FRONTIER GEOSCIENCES INC.

MARINE SEISMIC REFRACTION, BATHYMETRY

AND SUB-BOTTOM ACOUSTIC PROFILING

SURVEY REPORT

RVYC COAL HARBOUR MARINA RECONFIGURATION

VANCOUVER, BC

Submitted to:

Royal Vancouver Yacht Club

March 2, 2018

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Illustrations

1. Introduction

During the periods of January 16 to January 18 and February 7, 2018, Frontier Geosciences Inc. carried out a marine seismic refraction and sub-bottom acoustic profiling investigation for Royal Vancouver Yacht Club at the Coal Harbour Marina in Vancouver, BC. A Survey Location Plan of the area is shown at a scale of 1:50,000 in Figure 1 of the Appendix.

The purpose of the survey was to determine ocean bottom contours, thicknesses of overburden materials and the depths to and configuration of the bedrock surface. This information will be used to aid in the Coal Harbour Marina reconfiguration. The survey area encompassed the western half of the marina and surrounding areas. The surveyed area covers approximately 300 metres by 300 metres, with a total of approximately 1020 metres of marine seismic refraction surveying completed on seven separate lines. A Site Plan illustrating the locations of the seismic refraction transects and the boat track is presented at a 1:2,500 scale in the Appendix.

2. The Sub-bottom Acoustic Profiling Survey

2.1 Bathymetry Survey

2.1.1 Survey Equipment

The overwater bathymetry survey was completed using an Imagenex DeltaT multibeam sonar. This sonar sounder operates at 675 kHz, and provides a resolution of 0.2% of range. The sonar employs an ethernet connection to transmit the data at high speed to the acquisition system for real-time display and logging. The motion and orientation of the sonar system was monitored with a Honeywell HMR gyro-compass. The resolution of the Honeywell heading measurement is 0.1 degrees and the roll and pitch measurement is 0.04 degrees. Power for the field computers and sonar was provided by ship's power. Royal Vancouver Yacht Club's aluminium boat the Northwest was used for the survey.

The position of the sonar system was monitored with a Hemisphere S320 GNSS/GLONASS RTK Global Positioning System (GPS) receiver. The Hemisphere S320 is a 24-channel, dual frequency receiver with L1 and L2 carrier phase measurements. The system includes a GPS antenna, receiver, internal radio and a battery in a unit that is utilized as a RTK rover. The RTK position corrections can be received either by the internal radio, or by the built-in GSM module for mobile phone communication. Communication between the receiver and handheld controller is provided through Bluetooth wireless technology.

2.1.2 Survey Procedure

The multibeam sonar was placed in the water at a depth of 0.27 metres on the port side of the vessel. Data collected from the Imagenex DeltaT was logged in real-time, together with position information, and the HMR gyro-compass. All data was stored in time synced notebook computers. The horizontal datum is UTM, zone 10 North. The survey was carried out in good conditions, and the continuity and quality of the data was excellent. Tidal corrections were taken form the observed tidal measurements provided by the Canadian Hydrographic Service (CHS) for Vancouver.

The sonar position and orientation measurements, and sonar depth measurements were combined and analyzed using the MB-System multibeam data processing software, written by the Monterey Bay Aquarium Research Institute and the Lamont-Doherty Earth Observatory. The resulting sonar files were processed to produce a map that merges each individual swath to produce a final detailed map. Gridding and contouring of the data was achieved with the Golden Software program Surfer. A value of 1470 m/s was used to convert the sonar range information into depth.

Example of Sub-bottom Acoustic Profiling Setup

2.2 Sub-Bottom Acoustic Profiling System

2.2.1 Survey Equipment

The sub-bottom acoustic profiling (seismic reflection) survey was completed with an electric pulser source (precision double coil, vertical boomer) and hydrophone receiver system. The source is an electromagnetic transducer system that generates a broad-band, acoustic signal source operating at a dominant frequency of 250 Hz. The receiver system is a pressure sensitive, multi-element hydrophone receiver array contained in an oil-filled eel. The spacing of the receiver elements is designed to maximise the signal of the wavefront arriving vertically from the sub-bottom reflection, and minimise noise due to movement through the water and the direct wave arriving horizontally from the pulser source. The reflected signals are amplified and digitised with a 24-bit data acquisition system, and recorded on a survey system computer. Power for the seismic system was provided by ship's power.

2.2.2 Survey Procedure

The pulser source was towed at a distance of 10 metres behind the vessel, and the midpoint of the receiver system was 16 metres behind the source. In operation, pulses from the source were reflected from the bottom and sub-bottom horizons, summed in the elements of the hydrophone array, and transferred to the recording amplifiers. The computer recorded a seismogram of 200 milliseconds two-way time duration approximately twice per second.

2.2.3 Data Processing and Interpretation Procedure

The sub-bottom acoustic profiling data was processed into SEG-2 format and imported into the Seismic Unix reflection processing package. The positioning information was processed to account for the lay-back of the source and receiver from the GPS receiver. After processing steps that include trace balancing, bandpass filtering and Stolt migration, the data was converted to SEG-Y format, correlated to the GPS position information, and imported into the Seismic Micro Technologies (SMT) 2D/3D seismic interpretation package. This software is a comprehensive 2D/3D seismic interpretation program that provides interpretive and horizon picking tools integrated into a map and section database, data management and display system. In addition, the bathymetry data were imported as a horizon into the SMT package for interpretation and to allow full handling of the time to depth conversion.

The first stage in the analysis was the use of the horizon picking tools to identify the bedrock reflector and reflectors present within the sediment column. The software shows time markers at the intersection of lines and tie-lines, facilitating the picking of a consistent event throughout the map area. The data was then converted to depth, and the surfaces were plotted in the colour contour format.

3. The Seismic Refraction Survey

3.1 Survey Equipment

The seismic refraction investigation was carried out using a Geometrics, Geode, 24 channel, signal enhancement seismographs and Marks Products 10 Hz hydrophones. hydrophone intervals along the multicored seismic cable were maintained at 5 metres in order to ensure high resolution data on subsurface layering. Seismic energy was provided by a small Bolt airgun, which released 10 cubic inches of compressed air into the water. Shot initiation or zero time was established by a Gisco seismic radio trigger.

Marine Seismic Refraction Instrument Setup

3.2 Survey Procedure

For each spread, the seismic cable was stretched out in a straight line along the wharf and the hydrophones sunk to the ocean bottom. Multiple separate 'shots' were then initiated: one at either end of the hydrophone array, two at intermediate locations along the seismic cable, and one off each end of the line, to ensure adequate coverage of the subsurface. The shots were triggered individually and arrival times for each hydrophone were recorded digitally in the seismograph. For quality assurance, field inspection of raw data after each shot was carried out, with additional shots recorded if first arrivals were unclear. Data recorded during field surveying operations was generally of good to excellent quality.

Throughout the survey, notes were recorded regarding seismic line positions in relation to features along the marina structure. The elevation of the hydrophones was determined from the bathymetric survey, and lead line depth measurements taken at each hydrophone location. All the depths were then corrected to tide and chart datum.

3.3 Data Reduction and Processing

The final interpretation of the seismic data was arrived at using the method of differences technique. This method utilises the time taken to travel to a hydrophone from shotpoints located to either side of the hydrophone. Velocities are calculated as the slope of first break pick times and hydrophone distances. When there is a significant change in slope a new velocity is calculated and assigned to the new layer. Basal velocities are calculated by the arrivals of off end shots where picked arrivals are refracted from the basal layer. Each hydrophone is assigned a velocity and time for each layer. Using the total time, a small vertical time is computed which represents the time taken to travel from the refractor up to the ground surface. This time is then multiplied by the velocity of each overburden layer to obtain the thickness of each layer at that point. The thicknesses are splined along the seismic line to create a continuous boundary between layers.

