23 Harold Street,
North Parramatta, NSW. 2151.
Tel: (02) 9890 2122. Fax: (02) 9890 2922.
ABN: 77 009 550 869
E-Mail: jamie@gbgoz.com.au

Draft Report

Geophysical Investigation to Delineate Bedrock at Snowy Mountains Grammar School, Jindabyne, NSW.

Date: 2 December 2020
Job Number: GBGA2386

FINAL

DOCUMENT HISTORY

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Project Number:	GBGA2386
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Site Address	Snowy Mountains Grammar School, 6339 Kosciuszko Rd, Jindabyne NSW 2627.
Report prepared for	Conrad Moore, Munns Sly Moore Architects Pty Ltd

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COMPANY DETAILS

Business Name:	GBG Australia Pty Ltd
ABN:	77 009 550 869
Business Address:	23 Harold Street, North Parramatta NSW 2151
Phone / fax:	(02) 9890 2122 (02) 9890 2129
Email:	info@gbgoz.com.au

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DISCLAIMER:

The results are based on destructive & non-destructive testing. Although every effort has been made to accurately determine the below ground impediments to construction, GBG Australia cannot guarantee that all relevant information has been obtained. The findings are limited to those locations specifically covered in this report and are subject to the scope, assumptions and limitations as set out in the report. Many of the findings are based on indirect measurements and scanning carried out on site, based on interpretation of electrical signals in conjunction with limited information supplied by the client or determined by physical spot testing. The conclusions drawn represent the best professional opinions of the authors, based on their experience and results from previous investigations on similar materials elsewhere. The opinions conclusions and any recommendations in this report are based on conditions at the time of testing and do not consider events or changes after the time of testing.

1 INTRODUCTION

GBG Australia (GBG) carried out a geophysical investigation to determine the depth to the top of the granite basement within the grounds of Snowy Mountains Grammar School, Jindabyne, NSW. The survey was required to gain data to inform on design and construction details for planned additional buildings at the site. The site is located at 6339 Kosciuszko Rd, Jindabyne NSW. The geophysical site work was carried out over two days between the dates of the 29th and 30th September 2020 by a two-person team from GBG consisting of qualified Geophysicists.

The investigation was initially planned to include trialling Ground Penetrating Radar (GPR) and collecting transects using Multichannel Analysis of Surface Waves (MASW). However, on attending the site it was found that the topography was such that the constraints of MASW would have precluded most of the school site. The MASW technique requires that the profile has no change in slope along any profile. As a result of this several refraction seismic profiles were acquired instead.

The survey was to locate the top of bedrock and gain information on velocities of rock and overburden material to a depth of six to eight metres Below Ground Level (BGL). Testing occurred within the current school facility and within the vacant land to the east of the school site.

The results will be used to inform any excavation work within the current school grounds and to allow planning for future expansion.

We are pleased to present the results and findings of the investigation in this report.

2 GEOPHYSICAL INVESTIGATION SITE

The investigation was undertaken predominately over grassed and gravelled manmade landform, excepting an area to the west of the school buildings that has several exposed boulders (granite) present on top of the hill. The vacant land to the east of the school buildings previously occupied by the Snowy Mountains Scheme is believed to be cut and fill material.

3 DATA ACQUISITION

GPR profiles were collected with lines set out to cover natural, disturbed and compacted ground. Figure 1 & Figure 2 below, show the extent of the GPR data acquisition. The initial testing was to ascertain if the technique would be able to map the top of the bedrock (see results section for full details). Suffice to say the use of GPR was abandoned on the first day in favour of using refraction seismics.

Refraction seismic data collection was designed to capture the profiles as close as possible to those defined in our proposal (P21086). After inspection of the site and in consultation with Dan Butterworth (D & N Geotechnical) and notifying Conrad Moore (Munns Sly Moore Architects Pty Ltd), collection of seismic refraction data was undertaken.

Sixteen (16) spreads of Refraction Seismics were collected, this amounted to seven lines of data. The spread geometry used a one metre spaced, 24 geophone array. Figure 3 & Figure 4 below for the location of the Refraction Seismic data acquisition undertaken.

Figure 1: Location of the GPR profiles collected on the school site. Image from Google Earth.

Figure 2: Location of the GPR profiles collected on the vacant lot east of the school site. Image from Google Earth.

Figure 3: Location of the refraction seismic profiles collected on the school site. Image from Google Earth.

Figure 4: Location of the refraction seismic profiles collected on the vacant lot east of the school site. Image from Google Earth.

3.1 Locating and Positioning

Positioning of the geophysical data during the investigation was achieved using a Differential GPS receiver providing high-precision accuracy. Horizontal positions are given in UTM Zone 55.

Twenty-nine (29) GPR Profiles (6 of which were collected with a different antenna), and seven (7) Refraction Seismic lines (16 spreads) were collected. Details of the Refraction lines and GPR lines are provided in Table I: Acquired Seismic Lines.

Seismic Line	Number of Spreads	Length (m)	Start Coordinate (m)		End Coordinate (m)	
			Easting*	Northing*	Easting*	Northing*
Seismic Line 1	4	89	644,123.65	5,968,820.35	644,189.01	5,968,763.55
Seismic Line 2	2	45	644,173.56	5,968,775.23	644,190.92	5,968,815.98
Seismic Line 3	4	89	644,137.01	5,968,845.91	644,196.12	5,968,814.57
Seismic Line 4	1	23	644,150.01	5,968,818.43	644,165.61	5,968,834.47
Seismic Line 5	1	23	644,139.91	5,968,799.37	644,150.13	5,968,819.34
Seismic Line 6	1	23	644,173.20	5,968,801.59	644,193.82	5,968,791.31
Seismic Line 7	3	67	644,370.56	5,968,734.58	644,388.42	5,968,799.84

*****co-ordinates given in UTM Zone 55H

Table II & Table I below. Appendix A contains further information of the methods used during this investigation.

Table I: Acquired Seismic Lines.

Seismic Line	Number of Spreads	Length (m)	Start Coordinate (m)		End Coordinate (m)	
			Easting*	Northing*	Easting*	Northing*
Seismic Line 1	4	89	644,123.65	5,968,820.35	644,189.01	5,968,763.55
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Seismic Line 6	1	23	644,173.20	5,968,801.59	644,193.82	5,968,791.31
Seismic Line 7	3	67	644,370.56	5,968,734.58	644,388.42	5,968,799.84

***co-ordinates given in UTM Zone 55H**

Table II: Acquired GPR Lines. Lines 1 to 6 were collected with both 270 and 200MHz antenna

GPR Line	Length (m)	Start Coordinate (m) as collected		End Coordinate (m) as collected	
		Easting*	Northing*	Easting*	Northing*
1	89.02	644,193.66	5,968,758.14	644,114.81	5,968,799.45
2	64.15	644,196.17	5,968,762.90	644,138.90	5,968,791.80
3	48.16	644,152.93	5,968,801.80	644,110.33	5,968,824.26
4	73.17	644,104.03	5,968,801.95	644,131.82	5,968,869.64
5	84.31	644,127.85	5,968,870.34	644,203.65	5,968,833.43
6	80.33	644,200.57	5,968,839.37	644,169.34	5,968,765.36
7	29.76	644,198.70	5,968,778.83	644,171.11	5,968,789.99
8	37.16	644,201.40	5,968,783.69	644,168.75	5,968,801.43
9	40.67	644,166.63	5,968,810.00	644,204.49	5,968,795.16
10	21.32	644,199.13	5,968,808.59	644,179.59	5,968,817.12
11	105.38	644,216.20	5,968,805.53	644,123.40	5,968,855.45
12	33.58	644,173.53	5,968,842.69	644,150.48	5,968,818.28
13	15.80	644,150.61	5,968,818.10	644,146.66	5,968,802.81
14	31.01	644,134.03	5,968,836.80	644,120.93	5,968,808.69
15	31.03	644,128.16	5,968,805.11	644,141.81	5,968,832.98
16	31.11	644,147.33	5,968,830.56	644,134.66	5,968,802.15
17	15.21	644,134.65	5,968,802.12	644,120.94	5,968,808.69
18	55.10	644,140.54	5,968,809.08	644,181.76	5,968,772.52
19	27.86	644,146.54	5,968,803.07	644,152.44	5,968,775.84
20	119.75	644,407.89	5,968,704.72	644,412.60	5,968,824.38
21	119.61	644,364.50	5,968,713.19	644,401.65	5,968,826.89
22	90.99	644,309.67	5,968,748.52	644,351.78	5,968,829.18
23	150.48	644,337.74	5,968,815.35	644,441.78	5,968,706.63

***co-ordinates given in UTM Zone 55H**

3.2 Ground Penetrating Radar Methodology

Data collection involved pulling a GPR system at a steady pace over the survey area. The data was acquired as a series of profile lines. Data collection was undertaken in Distance Mode at 150 or 100 scans per metre. Locations along each line were marked in the data and later logged by GPS. Onsite quality control of the data was achieved by viewing profiles in real time during data acquisition.

