Hatch Mott
MacDonald

TRANSMOUNTAIN

TRANS MOUNTAIN EXPANSION PROJECT

Burnaby Mountain Tunnel and Trenchless
Feasibility Report

Prepared for:

Trans Mountain
Suite 2700, 300 – 5 Avenue SW
Calgary, AB T2P 5J2

Hatch Mott MacDonald Ltd.
Suite 1000 – 1066 West Hastings Street
Vancouver, BC V6E 3X2
T 604.629.1736 – F 604.639.1191
www.hatchmott.com

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Primary Contact

Daniel Jezek, P. Eng.
Senior Project Engineer
1066 West Hastings Street, Suite 1000
Vancouver BC V6E 3X2
T 604.637.4549
F 604.639.1191
daniel.jezek@hatchmott.com

Engineer of Record

Professional Engineer
Province of British Columbia
D. JEZEK
32281

Daniel Jezek
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1 INTRODUCTION

Hatch Mott MacDonald (HMM) has been retained by Trans Mountain Pipeline ULC (Trans Mountain) to undertake the routing and engineering design for the portion of the Trans Mountain Expansion Project (TMEP) from Chilliwack, BC to the Westridge Marine Terminal in Burnaby, BC. As part of this work, HMM has completed a feasibility study to evaluate the trenchless crossing between the Burnaby Terminal (Burnaby) and the Westridge Marine Terminal (Westridge) under Burnaby Mountain including options with intermediate staging at the Kask Bros. property (Kask).

The purpose of this report is to provide an evaluation of the feasibility of a tunnel and other trenchless construction methods for this part of the alignment, based on the alignment criteria, and geotechnical and geophysical site investigations completed to date. The conclusions and recommendations based on this evaluation can be found in Section 9 of this report.

2 AVAILABLE INFORMATION

2.1 SITE VISIT

Site visits were completed at Burnaby Mountain by HMM and BGC Engineering Inc. (BGC) to gather geological information from the surface, and to obtain specific information needed to evaluate constructability, and site area limitations. Figures 2-1, 2-2, and 2-3 show the likely pipeline entrance and exit areas within the terminals, and the intermediate staging area for the tunnel and trenchless crossings.

FIGURE 2-1 BURNABY TERMINAL

FIGURE 2-2 WESTRIDGE MARINE TERMINAL

2014/06/06

FIGURE 2-3 KASK BROS. PROPERTY

2.2 GEOTECHNICAL/GEOPHYSICAL SITE INVESTIGATION

As part of the feasibility assessment for Burnaby Mountain, BGC has completed a geotechnical and geophysical investigation of the area, the findings of which are briefly summarized below, and are detailed in their 2014 Site Investigation Data Report.

At the time of issue of this report, a total of three geotechnical boreholes were drilled including one borehole located at Burnaby (HMM-BH-03), one hole within the Burnaby Mountain Conservation Area (HMM-BH-02) and one at Kask (HMM-BH-05). Drilling at the other geotechnical borehole within the Burnaby Mountain Conservation Area (HMM-BH-01) is nearing drilling completion. The available borehole logs are presented in Appendix A. A geophysical investigation at Burnaby was also completed and the results of the investigation are presented in Appendix B. A geophysical investigation at Westridge is currently underway.

Borehole HMM-BH-03 at Burnaby was completed to the target depth of 182 m below the ground surface. The rock encountered in HMM-BH-03 is comprised of sedimentary bedrock including conglomerate, sandstone, and siltstone. The conglomerate is poorly lithified in places and disintegrates with handling.

Borehole HMM-BH-05 at Kask was completed to the target depth of 44 m below the ground surface. The rock encountered in HMM-BH-05 is comprised of sedimentary bedrock including conglomerate and sandstone. The soil cover was approximately 5 m thick. Very poor quality, highly to completely weathered conglomerate was encountered from 5 m to 31.5 m below the ground surface. For most of the borehole, the conglomerate matrix was extremely weak to very weak and highly weathered, and typically could not be recovered by the coring process. Fresh to slightly weathered sandstone with higher recovery was encountered below 31.5 m.

Difficult drilling conditions including lost circulation and high wear rate on the casing shoe were experienced in the highly weathered conglomerate in HMM-BH-05. Drilling had to be advanced through casing to approximately 15 m below ground surface.

The data collected from HMM-BH-03 and HMM-BH-05 suggests that the mountain consists of a vertical strata of sandstone and conglomerate with minor mudstone. The preliminary data collected from the core that has been inspected at the time of this report from HMM-BH-01 and HMM-BH-02 supports the interpretation of the bedrock geology within the project area, and the geology appears to be consistent between the Burnaby Terminal and the north side of Burnaby Mountain, between boreholes HMM-BH-03 and HMM-BH-05.

The engineering feasibility studies conducted based on the available borehole information, geophysical data, and report produced by BGC suggest the following:

- A tunnel is feasible for the crossing of Burnaby Mountain. The data being collected from boreholes HMM-BH-01 and HMM-BH-02 will be used to characterize typical rockmass conditions along the tunnel alignment, and to refine detailed tunnel design and tunnelling methodology.
- The feasibility of a HDD construction method is questionable. The HDD installations would carry significant constructability risk due to the unknown extent of the weathered conglomerate encountered in borehole HMM-BH-05 at Kask and a limited understanding of the groundwater regime along the deeper portion of the alignment.

3 REVIEW OF AVAILABLE CONSTRUCTION METHODOLOGIES

A number of construction methods for crossing under Burnaby Mountain were considered.

3.1 HORIZONTAL DIRECTIONAL DRILL (HDD)

This method involves setting up an HDD rig to drill a pilot hole with subsequent reaming and swabbing passes to enlarge the hole to the final hole diameter (typically 12 inches greater than the pipe diameter). A drill and intersect method utilizes two drill rigs (one on either side of a crossing), which each drill a pilot hole towards each other. The pilot holes intersect midway along the alignment. This method is typically used for longer crossings and has been

proven for lengths up to 4,000 m for NPS 30 pipe, however, is limited in loose materials such as sands and gravels.

3.2 TUNNEL

For crossings of this length, tunnelling is a commonly accepted construction method. This method can involve the use of mechanized methods or conventional tunnelling. Mechanized methods can include the use of a tunnel boring machine (TBM) or other mechanized equipment with teeth, picks, or discs such as a roadheader. Conventional tunnelling is defined as the construction using cyclical processes, such as drill-and-blast. Tunnel size and alignment are flexible and can be adapted for installing pipes in tunnels. Tunnelling has been proven for lengths over 50 km.

3.3 DIRECT PIPE®

The Direct Pipe® method has been developed by Herrenknecht AG, and combines the advantages of the established microtunnelling method and Horizontal Directional Drilling technology. The pipeline, which is laid out on the surface on rollers and welded to the end of the microtunnelling machine, is pushed into the borehole at the same time as excavation takes place. The necessary thrust force is provided by a pipe thruster, which pushes the microtunnelling machine forward together with the pipeline. Direct Pipe® is limited in the length of installations that can be achieved; lengths of approximately 300 m, up to 800 m can be achieved depending on ground conditions and installation diameter.

4 CONSTRUCTION OPTIONS

The preliminary construction options for Burnaby Mountain that have been developed for construction cost and schedule estimating purposes and assessed for feasibility are summarized in Table 4-1.

TABLE 4-1 SUMMARY OF CONSTRUCTION OPTIONS

Option	Construction Method	Alignment			
		Description	From	To	Length (m)
1	HDD	Two drill & intersect HDD installations	Burnaby	Kask	2,197 2,200
	Direct Pipe®	Two Direct Pipe® installations	Kask	Westridge	414 418
2A	Shield TBM	One curved tunnel	Burnaby	Westridge	2,584
2B	Shield TBM	One straight tunnel	Burnaby	Kask	2,151
	Direct Pipe®	Two Direct Pipe® installations	Kask	Westridge	414 418

5 OPTION 1: HORIZONTAL DIRECTION DRILL AND DIRECT PIPE® DESIGN

5.1 HDD ALIGNMENT CRITERIA

The governing alignment criterion is to stay within the existing pipeline study corridor (Version 10), which has not changed since NEB IR No. 1.40b (Filing ID A3W9H8). Construction by HDD is considered between Burnaby and Kask. In general, the proposed HDD alignments were developed based on the following criteria: curvature, entry and exit angles, depth of cover, and bore separation.

5.1.1 Curvature

HDD industry standard geometrical criterion for a minimum curvature of the product pipeline (1200 times the outside diameter) is adopted for determining a minimum curvature, assuming the pipeline is fully fabricated on the surface. As such, the minimum design radius is approximately 900 m for the NPS 30 product pipeline. Compound curvatures (i.e. vertical and horizontal curves at any location of the alignment) are not a standard industry practice.

5.1.2 Entry and Exit Angles

The available area for pipeline fabrication dictates the locations of the HDD entry and exit locations. HDD operations are typically designed with entry angles between 8° and 16°; although steeper entry angles have been used where insufficient setback distance or steeply sloping ground exists for a given alignment. Exit angles are typically lower than a given entry angle due to pipe installation requirements, as consideration must be given to product pipe diameter, equipment necessary to transition the product pipe into the bore, and the induced stresses as the pipe is forced to conform to the alignment geometry.

For the Burnaby Mountain HDD crossings, the entry (Kask) and exit (Burnaby) angles in the proposed alignments are approximately 10° and 14˚ respectively, relative to the horizontal. These bore angles have been selected to achieve a sufficient depth of cover and to reduce the length of unsupported bore, while maintaining allowable pipe stress during installation of the product pipe during pullback operations.

5.1.3 Depth of Cover

The depth of cover for a given HDD installation is dependent on several factors. These include the anticipated geotechnical materials, presence of preferential flow pathways, design bending radius, presence of existing utilities and/or structures, and installation length. The most important factor in determining the appropriate depth of cover for a given HDD installation is the material properties of the overlying geotechnical material and the resistance that it provides against the required installation induced bore fluid pressures necessary to remove the cuttings. Another important factor in establishing the proper installation depth is the ability to maintain bore stability over the course of the installation. This is generally accomplished by placing the HDD bore through geotechnical materials that are favourable to HDD operations.

5.1.4 Bore Separation – Parallel HDD Installations

Parallel HDD installations need to be separated sufficiently to avoid intersection of each individual pilot bore. A separation distance of 10 to 20 m is typical for parallel HDD installations, depending on the ability of the tracking system used to complete the pilot bore drilling. This distance can be provided in both the vertical and horizontal planes to maintain a smaller width permanent easement.

5.2 HDD BORE DIAMETER

The final diameter of the HDD bore must be greater than the outside diameter of the product pipe to facilitate the flow of drilling fluids around the product pipe, to reduce the frictional force acting on the product pipe as it is installed, and to help the product pipe negotiate curves in the alignment. The acceptable HDD industry standard for the final bore diameter is generally 1.5 times larger than the outer diameter of the product pipe for pipe diameters up to 500 mm, and 300 mm larger than the outer diameter of the product pipe for diameters greater than 500 mm. These guidelines may need to be adjusted based on the anticipated geotechnical conditions and required bore geometry.

It is highly recommended that the final bore diameter is selected by the contractor based on their experiences with similar geotechnical materials, pipe diameters, and installation lengths that will suit their means and methods.

5.3 HDD STAGING AREAS

The drill entry location must accommodate the drill rig and supporting equipment and requires satisfactory access, as well as stable ground conditions to support heavy equipment. Equipment typically found on the drill rig side of an HDD includes: the rig unit; power unit and generators, drill pipe rack and drill pipe; drill mud supply and mud mixing tanks and mud handling and cleaning system. Typically a 60 m x 60 m workspace is adequate for large drilling rigs. Additional workspace may be required for spoil handling.

The drill exit side is the location for the fabrication of the pipe string as well as where the pipe string is inserted into the drill hole, the workspace required is typically longer to accommodate the pipe string. Equipment typically found on the exit or pipe string side of the HDD includes: exit mud containment tanks/pits; cuttings settlement tanks/pits; pipe racks and product pipe; rollers and pipeline handling equipment; side booms and other heavy equipment; and pipeline welding, coating, and testing equipment.

The drill entry and exit locations must be cleared, levelled and suitable for the work (sites with negligible slopes are preferred); entry and exit locations should be of sufficient size and configuration to undertake the work safely.

Due to utilization of the drill and intersect method, drill rigs at both sides of the crossing are required. See Appendix D for HDD staging areas.

5.4 HDD FROM BURNABY TO KASK

Sketches M002-XD20025 and M002-XD20026 in Appendix C show a conceptual HDD plan and profile for this alignment.

The two HDD installations are approximately 2,200 m long with a straight horizontal alignment. The entry angle at the north side (Kask) is 10˚ and the exit angle at the south side (Burnaby) is 14˚. The bore diameter is assumed to be approximately 42 inches and a bore separation of between 10 m to 20 m is assumed.

An elevation difference of approximately 100 m exists between the HDD entry and exit locations, which may pose construction challenges.

Based on the assumed geological conditions, the proposed HDD installations are situated primarily in bedrock; overburden (5 m to 10 m thick) is expected at each end of the installations which will be removed as part of each entry/exit pit construction.

The HDD staging areas will be entirely within the Trans Mountain and Kask Bros. properties. No construction disturbance outside of these staging areas is currently envisioned.

5.4.1 Preliminary Hydraulic Fracture Evaluation

The hydraulic fracture evaluation for the proposed HDD installations have been completed in general accordance with the Delft Geotechnics Method outlined in Appendix F of the Army Corps of Engineers 1998 Report CPAR-GL-98 (Installation of Pipelines Beneath Levees Using Horizontal Directional Drilling) by Staheli, et. al. This method is used to estimate the maximum effective pressure (i.e. drilling fluid pressure) that can be induced during an HDD operation within a particular ground horizon. This pressure is then compared with the fluid pressure required to induce slurry flow within the HDD bore to determine the potential for a hydraulic fracture for a given HDD alignment. The required fluid pressure for an HDD installation is governed by the drilling fluid weight (commonly referred to as the mudweight), installation length and depth, and drilling fluid flow properties (plastic viscosity, yield point, etc.).

The hydraulic fracture evaluation method described above and used in the HDD industry was developed for soil installations. Currently, no accepted method is available to model/predict the maximum allowable drilling fluid pressure within bedrock materials. While bedrock

tensile strength and unconfined compressive strength evaluations have been used to estimate the allowable drilling fluid pressure within bedrock materials, these methods tend to provide results that are not considered suitably conservative and greatly over-predict the true maximum allowable drilling fluid pressures. These over-predictions are a result of laboratory testing on sound or high quality bedrock samples that are not representative of the strengths of the weaker bedrock materials that contain natural fractures/joints that are washed out or impacted by the geotechnical coring process. Hence, for bedrock hydraulic fracture evaluation, HMM has elected to model sandstone and conglomerate bedrock as medium stiff clay. This conservative approach has been used by HMM on several HDD installations successfully completed in similar bedrock materials. It has also been compared against hydraulic jacking criteria for rock, and has been found to be provide similar values, therefore is deemed acceptable to use for this rock application.

The Delft Geotechnics Method assumes a uniform column of soil above any point of interest along the alignment. Where an increased risk of hydraulic fracture is identified, it does not necessarily mean that a hydraulic fracture will occur. A proper HDD execution plan based on HDD industry standard construction practices can reduce the risk of a hydraulic fracture from occurring.

In order to complete the hydraulic fracture evaluation, it is necessary to make several assumptions relative to the bore diameter, drilling fluid pumping rate, and drilling fluid properties. Parameters used in HMM’s evaluation are provided in Table 5-1. These parameters have been selected based on HMM’s experience in drilling within similar anticipated geotechnical materials.

TABLE 5-1 ASSUMPTIONS USED FOR THE BURNABY MOUNTAIN HYDRAULIC FRACTURE EVALUATION

Evaluation Parameter	Value
Pilot Bore Diameter	311 mm
Drill Pipe Diameter	168 mm
Drilling Fluid Pumping Rate	2.3 m^3/min
Drilling Fluid Weight (Specific Gravity)	1.32 g/cm^3
Yield Point	114.9 $dyne/cm^2$
Plastic Viscosity	16 cP

In addition to the assumptions provided in Table 5-1 (above), assumptions are also required for the anticipated rock or soil formation(s) and their properties including, but not limited to, strength, unit weight, cohesion, friction angle, and shear modulus. These assumptions are provided in Table 5-2. For this evaluation, HMM assumes that the encountered subsurface material will consist of sandstone and conglomerate bedrock. For the following evaluation, individual HDD rigs have been assumed on each side of the crossing, consistent with the use of the drill and intersect method. In addition, undrained, medium stiff clay properties have been assigned to the bedrock materials in order to assess a worst-case scenario.

TABLE 5-2 MATERIAL PROPERTY ASSUMPTIONS FOR THE BEDROCK ANTICIPATED TO BE ENCOUNTERED ALONG THE BURNABY MOUNTAIN HYDRAULIC FRACTURE EVALUATION

Evaluation Parameter	Value
Soil Unit Weight Above / Below Water Table	19.6 kN/m^3 / 21.2 kN /m^3
Effective Cohesion	191.5 kPa
Internal Friction Angle	0°
Young’s Modulus	45,000 kPa
Poisson’s Ratio	0.33

The results of the preliminary hydraulic fracture evaluation are provided in Figure 5-1 for the pilot bore phase of the installation process. As the pilot bore progresses from either side, the required drilling fluid pressure increases. As shown in Figure 5-1, the required bore pressure ($P_{required}$) to facilitate the installation process is well below the allowable bore pressure ($P_{allowable}$) for the installation.

Once the pilot bore is completed, the hydraulic fracture risk associated with the reaming, swab, and pullback phase of the installation typically decreases, assuming the bore is reamed to its full extent and a subsequent swab pass is completed through the bore prior to installing the product pipe. However, it is important to note that although the hydraulic fracture potential is significantly reduced, a hydraulic fracture event may still occur during the reaming pass if the bore becomes plugged or blocked such that the required drilling fluid pressure increases in magnitude to the point where it exceeds the estimated allowable mud pressure for the overlying soils. HDD industry standard construction practices, such as pumping sufficient drilling fluids, maintaining drilling fluid returns, monitoring and maintaining drilling fluid and returning slurry properties, etc., should decrease this potential.

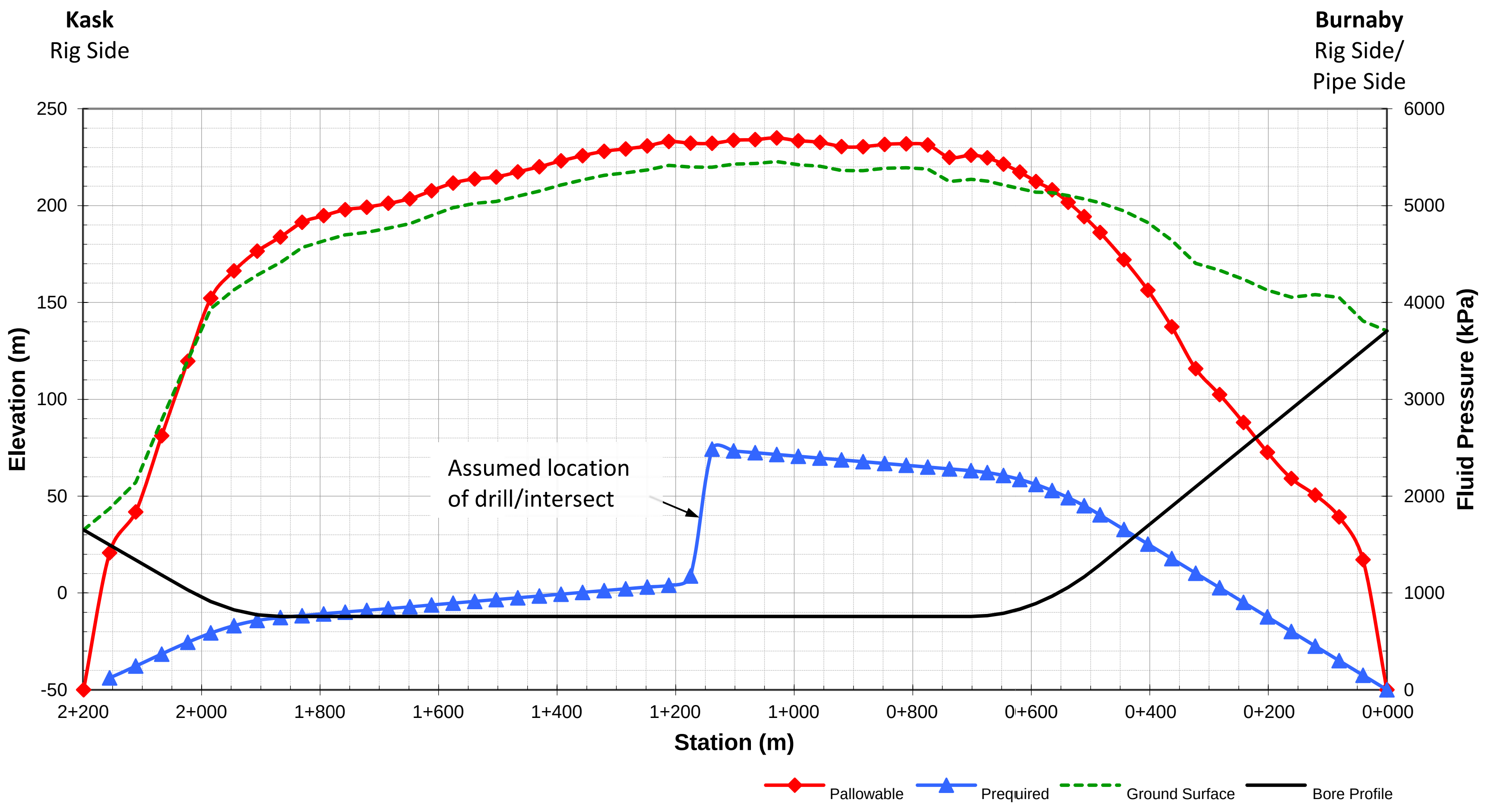


FIGURE 5-1 HYDRAULIC FRACTURE EVALUATION – LIMITING FORMATION PRESSURE FOR BURNABY MOUNTAIN PIPELINE CROSSING

5.4.2 HDD Installation Loads and Operating Stresses Evaluation

Pipe Properties

The pipeline properties used for the evaluation of the Burnaby Mountain HDD crossing have been provided by TransMountain and are summarized in Table 5-3 below.

TABLE 5-3 PIPELINE PROPERTIES AND INPUT PARAMETERS FOR THE HDD EVALUATION

Evaluation Parameter	Value
Pipe Size	NPS 30
Outer Diameter	762 mm
Wall Thickness	15.9 mm
Pipe Grade	Grade 483
Maximum Allowable Operating Pressure	4964 kPa
Minimum Operating Temperature	15°C
Maximum Operating Temperature	50°C
Poisson's Ratio	0.30
Elastic Modulus	207,000 MPa
Coefficient of Thermal Expansion	1.2×10^{-6} 1/^{o}C
Design Factor	0.8
Location Factor	0.625
Temperature Derating Factor	1.0
Joint Factor	1.0

HDD Pullback Loads and Stresses

A total of six (6) pull load evaluations were completed for the proposed bore profile. These calculations are based on a modified version of the installation load calculation method provided in American Society of Civil Engineer MREP 108 (2005) and the Pipeline Research Committee at the American Gas Association publication entitled “Installation of Pipelines by Horizontal Directional Drilling, an Engineering Guide”. The modification includes inclusion of an updated fluidic drag calculation based on observed drilling fluid properties and the anticipated bore diameter.

The pull load evaluation includes assumptions for final bore diameter, soil and pipe roller friction coefficients, drilling fluid yield point and plastic viscosity, drilling fluid pumping rate, and other installation parameters such as buoyancy control measures (i.e., whether or not the pipe will be filled with water during pullback operations). In addition, the evaluation accounts for the capstan effect induced by curves in the alignment, fluidic drag, buoyancy of the pipe string within the bore, and the weight of the tail string at start-up and throughout the installation process.

Six (6) installation evaluations have been completed to investigate the effects of varying mud weights and buoyancy control measures during the installation of the product pipe. A summary of the pull load evaluation for each pull load scenario is provided in Table 5-4. Detailed calculations are provided in Appendix F. The anticipated installation loads shown in Table 5-4 are well below the ultimate allowable load of the steel product pipe of

approximately 14,368 kN (3,229,950 lb), based on a tensile stress equivalent to 80% of the yield stress. It is important to note the difference in pull loads when buoyancy control measures are implemented and water is added to the product pipe during pullback, as the estimated installation loads are much lower when buoyancy control measures are used.

TABLE 5-4 SUMMARY OF ANTICIPATED HDD PULLBACK LOADS

Case #	Drilling Fluid Specific Gravity	Product Pipe Buoyancy Condition	Estimated Pullback Force (kN)	Initial Start-Up Force-String 1 (kN)	Initial Start-Up Force-String 2 (kN)	Initial Start-Up Force-String 3 (kN)
1	1.20	Empty	2,293	1,933	2,239	3,085
2	1.20	Full	995	1,933	955	1,497
3	1.32	Empty	2,687	1,933	2,493	3,523
4	1.32	Full	758	1,933	793	1,150
5	1.44	Empty	3,079	1,933	2,747	3,961
6	1.44	Full	520	1,933	630	803

The results of the installation stress evaluation based on a minimum allowable radius of 900 m are summarized in Table 5-5.

