# Appendix H
# Golder Associates Geophysical Investigation Report for Supplemental Offshore Geotechnical Investigation, May 13, 2016

May 13, 2016

## KINDER MORGAN / TRANS MOUNTAIN - WESTRIDGE MARINE TERMINAL

# Geophysical Investigation Report for Supplemental Offshore Geotechnical Investigation

**Submitted to:**
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T2P 5J2

Attention: Rob Kozak

REPORT

**Reference Number: 1403337-001-R-Rev0-12000**

**Distribution:**

1 Electronic Copy - Kinder Morgan
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# Record of Issue

| Company | Client Contact | Version | Date Issued | Method of Delivery |
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| Kinder Morgan Canada | Ron Kozak | Rev B | April 22, 2016 | Email |
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# Table of Contents

# 1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by Kinder Morgan Canada (KMC) to conduct a marine multi-channel seismic reflection survey for the purpose of mapping bedrock and till stratigraphy at the Westridge Marine Terminal in Burnaby, BC. This work was carried out in support of engineering planning studies associated with the proposed terminal expansion project.

Prior to this multi-channel survey, a single-channel marine seismic reflection survey was carried out at the site, the results of which indicated there was an apparent lack of penetration of acoustic energy (Golder, 2014). For the current work, multi-channel seismic reflection surveying was proposed as this technique has been successful at other sites for delineating deeper bedrock and till surfaces below sediments with characteristics which attenuate or limit penetration of acoustic energy.

This report presents the results of the multi-channel seismic reflection survey conducted in February 2016. The single-channel seismic reflection data acquired in 2014 was also revisited in light of the newly available borehole information. An integrated interpretation of the multi-channel and single-channel data constrained by the available intrusive investigation information is provided.

## 2.0 OBJECTIVE AND SCOPE OF WORK

The proposed objective of the survey was to profile till and bedrock stratigraphy below the seabed in the vicinity of the existing Westridge Marine Terminal to support engineering planning studies associated with the proposed terminal expansion project.

The proposed scope of work was as follows:

- provide all equipment and personnel to complete the multi-channel seismic reflection work;
- provide support for environmental permitting for deployment of seismic airgun and sparker/boomer sources;
- provide marine mammal observation for the data collection, if required by regulatory authorities;
- collect one day of multi-channel seismic reflection data and interpretation to cover the survey area and develop bedrock contours in the offshore area; and
- provide a report summarizing the methods and equipment with interpreted data and figures in ACAD or appropriate format.

In addition to the proposed scope we revisited the sub-bottom profiler (single-channel seismic reflection) data acquired at the Westridge Marine Terminal site in February, 2014.

# 3.0 INVESTIGATION AREA

Westridge Marine Terminal is located in Burnaby, BC, on the south side of Burrard Inlet near the entrance to Indian Arm. A map of the survey area and selected seismic survey lines is shown in Figure 1. The original survey area included an over-water area extending from the shallow working limits of the survey vessel (intertidal) out to a maximum water depth of approximately 24 m below chart datum (Port Metro Vancouver LLWLT [lower low water, large tide]). Two seismic lines were also acquired across the channel to facilitate mapping the bedrock profile away from the Terminal, one from the Terminal to Cates Park, and one from near a granitic bedrock outcrop at Admiralty Point to the Terminal.

The local geologic setting includes Burnaby Mountain to the southeast of the site which comprises mainly interbedded sandstone and shale. Till covers this sandstone bedrock in the onshore part of the terminal. About 2 km to the northeast of the site across Burrard Inlet there are granitic rocks, which indicates that a geologic contact between the sedimentary and plutonic rocks occurs somewhere in Burrard Inlet. There is little published information available on the detailed geology beneath Burrard Inlet in the vicinity of the site.

# 4.0 METHODOLOGY

## 4.1 Seismic Reflection

The seismic reflection geophysical method was employed for the investigation. Seismic reflection is a commonly accepted method for mapping subsurface stratigraphic boundaries. This method uses a controlled energy source (e.g., an airgun) at given locations (shot points) to introduce a seismic signal into the subsurface. The seismic signal is reflected from interfaces between materials having differing acoustic characteristics, such as the interface between sediments and bedrock.

In multi-channel marine surveys, the reflected seismic signals are received by a group of hydrophones set at fixed spacing in a seismic streamer which is towed behind the survey vessel. The seismic source, which is either attached to the survey vessel or towed at some distance behind the vessel, is discharged at either a fixed timing or distance as the vessel travels along the survey line.

The groups of shot records are put through an extensive processing flow to obtain seismic time/depth profiles. The times and amplitudes of the reflections, with correlation to any available borehole or well log information, are used to interpret the subsurface stratigraphy and structure. For this project 22 boreholes were available to constrain the interpretation as shown in Figure 1.

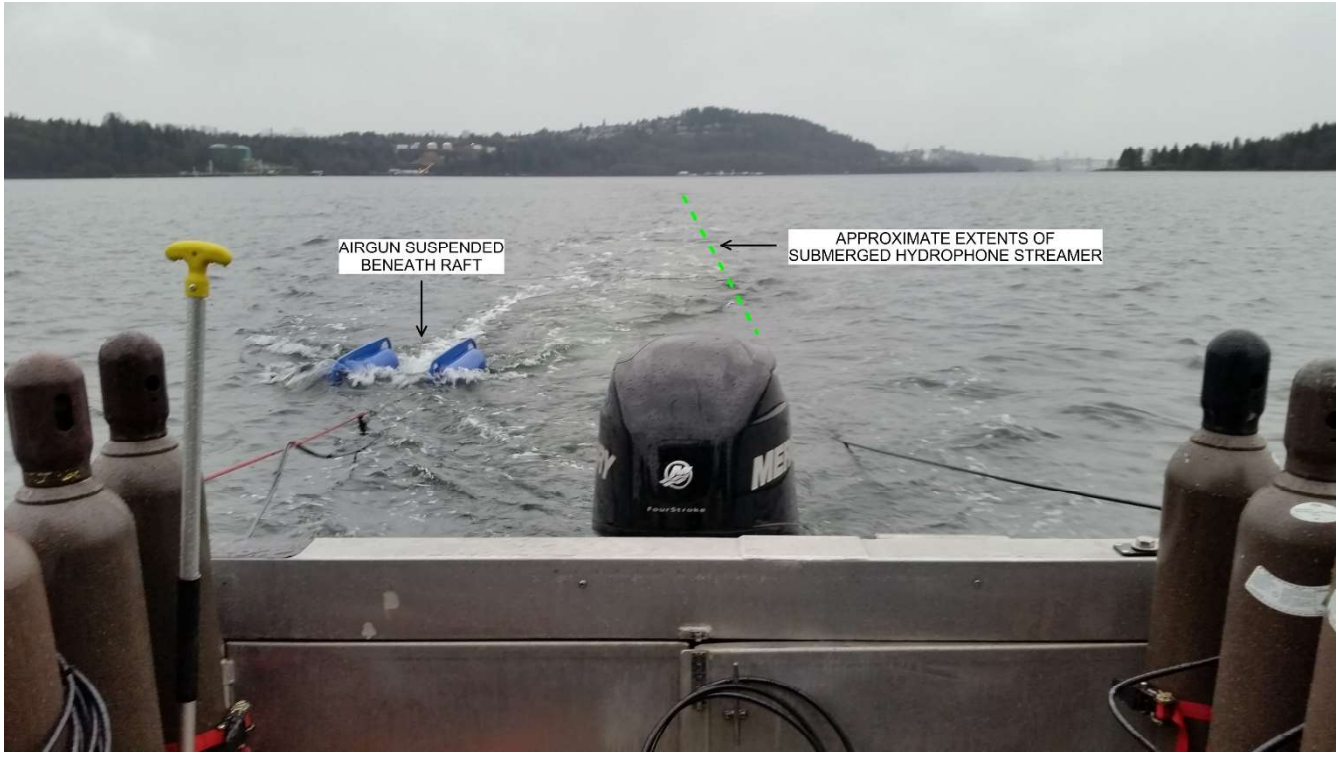
## 4.2 Instrumentation and Field Investigation

The fieldwork was completed over one day on February 5, 2016 with a crew of three geophysicists and one marine mammal observer (MMO). Table 1 specifies the list of equipment used for the seismic reflection survey.