Antennas of higher frequency provide high-resolution data but penetrate to a shallower depth, whilst low-frequency antennas provide deeper penetration but with decreased resolution. The depth of penetration achievable with an antenna of any frequency is also dependent on the local subsurface conditions. Therefore, the GPR component of the investigation was carried out using two GPR antennas coupled to a GSSI SIR3000 system.

- A GSSI ground-coupled antenna of 270 MHz to obtain shallower, higher resolution images of the subsurface, 0 to 3 m below the current surface. The 270 MHz antenna data was collected at 150 scans per metre.

- A GSSI ground-coupled antenna of 200 MHz to obtain deeper, lower resolution images of the subsurface, 0 to 5 m below the current surface. The 200 MHz antenna data was collected at 100 scans per metre.

A total of 29 GPR profiles were collected on the morning of the morning of 29th September 2020. Data from Lines 1 to 6 was collected using both antennas. Onsite evaluation was undertaken with basic data processing being undertaken on site. On review and with consultation the GPR survey was discontinued, see Results and Interpretation section below. The processed and interpreted sections are displayed in Appendix A attached.

An overview of the GPR method is given in Appendix B.

3.3 Seismic Refraction Methodology

Data was collected from each of spread using a Geometrics Geode Seismograph coupled to a 24-channel array of geophones at 1 metre spacing. Energy was supplied by a sledgehammer impacting on a metal plate. ‘Shots’ were stacked as required to increase the arrival signal sufficiently to overcome the site noise from nearby traffic and wind noise. Shots were stacked until no appreciable signal improvement was observed. Shots were taken for the spread at the following relative chainages: -11.5, -5.5, -0.5, 0.5, 5.5, 11.5, 17.5, 22.5, 23.5, 28.5, 34.5 m. Each shot was reviewed by the site geophysicist. The equipment setup is shown in Figure 5 below.

Modelled seismic profiles are given in Appendix A attached.

Figure 5: Seismic array setup at Seismic Line 5, photographed facing south.

4 GEOPHYSICAL PROCESSING AND ANALYSIS

4.1 Ground Penetrating Radar

The recorded profiles were processed, analysed and interpreted on site and later in more detail at our Sydney office. GPR data was analysed and interpreted using Reflexw (version 9.0.5). Data processing involved:

- Static Correction, to correct depths to the surface;
- Background Removal 2D filtering, to remove noise bands and enhance the return signal;
- Correction of the signal velocity to provide calibrated depths.

4.2 Seismic Refraction

The collected seismic data was analysed and interpreted using “REFRACT 2006” which employs the Reciprocal Method supplemented by the Intercept Time method. With these two inversion routines, lateral seismic velocity variations within the layers and variations in the number and thickness of seismic layers along the lines were determined. The processing and interpretation of all datasets was carried out as outlined in *Appendix B – the use of interpreted seismic sections*.

Resulting models were plotted in Surfer 13 (Golden Software) for presentation and compared to relevant borehole data.

The main limitations of this program is that an increasing p-wave velocity with increasing depth is assumed, and variations within layers are limited to bulk lateral changes.

5 RESULTS AND INTERPRETATION

The results of the geophysical investigation carried out have been provided in the following figures and drawings attached in Appendix A of this report:

- GPR The processed and interpreted sections
- Drawings GBGA2386 01-06 – Seismic Refraction Modelled Results.

5.1 Ground Penetrating Radar Results.

Comparison of the data from both antennas shows that on this site the 200 MHz antenna gave the best results. Figure 6 and Figure 7 below, show examples from the 270 and 200 MHz data. The location of the profile line is also shown in the bottom of the figures.

The Data profiles collected with GPR did not show a defined continuous layer that could be interpreted as the bedrock, some features are seen and are interpreted as representative of boulders, see Figure 7 below. Image highlighting location of shallow boulders along the profile

Several possible services we located within the GPR data. However, the line spacing is insufficient to identify the exact alinement of the services or their type.

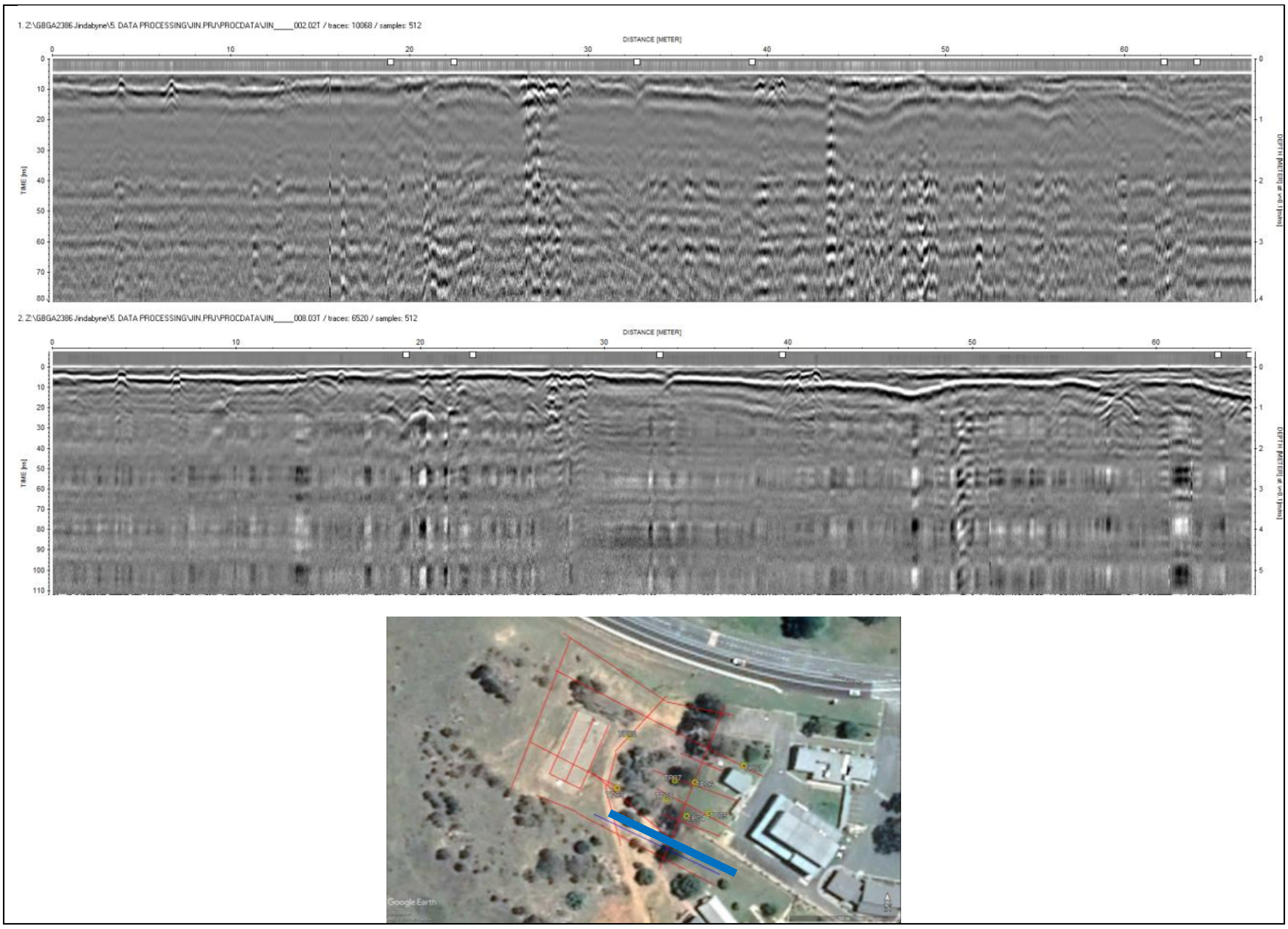


Figure 6: Comparison of results from GPR Line 2, 270 MHz antenna (top) and from 200 MHz antenna (middle). The 200MHz antenna shows better results from this site. The location of the profile is shown in the lower image.

