PAKALNIS & ASSOCIATES
Mining Engineers

Addendum to Review of Burnaby Mountain Tunnel Option
to
City of Burnaby-Engineering Department
No. CoB-01A/14

February 27, 2015

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PAKALNIS & ASSOCIATES
Mining Engineers

February 27, 2015

Mr. D. Doepker/Development Engineer
City of Burnaby-City Hall/Engineering Department
4949 Canada Way
Burnaby, BC
V5G 1M2

Ref: Addendum to "Report on Geotechnical Review of Burnaby Mountain-Tunnel Option" CoB-01/14.

This letter report summarizes my comments and observations with respect to the recently submitted

Trans Mountain Pipeline ULC, TMEP Westridge Tunnel Investigation 2014 Site Investigation Data Report – Revision 1 January 23, 2015 Project No.: 0095150-15.

The original review CoB-01/14 was conducted on documents provided as follows:

1) Westridge Delivery Pipelines Routing Update, Dec 1/14 (Trans Mountain Pipeline ULC)
2) Burnaby Mountain Terrain mapping Update, Nov 27/14 (BGC)
3) Burnaby Mountain Tunnel and Trenchless Feasibility Report, Nov 27/14 (Hatch Mott MacDonald)
4) Appendix C: Preliminary Tunnel and Trenchless Plans and Profiles, Nov 27/14 (Hatch Mott MacDonald)
5) Burnaby Mountain Seismic Hazard Update, Nov 27/14 (BGC)
6) **TMEP Westridge Tunnel Investigation-2014 Site Investigation Data Report, Nov 26/14 (BGC) - Final**
7) SFU Geology Letter Report-Engineering Geology of Burnaby Mountain, Nov 7/14 (SFU)
8) Application to City of Burnaby to Conduct Geotechnical Drilling within Burnaby Mountain Conservation Area, July 24/14 (BGC)

Discussion with D. Doepker/G. Tsuyuki (City of Burnaby) on Tuesday, February 24th was a request to comment on the recent report completed by BGC which is a "Revision 1" of that termed "Final" and identified as Document 6 above. This document largely provides information on the 1) HMM-BH-02 drill hole log/photographs, 2) location of the "invert" with respect to the individual drill holes, 3) reduction of the televiewer results to dip/dip direction and 4) the first indication that future core holes are planned for geotechnical delineation prior to excavation.

Appendix I outlines the comments upon review of the BGC document and appendices. This memo

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summarizes the overall assessment as it relates to the initial review and detailed in CoB-01/14. The questions/comments as outlined in CoB-01/14 are still valid as the revision report has largely presented information for HMM-BH-02 which now provides a single hole to characterize the proposed 2km tunnel profile between ~2+200m to ~0+200m. This is insufficient to characterize the stability of the proposed tunnel route in my professional opinion and as outlined in Page 16 of the BGC report will be augmented by future proposed boreholes as only subsurface investigations are only known at the specific borehole location. This is the first indication that this is to be conducted.

Excerpt:

Trans Mountain Pipeline ULC, TMEP Westridge Tunnel Investigation 2014 Site Investigation Data Report – Revision 1 January 23, 2015 Project No.: 0095150-15

3.0 INFERRED CONDITIONS ALONG PROPOSED PIPELINE ROUTE

Based on the results of geotechnical drilling, geologic mapping completed by SFU and geophysical surveys obtained to date, BGC has developed interpreted geological sections of the proposed trenchless pipeline profiles, as shown on Drawing 02. The following sections describe the surficial geology, bedrock geology and hydrogeology interpretations made to date. ***Further details and improvement to the interpretations will be provided following the completion of the remaining proposed boreholes and geophysical lines as part of planned subsequent investigations. Subsurface conditions are only known at the specific borehole locations. Interpreted ground conditions between these locations are subject to variance.***

OTHER OBSERVATIONS

This has been detailed in Appendix I and compiled below:

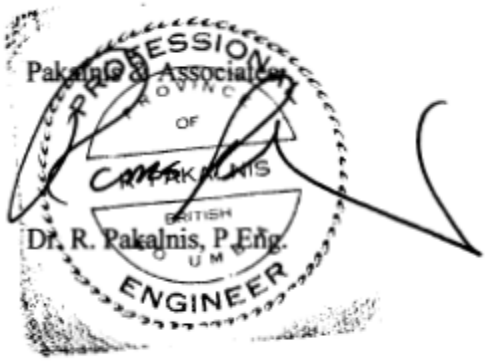
- It must be noted that the recovery of the core from HMM-BH-02 was ~50% and the rock quality ranged from Q~0.2 to Q~7. This is an approximate equivalent RMR_{76} (RMR=9LnQ + 44) of ~30% to ~60% which is approximately double in magnitude.
- The core logs for HMM-BH-02 show the variability in the rock mass particularly as the TBM will incur primarily conglomerates, however, also sandstones/other units which are variable in rock quality (Q/RMR) and have a direct impact on the performance of the tunnelling machine in terms of potential squeeze/closure/ground behaviour/support requirements/advance
- The report states that the ***"Q values have been derived based on the proposed tunnel invert elevation for discussion purposes only and are not to be used for design"***. This requires further explanation in terms of its accuracy and usefulness. Note what confidence does the geotechnical consultant have in terms of characterizing the Q/RMR for the 2km of tunnel from a single drill hole?
- The tunnel route should be shown on all drawings ie. Logs/photos/discussions as this is the location that one is assessing in terms of stability and requires characterization at the tunnel horizon.
- The revision should have been made evident in the report indicated as "Final" and submitted November 26, 2014 as it would of assisted in the initial assessment, however, has not changed the conclusions made in the initial report CoB-01/14 due to lack of information at

the tunnel horizon (drilling).

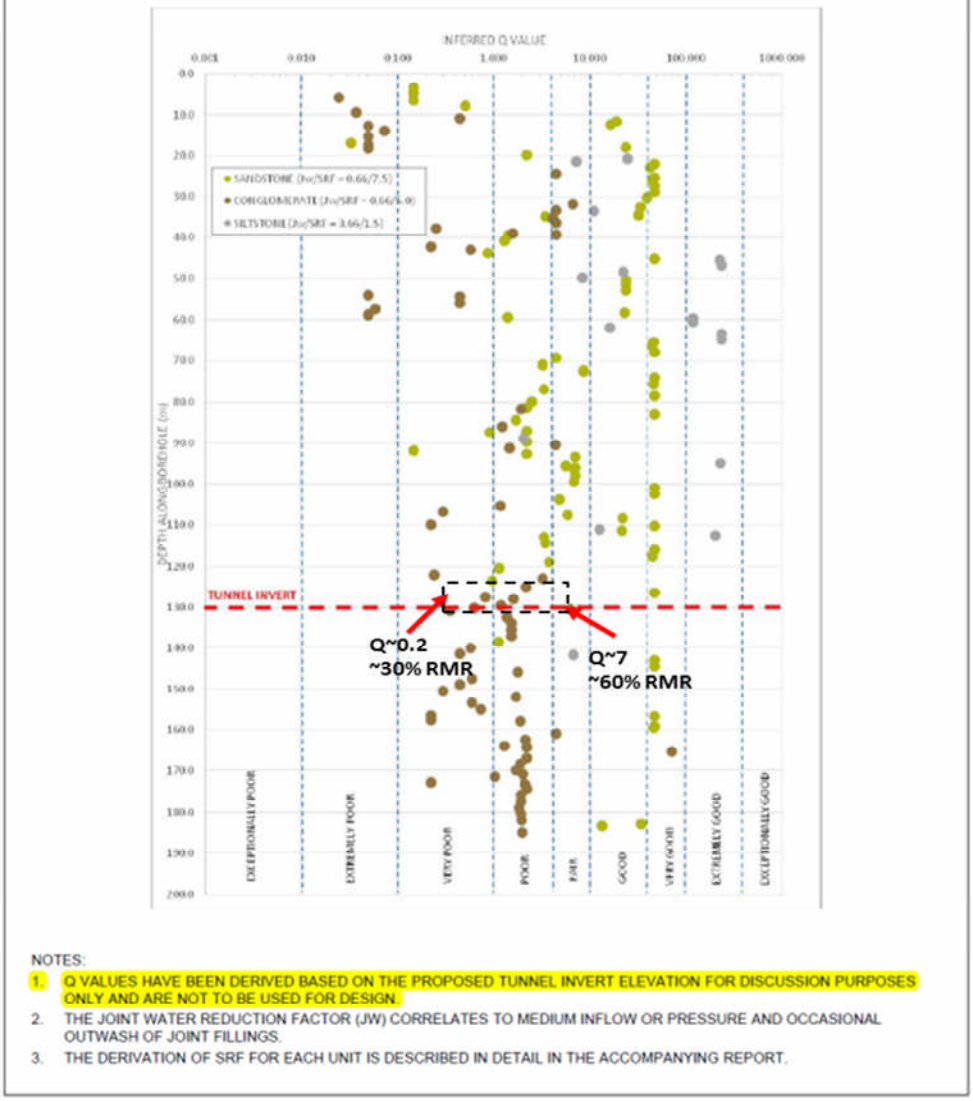
The revised report provides a detailed data gathering of existing information, however, in my professional opinion does not enable one to determine the rock mass characteristics (RMR/Q) to be expected along the tunnel as largely only one(1) drill hole is available HMM-BH-02 to characterize 2km of tunnel routing. This is evident as future drilling is expected with subsequent evaluation.

Please contact me if any questions or comments arise.

Pakalnis & Associates



Dr. R. Pakalnis, P.Eng., FEC.



NOTES:
1. Q VALUES HAVE BEEN DERIVED BASED ON THE PROPOSED TUNNEL INVERT ELEVATION FOR DISCUSSION PURPOSES ONLY AND ARE NOT TO BE USED FOR DESIGN.
2. THE JOINT WATER REDUCTION FACTOR (JW) CORRELATES TO MEDIUM INFLOW OR PRESSURE AND OCCASIONAL OUTWASH OF JOINT FILLINGS.
3. THE DERIVATION OF SRF FOR EACH UNIT IS DESCRIBED IN DETAIL IN THE ACCOMPANYING REPORT.