**Table 1: Equipment**

| Equipment Purpose | Manufacturer/Model |
|---|---|
| Survey Vessel | Tsuga, 22’ aluminum survey vessel. |
| Vessel Positioning | Trimble Ag132 DGPS |
| Multi-channel Seismic Reflection Acquisition | Geometrics Geode seismograph with G-Marine software, SEGY |
| Multi-channel Seismic Receiver | 24-channel Geometrics MicroEel analog hydrophone streamer with 3.125 m hydrophone spacing |
| Navigation Software | HYPACK 2015 |
| Seismic Processing Software | RadExPro |
| Seismic Interpretation Software | Geosuite Allworks |
| Seismic Source | 10 cu. in. Airgun (Bolt Technology Corporation) |

The 71.9 m long streamer was deployed 9.5 m behind the vessel (11.3 m behind the GPS antenna) and the airgun was located between the streamer and the vessel at 5.6 m behind the vessel (7.4 m behind and 2.6 m to starboard from the GPS antenna; Photograph 1).




*Photograph 1: Hydrophone and Airgun Setup*

The seismic data were recorded in SEGY format with 1 s record lengths. Shots were fired at a fixed timing of 4 s. A total of 11 lines were acquired (including two lines repeated using different acquisition settings), totalling 7.8 line-km of surveying.

The Bolt firing box which was used for triggering the airgun stopped transmitting the firing signal on occasion during the survey which resulted in small gaps in the seismic records. There was also a relatively long (approximately 45 ms) triggering delay on some of the shot records which resulted in the seabed reflector being clipped on some records. This was resolved in the later records by specifying a much longer trigger delay time. Neither of these problems significantly impacted the final processed results however the impact of these on the interpretation is worth noting and are discussed further in Section 5.0.

A Golder marine mammal observer (MMO) was present for the testing of the airgun prior to the survey, which included sound level monitoring, and on board the vessel during seismic surveying operations.

# 5.0 DATA PROCESSING AND RESULTS

Following preliminary QA/QC of the data, 7 of the 11 lines were selected for further data processing using RadExPro software (DECO Geophysical). The following processing steps were applied to the data:

- Static Time Shift - correct for source trigger delay (resulting from firing box).
- Assign Marine Geometry - based on fixed offsets of hydrophone array and source relative to the GPS antenna.
- Import GPS UTM Positions - Calculate hydrophone, source and common depth point (CDP) positions in UTM coordinates for each shot record.
- Geometry Check/Crossplots – checks to ensure survey geometry and coordinates are correct.
- Pre-Stack Editing – Amplitude correction, Bandpass Filter (50-1000 Hz), Trace Equalization.
- Velocity Analysis – Semblance plots of CDP super gathers to create 2D velocity model.
- Normal Move-Out Correction.
- CDP Stack.
- Seafloor Pick and Top Mute.
- Demultiple – to reduce unwanted energy reverberating between the water surface and seafloor.
- Deghost – to reduce unwanted energy reflecting from the water/air interface.
- Time Migration – to collapse diffraction energy.
- F-K Spectral Whitening.

A basic time-to-depth conversion of the processed section was carried out using a constant velocity of 1500 m/s. Stacking velocities ranged from 1450 m/s to 1600 m/s. A velocity of 1500 m/s is assumed to be a more representative average velocity of the sediments above the top of till than that for till to top of bedrock layer. Because of this, the depth estimation of the top of till is slightly more precise than the estimated depth to top of bedrock. Depth profiles and horizons are presented relative to chart datum (CD).

The multi-channel data was subject to several limitations which affect the level of accuracy in the reflector interpretations. These include:

- Due to trigger delays on some lines the seabed reflection was missed in areas which resulted in difficulties with the autocorrelation and demultiplying efforts. With extra processing work, these difficulties were mostly resolved.
- The bedrock reflector in the nearshore area occurs at about the same depth as strong seabed multiples resulting in the reflector not being able to be traced in this area.

- As with all seismic data, resolution deteriorates with depth due to longer wavelengths because of increasing velocity, lowering of frequency and loss of energy penetration.

The results of the seismic profile interpretations are presented for four illustrative survey lines in Figure 2 to Figure 5. The interpretation of these results are discussed in detail in the following section, and contoured top of till and bedrock horizons and 3D views of these surfaces are provided in Figure 6 to Figure 9. Note that the coordinate system used is NAD83 (CSRS), UTM Zone 10 and all results are presented relative to CHS Chart Datum.

# 6.0 INTERPRETATION

The processed multi-channel reflection lines were reviewed together for interpretation of the glacial till and bedrock reflectors. To improve the interpretation, a selection of 22 single-channel reflection lines (Figure 1; multi-channel lines in blue, single-channel lines in black) collected in 2014 were also used because the additional multi-channel reflection and borehole data permitted delineation of lower energy and deeper reflectors in the single channel data. In general, the till and bedrock horizons were interpreted as higher amplitude semi-continuous reflectors and were constrained by the test hole logs.

The test hole logs were used both to ground truth the correct selection of reflectors to be interpreted as till and as bedrock, and to provide spot elevations in the interpolated map products. All of the test hole logs intersected till, therefore the till interpretation is better constrained than the bedrock interpretation. Only two test holes that were drilled, SH15-03 and SH15-12, intersected confirmed bedrock.

Selected interpreted multi-channel and single-channel seismic sections are presented in Figure 2 to Figure 5. Interpreted bedrock depths across the extent of the interpreted area range between 45 m and 115 m depth below Chart Datum. Interpreted top of till ranges between 19 m and 91 m depth below Chart Datum.

Based on the frequency content of the data, the theoretical vertical resolution is anticipated to be on the order of 10% of the depth. The uncertainty increases further with the occurrence of noise and the assumed velocities used for the time-to-depth conversion, resulting in an estimated vertical resolution of up to 10% to 20% of the depth. Based on the interpreted depth ranges of the till and bedrock, this results in estimated maximum errors of ±4 m to ±18 m for the shallowest and deepest interpreted extents of the till, and ±9 m to ±23 m for the shallowest and deepest extents of the interpreted bedrock.

To produce a contour map of the top of till and top of bedrock surfaces, the seismic profiles were interpolated using a kriging gridding process to generate Figure 6 and Figure 7. In addition, the interpolated surfaces were then used to create 3D visualizations as presented in Figure 8 and Figure 9.