4. Geophysical Results

4.1 General

The results of the overwater survey are displayed in map format, at a scale of 1:2,000 in Figures 3 to 5 of the Appendix. The interpreted bathymetric elevation contour plan, illustrated in Figure 3 of the Appendix, shows the interpreted ocean bottom contours. The interpreted bedrock surface elevation contour plan of the area is illustrated in Figure 4 of the Appendix. Figure 5 of the Appendix, displays an isopach of the sediment thickness overlying the bedrock surface. Additionally, seven marine refraction lines were completed along the marina docks, the interpreted profiles of these transects are illustrated at 1:500 scale in Figures 6 to 12 in the Appendix. All results were calibrated to Tide and Chart datum elevations.

An example of acoustic profiling data illustrating key sub-bottom reflectors is illustrated in Figure 13. The interpreted bedrock reflector is shown in red. The shallow, blue line is the sea floor reflector.

4.2 Discussion

In Figure 3, the results of the bathymetry survey shows the general ocean bottom configuration at a scale of 1:2,000. The contour plan displays a generally flat-lying surface underlying the existing dock structures, ranging from an elevation high of approximately -1.5 metres and reaching a low of approximately -4 metres elevation. To the southeast of the existing marina, in the channel, depths to the ocean bottom increase to approximately -5.5 metres elevation, likely due to dredging within the entrance channel.

The interpreted bedrock elevations are displayed in colour contour format in Figure 4. The bedrock surface contours vary throughout the survey area, with an average elevation of -17 metres. The maximum observed bedrock depth in the eastern area of the survey area is approximately -24 metres elevation. Additional bedrock lows of note are observed in the southern portion of the survey area and beneath the existing dock structures centred on location 490697E, 5460275N. Surrounding this bedrock low located near the intersection of seismic line SL18-02 and SL18-04, interpreted bedrock elevations increase up to -7 m. Another interpreted bedrock high, reaching approximately -12.5 m elevation is observed near the southeast end of the existing docks. The results of the marine seismic refraction indicate a compressional wave velocity range of 2250 m/s to 2450 m/s for the interpreted bedrock. This velocity is consistent with sedimentary sandstone bedrock, commonly encountered in the area.

An interpreted sediment isopach plan was prepared by contouring the thicknesses of sediments overlying bedrock. The plot is illustrated in Figure 5, and displays an average sediment thickness of approximately 13 m. Underlying the proposed dock structures, thicknesses range from a maximum of 21.5 metres to a minimum of approximately 8 metres. Calculated compressional (P) wave velocities for the overlying sediments vary from 1680 m/s to 1900 m/s. The slower velocity of 1680 m/s is present over the middle of the survey area, with higher velocities of 1900 m/s observed on the southeast, south and northwest edges of the survey area. Higher velocities are indicative of an increase in compaction or density of the sediments.

5. Limitations

The depths to subsurface boundaries derived from seismic refraction surveys are generally accepted as accurate to within fifteen percent of the true depths to the boundaries. In some cases, unusual geological conditions may produce false or misleading data points with the result that computed depths to subsurface boundaries may be less accurate. In seismic refraction surveying difficulties with a 'hidden layer' or a velocity inversion may produce erroneous depths. The first condition is caused by the inability to detect the existence of a layer because of insufficient velocity contrasts or layer thicknesses. A velocity inversion exists when an underlying layer has a lower velocity than the layer directly above it. The interpreted depths shown on drawings are to the closest interface location, which may not be vertically below the measurement point if the refractor dip direction departs significantly from the survey line location. Structural discontinuities occurring on a scale less than the hydrophone spacing or isolated boulders would go undetected in the interpretation of the data. The seismic refraction method may not detect a narrow canyon-like feature incised into bedrock, if the canyon width is narrow relative to the depth of burial of the feature.

The depths to subsurface boundaries derived from overwater seismic sub-bottom profiling surveys are generally accepted as accurate to within fifteen percent of the true depths to the boundaries. In practice, the seismic velocity of sub-bottom materials is not determined in the course of an overwater acoustic profiling investigation. Errors may arise from application of an assumed velocity for saturated materials to determine the depths to sub-surface horizons when only the travel time to the horizon is known. An underestimate of the velocity function would produce depths that are too shallow, and the reverse occurring with an overestimate of velocity. True depths may be established by carrying out overwater seismic refraction surveying or by determining velocities with known borehole intersections. Small errors may also occur in data gridding. Additionally, near surface shallow reflectors may be masked by strong bathymetry returns in the data.

The information in this report is based upon geophysical measurements and field procedures and our interpretation of the data. The results are interpretive in nature and are considered to be a reasonably accurate representation of existing subsurface conditions within the limitations of the seismic refraction and sub-bottom acoustic profiling methods.

For: Frontier Geosciences Inc.