TABLE 5-5 SUMMARY OF HDD INSTALLATION STRESS EVALUATION AT THE DESIGN BENDING RADIUS OF 900 M

Stress Condition	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Maximum Tensile Stress (Percent of Allowable)	61.6 MPa (12.8%)	52.0 MPa (10.8%)	103.7 MPa (21.5%)	52.0 MPa (10.8%)	118.1 MPa (24.5%)	52.0 MPa (10.8%)
Maximum Bending Stress (Percent of Allowable)	88.0 MPa (18.2%)	88.0 MPa (18.2%)	88.0 MPa (18.2%)	88.0 MPa (18.2%)	88.0 MPa (18.2%)	88.0 MPa (18.2%)
Maximum Hoop Stress (Percent of Allowable)	41.6 MPa (8.6%)	41.6 MPa (8.6%)	45.7 MPa (9.5%)	45.7 MPa (9.5%)	49.9 MPa (10.3%)	49.9 MPa (10.3%)
Maximum Unity Check – Tensile and Bending	0.52	0.39	0.55	0.36	0.59	0.33
Maximum Unity Check – Tensile, Bending, and Hoop	0.22	0.12	0.33	0.10	0.40	0.09

Installation and Operating Stress Evaluation

Evaluation of operating loads for pipelines installed by HDD methods is generally similar to the evaluation for pipelines installed by open-cut construction methods. The main difference between the two scenarios is that the condition of elastic bending has to be considered for HDD installations. Elastic bending stresses occur as the product pipe takes on the final shape of the HDD bore. As a rule, the bending stresses induced are not a critical stress condition on its own, but must be considered in a combined loading condition with other stress conditions such as hoop stress and longitudinal stress. The operating stress evaluation has been completed in compliance with the American Society of Mechanical Engineers B31.4 and B31.8 and CSA Z662-11 (Revised August 2013). The input parameters for this analysis are

provided in Table 5-3. The results of the evaluation are provided below in Table 5-6. The bending stress results are based on the minimum allowable bending radius of 610 m to account for bending in excess of the designed curvature discussed in Section 5.1.1. Detailed calculations are provided in Appendix F.

TABLE 5-6 SUMMARY OF HDD OPERATING STRESS EVALUATION

Stress Condition	Estimated Stress (MPa)	Percent of SMYS[1] (%)	Maximum Allowable Percent of SMYS[1] (%)
Longitudinal Bending Stress	129.4	26.8	--
Hoop Stress	24.7		50(2)
Longitudinal Tensile Stress from Hoop Stress	35.7	7.4	--
Longitudinal Stress from Thermal Expansion	-83.3	17.3	90(3)
Net Longitudinal Stress (Compression Side of the Curve)	-177.0	36.7	90(4)
Net Longitudinal Stress (Tension Side of the Curve)	81.8	16.9	90(4)
Maximum Shear Stress	148.1	30.7	45
Combined Biaxial Stress	296.1	61.4	90(4)

Notes: [1] Specified Minimum Yield Stress
[2] Limited by design factor multiplied by location factor (0.8 x 0.625 = 0.5) per CSA Z662-11
[3] Limited by ASME B31.4
[4] Limited by ASME B31.8

5.5 DIRECT PIPE® ALIGNMENT CRITERIA

The governing alignment criterion is to stay within the existing pipeline study corridor (Version 10), which has not changed since NEB IR No. 1.40b (Filing ID A3W9H8). Direct Pipe® is considered as a construction method between Kask and Westridge. A microtunnel boring machine (e.g. Herrenknecht AVN) will be used to first install a casing pipe. The product pipe will subsequently be pulled and/or pushed through while extracting the casing pipe. The vertical alignment is primarily governed by the allowable stresses during the pull through of the final NPS 30 product pipe, provided that buckling checks are also satisfactory for the casing pipe.

The drilling alignment is designed to reduce the friction between borehole wall and pipeline and therefore minimize the risk of coating damage. Generally, the design radius of a Direct Pipe® alignment for the installation of a steel pipeline depends on the outer diameter of the pipe, its wall thickness, and the geological conditions.

The Direct Pipe® microtunnelling machine (AVN) can be launched and recovered without sinking a shaft. To allow this to happen, the machine and the pipeline are pushed into a pit excavated near the surface. Here, the machine can be recovered and separated from the pipeline, dismantled, transported away, and reused for the next crossing as required. The

entry/exit angles can be as low as 0˚ up to 15˚ depending on the pipe thruster model and the anticipated geology.

5.6 DIRECT PIPE® BORE DIAMETER

Larger diameter (approx. 40 inches and above) AVNs have an integrated Power Pack. The unit creates the hydraulic pressure required to turn the rotating cutterhead and power the steering cylinders. It is located in the backup pipe behind the cutterhead and the steering cylinders. The advantage of generating energy locally in this way is that longer drive lengths can be achieved. However, due to the lack of space, smaller machines (28 to 40 inches) cannot be equipped with a Power Pack. The hydraulic losses resulting from necessary hydraulics supply from the control container thus restrict the drive length to approximately 300 m for bores with a diameter of 40 inches or less. Since the drive length considered is over 400 m a machine larger than 40 inches is likely required with an integrated Power Pack.

Cutting tools are designed or usable for a maximum specific compressive strength of the ground. The larger the cutterhead, the more space there is for larger disc cutters. The contact pressure required to loosen chips from the rock formation needs to be transferrable to the disc cutter bearing without causing it damage. Based on the expected geological conditions (weathered conglomerates with cobbles and boulders), the required cutterhead diameter is likely to be 42 to 48 inches to allow enough space for the required disc cutters.

Given the relatively large machine diameter, compared to the NPS 30 carrier pipe, a casing pipe will be needed for the AVN to push against with the required thrust force. Based on industry standards the minimum pipe diameter an AVN can safely thrust against is 4 inches less than the machine diameter. Therefore, the NPS 30 product pipe would not provide sufficient thrust resistance for a 42 to 48 inch diameter machine and a 38 to 40 inch casing pipe will likely be required. The product pipe will be attached to the casing using a conical connector and thrust through as the casing is pulled out.

5.7 DIRECT PIPE® STAGING AREAS

The foot print of the equipment at the launch and reception points is minimal for Direct Pipe®. The AVN is recovered in segments of approximately 3 m in length after excavation is finished. In a final step, the supply and discharge lines are removed from the pipeline. The crossing is complete and the pipeline has been installed in one single step, with the product pipe pulled through directly after the casing pipe. For planning, the same size of workspace as for HDD is assumed for the Direct Pipe® operations (e.g. 60 m x 60 m) although this footprint could potentially be reduced if required. In addition, a pipe string area for the casing and the NPS 30 carrier pipe is required at the AVN launch side.

See Appendix D for Direct Pipe® staging areas.

5.8 DIRECT PIPE® FROM KASK TO WESTRIDGE

Sketches M002-XD20025 and M002-XD20026 in Appendix C show a conceptual Direct Pipe® plan and profile for this alignment with a HDD option (i.e. Option 1).

The Direct Pipe® installations are approximately 415 m long with a straight horizontal alignment. The entry at Kask is approximately 5˚ and the exit angle at Westridge is

approximately 5˚. It is assumed that the bore diameter will be 42 to 48 inches and the bore separation will be between 10 to 20 m.

Based on the assumed geological conditions, the proposed Direct Pipe® alignment is situated in weathered conglomerates; overburden (5 to 10 m thickness) is expected at each end of the installation, which will be removed as part of the entry/exit pit constructions.

At the AVN launch side, the Direct Pipe® staging area including the pipe string area is situated partially within the Kask Bros. property and partially on the Crown municipal land. The staging area at the AVN reception side will be entirely within the Trans Mountain property. No construction disturbance outside of these staging areas is currently envisioned.

5.9 HDD CONTINGENCY PLAN

As per requirement of NEB Filing Manual for HDD, the contingency plan is to install the two NPS 30 delivery pipelines in the streets between Burnaby and Westridge following the route filed in Facility Application, December 2013.

6 OPTION 2: TUNNEL DESIGN

6.1 TUNNEL ALIGNMENT

The governing alignment criterion is to stay within the existing pipeline study corridor (Version 10), which has not changed since NEB IR No. 1.40b (Filing ID A3W9H8). It is understood that an area at Kask may be utilized for temporary and permanent easement. As such, staging areas at Burnaby, Westridge, and Kask have been considered for development of the alignments.

Selection of the tunnel alignment for Burnaby Mountain must consider the geological, geotechnical (including geohazards), and groundwater conditions at the site, location of existing utilities, available staging areas, and areas to efficiently perform the TBM launch, tunnelling operations, pipeline installation, and tunnel backfilling.

An appropriate tunnel depth needs to be selected which avoids any hidden valleys along the alignment (particularly at Westridge). A minimum rock cover equivalent to a one tunnel diameter can be used for excavation stability purposes.

A draft Quantitative Geohazards Frequency Assessment has been carried out by BGC. This report has identified an area with the potential for a deep-seated earth landslide event, just south of the Barnet highway at the Kask end of the alignment. Although the likelihood of such an event is negligible during the serviceable design life of the pipeline, any risks associated with geohazards will be further studied during detailed design, and mitigated if required. The ongoing geotechnical investigations at Burnaby Mountain will provide additional information to further quantify these risks and to ensure mitigation measures are selected as appropriate.

Two tunnel alignments have been selected as part of this feasibility study and are described below in detail. Option 2B requires that the Direct Pipe® alignment described in Section 5.8 be considered to complete the installation of the pipeline between Kask and Westridge.

6.1.1 Tunnel from Burnaby to Westridge

Sketch M002-XD20020 in Appendix C shows a conceptual tunnel plan and profile for this alignment (Option 2A).

The tunnel is to be excavated from a portal at Burnaby and is approximately 2,584 m long. The tunnel alignment follows a 4.5% downward gradient and at 158 m begins an 800 m radius horizontal curve to the left followed by a 1,482 m long tangent starting at 466 m. As the tunnel continues, the vertical alignment begins a 2,000 m radius vertical curve at approximately 1,820 m, and then enters a second 300 m radius horizontal curve to the left between 1,948 m and 2,360 and a final 224 m long tangential portion with a gradient of 0.1% to Westridge.

All construction activities can be completed from the staging areas at Burnaby and Westridge. No construction disturbance outside of these staging areas is currently envisioned.

Based on the anticipated geological conditions, the tunnel alignment is assumed to be situated primarily in bedrock.

6.1.2 Tunnel from Burnaby to Kask

Sketches M002-XD20021 and M002-XD20022 in Appendix C show the conceptual tunnel plan and profile for this alignment (i.e. Option 2B).

The tunnel is to be excavated from a portal at Burnaby and is approximately 2,150 m long. The tunnel alignment follows a 4.25% downward gradient and at 146 m begins a 900 m radius horizontal curve to the left, then continues straight from 506 m at a constant gradient to Kask.

All construction activities can be completed from the staging areas at Burnaby and the Kask Bros. property. No construction disturbance outside of these staging areas is currently envisioned.

Based on the anticipated geological conditions, the tunnel alignment is assumed to be situated primarily in bedrock.

6.2 TUNNEL EXCAVATION

Multiple tunnel excavation and initial support methods, listed in Table 6-1, are considered feasible for the construction at Burnaby Mountain. The drill-and-blast method has not been included as an excavation method because nearby case histories suggest that blasting is not typically necessary in the expected ground conditions, although there may be limited use of controlled blasting for hard cemented layers if a roadheader or digger shield are selected as the excavation method.

TABLE 6-1 FEASIBLE TUNNEL EXCAVATION AND INITIAL SUPPORT METHODS

Location	North of Barnet Highway	South of Barnet Highway
Rock Type	Highly Weathered Conglomerate	Interbedded Conglomerate and Sandstone
Primary Tunnel Excavation Methods	Digger Shield	Roadheader Shield
	Shield TBM	Shield TBM
	Roadheader	Roadheader
Initial Support	Steel Sets	Steel Sets
	Pre-cast Concrete	Pre-cast Concrete
	Shotcrete	Shotcrete

The weathered conglomerates that were encountered in HMM-BH-05 at Kask may represent poor ground conditions for single shield TBM tunnelling due to the presence of large clasts and a lack of lithification. Weathered conglomerates, if uncemented, may be considered to behave like cohesionless soil. When cohesionless ground is encountered, problems with running or flowing behaviour can develop at the tunnel face depending on groundwater conditions (see Table 6-2). Flowing ground can instantly enter the tunnel from the invert, as well as from the face, crown, and walls if unsupported. A shield can provide protection around the perimeter of the tunnel; however, tunnel face stability must be maintained to control flowing ground behaviour to prevent ground loss that may result in excessive surface settlement. Dewatering and use of breasting, pre-support, and sand shelves can be used to control face stability. Pre-excavation grouting may be required to modify the potential cohesionless ground by increasing the cohesive strength, thereby limiting or eliminating the flowing ground problem. The tunnel support may include a geotextile filter fabric to control soil piping through the gaps in the support.

TABLE 6-2 TUNNELLING CLASSIFICATION SYSTEM (AFTER TERZAGHI, 1950 AND HEUER, 1974)

Classification		Behaviour	Typical Soil Type
Firm		Heading can be advanced without initial support, and final lining can be constructed before ground starts to move.	Hard clay, cemented sand and gravel, glacial till and till-like deposits when not highly overstressed
Ravelling	**Slow Ravelling**	Chunks or flakes of material begin to drop out of the arch or walls sometime after the ground has been exposed; due to loosening or to overstress and "brittle" fracture (ground separates or breaks along distinct surfaces, opposed to squeezing ground).	Residual soils or sand with small amounts of binder may be fast ravelling below the water table, slow ravelling above. Stiff fissured clays, tills and till-like soils may be slow or fast ravelling depending upon degree of overstress and presence of fractures.
	Fast Ravelling		
Squeezing		Ground squeezes or extrudes plastically into tunnel, without visible fracturing or loss of continuity, and without perceptible increase in water content. Ductile, plastic yield, and flow due to overstress. Rate of squeeze depends on degree of overstress.	Ground with low frictional strength. Occurs at shallow to medium depth in clay of very soft to medium consistency. Stiff to hard clay under high cover may move in combination of ravelling at excavation surface and squeezing at depth behind surface.
Running	**Cohesive Running**	Granular materials without cohesion are unstable at a slope greater than their angle of repose (-30° to 35°). When exposed at steeper slopes, they run like granulated sugar or dune sand until the slope flattens to the angle of repose.	Clean dry granular materials. Apparent cohesion in moist sand, or weak cementation in any granular soil may allow the material to stand for a brief period of ravelling before it breaks down and runs. Such behaviour is cohesive-ravelling.
	Running		
Flowing		A mixture of soil and water flows into the tunnel like a viscous fluid. The material can enter from the invert, as well as the face, crown, and walls, and can flow for great distances, completely filling the tunnel in some cases. Where narrow lenses occur, piping may initiate first, followed by progressive flows.	Below the water table in silt, sand, or gravel without enough clay content to give significant cohesion and plasticity. May also occur in sensitive clay when such material is disturbed.
Swelling		Ground absorbs water, increases in volume, and expands slowly into the tunnel.	Highly pre-consolidated clay with plasticity index in excess of about 30, generally containing significant percentages of montmorillite.

To avoid the highly weathered conglomerate, a deeper tunnel alignment approaching Kask from Burnaby and from Kask to Westridge may be selected to target more competent ground conditions. As a result, a deep excavation tunnel portal or shaft may be required at the tunnel end at Westridge or Kask.

The tunnel construction can also be advanced concurrently from both ends of the alignment. This would include a single shield TBM progressing from Burnaby with other tunnelling methods (per Table 6-1), such as a Digger Shield TBM, capable of handling cobbles and boulders as well as allowing free access to the face, progressing from Westridge to Kask. The two tunnel headings would intersect in a suitable location along the alignment outside the zone of difficult ground conditions.

While a Digger Shield TBM is expected to be able to cope with the difficult ground conditions around the Kask/Westridge area, this portion of the tunnel alignment may also be excavated by conventional tunnelling as an alternative.

With these types of measures available for construction, it is concluded that tunnelling is feasible in the range of anticipated ground conditions. Final responsibility for selection of appropriate tunnelling means and methods will be by the tunnel contractor, and minimum technical requirements to manage risks associated with anticipated ground conditions will be stipulated in the construction contract.

6.3 TUNNEL SIZE

For this project, the tunnel size will be dictated by the space necessary to complete tunnelling activities efficiently including excavation and installation of tunnel support/lining, tunnel spoil removal, material supply to the tunnel heading, installation of the pipelines and tunnel backfilling. The pipeline transport envelope has to be sufficient to avoid interference with the tunnel support/lining and temporary equipment (e.g. lights, electrical cables, pre-installed delivery lines for tunnel backfilling, etc.) that will be in the tunnel. A minimum 600 mm work space envelope around each pipe is recommended to permit pipeline installation activities including welding, non-destructive testing, sand blasting, and coating of joints completed inside the tunnel and for visual inspection during hydro-testing. The final clearance between pipelines should be at a minimum 300 mm as per Canada CSA Z662-11, Clause 4.11.2 and 4.11.3 and Table 4.9, Clearance for buried pipelines. Final responsibility for the selection of the tunnel diameter will be by the tunnelling contractor, but it is expected that the excavated diameter will be between 4 m and 5 m.

The information from boreholes HMM-BH-01 and HMM-BH-02 is expected to be available for the tunnelling contractor and with this additional geotechnical and groundwater data the contractor will be able to refine his design, tunnelling methodology, construction cost, and schedule, and to better understand constructability risk.

6.4 TUNNEL STAGING AREAS

Suitable staging areas for tunnel construction are characterized by good accessibility for delivery of equipment and material, and excavation spoil hauling, adequate size for equipment and material storing and staging; availability of utilities including a high voltage power supply (for the TBM, if used), ventilation, sewage and construction water, and other rules and requirements including environmental and work-related restrictions (e.g. noise, lighting, work time, etc.). Staging areas are needed at each work site. Tunnel staging areas on both ends (portals) of the alignment are required to enable the contractors to efficiently execute the work. The portals and work areas will be entirely within the Trans Mountain properties for Option 2A, and within the Trans Mountain and Kask Bros. properties for Option 2B.

See Appendix D for tunnel staging areas.

6.5 PIPELINE INSTALLATION METHOD IN TUNNEL

Installation of large diameter sewer or water pipelines inside the tunnel is relatively common in the tunnel construction industry. This typically involves carrying the pipeline into the tunnel joint by joint (or occasionally in longer prefabricated pipeline segments), fitting them up, and then welding from the interior of the pipe. This basic approach modified for smaller diameter pipe involves welding from outside the pipe. The use of semi-automatic welding either inside or outside the tunnel can offer cost and schedule savings. If the pipeline is welded outside the tunnel, it can be coated and hydro-tested outside concurrently with tunnelling and then may be moved inside the tunnel utilizing various type of methods including standard pipe rollers, HDD drilling equipment, the Direct Pipe® thruster, or even using motorized rollers. Since the method of pipeline installation will be part of the contractor’s means and methods, minimum requirements will be specified in the construction contract to ensure pipeline integrity is satisfied during pipeline installation, testing, tunnel backfilling and in operation.

See Appendix E for typical tunnel cross sections.

6.5.1 Tunnel from Burnaby to Westridge (Option 2A)

For Option 2A, it is assumed the construction and pipe installation for the tunnel would be staged from Burnaby. Once tunnel excavation is completed, the pipes would be transported to the site and unloaded at the storage and yard area near the tunnel portal. Pipeline segments would be prefabricated at the pipe storage area. Then the pipeline segments would be transported to the tunnel portal using side booms and unloaded onto a pipe carrier and transported into the tunnel. It is envisaged that the pipeline segments would be driven into the tunnel in their final configuration in a bundle, and it is assumed that pipeline segments can be efficiently and safely transported to the location in the tunnel for welding. Pipe fit-up, welding, non-destructive testing, coating, pipe support installation, and unloading onto the pipe supports would follow and occur within the tunnel.

6.5.2 Tunnel from Burnaby to Kask (Option 2B)

For Option 2B, it is assumed the pipeline installation would be staged from Burnaby. The tunnel alignment permits pipe welding inside and/or outside the tunnel. If pipeline welding is to occur inside the tunnel, the method described in Section 6.5.1 could be used.

6.6 TUNNEL BACKFILLING

It is assumed the tunnel will be backfilled, as a backfilled tunnel does not require Fire, Life & Safety or other installations in the tunnel, which reduces the cost and the schedule for construction and eliminates the cost of tunnel operation. Backfill will provide permanent tunnel support and pipe confinement, allow the use of less expensive temporary support during tunnel excavation, and negates the necessity of a permanent tunnel lining.

The backfill will be placed from within the tunnel or from the portals to completely fill the tunnel and seal off groundwater discharge. During backfilling, emphasis will be made to control pipe buoyancy due to uplift forces from the backfill weight, to prevent pipe buckling

due to excessive injection pressure during backfilling, and to limit the heat generated during hydration of cement to prevent development of a gap between the backfill and the pipe. The backfill material will be designed to prevent damage of the pipe and to provide both final support and seepage cut-off. The typical tunnel backfill materials that can be used are cement grout and concrete.

7 CONSTRUCTION IMPACTS

A number of construction impacts may be associated to some degree with the construction of the Burnaby Mountain tunnel and trenchless crossings and have been considered in the feasibility assessment including:

- Potential disruption during detailed site investigation phase (i.e. surveying, drill rigs along alignment, geophysical studies, etc.)
- Increased levels of noise, emissions from heavy vehicles and dust
- Construction lighting used at night
- Vibrations (due to limited use of controlled blasting and TBM excavation at depth)
- Potential excavation induced ground subsidence
- Construction traffic will be added to the local roads
- Temporary changes to groundwater table and resources
- Potential for groundwater contamination
- Construction wastewater disposal
- Spoil disposal including potentially acid rock generating and metal leaching spoil
- Loss of vegetation and micro-habitats during site clearing and mobilization

8 CONSTRUCTION COST ESTIMATE AND SCHEDULE

A capital cost estimate for construction has been prepared for each option. For tunnelling costs, a resource based estimating approach similar to how a contractor prepares a bid was used.

The construction costs exclude detailed design, project and construction management, environmental mitigations, and the right-of-way and property acquisitions that may need to be required for each of the construction options. The construction costs also exclude owner’s contingency.

A preliminary construction schedule for each construction option has been developed based on the length of the individual construction activities. Both the summary of the construction costs and durations are shown in Table 8-1.

TABLE 8-1 SUMMARY OF CONSTRUCTION COSTS AND DURATIONS

	HDD & Direct Pipe®	Single Curved Tunnel	Straight Tunnel & Direct Pipe®
	Option 1	Option 2A	Option 2B
Total Cost	**$46.5 M**	**$64.6 M**	**$75.6 M**
Construction Duration	**21 months**	**23 months**	**21 months**

Notes:

1. Costs are in 2014 Canadian dollars, excluding GST and owner's contingency.
2. Costs should be escalated to the actual start date for budgeting purposes.

It is assumed that once tunnel construction works (including pipe installation and tunnel backfill) are completed, allowance is made for an additional one month for pipeline tie-ins and three months for commissioning to achieve the Q3 of 2018 in-service date.

The lead time required to design, build, and deliver a TBM to site (whether new or refurbished) can be 12 months, dictated mostly by the capacity of the manufacturer at the time of order when considering other TBM work backlog. In order to have the pipeline in service by Q3 of 2018, early TBM procurement ahead of the construction period is assumed.

9 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are presented regarding the Burnaby Mountain tunnel and trenchless construction options:

Construction options to install two NPS 30 pipelines between the Burnaby Tank Farm and the Westridge Marine Terminal have been evaluated for feasibility, construction cost and schedule. These include a direct tunnel, a tunnel with Direct Pipe®, and HDD with Direct Pipe®.

Option 1: Twin HDD installations from Burnaby to Kask, and twin Direct Pipe® installations from Kask to Westridge.

Option 2A: A single curved tunnel excavated using a Tunnel Boring Machine (TBM) from Burnaby to Westridge.

Option 2B: A single straight tunnel excavated using a Tunnel Boring Machine (TBM) from Burnaby to Kask, and twin Direct Pipe® installations from Kask to Westridge.

Based on the geotechnical and geophysical information accompanying this report, the feasibility of a HDD outlined in Option 1 is questionable, and a tunnel, outlined in Options 2A and 2B, is feasible.

The HDD installations carry significant constructability risk, due to the unknown extent of the weathered conglomerate encountered in borehole HMM-BH-05 at Kask. Further geotechnical investigation, including the drilling of boreholes HMM-BH-01 and HMM-BH-02 would provide additional information on the feasibility of the HDD construction method. If an HDD installation is selected, Trans Mountain should still proceed with the detailed design of the street option as the contingency plan in case the HDD installations are unsuccessful. This would include acquisition of all the necessary approvals and permits, and the streets option may result in potentially significant disruption to residents and business that Burnaby Mountain trenchless option is trying to avoid.