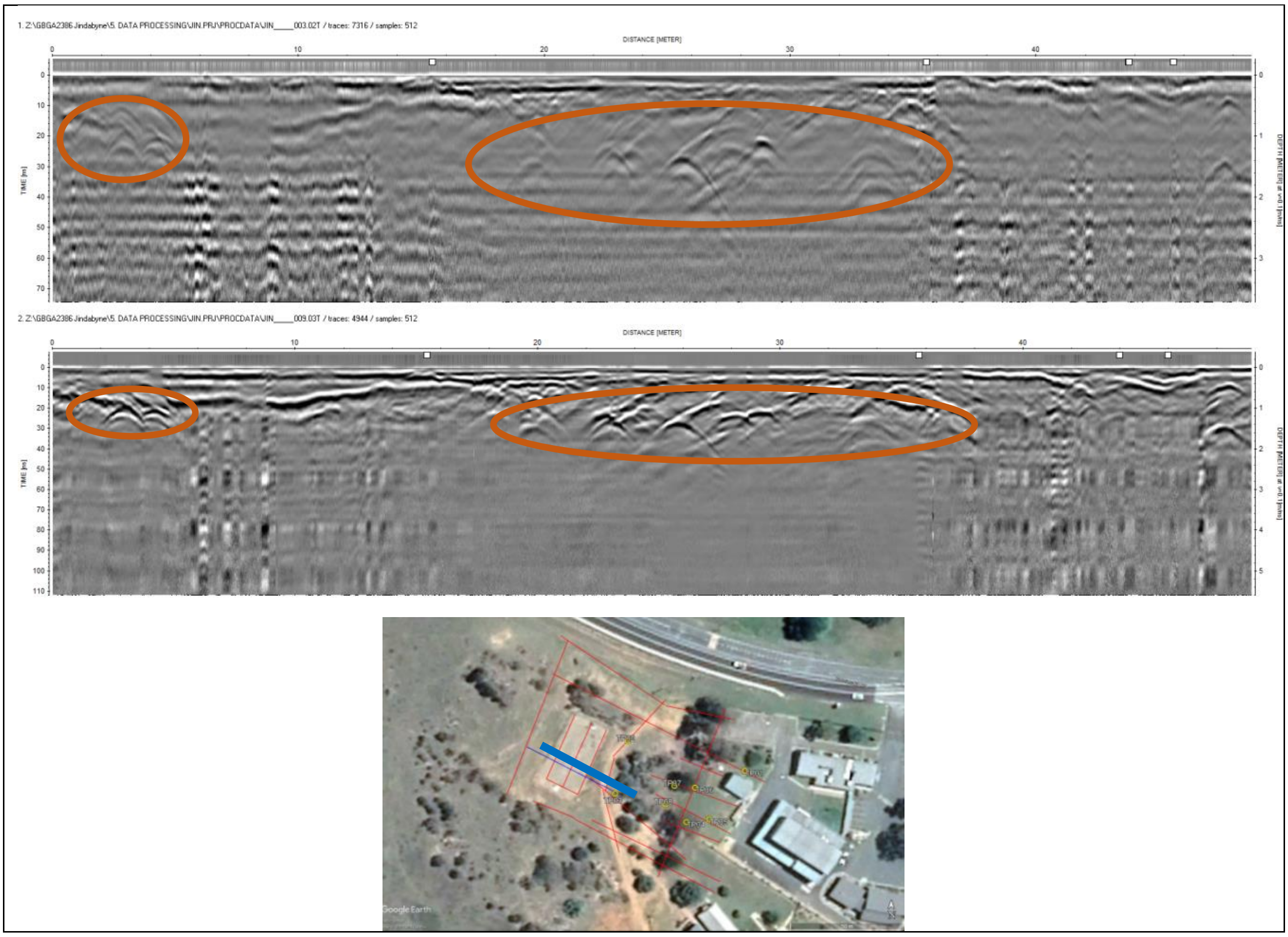


Figure 7: Comparison of results from GPR Line 3, 270 MHz antenna (top) and 200 MHz antenna (middle). The 200 MHz antenna returned better results from this site. The brown ovals highlight signal believed to show boulders. The area in the centre of the profiles is beneath the basketball court.

5.2 Seismic Refraction.

The collected data was of high quality with first breaks clearly visible in the individual traces. The profiles were modelled, and the resulting model and interpretations are shown in Drawings GBGA2386 01 – 06 attached in Appendix A.

The soil and highly compacted fill and soil are represented by the upper layer in all profiles (up to 600 m/sec p-wave seismic velocity). Beneath this are areas of variable velocities in on most sections, this represents extremely to highly weathered rock profile over burden. Regions of over 800 m/s are interpreted to be weathered bedrock. Velocities of 1,800 m/s are interpreted to be sound bedrock.

The faster material is deemed to be of marginal to non-rippable by a Caterpillar D8R with a No 8 shank D-Ripper. Refer to Figure 8 below, Caterpillar Rippability Chart.

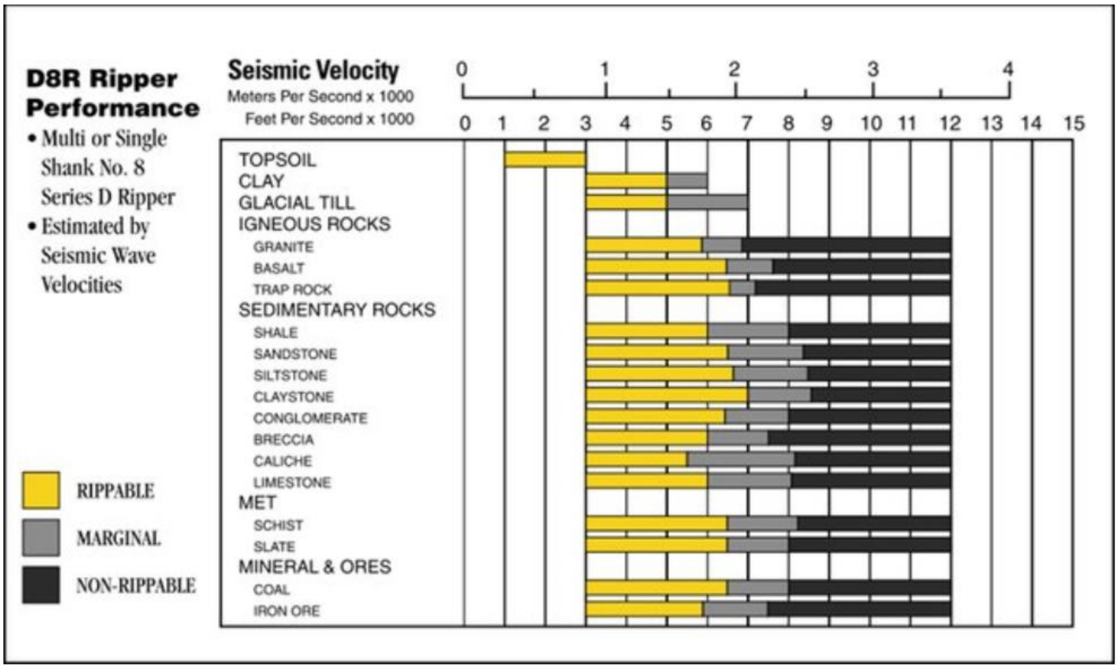


Figure 8: Caterpillar D8R Rippability Chart

6 CONCLUSIONS

The geophysical investigation was carried out by GBG in and to west and east of the existing Snowy Mountains Grammar School buildings 6339 Kosciuszko Rd, Jindabyne NSW. The results of the survey have been provided as 2D modelled profile lines along with geological interpretations.

The GPR data collection was discontinued midway through the first day as it was considered that no useful responses from the bed rock or boulders was in evidence 2 m below the surface.

GPR data from both antennas showed that either.

- The antennas did not achieve enough penetration to locate the bedrock across the site, or
- the site conditions were such that there was no electrical contrast between the soil and rock.
- GPR did however allow the definition of boulders in several areas where they were in evidence in the top 1.5 m

Refraction Seismic data profiles were collected using a 1 m spaced geophone array. Seven lines in total were collected. Six from the school grounds and one across the vacant land to the east of the school. The data collected was reasonable clear of noise.

Three layers have been interpreted in all but one seismic line. Usually a surface layer with less than 600 m/s p-wave seismic velocity was found representing soil, highly compacted and extremely weathered material. Where the surface material was found to have a faster velocity, it is assumed that the bedrock is very near the surface or the soil has been compacted by heavy vehicle traffic. The second layer was found to be between 600 and 1,250 m/s, which is interpreted as less weathered material, most probably the lower B Horizon of the granite. In places this material contains zones of higher velocity material, possibly large boulders. The bottom of this layer is interpreted as the limits of excavation or “rippability” using a D8 Caterpillar.