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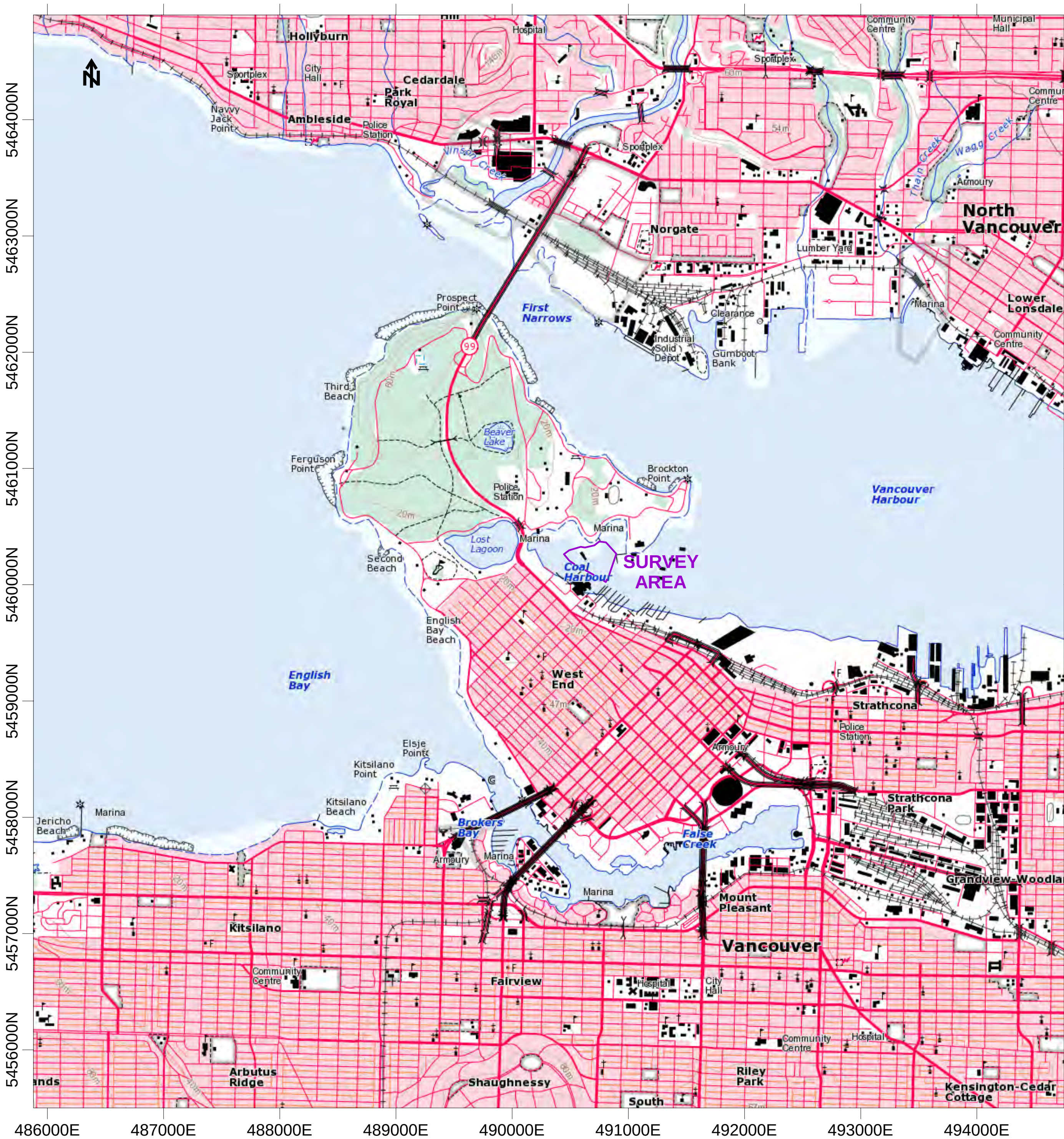
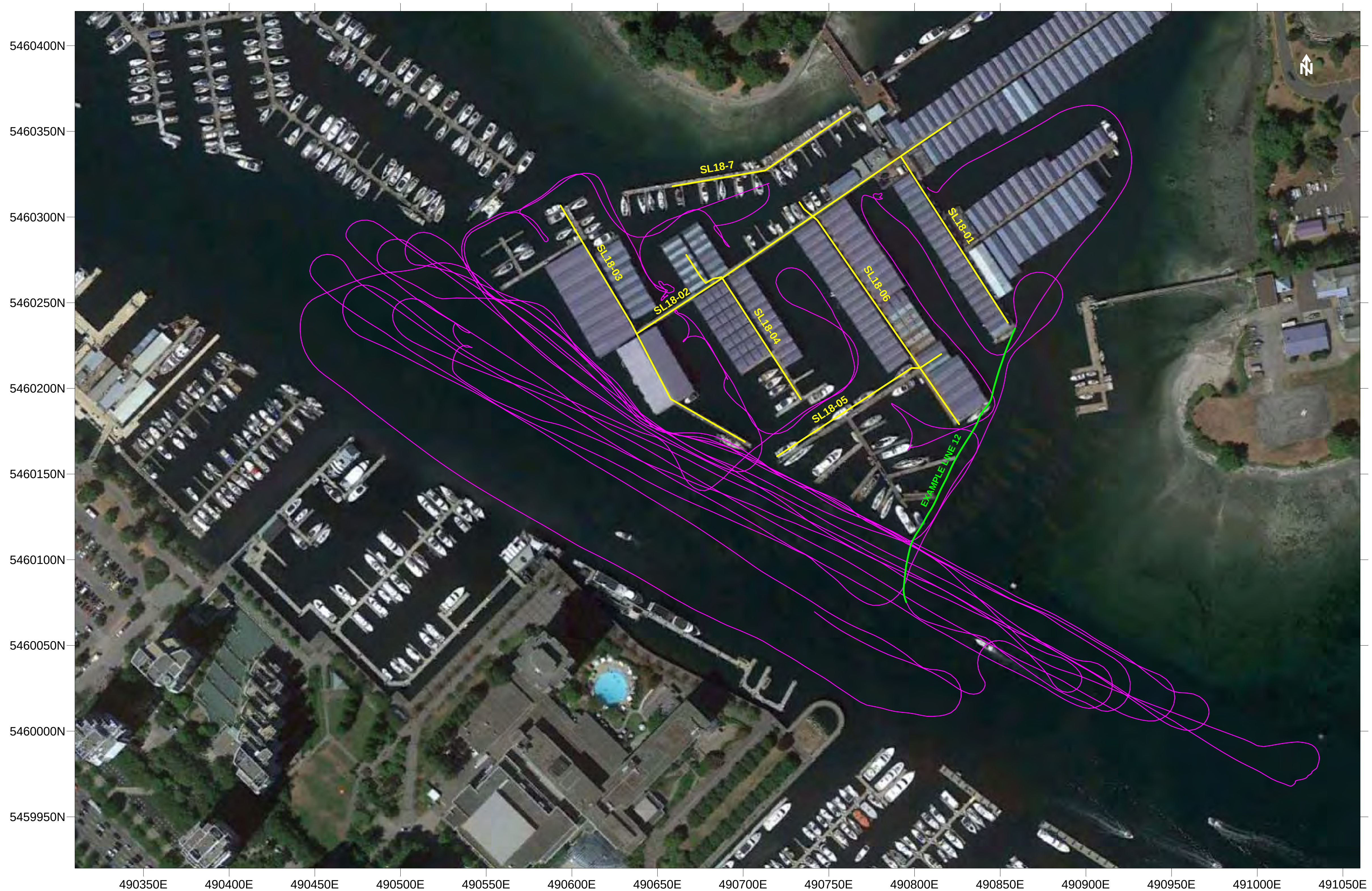
APPENDIX



0 0.5 1 1.5 2

KILOMETRES

ROYAL VANCOUVER YACHT CLUB COAL HARBOUR MARINA RECONFIGURATION		
GEOPHYSICAL SURVEY		
SURVEY LOCATION PLAN		
FRONTIER GEOSCIENCES INC.		
DATE: FEB. 2018	SCALE 1:50,000	FIG. 1