Detailed design is recommended to proceed on the basis that tunnelling Option 2A will be the construction method as the constructability risk of Option 1 cannot be fully understood at this point. The information from boreholes HMM-BH-01 and HMM-BH-02 will allow for further refinement of the tunnel detailed design, tunnelling methodology, construction cost and schedule, and development of a better understanding of constructability risk.

Appendix A BOREHOLE LOGS

SYMBOLS AND TERMS

FOR SOIL DESCRIPTIONS ON TEST HOLE AND TEST PIT LOGS

Project Name: Trans Mountain Expansion Project   Number: 0095-150-04

SAMPLE SYMBOLS

CLASSIFICATION BY PARTICLE SIZE[1]

NAME	SIZE RANGE (mm) [2]	US STANDARD SIEVE SIZE Retained	US STANDARD SIEVE SIZE Passing
Boulders	>300	12 inch	-
Cobbles	75 - 300	3 inch	12 inch
Gravel:			
Coarse	19 - 75	0.75 inch	3 inch
Fine	5 - 19	No. 4	0.75 inch
Sand:			
Coarse	2 - 5	No. 10	No. 4
Medium	0.4 - 2	No. 40	No. 10
Fine	0.074 - 0.4	No. 200	No. 40
Fines (Silt or Clay)[3]	<0.074	-	No. 200

DENSITY OF GRANULAR SOILS

DESCRIPTION	SPT - "N"[4]	FIELD IDENTIFICATION
"Very Loose"	0-4	
"Loose"	4-10	Easy to drive wooden stake
"Compact"	10-30	
"Dense"	30-50	Difficult to drive wooden stake more then 50 mm.
"Very dense"	>50	

PROPORTION OF MINOR COMPONENTS BY WEIGHT

"and"	35% to 50%.
"y/ey"	20% to 35%
"Some"	10% to 20%
"Trace"	0% to 10%

PARTICLE SHAPE

Flat	Particles with width/thickness >3
Elongated	Particles with length/width >3
Flat and Elongated	Particles that meet both criteria

ANGULARITY

"Angular"	Particles have sharp edges and relatively planar sides with unpolished surfaces.
"Subangular"	Particles are similar to angular description but have some rounded edges.
"Subrounded"	Particles have nearly planar sides but have well rounded corners and edges.
"Rounded"	Particles have smoothly curved sides and no edges.

CONSISTENCY OF COHESIVE SOILS

DESCRIPTION	SPT- "N" (6,7)	UNDRAINED SHEAR STRENGTH - "S_u" kPa (5)	FIELD IDENTIFICATION
"Very soft"	<2	<12	Easily penetrated several cm by the fist.
"Soft"	2-4	12-25	Easily penetrated several cm by the thumb.
"Firm"	4-8	25-50	Can be penetrated several cm by the thumb with moderate effort.
"Stiff"	8-15	50-100	Readily indented by the thumb but penetrated only with great effort.
"Very Stiff"	15-30	100-200	Readily indented by the thumb nail.
"Hard"	>30	>200	Indented with difficulty by the thumbnail.

(1) Unified Soil Classification System (USCS).
(2) Approximate metric conversion.
(3) Fines are classified as silt or clay on the basis of Atterberg limits (refer to Plasticity Chart).
(4) Standard Penetration Test (SPT) blow count uncorrected, after Terzaghi and Peck, 1948.
(5) Undrained shear strength can be estimated by vane (gives S_u), pocket penetrometer (gives unconfined compressive strength, i.e., 2 S_u), or unconfined compression test (gives 2 S_u).
(6) Approximate correlation with Standard Penetration Test blow counts, after Terzaghi and Peck, 1948.
(7) "R" represents sampler refusal during Standard Penetration Test.

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

TRANSMOUNTAIN

SYMBOLS AND TERMS

FOR SOIL DESCRIPTIONS ON TEST HOLE AND TEST PIT LOGS

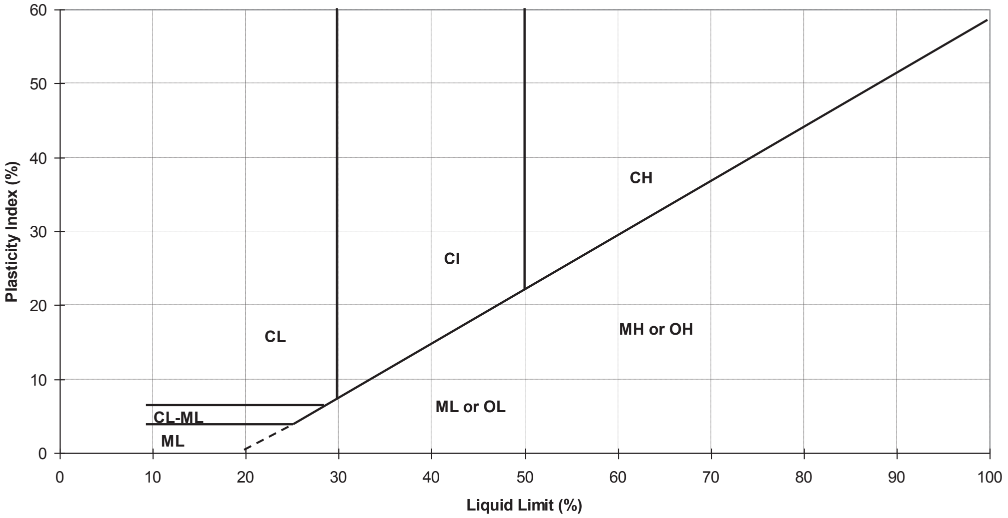
Project Name: Trans Mountain Expansion Project

Number: 0095-150-04

PLASTICITY OF COHESIVE SOILS $^{(7)}$

DESCRIP-TION	SILT	CLAY	CRITERIA
High	$W_L^{(8)} >50$	$W_L >50$	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.
Medium	-	$30 < W_L < 50$	The thread is easy to roll and not much time is required to reach the plastic limit. The lump crumbles when drier than the plastic limit.
Low	$W_L<50$	$W_L<30$	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit.
Non-Plastic	NP	-	A 1/8 inch (3 mm) thread cannot be rolled at any water content.

PLASTICITY OF COHESIVE SOILS $^{(8)}$



MOISTURE CONDITION

Description	Criteria
Dry	Absence of moisture
Moist	Damp but no visible water
Wet	Visible free water, usually soil is below water table

CEMENTATION

Description	Criteria
Weak	Crumbles or breaks with handling or little pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

DILATANCY $^{(11)}$

Descrip-tion	Criteria
None	No visible change in the spec-men during shaking or squeezing
Slow	Water appears slowly on the surface of the specimen during shaking and disappears slowly upon squeezing
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing

---

(8) This plasticity classification conforms to the Unified Soil Classification System (USCS) and to ASTM D-2487, except for the addition of an intermediate category for clay, where the liquid limit is between 30% and 50% (CI). Under ASTM and USCS, all clays with a liquid limit less than 50% are classified as low plasticity (CL).

(9) W_L = Liquid Limit (%)

(10) Classifications as per USCS.

(11) Test for dilatancy conducted by shaking and squeezing a moulded ball of soil that is 12 mm in diameter.

(12) Test for dry strength conducted on natural soil pieces or moulded balls about 25 mm in diameter that have been dried at less than 60°C.

SYMBOLS AND TERMS

FOR SOIL DESCRIPTIONS ON TEST HOLE AND TEST PIT LOGS

Project Name: Trans Mountain Expansion Project

Number: 0095-150-04

STRUCTURE

Description	Criteria
Stratified	Alternating layers of varying material or colour with layers at least 6 mm thick; note thickness
Laminated	Alternating layers of varying material or colour with the layers less than 6 mm thick; note thickness
Fissured	Breaks along definite planes or fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay; note thickness
Homogeneous	Same colour and appearance throughout
Heterogeneous	Colour and appearance vary throughout

IDENTIFICATION OF INORGANIC FINE-GRAINED SOILS FROM MANUAL TESTS

Soil Symbol	Dry Strength	Dilatancy
ML	None to Low	Slow to Rapid
CL	Medium to High	None to Slow
MH	Low to Medium	None to Slow
CH	High to Very High	None

DRY STRENGTH

Description	Criteria[12]
None	The dry specimen crumbles into powder upon applying pressure or handling
Low	The dry specimen breaks into pieces or crumbles with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface
Very High	The dry specimen cannot be broken between the thumb and a hard surface

Lithological Graphic Log Legend [10]

Cohesive Soils

▨	CH/SM USCS High Plasticity Clay / Silt / Sand	▨	CL/SM USCS Low Plasticity Silt, Clay, & Sand
▨	MH USCS Elastic Silt	▨	OL USCS Low Plasticity Organic Silt or Clay
▨	CL USCS Low Plasticity Clay	▨	MLS USCS Sandy Silt
▨	ML USCS Silt	▨	CL/ML USCS Low Plasticity Silty Clay
▨	CH/MH USCS High Plasticity Clay	▨	CH USCS High Plasticity Clay
▨	CH/MH/S/G USCS Low Plasticity Clay, Gravel, Sand, Silt	▨	CL/ML SAND USCS Low Plasticity Silty Clay
▨	MLGS USCS Gravelly Silt	▨	CLG USCS Low Plasticity Gravelly Clay

Granular Soils

▨	GW USCS Well-graded Gravel	▨	GW/SW&B USCS Well-graded Gravel/Sand/Boulders
▨	SPG USCS Poorly-graded Gravelly Sand	▨	SC USCS Clayey Sand
▨	SW USCS Well-graded Sand	▨	SP-SM USCS Poorly-graded Sand with Silt
▨	BLDRCBBL Boulders and Cobbles	▨	SW-SM USCS Well-graded Sand with Silt
▨	GW/SW USCS Well-graded Sandy Gravel	▨	GP USCS Poorly-graded Gravel
▨	SP-SC USCS Poorly-graded Sand with Clay	▨	GM USCS Silty Gravel
▨	SWG USCS Well-graded Gravelly Sand	▨	SP USCS Poorly-graded Sand
▨	GW-GM USCS Well-graded Gravelly with Silt	▨	SP USCS Poorly-graded Sand
▨	SM USCS Silty Sand		

Other

▨	BEDROCK Bedrock	▨	PT USCS Peat

LEGEND FOR ROCK DRILL HOLE LOGS

The parameters depicted on the provided drill holes logs are described below according to the column headings found on the logs.

DEPTH ALONG HOLE

Depth is measured in decimal feet along borehole. Depth along hole and elevation in feet above sea level are displayed on the left and right hand sides of the logs, respectively.

TOTAL CORE RECOVERY (%)

Total Core Recovery (TCR) is defined as the percentage of core length successfully recovered from a drilled interval. This is mathematically defined as follows:

$$\text{TCR} = \frac{\sum \text{Length of core pieces}}{\text{Total length of core interval}} \times 100\%$$

RQD (%)

The Rock Quality Designation (RQD) is defined as the percentage of sound core recovered of intact pieces of 100 mm or more in length, as measured along the core axis, for the total length of core interval (Deere and Deere, 1988). Only natural core breaks (i.e. joints, faults) are considered in this calculation. Mechanical breaks due to drilling or handling are ignored, and the affected core pieces are considered intact. Core pieces which are very weak (strength grade $\leq$ R1) or are weathered/altered to a soil-like material do not count towards the intact core length for RQD. RQD is mathematically defined in the following formula:

$$\text{RQD} = \frac{\sum \text{Length of sound intact core pieces} > 100\text{ mm}}{\text{Total length of core interval}} \times 100\%$$

LONGEST STICK (ft)

Longest stick is the longest piece of sound and intact core measured in each interval. Core pieces which are very weak (strength grade $\leq$ R1) or are weathered/altered to a soil-like material are not considered for the longest stick measurement. Mechanical breaks due to drilling or handling are ignored.

FRACTURE INTERCEPT (ft)

Fracture intercept is the average distance between discontinuities. It is calculated for each interval as follows:

$$\text{Fracture Intercept} = \frac{\text{Total recovered length of core}}{\text{\# Natural discontinuities in the interval}}$$

JOINT SET NUMBER (Jn)

Joint set number if a numeric index which considers the number of discontinuity sets present in a rock mass, values are assigned as per the table provided below:

Joint set number	**Jn**
Massive, no or few joints	0.5-1
One joint set	2
One joint set plus random joints	3
Two joint sets	4
Two joint sets plus random joints	6
Three joint sets	9
Three joint sets plus random joints	12
Four of more joint sets, random, heavily jointed, sugar-cube, etc.	15
Crushed rock, earthlike	20

JOINT CONDITION (1976)

Joint condition (1976) is a numeric index which summarizes the typical surface properties and infilling of discontinuities within an interval. The joint condition is logged based on the descriptions proposed by Bieniawski (1976), as provided in Table A-1.

Rating	**Condition of Discontinuity (RMR 1976)**	**BGC Notes**
25	Very rough surface; not continuous; no separation; unweathered wall rock	Includes intervals with no discontinuities; JRC > 16
20	Slightly rough surfaces; separation <1 mm; slightly weathered walls	> R3 wall rock; interlocking discontinuities with 8 < JRC < 14
12	Slightly rough surfaces; separation <1 mm; highly weathered walls	< R3 wall rock and slightly rough OR > R3 planar/smooth surfaces with no infill
6	Slickensided surfaces or gouge < 5 mm thick or separation 1 to 5 mm; continuous	Veins ≤ R1 or Mohs # ≤ ~3 included as “infilling”
0	Soft gouge >5mm or separation > 5 mm; continuous joints	Veins ≤ R1 or Mohs # ≤ ~3 included as “infilling”

JOINT ROUGHNESS NUMBER (Jr)

Joint Roughness number is a numeric index which represents the surface roughness of discontinuity walls, values are assigned as per the table below:

Discontinuity Roughness Characteristics	**Jr**
Discontinuous Joints	4
Rough or irregular, undulating	3
Smooth, undulating	2
Slickensided, undulating	1.5
Rough or irregular, planar	1.5
Smooth, planar	1
Slickensided, planar	0.5
Zone containing clay minerals thick enough to prevent rock wall contact	1
Sandy, gravelly or crushed zone thick enough to prevent rock wall contact	1

JOINT ALTERATION NUMBER (Ja)

Joint alteration number is a numeric index which represents the surface conditions of discontinuity walls, e.g. surface staining or infill properties, values are assigned as per the table below:

	Description	Ja
a) Rock Wall Contact	Tightly healed, hard, non-softening, impermeable filling, i.e. quartz or epidote	0.75
	Unaltered joint walls, surface staining only	1
	Slightly altered joint walls. Non-softening mineral coatings, sandy particles, clay-free disintegrated rock etc.	2
	Silty- or sandy-clay coatings, small clay fractions (non-softening)	3
	Softening or low friction clay mineral coatings, i.e. kaolinite, mice. Also chlorite, talc, gypsum and graphite etc., and small quantities of swelling clays (Discontinuous coatings, 1-2 mm or less in thickness)	4
b) Rock Wall contact before 10 cm shear	Sandy particles, clay-free disintegrated rock etc.	4
	Strongly over-consolidated clay mineral fillings (Continuous, <5 mm in thickness)	6
	Medium or low over-consolidation, softening, clay mineral fillings. (Continuous, <5 mm in thickness)	8
	Swelling clay filling, i.e. montmorillonite (Continuous, <5 mm in thickness) Value of Ja depends on percent of swelling clay-size particles, and access to water etc.	8-12
c) No rock wall contact when sheared	Zones of bands of disintegrated or crushed rock and clay (see (b) descriptions of clay condition)	6, 8, or 8-12
	Zones or banks of silty- or sandy-clay, small clay fraction (non-softening)	5
	Thick, continuous zones or bands of clay (see (b) descriptions of clay condition)	10, 13, or 13-20

INTACT STRENGTH (‘R’)

Intact strength (R) is based on simple mechanical tests, which are performed in the field using a rock hammer, pocket knife, and fingernail. The strength grades vary from extremely weak (R0) to extremely strong (R6) as shown in the table below:

Grade	Description	Field Identification	UCS (MPa)	Point Load Index “Is_{50}” (MPa)
R6	Extremely Strong	Specimen can only be chipped with flat end geological hammer.	> 250	> 10
R5	Very Strong	Specimen requires many blows with flat end geological hammer to fracture.	100-250	4-10
R4	Strong	Specimen requires more than one blow of flat end geological hammer to fracture.	50-100	2-4
R3	Medium Strong	Cannot be scraped or peeled with pocket knife; can be fractured with single firm blow of flat end geological hammer.	25-50	1-2
R2	Weak	Can be peeled by a pocket knife with difficulty; shallow indentation made by firm blow with point geologic hammer.	5-25	-
R1	Very Weak	Crumbles under firm blows with point of geological hammer.	1-5	-
R0	Extremely Weak	Indented by thumbnail.	< 1	-

POINT LOAD INDEX (MPa)

Point load test data (Is_{50}) provides a relative indication of rock strength, as shown in Table A-2. It can also be used to predict uniaxial compressive strength using site specific correlation factors. The results presented on the logs are from diametral point load tests.

UCS (MPa)

Laboratory testing results from uniaxial compressive strength (UCS) tests provide a relative indication of the intact strength of the rock, according to the ranges of values shown in Table A-2.

ROCK MASS RATING (1976)

The Rock Mass Rating (RMR) system, published in 1976 by Bieniawski, classifies rock on a linear scale of 0-100 based on the sum of the ratings given to five parameters. The five

parameters are:

- Rock Quality Designation (RQD)
- Fracture Intercept
- Joint Condition (1976)
- Intact Strength (‘R’)
- Groundwater Conditions

For the core logging purposes, the value of the “Groundwater Conditions” parameter is assumed to be 10. The sum of the ratings may then be used to assess the quality of the rock based on the following classification table:

RMR	Rock Quality
81-100	Very Good
61-80	Good
41-60	Fair
21-40	Poor
0-20	Very Poor

Q’

The Q’ value, a simplification of the original Q-system published in 1974 by Barton, classifies rock on a log based scale based on the product of ratings given to four parameters. The parameters are:

- Rock Quality Designation (RQD)
- Joint Set Number (Jn)
- Joint Roughness Number (Jr)
- Joint Alteration Number (Ja)

Where Q’ = RQD / Jn * Jr / Ja

The Q’ values may then be used to assess the quality of the rock based on the following classification table:

Q’	Rock Quality
0.01-0.1	Extremely Poor
0.1-1	Very Poor
1-4	Poor
4-10	Fair
10-40	Good
40-100	Very Good
100-400	Extremely Good
400-1000	Exceptionally Good

PACKER TESTING AND HYDRAULIC CONDUCTIVITY (m/s)

Packer testing is a method for obtaining hydraulic conductivity “K” estimates of geologic units. This can be performed using a single or double packer test set-up, effectively monitoring the change in volume of water into a formation over a known period of time, under various pressure intervals by implementing a constant head, falling head or flow recession test. Packer tests were executed over zones of interest (i.e. low recovery, loss of drilling return). The results presented on the logs (i.e. K = 2.8E-06 m/s) were obtained from the constant head test, using the single packer setup.

VIBRATING WIRE PIEZOMETER (VWP)

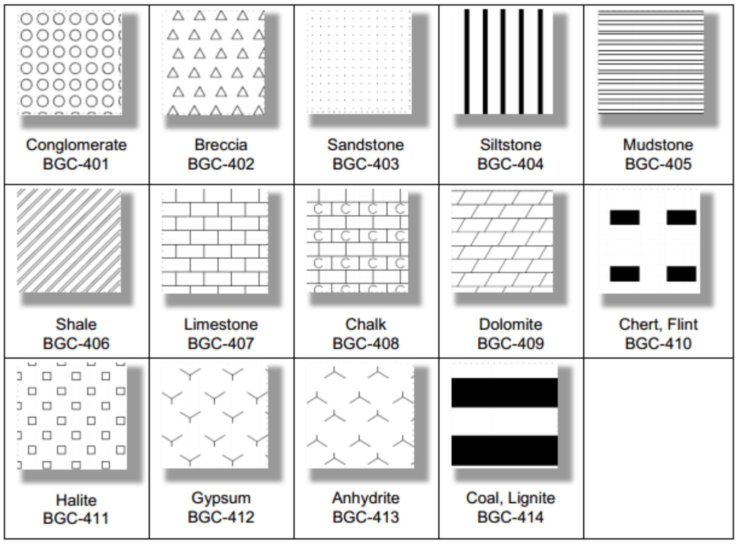
A vibrating wire piezometer (VWP) is a pressure transducer that records measurements of water pressure and temperature. This data may then be converted into a groundwater elevation. Repeated measurements of the transducer allow for monitoring changes in groundwater pressures over time. The depth and serial number of each VWP installed is indicated on the logs.

TELEVIEWER SURVEY (TV)

Televiewer surveying utilizes a downhole probe to collect data imagery which is used to estimate the orientation and in-situ aperture of discontinuities intersected by the drill holes. A drill hole survey is recorded from the end of hole to ground surface, and it is often completed in multiple intervals. Where rock quality is very poor, it is possible to have zones where no data is collected in order to preserve the integrity of the probe. The tested intervals are

distinguished clearly on the logs, under the Testing and Instrumentation section.

ROCK LITHOLOGY SYMBOLS



Project: Burnaby Mountain Westridge Tunnel Site Investigations

Project No.: 0095-150-15

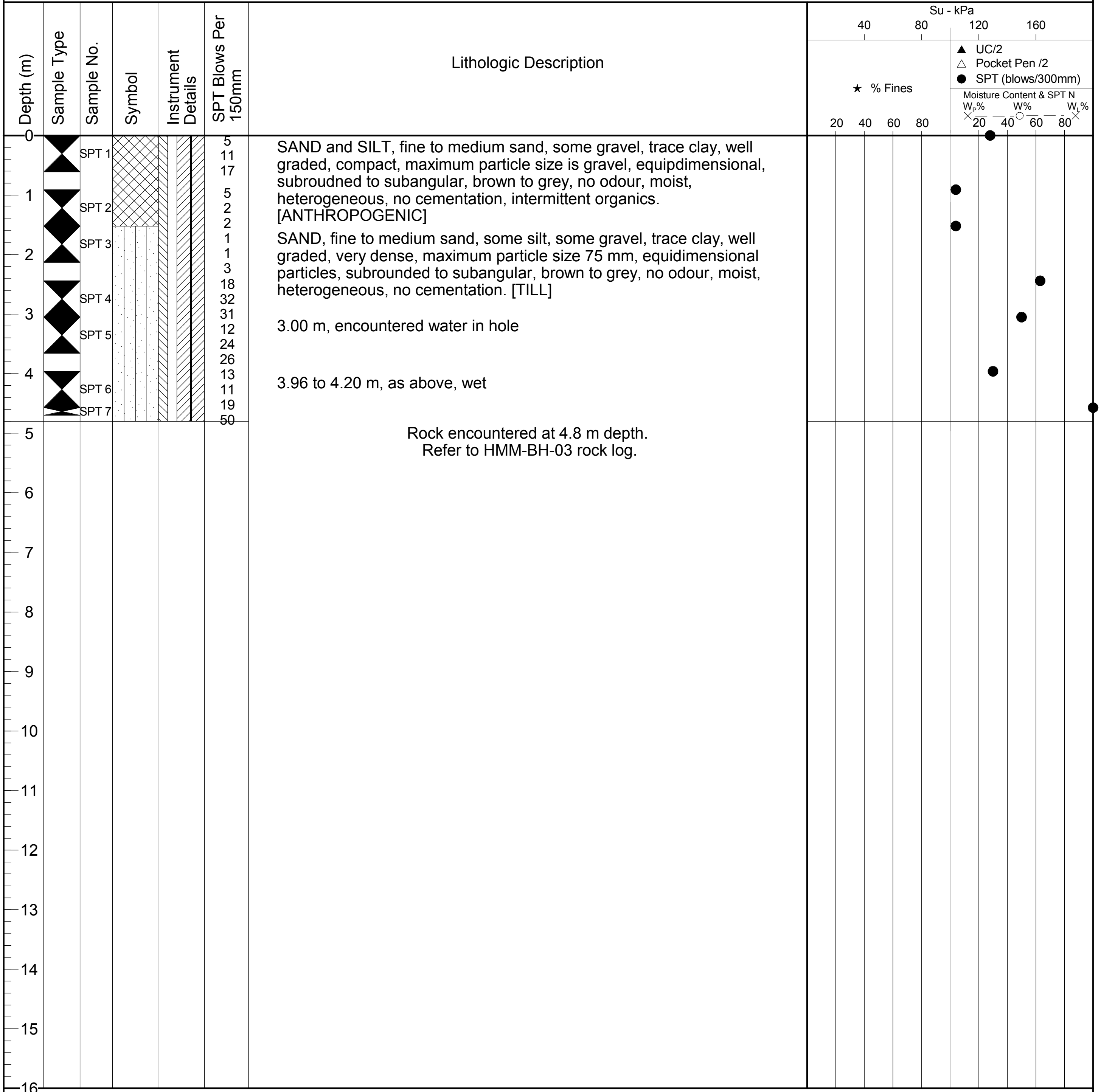
DRILL HOLE # HMM-BH-03

Location: Burnaby Tank Farm

Co-ordinates (m): 504,629E - 5,457,797N
Ground Elevation (m): 165.0
Survey Method: Handheld GPS
Datum: UTM 10 NAD83
Plunge (°): -90
Trend (°): N/A

Drill Designation: B-80
Drilling Contractor: Geotech Drilling
Drill Method: Diamond Coring
Core: HQ3
Fluid: Water
Cased To (m) : 10.7

Start Date: 11 Sep 14
Finish Date: 22 Sep 14
Final Depth (m): 181.9
Depth To Top Of Rock (m): 4.8
Logged By: SG/CC
Reviewed By: CJS



Sample No.	SPT Blows Per 150mm
SPT 1	5 11 17
SPT 2	5 2 2
SPT 3	1 1 3
SPT 4	18 32 31
SPT 5	12 24 26
SPT 6	13 11 19
SPT 7	50

SAND and SILT, fine to medium sand, some gravel, trace clay, well graded, compact, maximum particle size is gravel, equipdimensional, subroudned to subangular, brown to grey, no odour, moist, heterogeneous, no cementation, intermittent organics. [ANTHROPOGENIC]

SAND, fine to medium sand, some silt, some gravel, trace clay, well graded, very dense, maximum particle size 75 mm, equidimensional particles, subrounded to subangular, brown to grey, no odour, moist, heterogeneous, no cementation. [TILL]

3.00 m, encountered water in hole

3.96 to 4.20 m, as above, wet

Rock encountered at 4.8 m depth.
Refer to HMM-BH-03 rock log.

