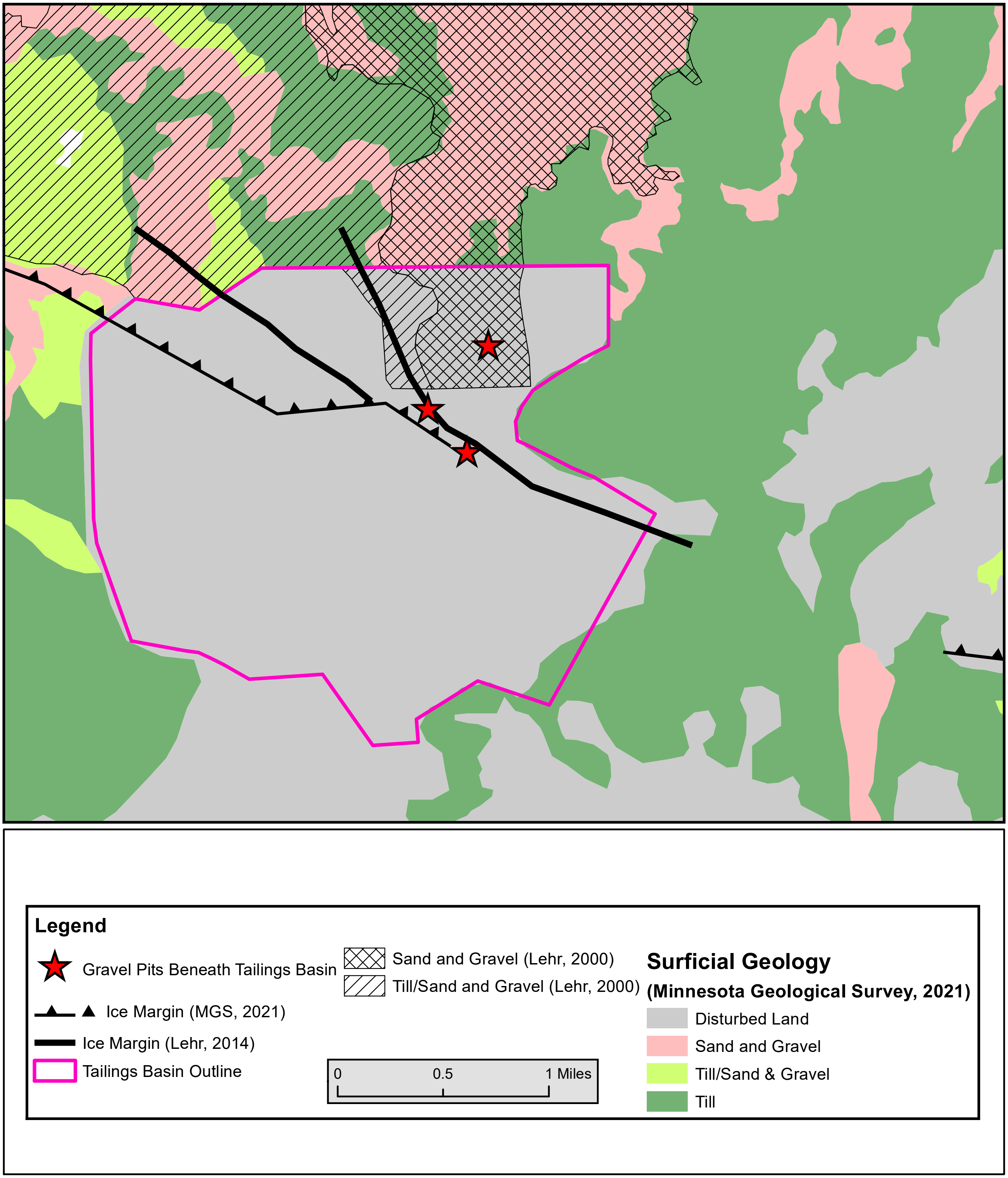


FIGURE 17. SURFICIAL GEOLOGY INDICATES INCREASED SEEPAGE ALONG NORTHERN PERIMETER OF FTB

Source: Minnesota Geological Survey (2021) Compilation of mapping to create statewide surficial geology map: Minnesota Geological Survey Database D1.

Lehr, J.D. (2000) Pleistocene geology of the Embarrass area, St. Louis County, Minnesota: M.S. Thesis, University of Minnesota, 157 p., scale 1:48,000.

Lehr, J.D. (2014) Unpublished mapping. Gravel pit locations from historic USGS 7.5 minute quadrangles.

From: Appendix A - Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls (J.D. Lehr, January, 2022)