BOAT TRACK

SEISMIC REFRACTION LINES

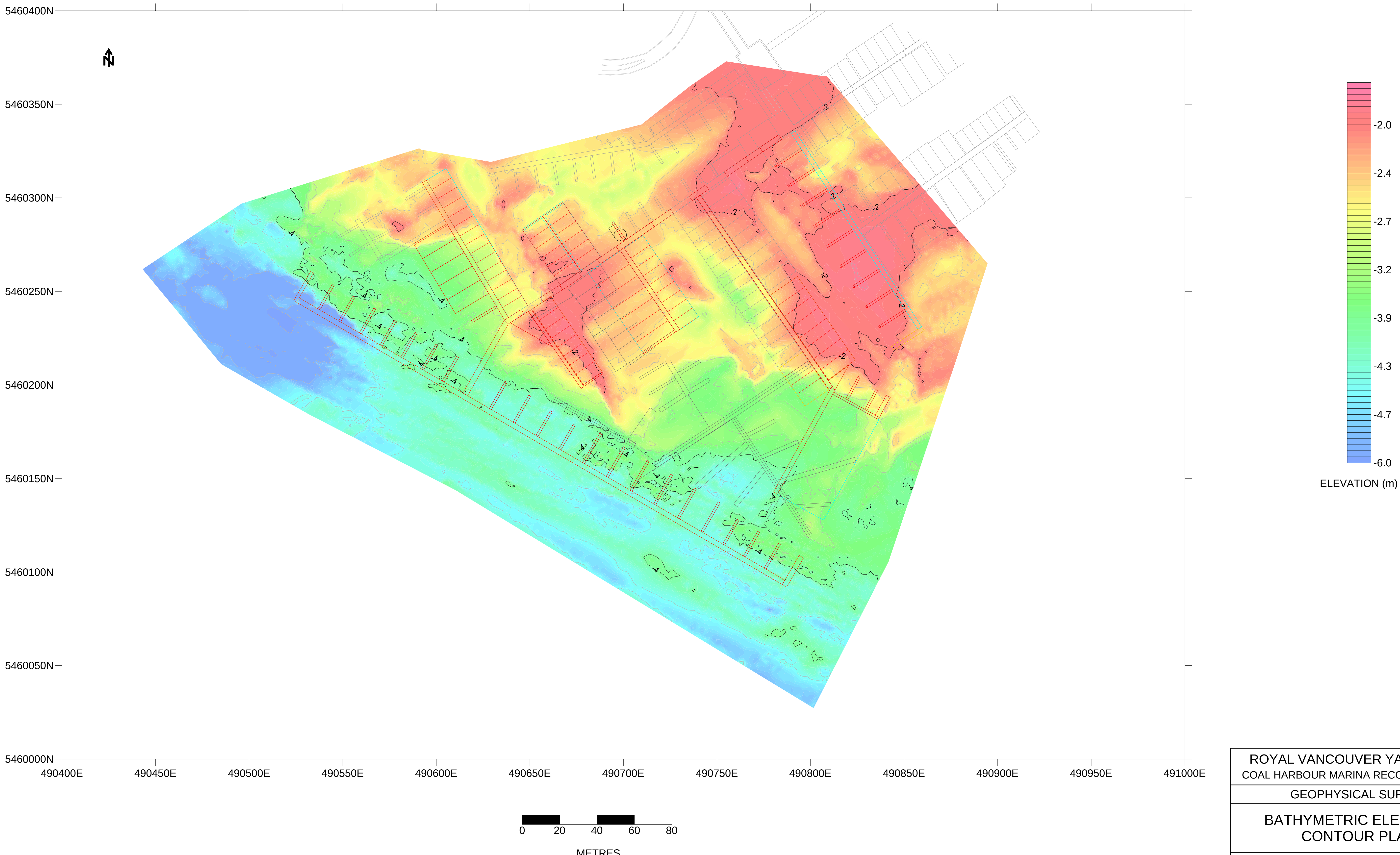
SUB-BOTTOM EXAMPLE PROFILE

0 25 50 75 100

METRES

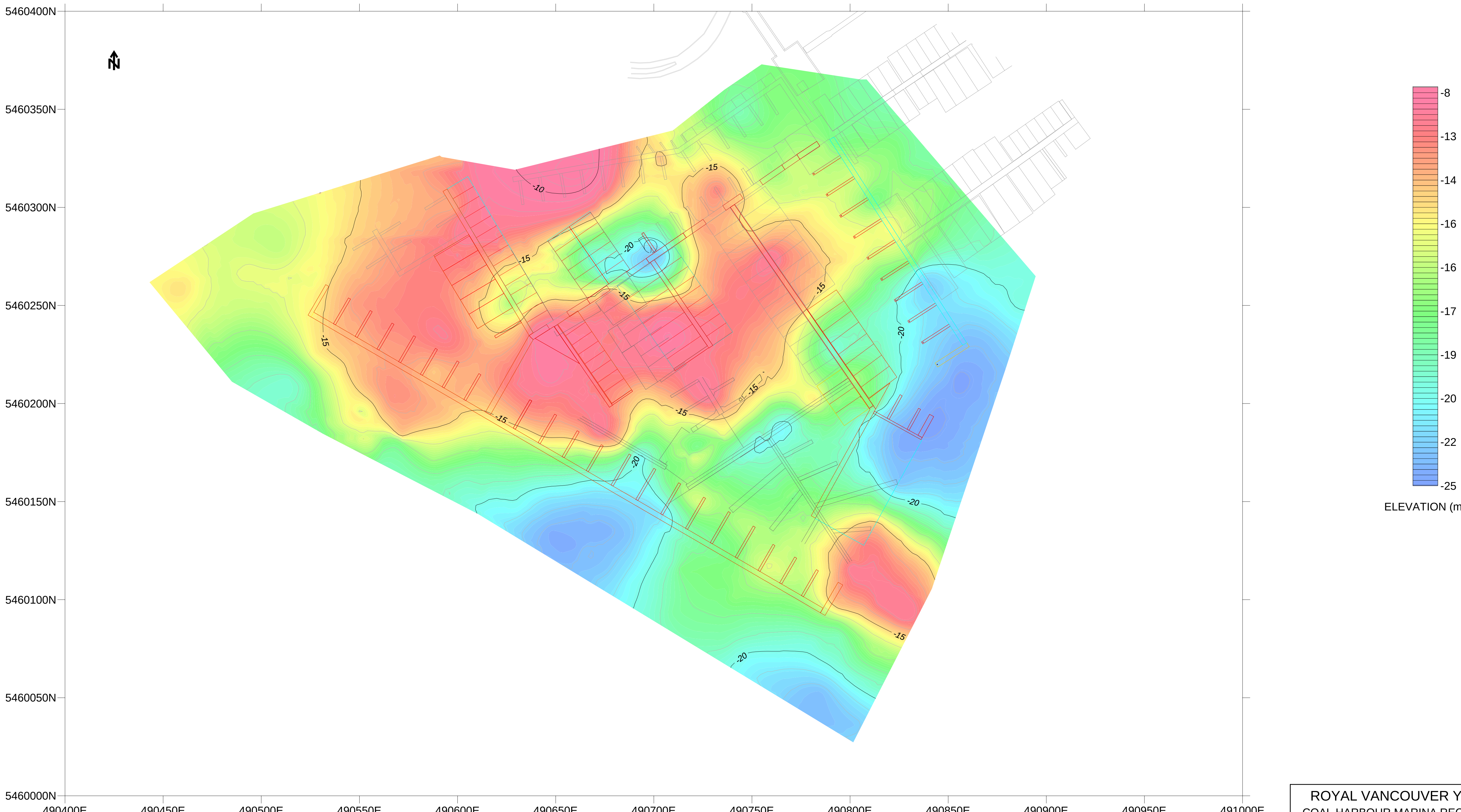
NOTE: NAD83 ZONE 10

ROYAL VANCOUVER YACHT CLUB COAL HARBOUR MARINA RECONFIGURATION		
GEOPHYSICAL SURVEY		
SITE PLAN		
FRONTIER GEOSCIENCES INC.		
DATE: FEB. 2018	SCALE 1:2,500	FIG. 2



NOTE: DATUM TIDE AND CHART
NAD83 ZONE 10

ROYAL VANCOUVER YACHT CLUB COAL HARBOUR MARINA RECONFIGURATION		
GEOPHYSICAL SURVEY		
BATHYMETRIC ELEVATION CONTOUR PLAN		
FRONTIER GEOSCIENCES INC.		
DATE: FEB. 2018	SCALE 1:2,000	FIG. 3