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Client: Trans Mountain Pipeline ULC

Project : Burnaby Mountain Westridge Tunnel Site Investigations
Project No.: 0095-150-15

DRILL HOLE # HMM-BH-03

Location: Burnaby Tank Farm

Co-ordinates (m): 504,629E - 5,457,797N	**Drill Designation:** B-80	**Start Date:** 11 SEP 14
Ground Elevation (m): 165	**Drilling Contractor:** Geotech Drilling	**Finish Date:** 22 SEP 14
Survey Method: Handheld GPS	**Drill Method:** Diamond Coring	**Final Depth (m):** 181.9
Datum: UTM 10 NAD83	**Core:** HQ3	**Depth To Top Of Rock (m):** 4.8
Plunge (°): -90	**Fluid:** Water	**Logged By:** SG/CC
Trend (°): N/A	**Cased To (m) :** 10.7	**Reviewed By:** CJS

DEPTH ALONG HOLE (m) | INSTRUMENTATION & HOLE COMPLETION DETAILS | DRILLING ACTION OR SAMPLE TYPE | GEOTECHNICAL DESCRIPTION, MAJOR DISCONTINUITIES, AND ADDITIONAL NOTES

4.80 m, possible bedrock contact

Poor quality SANDSTONE
Fresh and unweathered. Very weak to weak (R 1 - 2), grey, sand grains range white/clear to black, medium to coarse grains, trace fines, sub-rounded to sub-angluar, degree of cemetation varies from weak to moderate. RQD ~ 0%, rock is fractured along bedding, very close spacing, bedding surfaces typically planar, 0.8 - 2 mm apperture filled with sand grains disintegrated from the formation, typical alpha angle of 85-90 degrees to core axis.

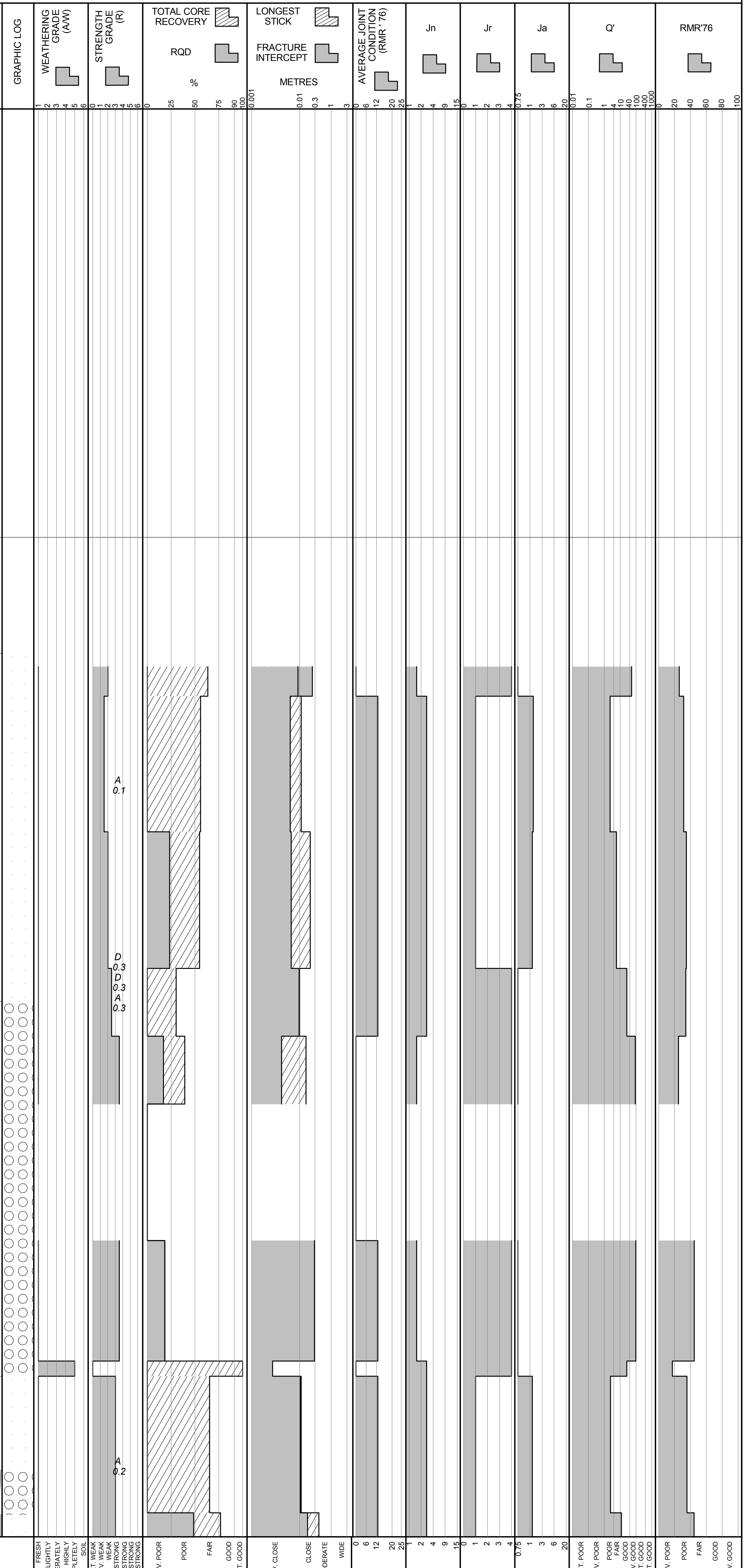
6.25 m, switched to coring

Very poor to fair quality CONGLOMERATE
Fresh and Unweathered, matrix is very weak to weak (R 0 - 2), with strength increasing to medium-strong where carbonate cementation is present, clasts are medium-strong to strong, grey matrix with multilithic light-dark grey clasts, matrix composed primarily of medium to coarse sand with some fines, matrix grains are angular to sub-rounded, clasts are sub-rounded to rounded, bedding is not visible in recovered material. Drill recovery was very poor in this zone, description is based on recovered material.

11.15 to 12.68 m, no recovery.

Very poor to fair quality SANDSTONE
Fresh and unweathered, weak (R 2), grey, clear/white to dark grey medium to coarse sand grains, trace fines, bedded. Trace coal laminations/lenses 0.5 - 4 mm thick, black.
Discontinuities are primarily parallel to bedding with aperture 0.5 - 2 mm, infilling with trace disintegrated sand grains, planar and slightly rough, spaced 0.1 - 0.5 m at an alpha angle of 80 - 90 degrees to core axis.

Poor to fair quality CONGLOMERATE
Fresh and unweathered, uncemented, extremely weak to very weak matrix (R 0) clasts are medium-strong to strong



POINT LOAD TESTS
D — TEST TYPE: DIAMETRAL (D); AXIAL (A)
1.5— Is_{50} (MPa)

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Client: Trans Mountain Pipeline ULC

KINDER MORGAN UNDERGROUND (ROCK) KINDERMORGAN_ROCK.GDL BGC.GDT 11/4/14

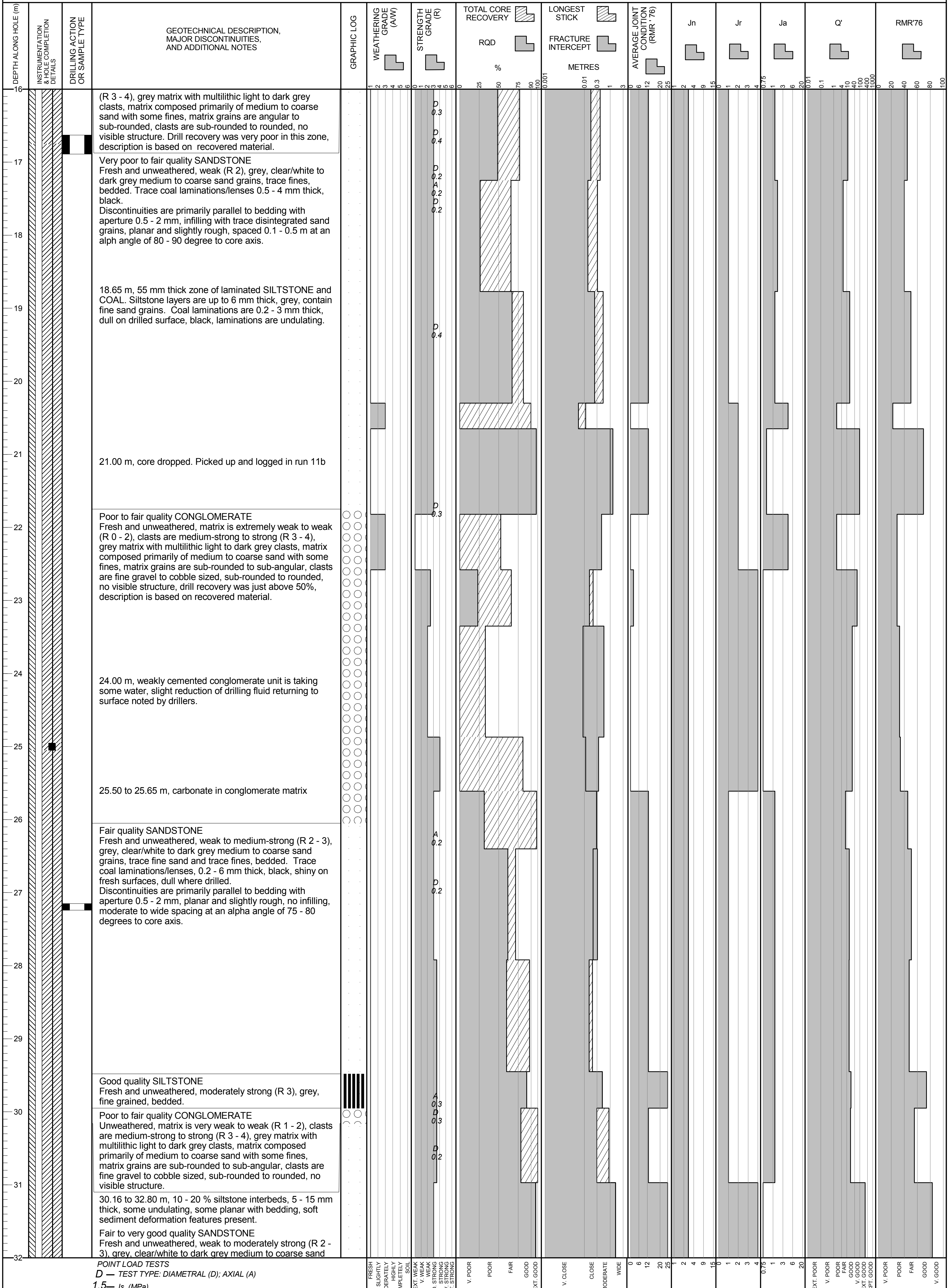
DRILL HOLE # HMM-BH-03

Location: Burnaby Tank Farm

Co-ordinates (m): 504,629E - 5,457,797N
Ground Elevation (m): 165
Survey Method: Handheld GPS
Datum: UTM 10 NAD83
Plunge (°): -90
Trend (°): N/A

Drill Designation: B-80
Drilling Contractor: Geotech Drilling
Drill Method: Diamond Coring
Core: HQ3
Fluid: Water
Cased To (m) : 10.7

Start Date: 11 SEP 14
Finish Date: 22 SEP 14
Final Depth (m): 181.9
Depth To Top Of Rock (m): 4.8
Logged By: SG/CC
Reviewed By: CJS



(R 3 - 4), grey matrix with multilithic light to dark grey clasts, matrix composed primarily of medium to coarse sand with some fines, matrix grains are angular to sub-rounded, clasts are sub-rounded to rounded, no visible structure. Drill recovery was very poor in this zone, description is based on recovered material.

Very poor to fair quality SANDSTONE
Fresh and unweathered, weak (R 2), grey, clear/white to dark grey medium to coarse sand grains, trace fines, bedded. Trace coal laminations/lenses 0.5 - 4 mm thick, black.
Discontinuities are primarily parallel to bedding with aperture 0.5 - 2 mm, infilling with trace disintegrated sand grains, planar and slightly rough, spaced 0.1 - 0.5 m at an alph angle of 80 - 90 degree to core axis.

18.65 m, 55 mm thick zone of laminated SILTSTONE and COAL. Siltstone layers are up to 6 mm thick, grey, contain fine sand grains. Coal laminations are 0.2 - 3 mm thick, dull on drilled surface, black, laminations are undulating.

21.00 m, core dropped. Picked up and logged in run 11b

Poor to fair quality CONGLOMERATE
Fresh and unweathered, matrix is extremely weak to weak (R 0 - 2), clasts are medium-strong to strong (R 3 - 4), grey matrix with multilithic light to dark grey clasts, matrix composed primarily of medium to coarse sand with some fines, matrix grains are sub-rounded to sub-angular, clasts are fine gravel to cobble sized, sub-rounded to rounded, no visible structure, drill recovery was just above 50%, description is based on recovered material.

24.00 m, weakly cemented conglomerate unit is taking some water, slight reduction of drilling fluid returning to surface noted by drillers.

25.50 to 25.65 m, carbonate in conglomerate matrix

Fair quality SANDSTONE
Fresh and unweathered, weak to medium-strong (R 2 - 3), grey, clear/white to dark grey medium to coarse sand grains, trace fine sand and trace fines, bedded. Trace coal laminations/lenses, 0.2 - 6 mm thick, black, shiny on fresh surfaces, dull where drilled.
Discontinuities are primarily parallel to bedding with aperture 0.5 - 2 mm, planar and slightly rough, no infilling, moderate to wide spacing at an alpha angle of 75 - 80 degrees to core axis.

Good quality SILTSTONE
Fresh and unweathered, moderately strong (R 3), grey, fine grained, bedded.

Poor to fair quality CONGLOMERATE
Unweathered, matrix is very weak to weak (R 1 - 2), clasts are medium-strong to strong (R 3 - 4), grey matrix with multilithic light to dark grey clasts, matrix composed primarily of medium to coarse sand with some fines, matrix grains are sub-rounded to sub-angular, clasts are fine gravel to cobble sized, sub-rounded to rounded, no visible structure.

30.16 to 32.80 m, 10 - 20 % siltstone interbeds, 5 - 15 mm thick, some undulating, some planar with bedding, soft sediment deformation features present.

Fair to very good quality SANDSTONE
Fresh and unweathered, weak to moderately strong (R 2 - 3), grey, clear/white to dark grey medium to coarse sand

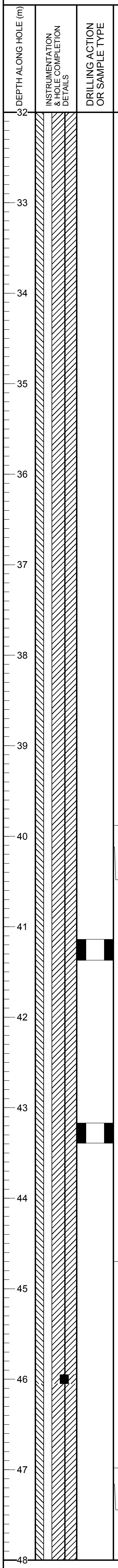
POINT LOAD TESTS
D — TEST TYPE: DIAMETRAL (D); AXIAL (A)
1.5— Is_{50} (MPa)

Project : Burnaby Mountain Westridge Tunnel Site Investigations
Project No.: 0095-150-15

DRILL HOLE # HMM-BH-03

Location: Burnaby Tank Farm

Co-ordinates (m): 504,629E - 5,457,797N	**Drill Designation:** B-80	**Start Date:** 11 SEP 14
Ground Elevation (m): 165	**Drilling Contractor:** Geotech Drilling	**Finish Date:** 22 SEP 14
Survey Method: Handheld GPS	**Drill Method:** Diamond Coring	**Final Depth (m):** 181.9
Datum: UTM 10 NAD83	**Core:** HQ3	**Depth To Top Of Rock (m):** 4.8
Plunge (°): -90	**Fluid:** Water	**Logged By:** SG/CC
Trend (°): N/A	**Cased To (m) :** 10.7	**Reviewed By:** CJS



GEOTECHNICAL DESCRIPTION, MAJOR DISCONTINUITIES, AND ADDITIONAL NOTES

grains, trace fine sand and trace fines, bedded. Trace coal laminations/lenses, 0.2 - 6 mm thick, black, shiny on fresh surfaces, dull where drilled.
Discontinuities are primarily parallel to bedding with aperture 0.5 - 2 mm, planar and slightly rough, no infilling, moderate to wide spacing at an alpha angle of 75 - 80 degrees to core axis.

33.12 m, 3 - 6 mm thick coal seam

33.17 m, 5 mm thick coal seam

33.56 to 33.63 m, 0.2 - 4 mm thick coal laminations within sandstone at 70 degrees to core axis. Approximately 10 % of interval is coal.

37.89 m, 2 coal intervals, 1 seam, 1 lens, 60 - 75 degrees to core axis, 5 to 30 mm thick.

38.01 m, 60 mm zone of uncemented conglomerate, subrounded gravel clasts.

38.88 to 39.06 m, zone of laminated coal and sandstone, coal laminations 0.2 - 3 mm thick, 70 - 80 degrees to core axis, approximately 20 % coal.

Fair quality CONGLOMERATE
Fresh and unweathered, moderately strong (R 3), grey matrix composed of medium sand and silt, gravel sized multilithic greenish-grey clasts, sub-rounded.

Fair to good quality SANDSTONE
AS ABOVE, see description at 26.05 m.

40.50 to 40.90 m, layer of very coarse sand with gravel sized clasts.

42.00 m, bedding dip 70 degrees to core axis.

42.53 to 42.59 m, thin conglomerate layer with 65 mm maximum sized gravel clasts.

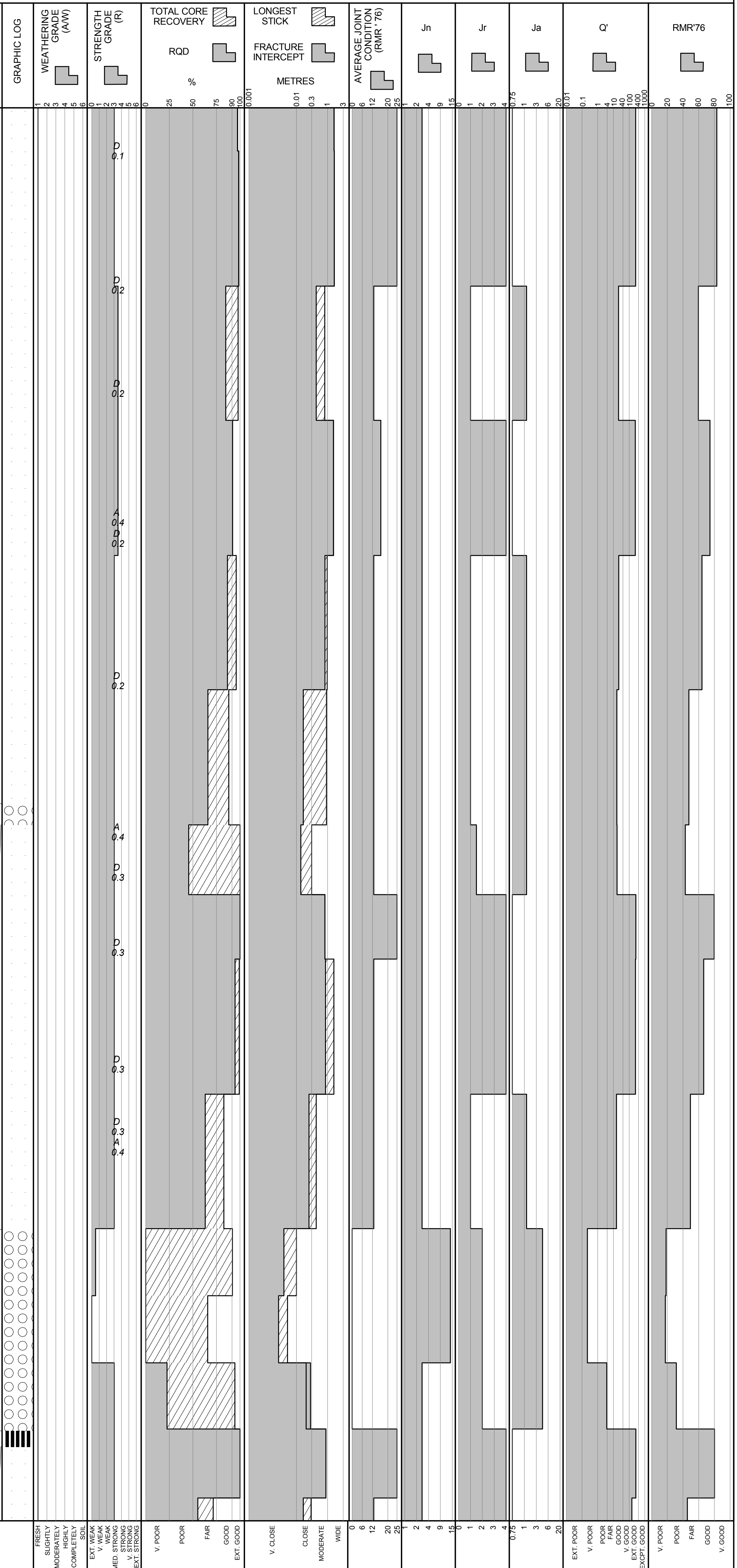
44.00 m, bedding dip 80 degrees to core axis.

Very poor to poor quality CONGLOMERATE
Fresh and unweathered, matrix is very weak to moderately strong (R 1 - 3), strongest matrix where carbonate cementation is present, clasts are moderately strong to strong (R 3 - 4), grey matrix with multilithic light to dark grey with some greenish clasts, matrix composed primarily of fine to medium sand with trace fines, clasts are fine gravel to cobble sized.

Good quality SILTSTONE
Fresh and unweathered, moderately strong (R 3), light grey, fine grained, no visible structure.

Fair to good quality SANDSTONE
Fresh and unweathered, moderately strong (R 3), grey, clear/white to dark grey medium to coarse sand grains, medium to coarse sand grains, trace fine gravel, bedded.