The faster third layer material is believed to be unweathered bedrock and has a P-wave velocity greater than 1,850 m/s. Some regions of slower velocities are in evidence and are interpreted to be zones of deeper weathering.

The seismic refraction profiles appear to be geologically reasonable for the local setting. With some zones of deep weathering and very variable layer thicknesses, possibly due to the presence of large boulders.

Test pit information has been made available and has informed our selection of the velocity contours used to define the layers. The borehole logs are plotted on the relevant drawings

We trust that this report and the attached drawings provide you with the information required. If you require clarification on any points arising from this investigation, please do not hesitate to contact myself through our office on (02) 9890 2122.

For and on behalf of

GBG Australia

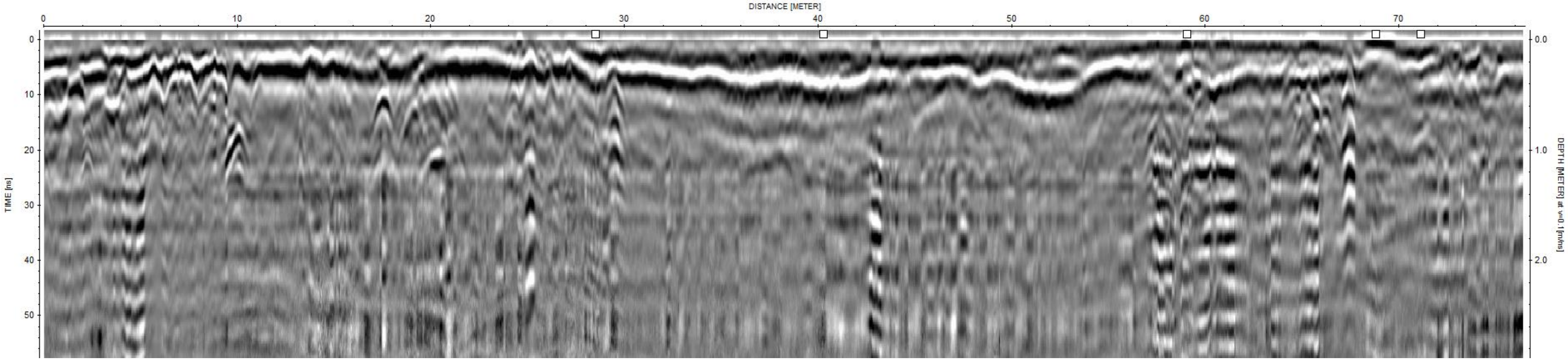
Jamie Speer (BSc Hons Geophysics and Analytical Geochemistry)
Senior Geophysicist.

APPENDIX A: GEOPHYSICAL RESULTS.

GROUND PENETRATING RADAR

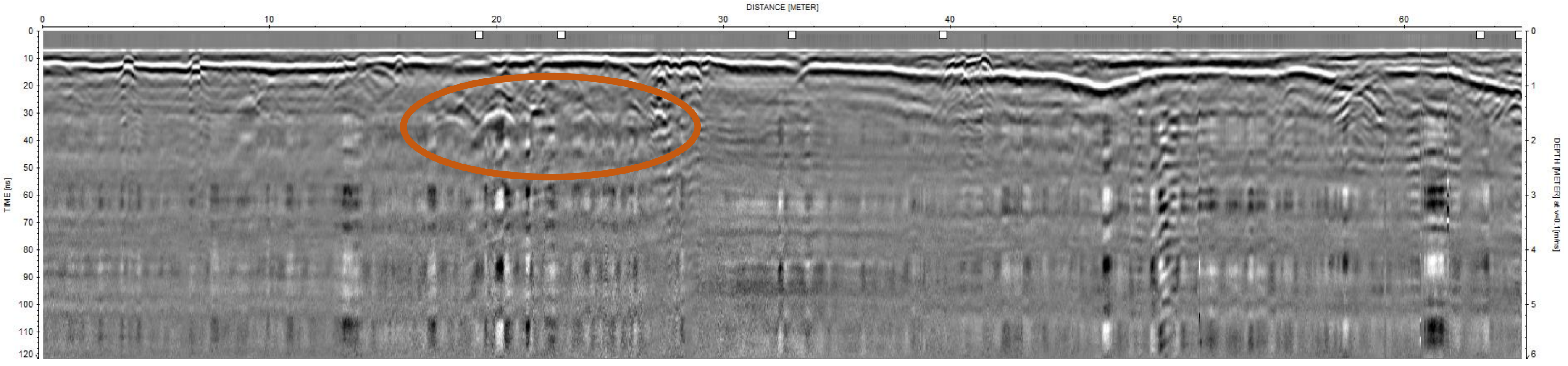
GPR Line 1 (Blue Line on Plan Below):

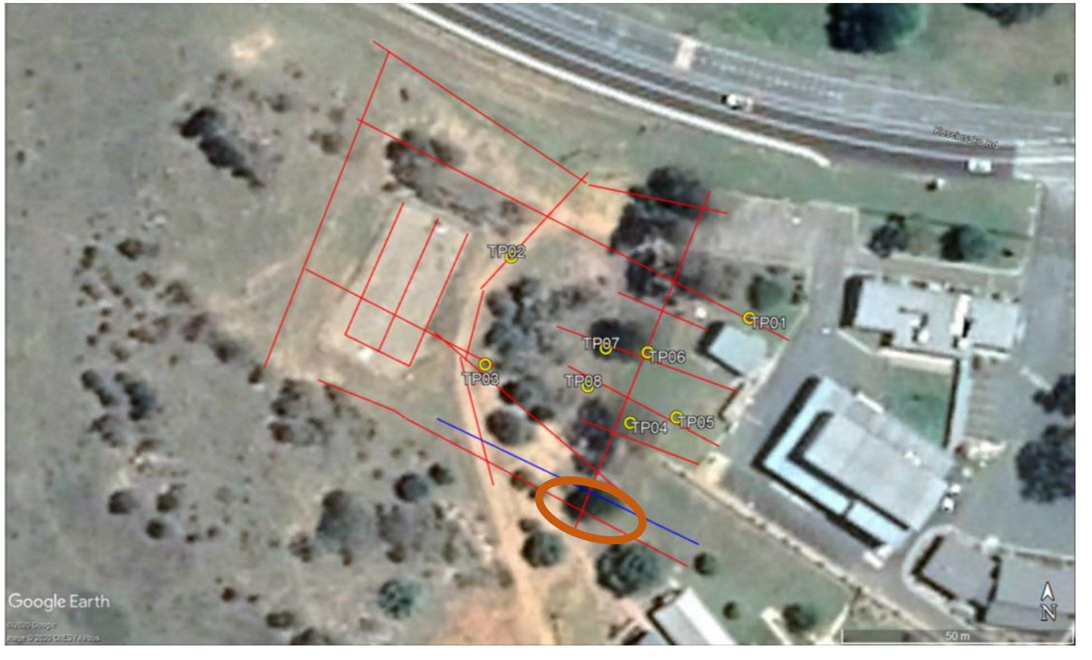
East West



GPR Line 2 (Blue Line on Plan Below): Probable boulders at 1.5m below ground level, highlighted in orange.

