REPORT

Geophysical Investigation

2nd Ave West and McBride Street, Prince Rupert, BC

Submitted to:

BC Ministry of Transportation and Infrastructure

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1.0 INTRODUCTION

This report summarizes the methods and interpretations for a multiple method geophysical investigation at the Highway 16 intersection of 2nd Avenue West and McBride Street in Prince Rupert, BC (Figure 1). The geophysical methods used for this investigation include seismic refraction tomography (SRT), multi-channel analysis of surface waves (MASW), ground penetrating radar (GPR), and frequency-domain electromagnetics (FDEM). This work was conducted under the existing Consulting Services Contract 863CS1087 between Golder Associates Limited (Golder) and the British Columbia Ministry of Transportation and Infrastructure (MoTI).

The investigation site is located along Yellowhead Highway 16 at the intersection of 2nd Avenue West and McBride Street (Site). The geophysical investigation area is outlined in Figure 1 and encompasses two blocks along McBride Street and one block along 2nd Avenue West. Additional geophysics coverage was included at the base of the stacked rock wall which borders the sunken parking lot near the corner of 2nd Avenue West and 1st Street.

2.0 OBJECTIVES

The geophysical investigation objectives are detailed in the proposal and cost estimate document *19115216-018-L-Rev0-2080-2nd AVE and McBride-09FEB_21*, which was granted authorization to proceed from MoTI on 1 March 2021. The primary objectives of the geophysical investigation were to provide depth to bedrock, assess bedrock rippability, and identify any anomalies within the stacked rock wall. As a secondary objective Golder would conduct FDEM and GPR surveys to, if possible, determine the location of a ductile iron sanitary line. The interpreted geophysical results will be used for planning and design of the McBride Street and 2nd Avenue West intersection upgrade.

3.0 REVIEW OF SITE INFORMATION

Past environmental and geotechnical studies of the intersection location and surrounding area were compiled by MoTI and provided to Golder in advance of the field investigation. These reports were analyzed for relevant geotechnical information to assist in the geophysical interpretation.

3.1 Infrastructure at Site

Local infrastructure at the Highway 16 intersection site includes:

- Utility poles with overhead wires and underground electrical conduits located on the north side of McBride Street and both sides of 2nd Avenue West.
- Existing ductile iron and cast-iron water mains under all three approaches.
- Concrete sanitary main beneath northbound lanes of 2nd Avenue West.

The sanitary main and electrical infrastructure in the northbound lane of 2nd Avenue West caused data quality issues during the collection of seismic and GPR data. As a result, the proposed geophysics coverage along the northbound lane was moved into the middle of 2nd Avenue for improved data quality.

3.2 Geotechnical Site Conditions

Test hole information from the results of a previous geotechnical drilling investigation by EXP Services Ltd. (2020) was used to calibrate the geophysical results from this investigation. Test hole data show a high degree of variability in bedrock depth across the Site. Fill materials were reported to be variable with the dominant soil types including road fill, silt, clay, sand, and gravel. Peat and silty soils were encountered beneath fill materials at some areas of the site. The geophysical investigation attempted to further refine these locations using GPR and FDEM to identify areas of contrasting electrical properties between the conductive soils (silt, clay, organics) and the more resistive soils (sand and gravel).

A geotechnical investigation report from McElhanney Ltd. (2020) near the intersection of McBride Street and 3rd Avenue also revealed variable bedrock depths, from 1.5 to 6.1 metres below ground surface (mbgs). Typically, the soils comprised a unit of fill containing sands and gravels. Layers of peat were encountered in all test holes. Bedrock from the site at 3rd Avenue is composed of a metasedimentary schist rock. As part of the geotechnical investigation, Golder completed seismic surveys and measured shear and compressional wave bedrock velocities of 1200-1400 and 3500-4500 metres per second (m/s), respectively. These seismic velocities are representative of slightly weathered to fresh bedrock and indicate that bedrock is non-rippable based on seismic properties alone.

3.3 Stacked Rock Wall

The stacked rock wall, identified in Figure 1 (Site Map), consists of locally sourced schist boulders and mortar. Bedrock depths across the rock wall alignments are assumed to be highly variable based on findings from a nearby geotechnical investigation completed by McElhanney Ltd. (2018). Depths range from outcropping down to 4.3 metres below ground surface (mbgs) and soil units comprise organics, silt, sand, and gravel. A bedrock outcrop is noted at the base of the wall approximately 30 metres (m) northeast from the corner of 1st Street and 2nd Avenue.

4.0 GEOPHYSICAL METHODS

Geophysical methods that measure different physical properties of the subsurface often provide the most robust understanding of site conditions. The methods used in this investigation were designed to estimate primary and shear wave velocities, subsurface conductivity, and dielectric contrasts of subsurface materials.

4.1 Seismic Methods

Seismic energy travels through soil and rock in various modes or wave types. Three common wave types are known as primary wave (p-wave), secondary or shear wave (s-wave) and Rayleigh or Surface wave. P-waves are longitudinal or compressional waves, meaning particle motion is in the same direction as the direction of travel for the wave. S-waves are transverse waves, meaning particle motion is perpendicular to the direction of travel for the wave. Rayleigh waves travel near the surface of solids and include both longitudinal and transverse particle motions that decrease exponentially in amplitude as distance from the surface increases. Rayleigh waves are typically compared to ocean waves for illustration purposes. In earthquake studies, p-waves are the fastest and arrive at a destination first, thus are called primary waves. S-waves are slower, arriving after p-waves, thus are called secondary waves. Rayleigh waves are a special type of wave that are confined to the near surface portion of the earth. All three wave types may be useful in determining elastic moduli and the assessment of engineering soil and rock properties.

The SR method is one of the most widely applied geophysical methods used to assist in geotechnical engineering investigations. The method is typically used for stratigraphic assessments including 2D profiling depth to bedrock, characterization of primary wave (p-wave) velocities of subsurface material, and assessment of material rippability. Primary (or compressional) waves are generated by a seismic source and recorded as the waves propagate along a linear array of seismic recording devices. The recorded waveform data is analyzed for first arrivals which represent direct arrivals through the first layer of material and subsequent refracted arrivals produced at the interface of geologic materials that have contrasting densities. These arrival times are turned into 2D models of subsurface velocity distribution, which can be interpreted to represent different geologic materials based on test hole information from a specific site. P-wave velocity (Vp) may also be used to determine the rippability of rock.

MASW data are typically collected using the same equipment as seismic refraction with different source locations and recording parameters to determine shear wave velocity. Since limited additional effort is required to gather MASW data it is highly recommended as a complement to SR. The method measures Rayleigh wave velocity versus frequency, which is processed and modelled to produce a 1D plot of Rayleigh wave velocity versus depth. Rayleigh wave velocity is approximately equal to shear wave velocity in most settings, thus the output is treated as s-wave velocity versus depth. S-wave velocity (Vs) can be directly used to determine the National Building Code of Canada (NBCC) Vs30 site classification for seismic response and is a direct indicator of ground strength (stiffness) and is commonly used to derive load-bearing capacity. Derivation of Vp, Vs and density allows for estimation of various elastic moduli (e.g., Young’s Modulus, Shear Modulus, Bulk Modulus, Poisson’s ratio).

4.2 Ground Penetrating Radar

Ground-penetrating radar (GPR) is often used to identify subsurface infrastructure, such as buried drums or utilities. GPR can also be used to estimate the depth of geologic interfaces, such as depth to the top of bedrock. GPR is used to detect contrasts in subsurface electromagnetic properties primarily responding to dielectric permittivity and to a lesser extent electrical conductivity and magnetic permeability. A single GPR unit contains a transmitting and receiving antenna pair which are towed behind the operator. The transmitting antenna produces an EM pulse which travels downwards into the subsurface. At material interfaces, some portion of the EM energy is reflected and returned to surface where it is recorded by the receiving antenna. By measuring the time required for the EM pulse to be reflected back to surface and converting this time to depth by estimating the velocity of the medium, a depth estimate for the material interface is derived. A two-dimensional profile is produced by moving the GPR unit along a selected transect while recording depth soundings at regular intervals. Resultant data is plotted in distance versus time/depth. Laterally continuous material interfaces (e.g., top of bedrock) appear as continuous reflections in section. Localized material differences (e.g., buried utilities, voids, boulders) appear as hyperbolic or “boomerang” shaped features.

Depth of investigation and resolution may be optimized by selection of radar antenna frequency, based on the objectives of a project. In general, lower frequencies provide greater depth of investigation but lower resolution. Deeper geologic investigations (>5 m) typically require antenna frequencies between 50 and 250 MHz, while shallow utility investigations range from 500 to 1500 MHz or greater. A Mala Ground Explorer 160 MHz shielded antenna and system was used for this investigation.

4.3 Electromagnetics

Frequency domain electromagnetic (FDEM) geophysical data is commonly used to prospect for buried metallic infrastructure and map lateral changes in soil conductivity. The EM31-MK2 Terrain Conductivity Meter measures soil conductivity to a maximum depth of approximately 5 m below grade, by measuring the inductive response of the ground. An alternating current is supplied to a wire transmitter coil, producing a time-varying magnetic field that penetrates the ground and induces electrical eddy currents within the subsurface materials. The eddy currents give rise to a secondary magnetic field that is measured, together with the primary field, by the receiver coil. Two components of the secondary field are measured:

- quadrature component, i.e., that which is 90º out of phase with the primary field
- in-phase component, i.e., in-phase with the primary (transmitted) field

The strength of the quadrature component, measured in millisiemens per metre (mS/m), is approximately equivalent to ground conductivity. The in-phase response, measured in parts per thousand (ppt) of the primary field, has no direct physical interpretation but may be a useful indicator of buried metallic objects if instrument orientation results in suitable coupling.

Ground conductivity is controlled principally by porosity, relative pore saturation, pore water ion concentrations (i.e., TDS), soil type, temperature, and the presence of metal. In general, clays and silts are typically more conductive than sands and gravels. In addition, both surface and subsurface metal (ferrous and non-ferrous), including fences, steel frame structures, vehicles, underground utilities, buried metallic debris and storage tanks typically produce a characteristic low-valued response flanked by an anomalously high-valued apparent conductivity.

EM survey data are typically collected and digitally recorded at one-second intervals as the operator walks along survey lines or as the instrument is towed along survey lines. Positions of the survey stations are recorded in real time using a GPS receiver. The EM31 has a maximum depth of investigation of approximately 5 m with a peak sensitivity at a depth of 1.3 m. The instrument response should be interpreted as a weighted average (apparent) conductivity for hemispherical subsurface volumes with a radius of approximately 5 m. Results are typically presented as spatial colour contour maps of apparent conductivity and in-phase response.