POINT LOAD TESTS
D — TEST TYPE: DIAMETRAL (D); AXIAL (A)
1.5— Is_{50} (MPa)



BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

Client: Trans Mountain Pipeline ULC

Project : Burnaby Mountain Westridge Tunnel Site Investigations
Project No.: 0095-150-15

DRILL HOLE # HMM-BH-03

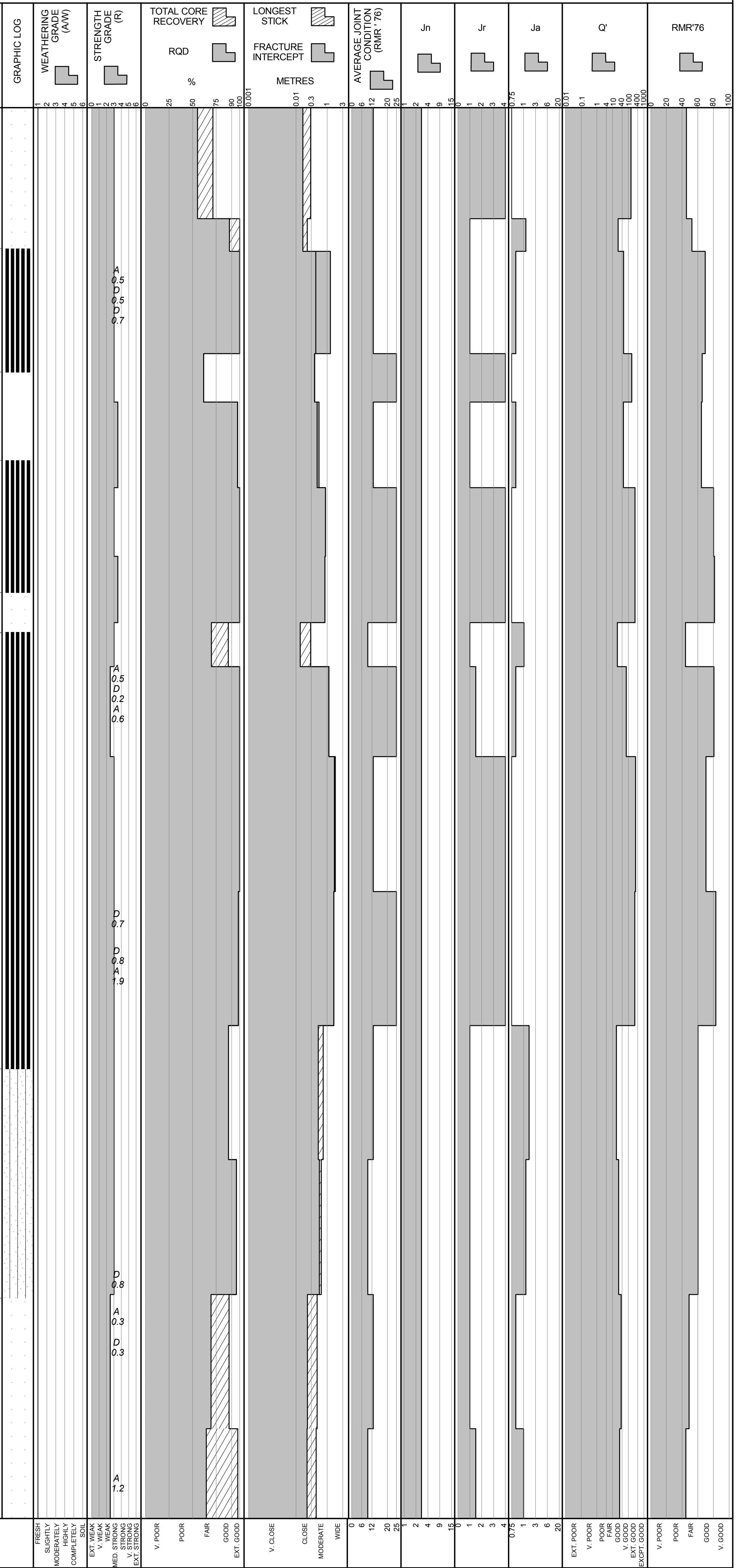
Location: Burnaby Tank Farm

Co-ordinates (m): 504,629E - 5,457,797N
Ground Elevation (m): 165
Survey Method: Handheld GPS
Datum: UTM 10 NAD83
Plunge (°): -90
Trend (°): N/A

Drill Designation: B-80
Drilling Contractor: Geotech Drilling
Drill Method: Diamond Coring
Core: HQ3
Fluid: Water
Cased To (m) : 10.7

Start Date: 11 SEP 14
Finish Date: 22 SEP 14
Final Depth (m): 181.9
Depth To Top Of Rock (m): 4.8
Logged By: SG/CC
Reviewed By: CJS

DEPTH ALONG HOLE (m)	GEOTECHNICAL DESCRIPTION, MAJOR DISCONTINUITIES, AND ADDITIONAL NOTES
48	Trace coal laminations/lenses, 0.2 - 5 mm thick, black, shiny on fresh surfaces, dull where drilled. Few discontinuities, parallel to bedding. 49.05 to 49.60 m, increased coal content to 5 - 10 %, bedding parallel, planar to undulating joint surfaces, laminations 0.5 - 5 mm thick.
49.60	49.60 to 49.75 m, dark grey laminations and soft sediment deformation features present. Good quality SILTSTONE Fresh and unweathered, moderately strong (R 3), light grey, fine grained, bedded.
51	Good quality SANDSTONE Gradational contact fining upward from medium grained grey sandstone to siltstone above.
52	Very good quality SILTSTONE Fresh and unweathered, moderately strong (R 3), light grey, fine grained, bedded.
53.5	Good to very good quality SANDSTONE Gradational contact fining upward from medium grained grey sandstone to siltstone above.
54	Good to very good quality SILTSTONE AS ABOVE, see description at 52.00 m.
59	Good quality SANDSTONE (60%) and SILTSTONE (40%) Siltstone is fresh and unweathered, moderately strong (R 3), light grey, fine grained, bedded. Sandstone is fresh, moderately strong (R 3), light grey to grey, medium-grained, bedded. Units are interbedded with thicknesses from 10 mm to 100 mm, dip of contacts varies from 45 to 90 degrees to core axis, with an average of 70 degrees, trace coal laminations and soft sediment deformation features are visible. 59.75 m, coal layer 10 mm thick, black, glassy fresh face, 60 degree to core axis. 60.35 m, coal layer 5 - 7 mm thick at 85 degrees to core axis. Undulating contacts.
61.5	Fair to good quality SANDSTONE Fresh and unweathered, moderately strong (R 3), clear/white to black, medium to coarse grained sand, bedded. Layers bedded at 75 to 80 degrees to core axis. 62.93 to 62.98 m, coal laminations, 0.2 - 2 mm thick, about 20 % of total interval, 70 degrees to core axis. 63.38 to 63.57 m, coal laminations, 0.5 - 4 mm thick, about 10 % of total interval, 70 degrees to core axis.
64	



POINT LOAD TESTS
D — TEST TYPE: DIAMETRAL (D); AXIAL (A)
1.5— $I_{s_{50}}$ (MPa)

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

Client: Trans Mountain Pipeline ULC

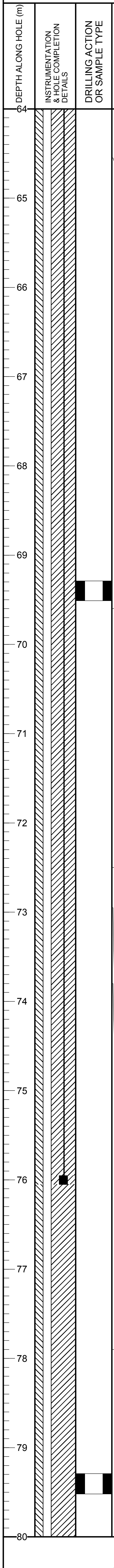
DRILL HOLE # HMM-BH-03

Location: Burnaby Tank Farm

Co-ordinates (m): 504,629E - 5,457,797N
Ground Elevation (m): 165
Survey Method: Handheld GPS
Datum: UTM 10 NAD83
Plunge (°): -90
Trend (°): N/A

Drill Designation: B-80
Drilling Contractor: Geotech Drilling
Drill Method: Diamond Coring
Core: HQ3
Fluid: Water
Cased To (m) : 10.7

Start Date: 11 SEP 14
Finish Date: 22 SEP 14
Final Depth (m): 181.9
Depth To Top Of Rock (m): 4.8
Logged By: SG/CC
Reviewed By: CJS



GEOTECHNICAL DESCRIPTION, MAJOR DISCONTINUITIES, AND ADDITIONAL NOTES

63.90 to 64.13 m, very coarse sand and fine gravel grains.

64.26 to 64.40 m, conglomerate bed. Sub-rounded to rounded, max 55 mm gravel clasts.

Fair to good quality SANDSTONE
Fresh and unweathered, moderately strong (R 3), light grey, fine grained sand, trace silt, bedded. Layers bedded at 75 to 80 degrees to core axis. Silt layers are 1 - 15 mm thick parallel to bedding.

66.30 m, 20 mm thick coal lamination zone, 0.2 - 2 mm thick, about 20 % of total interval, 82 degrees to core axis.

Fair to good quality SANDSTONE
Fresh and unweathered, moderately strong (R 3), clear/white to dark grey, medium to coarse grained sand, trace fine to medium gravel, bedded. Layers bedded at 75 to 80 degrees to core axis.

70.61 m, 130 mm thick coal lamination zone, 1 - 10 mm thick, about 5 - 10 % of total interval, sub-parallel to bedding.

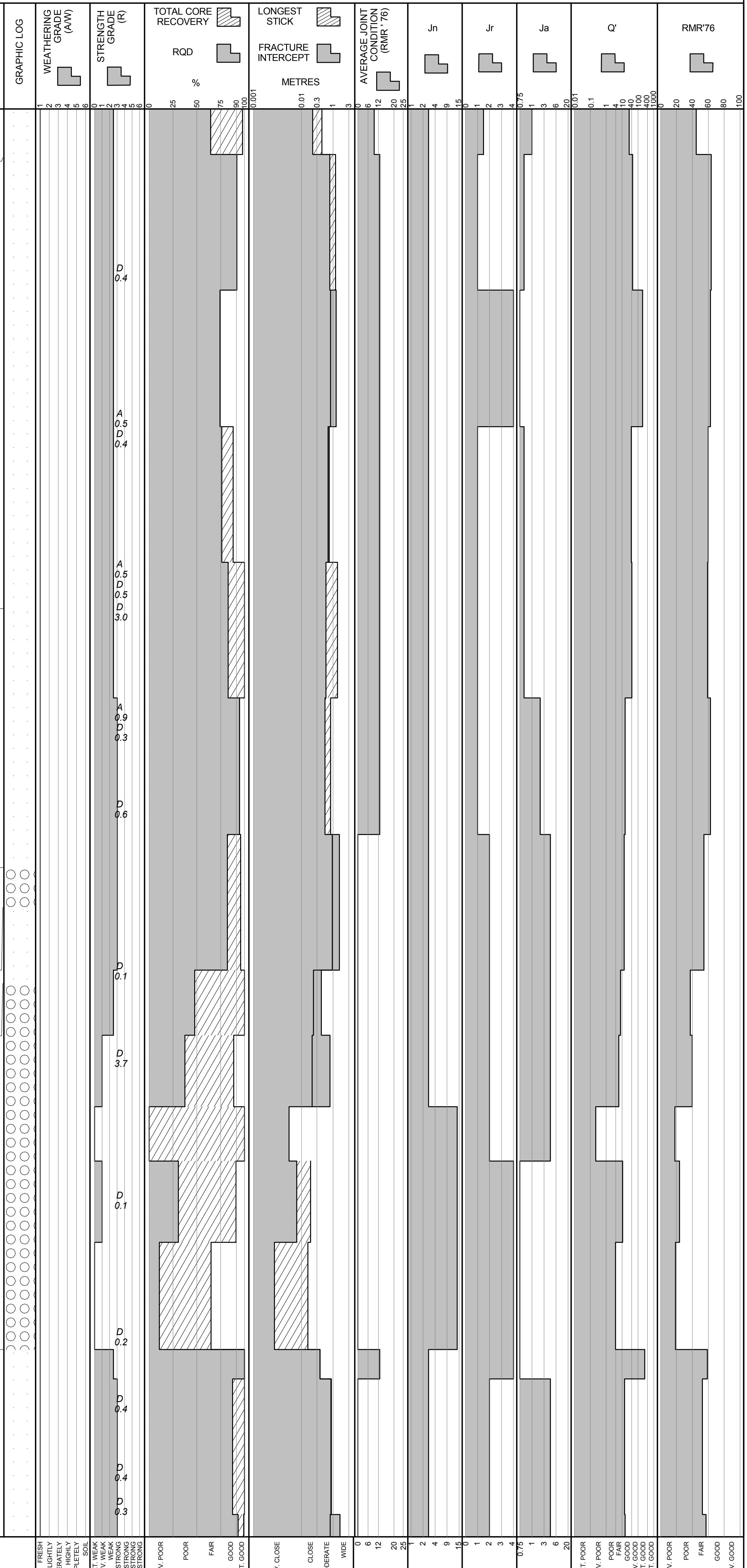
Very poor to poor quality CONGLOMERATE
Fresh, matrix-supported, matrix weak (R 2), clasts moderately strong to strong (R 3 - 4), grey matrix, matrix composed of medium to coarse grained sand, trace fine sand, multilithic grey to greenish-purplish-grey clasts, gravel to cobble sized, sub-rounded to rounded, no visible structure, poorly lithified in places, disintegrates with handling.

Fair to good quality SANDSTONE
Fresh and unweathered, moderately strong (R 3), clear/white to dark grey, medium to coarse grained sand, trace fine to medium gravel, bedded. Layers bedded at 75 to 80 degrees to core axis.

Very poor to poor quality CONGLOMERATE
Fresh and unweathered, matrix weak to moderately strong (R 2 - 3), clasts moderately strong to strong (R 3 - 4), grey matrix, matrix composed of medium to coarse grained sand, trace fines, multilithic grey to greenish-purplish-grey clasts, gravel to cobble sized, sub-rounded to rounded with trace sub-angular clasts, no visible structure, poorly lithified in places, disintegrates with handling.

Fair quality SANDSTONE (80%) with CONGLOMERATE
Fresh and unweathered, moderately strong (R 3), when dry some areas can be scraped with knife (R 2), clear/white to dark grey, medium to coarse grained sand, layers bedded at 75 to 80 degrees to core axis.
Thin interbedded conglomerate beds 10 - 20 mm thick, fresh and unweathered, matrix weak to moderately strong (R 2 - 3), clasts moderately strong to strong (R 3 - 4), grey matrix, matrix composed of medium to coarse grained sand, trace fines, multilithic grey to greenish-purplish-grey clasts, gravel to cobble sized, sub-rounded to rounded, trace sub-angular, no visible structure, poorly lithified in places, disintegrated with handling,

78.15 to 78.30 m, conglomerate bed. Fresh and



POINT LOAD TESTS
D — TEST TYPE: DIAMETRAL (D); AXIAL (A)
1.5— Is_{50} (MPa)

Co-ordinates (m): 504,629E - 5,457,797N	**Drill Designation:** B-80	**Start Date:** 11 SEP 14
Ground Elevation (m): 165	**Drilling Contractor:** Geotech Drilling	**Finish Date:** 22 SEP 14
Survey Method: Handheld GPS	**Drill Method:** Diamond Coring	**Final Depth (m):** 181.9
Datum: UTM 10 NAD83	**Core:** HQ3	**Depth To Top Of Rock (m):** 4.8
Plunge (°): -90	**Fluid:** Water	**Logged By:** SG/CC
Trend (°): N/A	**Cased To (m) :** 10.7	**Reviewed By:** CJS

GEOTECHNICAL DESCRIPTION, MAJOR DISCONTINUITIES, AND ADDITIONAL NOTES

unweathered, matrix weak to moderately strong (R 2 - 3), clasts moderately strong to strong (R 3 - 4), grey matrix, matrix composed of medium to coarse grained sand, trace fines, multilithic grey to greenish-purplish-grey clasts, gravel to cobble sized, sub-rounded to rounded, trace sub-angular

78.90 to 79.10 m, as at 78.15 m.

79.70 to 79.80 m, as at 78.15 m.

80.10 to 80.30 m, as at 78.15 m.

80.50 to 80.60 m, as at 78.15 m.

Fair to good quality SANDSTONE
Fresh and unweathered, moderately strong (R 3), when dry some areas can be scraped with knife (R 2), clear/white to dark grey, medium to coarse grained sand, trace gravel, trace fines, layers bedded at 70 to 80 degrees to core axis.

83.65 to 83.75 m, carbonate in matrix, increased matrix strength.

84.90 m, greenish cobble 60 mm max dimension observed.

Good quality SILTSTONE
Fresh and unweathered, weak to moderately strong (R 2 - 3), light grey to grey, fine grained, no visible structure.

87.80 to 87.95 m, coal laminations zone, 0.5 - 5 mm thick, 60 - 70 degrees to core axis.

Good to very good quality SANDSTONE
Fresh and unweathered, moderately strong (R 3), when dry some areas can be scraped with knife (R 2), clear/white to dark grey, medium grained sand, trace gravel, trace fines, layers bedded at 70 to 80 degrees to core axis.

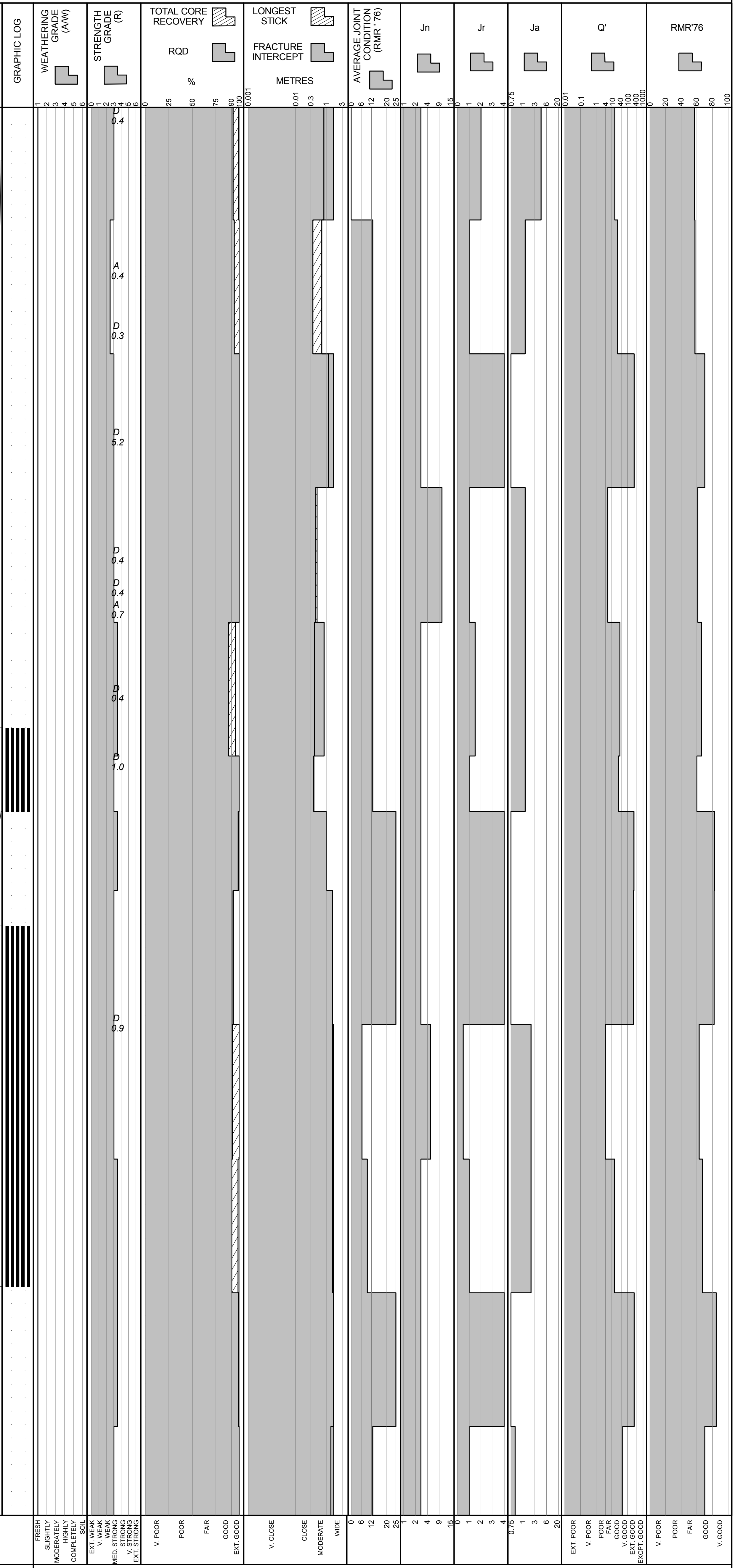
Good to very good quality SILTSTONE
Fresh and unweathered, moderately strong (R 3) when fresh, weak (R 2) when dry, grey, fine grained, some sand in stratified layers, very gradational changes, bedded at 70 - 80 degrees to core axis, some 0.2 to 2 mm thick organic mud laminations.

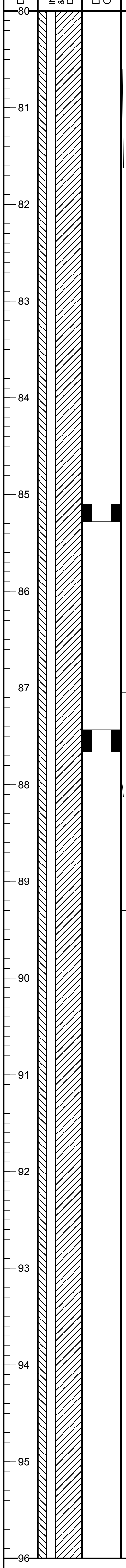
91.31 m, coal seam, 10 mm thick, 72 degrees to core axis.

91.55 m, coal seam, 10 mm thick, 85 degrees to core axis.

Good to very good quality SANDSTONE
Fresh and unweathered, moderately strong (R 3), grey, medium to coarse grained sand, trace sub-rounded gravel, layers bedded at 75 to 80 degrees to core axis. Very few discontinuities along bedding, planar, slightly rough to smooth. < 5% coal laminations sub-parallel to bedding 0.5 - 6 mm thick.

95.20 to 95.70 m, coal lamination zone, 0.5 - 3 mm thick, less than 5 % of total interval, sub-parallel to bedding.





POINT LOAD TESTS
D — TEST TYPE: DIAMETRAL (D); AXIAL (A)
1.5— $I_{s_{50}}$ (MPa)

Project : Burnaby Mountain Westridge Tunnel Site Investigations
Project No.: 0095-150-15

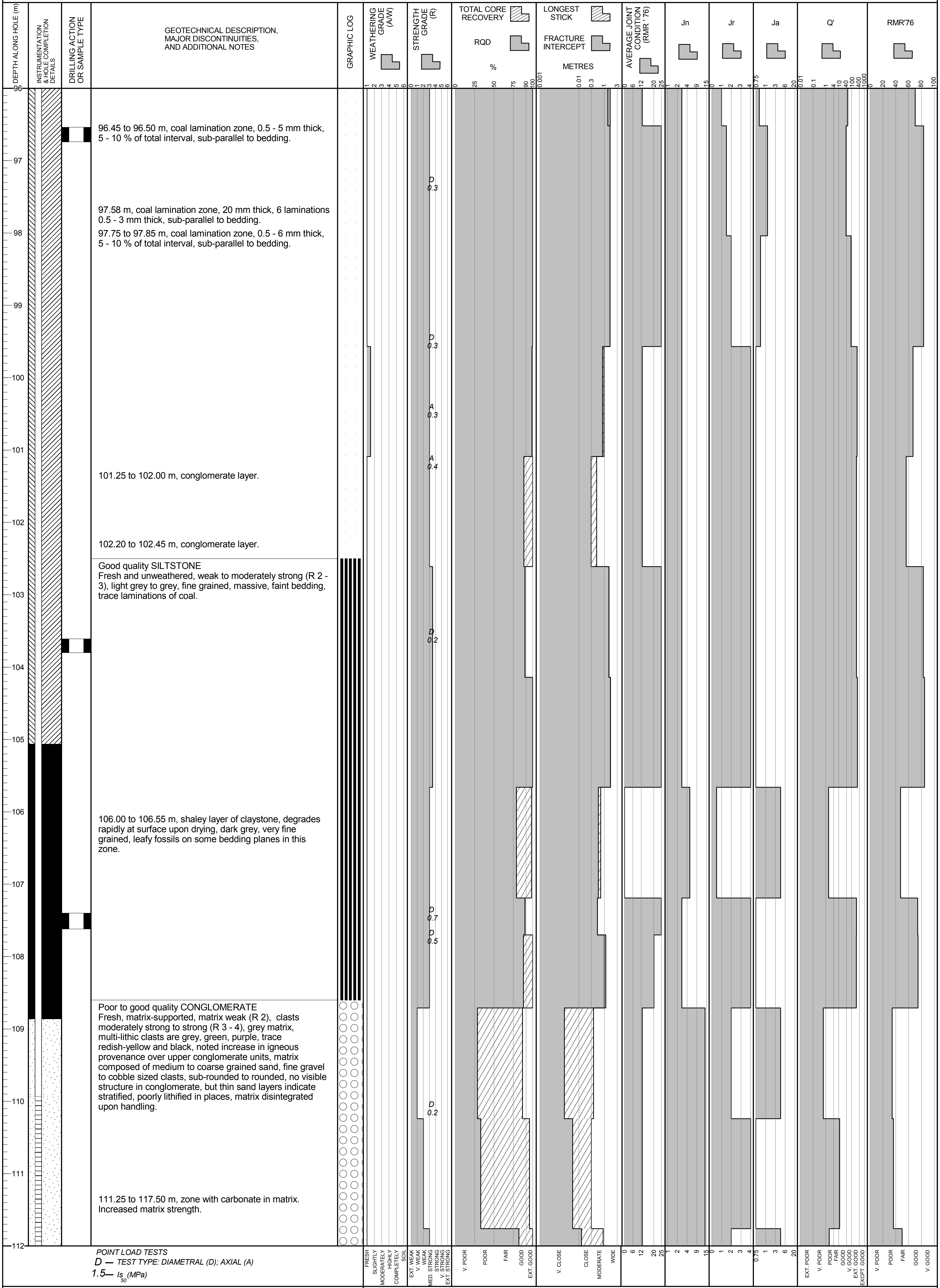
DRILL HOLE # HMM-BH-03

Location: Burnaby Tank Farm

Co-ordinates (m): 504,629E - 5,457,797N
Ground Elevation (m): 165
Survey Method: Handheld GPS
Datum: UTM 10 NAD83
Plunge (°): -90
Trend (°): N/A

Drill Designation: B-80
Drilling Contractor: Geotech Drilling
Drill Method: Diamond Coring
Core: HQ3
Fluid: Water
Cased To (m) : 10.7

Start Date: 11 SEP 14
Finish Date: 22 SEP 14
Final Depth (m): 181.9
Depth To Top Of Rock (m): 4.8
Logged By: SG/CC
Reviewed By: CJS



96.45 to 96.50 m, coal lamination zone, 0.5 - 5 mm thick, 5 - 10 % of total interval, sub-parallel to bedding.