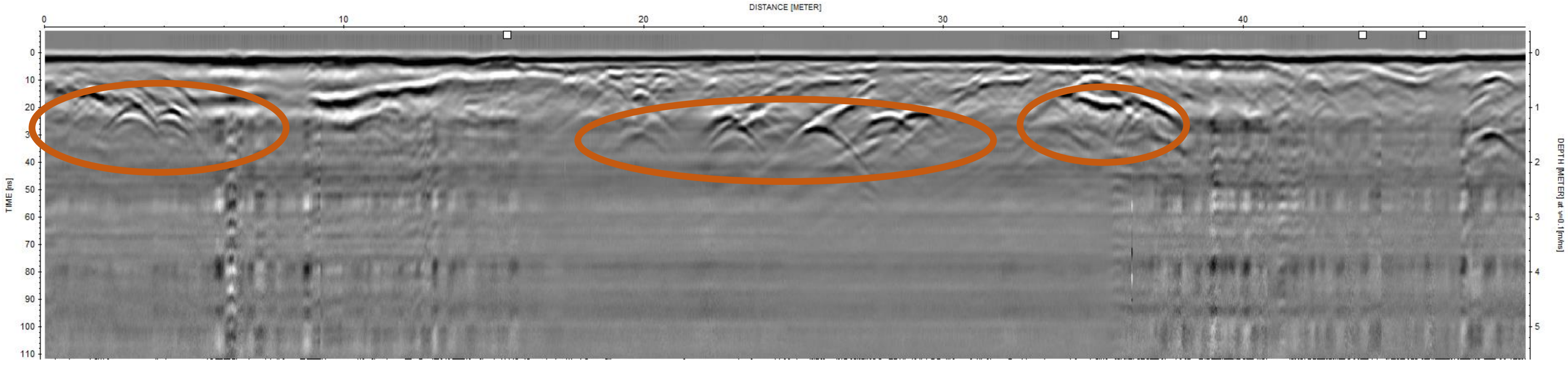
East West

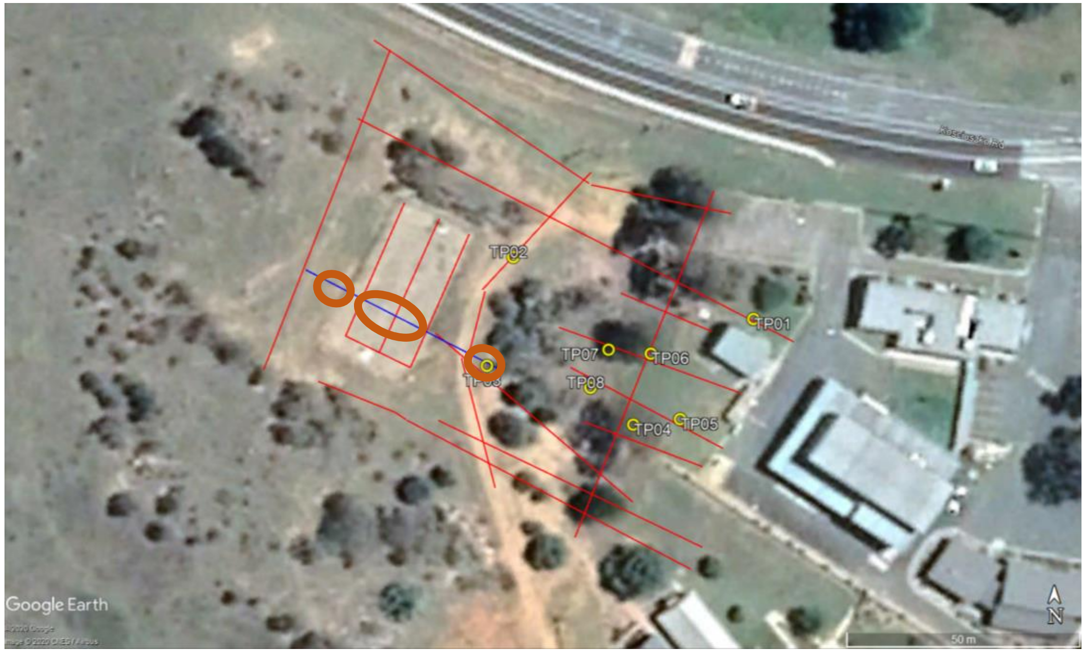




GPR Line 3 (Blue Line on Plan Below): Probable boulders at 1m below ground level, highlighted in orange.

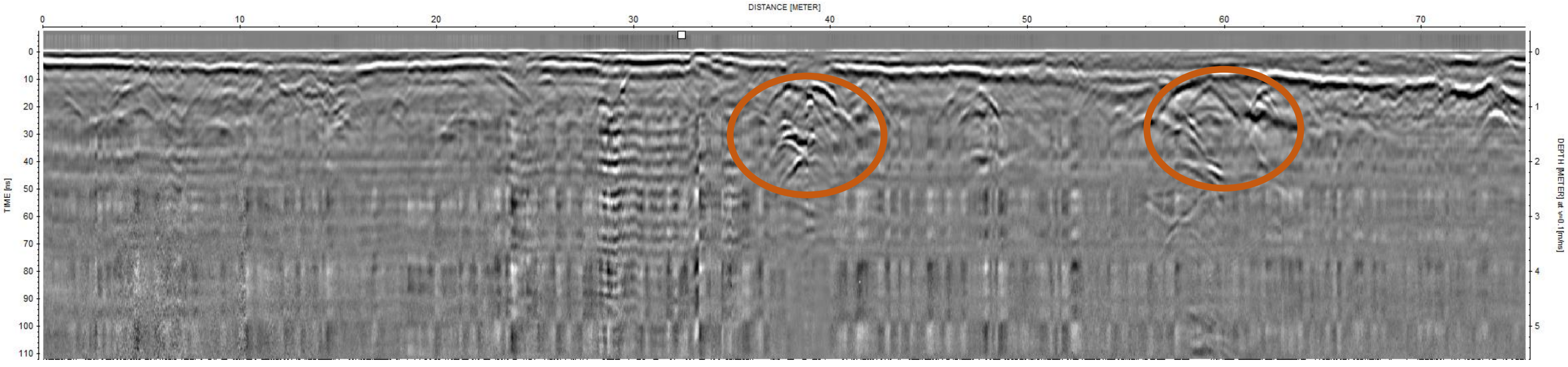
East West

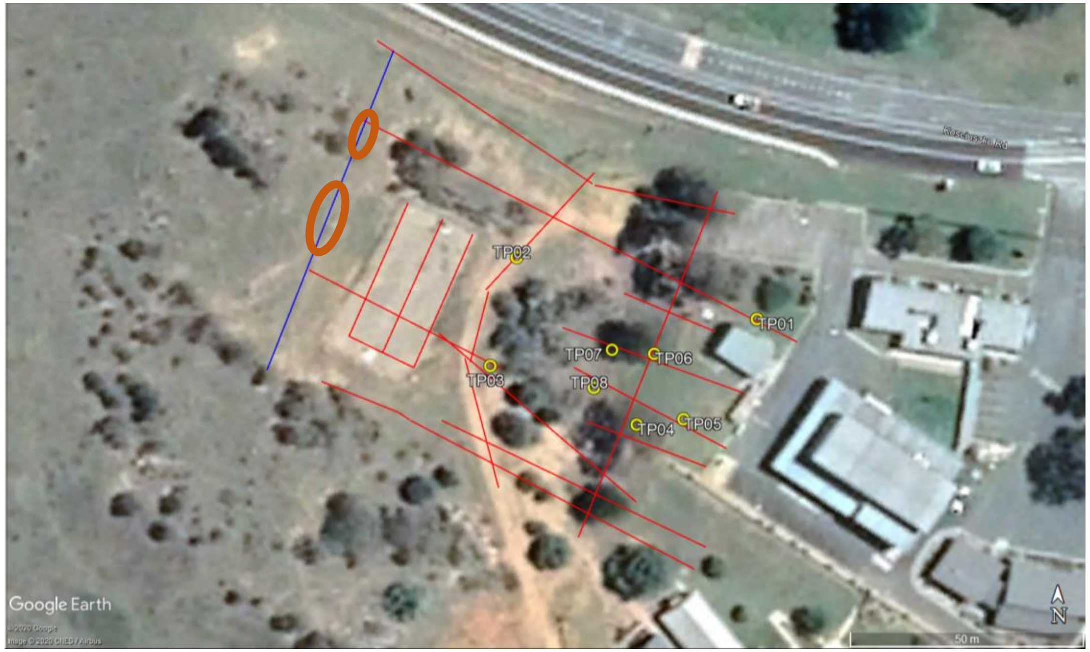




GPR Line 4 (Blue Line on Plan Below): Probable boulders at <1m below ground level, highlighted in orange.