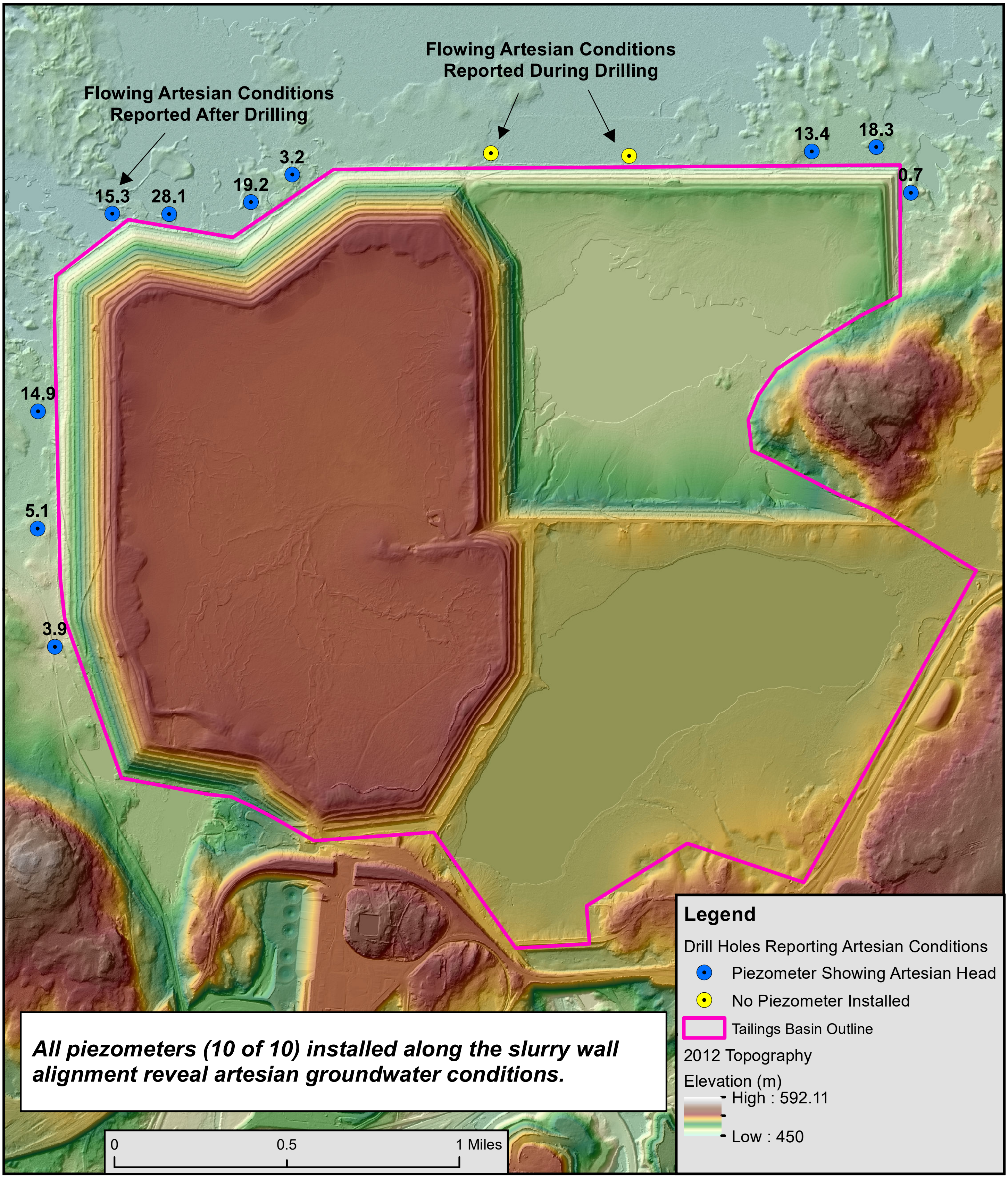


FIGURE 18. ARTESIAN GROUNDWATER CONDITIONS MAY PRECLUDE PROPOSED SLURRY WALL

All piezometers installed along alignment of proposed slurry wall are shown. Labels indicate artesian head (feet)

Data Source: NorthMet Project, Geotechnical Data Package, Volume 1 – Flotation Tailings Basin, Version 8. Issue Date: May 15, 2017

Base map shows topography based on Spring 2012 LiDAR survey

From: Appendix A - Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls (J.D. Lehr, January, 2022)

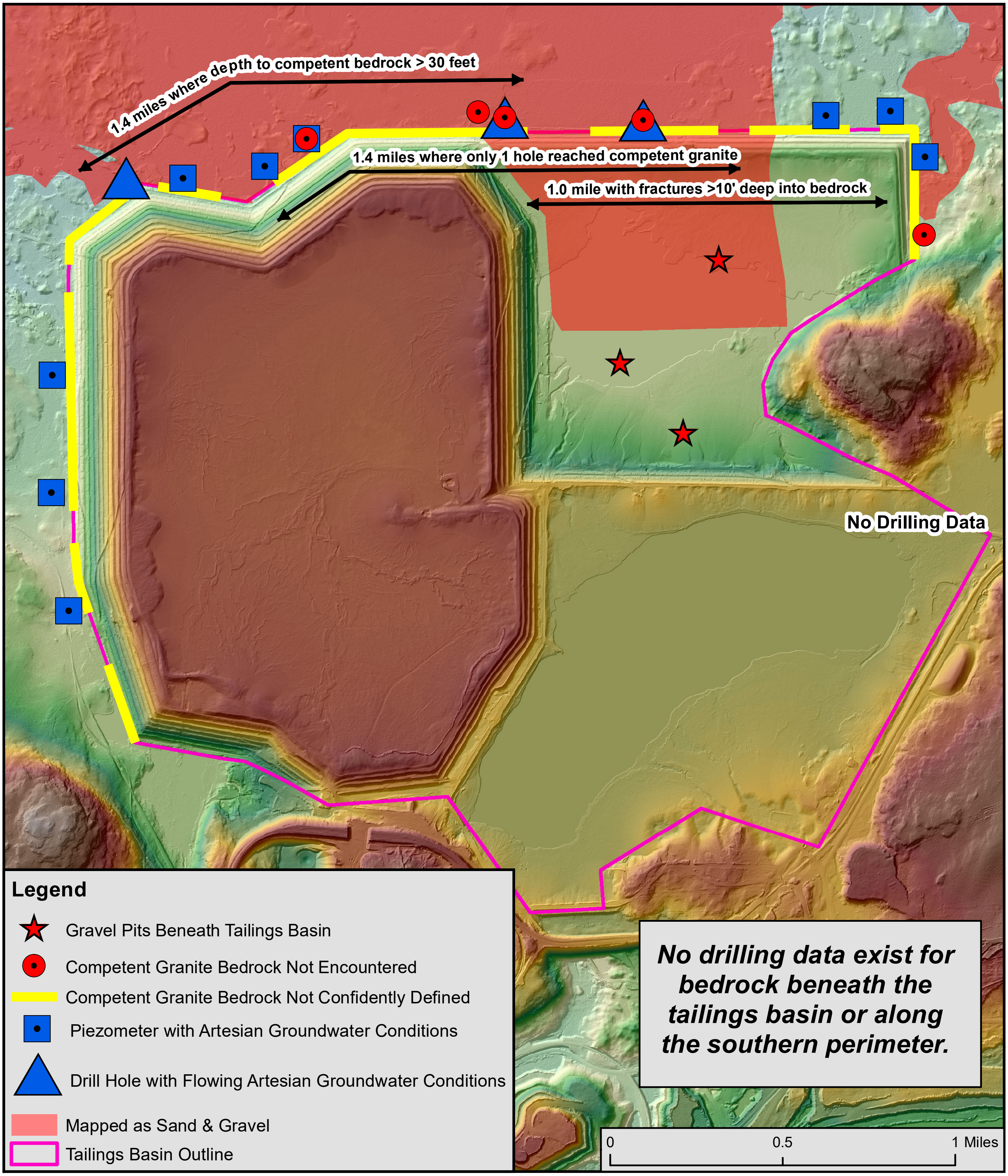


FIGURE 19. CUMMULATIVE SUBSURFACE CONDITIONS DO NOT SUPPORT PROPOSED DESIGN

Source: Barr Engineering, NorthMet Project, Geotechnical Data Package, Volume 1 - Flotation Tailings Basin, Version 8. Issue Date: May, 2017
Lehr, J.D., 2000, Pleistocene geology of the Embarrass area, St. Louis County, Minnesota: M.S. Thesis, University of Minnesota, 157 p., scale 1:48,000
Minnesota Geological Survey, 2021, Compilation of mapping to create statewide surficial geology map: Minnesota Geological Survey Database D-1
Gravel pits and streams beneath tailings basin from historic US Geological Survey 7.5 minute quadrangles

From: Appendix A - Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls (J.D. Lehr, January, 2022)

TABLE 1. SUMMARY OF GEOLOGY (ROTASONIC DRILLING)

DRILL HOLE	THICKNESS (ft) ABOVE TILL Sand	THICKNESS (ft) ABOVE TILL Silt/Clay	Glacial Till	Weathered Granite	Fractured Granite	Competent Granite	DEPTH (ft) Competent Granite	DEPTH (ft) Total Depth	Bedrock Core Recovery	Notes
R14-01	***NOT DRILLED - NO REASON GIVEN***									
R14-02	0	0	6	0	0	3.5	7.5	11	72%	
R14-03	***NOT DRILLED - NO REASON GIVEN***									
R14-04	0	4	6.5	1	0	2	13	15	100%	*1*
R14-05	0	0	5.5	1.5	0	6.5	8.5	15	54%	*2*
R14-06	0	0	17	0.5	0	2.5	17.5	20	100%	*3*
R14-07	0	0	2.3	0	0	6.7	5.3	12	63%	
R14-08	0	0	17	0	0	3	21	24	83%	
R14-09	0	0	13	2	0	4	15	19	67%	*4*
R14-10	0	0	1.7	0	0	8	2	10	89%	
R14-10A	0	0	13.5	0	0	7	14	21	57%	*5*
R14-11	0	0	9.7	0	0	6	10	16	83%	
R14-12	0	1.5	29	0	0	4	31	35	83%	*6*
R14-13	2.2	0	36.5	0	0	6	39	45	67%	*7*
R14-14	***NOT DRILLED DUE TO OPEN WATER CONDITIONS***									
R14-15	4	0	27.5	0	0	3	32	35	83%	*8*
R14-16	0	0	25	4.5	0	0	>30	30	23%	*9*
R14-17	***NOT DRILLED DUE TO OPEN WATER CONDITIONS***									
R14-18	***NOT DRILLED DUE TO OPEN WATER CONDITIONS***									
R14-19	***NOT DRILLED DUE TO OPEN WATER CONDITIONS***									
R14-20	0	0	30	4	0	0	>35	35	100%	*10*
R14-21	***NOT DRILLED DUE TO OPEN WATER CONDITIONS***									
R14-22	***NOT DRILLED DUE TO OPEN WATER CONDITIONS***									
R14-23	***NOT DRILLED DUE TO OPEN WATER CONDITIONS***									
R14-24	0	0	4.5	0	0	8.5	5.5	14	76%	
R14-25	0	0	3.5	0	0	7	3.5	10.5	74%	
R14-26	0	0	20.5	0	0	6.5	21.5	28	100%	
R14-27	0	0	25.5	0	0	4	26	30	75%	
R14-28	0	0	10.5	0	0	6	10.5	16.5	100%	
R14-29	0	0	29	0	0	5	29	34	87%	
R14-30	0	0	26	0	3	0	>29	29	83%	*11*