Figure 6 INFERRED Q WITH DEPTH – HMM-BH-02

- *It must be noted that the recovery of the core from HMM-BH-02 was ~50% and the rock quality ranged from Q~0.2 to Q~7. This is an approximate equivalent RMR_{76} (RMR=9LnQ + 44) of ~30% to ~60% which is approximately double in magnitude.*

- *The report states that the "Q values have been derived based on the proposed tunnel invert elevation for discussion purposes only and are not to be used for design". This requires further explanation in terms of its accuracy and usefulness. Note what confidence does the geotechnical consultant have in terms of characterizing the Q/RMR for the 2km of tunnel from a single drill hole?*

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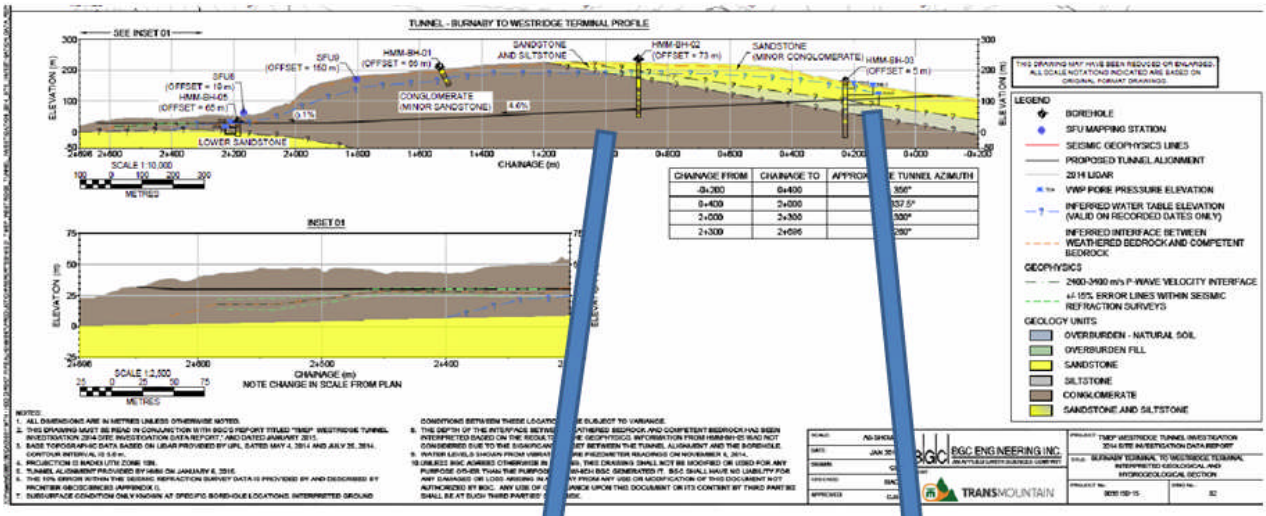
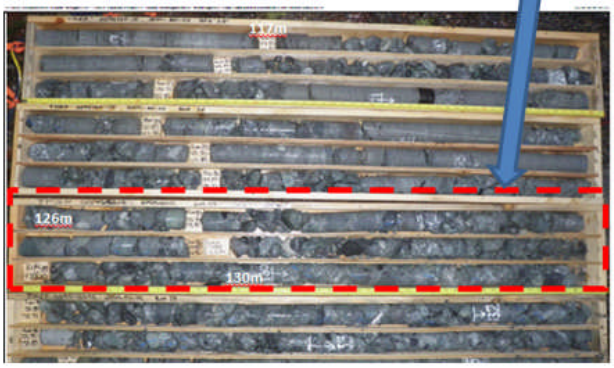
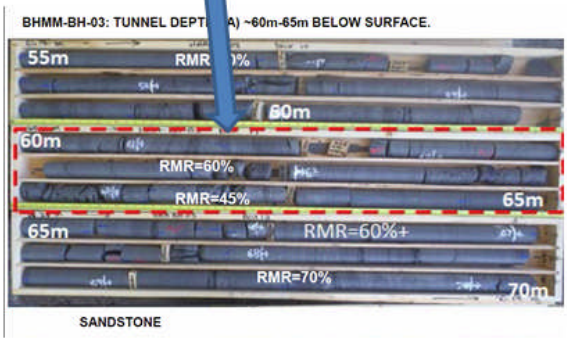






APPENDIX I

REVIEW – FEBRUARY 2015

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

TRANS MOUNTAIN PIPELINE ULC

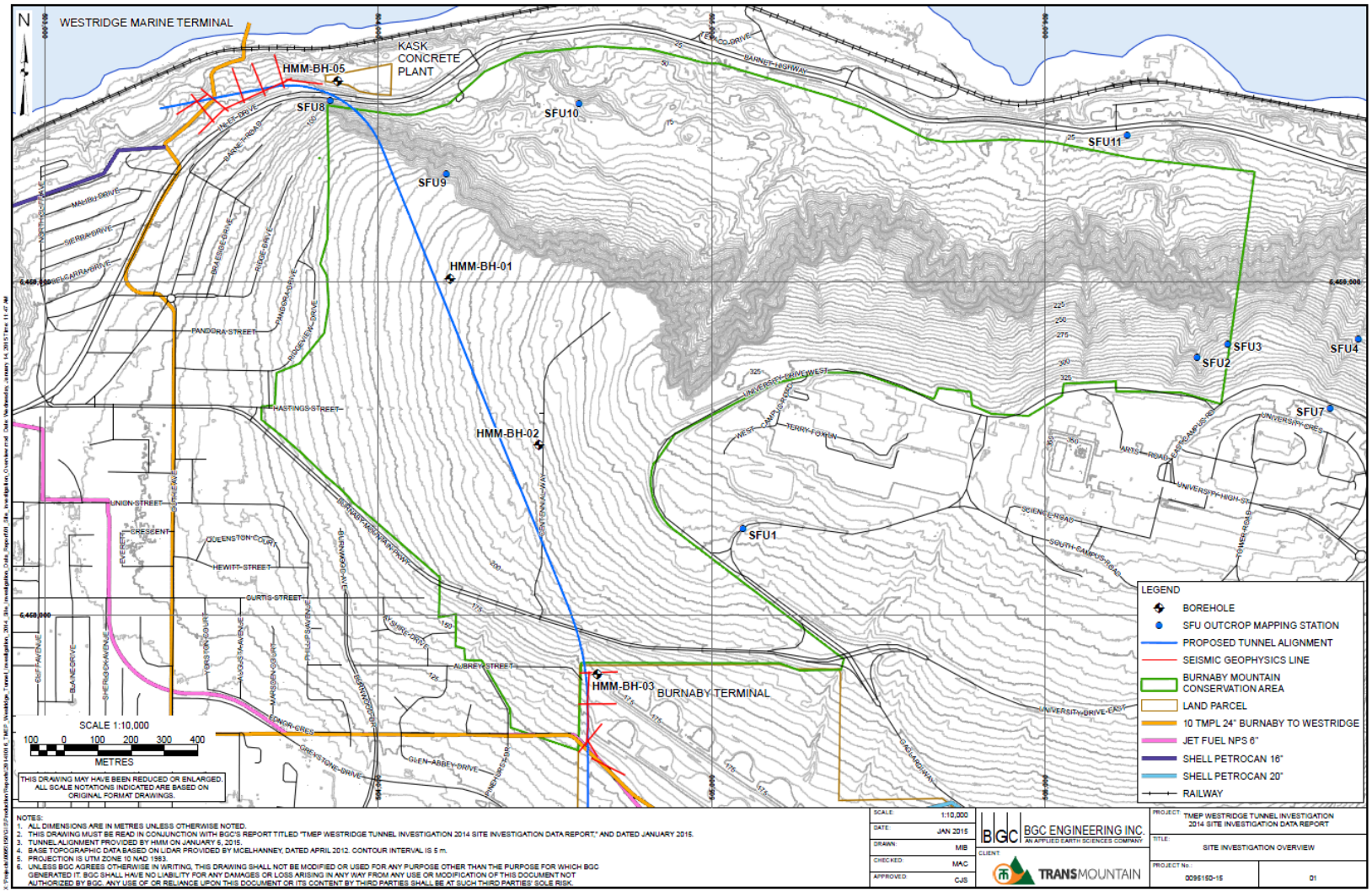
TMEP WESTRIDGE TUNNEL INVESTIGATION

2014 SITE INVESTIGATION DATA REPORT

REVISION 1

PROJECT NO.:	0095150-15
DATE:	January 23, 2015
DOCUMENT NO.:	0095150.0107

DISTRIBUTION:	
TRANS MOUNTAIN:	1 digital copy
BGC:	1 digital copy
HMM:	1 digital copy


N
WESTRIDGE MARINE TERMINAL
KASK CONCRETE PLANT
HMM-BH-05
SFU8
SFU10
SFU11
SFU9
HMM-BH-01
HMM-BH-02
HMM-BH-03
BURNABY TERMINAL
SFU1
SFU2
SFU3
SFU4
SFU7
BARNET HIGHWAY
LEGEND
BOREHOLE
SFU OUTCROP MAPPING STATION
PROPOSED TUNNEL ALIGNMENT
SEISMIC GEOPHYSICS LINE
BURNABY MOUNTAIN CONSERVATION AREA
LAND PARCEL
10 TMPL 24" BURNABY TO WESTRIDGE
JET FUEL NPS 6"
SHELL PETROCAN 16"
SHELL PETROCAN 20"
RAILWAY
SCALE 1:10,000
METRES
THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.
NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "TMEP WESTRIDGE TUNNEL INVESTIGATION 2014 SITE INVESTIGATION DATA REPORT," AND DATED JANUARY 2015.
3. TUNNEL ALIGNMENT PROVIDED BY HMM ON JANUARY 6, 2015.
4. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY MCELHANNEY, DATED APRIL 2012. CONTOUR INTERVAL IS 5 m.
5. PROJECTION IS UTM ZONE 10 NAD 1983.
6. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.
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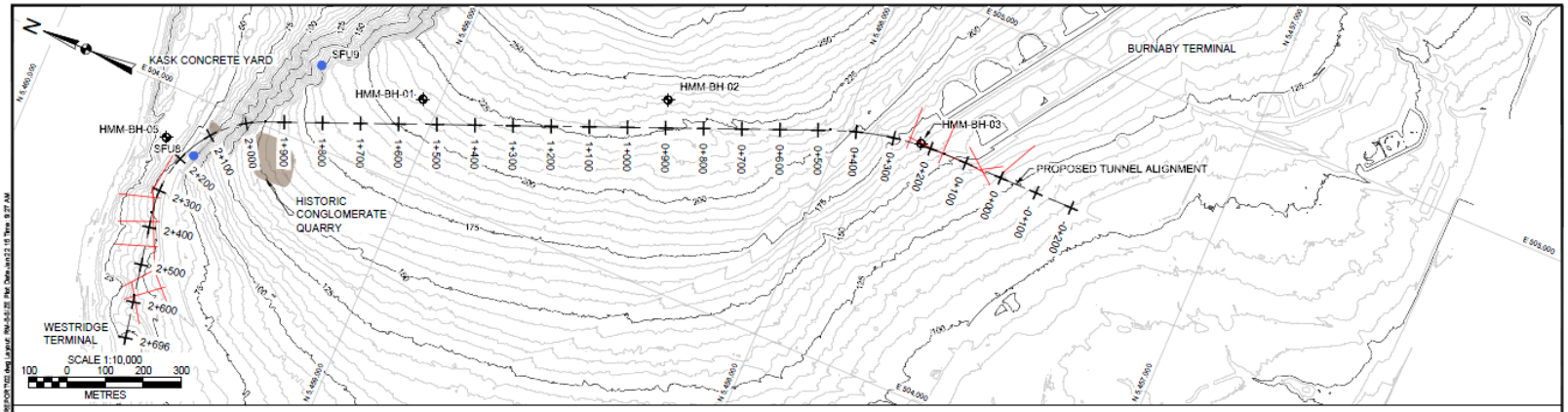
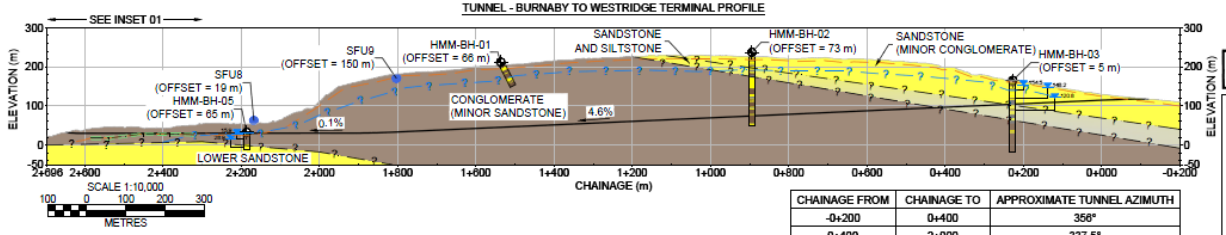
DATE: JAN 2015
DRAWN: MIB
CHECKED: MAC
APPROVED: CJS
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY
CLIENT: TRANSMOUNTAIN
PROJECT: TMEP WESTRIDGE TUNNEL INVESTIGATION 2014 SITE INVESTIGATION DATA REPORT
TITLE: SITE INVESTIGATION OVERVIEW
PROJECT No: 0095150-15
01