4.4 Survey Positioning

All GPR and SR data was positioned using a Trimble R8 RTK base and receiver system. Seismic data were corrected for topography along the alignments and are displayed relative to the surveyed RTK elevations, LiDAR was not available at the time of this report. Positions were recorded for every geophone location and at the start, middle, and end of each GPR profile. FDEM data was positioned using a handheld dGPS unit capable of position precisions of 0.5 to 0.75 m horizontal accuracy.

5.0 GEOPHYSICAL INVESTIGATION

The entire geophysical investigation was conducted between 10 and 12 March 2021 using industry standard procedures and equipment. A road closure was implemented using traffic control personnel and a traffic control plan provided by Gitxsan Safety Services. Field work was completed between the hours of 1700 and 0200 and the intersection area was completely blocked off from local traffic to reduce ambient vibrations at the site.

A total of 7 seismic refraction lines were collected at the site using 2 m geophone spacing. Data was recorded in spreads of 24 geophones and the standard roll-along procedure was used to extend data to the proposed line lengths. To generate seismic waves a sledgehammer was used to impact an aluminum plate placed at each shot location. A minimum of five shot records were recorded along each 24-geophone spread. During the MASW data collection the aluminum plate was substituted for a high-density polyethylene (HDPE) plate to improve shear wave generation. After the completion of each refraction survey, MASW data was collected using a shot location offset equal to half the total array length. Geophones used for the survey had a 4.5 Hertz (Hz) centre frequency to capture low frequency seismic data.

The GPR data was recorded using a Mala Ground Explorer system with a 160 Megahertz (Mhz) antenna. Traces were positioned within the radargram using the 0.3 m diameter survey wheel and geospatial referencing was completed with a combination of external RTK surveying locations and internal DGPS positioning. A distance calibration was completed at the start of the survey to ensure accurate trace positioning using the survey wheel. GPR profiles were collected along seismic refraction profiles deemed to require additional calibration and depth to bedrock control. GPR profiles were also collected along the top and at the base of the stacked rock wall.

FDEM data was collected with the EM31 terrain conductivity meter manufactured by Geonics. Data was paired in real-time with dGPS positioning on a handheld Trimble Geo 7x unit. The EM31 instrument was calibrated by Geonics in November 2020 and was tested in the field for responsiveness to local surface metal. FDEM data was collected along transects to prospect for buried infrastructure and provide an understanding of conductivity variations across the site.

6.0 GEOPHYSICAL RESULTS AND INTERPRETATION

The geophysical investigation consisted of four main objectives and the results as pertaining to each objective are discussed in the following subsections. This section includes a summary of the processing stages involved in producing the geophysical results.

6.1 Objective 1: Bedrock Depth

Seismic refraction, MASW and GPR data were collected at the site and correlated to existing geotechnical test holes to estimate bedrock depth. The following sections discuss data processing and results of the bedrock depth component of the investigation.

6.1.1 Seismic Refraction Analysis

P-wave arrival times were manually picked for each geophone location using SeisImager Pickwin software. First arrivals must be separated from background noise and travel-time accuracy can be significantly reduced by noisy seismic records. Noise in seismic records is caused by weak source signal strength compared to ambient vibrations such as strong winds and rain. Data quality was affected by strong winds, which had the greatest effect in areas where bedrock depths are greater than 4 metres. Along 2nd Avenue, all seismic shot locations were collected on the pavement. The seismic arrivals of interest were interfered with by waves propagating along the high velocity asphalt boundary. The high velocity arrivals attenuated at approximately 20 metres from the shot location to allow picking of the refracted bedrock arrival of interest beyond this distance. A constant overburden velocity, estimated to be 800 m/s, was imposed in the model where the high velocity pavement arrivals masked overburden arrivals.

Two methods for modelling the seismic data were used to estimate the bedrock velocity and depth and to identify any lateral velocity variations associated with increased weathering: the reciprocal time method and the tomographic inversion method. A preliminary layer-based analysis was completed using the reciprocal time method. The resulting bedrock velocity from the layer-based modelling is used to determine the top of bedrock on each seismic profile (Figures 2 and 3). Plate 1 shows an example from seismic line SL21-01 of a two-layer velocity analysis. A constant overburden velocity of 426 m/s is shown above a bedrock layer of 3125 m/s. Layer based methods result in accurate bedrock velocities but less precise resolution of lateral velocity variations or more complex features such as weathering. The tomographic inversion method was also used in the analysis and the results are shown as the color contoured background on each seismic profile (Figures 2 and 3). Tomographic inversions artificially smooth the transition between soil and rock and may result in underestimated bedrock velocities along the upper bedrock surface.

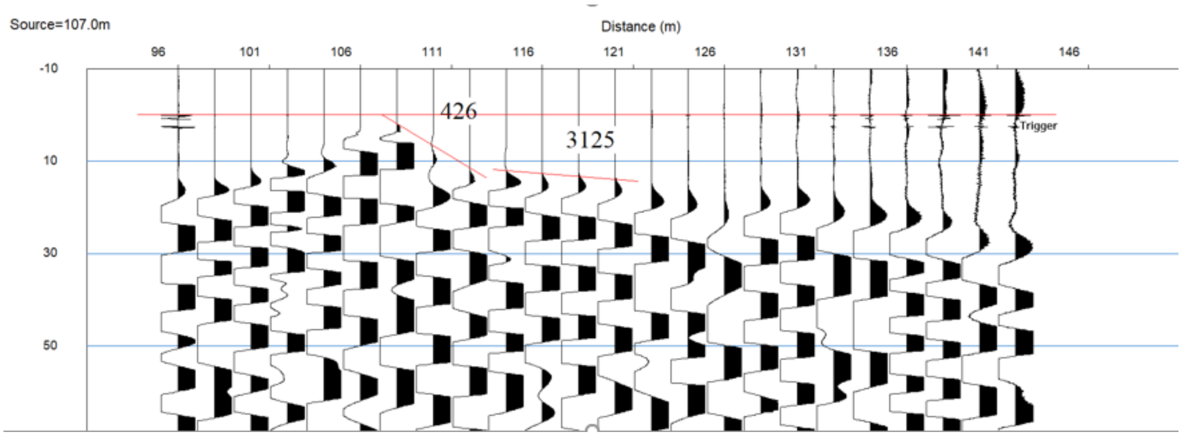

Plate 1: Two-layer velocity analysis for a single shot record along seismic line SL21-01. Direct arrivals from overburden material velocity measured at 426 m/s and bedrock velocity at 3125 m/s.

6.1.2 MASW Analysis

MASW data were processed by transforming the recorded seismic waveforms into the frequency-phase velocity domain and plotting the result. The plot, called the dispersion curve, is used to identify the velocity versus frequency function for the fundamental surface wave mode. This method is based on the principal that surface waves propagate at different depths and velocities depending upon their frequency, and this information can be used to model the subsurface shear wave velocity distribution with depth, which are used to determine seismic site classification but may also inform depth to bedrock and rippability. Dispersion curves were analyzed for each seismic line collected but in general did not yield representative results. This is attributed to shallow bedrock conditions at site. Only two MASW soundings resulted in representative overburden shear wave values, where bedrock depths exceeded 5 m (presented in Section 6.2). The remaining unrepresentative MASW results are not presented.

6.1.3 Bedrock Depth Results

Bedrock topography in the Prince Rupert area can vary significantly over short distances. The undulating bedrock surface identified along seismic profiles highlights the variability in bedrock depth across the site.

The modelled seismic refraction profiles are presented in Figures 2 and 3. Both tomographic and layer-based models are shown for each profile. The layer-based modelling was used as primary guidance to determine the top of bedrock and bedrock velocity (black line indicating top of bedrock and annotated bedrock velocity, Figures 2 and 3), and is plotted over the colour-contour tomographic model. Because tomographic models can create an artificially smooth transition zone from soil to rock, and tomographic model velocities tend to be more relative and less absolute than layer-based models, the tomographic model is only used as secondary guidance for depth to bedrock and bedrock velocity determination. The advantage of tomographic models is they can show more detail in lateral variation and more complex structures than layer-based models.

Figures 2 and 3 present results of the bedrock depth investigation. Seismic line SL21-01 extends 149 metres parallel to McBride street in the northeast of the Site. SL21-01 intersects test holes BH19-04, 05, and 06 and does not intersect any other seismic lines. Overburden velocities along profile SL21-01 range from 0.5 km/s (loose material) to 0.8 km/s (more compact material). Test hole data show a compact overburden material composed of sand, gravel, and organic silt. Bedrock depths range from 0.5 to 3.4 metres. The profiled bedrock surface occurs slightly deeper than the bedrock depths shown in the test holes, suggesting there may be a thin layer of low velocity weaker rock above the bedrock surface in these areas of the site. This slight difference may also be due to a lateral offset between the seismic line and test holes. Approximately 12 m off the southeast end of SL21-01, test hole data from a prior geotechnical investigation by McElhanney (2020) shows a bedrock depth of 3 m and a 1.5 m thick layer of peat.

Seismic lines SL21-02, 03 and 04 begin in the northeast of 2nd Avenue and progress southwest away from the intersection and along the 2nd Avenue approach. Bedrock in the vicinity of the McBride and 2nd Avenue intersection ranges from shallower than 0.5 m to 2.5 m. The bedrock profile along SL21-05 drops off from 0.7 m depth near the BH19-07 and 08 locations to 2.5 m in the northwest of the profile, close to the intersection location. A section of deeper bedrock is observed in the southeast of SL21-05. Bedrock depth tends to increase to the northwest of the intersection location, being deeper at SL21-04 than at SL21-03. Bedrock drops off sharply to the southwest along the 2nd Avenue approach and depths increase along SL21-03 to a maximum of 7 metres in the far southwest of the profile.

Seismic lines SL21-06 and 07 along the base of the stacked rock wall indicate bedrock depths increase toward the corner at the intersection of 2nd Avenue West and 1st St, where depths are reported to be 3.5 to 4 m. At the northeast end of SL21-06 bedrock becomes shallower and outcrops along the stacked rock wall. At the southeast end of SL21-07 bedrock depths begin to rise. Observations from McElhanney (2018) suggest the steep topography located 4 m off the southeast end of the line is controlled by shallow bedrock. No outcrop was observed at that location.

GPR data were collected coincident to seismic refraction profiles to refine the bedrock interface, if possible. Radar reflection data is highly site specific, and any stratigraphic interpretation should be based on test hole results. Typically, changes in the character of the reflections depend upon the conductivity of the soil material. Conductive soils like clay and silt contain few reflections and limit the possible depth of investigation due to attenuation of the radar signal. Less conductive material like organic soil, sands and gravels may produce scattered reflections and result in greater depth of investigation compared to conductive soils. The bedrock character was ambiguous in the radar profiles at the Site and did not further refine the seismic results. The radar data did provide insight into the overburden stratigraphy along the 2nd Avenue approach. In Figure 4, the calibration profile GPR_1018 is displayed and interpreted based upon test hole lithology (EXP 2020). The conductive silt and clay material is outlined within the orange polygon and shows few internal reflections. This transitions to organics material showing internal chaotic reflections, outlined within the green polygon. A radar velocity of 0.075 m/ns was used to convert travel-times to depth. This velocity is an average over all overburden material across the site, and agrees with typical radar velocities for saturated sand, gravel, or clay.