Source: Drilling logs contained in the Geotechnical Report, pages 781-802

Notes

1. *Clay reported from 1 to 5.5 feet. Granite reportedly "highly weathered" from 12 to 13 feet.*
2. *Granite reported "weathered to 8.5 feet".*
3. *Drilling log 17 to 17.5 feet: "weathered granite"*
4. *Drilling log 13 to 15 feet: "weathered granite"*
5. *"No recovery from 20 to 21 feet", indicating either weathered or fractured bedrock at bottom of drill hole.*
6. *Silt reported from 0.5 to 2 feet.*
7. *Sand with silt reported from 0.3 to 2.5.*
8. *Sand with silt reported from 0.5 to 4.5 feet.*
9. *Drilling log 25.5 to 30 feet: "highly weathered" granite and "poor recovery"*
10. *Drilling log 31 to 25 feet: "highly weathered" granite.*
11. *Drilling log 26 to 29 feet: "Fractured bedrock"*

TABLE 2. SUMMARY OF GEOLOGY (SPT AND CORE DRILLING)

DRILL HOLE	THICKNESS (ft)						DEPTH (ft)		Wt. Ave. RQD[1]	Notes
	ABOVE TILL		Glacial	Weathered	Fractured	Competent	Competent	Total		
	Sand	Silt/Clay	Till	Granite	Granite	Granite	Granite	Depth		
B14-36	0	0	6.5	0	0	13	13.5	26.5	77	*2*
B14-40	0	0	14.2	0.5	0	15	15.5	30.5	69	*3*
B14-44	0	0	14.5	5	0	9.5	36.5	46	84	*4*
B14-48	0	0	9.2	1.5	0	14	11	25	61	*5*
B14-52	14.5	14	4.5	6	1.5	15.8	50	65.8	88	*6*
B14-55	0	0	29	5.5	0	15	35.5	50.5	67	*7*
B14-62	1.7	0	15	10	0	0	>27	27	22	*8*
B14-65	0	5	8.5	1.5	0	15	22	37	72	*9*
B14-69	0	0	9	5	0	0	>34	34	20	*10*
B14-72	0	0	5	1	?	?	?	25	56	*11*
B14-76	0	0	17	0	0	15.5	27	42.5	66	*12*
B14-80	0	0	9.7	1.5	0	9.5	11.5	21	76	*13*

Source: Drilling logs contained in the Geotechnical Report, pages 832-844 except as noted below.

Notes

1 *PolyMet's RQD data from Table 3-2 within the Geotechnical Report (p. 745-746). Weighted averages reported here*

2 *Fine tailings reported from 0 to 7 feet. Reported difficulty sealing hole.*

3 *Granite reported at 15 feet, but no core was recovered 15 to 15.5, indicating either highly weathered or highly fractured granite 15 to 15.5*

4 *Tailings reported from 0.3 to 17 feet. Granite reported "weathered" from 31.5 to 36.5 feet.*

5 *Granite reported at 9.5 feet, but split spoon sampling from 9.5 to 11 feet indicates highly weathered or extremely fractured rock 9.5 to 11 feet*

6 *Clayey sand 2 to 6 feet, silty sand 6 to 16.5 feet, boulder 16.5 to 24 feet, silt 24 to 38 feet. "Highly weathered granite" reported 44 to 47 feet. Drilling log reports competent granite at 47 feet but no core was recovered from 47 to 50 feet indicating this interval is likely an extension of the overlying weathered zone.*

7 *Granite reported at 30 feet but split spoon sampling continued until 35.5 feet indicating either highly weathered or extremely fractured rock from 30 to 35.5 feet*

8 *Drill hole terminated at 27 feet due to "difficult drilling". Interval 17 to 27 feet described as: "Granite, highly weathered bedrock, appears to be silty gravel with up to 1 foot boulders throughout"*

9 *Organic silt reported from 7 to 12 feet, grading upward into peat 0.3 to 7 feet. One to 2 blows per foot from 4 to 11 feet (very soft). Drilling log reports granite at 20.5 feet, but Shelby Tube sample taken 20.5 to 22 feet indicates the interval 20.5 to 22 feet is either highly weathered or extremely fractured.*

10 *Drill hole "abandoned when artesian flow was encountered". "Highly weathered bedrock" reported 29 to 34 feet.*

11 *Tailings reported from 0.5 to 5 feet. Interval 10-25 logged as granite, "highly fractured" at 17.5, 20-22 and 23-23.5. Entire interval from 11 to 25 feet may represent fractured rather than competent bedrock.*

12 *Interval 27 to 42.5 logged as granite. "…appears previously highly fractured but is now fully healed"*

13 *Granite reported at 10 feet, but no core was recovered from 10 to 11.5 feet. This interval is likely highly weathered or extremely fractured.*

TABLE 3. SUMMARY OF HYDROGEOLOGY (ROTASONIC DRILLING)