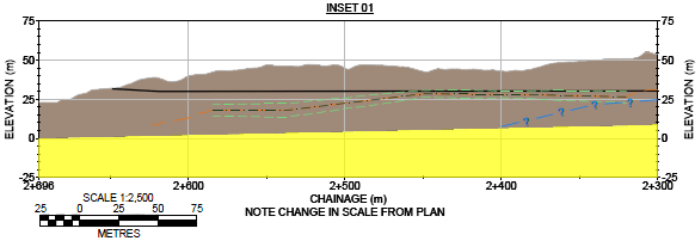


TUNNEL - BURNABY TO WESTRIDGE TERMINAL PROFILE



CHAINAGE FROM	CHAINAGE TO	APPROXIMATE TUNNEL AZIMUTH
-0+200	0+400	356°
0+400	2+000	337.5°
2+000	2+300	300°
2+300	2+696	260°

INSET 01



THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

LEGEND

- BOREHOLE
- SFU MAPPING STATION
- SEISMIC GEOPHYSICS LINES
- PROPOSED TUNNEL ALIGNMENT
- 2014 LIDAR
- VWP PORE PRESSURE ELEVATION
- INFERRED WATER TABLE ELEVATION (VALID ON RECORDED DATES ONLY)
- INFERRED INTERFACE BETWEEN WEATHERED BEDROCK AND COMPETENT BEDROCK

GEOPHYSICS

- 2400-3400 m/s P-WAVE VELOCITY INTERFACE
- +/-15% ERROR LINES WITHIN SEISMIC REFRACTION SURVEYS

GEOLOGY UNITS

- OVERBURDEN - NATURAL SOIL
- OVERBURDEN FILL
- SANDSTONE
- SILTSTONE
- CONGLOMERATE
- SANDSTONE AND SILTSTONE

NOTES:

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2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "TMEP WESTRIDGE TUNNEL INVESTIGATION 2014 SITE INVESTIGATION DATA REPORT," AND DATED JANUARY 2015.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY UPL, DATED MAY 4, 2014 AND JULY 25, 2014. CONTOUR INTERVAL IS 5.0 m.
4. PROJECTION IS NAD83 UTM ZONE 10N.
5. TUNNEL ALIGNMENT PROVIDED BY HMM ON JANUARY 6, 2015.
6. THE 15% ERROR WITHIN THE SEISMIC REFRACTION SURVEY DATA IS PROVIDED BY AND DESCRIBED BY FRONTIER GEOSCIENCES (APPENDIX I).
7. SUBSURFACE CONDITION ONLY KNOWN AT SPECIFIC BOREHOLE LOCATIONS. INTERPRETED GROUND CONDITIONS BETWEEN THESE LOCATIONS ARE SUBJECT TO VARIANCE.
8. THE DEPTH OF THE INTERFACE BETWEEN WEATHERED BEDROCK AND COMPETENT BEDROCK HAS BEEN INTERPRETED BASED ON THE RESULTS OF THE GEOPHYSICS. INFORMATION FROM HMM-BH-05 WAS NOT CONSIDERED DUE TO THE SIGNIFICANT OFFSET BETWEEN THE TUNNEL ALIGNMENT AND THE BOREHOLE.
9. WATER LEVELS SHOWN FROM VIBRATING WIRE PIEZOMETER READINGS ON NOVEMBER 6, 2014.
10. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	AS SHOWN
DATE:	JAN 2015
DRAWN:	CS
CHECKED:	MAC
APPROVED:	CJS

BGC ENGINEERING INC. AN APPLIED EARTH SCIENCES COMPANY

CLIENT: TRANSMOUNTAIN

PROJECT: TMEP WESTRIDGE TUNNEL INVESTIGATION 2014 SITE INVESTIGATION DATA REPORT

TITLE: BURNABY TERMINAL TO WESTRIDGE TERMINAL INTERPRETED GEOLOGICAL AND HYDROGEOLOGICAL SECTION

PROJECT No.: 0095150-15

DWG No.: 02

The structural orientation data collected from the borehole televiewer is consistent with the orientation data collected during outcrop mapping. In general, bedding dips shallowly to the south, with the mean pole from each dataset showing a dip of 8° to 12° and dip direction of 182° to 185°. A single sub-vertical north-dipping joint set is shown in the televiewer data from HMM-BH-05. Several sub-vertical joint sets were observed during outcrop mapping but do not appear in the televiewer data.

Average laboratory unconfined compressive strength testing results are 22 MPa in the siltstone, 10 MPa in the sandstone and 16 MPa in the conglomerate and are considered weak (R2) (Hoek, 1999).

In general, the rock mass quality of each unit is quite consistent and does not vary significantly with depth once outside the zone of weathering. HMM-BH-02, which is the most

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complete dataset relevant to the tunnel at depth, shows that the tunnel will primarily be excavated within 'very poor' to 'poor' (NGI, 2013) conglomerate.

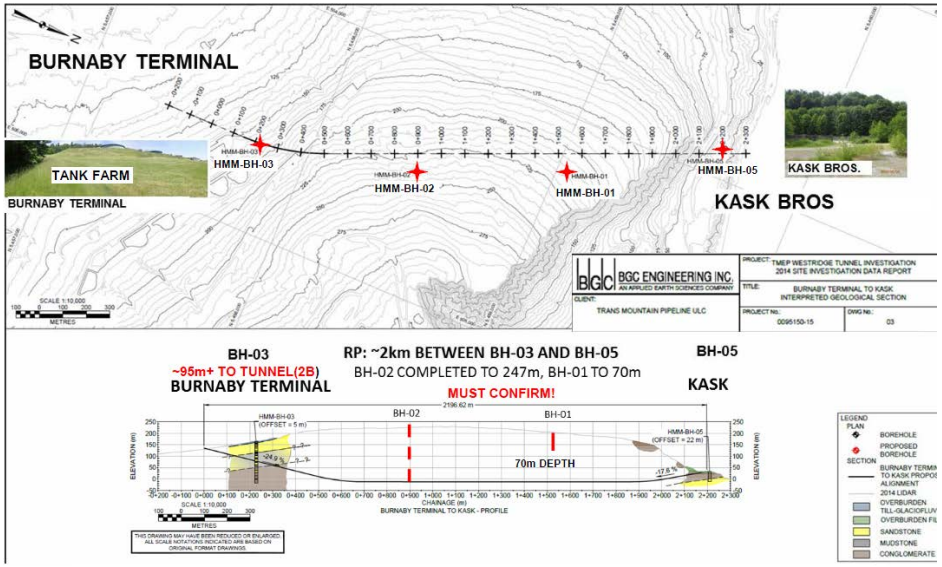

Table 2. Borehole Summary

Borehole ID	Coordinates[1,2] (m)	Trend/Plunge[3]	Start Date End Date	Final Depth (m bgs)	Core Size
HMM-BH-01	N: 5,459,042 E: 504,235 Elev. 224[4]	185°/60°	23-Nov-2014 28-Nov-2014	70.1	HQ3 61 mm
HMM-BH-02	N: 5,458,507 E: 504,489 Elev. 237	000°/90°	21-Nov-2014 25-Nov-2014	186.4	HQ3 61 mm
HMM-BH-03	N: 5,457,797 E: 504,629 Elev. 165	000°/90°	11-Sep-2014 18-Sep-2014	181.9	HQ3 61 mm
HMM-BH-05	N: 5,459,625 E: 503,871 Elev. 33	000°/90°	3-Oct-2014 5-Oct-2014	44.5	HQ3 61 mm

Notes:

1. Coordinates are UTM Zone 10, NAD83.
2. Coordinates taken using handheld GPS, and could be +/- 10 m in any direction.
3. Reported trend/plunge are proposed, not as-built.
4. Elevations taken at borehole collar on ground surface.