0 20 40 60 80

METRES

NOTE: DATUM TIDE AND CHART
NAD83 ZONE 10

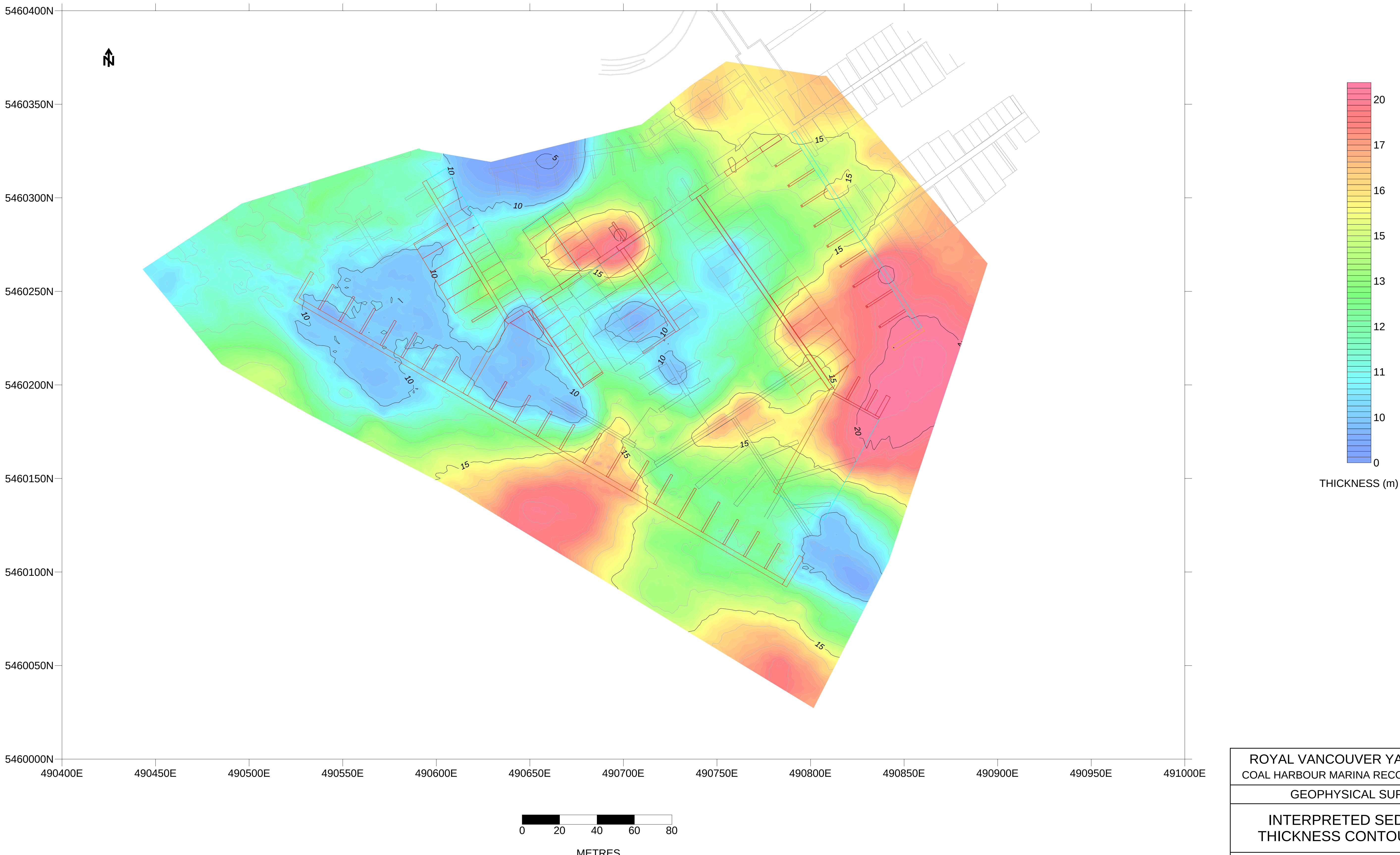
ROYAL VANCOUVER YACHT CLUB
COAL HARBOUR MARINA RECONFIGURATION

GEOPHYSICAL SURVEY

INTERPRETED BEDROCK
ELEVATION CONTOUR PLAN

FRONTIER GEOSCIENCES INC.

DATE: FEB. 2018	SCALE 1:2,000	FIG. 4



NOTE: DATUM TIDE AND CHART
NAD83 ZONE 10

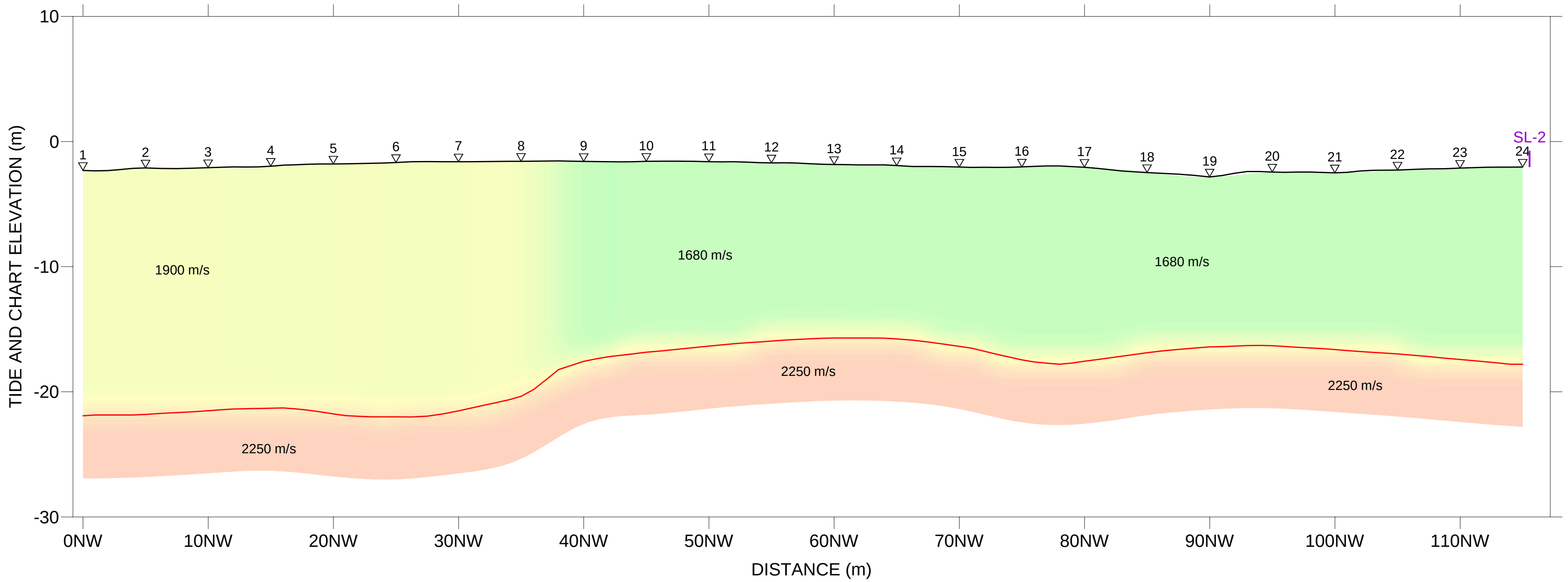
ROYAL VANCOUVER YACHT CLUB
COAL HARBOUR MARINA RECONFIGURATION

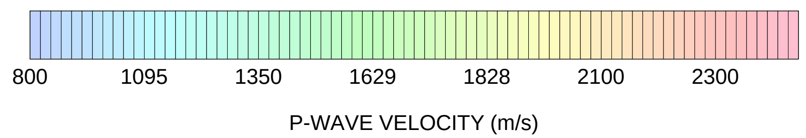
GEOPHYSICAL SURVEY

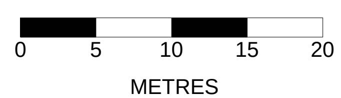
INTERPRETED SEDIMENT THICKNESS CONTOUR PLAN

FRONTIER GEOSCIENCES INC.

DATE: FEB. 2018	SCALE 1:2,000	FIG. 5







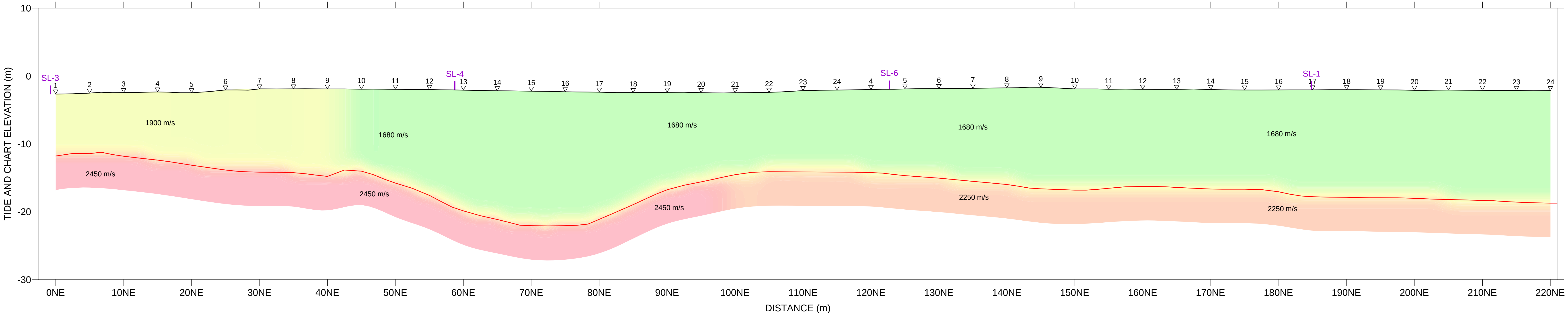
ROYAL VANCOUVER YACHT CLUB
COAL HARBOUR MARINA RECONFIGURATION

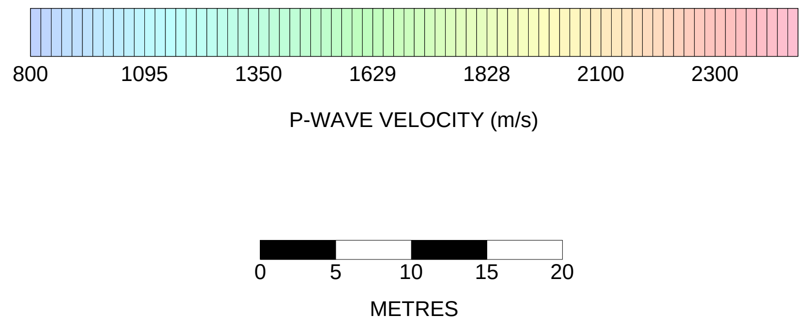
SEISMIC REFRACTION SURVEY

INTERPRETED DEPTH SECTION
SL18-01

FRONTIER GEOSCIENCES INC.