DRILL HOLE	THICKNESS (ft) Weathered Granite	Fractured Granite	Competent Granite	DEPTH (ft) Competent Granite	Total Depth	Bedrock Core Recovery	Artesian Conditions Present	Post Drilling Water Depth (ft)	Artesian Head[1] (ft)	Well Screened Interval[2] (ft)	Notes
R14-01	***NOT DRILLED - NO REASON GIVEN***										
R14-02	0	0	3.5	7.5	11	72%	**PIEZOMETER NOT INSTALLED**				
R14-03	***NOT DRILLED - NO REASON GIVEN***										
R14-04	1	0	2	13	15	100%	yes	1.1	3.9	5-10	*3*
R14-05	1.5	0	6.5	8.5	15	54%	***PIEZOMETER NOT INSTALLED***				*4*
R14-06	0.5	0	2.5	17.5	20	100%	yes	6.9	5.1	12-17	*5*
R14-07	0	0	6.7	5.3	12	63%	***PIEZOMETER NOT INSTALLED***				
R14-08	0	0	3	21	24	83%	yes	0.6	14.9	15.5-20.5	
R14-09	2	0	4	15	19	67%	***PIEZOMETER NOT INSTALLED***				*6*
R14-10	0	0	8	2	10	89%	***PIEZOMETER NOT INSTALLED***				
R14-10A	0	0	7	14	21	57%	***PIEZOMETER NOT INSTALLED***				
R14-11	0	0	6	10	16	83%	***PIEZOMETER NOT INSTALLED***				
R14-12	0	0	4	31	35	83%	flowing	-0.3	15.3	15-20	
R14-13	0	0	6	39	45	67%	yes	1.9	28.1	30-35	
R14-14	***NOT DRILLED DUE TO OPEN WATER CONDITIONS***										
R14-15	0	0	3	32	35	83%	yes	6.8	19.2	26-31	
R14-16	4.5	0	0	>30	30	23%	yes	16.8	3.2	20-25	*7*
R14-17	***NOT DRILLED DUE TO OPEN WATER CONDITIONS***										
R14-18	***NOT DRILLED DUE TO OPEN WATER CONDITIONS***										
R14-19	***NOT DRILLED DUE TO OPEN WATER CONDITIONS***										
R14-20	4	0	0	>35	35	100%	flowing	-2.9	***PIEZ. NOT INSTALLED***		*8*
R14-21	***NOT DRILLED DUE TO OPEN WATER CONDITIONS***										
R14-22	***NOT DRILLED DUE TO OPEN WATER CONDITIONS***										
R14-23	***NOT DRILLED DUE TO OPEN WATER CONDITIONS***										
R14-24	0	0	8.5	5.5	14	76%	***PIEZOMETER NOT INSTALLED***				
R14-25	0	0	7	3.5	10.5	74%	***PIEZOMETER NOT INSTALLED***				
R14-26	0	0	6.5	21.5	28	100%	yes	1.6	13.4	15-20	
R14-27	0	0	4	26	30	75%	yes	1.7	18.3	20-25	
R14-28	0	0	6	10.5	16.5	100%	yes	4.3	0.7	5-10	
R14-29	0	0	5	29	34	87%	***PIEZOMETER NOT INSTALLED***				
R14-30	0	3	0	>29	29	83%	***PIEZOMETER NOT INSTALLED***				

Source: Piezometer & drilling logs contained in the Geotechnical Report, p. 781-814.

Notes

1. *Artesian head is the distance above the screened interval where static water level is reported.*
2. *All piezometer screened intervals reported within till.*
3. *Reportedly "highly weathered" granite 12 to 13 feet.*
4. *Granite reported "weathered to 8.5 feet".*
5. *Drilling log 17 to 17.5 feet: "weathered granite"*
6. *Drilling log 13 to 15 feet: "weathered granite"*
7. *Drilling log 25.5 to 30 feet: "highly weathered" granite and "poor recovery"*
8. *"Artesian flow of 10-12 gpm started at 31 feet. Static water level was 34-36 inches above ground surface".*

TABLE 4. SUMMARY OF HYDROGEOLOGY (SPT AND CORE DRILLING)

DRILL HOLE	THICKNESS (ft)			DEPTH (ft)		Wt. Ave. RQD[1]	Artesian Conditions Present	Post Drilling Water Depth (ft)	Well Screened Interval[2] (ft)	Packer Testing Interval[3] (ft)			Notes
	Weathered Granite	Fractured Granite	Competent Granite	Competent Granite	Total Depth					1	2	3	
B14-36	0	0	13	13.5	26.5	77	***PIEZOMETER NOT INSTALLED***			14-18.5	20.5-26.5		
B14-40	0.5	0	15	15.5	30.5	69	***PIEZOMETER NOT INSTALLED***			***NO PACKER TESTING***			*4*
B14-44	5	0	9.5	36.5	46	84	***PIEZOMETER NOT INSTALLED***			34-42	42-46		*5*
B14-48	1.5	0	14	11	25	61	***PIEZOMETER NOT INSTALLED***			***NO PACKER TESTING***			*6*
B14-52	6	1.5	15.8	50	65.8	88	***PIEZOMETER NOT INSTALLED***			***NO PACKER TESTING***			*7*
B14-55	5.5	0	15	35.5	50.5	67	***PIEZOMETER NOT INSTALLED***			37-41.5	41.5-46.5	46-50.5	*8*
B14-62	10	0	0	>27	27	22	***PIEZOMETER NOT INSTALLED***			***NO PACKER TESTING***			*9*
B14-65	1.5	0	15	22	37	72	***PIEZOMETER NOT INSTALLED***			24-30	27.5-33.5		*10*
B14-69	5	0	0	>34	34	20	flowing	-1.0	NA	***NO PACKER TESTING***			*11*
B14-72	1	?	?	?	25	56	***PIEZOMETER NOT INSTALLED***			***NO PACKER TESTING***			*12*
B14-76	0	0	15.5	27	42.5	66	***PIEZOMETER NOT INSTALLED***			37-42			*13*
B14-80	1.5	0	9.5	11.5	21	76	***PIEZOMETER NOT INSTALLED***			***NO PACKER TESTING***			*14*

Source: Drilling logs contained in the Geotechnical Report, 832-844 except as noted below.

Notes

1 *PolyMet's RQD data from Table 3-2 within the Geotechnical Report (p. 745-746). Weighted averages reported here.*

2 *No piezometers (wells) were installed in bedrock*

3 *Packer testing intervals from Geotechnical Report, p. 846.*

4 *Granite reported at 15 feet, but no core was recovered 15 to 15.5, indicating either weathered or fractured granite 15 to 15.5.*

5 *Granite reported "weathered" from 31.5 to 36.5 feet.*

6 *Granite reported at 9.5 feet, but split spoon sampling from 9.5 to 11 feet indicates highly weathered or extremely fractured rock 9.5 to 11 feet.*

7 *"Highly weathered" granite reported 44 to 47 feet. Drilling log reports competent granite at 47 feet but no core was recovered from 47 to 50 feet indicating this interval is likely an extension of the overlying weathered zone.*

8 *Granite reported at 30 feet but split spoon sampling continued until 35.5 feet indicating either highly weathered or extremely fractured rock from 30 to 35.5 feet.*

9 *Drill hole terminated at 27 feet due to "difficult drilling". Interval 17 to 27 feet described as: "Granite, highly weathered bedrock, appears to be silty gravel with up to 1 foot boulders throughout."*

10 *Drilling log reports granite at 20.5 feet, but Shelby Tube sampling taken 20.5 to 22 feet indicates the interval 20.5 to 22 feet is either highly weathered or extremely fractured.*

11 *"Highly weathered bedrock" reported from 29 to 34 feet. Artesian flow started at 23' during drilling. No piezometer installed.*

12 *Interval 10-25 logged as granite, "highly fractured" at 17.5, 20-22 and 23-23.5. Entire interval from 11 to 25 feet may represent fractured rather than competent bedrock.*

13 *Interval 27 to 42.5 feet logged as granite…"appears previously highly fractured but is now fully healed".*

14 *Granite reported at 10 feet, but no core was recovered from 10 to 11.5 feet. This interval is likely highly weathered or extremely fractured.*

TABLE 5. SUMMARY OF AVAILABLE RQD RESULTS FOR FTB SITE (PART 1)