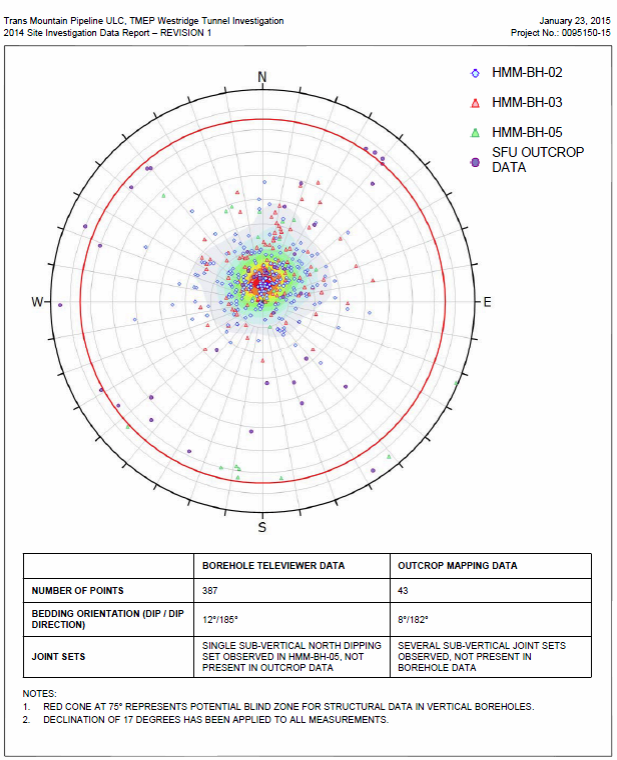

Figure 4. STRUCTURAL STEREONET ANALYSIS

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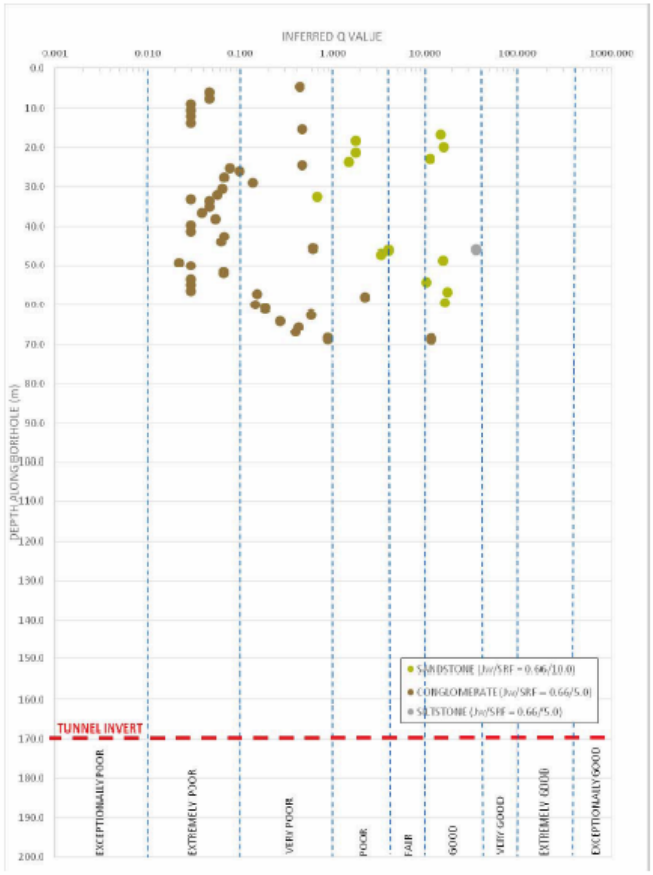

NOTES:
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2. THE JOINT WATER REDUCTION FACTOR (JW) CORRELATES TO MEDIUM INFLOW OR PRESSURE AND OCCASIONAL OUTWASH OF JOINT FILLINGS.
3. THE DERIVATION OF SRF FOR EACH UNIT IS DESCRIBED IN DETAIL IN THE ACCOMPANYING REPORT.

Figure 5 INFERRED Q WITH DEPTH – HMM-BH-01

Trans Mountain Pipeline ULC, TMEP Westridge Tunnel Investigation
2014 Site Investigation Data Report – REVISION 1
January 23, 2015
Project No.: 0095150-15

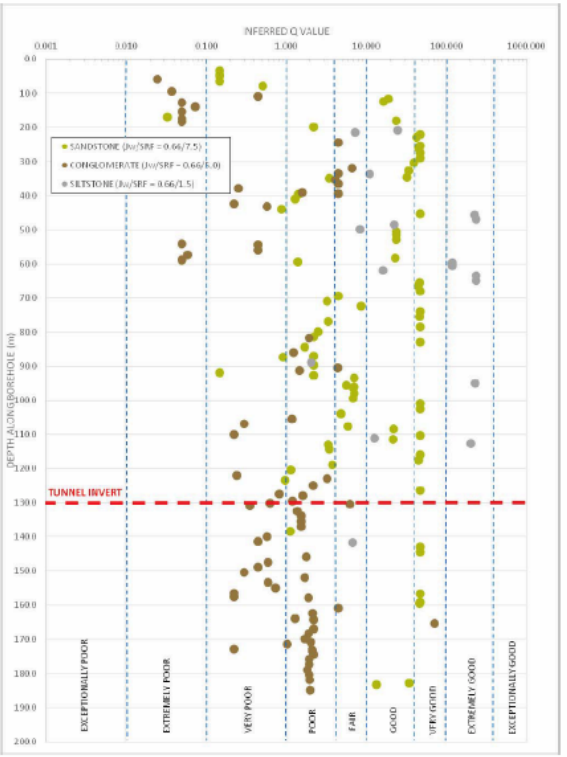

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Figure 6 INFERRED Q WITH DEPTH – HMM-BH-02

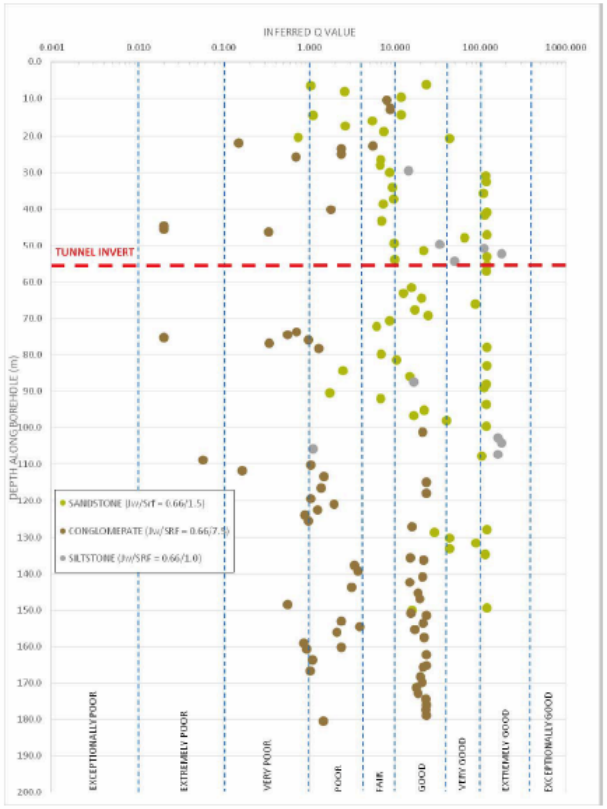

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Figure 7 INFERRED Q WITH DEPTH – HMM-BH-03

Trans Mountain Pipeline ULC, TMEP Westridge Tunnel Investigation
2014 Site Investigation Data Report – REVISION 1
January 23, 2015
Project No.: 0095150-15

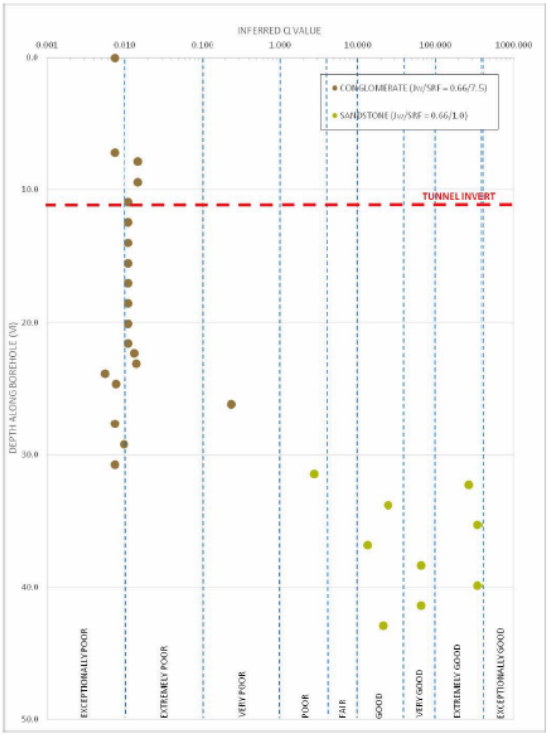

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Figure 8 INFERRED Q WITH DEPTH – HMM-BH-05