DATE: FEB. 2018	SCALE 1:500	FIG. 6





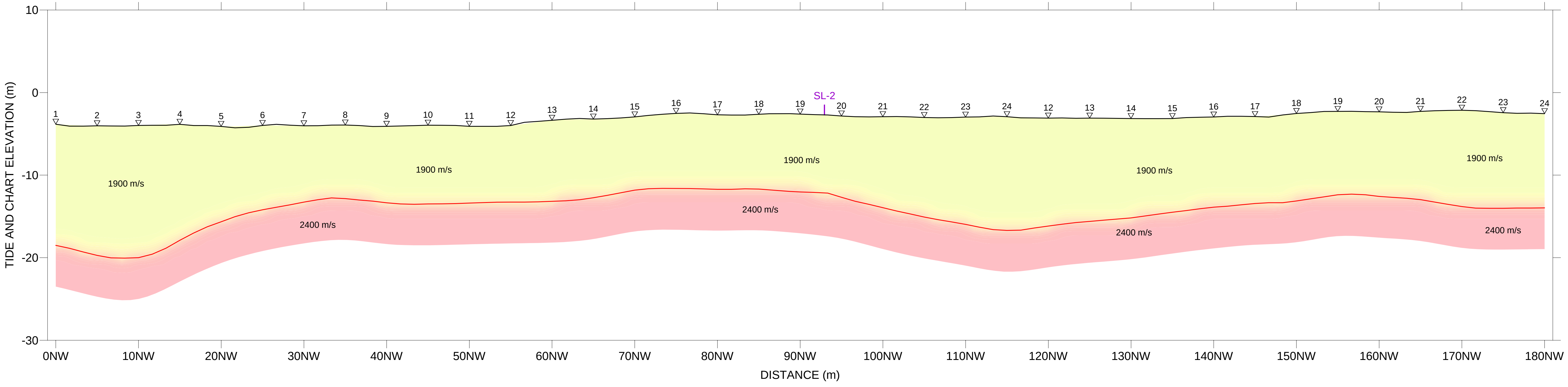
ROYAL VANCOUVER YACHT CLUB
COAL HARBOUR MARINA RECONFIGURATION

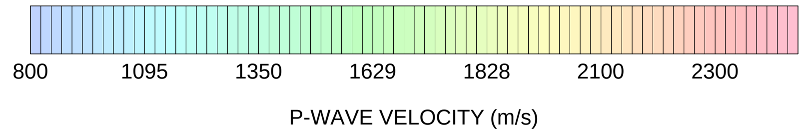
SEISMIC REFRACTION SURVEY

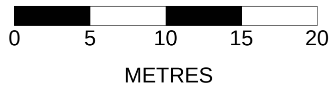
INTERPRETED DEPTH SECTION
SL18-02

FRONTIER GEOSCIENCES INC.