Drill Hole	Interval From (ft)	Interval To (ft)	Reported RQD	Adjusted RQD	Notes
B14-36	13.5	17.5	77	77	
	17.5	21.5	48	48	
	21.5	26.5	100	100	
Overall Average RQD			**77**	**77**	
Average RQD Below 10'			**100**	**100**	*Only 3 feet thick*
B14-40	15	15.5	missing	0	*Granite reported at 15 feet. No recovery from 15 to 15.5 feet. RQD should be zero.*
	15.5	20.5	68	68	
	20.5	25.5	47	47	
	25.5	30.5	92	92	
Overall Average RQD			**69**	**67**	
Average RQD Below 10'			**92**	**92**	
B14-44	31.5	37	33	0	*Granite reported at 31.5 feet. Interval 31.5 to 36.5 feet is "weathered". RQD should be zero.*
	37	42	77	77	
	42	46	92	92	
Overall Average RQD			**84**	**52**	
Average RQD Below 10'			**?**	**?**	
B14-48	9.5	11	missing	0	*Granite reported at 9.5 feet. Split spoon sampling from 9.5 to 11 feet, indicates highly weathered rock. RQD should be zero.*
	11	15	15	15	
	15	20	72	72	
	20	25	88	88	
Overall Average RQD			**61**	**55**	
Average RQD Below 10'			**88**	**88**	
B14-52	42.5	44	100	100	
	44	47	100	0	*44 to 47 "highly weathered" No recovery 47 to 50 feet. RQD should be zero.*
	47	50	missing	0	
	50	55	86	86	
	55	59	84	84	
	59	61.5	90	90	
	61.5	63.5	missing	0	*No recovery 61.5 to 63.5 feet. RQD should be zero.*
	63.5	65.8	75	75	
Overall Average RQD			**88**	**56**	
Average RQD Below 10'			**84**	**53**	
B14-55	30	35.5	missing	0	*Granite reported at 30 feet. Split spoon sampling apparently continued to 35.5 feet indicating highly weathered or fractured rock 30 to 35.5. RQD should be zero.*
	35.5	39	33	33	
	39	44	63	63	
	44	47.5	85	85	
	47.5	50.5	91	91	
Overall Average RQD			**67**	**49**	
Average RQD Below 10'			**89**	**89**	

Source: RQD values and intervals from Table 3-2 in the Geotechnical Report. Notes from drilling logs
The averages reported here represent weighted averages and were calculated for this report

TABLE 6. SUMMARY OF AVAILABLE RQD RESULTS FOR FTB SITE (PART 2)

Drill Hole	Interval From (ft)	Interval To (ft)	Reported RQD	Adjusted RQD	Notes
B14-62	17	20	53	0	*Interval 17 to 27 feet is "highly weathered bedrock; appears to be silty gravel with up to 1 foot boulders throughout". RQD should be zero.*
	20	25	13	0	
	25	27	0	0	
Overall Average RQD			**22**	**0**	
Average RQD Below 10'			**?**	**?**	
B14-65	20.5	22	missing	0	*Granite reported at 20.5 feet. Shelby tube sample taken 20.5 to 22 feet, indicating highly weathered or fractured rock. RQD should be zero.*
	22	27	86	86	
	27	32	80	80	
	32	37	51	51	
Overall Average RQD			**72**	**66**	
Average RQD Below 10'			**51**	**51**	
B14-69	29	34	20	0	*"Highly weathered bedrock" from 29 to 34 feet. RQD should be zero.*
Overall Average RQD			20	0	
Average RQD Below 10'			**?**	**?**	
B14-72	10	11	missing	0	*Granite reported at 10 feet. Combination of split spoon sampling and no recovery 10 to 11 feet. RQD should be zero.*
	11	16	63	63	
	16	21	50	50	
	21	25	56	56	
Overall Average RQD			**56**	**53**	
Average RQD Below 10'			**56**	**56**	
B14-76	27	30	53	53	
	30	35	87	87	
	35	40	53	53	
	40	42.5	63	63	
Overall Average RQD			**66**	**66**	
Average RQD Below 10'			**58**	**58**	
B14-80	10	11.5	missing	0	*Granite reported at 10 feet. No recovery 10 to 11.5. RQD should be zero.*
	11.5	16.5	67.5	67.5	
	16.5	19.5	79	79	
	19.5	21	100	100	
Overall Average RQD			**76**	**66**	
Average RQD Below 10'			**?**	**?**	

Source: RQD values and intervals from Table 3-2 in the Geotechnical Report. Notes from drilling logs
Averages reported here represent weighted averages and were calculated for this report

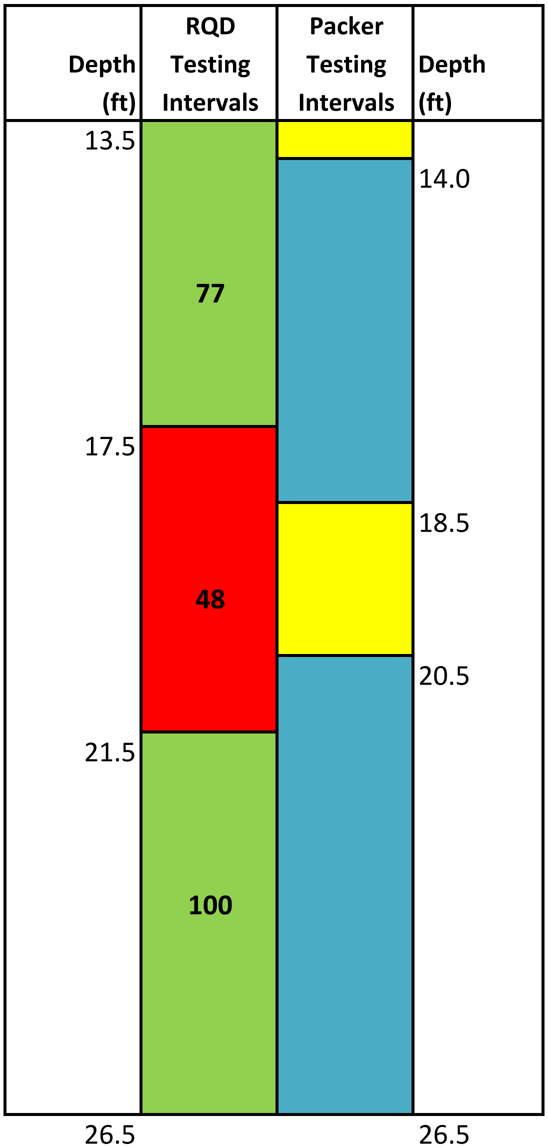
NOTE: Unweathered bedrock was sampled by diamond core drilling. Split spoon and Shelby tube sampling cannot penetrate competent granite. Therefore intervals sampled that way are either highly weathered or extremely fractured.

RQD results for 10 of the 12 holes drilled into bedrock were adjusted because either no core was recovered or because weathered rock was counted as sound for certain intervals highlighted in PINK.