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

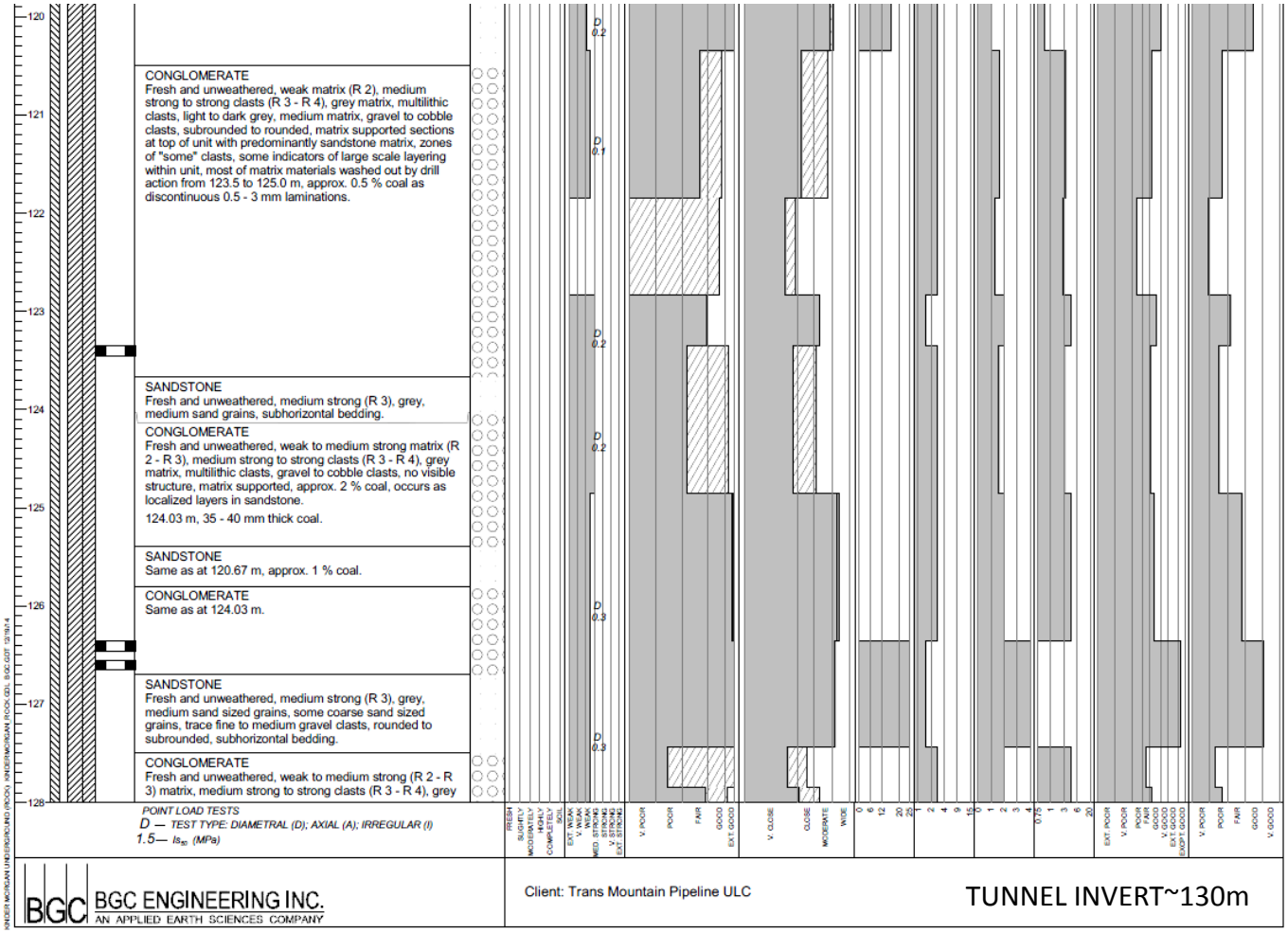
DRILL HOLE # HMM-BH-02

Location: Burnaby Mountain

Co-ordinates (m): 504,475E - 5,458,452N
Ground Elevation (m): 237
Survey Method: GPS
Datum: UTM 10 NAD83
Plunge (°): -90
Trend (°): N/A

Drill Designation: FRASTE MD-XL
Drilling Contractor: Geotech Drilling Services
Drill Method: Diamond Coring
Core: HQ3
Fluid: Water
Cased To (m) : 5.7

Start Date: 21 NOV 14
Finish Date: 26 NOV 14
Final Depth (m): 186.4
Depth To Top Of Rock (m): 4.9
Logged By: SB/SG/JVH
Reviewed By: CJS



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

DRILL HOLE # HMM-BH-02

Location: Burnaby Mountain

Co-ordinates (m): 504,475E - 5,458,452N
Ground Elevation (m): 237
Survey Method: GPS
Datum: UTM 10 NAD83
Plunge (°): -90
Trend (°): N/A

Drill Designation: FRASTE MD-XL
Drilling Contractor: Geotech Drilling Services
Drill Method: Diamond Coring
Core: HQ3
Fluid: Water
Cased To (m) : 5.7

Start Date: 21 NOV 14
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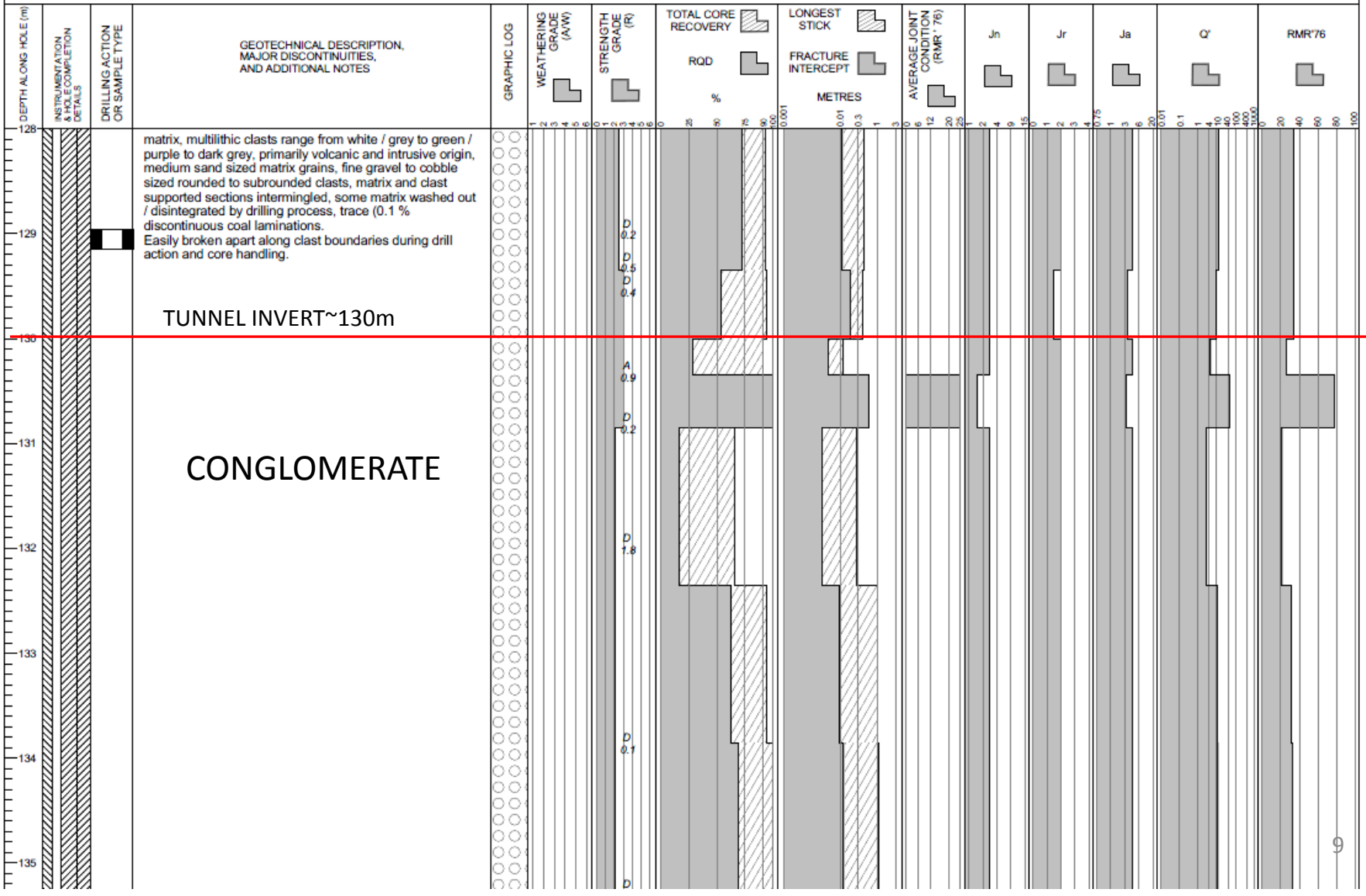
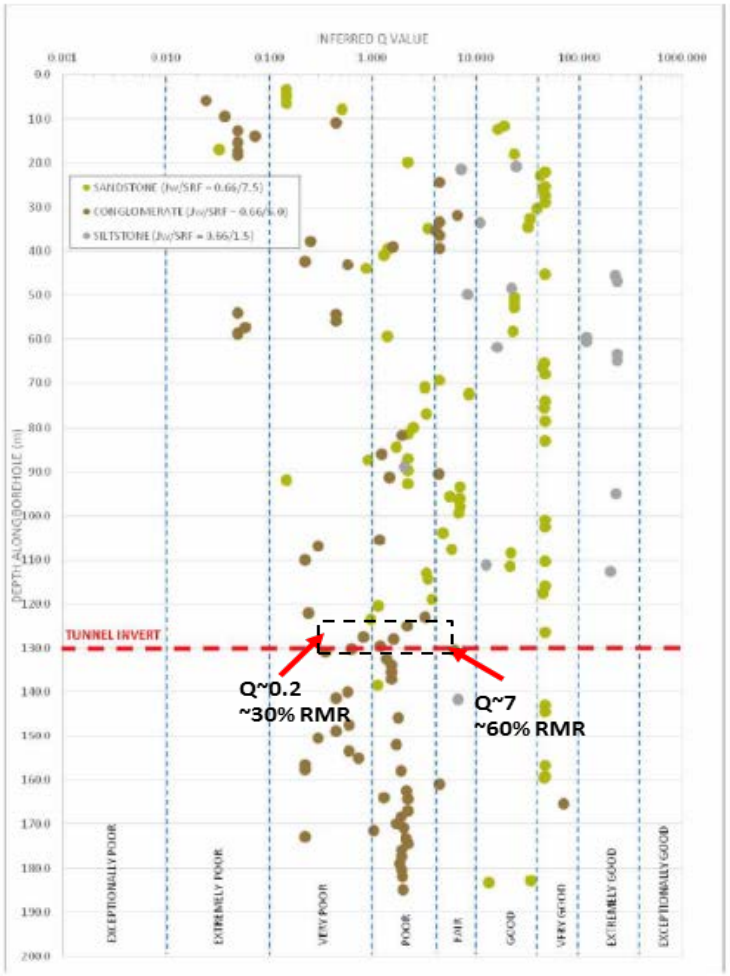
Depth To Top Of Rock (m): 4.9
Logged By: SB/SG/JVH
Reviewed By: CJS





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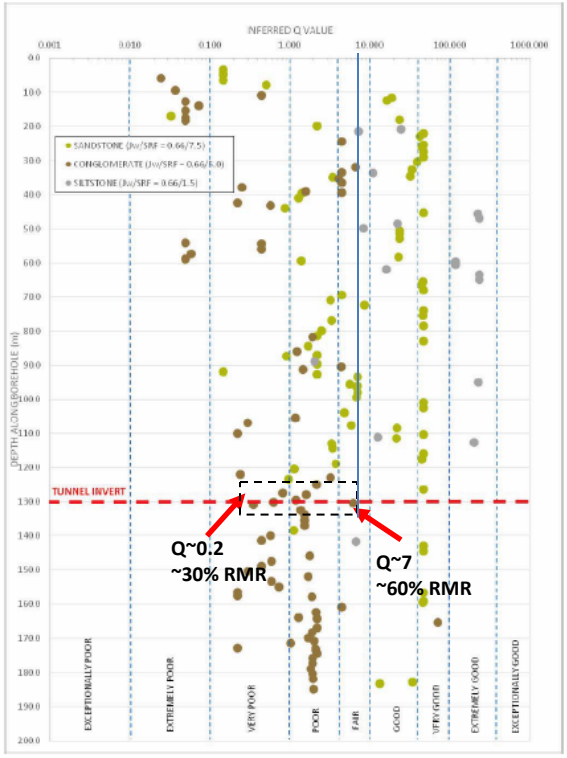
3. THE DERIVATION OF SRF FOR EACH UNIT IS DESCRIBED IN DETAIL IN THE ACCOMPANYING REPORT.