Figure 6 presents a bedrock depth isopach map generated from the geophysical results and available geotechnical test-hole data. The bedrock depth contours are provided to help visualize information from the Site and should only be used with the understanding that actual bedrock depths may vary significantly in areas of sparse or no data.

6.2 Objective 2: Bedrock Rippability

Seismic refraction data may provide a qualitative assessment of the rock strength at a particular site. Compressional wave velocities measured by the refraction survey can be referenced to the Caterpillar Handbook of Ripping (Caterpillar 2001). A chart from the Handbook of Ripping shown in Plate 2 relates seismic velocities for different bedrock geology to rippability for a D8 bulldozer. It is important to consider the degree of weathering and the frequency of planes of weakness within the rock in a metasedimentary bedrock environment, such as Prince Rupert, when assessing rippability. While seismic refraction cannot quantify the dominant planes of weakness within the bedrock it can provide insight into the degree of rock weathering. Bedrock velocities at Site have been reported in km/s for direct comparison to the Caterpillar Inc. rippability chart shown in Plate 2.

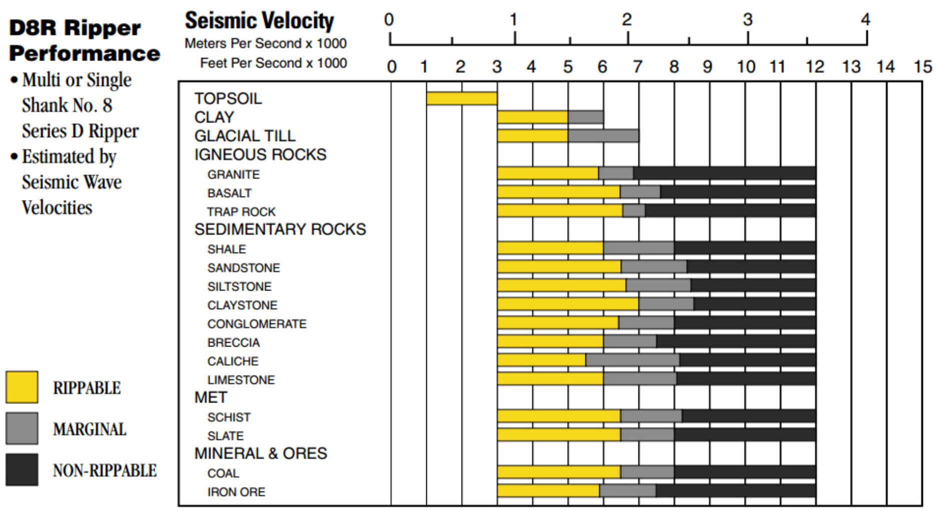

Plate 2: Caterpillar Handbook of Ripping Seismic Velocity Chart

A two-layer model was used to determine bedrock velocity along each seismic refraction line. The upper layer presents an average velocity for the overburden materials, while the lower layer presents an average velocity for the upper bedrock. As discussed in Section 6.1.3, tomographic models should generally not be used for bedrock rippability analysis as they can create an artificially smooth transition zone from soil to rock, and because tomographic model velocities tend to be more relative and less absolute than layer-based models.

Generally, if the upper layer velocity is less than 0.5 km/s this indicates loosely consolidated material and potential organics. If the upper layer is greater than 0.5 km/s this indicates more compact silt, sand, and gravel. The overburden layer velocities range from 0.4 km/s to 1.1 km/s. All materials in the first layer are considered rippable. For seismic profiles occurring along 2nd Avenue the first layer arrivals were masked by high velocity arrivals propagating along the near surface asphalt-overburden interface which prevented a detailed analysis of overburden velocities in this area.

The bedrock layer velocities range from 2.9 to 4.5 km/s and depths range from 0.5 to 7 m below ground surface. Per the rippability chart presented in Plate 2, Schist is considered non-rippable for a D8 bulldozer when p-wave velocity is greater than 2.4 km/s, and marginal between 2 and 2.4 km/s. Therefore, the bedrock profiled at the Site is considered non-rippable based on seismic velocity information. In addition, no significantly thick layer of weathered bedrock was observed in the seismic data. It should be noted that larger machines have a greater rippability capacity. For instance, a D11 tractor may be able to rip Schist with p-wave velocity up to 3.0 km/s. However, even with a larger machine, the rock at the Site may still be considered non-rippable based on seismic velocity information.

MASW data were collected but did not generally improve understanding of rippability at the Site and showed a weak correlation with refraction data. The two MASW soundings (MASW-1 and MASW-2) collected near the southwest end of SL21-03 are shown in Plate 3. The soundings are shown as shear wave velocity versus depth. A bedrock depth estimate based on nearby refraction profiles SL21-03 and 06 is shown at 7.5 mbgs for comparison. The shear wave velocities in the overburden material are between 250 to 300 m/s. Modelled shear wave velocity at bedrock depth is 350 m/s, however, this is interpreted to be a significant underestimation and not representative of true bedrock conditions. The bedrock in this area is assumed to be consistent with nearby refraction profiles and non-rippable.

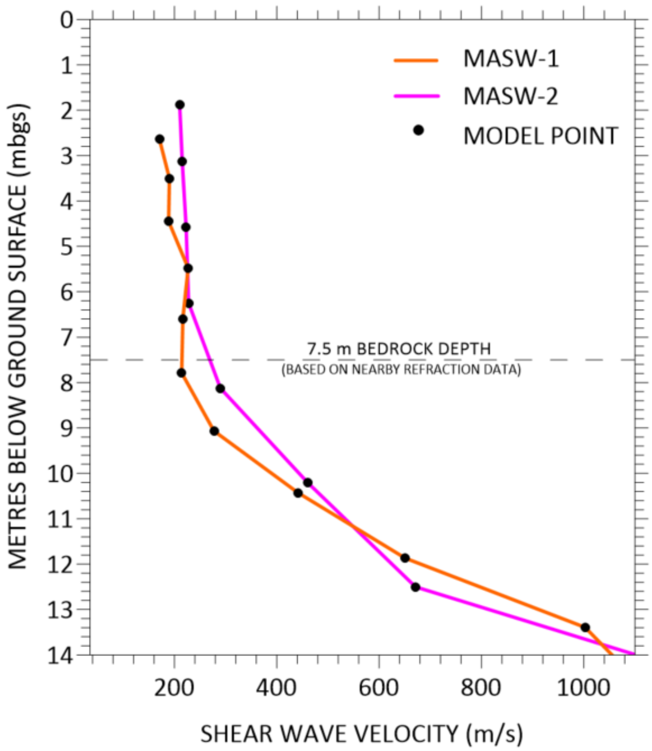

Plate 3: Shear Velocity Data from MASW-1 and MASW-2 Locations

6.3 Objective 3: Stacked Rock Wall Assessment

GPR profiles were completed along the top of the stacked rock wall to identify any anomalous signatures within the stacked rock wall that could represent air voids and at the base of the wall to profile the material properties of the overburden. SR and GPR profiles were collected at the base of the wall to determine bedrock depth and overburden material type beneath the wall.

Plate 4 presents a photo of the wall showing the approximate location of SR and GPR profiles along it.

Plate 4: Photograph with GPR and SR line locations, taken from top of stacked wall on 2nd Avenue looking southwest at 1st Street.

The non-uniform construction of the stacked rock wall inherently produces scattered radar reflections from within the wall. This scattering effect is caused by the contrasting properties of the mortar and bedrock boulders, as well as by the individual boulders themselves. Prospecting for voids within the wall requires identifying larger amplitude reflections occurring at the rock-air interface which may appear stronger and more coherent than the scattered internal reflections. Voids may appear as hyperbolic or boomerang-shaped reflections. Figure 4 presents radar profiles collected along the top of the wall. No major voids were noted, however, anomalies that could be related to smaller air voids are annotated on the figure as crosses. Higher amplitude reflections are shown with red crosses while lower amplitude anomalies are shown in orange. The most likely anomalies to be associated with air voids are the higher amplitude reflections located approximately 23 m along GPR_1022. Due to reflections from the non-uniform internal structure of the rock wall and considering the frequency of the GPR antenna, it is estimated that voids less than 30 centimetres would be difficult to detect.

GPR profiles completed along the base of the stacked rock wall provided some insight into overburden conditions. These profiles were characterized by a lack of clear subsurface radar reflections. The lack of clear reflectors is attributed to conductive organic silt in the shallow subsurface which attenuates radar signal causing a mostly uniform radargram in those areas.

Bedrock depths at the base of the stacked rock wall along profiles SL21-06 and 07 range from outcropping to 4 m. Bedrock topography dips toward the intersection point of the two profiles, which was also observed to be a topographic low with saturated organic silt material at surface. Tomographic modelling in this area shows some weathered bedrock or compact material up to 1 m thick overlying the bedrock surface. Relatively low overburden velocity in this area indicates compressible and loose overburden material. Test hole data (McElhanney 2018) show organic silt material mixed with sands and gravel.

6.4 Objective 4: Utility Investigation

A FDEM survey was completed in the parking lot area, identified on Figure 5, to locate the ductile iron sanitary line, if possible. EM31 data were collected on 2nd Avenue and on McBride Street and successfully delineated the metallic water mains, determining a characteristic response to buried metallic infrastructure. Figure 5 shows a colour contour map of the in-phase data which provides a representation of the magnetic susceptibility of the subsurface. The iron water mains along the roads produce a characteristic drop in the in-phase response, shown as cool colours. The approximate location of the water mains along the road identified by the EM31 are annotated on the figure. A similar response is not observed in the parking lot area. The anomaly in the centre of the parking lot was observed during the time of acquisition to align with an electrical utility box. While the survey was successful in identifying the shallow iron water mains along the roads, it was unable to resolve the primary target of the investigation, which was the deeper sewer line in the sunken parking lot area. The EM-31 has an effective investigation depth of 5 metres, but a peak sensitivity at 1.3 metres depth. Based on the results from McElhanney (2018) the sanitary line has a depth of cover ranging from 2.5 to 4.4 m. Assuming the sanitary line is present at these depths the EM31 depth of investigation should be sufficient to detect the sanitary line. The lack of EM in-phase variation coincident with the assumed position of the sanitary line may be due to: the line being deeper than expected, the assumed line location being incorrect, the line being non-metallic or corroded. Another possible cause would be that the in-phase response is too weak to be detected by the EM31 instrument.