Some interpreted features of interest include:

- A hump in the till and bedrock layers centred near the location of SH/BH15-03.
- Steep northward dip in the bedrock to the northwest and northeast of the site. The till is also interpreted to dip deeper in these areas albeit less abruptly.
- Flat to slightly southward dipping bedrock in the south of the site near the shore line. In this same area, till gets very shallow, extending towards the seabed.

When viewing the gridded surfaces, it is important to remember that there is interpolation between adjacent lines which are separated by up to 100 m. This factor must be taken into consideration when using these outputs. The higher confidence areas are directly on the line locations and where boreholes are located near the seismic lines.

# 7.0 SUMMARY

As requested by Kinder Morgan, Golder conducted a multi-channel seismic reflection survey at the Westridge Marine Terminal for the purpose of mapping bedrock and till stratigraphy. The results of this survey were interpreted together with reinterpretation of the 2014 single-channel seismic reflection data and the 2015 test hole logs.

Bedrock depths across the extent of the interpreted area range between 45 m and 115 m depth below Chart Datum. Interpreted top of till ranges between 19 m and 91 m depth below Chart Datum. The 3D surface shape of the till and bedrock layers exhibits significantly more detail than what would be obtained from the test hole logs alone.

## 8.0 CLOSURE

This report has been prepared based on the information obtained for the purposes outlined above. Should additional site investigation data become available, Golder Associates should be requested to review this report in light of this information, and provide revised and/or additional recommendations as appropriate. The reader is referred to the Study Limitations, which follows the text and forms an integral part of this report.

We trust that this report meets your immediate requirements. Please contact the undersigned should you have any questions or concerns.

**GOLDER ASSOCIATES LTD.**

Brodie Klue, M.Sc.
Geophysicist

Max Maxwell, Ph.D., P.Geo.
Principal, Senior Geophysicist

BK/MGM/bb



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# REFERENCES

Golder, 2014. Report on Hydrographic and Geophysical Seismic Surveys at Westridge Terminal. Report Reference 1414190001-005-R-Rev0-1000. Report submitted to Kinder Morgan Canada, dated June 26, 2014.

# STUDY LIMITATIONS

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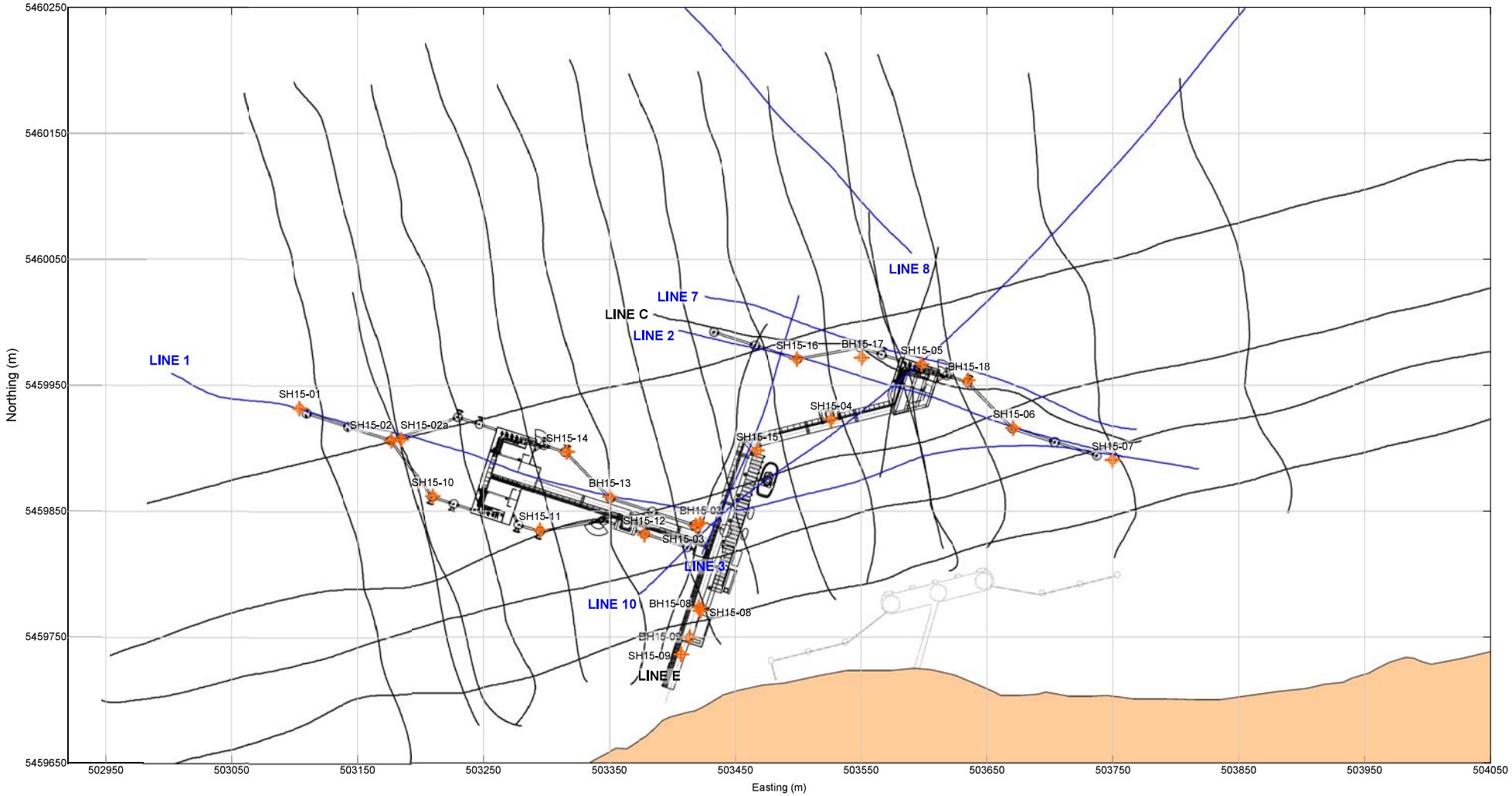



0 50 100 150 200 m

**LEGEND**

- MULTI-CHANNEL SEISMIC REFLECTION LINE (2016)
- SINGLE-CHANNEL SEISMIC REFLECTION LINE (2014)
- TEST HOLE (GOLDER 2015)

NOTES:
1. Coordinate System: NAD83(CSRS) / UTM Zone 10N
2. Proposed facilities layout on locality map from Moffatt & Nichol, June 15, 2015

| | |
|---|---|
| CLIENT | KINDER MORGAN CANADA |
| CONSULTANT | Golder Associates |
| YYYY-MM-DD | 2016-04-20 |
| PREPARED | BK |
| DESIGN | BK |
| REVIEW | JS |
| APPROVED | MM |
| PROJECT | WESTRIDGE MARINE TERMINAL SUPPLEMENTARY OFFSHORE GEOTECHNICAL INVESTIGATION, BURNABY, B.C. |
| TITLE | SEISMIC REFLECTION SURVEY LINES |
| PROJECT No. | 1403337 |
| PHASE | 12000 |
| Rev. | 0 |
| FIGURE | 1 |

**LEGEND**

SH15-01 TEST HOLE

TRANSITION ZONE (TEST HOLE)

TILL (TEST HOLE)