From: Appendix B - Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls (J.D. Lehr, January, 2022)

TABLE 7. PACKER TESTING INTERVALS AND RQD

Drill Hole B14-36



RQD TESTING INTERVALS		POLYMET'S REPORTED RQD	PACKER TESTING INTERVALS	
From (ft)	To (ft)		From (ft)	To (ft)
13.5	17.5	77	14	18.5
17.5	21.5	48	18.5	20.5
21.5	26.5	100	20.5	26.5

GRANITE REPORTED AT 13.5 FEET

Green	WHERE RQD >/=63 (fewer fractures)
Red	WHERE RQD <63 (more fractures)

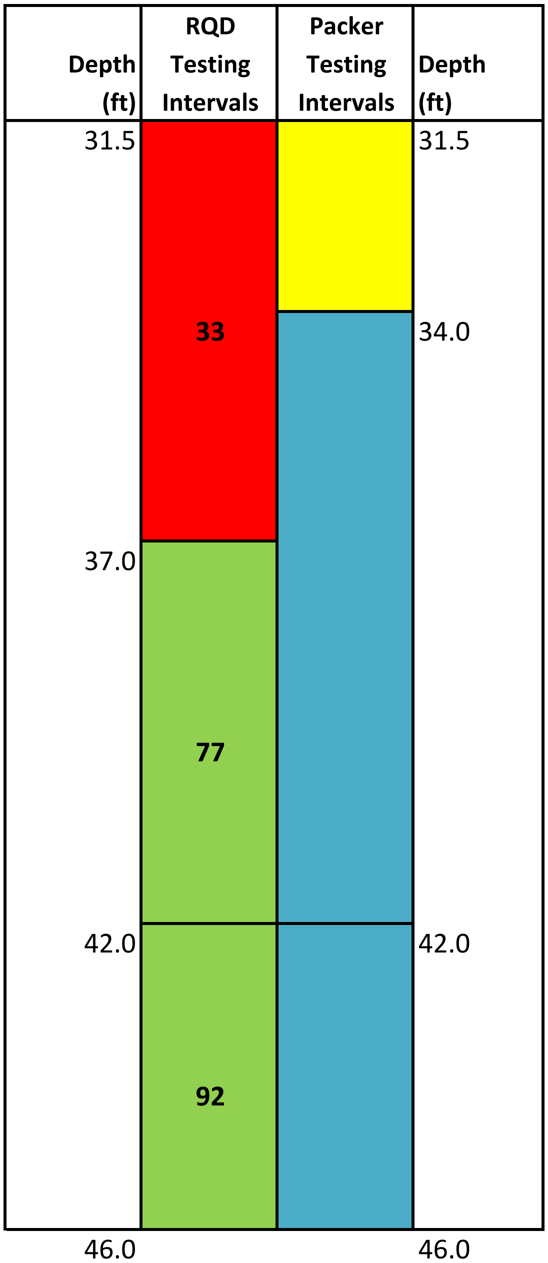
Blue	PACKER TESTING CONDUCTED
Yellow	EXCLUDED FROM PACKER TESTING

Source: Table 3-2 in the Geotechnical Report (p. 745-746) and Exhibit E: Packer Testing Results (Geotechnical Report, p. 845)

From: Appendix B - Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls (J.D. Lehr, January, 2022)

TABLE 8. PACKER TESTING INTERVALS AND RQD

Drill Hole B14-44



RQD TESTING INTERVALS		POLYMET'S REPORTED RQD	PACKER TESTING INTERVALS	
From (ft)	To (ft)		From (ft)	To (ft)
31.5	37	33	31.5	34
37	42	77	34	42
42	46	92	42	46

WEATHERED GRANITE REPORTED AT 31.5 FEET

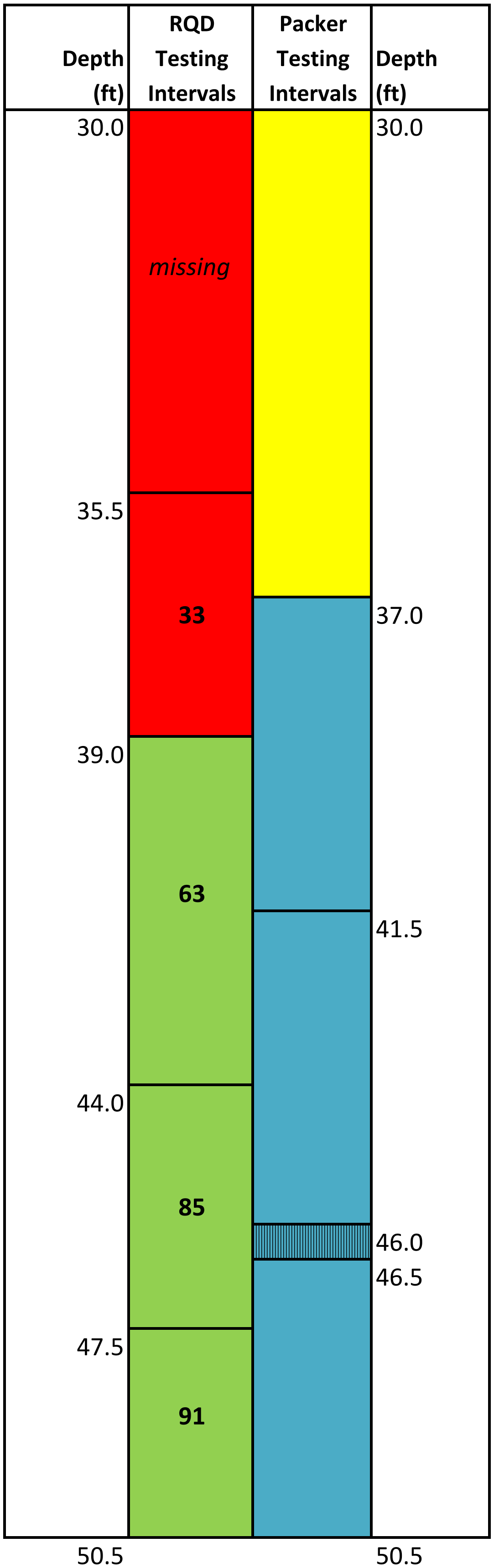
Green	WHERE RQD >/=63 (fewer fractures)
Red	WHERE RQD <63 (more fractures)

Blue	PACKER TESTING CONDUCTED
Yellow	EXCLUDED FROM PACKER TESTING

Source: Table 3-2 in the Geotechnical Report (p. 745-746) and Exhibit E: Packer Testing Results (Geotechnical Report, p. 845)

TABLE 9. PACKER TESTING INTERVALS AND RQD

Drill Hole B14-55



RQD TESTING INTERVALS		POLYMET'S REPORTED RQD	PACKER TESTING INTERVALS	
From (ft)	To (ft)		From (ft)	To (ft)
30.0	35.5	*missing*	30.0	35.5
35.5	39	33	35.5	37
39	44	63	37	41.5
44	47.5	85	41.5	46.5
47.5	50.5	91	46	50.5

GRANITE REPORTED AT 30 FEET

Apparently split spoon sampling continued from 30 to 35.5 feet, indicating either highly weathered or extremely fractured granite from 30 to 35.5 feet.

WHERE RQD >/=63 (fewer fractures)
WHERE RQD <63 (more fractures)