DATE: FEB. 2018	SCALE 1:500	FIG. 7







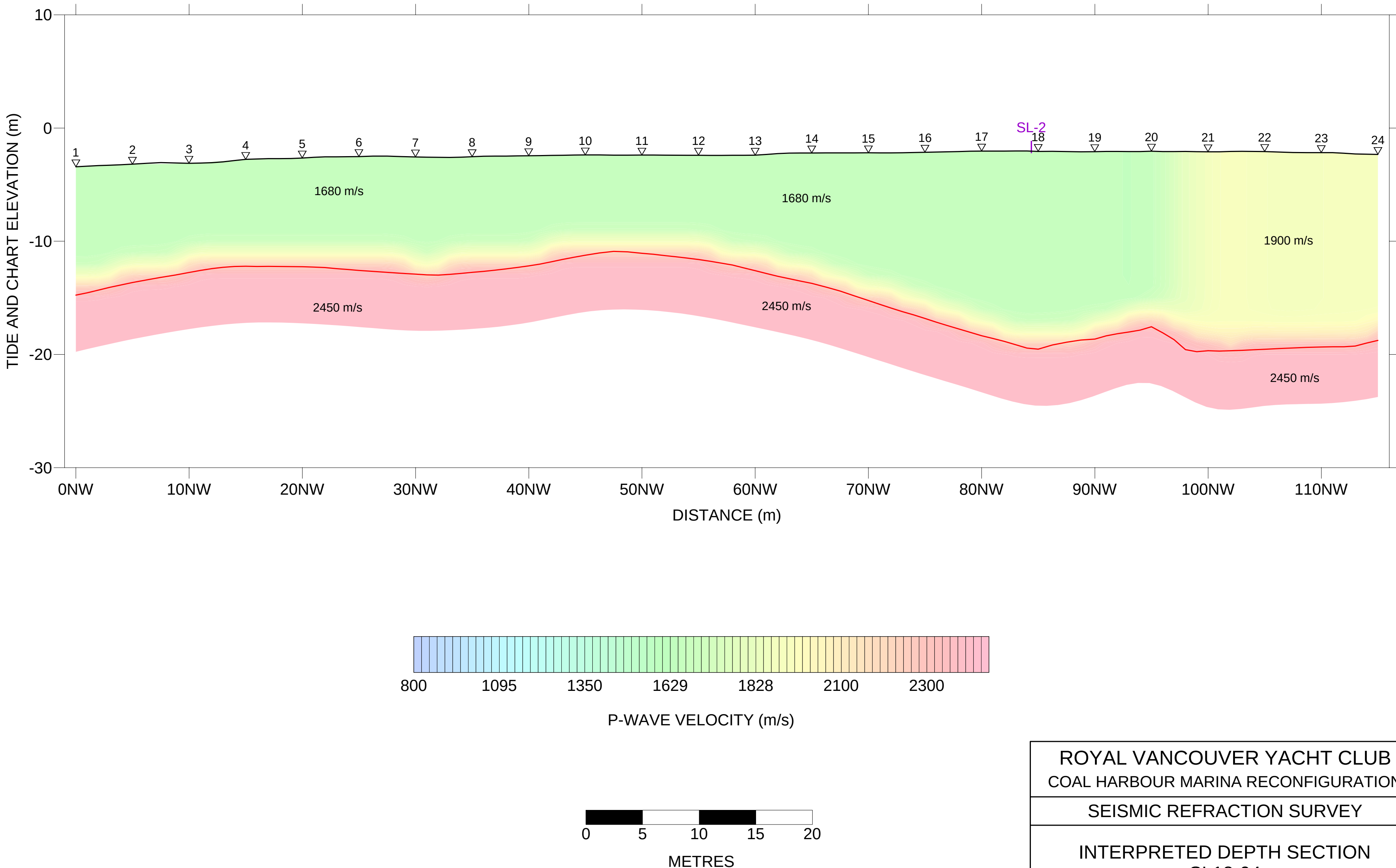
ROYAL VANCOUVER YACHT CLUB
COAL HARBOUR MARINA RECONFIGURATION

SEISMIC REFRACTION SURVEY

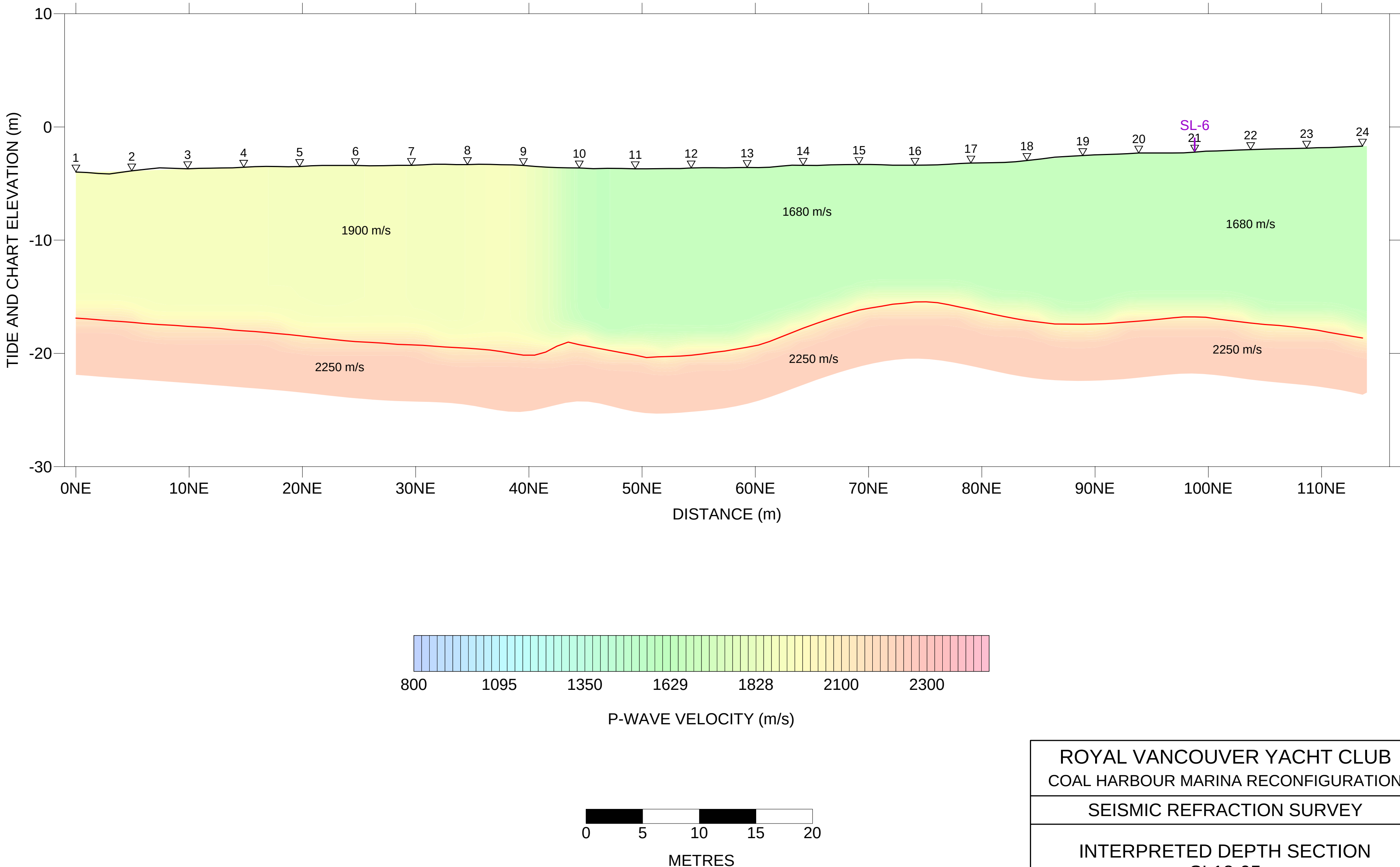
INTERPRETED DEPTH SECTION
SL18-03

FRONTIER GEOSCIENCES INC.

DATE: FEB. 2018	SCALE 1:500	FIG. 8



ROYAL VANCOUVER YACHT CLUB COAL HARBOUR MARINA RECONFIGURATION		
SEISMIC REFRACTION SURVEY		
INTERPRETED DEPTH SECTION SL18-04		
FRONTIER GEOSCIENCES INC.		
DATE: FEB. 2018	SCALE 1:500	FIG. 9



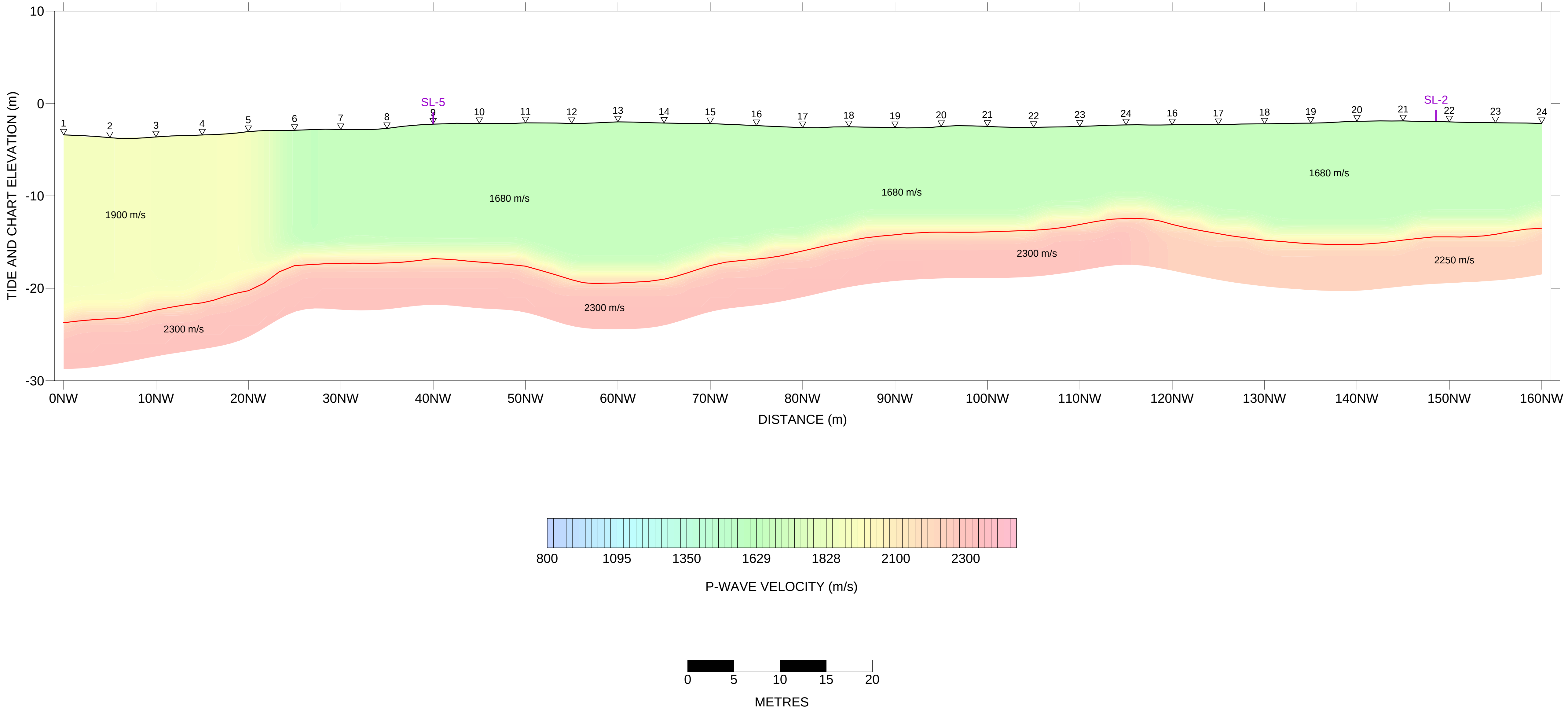
ROYAL VANCOUVER YACHT CLUB
COAL HARBOUR MARINA RECONFIGURATION

SEISMIC REFRACTION SURVEY

INTERPRETED DEPTH SECTION
SL18-05

FRONTIER GEOSCIENCES INC.