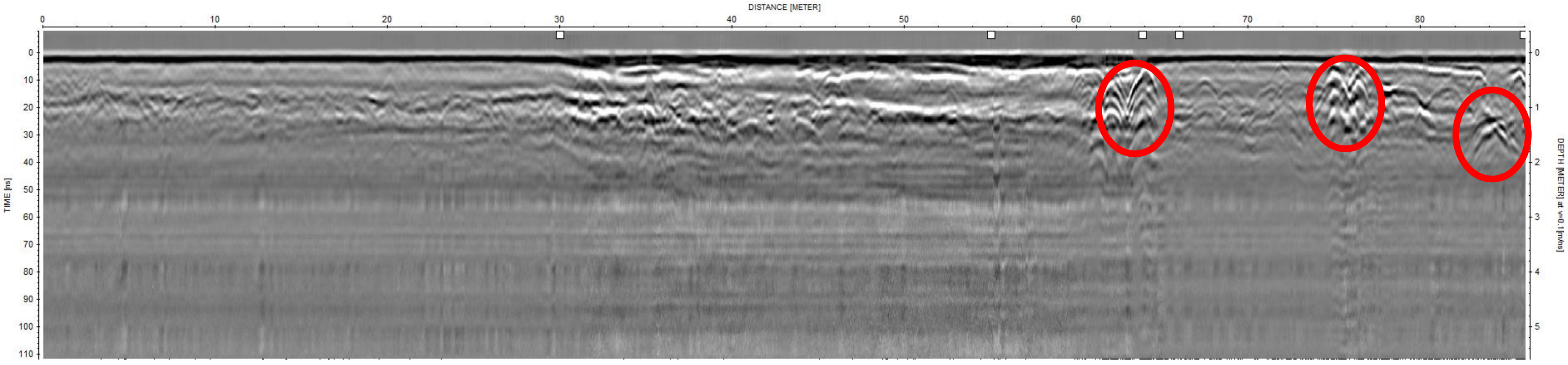
South North





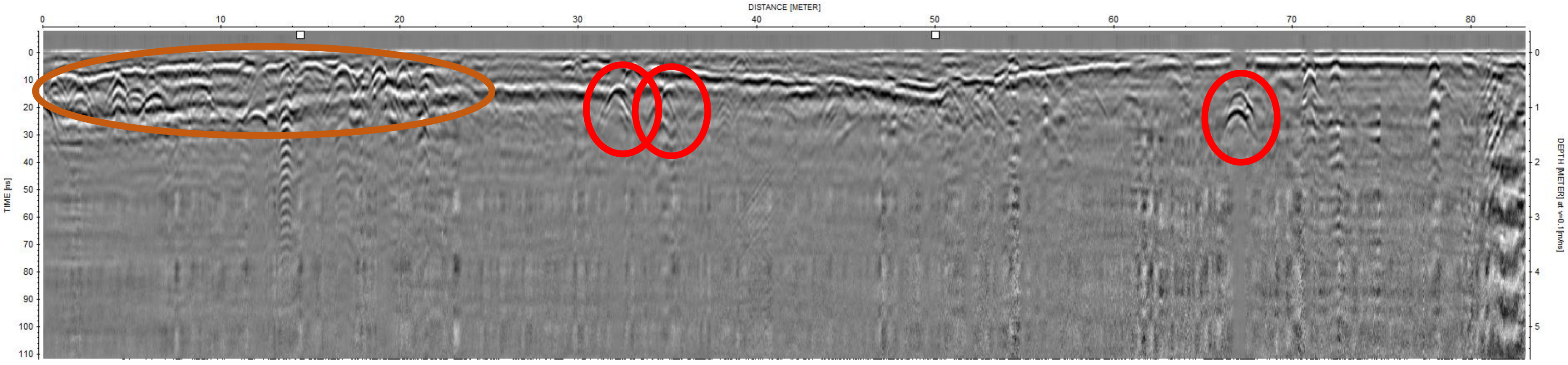
GPR Line 5 (Blue Line on Plan Below): Probable services, highlighted in red.

West East



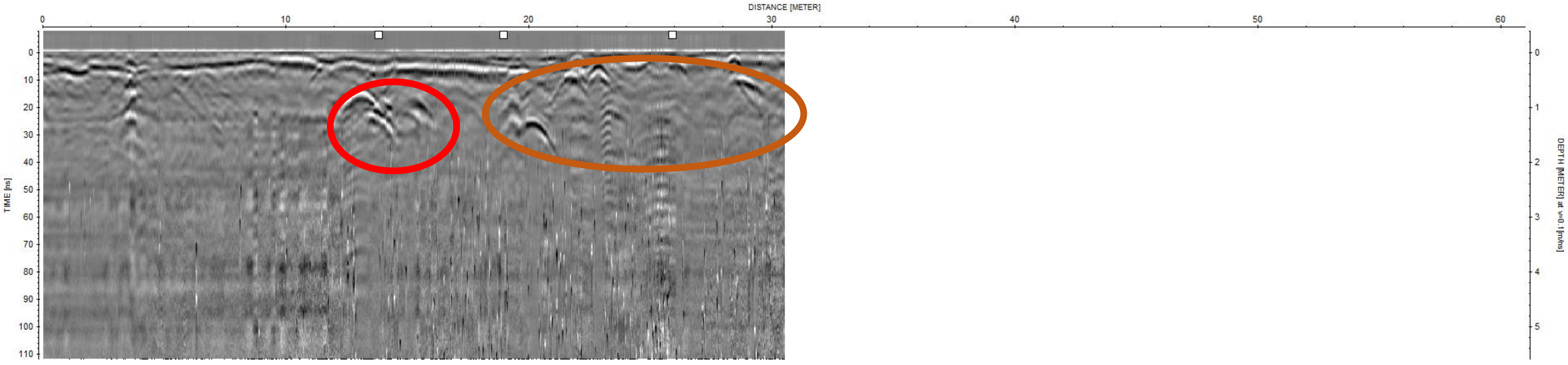
GPR Line 6 (Blue Line on Plan Below): Probable boulders at 0.5m below ground level (orange) and probable services (red)

South North



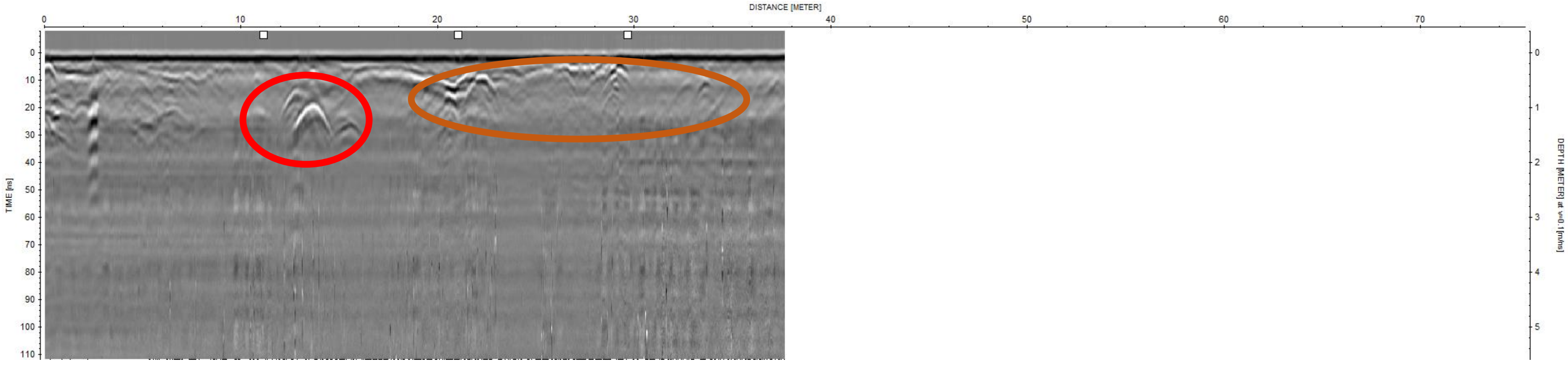
GPR Line 7 (Blue Line on Plan Below): Probable boulders at 0.5 to 1m below ground level (orange) and probable services (red).

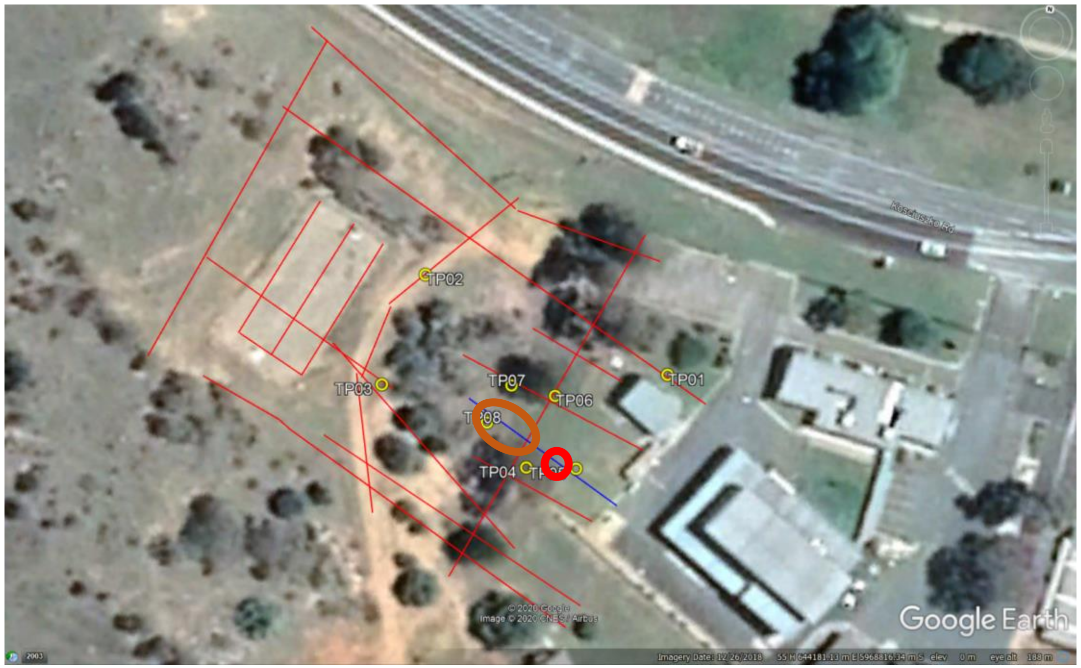
East West



GPR Line 8 (Blue Line on Plan Below): Probable boulders at 0.5m below ground level (orange) and probable services (red).