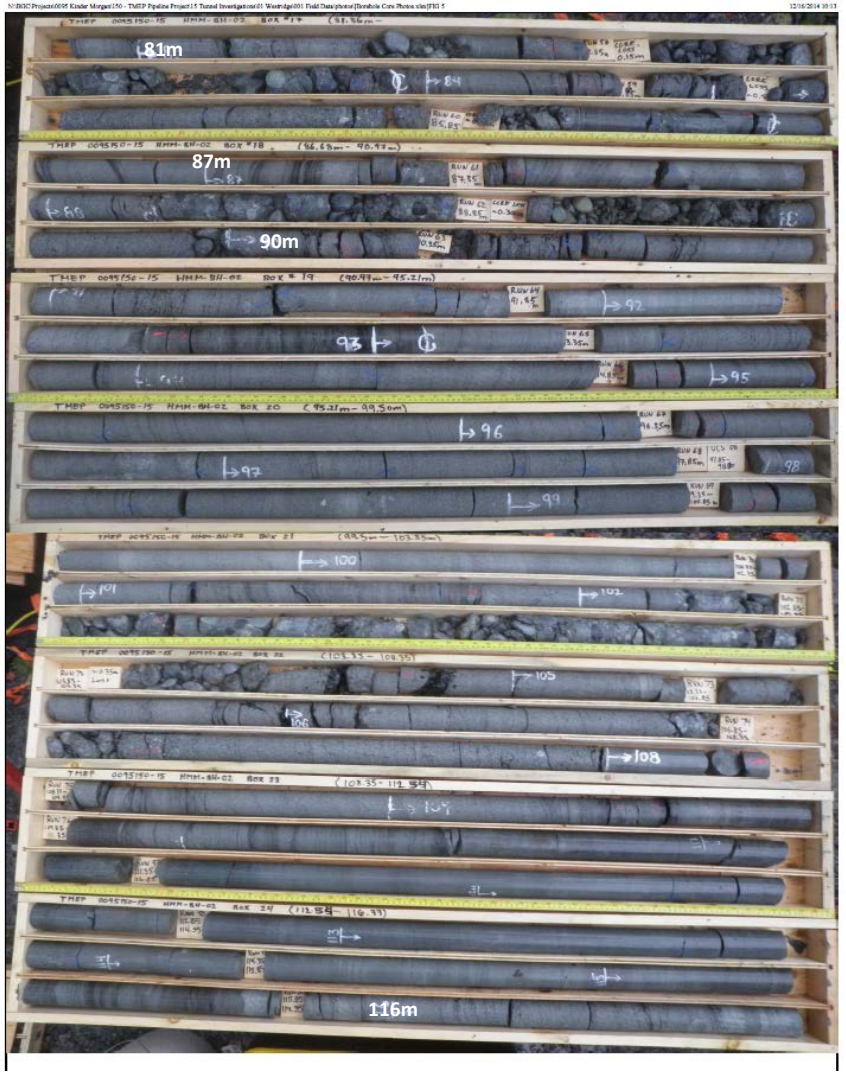
Figure 6 INFERRED Q WITH DEPTH – HMM-BH-02



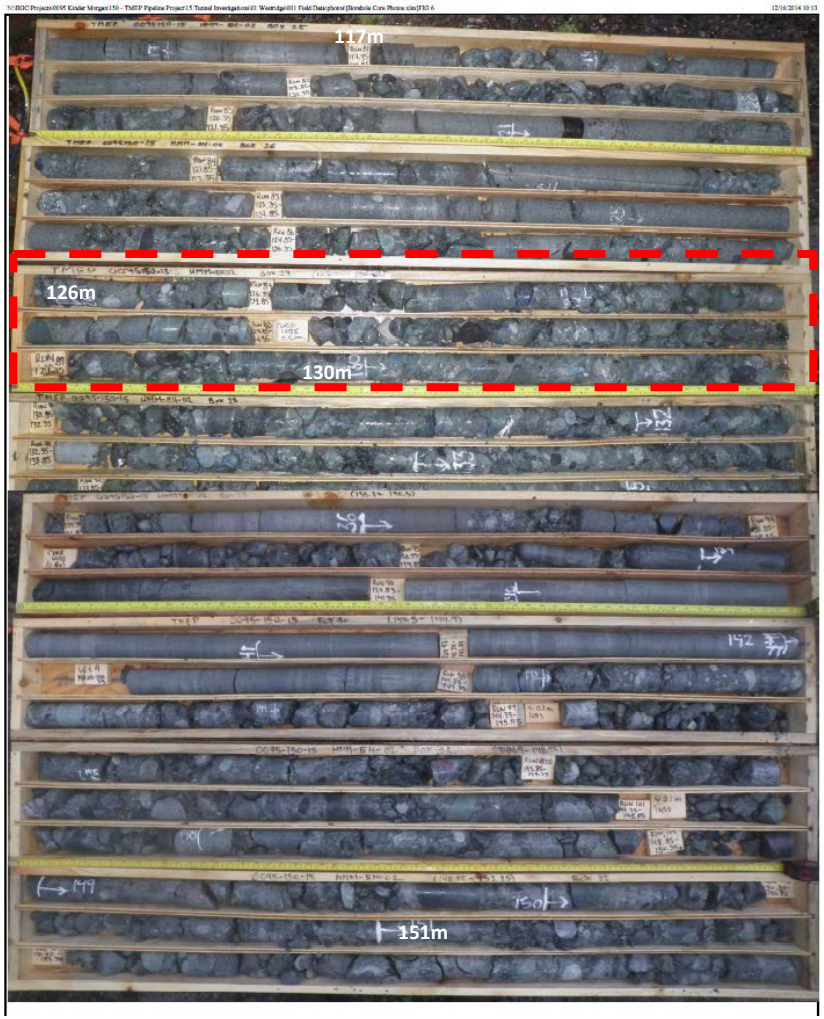
NOTES:
1. Q VALUES HAVE BEEN DERIVED BASED ON THE PROPOSED TUNNEL INVERT ELEVATION FOR DISCUSSION PURPOSES ONLY AND ARE NOT TO BE USED FOR DESIGN.
2. THE JOINT WATER REDUCTION FACTOR (JW) CORRELATES TO MEDIUM INFLOW OR PRESSURE AND OCCASIONAL OUTWASH OF JOINT FILLINGS.
3. THE DERIVATION OF SRF FOR EACH UNIT IS DESCRIBED IN DETAIL IN THE ACCOMPANYING REPORT.

Figure 6 INFERRED Q WITH DEPTH – HMM-BH-02

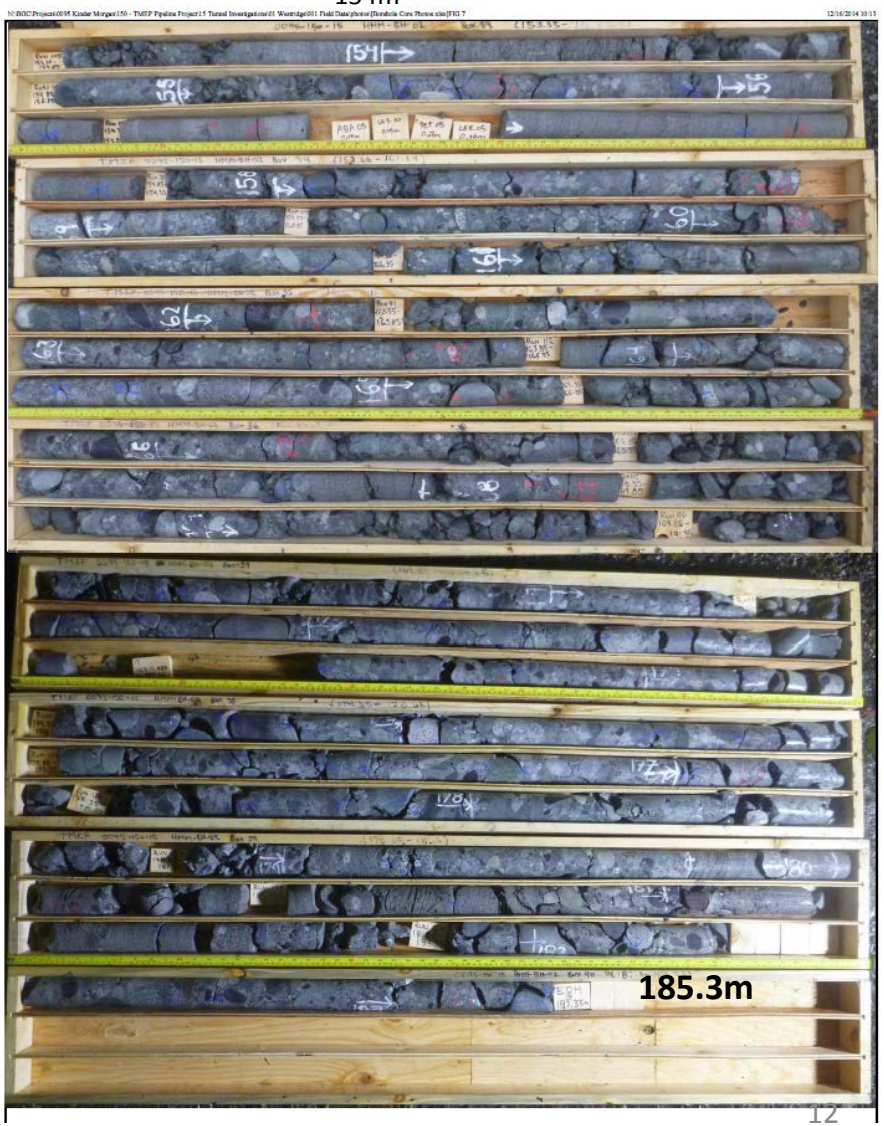
BGC ENGINEERING INC.