97.58 m, coal lamination zone, 20 mm thick, 6 laminations 0.5 - 3 mm thick, sub-parallel to bedding.

97.75 to 97.85 m, coal lamination zone, 0.5 - 6 mm thick, 5 - 10 % of total interval, sub-parallel to bedding.

101.25 to 102.00 m, conglomerate layer.

102.20 to 102.45 m, conglomerate layer.

Good quality SILTSTONE
Fresh and unweathered, weak to moderately strong (R 2 - 3), light grey to grey, fine grained, massive, faint bedding, trace laminations of coal.

106.00 to 106.55 m, shaley layer of claystone, degrades rapidly at surface upon drying, dark grey, very fine grained, leafy fossils on some bedding planes in this zone.

Poor to good quality CONGLOMERATE
Fresh, matrix-supported, matrix weak (R 2), clasts moderately strong to strong (R 3 - 4), grey matrix, multi-lithic clasts are grey, green, purple, trace redish-yellow and black, noted increase in igneous provenance over upper conglomerate units, matrix composed of medium to coarse grained sand, fine gravel to cobble sized clasts, sub-rounded to rounded, no visible structure in conglomerate, but thin sand layers indicate stratified, poorly lithified in places, matrix disintegrated upon handling.

111.25 to 117.50 m, zone with carbonate in matrix. Increased matrix strength.

POINT LOAD TESTS
D — TEST TYPE: DIAMETRAL (D); AXIAL (A)
1.5— Is_{50} (MPa)

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

Client: Trans Mountain Pipeline ULC

Project : Burnaby Mountain Westridge Tunnel Site Investigations
Project No.: 0095-150-15

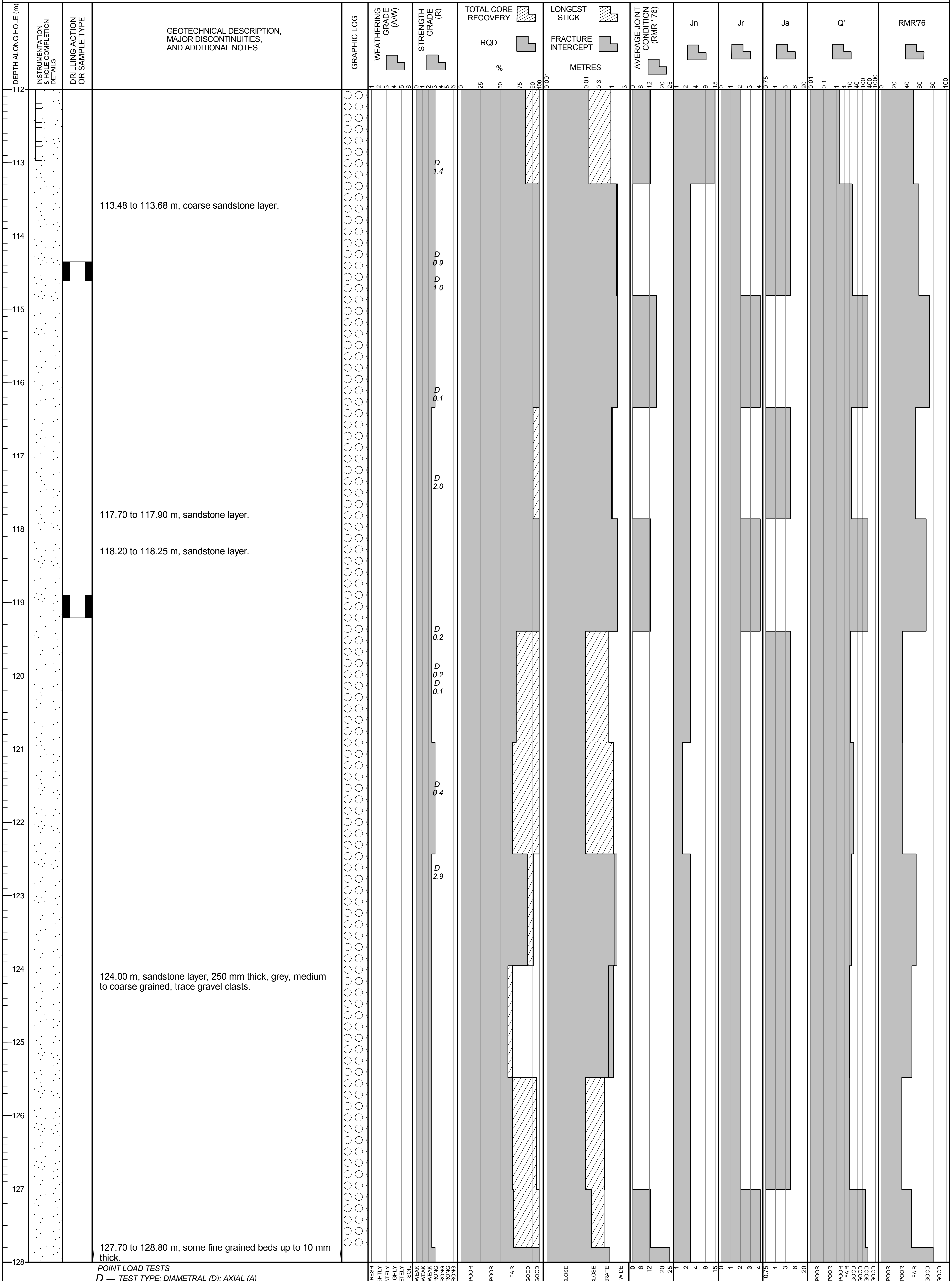
DRILL HOLE # HMM-BH-03

Location: Burnaby Tank Farm

Co-ordinates (m): 504,629E - 5,457,797N
Ground Elevation (m): 165
Survey Method: Handheld GPS
Datum: UTM 10 NAD83
Plunge (°): -90
Trend (°): N/A

Drill Designation: B-80
Drilling Contractor: Geotech Drilling
Drill Method: Diamond Coring
Core: HQ3
Fluid: Water
Cased To (m) : 10.7

Start Date: 11 SEP 14
Finish Date: 22 SEP 14
Final Depth (m): 181.9
Depth To Top Of Rock (m): 4.8
Logged By: SG/CC
Reviewed By: CJS



113.48 to 113.68 m, coarse sandstone layer.

117.70 to 117.90 m, sandstone layer.

118.20 to 118.25 m, sandstone layer.

124.00 m, sandstone layer, 250 mm thick, grey, medium to coarse grained, trace gravel clasts.

127.70 to 128.80 m, some fine grained beds up to 10 mm thick.

POINT LOAD TESTS
D — TEST TYPE: DIAMETRAL (D); AXIAL (A)
1.5— $I_{s_{50}}$ (MPa)

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

Client: Trans Mountain Pipeline ULC

KINDER MORGAN UNDERGROUND (ROCK) KINDERMORGAN_ROCK.GDL BGC.GDT 11/4/14

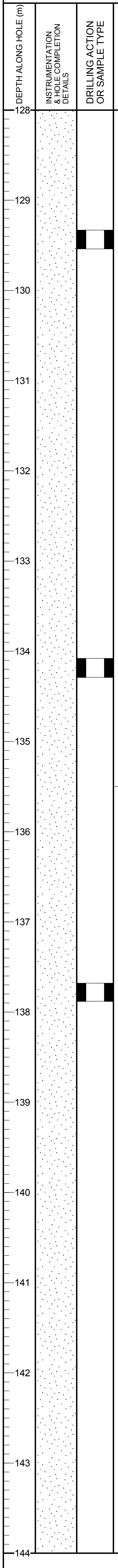
DRILL HOLE # HMM-BH-03

Location: Burnaby Tank Farm

Co-ordinates (m): 504,629E - 5,457,797N
Ground Elevation (m): 165
Survey Method: Handheld GPS
Datum: UTM 10 NAD83
Plunge (°): -90
Trend (°): N/A

Drill Designation: B-80
Drilling Contractor: Geotech Drilling
Drill Method: Diamond Coring
Core: HQ3
Fluid: Water
Cased To (m) : 10.7

Start Date: 11 SEP 14
Finish Date: 22 SEP 14
Final Depth (m): 181.9
Depth To Top Of Rock (m): 4.8
Logged By: SG/CC
Reviewed By: CJS



GEOTECHNICAL DESCRIPTION, MAJOR DISCONTINUITIES, AND ADDITIONAL NOTES

Good to very good quality SANDSTONE
Fresh and unweathered, moderately strong (R 3), grey, white to dark grey grains, medium to coarse grained sand, trace sub-rounded gravel, layers bedded at 65 to 85 degrees to core axis.

128.03 m, coal seam, 10 mm thick, black, 60 degrees to core axis, sub-parallel to bedding.

128.28 m, coal seam, 10 mm thick, black, 60 degrees to core axis, sub-parallel to bedding.

128.65 m, siltstone and coal layer, 10 mm thick, trace carbonate in matrix.

128.85 m, siltstone layer, 80 mm thick, dark grey, fine grained.

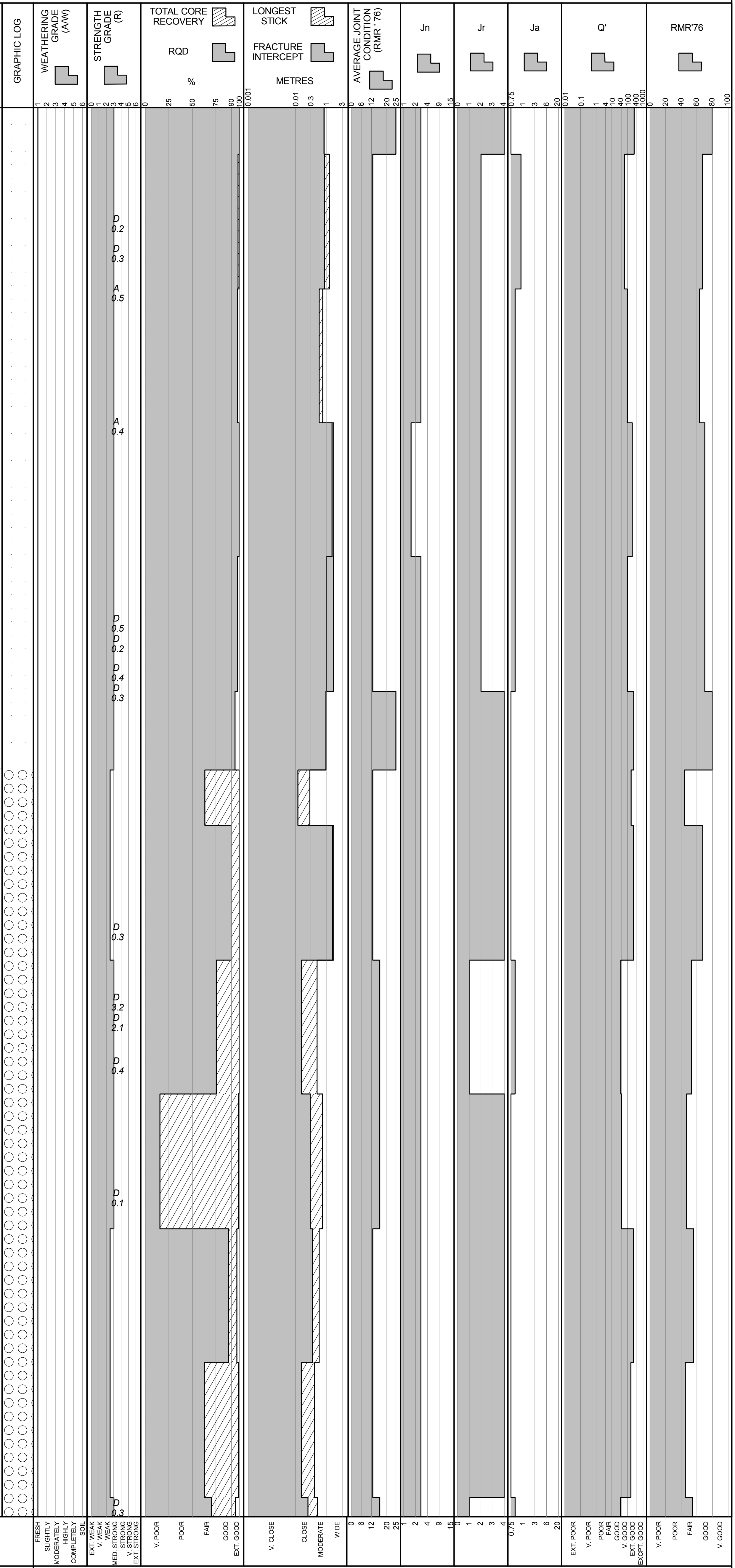
130.75 m, 10 mm zone with some multi-lithic gravel clasts.

130.86 m, coal lens, 20 mm thick, 65 degrees to core axis.

131.40 m, coal seam, 15 mm thick, 70 degrees to core axis, bedding changes direction.

131.70 to 131.90 m, conglomerate zone, matrix supported.

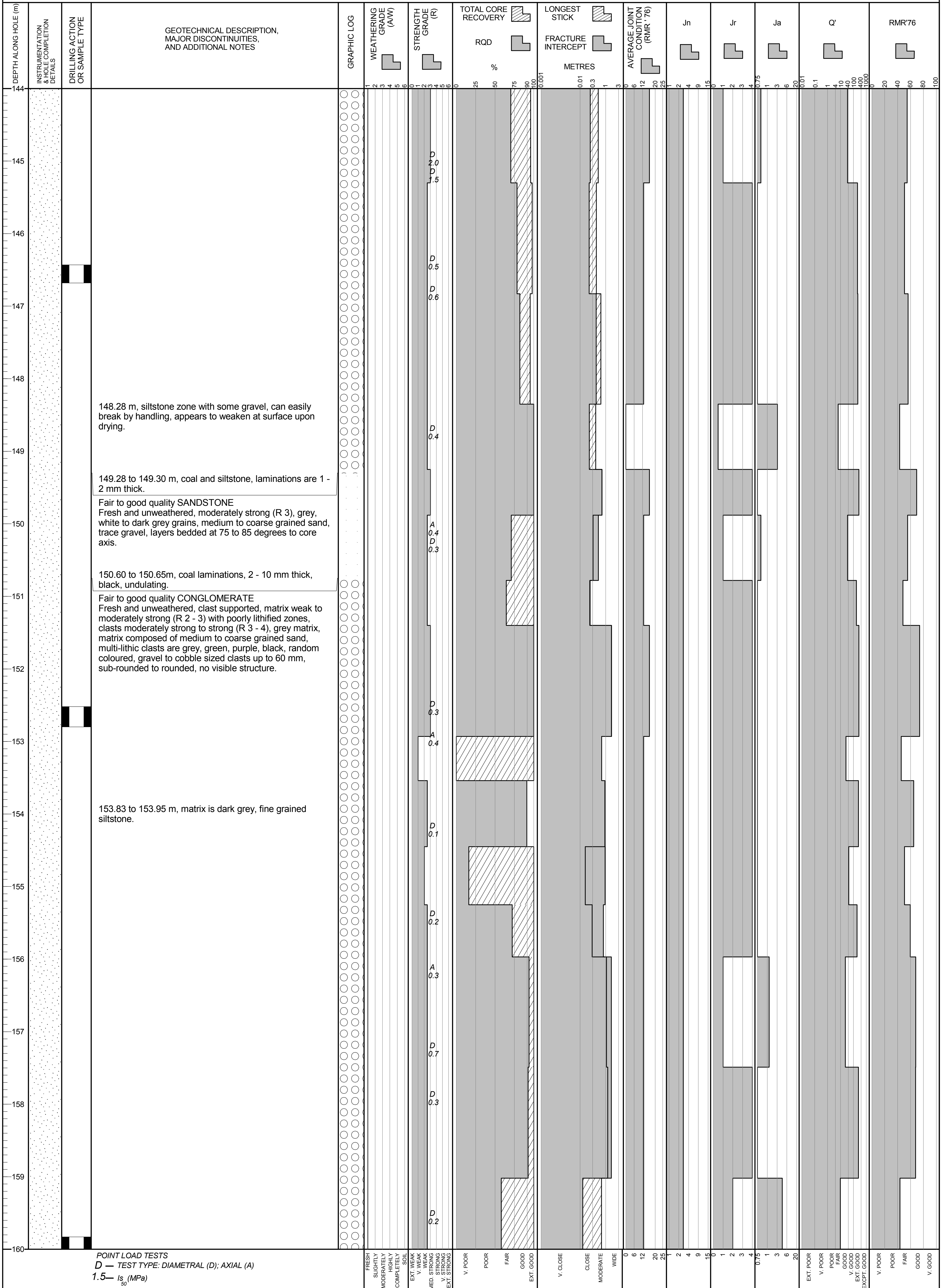
Fair to good quality CONGLOMERATE
Fresh and unweathered, clast supported, matrix weak to moderately strong (R 2 - 3) with poorly lithified zones, clasts moderately strong to strong (R 3 - 4), grey matrix composed of medium to coarse sand grains, multi-lithic clasts are grey, green, purple, and black coloured, gravel to cobble sized clasts up to 60 mm, sub-rounded to rounded clasts, no visible structure.



POINT LOAD TESTS
D — TEST TYPE: DIAMETRAL (D); AXIAL (A)
1.5— Is_{50} (MPa)

Location: Burnaby Tank Farm

Co-ordinates (m): 504,629E - 5,457,797N	***Drill Designation:*** B-80	***Start Date:*** 11 SEP 14
Ground Elevation (m): 165	***Drilling Contractor:*** Geotech Drilling	***Finish Date:*** 22 SEP 14
Survey Method: Handheld GPS	***Drill Method:*** Diamond Coring	***Final Depth (m):*** 181.9
Datum: UTM 10 NAD83	***Core:*** HQ3	***Depth To Top Of Rock (m):*** 4.8
Plunge (°): -90	***Fluid:*** Water	***Logged By:*** SG/CC
Trend (°): N/A	***Cased To (m) :*** 10.7	***Reviewed By:*** CJS



148.28 m, siltstone zone with some gravel, can easily break by handling, appears to weaken at surface upon drying.

149.28 to 149.30 m, coal and siltstone, laminations are 1 - 2 mm thick.

Fair to good quality SANDSTONE
Fresh and unweathered, moderately strong (R 3), grey, white to dark grey grains, medium to coarse grained sand, trace gravel, layers bedded at 75 to 85 degrees to core axis.

150.60 to 150.65m, coal laminations, 2 - 10 mm thick, black, undulating.

Fair to good quality CONGLOMERATE
Fresh and unweathered, clast supported, matrix weak to moderately strong (R 2 - 3) with poorly lithified zones, clasts moderately strong to strong (R 3 - 4), grey matrix, matrix composed of medium to coarse grained sand, multi-lithic clasts are grey, green, purple, black, random coloured, gravel to cobble sized clasts up to 60 mm, sub-rounded to rounded, no visible structure.

153.83 to 153.95 m, matrix is dark grey, fine grained siltstone.

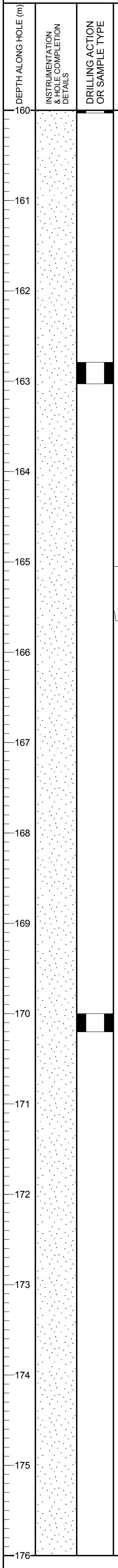
POINT LOAD TESTS
D — TEST TYPE: DIAMETRAL (D); AXIAL (A)
1.5— $I_{s_{50}}$ (MPa)

Project : Burnaby Mountain Westridge Tunnel Site Investigations
Project No.: 0095-150-15

DRILL HOLE # HMM-BH-03

Location: Burnaby Tank Farm

Co-ordinates (m): 504,629E - 5,457,797N	**Drill Designation:** B-80	**Start Date:** 11 SEP 14
Ground Elevation (m): 165	**Drilling Contractor:** Geotech Drilling	**Finish Date:** 22 SEP 14
Survey Method: Handheld GPS	**Drill Method:** Diamond Coring	**Final Depth (m):** 181.9
Datum: UTM 10 NAD83	**Core:** HQ3	**Depth To Top Of Rock (m):** 4.8
Plunge (°): -90	**Fluid:** Water	**Logged By:** SG/CC
Trend (°): N/A	**Cased To (m) :** 10.7	**Reviewed By:** CJS



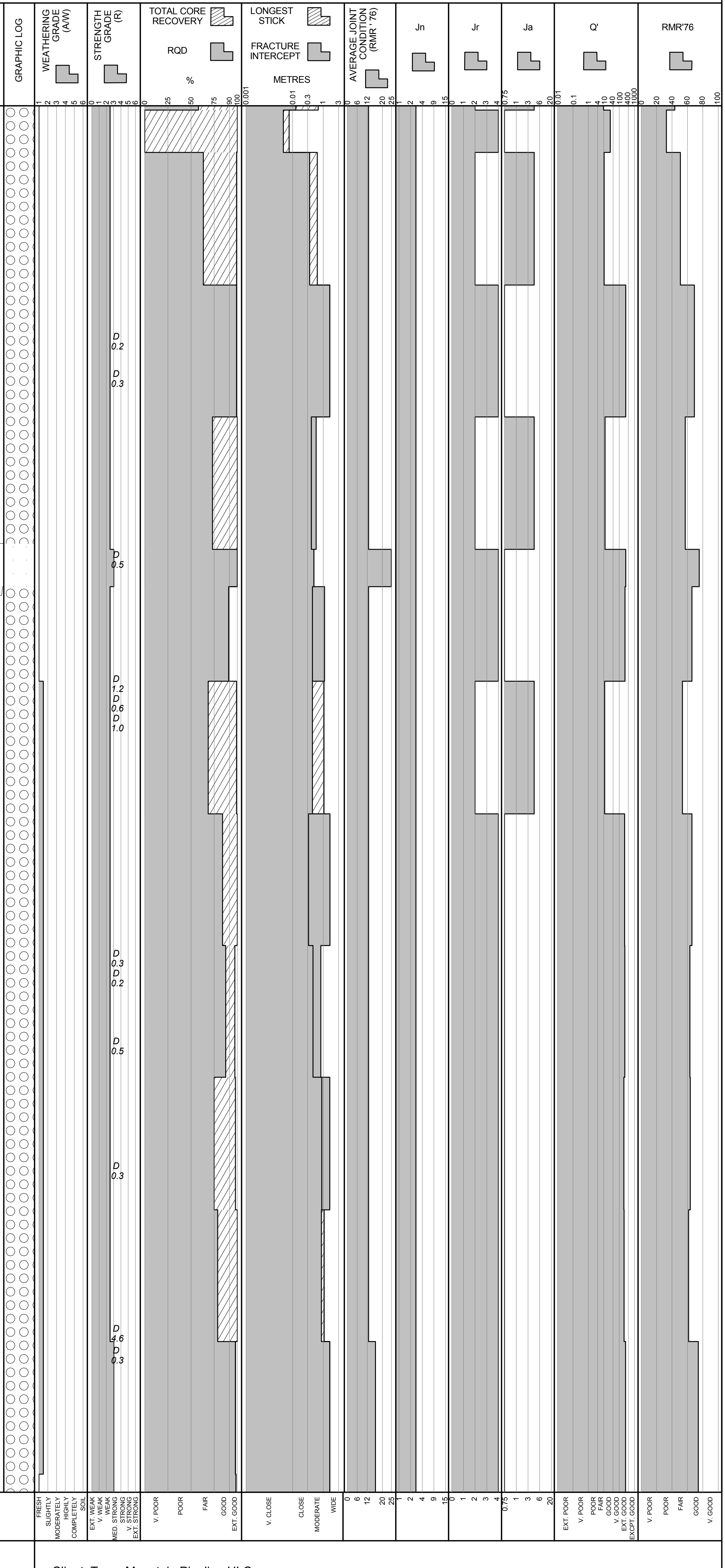
GEOTECHNICAL DESCRIPTION, MAJOR DISCONTINUITIES, AND ADDITIONAL NOTES

161.30 to 161.60 m, matrix supported layer, approximately 20 % clasts.

164.03 m, sandstone layer, 250 mm thick, grey, medium to coarse grains, bedded at 75 - 80 degrees to core axis.

Fair to good quality SANDSTONE Fresh and unweathered, moderately strong (R 3), greenish-grey, coarse to very coarse grained sand, some fine gravel, no visible structure.