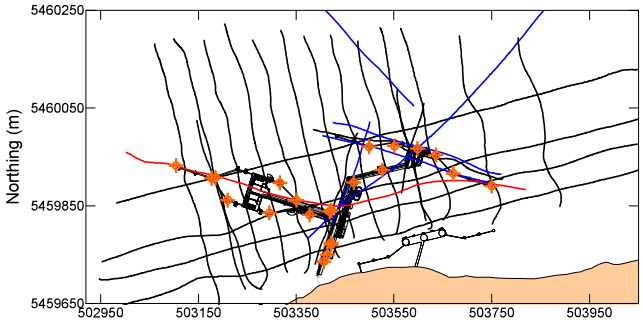
BEDROCK (TEST HOLE)

SEABED

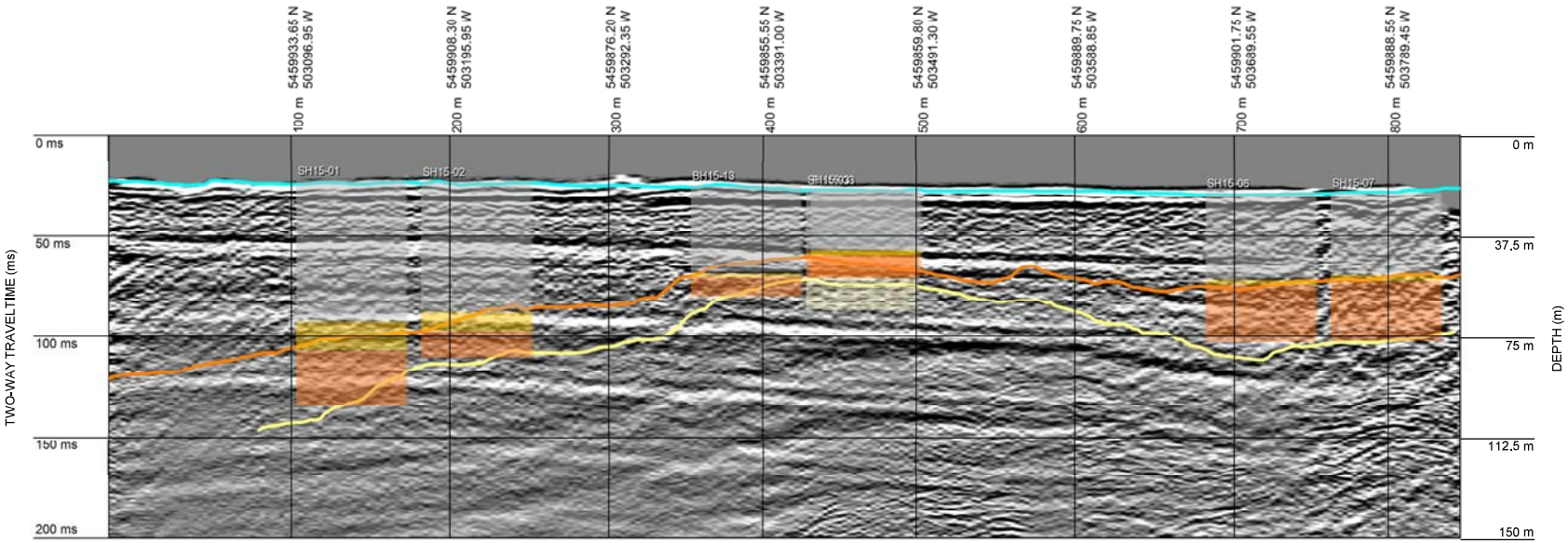
TOP OF TILL

TOP OF BEDROCK

LOCALITY MAP




PRESENTED LINE DISPLAYED IN RED




NOTES:
1. Coordinate System: NAD83(CSRS) / UTM Zone 10N
2. Profile presented in two-way traveltime (milliseconds)
3. Proposed facilities layout on locality map from Moffatt & Nichol, June 15, 2015

| | |
|---|---|
| CLIENT | KINDER MORGAN CANADA |
| PROJECT | WESTRIDGE MARINE TERMINAL SUPPLEMENTARY OFFSHORE GEOTECHNICAL INVESTIGATION, BURNABY, B.C. |
| CONSULTANT | Golder Associates |
| YYYY-MM-DD | 2016-04-20 |
| PREPARED | BK |
| DESIGN | BK |
| REVIEW | JS |
| APPROVED | MM |
| TITLE | **SEISMIC REFLECTION MULTI-CHANNEL LINE 1** |
| PROJECT No. | 1403337 |
| PHASE | 12000 |
| Rev. | 0 |
| FIGURE | 2 |

**LEGEND**

SH15-01 TEST HOLE

TRANSITION ZONE (TEST HOLE)

TILL (TEST HOLE)

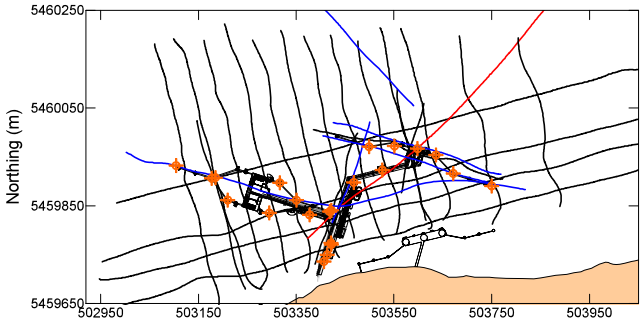
BEDROCK (TEST HOLE)

SEABED

TOP OF TILL

TOP OF BEDROCK

LOCALITY MAP

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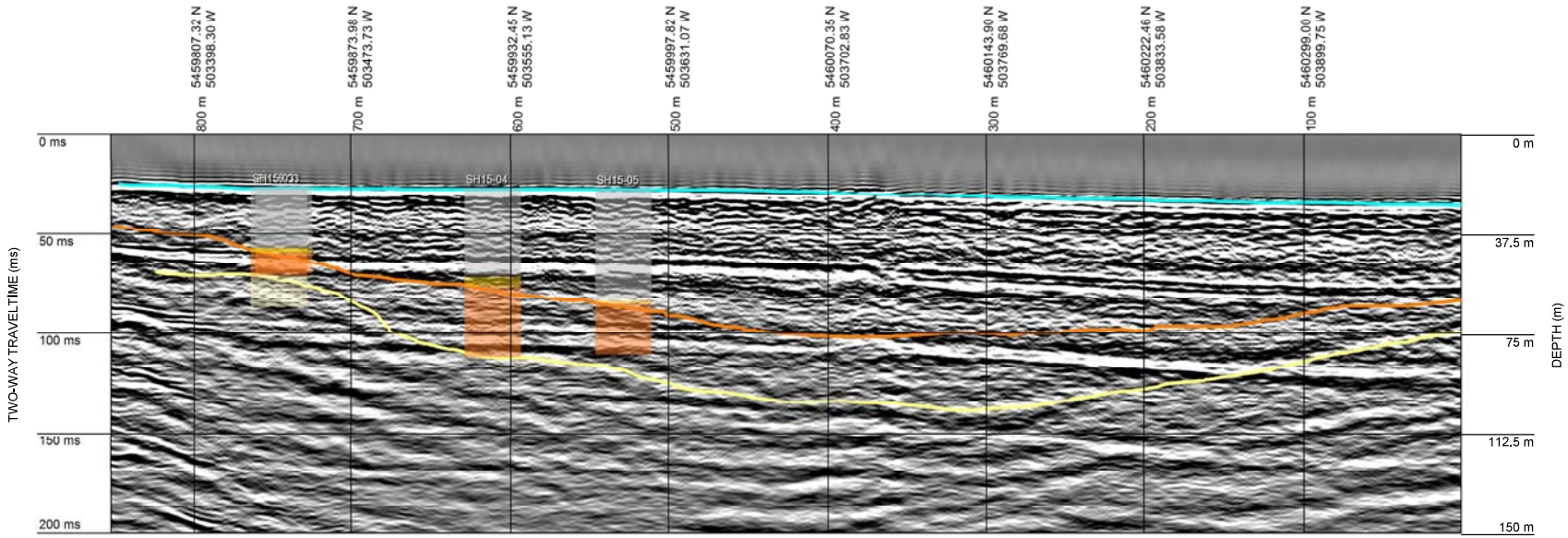