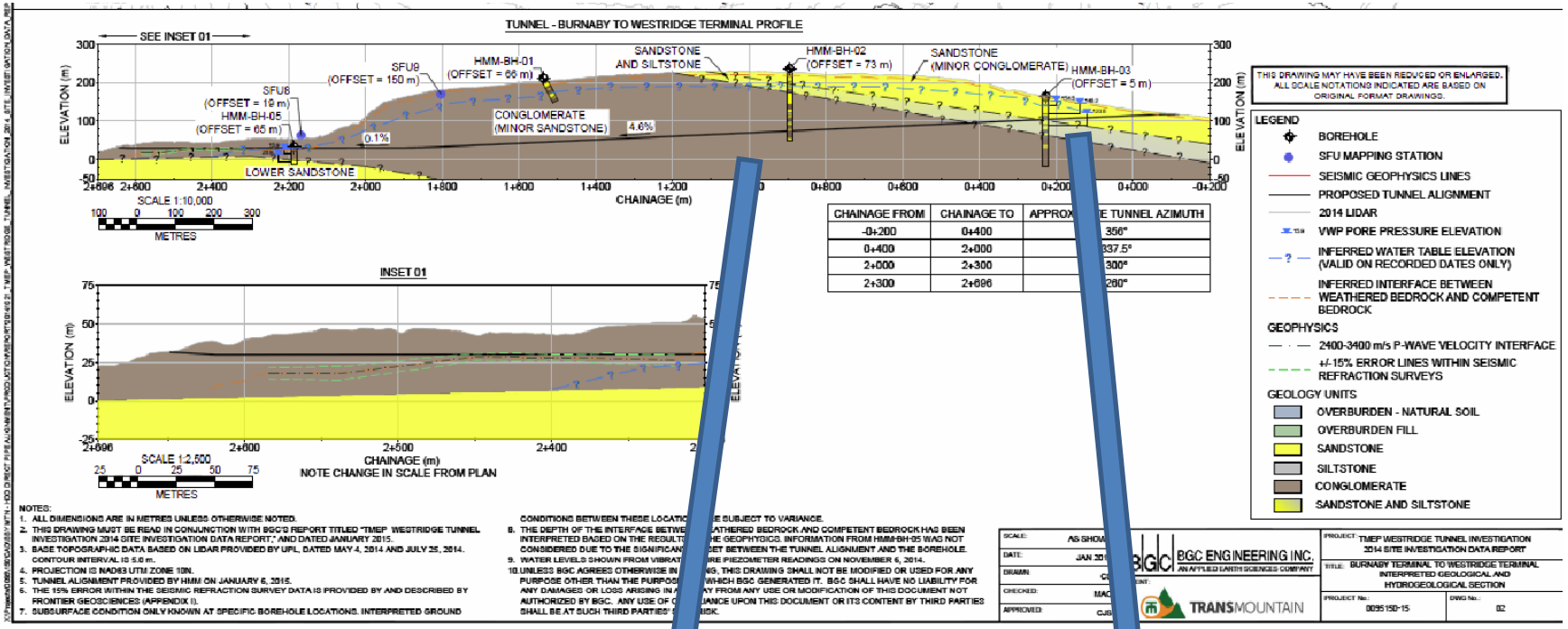


NOTE: USED RMR=9LnQ + 44 TO DETERMINE EQUIVALENCY. NOTE THAT RMR IS RECORDED IN LOGS BUT NOT DISCUSSED IN REPORT. SHOULD CONFIRM.



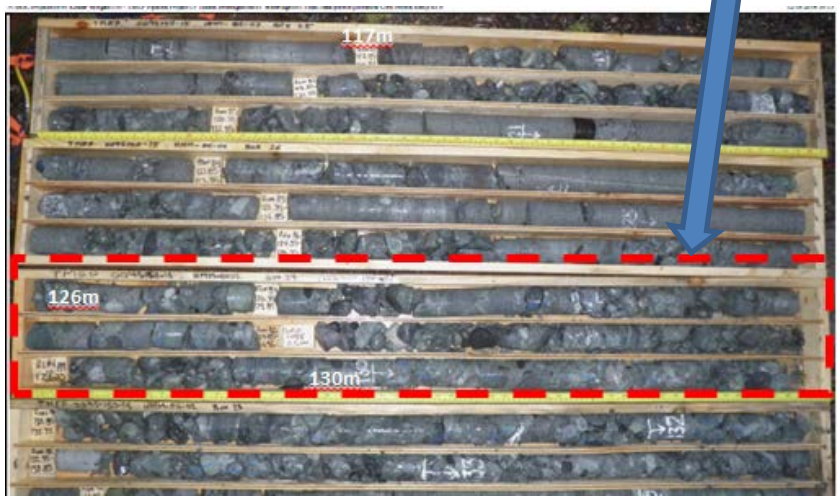
154m

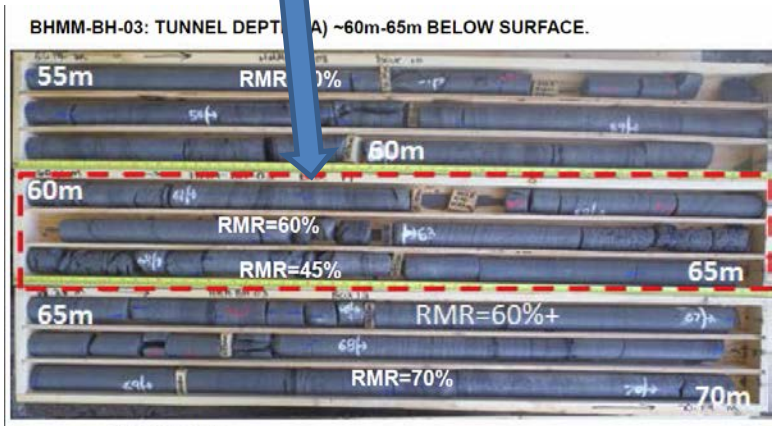




CHAINAGE FROM	CHAINAGE TO	APPROX	E TUNNEL AZIMUTH
-0+200	0+400		356°
0+400	2+000		337.5°
2+000	2+300		300°
2+300	2+696		280°

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "TMEP WESTRIDGE TUNNEL INVESTIGATION 2014 SITE INVESTIGATION DATA REPORT," AND DATED JANUARY 2015.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY UPL, DATED MAY 4, 2014 AND JULY 25, 2014. CONTOUR INTERVAL IS 5.0 m.
4. PROJECTION IS NAD83 UTM ZONE 10N.
5. TUNNEL ALIGNMENT PROVIDED BY HMM ON JANUARY 6, 2015.
6. THE 15% ERROR WITHIN THE SEISMIC REFRACTION SURVEY DATA IS PROVIDED BY AND DESCRIBED BY FRONTIER GEOSCIENCES (APPENDIX I).
7. SUBSURFACE CONDITION ONLY KNOWN AT SPECIFIC BOREHOLE LOCATIONS. INTERPRETED GROUND CONDITIONS BETWEEN THESE LOCATIONS MAY BE SUBJECT TO VARIANCE.
8. THE DEPTH OF THE INTERFACE BETWEEN WEATHERED BEDROCK AND COMPETENT BEDROCK HAS BEEN INTERPRETED BASED ON THE RESULTS OF THE GEOPHYSICS. INFORMATION FROM HMM-BH-05 WAS NOT CONSIDERED DUE TO THE SIGNIFICANT OFFSET BETWEEN THE TUNNEL ALIGNMENT AND THE BOREHOLE.
9. WATER LEVELS SHOWN FROM VIBRATING WIRE PIEZOMETER READINGS ON NOVEMBER 6, 2014.
10. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.





HMM-BH-02

- A gas monitor was present at the borehole collar and at no time during drilling was a LEL or H_2S alarm triggered.
- There was minimal drilling fluid loss during the drilling of the hole, with only minor loss within the upper poorly consolidated conglomerate units in the upper portion of the hole (within approximately 20 m below ground surface).
- Recovery of conglomerate units in the upper half of the borehole was generally less than 50%, due to wash out of matrix material.
- Water level observations during drilling are summarized in Table D-2 in Appendix D.

HMM-BH-05

- A gas monitor was present at the borehole collar and at no time during drilling was a LEL or H_2S alarm triggered.
- There were areas of drilling fluid loss within the highly weathered conglomerate. Drilling returns varied significantly from 7.3 to 31.5 m. Returns were completely lost to the formation from 7.2 to 11 m bgs, 16 to 25 m bgs and 26 to 28 m bgs. Bentonite was added to the drilling fluid near the bottom of the hole to aid in fluid retention down-hole.
- Drilling conditions at this borehole were poor. Borehole wall stability within the highly weathered conglomerate was poor. The conglomerate clasts became loosened by the drilling process and caused significant friction against the drill rods.
- Water level observations during drilling are summarized in Table D-2 in Appendix D.

3.0 INFERRED CONDITIONS ALONG PROPOSED PIPELINE ROUTE

Based on the results of geotechnical drilling, geologic mapping completed by SFU and geophysical surveys obtained to date, BGC has developed interpreted geological sections of the proposed trenchless pipeline profiles, as shown on Drawing 02. The following sections describe the surficial geology, bedrock geology and hydrogeology interpretations made to date. Further details and improvement to the interpretations will be provided following the completion of the remaining proposed boreholes and geophysical lines as part of planned subsequent investigations. Subsurface conditions are only known at the specific borehole locations. Interpreted ground conditions between these locations are subject to variance.

Detailed descriptions of the bedrock geotechnical units intercepted at Burnaby Mountain in HMM-BH-01, HMM-BH-02, HMM-BH-03 and HMM-BH-05 are provided below:

- SANDSTONE: the uppermost unit encountered in HMM-BH-02 and HMM-BH-03, consisting of predominantly fine to coarse grained sandstone with minor sections of conglomerate, part of the upper Kitsilano Member. At depth, the upper sandstone

  - CONGLOMERATE: predominantly conglomerate with minor sandstone, this is the middle unit of the Kitsilano Member. Fresh and un-weathered at HMM-BH-03, this unit is typically weak (R2) to medium strong (R3). The laboratory strength testing results average 16 MPa for the conglomerate, equivalent to a field strength grade of R2. RQD's in this unit are highly variable, generally ranging from fair to excellent (50% - 100%), with some very poor to poor (0% - 50%) sections which typically occur in the top 50 m of each borehole. The lower conglomerate unit is poorly lithified in places. In these intervals, the matrix disintegrates upon handling. Clasts are sub-rounded to rounded and medium strong to strong (R3 - R4). Observed maximum clasts size was 120 mm, with a typical range from 10 to 50 mm. The matrix is grey and comprised primarily of medium to coarse sand with some fines. Near surface in HMM-BH-05, this unit is highly to completely weathered and extremely weak (R0). At HMM-BH-05, weathering of this unit extended to approximately 31.5 m below ground surface. Discontinuity apertures generally varied from 0 to 3 mm, however geologic structure was often not visible within this unit.