Some GPR profiles were collected within the sunken parking lot in an attempt to profile the sanitary line in this location. Conductive ground conditions attenuated the radar signal and did not yield any definitive detection of the sanitary line.

7.0 CONCLUSIONS

A geophysical investigation was completed along Yellowhead Highway 16 at the proposed intersection upgrade location where 2nd Avenue West and McBride Street meet. The primary investigation objective was to profile bedrock across the site and determine rippability characteristics of the bedrock based on compressional wave velocity analysis. In addition, the stacked rock retaining walls along 2nd Avenue and 1st Street were assessed for bedrock depth at the base of the wall and anomalous conditions within the wall that could be attributed to air voids. As a final objective, FDEM and GPR data were collected to image the buried sanitary line in the parking lot area, if possible, and delineate other metallic infrastructure at the site. All data was collected over a three-day field program and a full closure of the intersection area was imposed to collect continuous data across the intersection and reduce vibrational noise at Site.

Bedrock depths from the geophysical investigation and previous geotechnical test-holes were used to produce a bedrock depth isopach shown in Figure 6. Bedrock depths range from outcropping to 7 m below ground surface along the seismic refraction profiles. Bedrock at the intersection of 2nd Avenue West and McBride Street ranges from 0.5 to 2 metres below ground surface and tends to increase to the west of the intersection. Along the 2nd Avenue approach bedrock drops off sharply, moving away from the intersection, and reaches a maximum depth of 7 m at the southwest end of SL21-03. Bedrock along the McBride Street approach ranges from 0.5 to 3 metres. Bedrock depths at the base of the stacked rock wall along profiles SL21-06 and 07 range from outcropping to 4 m.

Seismic refraction data were processed to accurately quantify bedrock velocity and identify any zones of weak or weathered bedrock that may be rippable. Bedrock velocities range from 2.9 km/s to 4.5 km/s. Per the Caterpillar rippability charts, bedrock profiled at the Site is considered non-rippable based on seismic velocity information for a D8 bulldozer. In addition, no significantly thick layer of weathered bedrock was observed in the seismic data.

GPR profiles were collected along the top of the stacked rock wall to identify potential voids within the wall. Some anomalous features have been identified that may be due to discontinuities within the wall. Scattering of radar energy due to the inherent discontinuities in the stacked rock wall design likely limit the effectiveness of the GPR method to identify voids in the rock wall.

Infrastructure mapping was completed using the FDEM method, which successfully resolved shallow water mains along the roads but could not image the deeper sanitary line located in the parking lot near the stacked rock wall. The lack of EM in-phase variation coincident with the assumed position of the sanitary line may be due to: the line being deeper than expected, the assumed line location being incorrect, the line being corroded or non-metallic, and/or the in-phase response is too weak to be detected by the EM31 instrument.

8.0 CLOSURE

The reader is referred to the Study Limitations, which precedes the main body and forms an integral part of this report.

We trust that this report meets your present requirements. If you have any questions regarding this investigation, please contacts the undersigned.

Golder Associates Ltd.

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June 2, 2021

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https://golderassociates.sharepoint.com/sites/102414/deliverables/issued to client_for wp/19115216-028-r-rev0-2000/19115216-028-r-rev0-2000-mcbride report 02jun_21.docx

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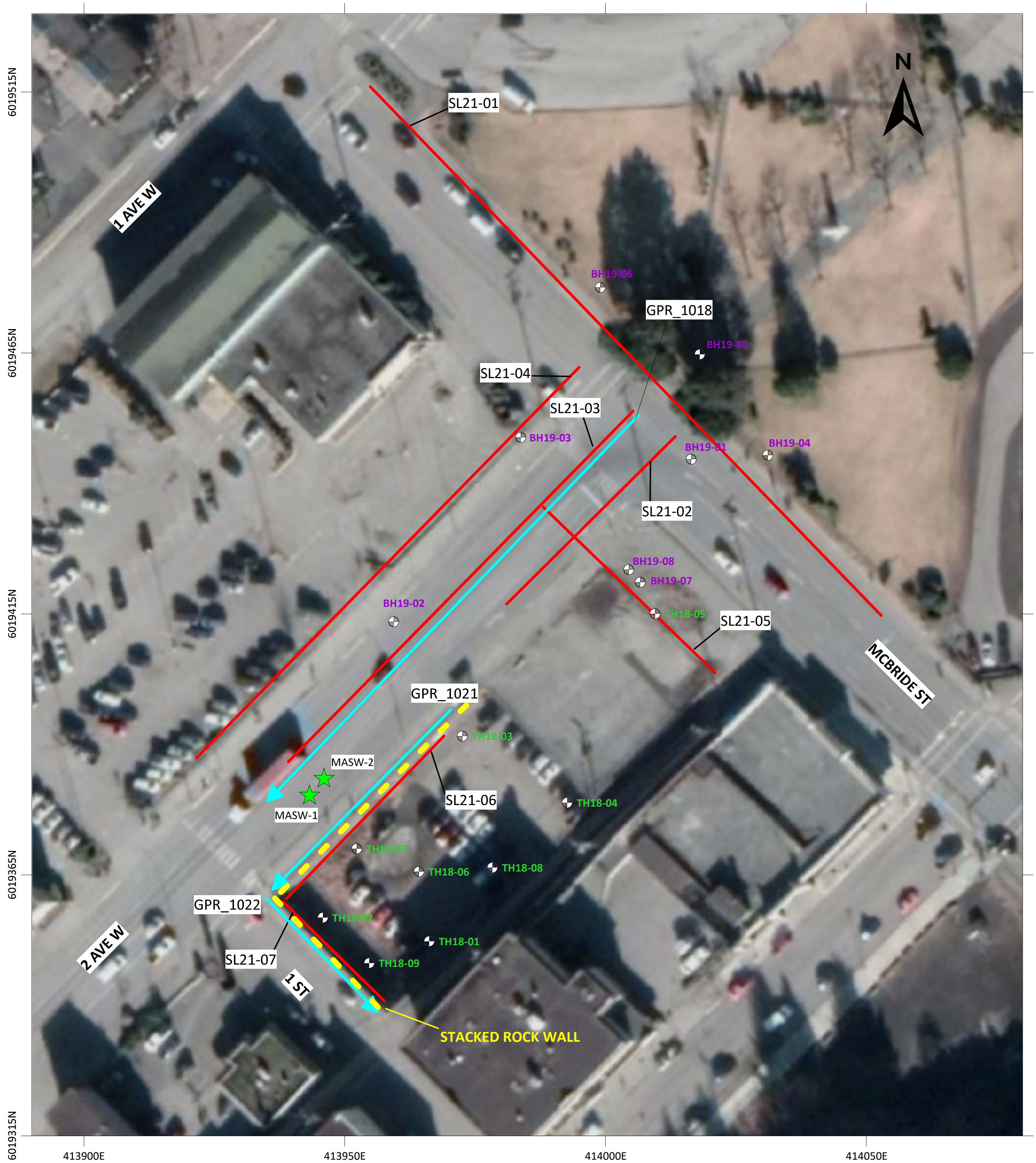

LEGEND:

- SEISMIC REFRACTION LINE
- GPR LINE
- TH18 2018 TEST HOLES (MCELHANNEY)
- BH19 2019 TEST HOLES (EXP)
- MASW SOUNDING LOCATION
- STACKED ROCK WALL

NOTES:

1. BOREHOLE LOCATIONS ARE APPROXIMATE.
2. BOREHOLE INFORMATION PROVIDED TO GOLDER BY MOTI.
3. FDEM LINE LOCATIONS ARE ACCURATE TO WITHIN 0.5 METRE.
4. COORDINATES SHOWN IN METRES USING NAD83 DATUM (UTM ZONE 9N).