DATE: FEB. 2018	SCALE 1:500	FIG. 10



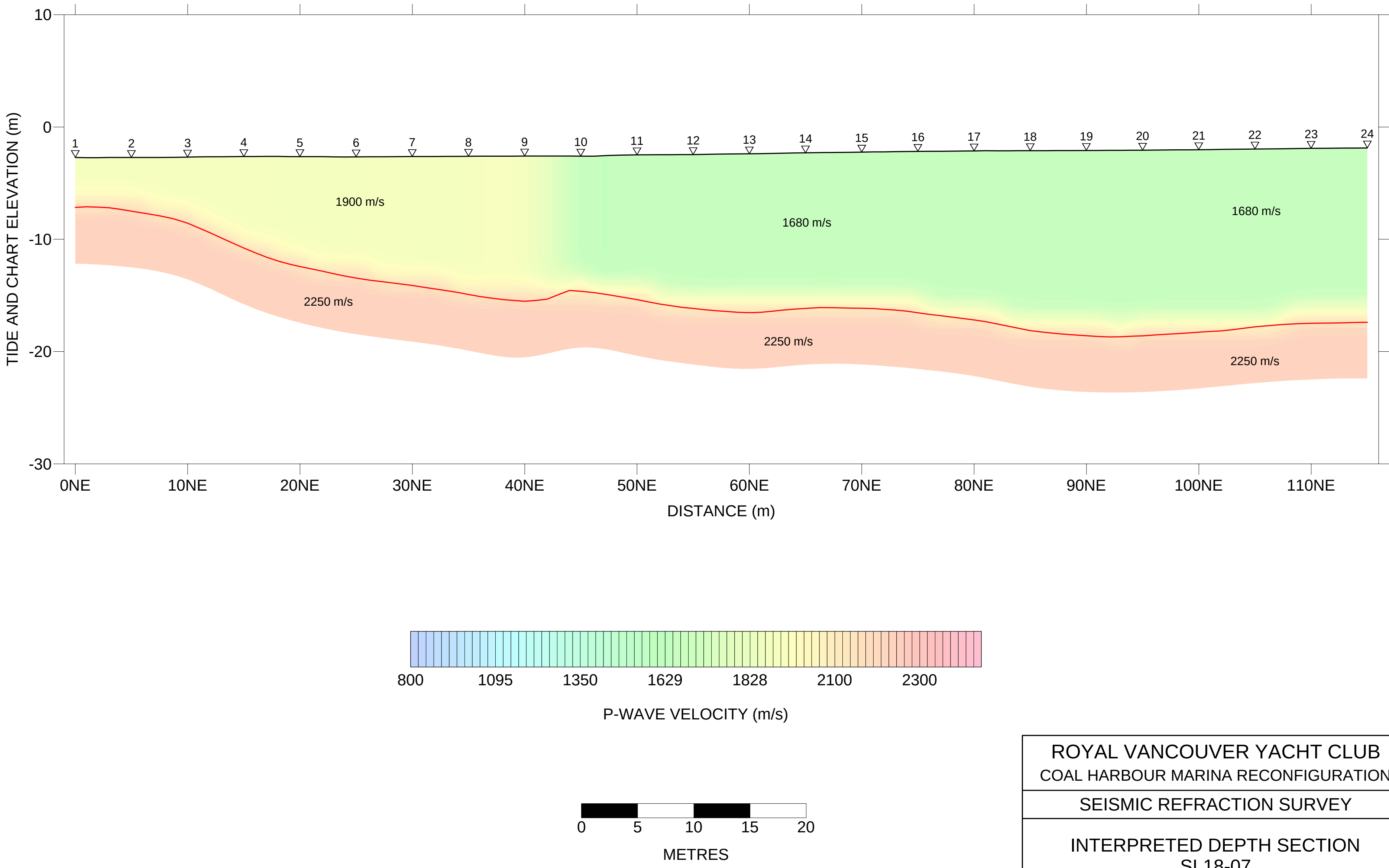
ROYAL VANCOUVER YACHT CLUB
COAL HARBOUR MARINA RECONFIGURATION

SEISMIC REFRACTION SURVEY

INTERPRETED DEPTH SECTION
SL18-06

FRONTIER GEOSCIENCES INC.

DATE: FEB. 2018	SCALE 1:500	FIG. 11



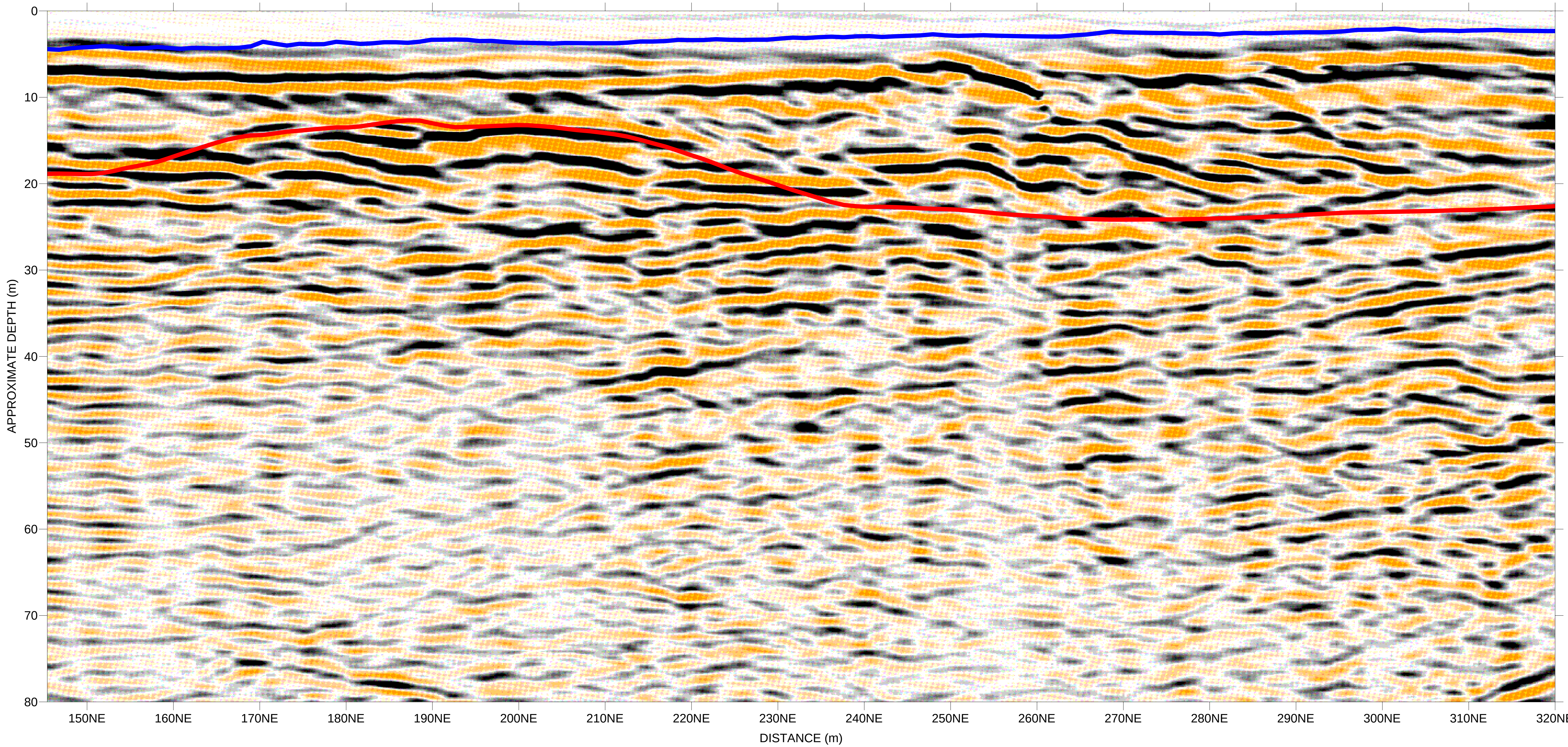
ROYAL VANCOUVER YACHT CLUB
COAL HARBOUR MARINA RECONFIGURATION

SEISMIC REFRACTION SURVEY

INTERPRETED DEPTH SECTION
SL18-07

FRONTIER GEOSCIENCES INC.

DATE: FEB. 2018	SCALE 1:500	FIG. 12



0 5 10 15 20

METRES

BATHYMETRY

INTERPRETED BEDROCK REFLECTOR

ROYAL VANCOVUER YACHT CLUB
COAL HARBOUR MARINA RECONFIGURATION

GEOPHYSICAL SURVEY

SUB-BOTTOM SEISMIC PROFILE
LINE 12

FRONTIER GEOSCIENCES INC.

DATE: FEB. 2018	SCALE 1:500	FIG. 13