NOTES:
1. Coordinate System: NAD83(CSRS) / UTM Zone 10N
2. Profile presented in two-way traveltime (milliseconds)
3. Proposed facilities layout on locality map from Moffatt & Nichol, June 15, 2015

| | | | |
|---|---|---|---|
| CLIENT<br>KINDER MORGAN CANADA | | PROJECT<br>WESTRIDGE MARINE TERMINAL<br>SUPPLEMENTARY OFFSHORE GEOTECHNICAL<br>INVESTIGATION, BURNABY, B.C. | |
| CONSULTANT<br>Golder Associates | YYYY-MM-DD 2016-04-20<br>PREPARED BK<br>DESIGN BK<br>REVIEW JS<br>APPROVED MM | TITLE<br>**SEISMIC REFLECTION**<br>**MULTI-CHANNEL LINE 10** | |
| | | PROJECT No. 1403337 | PHASE 12000 | Rev. 0 | FIGURE 3 |

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B
25 mm

**LEGEND**

SH15-01 TEST HOLE

TRANSITION ZONE (TEST HOLE)

TILL (TEST HOLE)

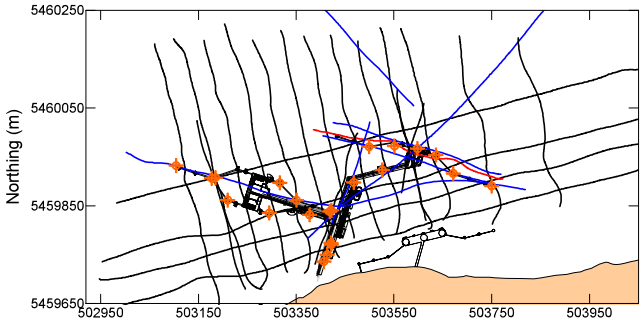
BEDROCK (TEST HOLE)

SEABED

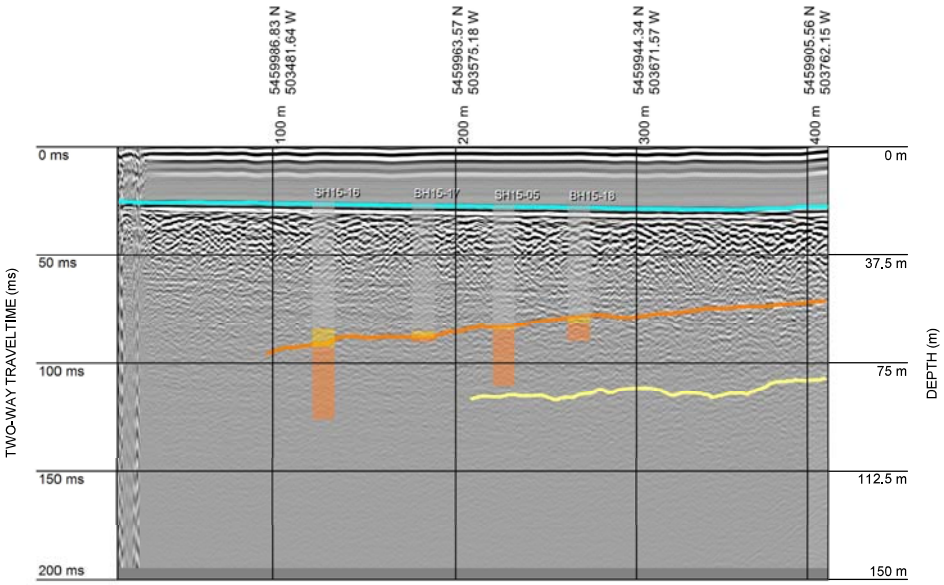
TOP OF TILL

TOP OF BEDROCK

LOCALITY MAP




PRESENTED LINE DISPLAYED IN RED




NOTES:
1. Coordinate System: NAD83(CSRS) / UTM Zone 10N
2. Profile presented in two-way traveltime (milliseconds)
3. Proposed facilities layout on locality map from Moffatt & Nichol, June 15, 2015

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|---|---|---|---|
| CLIENT<br>KINDER MORGAN CANADA | | PROJECT<br>WESTRIDGE MARINE TERMINAL<br>SUPPLEMENTARY OFFSHORE GEOTECHNICAL<br>INVESTIGATION, BURNABY, B.C. | |
| CONSULTANT<br>Golder Associates | YYYY-MM-DD 2016-04-20<br>PREPARED BK<br>DESIGN BK<br>REVIEW JS<br>APPROVED MM | TITLE<br>**SEISMIC REFLECTION**<br>**SINGLE-CHANNEL LINE C** | |
| | | PROJECT No. 1403337 | PHASE 12000 / Rev. 0 / FIGURE 4 |

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B
25 mm

**LEGEND**

SH15-01 TEST HOLE

TRANSITION ZONE (TEST HOLE)

TILL (TEST HOLE)

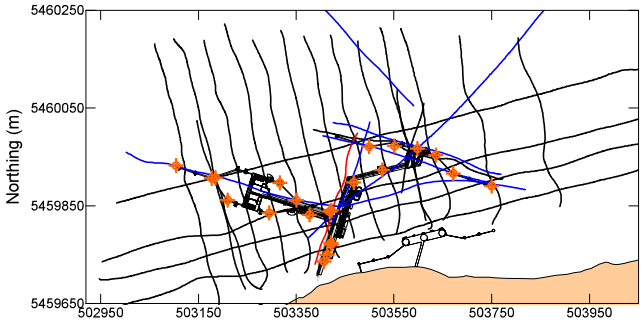
BEDROCK (TEST HOLE)