3.4. Rock Mass Quality

To facilitate an understanding of how rock mass quality will vary at the tunnel elevation, BGC has used the geotechnical logging data for the Q' system (NGI, 2013) to derive Q values at the proposed tunnel elevation using the following assumptions:

- The joint water reduction factor (Jw) has been set to 0.66, which correlates to medium inflow or pressure and occasional outwash of joint fillings. This assumption is based on the measured water levels and the relatively low bedrock hydraulic conductivities indicated by the testing completed to date.
- The stress reduction factor (SRF) for the conglomerate has been assigned with consideration to the potential for weakness zones intersecting the excavation, which may cause loosening of the rock mass when the tunnel is excavated. An SRF of 5.0 has been assigned to the conglomerate unit, which is considered to have the potential to be heavily jointed or 'sugar cube' at any depth.
- The stress reduction factor (SRF) for the sandstone and siltstone units have been assigned with consideration to the potential for rock stress problems within competent rock. The average UCS for each unit and the in-situ principal stress (σ_1) at the tunnel elevation at each borehole location have been used to estimate SRF for these units.

The results of the rock mass quality review for each borehole are shown in Figure 5 through Figure 8. Complete Q values are shown relative to length along the borehole and in relation to the various Q classes (as described in NGI, 2013). These preliminary classifications are provided only to help develop an understanding of the variation in rock mass quality and should not be used for design.

A zone of weathering occurs within the upper 15 - 25 m below ground surface and consists of 'extremely poor' to 'very poor' rock mass. The inferred extent of this zone of weathering is shown on Drawing 02. At the proposed north portal location, the interpretation of the extents of the zone of weathering was supported by the results of the geophysics (Appendix I). As discussed in the summary geophysics report (Appendix I), the depth to subsurface boundaries derived from seismic refraction surveys are generally accurate to within 15%. This 15% error could result in a depth of weathering that is deeper or shallower than indicated by the geophysics results; the potential depths of weathering bracketed by this margin of error are shown in Drawing 02.

In general, once outside the zone of weathering the rock mass quality of each unit is quite consistent and does not vary significantly with depth. The figures indicate that most of the conglomerates are described as 'poor' to 'very poor'. The sandstone varies from 'poor' to 'very good' at depth and the siltstone varies from 'fair' to 'extremely good' at depth. The figure for HMM-BH-02 (Figure 6), which is the most complete dataset relevant to the tunnel at depth (Drawing 02), shows that the tunnel will primarily be excavated within 'very poor' to 'poor' conglomerate.

VERY POOR TO POOR
THE VERY POOR HAS RATING FROM Q=0.1 RMR~25%-
TO POOR HAS RATING FROM Q=4.0 RMR~55%+
THIS IS DRAMATIC DIFFERENCE IN RMR AND RESPONSE TO TBM IN TERMS OF SQUEEZE, CLOSURE, BEHAVIOUR.
NOTE RANGE IS HALF IN TERMS OF RMR.
USED RMR=9Ln Q + 44 AS WELL AS FROM LOGS PROVIDED IN APPENDIX (BIENIAWSKI, 1976).

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

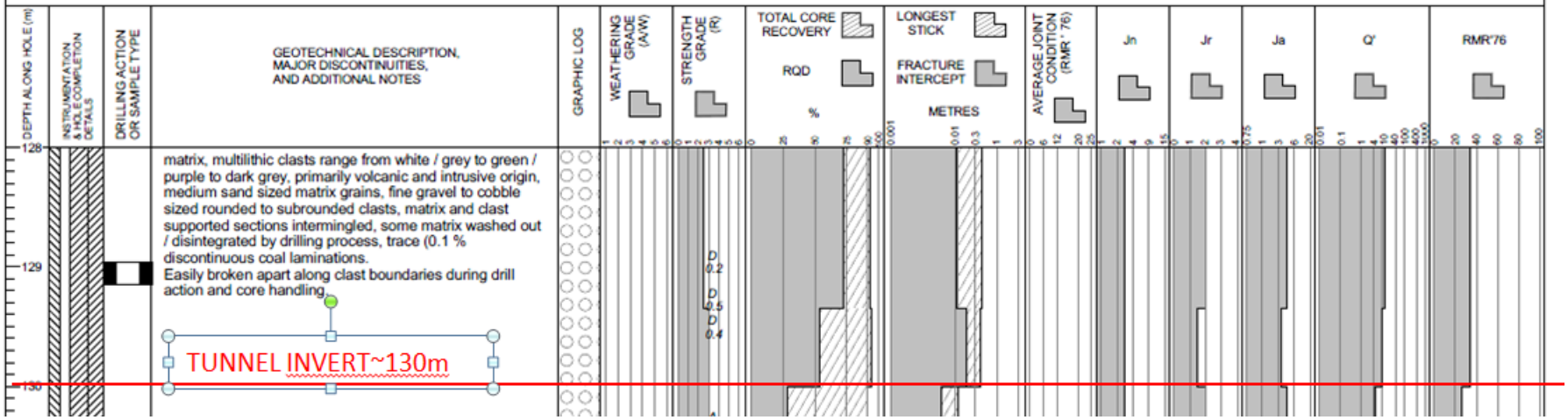
DRILL HOLE # HMM-BH-02

Location: Burnaby Mountain

Co-ordinates (m): 504,475E - 5,458,452N
Ground Elevation (m): 237
Survey Method: GPS
Datum: UTM 10 NAD83
Plunge (°): -90
Trend (°): N/A

Drill Designation: FRASTE MD-XL
Drilling Contractor: Geotech Drilling Services
Drill Method: Diamond Coring
Core: HQ3
Fluid: Water
Cased To (m) : 5.7

Start Date: 21 NOV 14
Finish Date: 26 NOV 14
Final Depth (m): 186.4
Depth To Top Of Rock (m): 4.9
Logged By: SB/SG/JVH
Reviewed By: CJS



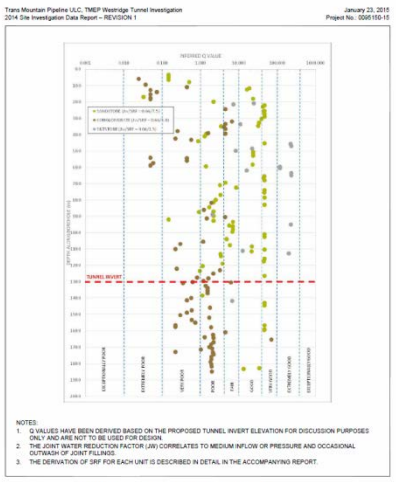


Figure 6 INFERRED Q WITH DEPTH – HMM-BH-02

OBSERVATIONS

- BH-02 GIVES GREATER VALIDITY AS IS WITHIN THE PROFILE AT INVERT. BUT NOT EVEN CLOSE TO MAKING CONCLUSIONS WITHOUT FURTHER DRILLING/CHARACTERIZATION ALONG THE TUNNEL LINE IN MY PROFESSIONAL OPINION. NOTE NOT TO BE USED FOR DESIGN AS INDICATED BY BGC.
- STILL THE RMR RANGES FROM 30% TO 60% AT THAT SAME ELEVATION. SO SELECT A NUMBER . THE REPORT SEEMS TO SAY ALL BAD WELL HOW DO THEY HANDLE ALL BAD IE. SQUEEZE POTENTIAL/TUNNEL BEHAVIOUR
- HAVE THE POLEPLOT NOW. EXCELLENT. WHY DID WE REVIEW THE INCOMPLETE INFORMATION IN DECEMBER'2014.
- NEED TO KNOW ACTUAL ELEVATION OF INVERT. NOTE ONLY ON FIGURE 5,6,7,8
- SEE BELOW – QUESTIONS VALID AS INDICATED.
- LOOKS LIKE FURTHER HOLES ARE PLANNED PRIOR TO EXCAVATION. THIS IS WHAT IS REQUIRED AS AT THIS STAGE THE INFORMATION IS LARGELY A POINT SOURCE FOR ~2kM OF TUNNEL. QUESTION: WOULD THIS BE SUFFICIENT FOR A TUNNELING CONTRACTOR TO BID ON IN TERMS OF THE TUNNEL CHARACTERIZATION.

3.0 CONCLUSIONS

3.1 Observations and Recommendations

The recommendations and conclusions have been discussed with Dion Doepker, P.Eng., (Development Engineer) and Geoff Tsuyuki, P.Eng., (Contracts Manager) of CoB during a conference call on December 22nd, 2014 with a summary as follows:

- No fatal flaw exists in terms of the tunnel caving and having disruption to surface. This is not possible due to the depth of cover exceeding 100m. It is important to ensure dry conditions for potentially weak rock masses/flowing so as to not propagate. The depth of cover is in excess of 100m other than at access and exit which must be delineated/ defined and designed.
- It is required to know/interpret RMR/ground conditions along the length of the tunnel. This will affect the performance of the TBM and stability of the tunnel. The potentially high variability of RMR within the sandstone/conglomerates requires a means of identifying the geotechnical characteristics along the length of the tunnel. This can be accomplished by further drill holes and/or horizontal probing of the face prior to the TBM advance in order to identify wet zones, weak zones, flow zones, squeezing ground.
- Low surface cover at north and south of Tunnel Option 2A, the preferred route, along with a weak cover requires the potential for steel liners within the tunnel. The Barnet Hwy undermining requires a detailed assessment in terms of methodology and geotechnical characterization. The effect of tunneling in proximity of the "scarp" should be identified and mitigated. This area was assessed as having high potential for terrain/natural hazard by BGC.
- Two drill holes that have been geotechnically assessed at ends of ~2km of tunnel. Note BH-05 is in excess of 100m from tunnel 2A routing and has minimal interpretive benefit for tunnel stability. Two(2) other holes have been drilled with BH-01 drilled short(70m depth) of the proposed option 2A/2B. The holes are not available for review and should be incorporated into this study upon assessment by BGC.
- Require a 3D representation of the entire area showing the tunnel, the topo, the infrastructure along with the geotechnical profile in 3D. This is not a numerical model but a Vulcan/Minesite generated model that is spatially accurate in UTM coordinates.
- The "scarp" may have a potential effect on the confinement of tunnel as not only have to look at profile along tunnel but to scarp to the NE at the Kask area.
- Plan for tunneling in proximity of weak material, low overburden and high risk infrastructure such as Barnet/Inlet Hwy has to be detailed
- The BGC seismic hazard report should address how variability in the tunnel in terms of rock mass characterization will affect the seismic concerns predicted along the tunnel.

- A question to address to the individual geotechnical reports is the absence of data for the tunneling machine or potential drill and blast from the Tank Farms to the Westridge Terminals. Note the BH01/02 holes have not been addressed as reports were not available. The cores show variability in RMR ranging from <20% to +60% for the same materials ie sandstone and conglomerates. How will the contractor bid with no data other than cost plus or adhere to a schedule. Concern is squeezing/rubble/unforeseen measures that may be required when incurred. Consider probe drilling from the face of the tunnel.