PACKER TESTING CONDUCTED
EXCLUDED FROM PACKER TESTING

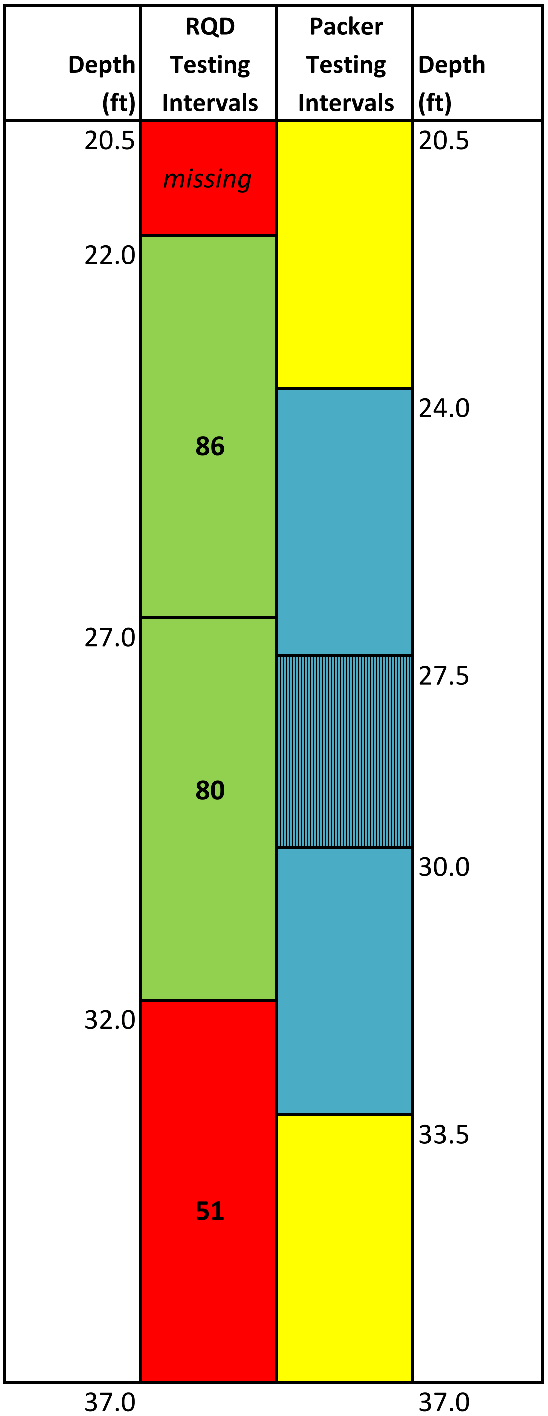
INTERVALS WHERE PACKER TESTS OVERLAP

Source: Table 3-2 in the Geotechnical Report (p. 745-746) and Exhibit E: Packer Testing Results (Geotechnical Report, p. 845)

From: Appendix B - Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls (J.D. Lehr, January, 2022)

TABLE 10. PACKER TESTING INTERVALS AND RQD

Drill Hole B14-65



RQD TESTING INTERVALS		POLYMET'S REPORTED RQD	PACKER TESTING INTERVALS	
From (ft)	To (ft)		From (ft)	To (ft)
20.5	22.0	*missing*	20.5	24.0
22	27	86	24	30
27	32	80	27.5	33.5
32	37	51	33.5	37

GRANITE REPORTED AT 20.5 FEET

Shelby tube sample taken from 20.5 to 22 feet indicates either highly weathered or extremely fractured granite 20.5 to 22 feet.

(green)	WHERE RQD >/=63 (fewer fractures)
(red)	WHERE RQD <63 (more fractures)

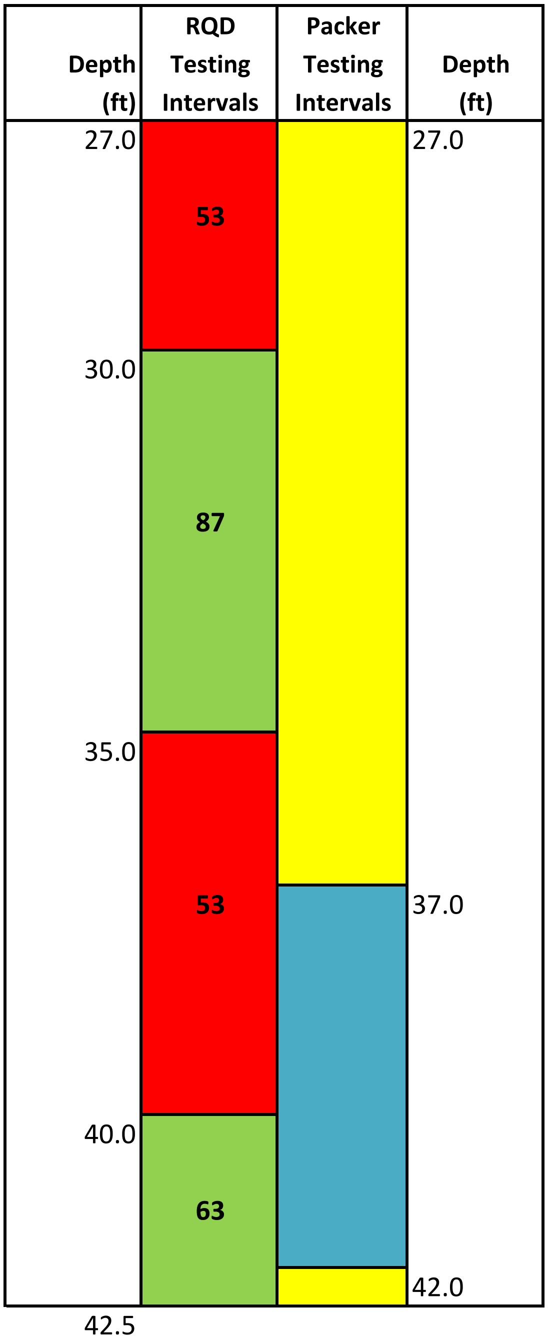
(blue)	PACKER TESTING CONDUCTED
(yellow)	EXCLUDED FROM PACKER TESTING

(hatched)	INTERVALS WHERE PACKER TESTS OVERLAP

Source: Table 3-2 in the Geotechnical Report (p. 745-746) and Exhibit E: Packer Testing Results (Geotechnical Report, p. 845)

TABLE 11. PACKER TESTING INTERVALS AND RQD

Drill Hole B14-76



RQD TESTING INTERVALS		POLYMET'S REPORTED RQD	PACKER TESTING INTERVALS	
From (ft)	To (ft)		From (ft)	To (ft)
27	30	53	27	30
30	35	87	30	35
35	40	53	35	37
40	42.5	63	37	42

GRANITE REPORTED AT 27 FEET

Green	WHERE RQD >/=63 (fewer fractures)
Red	WHERE RQD <63 (more fractures)

Blue	PACKER TESTING CONDUCTED
Yellow	EXCLUDED FROM PACKER TESTING

Source: Table 3-2 in the Geotechnical Report (p. 745-746) and Exhibit E: Packer Testing Results (Geotechnical Report, p. 845)

From: Appendix B - Report on PolyMet Tailings Basin Geology and Proposed Engineering Controls (J.D. Lehr, January, 2022)

CURRICULUM VITAE

J.D. Lehr
Professional Geologist
P.O. Box 217
Lutsen, Minnesota 55612

EXPERIENCE

2004 to Present - J.D. Lehr, PA (President)
J.D. Lehr provides independent geological consulting and expert witness services including identification, characterization and quantification of construction aggregate resources and research, mapping and database services to assist clients in the areas of strategic business planning, mineral resource acquisition and valuation, mine planning, permitting and environmental review.

1997 to 2004 - Aggregate Industries, Inc. (Regional Geologist, Senior Geologist)
Managed the company's aggregate reserves exploration and evaluation program both for secured properties and potential acquisition properties. Provided geologic, GIS and GPS expertise for mine planning, mine permitting, environmental review for mining projects, strategic business planning, mine operations, sales and marketing and aggregate quality control. Geographic scope of projects was primarily Minnesota, Wisconsin and Michigan, but also included Iowa, North Dakota, Indiana, Illinois and Colorado.

1988 to 1997 - Minnesota Department of Natural Resources (Research Scientist 2 - Surficial Geology)
Managed and conducted the Minerals Division's program to map surficial geology and construction aggregate resource potential of certain Minnesota counties. Evaluated aggregate resource potential of state lands and county tax-forfeited lands proposed for sale or exchange and contributed expertise in the areas of aggregate resources, other industrial minerals, glacial geology and remote sensing to other units within the Department of Natural Resources.