SEABED

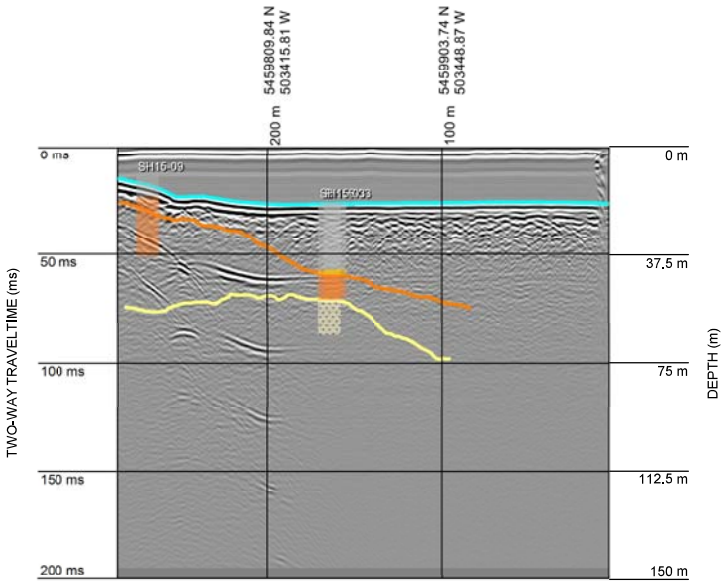
TOP OF TILL

TOP OF BEDROCK

LOCALITY MAP

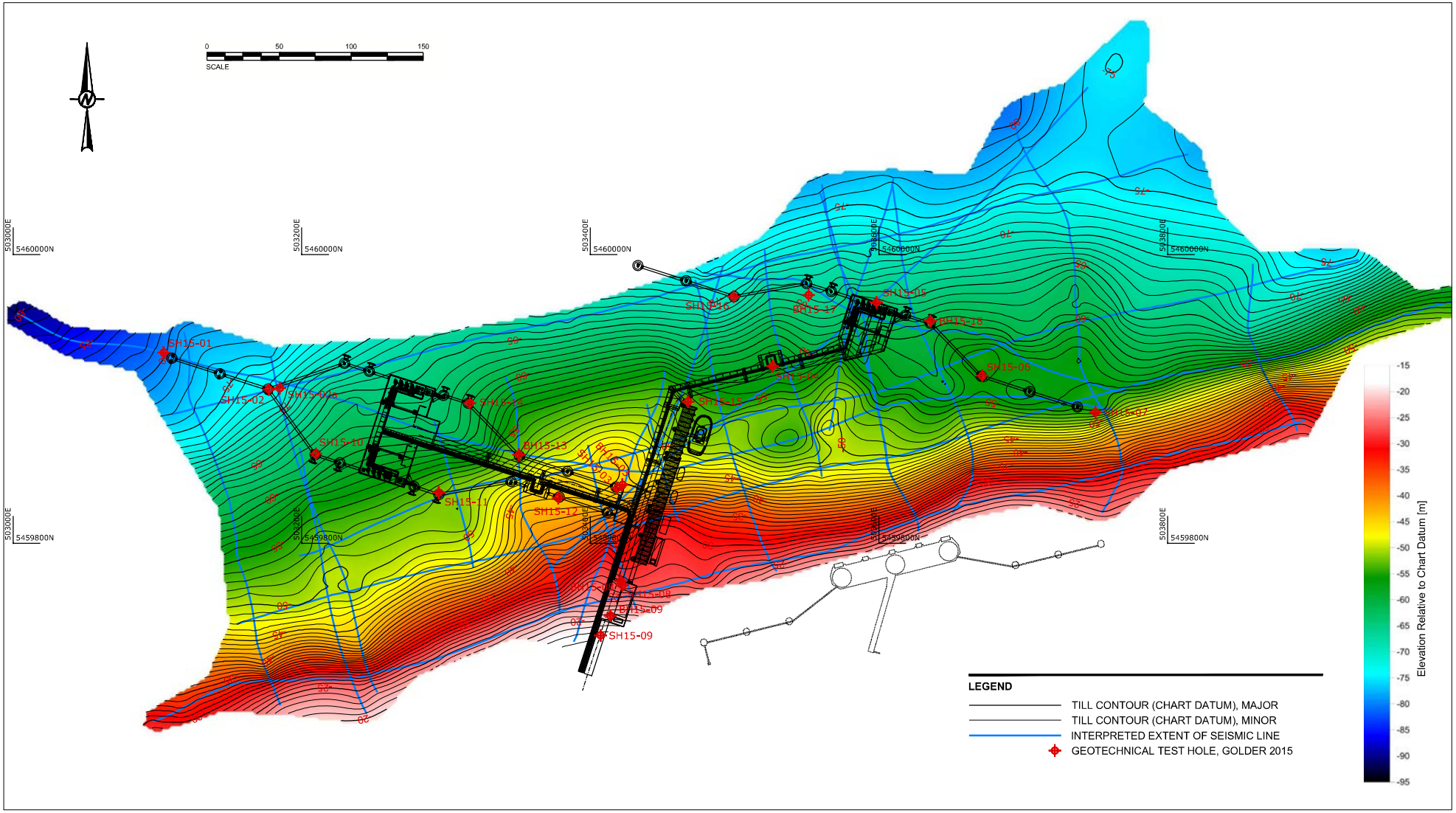



PRESENTED LINE DISPLAYED IN RED




NOTES:
1. Coordinate System: NAD83(CSRS) / UTM Zone 10N
2. Profile presented in two-way traveltime (milliseconds)
3. Proposed facilities layout on locality map from Moffatt & Nichol, June 15, 2015

| | | | |
|---|---|---|---|
| CLIENT: KINDER MORGAN CANADA | | PROJECT: WESTRIDGE MARINE TERMINAL SUPPLEMENTARY OFFSHORE GEOTECHNICAL INVESTIGATION, BURNABY, B.C. | |
| CONSULTANT: Golder Associates | YYYY-MM-DD: 2016-04-20 | TITLE: **SEISMIC REFLECTION SINGLE-CHANNEL LINE E** | |
| | PREPARED: BK | | |
| | DESIGN: BK | | |
| | REVIEW: JS | | |
| | APPROVED: MM | PROJECT No.: 1403337 | PHASE: 12000 |
| | | Rev.: 0 | FIGURE: 5 |




**NOTES**

1. COORDINATE SYSTEM: NAD83(CSRS) / UTM ZONE 10N
2. HORIZON PRESENTED IN METRES RELATIVE TO CHS CHART DATUM
3. INTERPRETATION BASED ON 2016 MULTI- AND 2014 SINGLE-CHANNEL SEISMIC REFLECTION DATA

**REFERENCE**

PROPOSED FACILITIES LAYOUT FROM MOFFAT & NICHOL, 2015-06-15

CLIENT
KINDER MORGAN CANADA

CONSULTANT
Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2016-04-21 |
| PREPARED | NFT |
| DESIGN | BK |
| REVIEW | JS |
| APPROVED | MM |

PROJECT
WESTRIDGE MARINE TERMINAL
SUPPLEMENTARY OFFSHORE GEOTECHNICAL INVESTIGATION, BURNABY, B.C.