CLIENT
BC Ministry of Transporation and Infrastructure

PROJECT
2nd and McBride Intersection
Geophysical Investigation

CONSULTANT

GOLDER

YYYY-MM-DD	2021-05-30
PREPARED	G. JONES
DESIGN	G. JONES
REVIEW	S. MAXWELL
APPROVED	S. MAXWELL

TITLE
SITE MAP

PROJECT No.	PHASE/TASK	Rev.	FIG.
19115216	2000/2090	0	01

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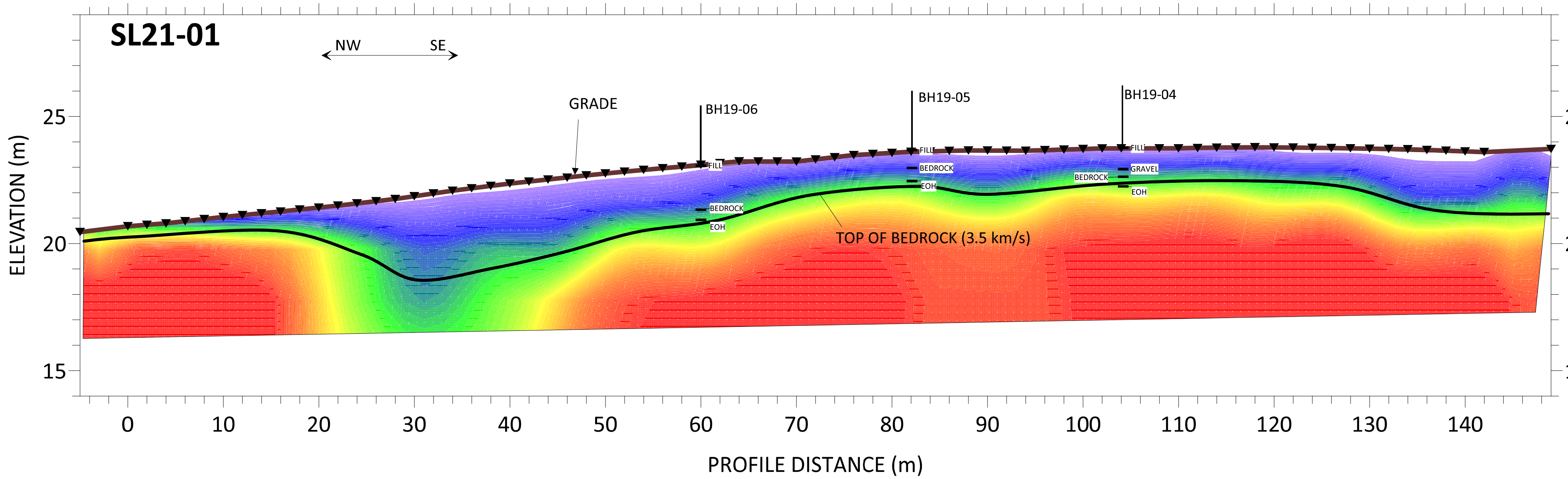
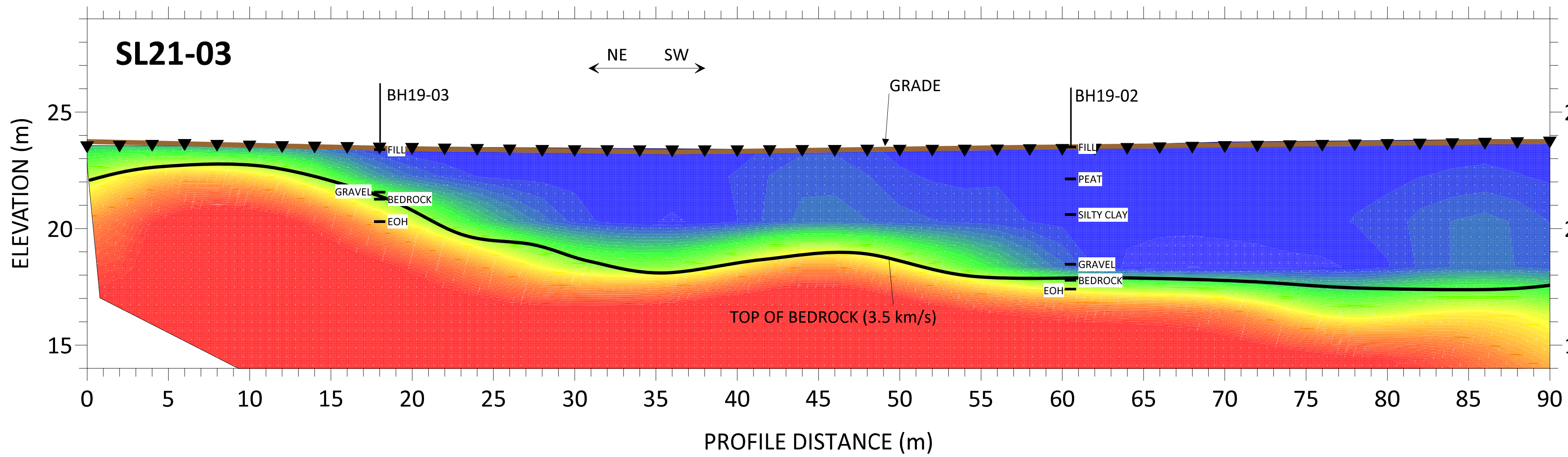
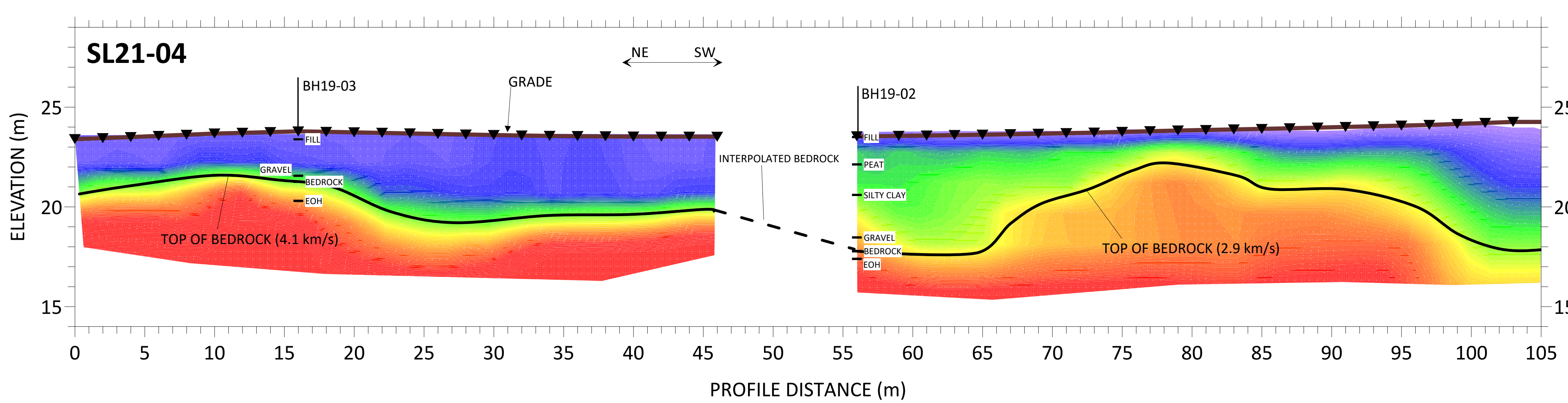
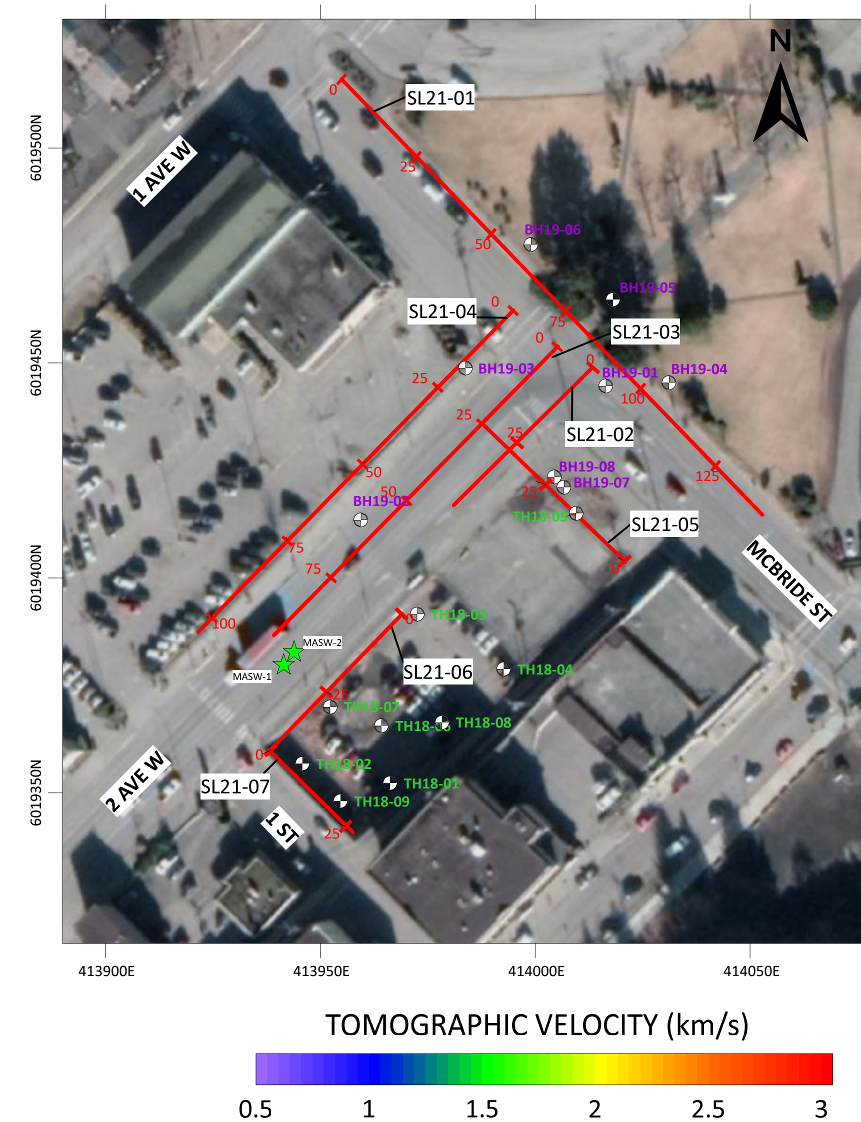








LEGEND:

- SEISMIC REFRACTION LINE
- TH18 — 2018 TEST HOLES (MCELHANNEY)
- BH19 — 2019 TEST HOLES (EXP)

NOTE(S)

1. SOILS LOGS HAVE BEEN SIMPLIFIED FOR GEOPHYSICAL INTERPRETATION. REFER TO THE SOURCE REPORTS FOR DETAILED GEOTECHNICAL LOGS.
2. ELEVATIONS SHOWN RELATIVE TO VERTICAL DATUM CGVD28 (HT2.0) WITH PLUS OR MINUS 0.5 METER ACCURACY.
3. TOP OF BEDROCK INTERFACE INTERPRETED USING LAYER-BASED MODELLING. TOMOGRAPHIC VELOCITIES DO NOT REPRESENT ACTUAL ROCK CONDITIONS AT THE TOP OF BEDROCK.

CLIENT
BC Ministry of Transportation and Infrastructure

PROJECT
2nd and McBride Intersection
Geophysical Investigation

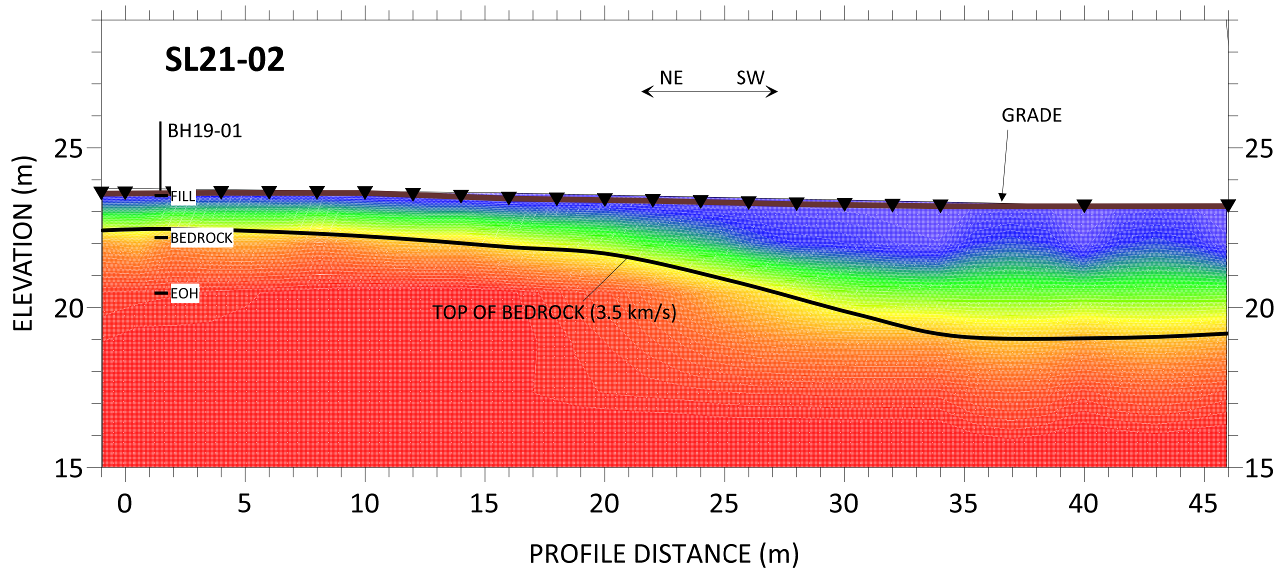
TITLE
SEISMIC REFRACTION MODELS
LINES SL21-01, 03, AND 04