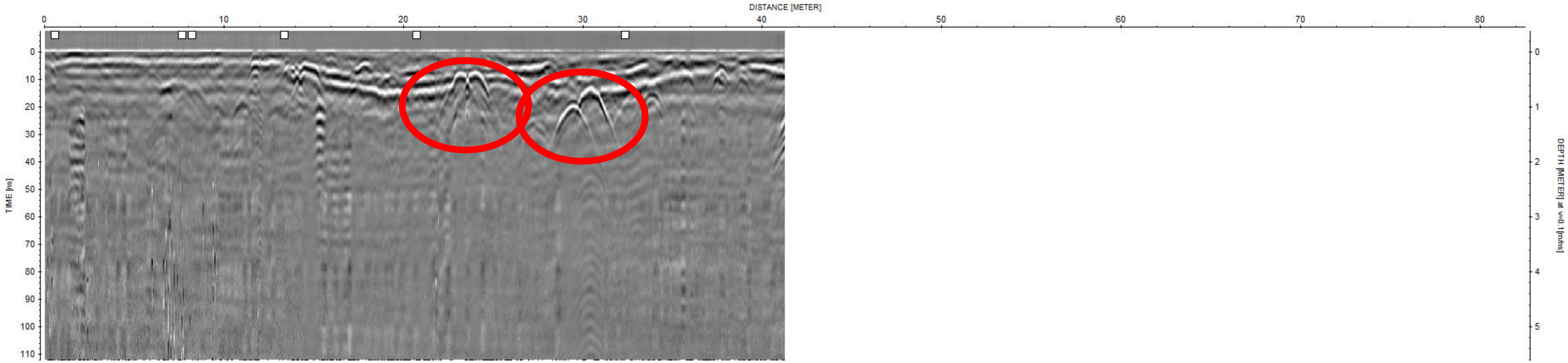
East West





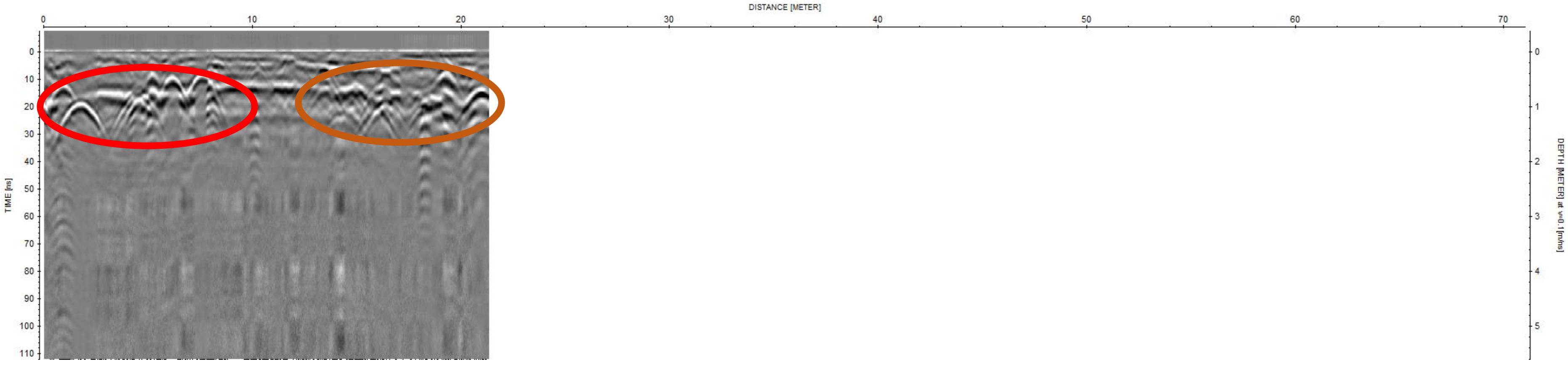
GPR Line 9 (Blue Line on Plan Below): Probable services, highlighted in red.

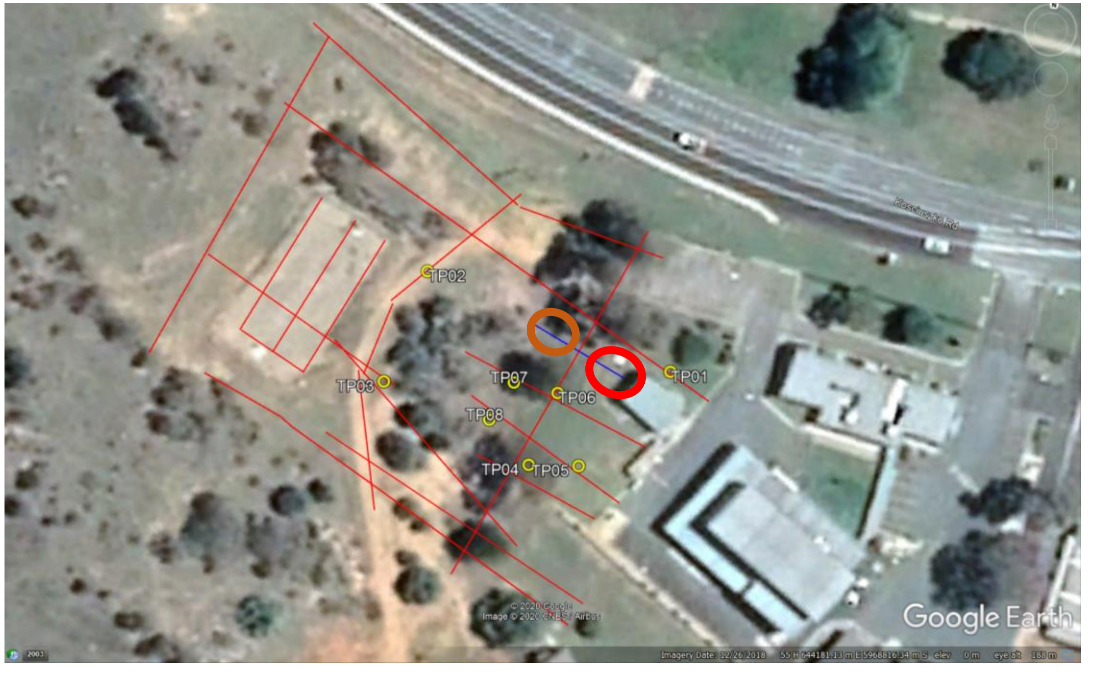
West East



GPR Line 10 (Blue Line on Plan Below): Probable boulders at 0.5m below ground level (orange) and probable services (red)