Fair to good quality CONGLOMERATE
Fresh and unweathered, clast supported, matrix moderately strong (R 3), clasts moderately strong to very strong (R 3 - 5), greenish-grey matrix, multi-lithic clasts are grey, green, purplish, and black, more mafic volcanics than upper conglomerate units, some clasts appear to be altered/weathered before deposition, medium gravel to large cobble sized clasts up to 140 mm, sub-rounded to rounded, no visible structure, breaks in core primarily along clast/matrix boundaries, many mechanical fractures.



POINT LOAD TESTS
D — TEST TYPE: DIAMETRAL (D); AXIAL (A)
1.5— Is_{50} (MPa)

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

Client: Trans Mountain Pipeline ULC

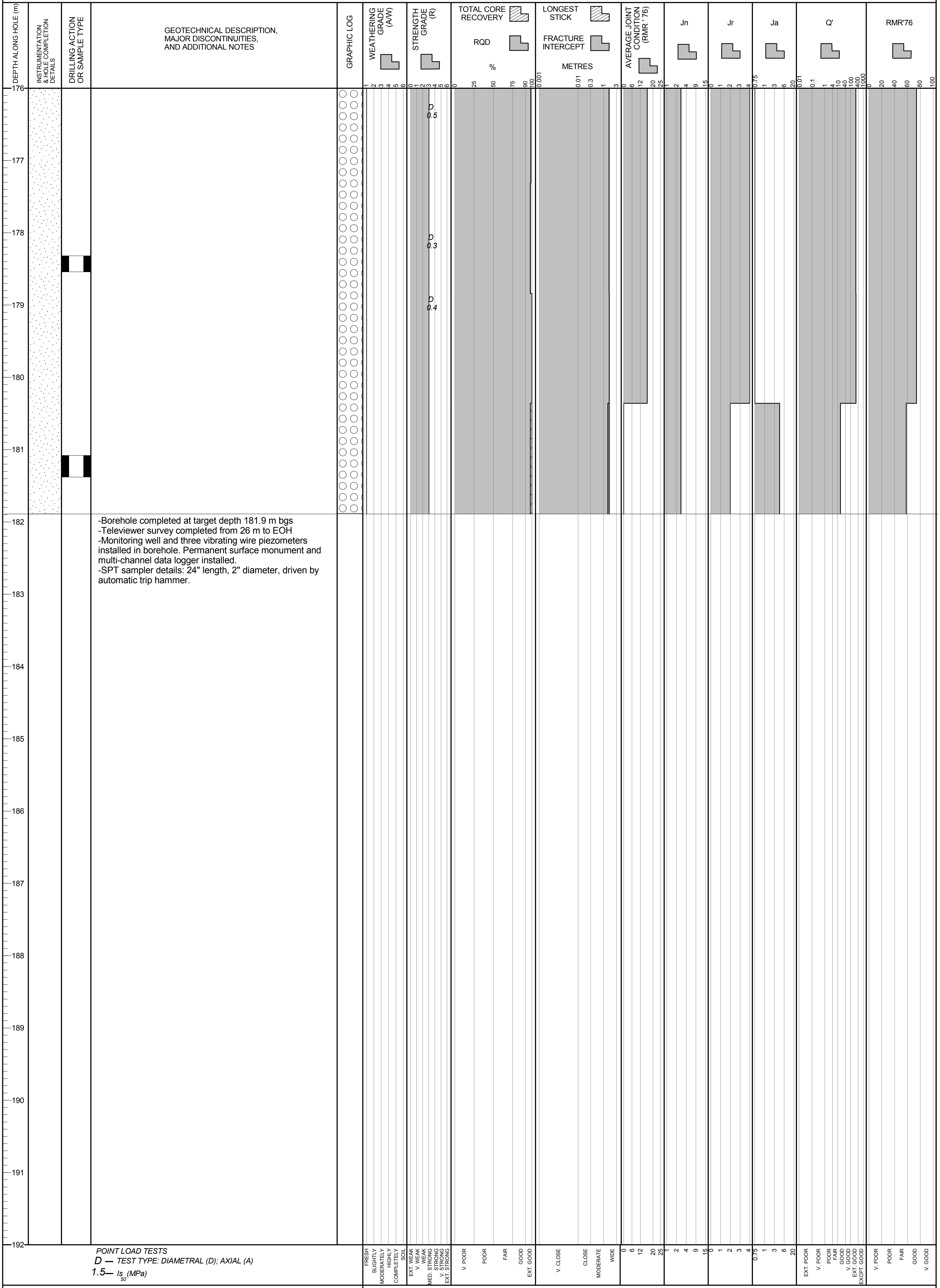
KINDER MORGAN UNDERGROUND (ROCK) KINDERMORGAN_ROCK.GDL BGC.GDT 11/4/14

Project : Burnaby Mountain Westridge Tunnel Site Investigations
Project No.: 0095-150-15

DRILL HOLE # HMM-BH-03

Location: Burnaby Tank Farm

Co-ordinates (m): 504,629E - 5,457,797N	***Drill Designation:*** B-80	***Start Date:*** 11 SEP 14
Ground Elevation (m): 165	***Drilling Contractor:*** Geotech Drilling	***Finish Date:*** 22 SEP 14
Survey Method: Handheld GPS	***Drill Method:*** Diamond Coring	***Final Depth (m):*** 181.9
Datum: UTM 10 NAD83	***Core:*** HQ3	***Depth To Top Of Rock (m):*** 4.8
Plunge (°): -90	***Fluid:*** Water	***Logged By:*** SG/CC
Trend (°): N/A	***Cased To (m) :*** 10.7	***Reviewed By:*** CJS



-Borehole completed at target depth 181.9 m bgs
-Televiewer survey completed from 26 m to EOH
-Monitoring well and three vibrating wire piezometers installed in borehole. Permanent surface monument and multi-channel data logger installed.
-SPT sampler details: 24" length, 2" diameter, driven by automatic trip hammer.

POINT LOAD TESTS
D — TEST TYPE: DIAMETRAL (D); AXIAL (A)
1.5— $I_{s_{50}}$ (MPa)

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

Client: Trans Mountain Pipeline ULC

Project: Burnaby Mountain Westridge Tunnel Site Investigations

Project No.: 0095-150-15

DRILL HOLE # HMM-BH-05

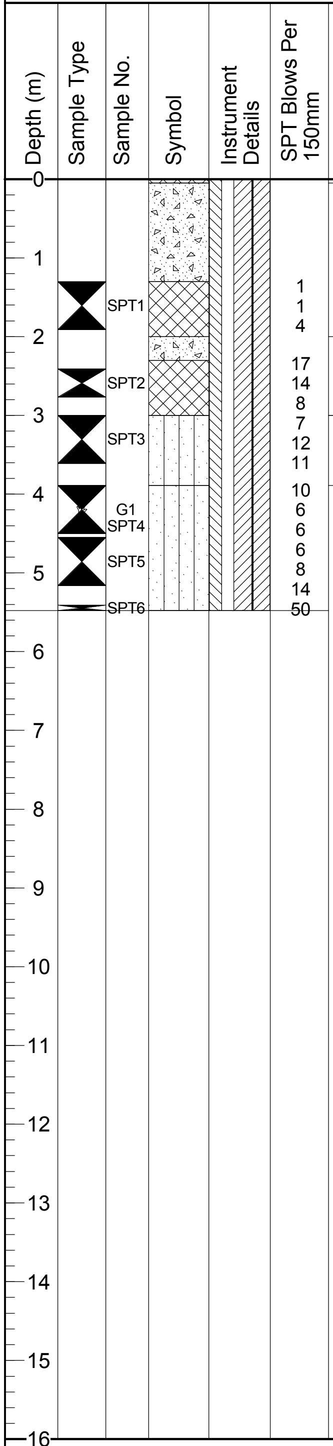
Page 1 **of** 4

Location: Kask Brothers Facility

Co-ordinates (m): 503,871E - 5,459,625N
Ground Elevation (m): 33.0
Survey Method: Handheld GPS
Datum: UTM 10 NAD83
Plunge (°): -90
Trend (°): N/A

Drill Designation: B-80
Drilling Contractor: Geotech Drilling Services
Drill Method: ODEX / Diamond Coring
Core: HQ3
Fluid: Water / Bentonite
Cased To (m) : 16.8

Start Date: 03 Oct 14
Finish Date: 05 Oct 14
Final Depth (m): 44.5
Depth To Top Of Rock (m): 5.5
Logged By: JS/SG
Reviewed By: CJS



Sample No.	SPT Blows Per 150mm
SPT1	1 1 4
SPT2	17 14 8
SPT3	7 12 11
G1 SPT4	10 6 6
SPT5	6 8 14
SPT6	50

Lithologic Description

SAND and SILT, fine to medium sand, gravelly, well graded, loose to compact, maximum particle size 30 mm, flat to equidimensional particles, subrounded to subangular, brown to black, no odour, dry to moist, stratified, no cementation, fines are medium plasticity, very stiff, rapid dilatancy, [ANTHROPOGENIC]

0.05 to 1.30 m, concrete

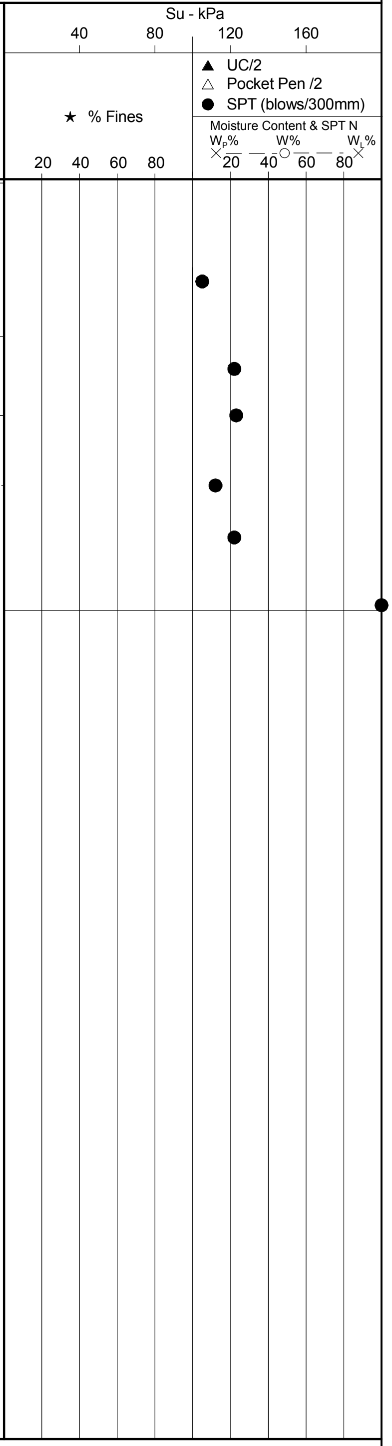
1.30 m, some woody particles.

2.00 to 2.30 m, concrete
2.41 to 2.71 m, possible diesel odour.

SAND and SILT, some gravel, fine to medium sand, well graded, loose to compact, maximum particle size 50 mm, flat to equidimensional particles, subrounded to subangular, brown, no odour, dry to moist, stratified, no cementation, fines are low plasticity, very stiff, rapid dilatancy, [COLLUVIUM]

3.89 m, Gravel content decreases to trace gravel, sand fraction becomes fine, maximum particle size decreases to 20 mm, becomes brown to black, fines become medium plasticity.

Rock encountered at 5.5 m depth.
Refer to HMM-BH-05 rock log.



Client: Trans Mountain Pipeline ULC

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

Project : Burnaby Mountain Westridge Tunnel Site Investigations
Project No.: 0095-150-15

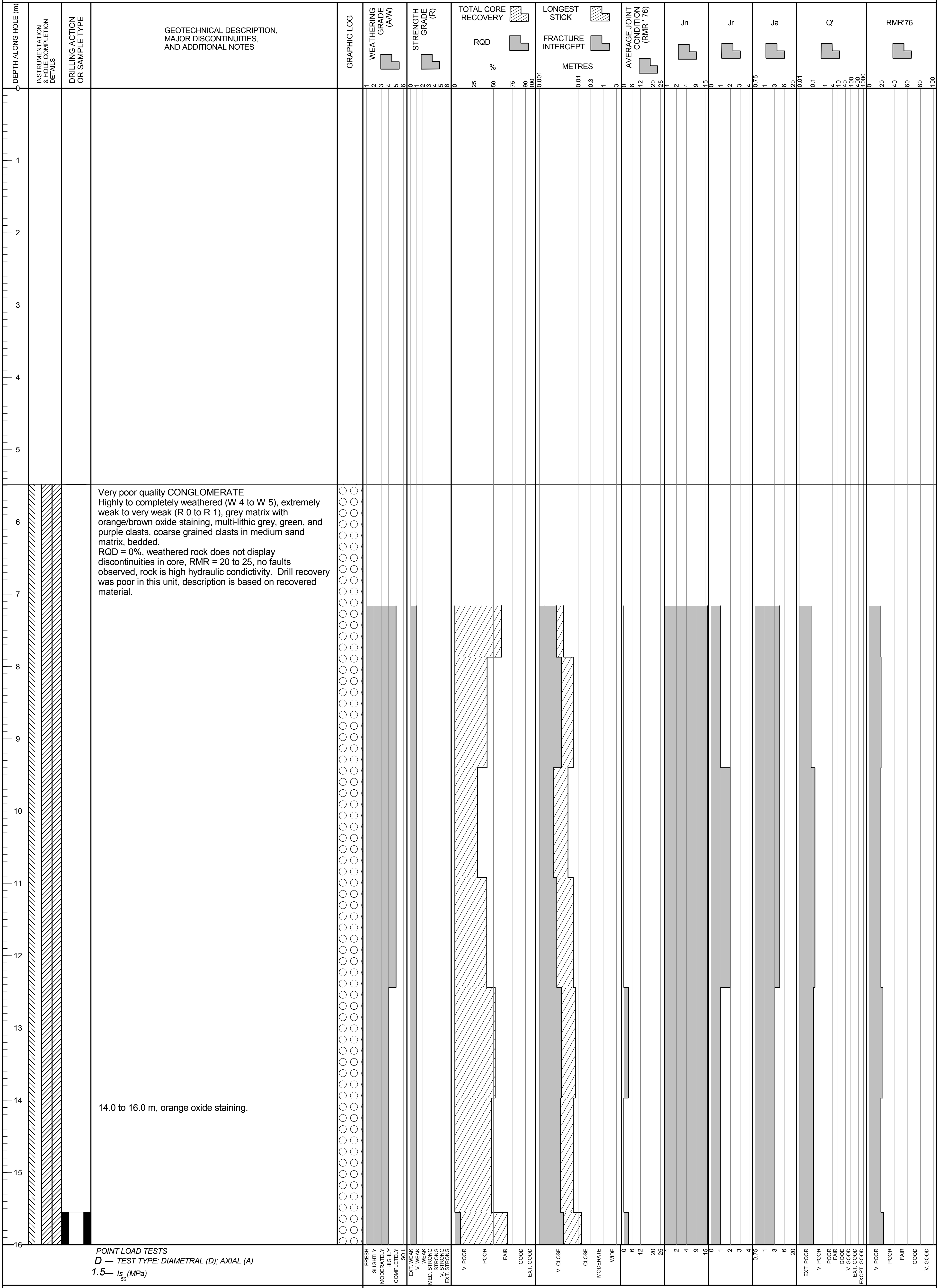
DRILL HOLE # HMM-BH-05

Location: Kask Brothers Facility

Co-ordinates (m): 503,871E - 5,459,625N
Ground Elevation (m): 33
Survey Method: Handheld GPS
Datum: UTM 10 NAD83
Plunge (°): -90
Trend (°): N/A

Drill Designation: B-80
Drilling Contractor: Geotech Drilling Services
Drill Method: ODEX / Diamond Coring
Core: HQ3
Fluid: Water / Bentonite
Cased To (m) : 16.8

Start Date: 03 OCT 14
Finish Date: 05 OCT 14
Final Depth (m): 44.5
Depth To Top Of Rock (m): 5.5
Logged By: JS/SG
Reviewed By: CJS



GEOTECHNICAL DESCRIPTION, MAJOR DISCONTINUITIES, AND ADDITIONAL NOTES

Very poor quality CONGLOMERATE
Highly to completely weathered (W 4 to W 5), extremely weak to very weak (R 0 to R 1), grey matrix with orange/brown oxide staining, multi-lithic grey, green, and purple clasts, coarse grained clasts in medium sand matrix, bedded.
RQD = 0%, weathered rock does not display discontinuities in core, RMR = 20 to 25, no faults observed, rock is high hydraulic condictivity. Drill recovery was poor in this unit, description is based on recovered material.

14.0 to 16.0 m, orange oxide staining.

POINT LOAD TESTS
D — TEST TYPE: DIAMETRAL (D); AXIAL (A)
1.5— Is_{50} (MPa)

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

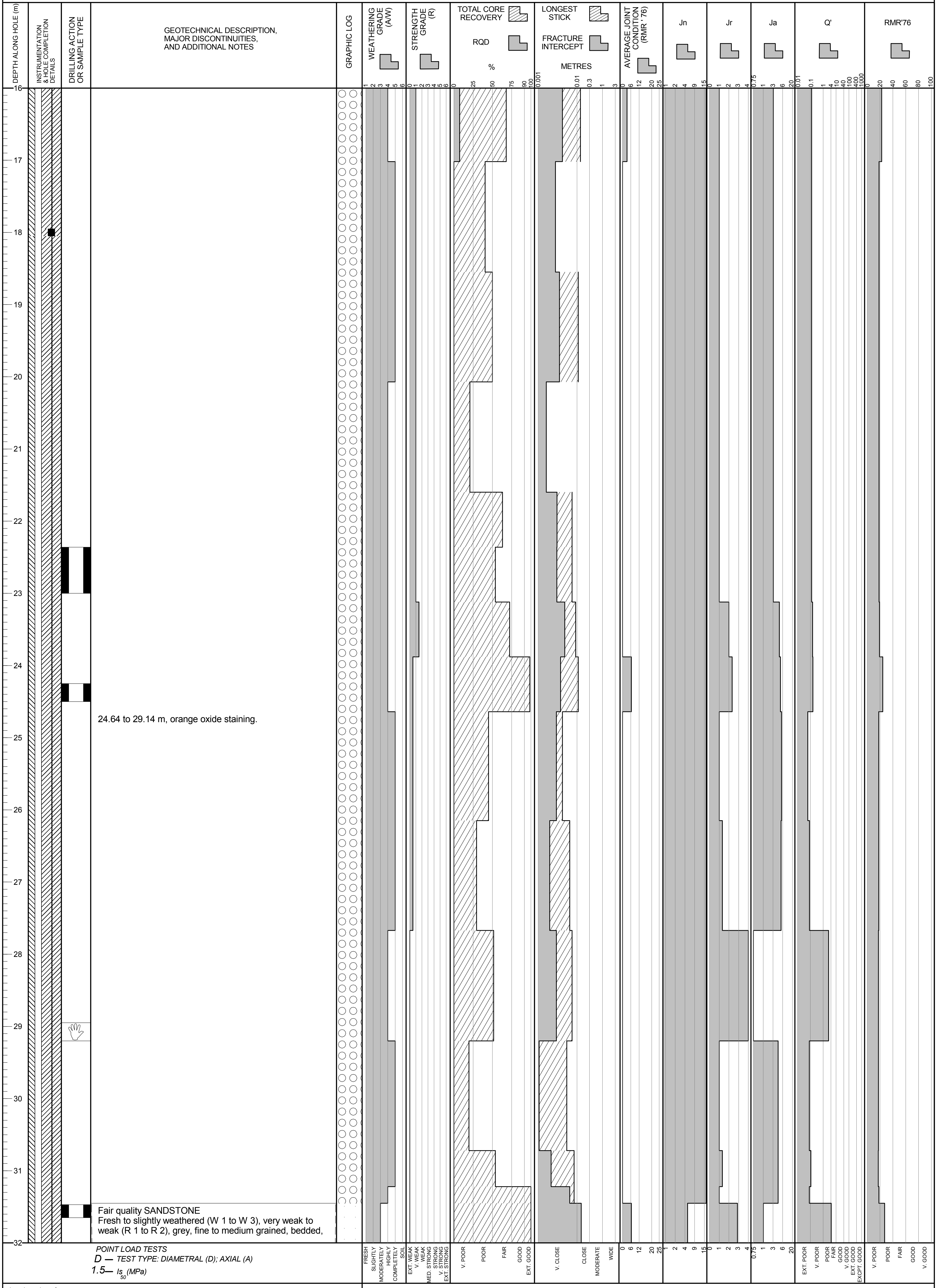
Client: Trans Mountain Pipeline ULC

Project : Burnaby Mountain Westridge Tunnel Site Investigations
Project No.: 0095-150-15

DRILL HOLE # HMM-BH-05

Location: Kask Brothers Facility

Co-ordinates (m): 503,871E - 5,459,625N	**Drill Designation:** B-80	**Start Date:** 03 OCT 14
Ground Elevation (m): 33	**Drilling Contractor:** Geotech Drilling Services	**Finish Date:** 05 OCT 14
Survey Method: Handheld GPS	**Drill Method:** ODEX / Diamond Coring	**Final Depth (m):** 44.5
Datum: UTM 10 NAD83	**Core:** HQ3	**Depth To Top Of Rock (m):** 5.5
Plunge (°): -90	**Fluid:** Water / Bentonite	**Logged By:** JS/SG
Trend (°): N/A	**Cased To (m) :** 16.8	**Reviewed By:** CJS



24.64 to 29.14 m, orange oxide staining.

Fair quality SANDSTONE
Fresh to slightly weathered (W 1 to W 3), very weak to weak (R 1 to R 2), grey, fine to medium grained, bedded,

POINT LOAD TESTS
D — TEST TYPE: DIAMETRAL (D); AXIAL (A)
1.5— Is_{50} (MPa)

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

Client: Trans Mountain Pipeline ULC

Project : Burnaby Mountain Westridge Tunnel Site Investigations
Project No.: 0095-150-15

DRILL HOLE # HMM-BH-05

Location: Kask Brothers Facility

Co-ordinates (m): 503,871E - 5,459,625N
Ground Elevation (m): 33
Survey Method: Handheld GPS
Datum: UTM 10 NAD83
Plunge (°): -90
Trend (°): N/A

Drill Designation: B-80
Drilling Contractor: Geotech Drilling Services
Drill Method: ODEX / Diamond Coring
Core: HQ3
Fluid: Water / Bentonite
Cased To (m) : 16.8

Start Date: 03 OCT 14
Finish Date: 05 OCT 14
Final Depth (m): 44.5
Depth To Top Of Rock (m): 5.5
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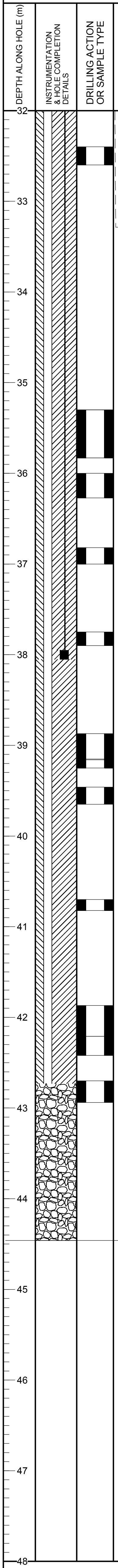
Reviewed By: CJS



GEOTECHNICAL DESCRIPTION,
MAJOR DISCONTINUITIES,
AND ADDITIONAL NOTES

intermittent orange oxide weathered zones.
RQD 60 to 100%, discontinuities form two dominant sets:
1) Along bedding: aperture ranges from 0 to 3 mm, typically iron stained surfaces, JRC 8 to 12, 0.5 m spacing, alpha angle 70 to 85 degrees to core axis.
2) Across bedding: aperture ranges from 1 to 2 mm, typically no infill, JRC 6 to 10, sporadic spacing, alpha angle 35 to 50 degrees to core axis, RMR 50 to 70. No faults observed, high hydraulic conductivity.

31.45 to 31.65 m, orange oxide staining of rock mass.

31.47 m, becomes moderately weathered (W 3), extremely weak (R 0), green.

39.25 m, fine gravel fragments, brown.