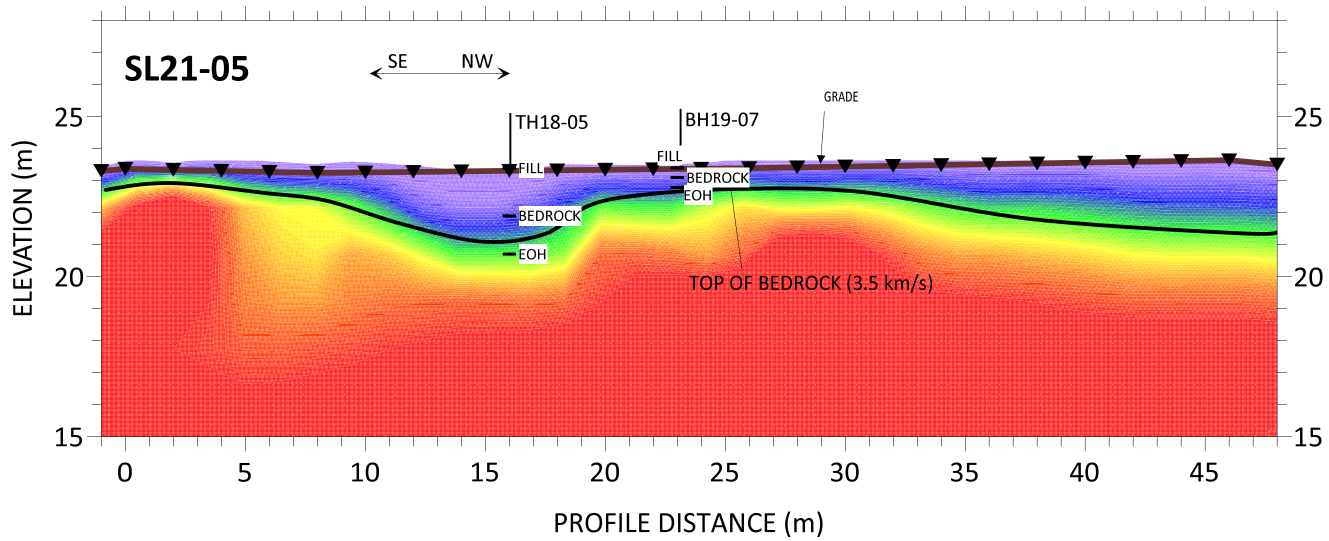
CONSULTANT

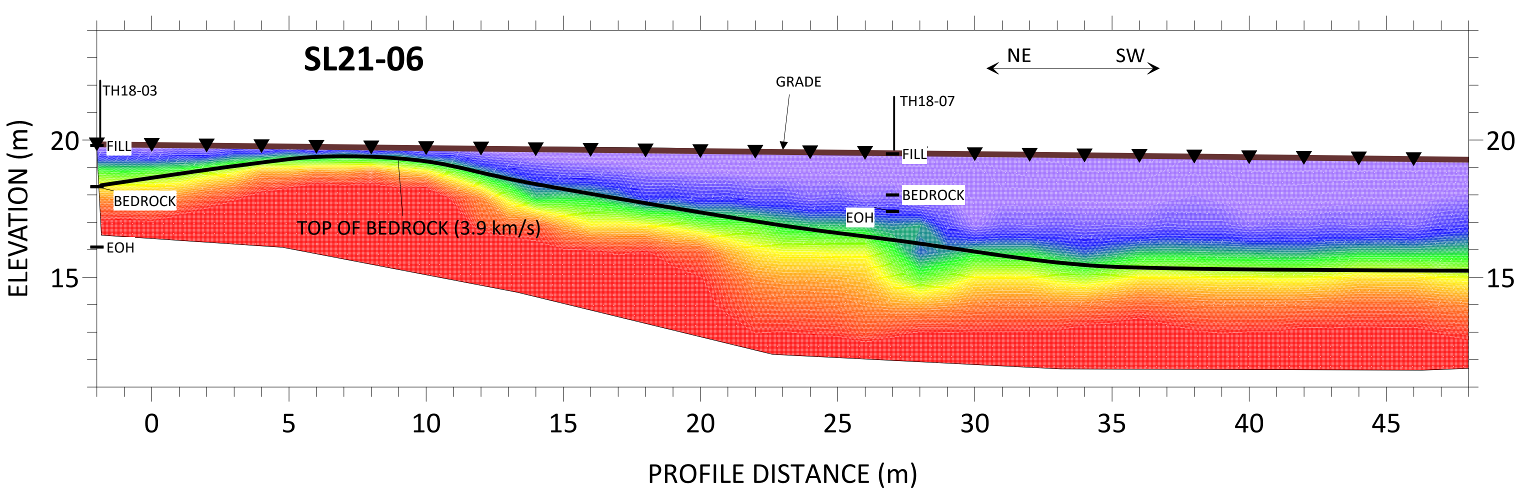
GOLDER

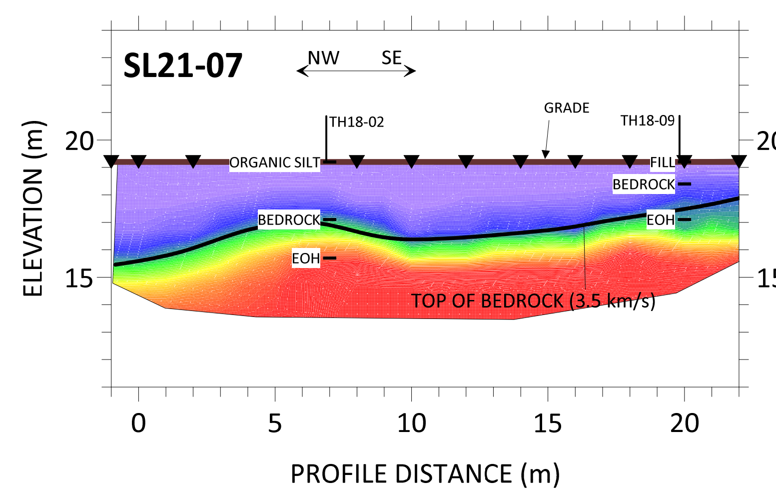
YYYY-MM-DD	2021-05-27
PREPARED	G. JONES
DESIGN	G. JONES
REVIEW	S. MAXWELL
APPROVED	S. MAXWELL

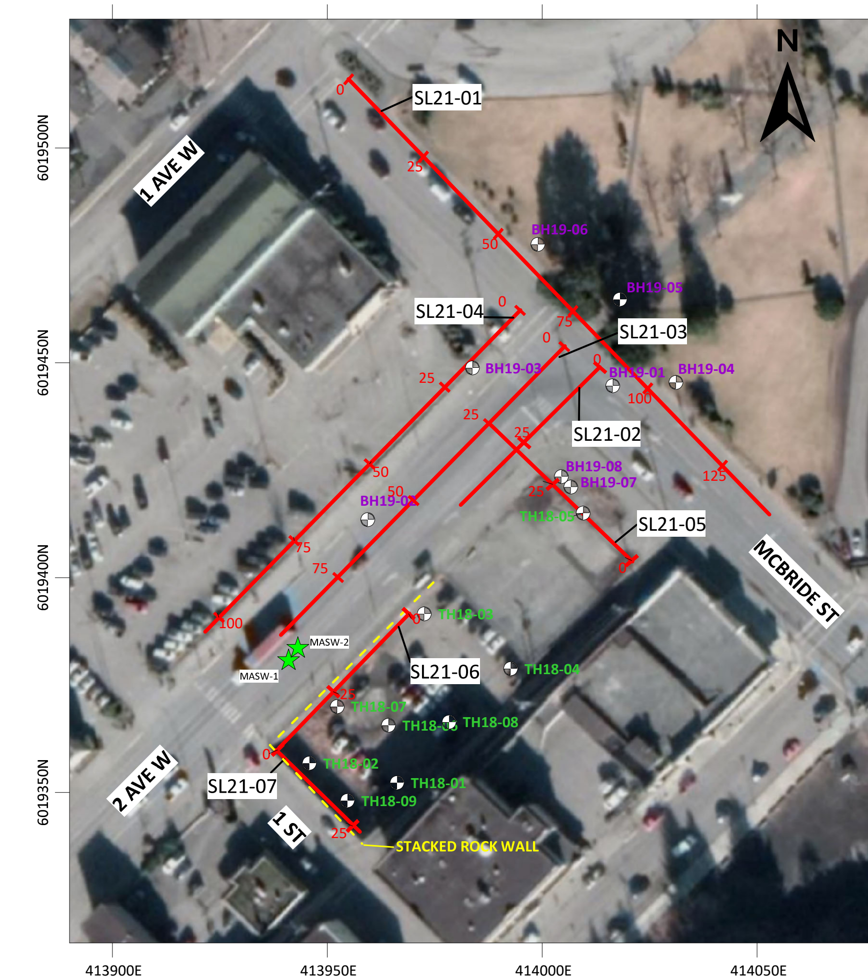
PROJECT No. 19115216-2000-2090 | Rev. 0 | FIG 02

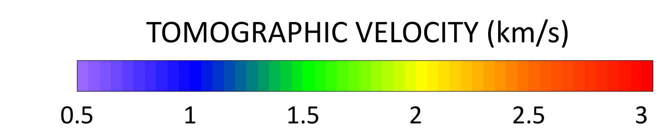












LEGEND:

- SEISMIC REFRACTION LINE
- TH18 — 2018 BOREHOLES (MCELHANNEY)
- BH19 — 2019 BOREHOLES (EXP)

NOTE(S)

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3. TOP OF BEDROCK SURFACE INTERPRETED USING LAYER-BASED MODELLING. TOMOGRAPHIC VELOCITIES DO NOT ALWAYS REPRESENT ACTUAL ROCK CONDITIONS AT THE TOP OF BEDROCK.