TITLE
**TILL ELEVATION (CHART DATUM)**

| PROJECT No. | PHASE | Rev. | FIGURE |
|---|---|---|---|
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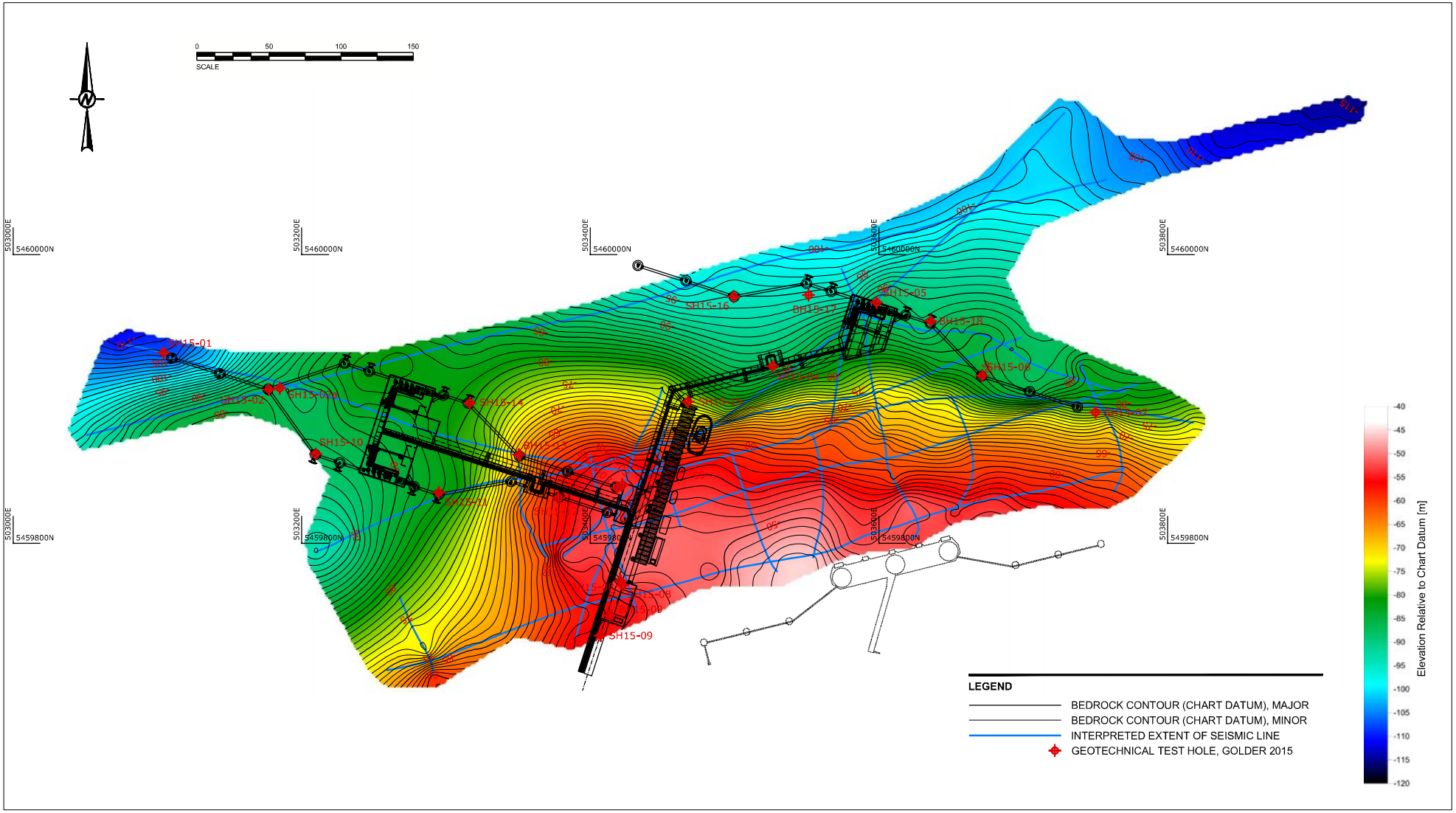


**NOTES**

1. COORDINATE SYSTEM: NAD83(CSRS) / UTM ZONE 10N
2. HORIZON PRESENTED IN METRES RELATIVE TO CHS CHART DATUM
3. INTERPRETATION BASED ON 2016 MULTI- AND 2014 SINGLE-CHANNEL SEISMIC REFLECTION DATA

**REFERENCE**

PROPOSED FACILITIES LAYOUT FROM MOFFAT & NICHOL, 2015-06-15

CLIENT
KINDER MORGAN CANADA

CONSULTANT

| | |
|---|---|
| YYYY-MM-DD | 2016-04-21 |
| PREPARED | NFT |
| DESIGN | BK |
| REVIEW | JS |
| APPROVED | MM |

PROJECT
WESTRIDGE MARINE TERMINAL
SUPPLEMENTARY OFFSHORE GEOTECHNICAL
INVESTIGATION, BURNABY, B.C.

TITLE
**BEDROCK ELEVATION (CHART DATUM)**

| PROJECT No. | PHASE | Rev. | FIGURE |
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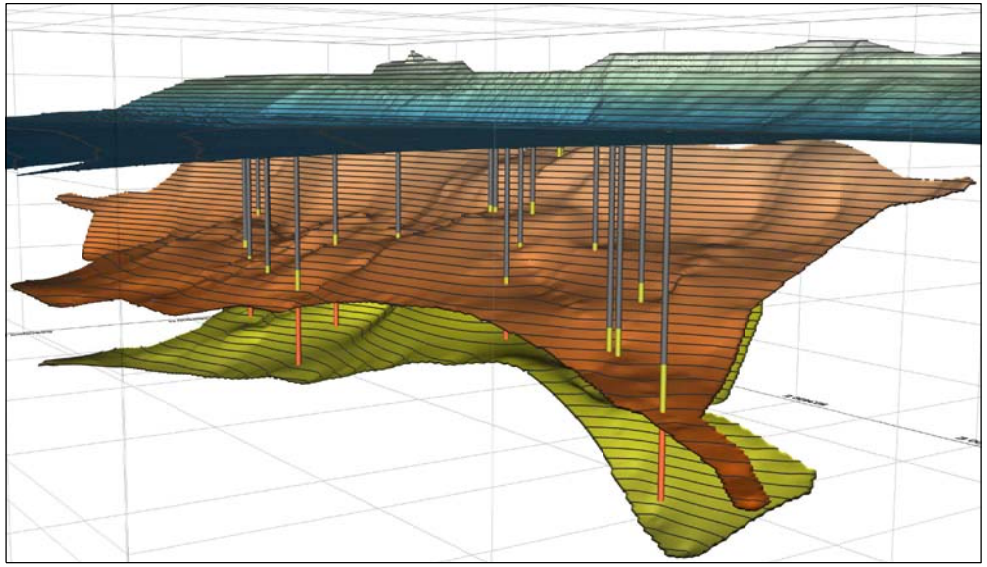
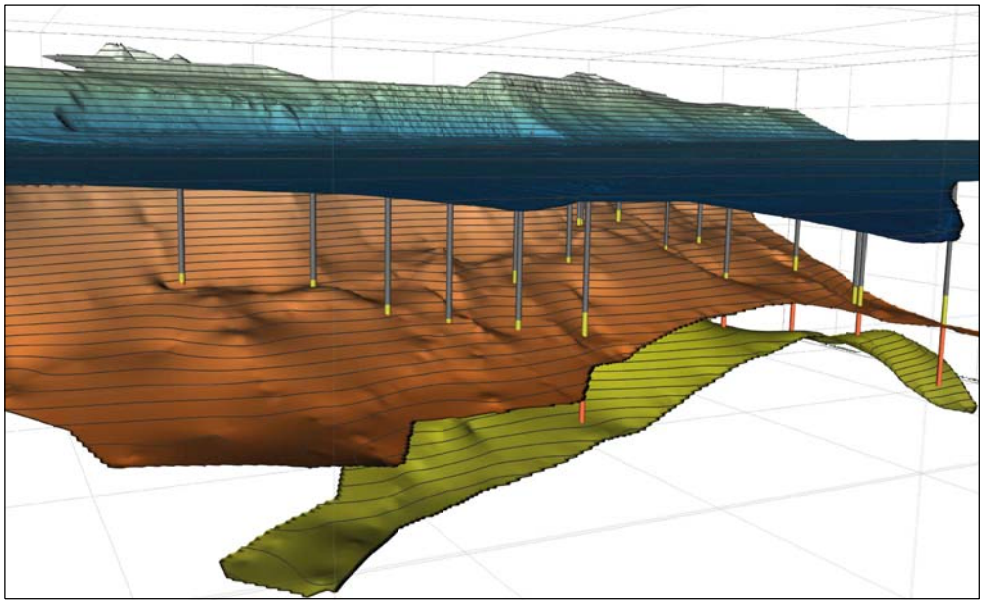