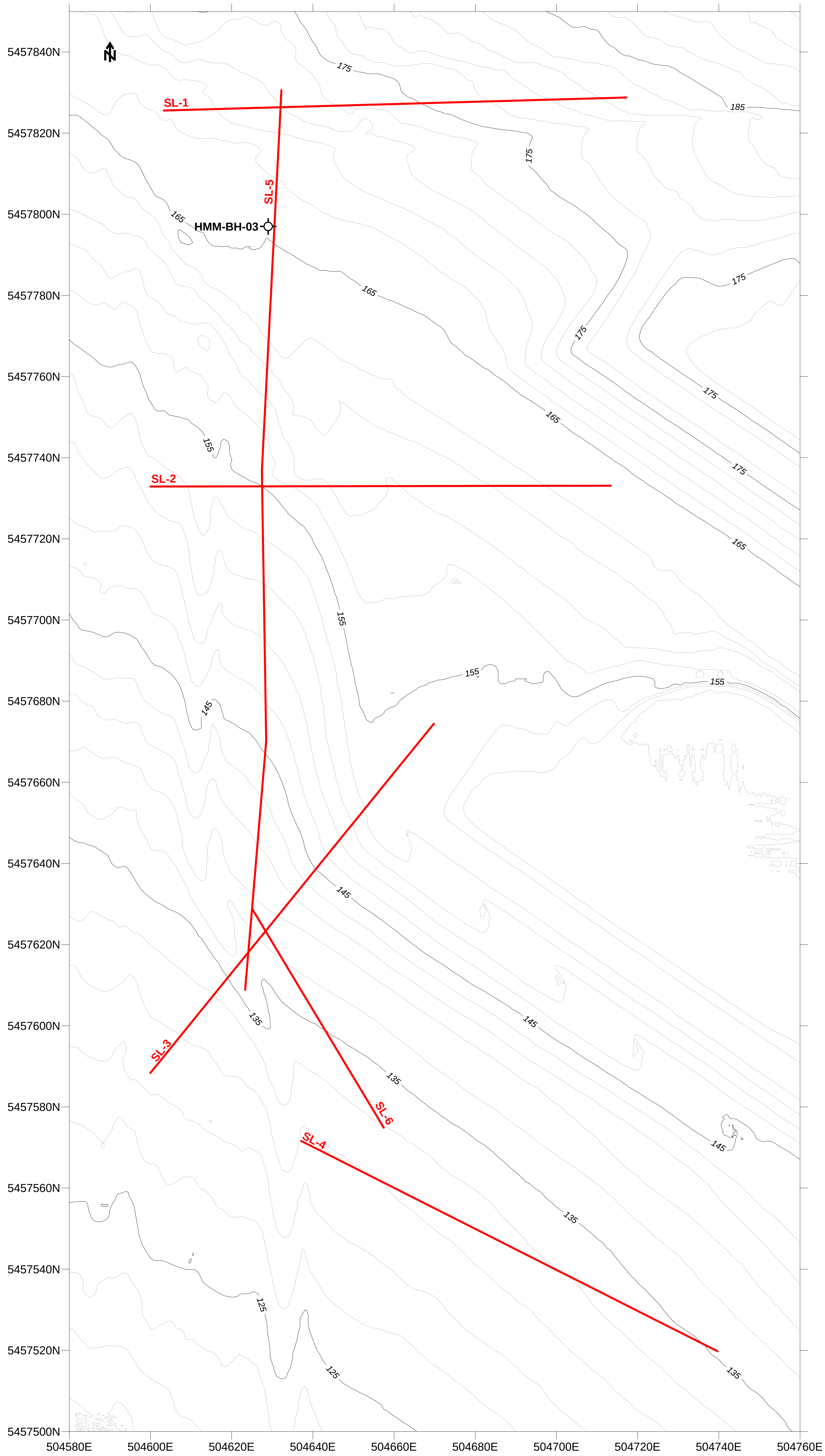
-Borehole completed at target depth 44.46 m bgs
-Televiewer survey completed from 33.25 to 42.73 mbgs.
-Two vibrating wire piezometers installed in drillhole at 18 and 38 m below ground surface. Permanent surface monument installed.
-SPT sampler details: 24" length, 2" diameter, driven by automatic trip hammer.

POINT LOAD TESTS
D — TEST TYPE: DIAMETRAL (D); AXIAL (A)
1.5— Is_{50} (MPa)

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

Client: Trans Mountain Pipeline ULC

Appendix B GEOPHYSICAL INVESTIGATION RESULTS



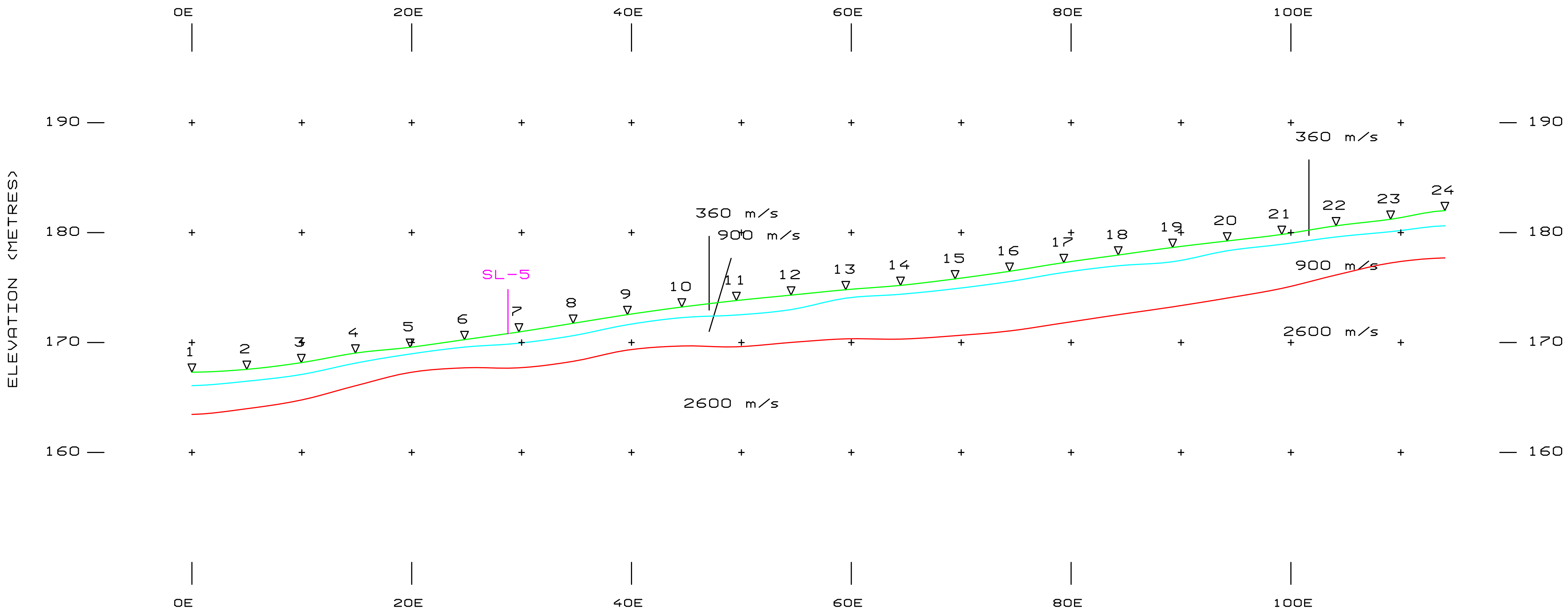
BGC ENGINEERING INC.
WESTRIDGE TUNNEL OPTION - SOUTH PORTAL

SEISMIC REFRACTION SURVEY

SITE PLAN

FRONTIER GEOSCIENCES INC.

DATE: SEPT. 2014 | SCALE 1:1,000 | FIG. 2



SEISMIC LINE SL-1

NOTE: THIS DRAWING MUST BE READ WITH
REFERENCE TO PROJECT REPORT FGI-1367

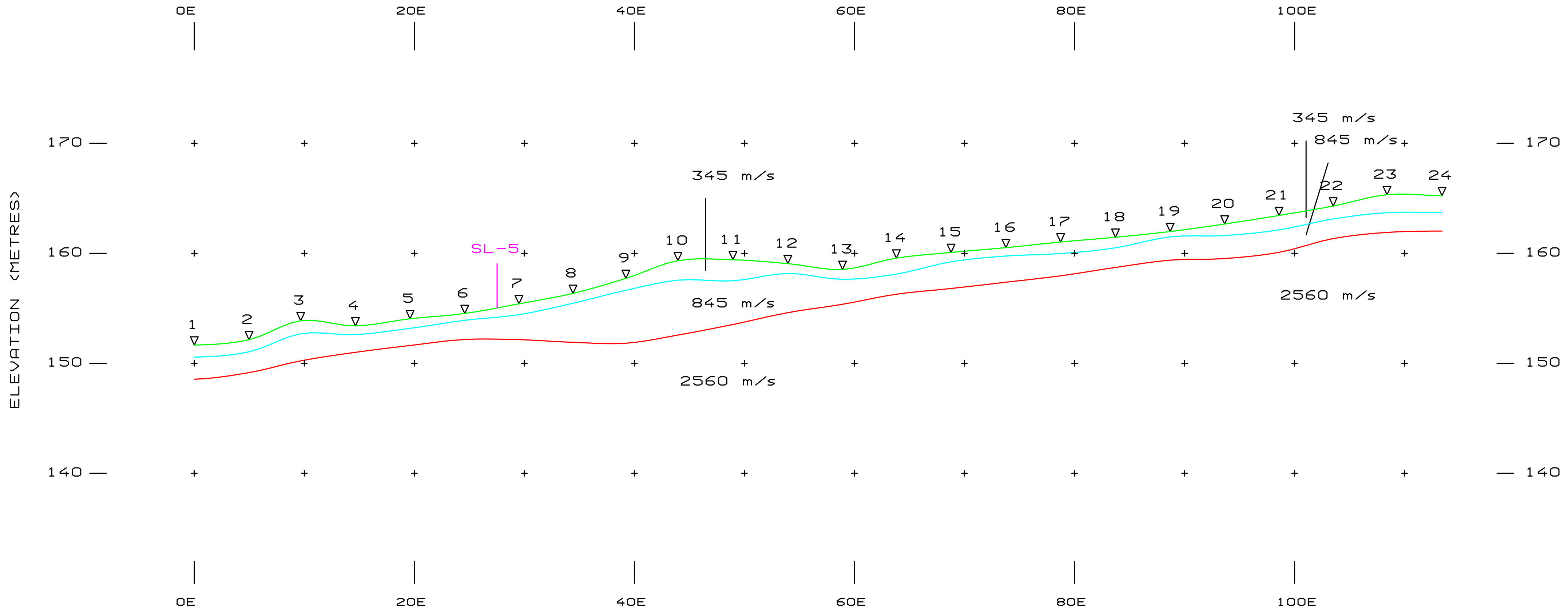
BGC ENGINEERING INC.
WESTRIDGE TUNNEL OPTION - SOUTH PORTAL

SEISMIC REFRACTION SURVEY

INTERPRETED DEPTH SECTION SL-1

FRONTIER GEOSCIENCES INC.

DATE: SEPT. 2014	SCALE 1:500	FIG. 3



SEISMIC LINE SL-2

NOTE: THIS DRAWING MUST BE READ WITH
REFERENCE TO PROJECT REPORT FGI-1367

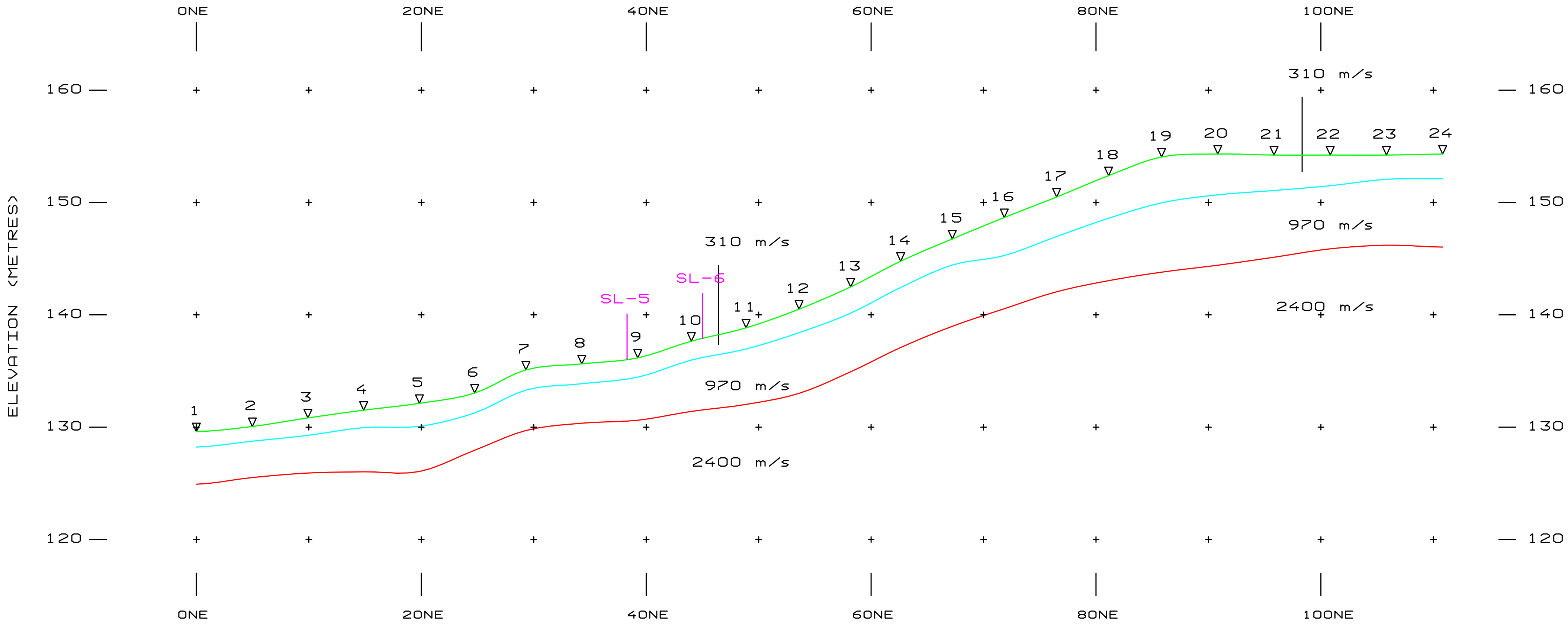
BGC ENGINEERING INC.
WESTRIDGE TUNNEL OPTION - SOUTH PORTAL

SEISMIC REFRACTION SURVEY

INTERPRETED DEPTH SECTION SL-2

FRONTIER GEOSCIENCES INC.

DATE: SEPT. 2014	SCALE 1:500	FIG. 4

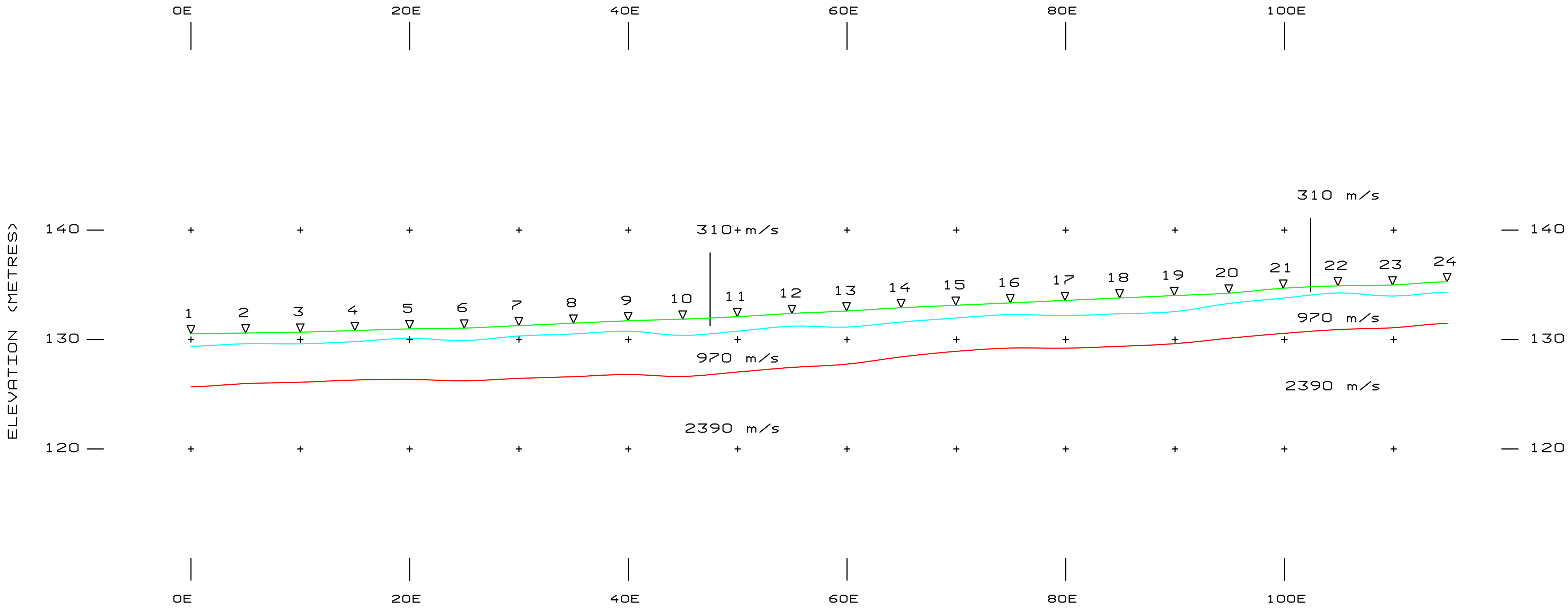


SEISMIC LINE SL-3

NOTE: THIS DRAWING MUST BE READ WITH
REFERENCE TO PROJECT REPORT FGI-1367

BGC ENGINEERING INC. WESTRIDGE TUNNEL OPTION - SOUTH PORTAL
SEISMIC REFRACTION SURVEY
INTERPRETED DEPTH SECTION SL-3
FRONTIER GEOSCIENCES INC.

DATE: SEPT. 2014	SCALE 1:500	FIG. 5



SEISMIC LINE SL-4

NOTE: THIS DRAWING MUST BE READ WITH
REFERENCE TO PROJECT REPORT FGI-1367

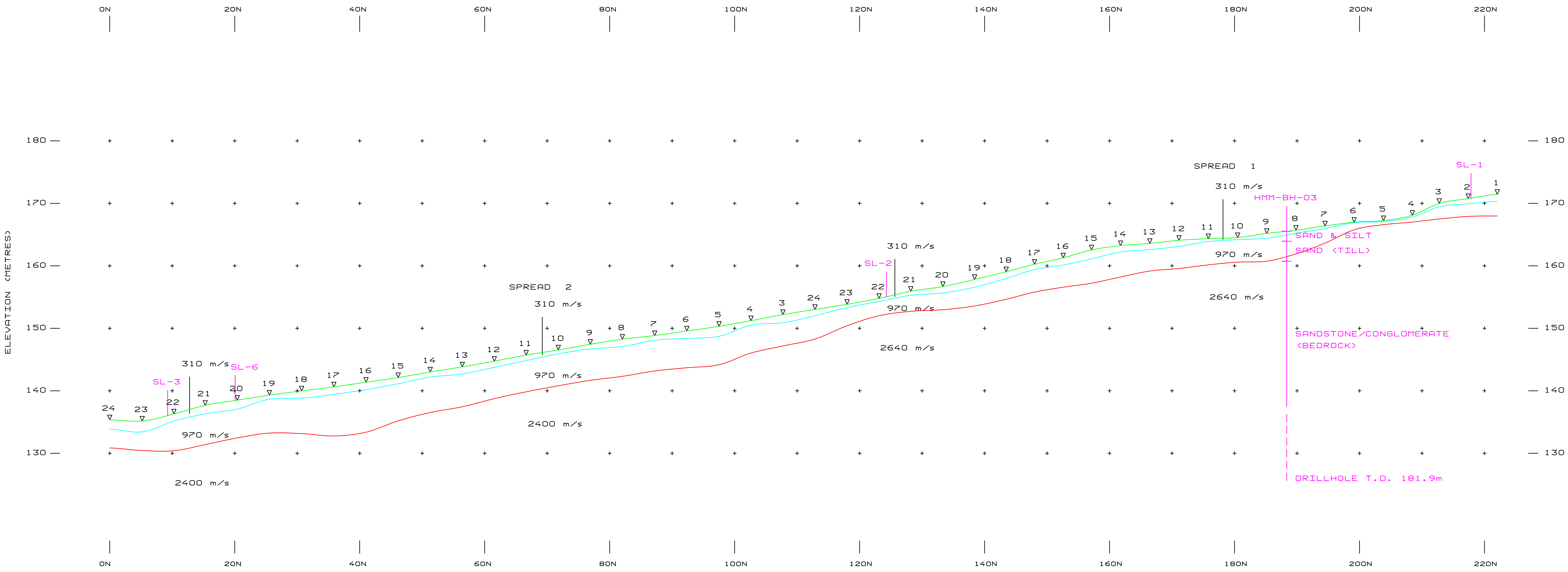
BGC ENGINEERING INC.
WESTRIDGE TUNNEL OPTION - SOUTH PORTAL

SEISMIC REFRACTION SURVEY

INTERPRETED DEPTH SECTION SL-4

FRONTIER GEOSCIENCES INC.

DATE: SEPT. 2014	SCALE 1:500	FIG. 6



SEISMIC LINE SL-5

NOTE: THIS DRAWING MUST BE READ WITH
REFERENCE TO PROJECT REPORT FGI-1367

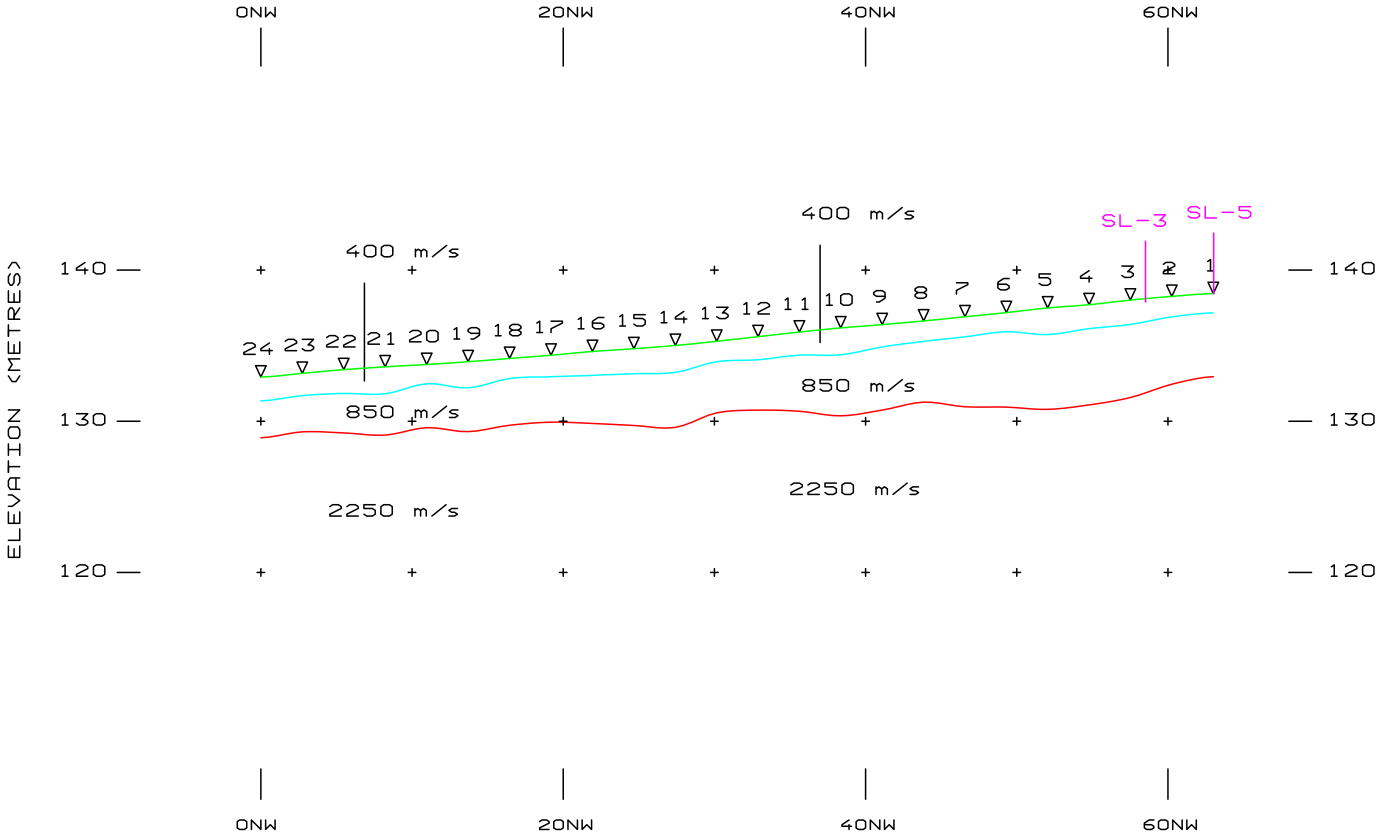
BGC ENGINEERING INC.
WESTRIDGE TUNNEL OPTION - SOUTH PORTAL

SEISMIC REFRACTION SURVEY

INTERPRETED DEPTH SECTION SL-5

FRONTIER GEOSCIENCES INC.

DATE: SEPT. 2014 | SCALE 1:500 | FIG. 7



SEISMIC LINE SL-6

NOTE: THIS DRAWING MUST BE READ WITH
REFERENCE TO PROJECT REPORT FGI-1367

BGC ENGINEERING INC.
WESTRIDGE TUNNEL OPTION - SOUTH PORTAL

SEISMIC REFRACTION SURVEY

INTERPRETED DEPTH SECTION SL-6

FRONTIER GEOSCIENCES INC.

DATE: SEPT. 2014	SCALE 1:500	FIG. 8