CLIENT
BC Ministry of Transportation and Infrastructure

PROJECT
2nd and McBride Intersection
Geophysical Investigation

TITLE
SEISMIC REFRACTION MODELS
LINES SL21-02, 05, 06, AND 07

CONSULTANT

GOLDER

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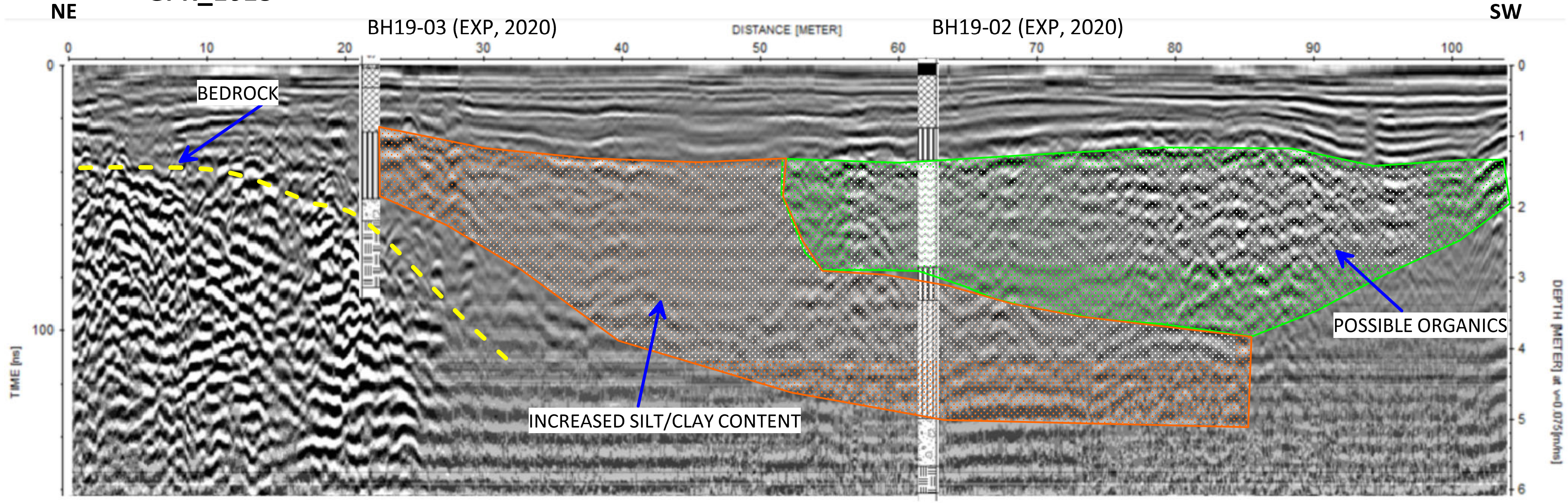
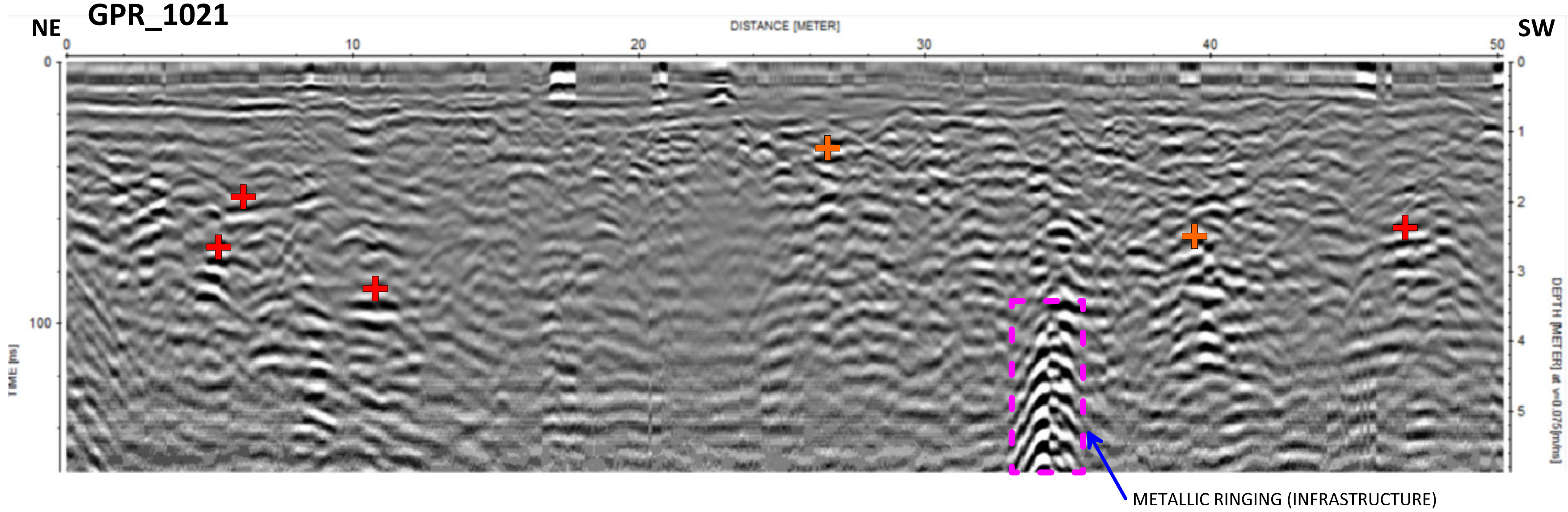
DESIGN	G. JONES
REVIEW	S. MAXWELL
APPROVED	S. MAXWELL

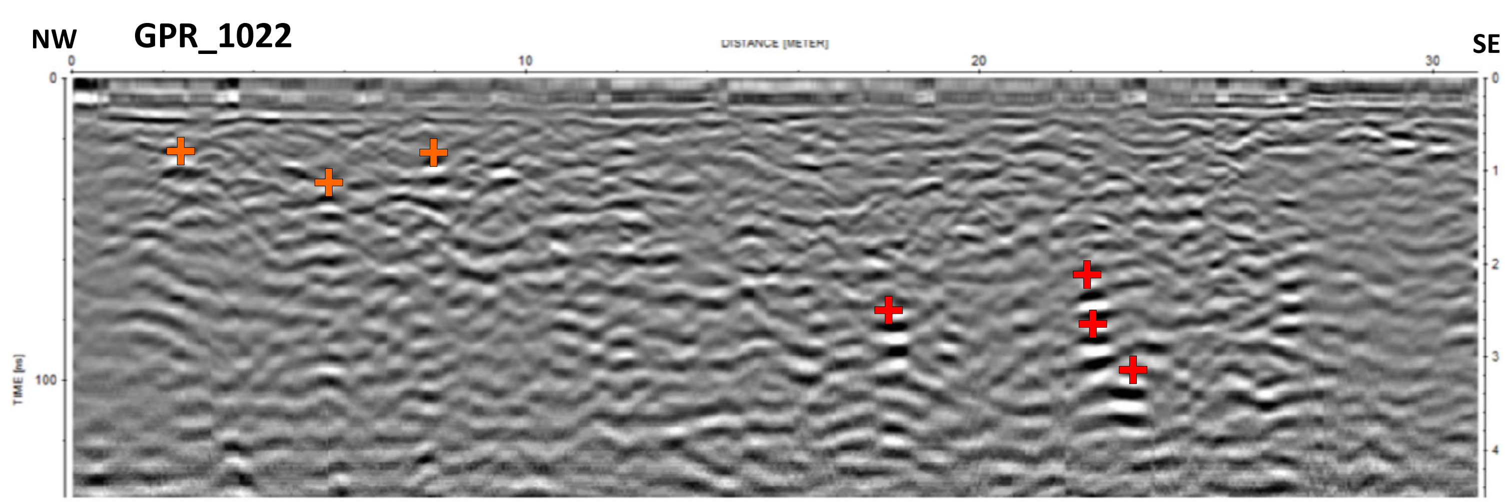
PROJECT No. 19115216-2000-2090 Rev. 0 FIG 03

BEDROCK/OVERBURDEN INVESTIGATION



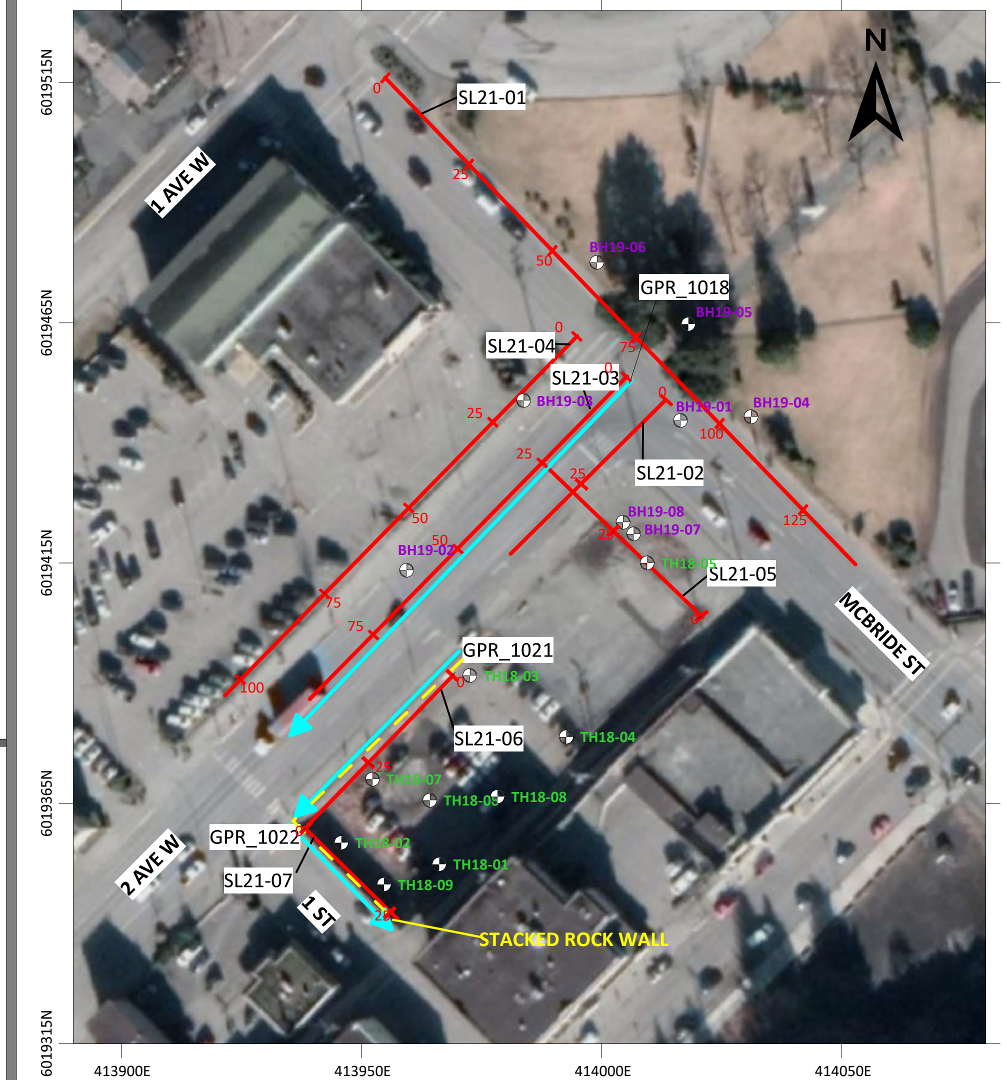
ROCK STACKED WALL INVESTIGATION





LEGEND

- HIGHER AMPLITUDE REFLECTION
- LOWER AMPLITUDE REFLECTION



LEGEND:

- SEISMIC REFRACTION LINE
- GPR LINE
- TH18 2018 BOREHOLES (MCELHANNEY)
- BH19 2019 BOREHOLES (EXP)

NOTE(S)

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2. ELEVATIONS SHOWN RELATIVE TO VERTICAL DATUM CGVD28 (HT2.0) WITH PLUS OR MINUS 0.5 METER ACCURACY.