VIEW LOOKING TOWARD SOUTH-EAST

VIEW LOOKING TOWARD SOUTH-WEST



**LEGEND: TEST HOLE SOIL UNITS**

- OVERBURDEN (UNITS 1 OR 2)
- TRANSITION ZONE (UNIT 3)
- TILL-LIKE SOIL (UNIT 4)
- BEDROCK (UNIT 5)

**NOTES**

1. COORDINATE SYSTEM: NAD83(CSRS) / UTM ZONE 10N
2. HORIZONS PRESENTED IN METRES RELATIVE TO CHS CHART DATUM
3. INTERPRETATION BASED ON 2016 MULTI- AND 2014 SINGLE-CHANNEL SEISMIC REFLECTION DATA
4. TEST HOLES SHOWN ARE FROM GOLDER GEOTECHNICAL SURVEY 2015
5. CONTOURS SHOWN ARE AT INTERVALS OF 2.0 m
6. TOP HORIZON IS SEABED FROM GOLDER MULTIBEAM BATHYMETRY SURVEY 2014
7. MIDDLE HORIZON IS INTERPRETED TOP OF "TILL-LIKE SOIL"
8. BOTTOM HORIZON IS INTERPRETED TOP OF "BEDROCK"
9. ALL IMAGES OUTPUT FROM VOXLER (PROGRAM BY GOLDEN SOFTWARE)
10. VERTICAL EXAGGERATION IS 2.5:1

CLIENT
KINDER MORGAN CANADA

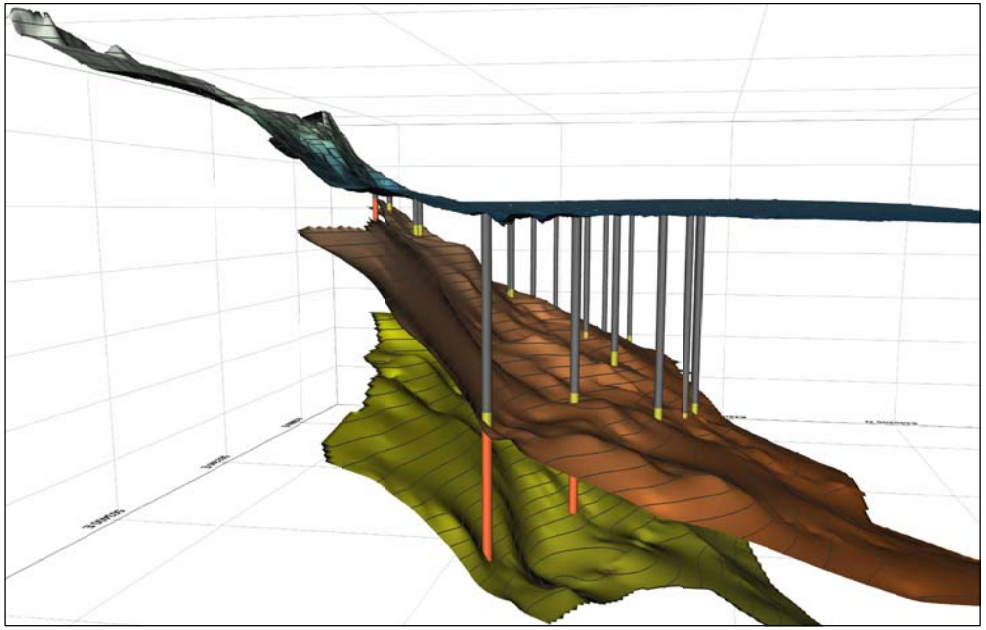
CONSULTANT
Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2016-04-29 |
| PREPARED | NFT |
| DESIGN | BK |
| REVIEW | JS |
| APPROVED | MM |

PROJECT
WESTRIDGE MARINE TERMINAL
SUPPLEMENTARY OFFSHORE GEOTECHNICAL
INVESTIGATION, BURNABY, B.C.

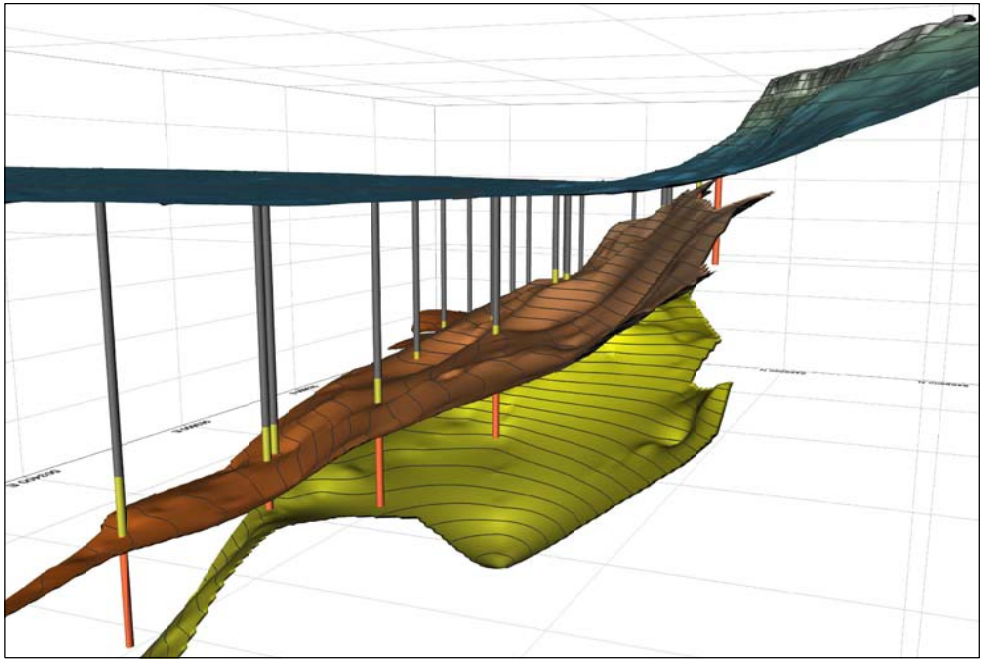
TITLE
**3D MODEL SURFACE VIEWS**
**SHEET 1 OF 2**

| PROJECT No. | PHASE | Rev. | FIGURE |
|---|---|---|---|
| 1403337 | 12000 | 0 | 8 |



VIEW LOOKING TOWARD WEST
MODEL HAS BEEN CLIPPED IN N-S PLANE NEAR DREDGING MID-POINT
TO SHOW HORIZON SLOPES AND SEABED FEATURES

VIEW LOOKING TOWARD EAST



**LEGEND: TEST HOLE SOIL UNITS**

- OVERBURDEN (UNITS 1 OR 2)
- TRANSITION ZONE (UNIT 3)
- TILL-LIKE SOIL (UNIT 4)
- BEDROCK (UNIT 5)

**NOTES**

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TITLE
**3D MODEL SURFACE VIEWS**
**SHEET 2 OF 2**

| PROJECT No. | PHASE | Rev. | FIGURE |
|---|---|---|---|
| 1403337 | 12000 | 0 | 9 |

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