1986 to 1988 - South Dakota Geological Survey (Geologist 1, Geologist 2)
Managed and conducted county geologic studies of glacial sediments and bedrock in support of U.S. Geological Survey county hydrologic studies. Tasks included geologic mapping of glacial sediments and bedrock, extensive drilling, borehole geophysical logging, and preparation of drilling logs, geologic cross-sections and geologic maps.

1984 to 1986 - University of Minnesota – Duluth (Teaching Assistant, Research Assistant)
Taught undergraduate geology laboratory classes. Prepared rock samples and thin sections for faculty research projects.

EDUCATION

Master of Science Degree - Geology - University of Minnesota (2000)
Graduate studies in geology - University of Minnesota, Duluth (1984-1986)
Graduate studies in geology - University of Iowa (1983-1984)
Bachelor of Science Degree - Soils, Earth Science Option - North Dakota State University (1982)
Undergraduate studies in geology - North Dakota State University (1979-1982)
Undergraduate studies in liberal arts - Concordia College, Moorhead (1977-1979)

LICENSES AND CERTIFICATIONS

Licensed Professional Geologist No. 30063, Minnesota
Certified Professional Geologist No. 10267, American Institute of Professional Geologists

OTHER PROFESSIONAL ACTIVITIES

Mapping of surficial geology in northern Minnesota (2011-Present)

Board of Directors at North House Folk School, Grand Marais, Minnesota (2016-2018)

Instructor at North House Folk School, Grand Marais, Minnesota - prepared and taught "The Geology of North Shore Eskers" (2012)

Chair of Minnesota Geological Survey Geologic Mapping Advisory Committee (2006)

Co-organizer of 2005 Minnesota Section of AIPG Fall Geology Field Trip

Co-organizer of Minnesota Aggregate Mining Conferences held in St. Cloud in 2003 and 2005

Invited presentation at U.S. Geological Survey-sponsored workshop on applied Quaternary geology mapping, Bloomington, Indiana (1993)

Organized and led the 1992 Midwest Friends of the Pleistocene Field Conference in northeastern Minnesota.

Organized 1991 a regional Workshop on Midwestern Quaternary geology mapping techniques

PUBLICATIONS

Lehr, J.D., 2000, The Pleistocene geology of the Embarrass area, St. Louis County, Minnesota: Minneapolis, University of Minnesota, 157 p., map scale 1:48,000.

Mooers, H.D., Ojakangas, R.W., Donaldson, J.A., Prest, V., and **Lehr, J.D.**, 1999, On the dispersal of Belcher Island erratics into the western Lake Superior region: *Geological Society of America Abstracts with Program.*

Mooers, H.D., and **Lehr, J.D.**, 1998, Terrestrial record of Laurentide Ice Sheet reorganization during Heinrich events, Comments and Reply: *Geology*, v. 26, no. 7, p. 666-669.

Lehr, J.D., 1997. Aggregate resource potential of eastern Clay County, Minnesota: Minnesota Department of Natural Resources, Division of Minerals Report 306, 4 Plates, map scale 1:50,000.

Mooers, H.D., and **Lehr, J.D.**, 1997, Terrestrial record of Laurentide Ice Sheet reorganization during Heinrich events: *Geology*, v. 25, no. 11, p. 987-990.

Nelson-Russell, S.L., Theobald, P.K., **Lehr, J.D.**, Johnson, R.L., Ryder, J.L., and Lawler, T.L., 1997, An interpretation of the results of a study of heavy minerals in Minnesota northeastern-provenance glaciofluvial sediments: Minnesota Department of Natural Resources, Division of Minerals Report 284-1, 110 p.

Mooers, H.D., and **Lehr, J.D.**, 1996, A terrestrial record of binge/purge oscillations and shifting ice divides of the late Wisconsinan Laurentide Ice Sheet: *Geological Society of America Abstracts with Programs*, v. 28.

Nelson, S.L., Lawler, T.L., **Lehr, J.D.**, Theobald, P.K., Ryder, J.L., Sutley, S., and Tripp, R., 1994, Heavy minerals from glaciofluvial sediments in Minnesota: Institute on Lake Superior Geology, 40th Annual Meeting, Proceedings, Part 1, Program and Abstracts, v. 40, p. 48-49.

Lehr, J.D., 1993, Minnesota's aggregate mapping program: *Applied Quaternary Research: Canadian Quaternary Association Program with Abstracts and Field Guide*, p. A28.

Lehr, J.D., 1993, Sand and gravel resources, in A compendium of mineral resource information, east-central Minnesota: Minnesota Department of Natural Resources, Division of Minerals Report 313, p. 15-19.

Meyer, G.N., Patterson, C.J., Hobbs, H.C., and **Lehr, J.D.**, 1993, Surficial geology, in Meyer, G.N., and Falteisek, J., eds., Regional Hydrologic Assessment - Anoka, Chisago, Isanti, and Sherburne Counties, Minnesota: Minnesota Department of Natural Resources, Division of Waters RHA-1, map scale 1:200,000.

Lehr, J.D., 1992, Aggregate resources and Quaternary geology of Isanti County, Minnesota: Minnesota Department of Natural Resources, Division of Minerals, map scale 1:100,000.

Lehr, J.D., 1992, Minnesota's aggregate mapping program, in Sidder, G.B., Sims, P.K., Chadima, S., and Biek, R.F., eds., Industrial Minerals - Today and Tomorrow: The Raw Materials to Build the Upper Midwest: U.S. Geological Survey Open-File Report 92-514, p. 31-32.

Lehr, J.D., and Hobbs, H.C., 1992, Field trip guidebook for the glacial geology of the Laurentian divide area, St. Louis and Lake Counties, Minnesota: Minnesota Geological Survey Guidebook Series No. 18, 73 p., map scale 1:250,000.

Lehr, J.D., 1991, Aggregate resources and Quaternary geology of Wright County, Minnesota: Minnesota Department of Natural Resources, Division of Minerals Report 294, 18 p. text, map scale 1:100,000.

Mooers, H.D., **Lehr, J.D.**, Hobbs, H.C., and Gilbertson, J.P., 1991, Correlation of late Wisconsin ice margins in Minnesota: *Geological Society of America, Abstracts with Programs*, v. 23, no.3, p. 50.

Gilbertson, J.P., and **Lehr, J.D.**, 1989, Quaternary stratigraphy of northeastern South Dakota, in Gilbertson, J.P., ed., Quaternary geology of northeastern South Dakota: South Dakota Geological Survey Guidebook No. 3, p. 1-13.

Lehr, J.D., and Gilbertson, J.P., 1988, Revised Pleistocene stratigraphy of the upper Big Sioux River basin, northeastern South Dakota: *American Quaternary Association Program and Abstracts*, v. 10, p. 130.

Gilbertson, J.P., and **Lehr, J.D.**, 1988, Summary of radiocarbon ages in eastern South Dakota: *American Quaternary Association Program and Abstracts*, v. 10, p. 71.

Lehr, J.D., and Matsch, C.L., 1987, The late Wisconsin Vermilion moraine in northeastern Minnesota: An ice-marginal complex of multiple origin: *Geological Society of America Abstracts with Programs*, v. 19, p. 231.

Gilbertson, J.P., Duchossois, G.E., Hammond, R.H., **Lehr, J.D.**, and Tomhave, D.W., 1987, Pleistocene geology of eastern South Dakota, U.S.A.: *International Union for Quaternary Research XII International Congress, Program with Abstracts*, p. 173.