CLIENT
BC Ministry of Transportation and Infrastructure

PROJECT
2nd and McBride Intersection
Geophysical Investigation

TITLE
GROUND PENETRATING RADAR PROFILES GPR_1018, 1021, AND 1022

CONSULTANT

GOLDER

YYYY-MM-DD	2021-05-30
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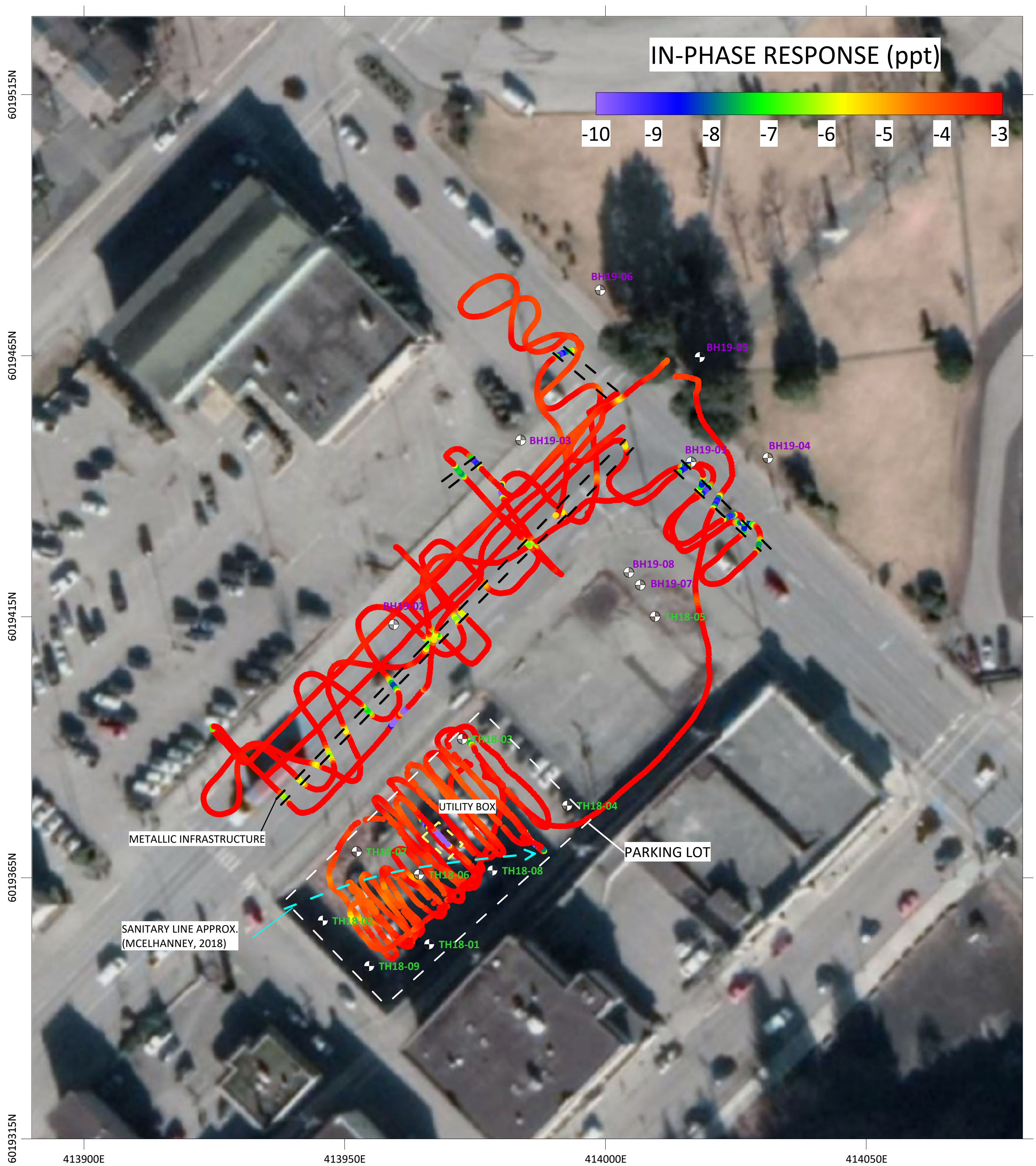
APPROVED	S. MAXWELL

PROJECT No.	Rev.	FIG
19115216-2000-2090	0	04



LEGEND:

TH18	2018 BOREHOLES (MCELHANNEY)
BH19	2019 BOREHOLES (EXP)

NOTES:

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2. BOREHOLE INFORMATION PROVIDED TO GOLDER BY MOTI.
3. FDEM LINE LOCATIONS ARE ACCURATE TO WITHIN 0.5 METRE.
4. COORDINATES SHOWN IN METRES USING NAD83 DATUM (UTM ZONE 9N).

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BC Ministry of Transportation and Infrastructure

PROJECT
2nd and McBride Intersection
Geophysical Investigation

CONSULTANT
GOLDER

YYYY-MM-DD	2021-05-28
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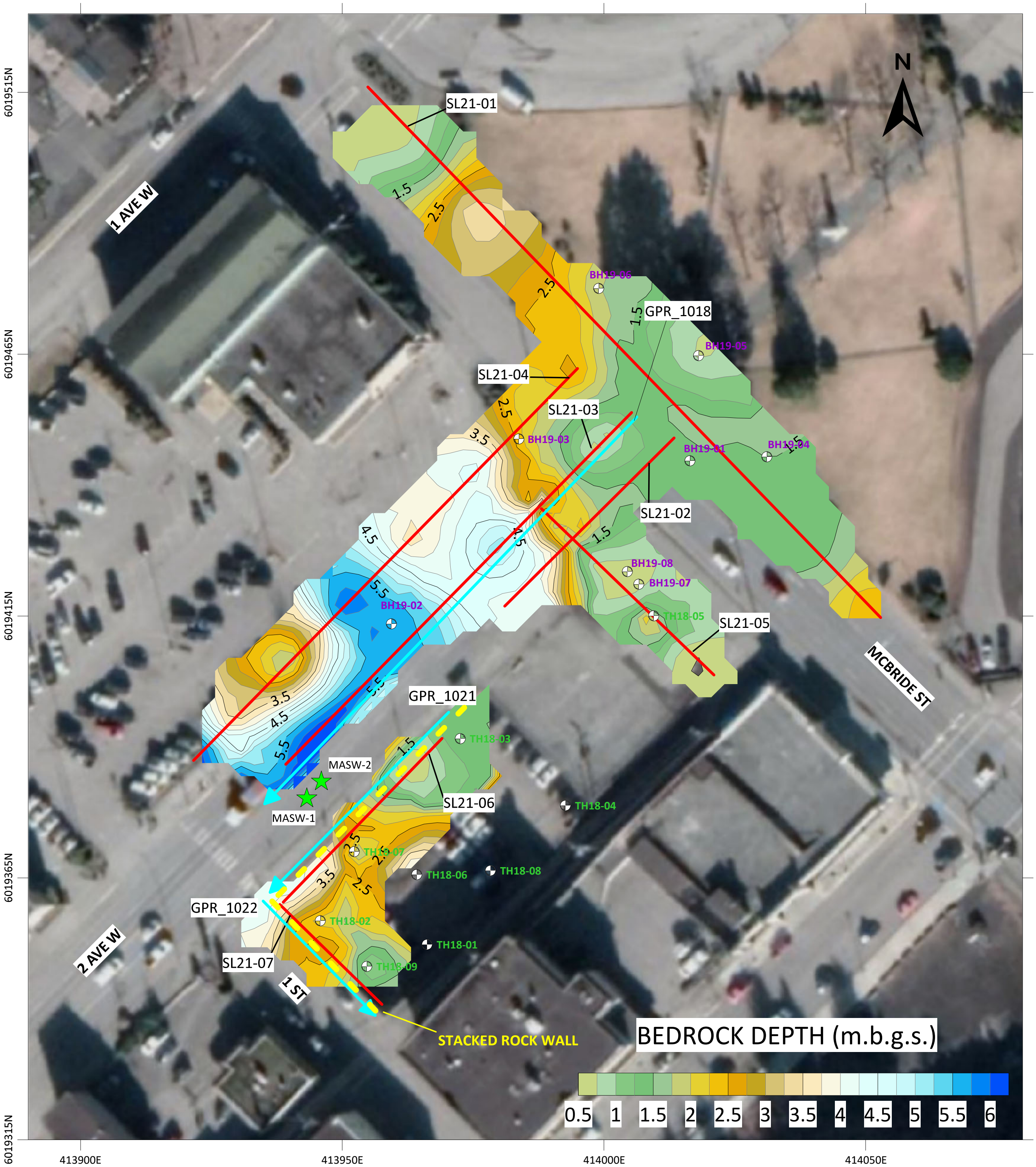
DESIGN	G. JONES
REVIEW	S. MAXWELL
APPROVED	S. MAXWELL

TITLE
IN-PHASE RESPONSE MAP

PROJECT No.	PHASE/TASK	Rev.	FIG.
19115216	2000/2090	0	05



LEGEND:

- SEISMIC REFRACTION LINE
- GPR LINE
- TH18 2018 TEST HOLES (MCELHANNEY)
- BH19 2019 TEST HOLES (EXP)
- MASW SOUNDING LOCATION
- STACKED ROCK WALL

NOTES:

1. BEDROCK CONTOUR DEPTHS ARE INTERPOLATED BETWEEN EXISTING DATA POINTS AND ACTUAL CONDITIONS MAY VARY SIGNIFICANTLY IN AREAS OF SPARSE OR NO DATA.
2. BOREHOLE INFORMATION PROVIDED TO GOLDER BY MOTI.
3. COORDINATES SHOWN IN METRES USING NAD83 DATUM (UTM ZONE 9N).

CLIENT	BC Ministry of Transporation and Infrastructure
PROJECT	2nd and McBride Intersection Geophysical Investigation
CONSULTANT	GOLDER
YYYY-MM-DD	2021-05-27
PREPARED	G. JONES
DESIGN	G. JONES
REVIEW	S. MAXWELL
APPROVED	S. MAXWELL
TITLE	BEDROCK DEPTH ISOPACH MAP
PROJECT No.	19115216
PHASE/TASK	2000/2090
Rev.	0
FIG.	06

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