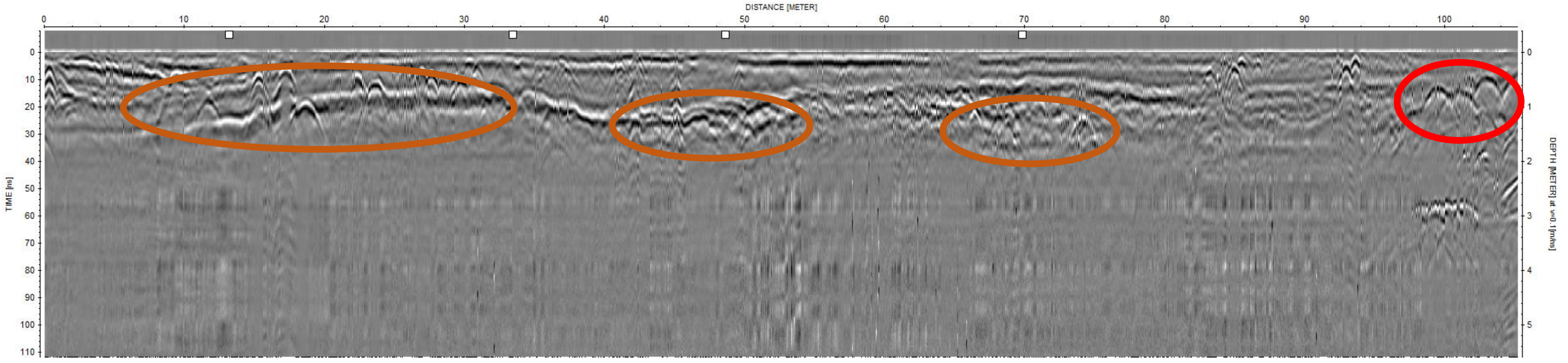
East West

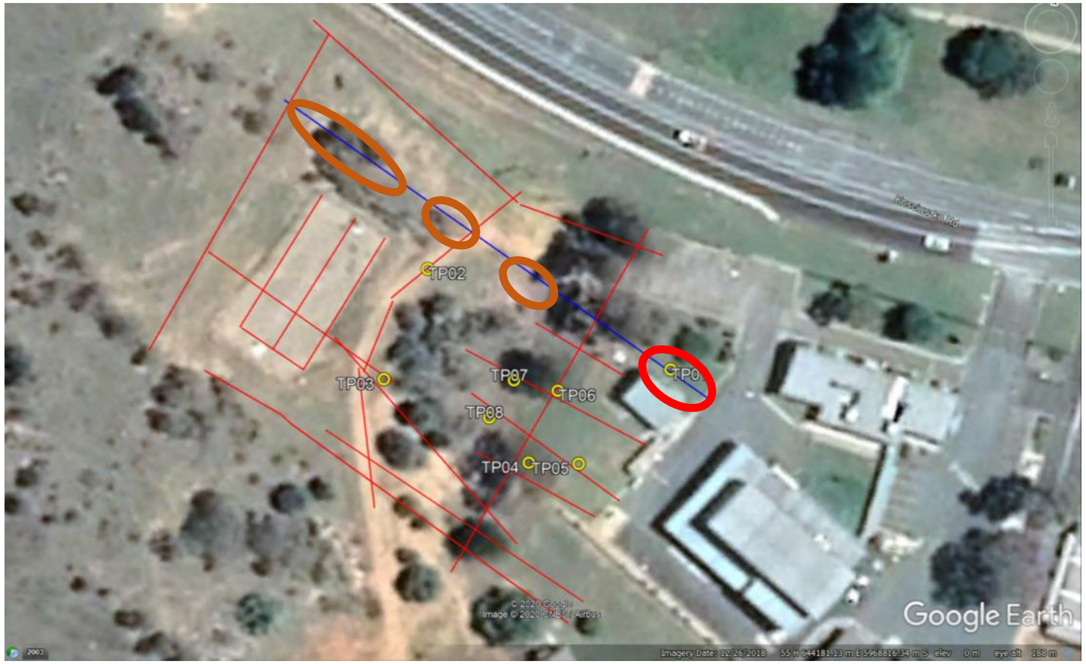




GPR Line 11 (Blue Line on Plan Below): Probable boulders at 0.5 to 1m below ground level (orange) and probable services (red)

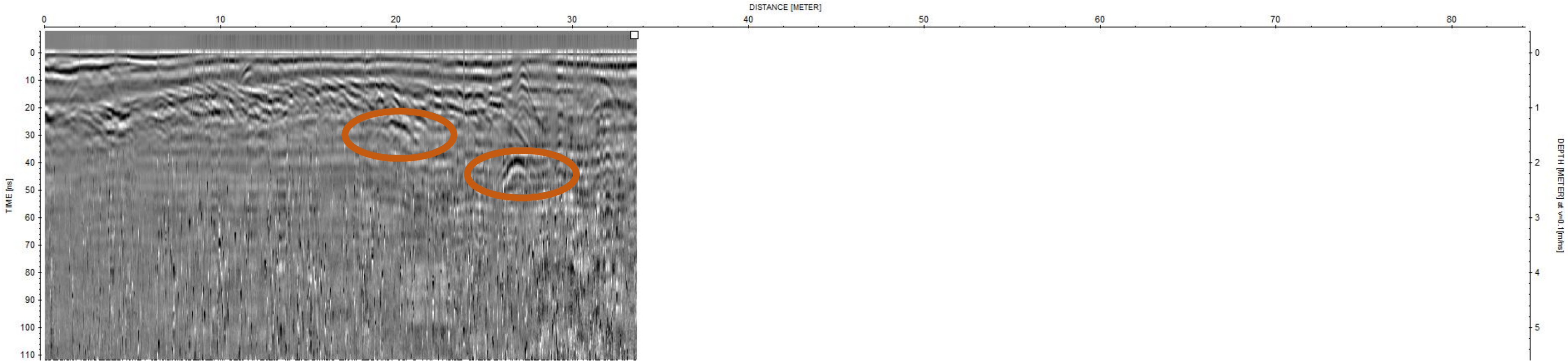
West East





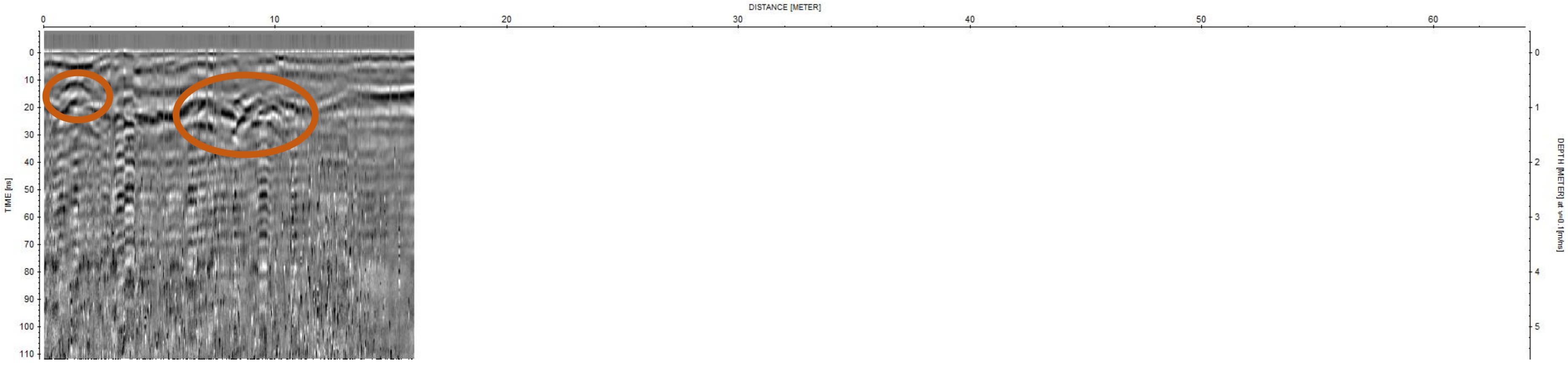
GPR Line 12 (Blue Line on Plan Below): Probable boulders at 1 to 2m below ground level, highlighted in orange.

North South



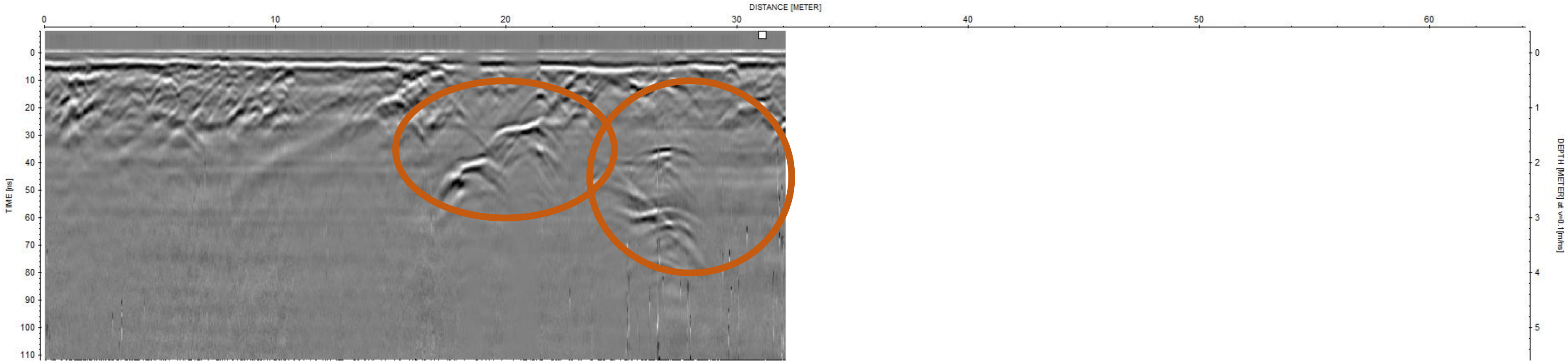
GPR Line 13 (Blue Line on Plan Below): Probable boulders at 0.5 to 1m below ground level, highlighted in orange.

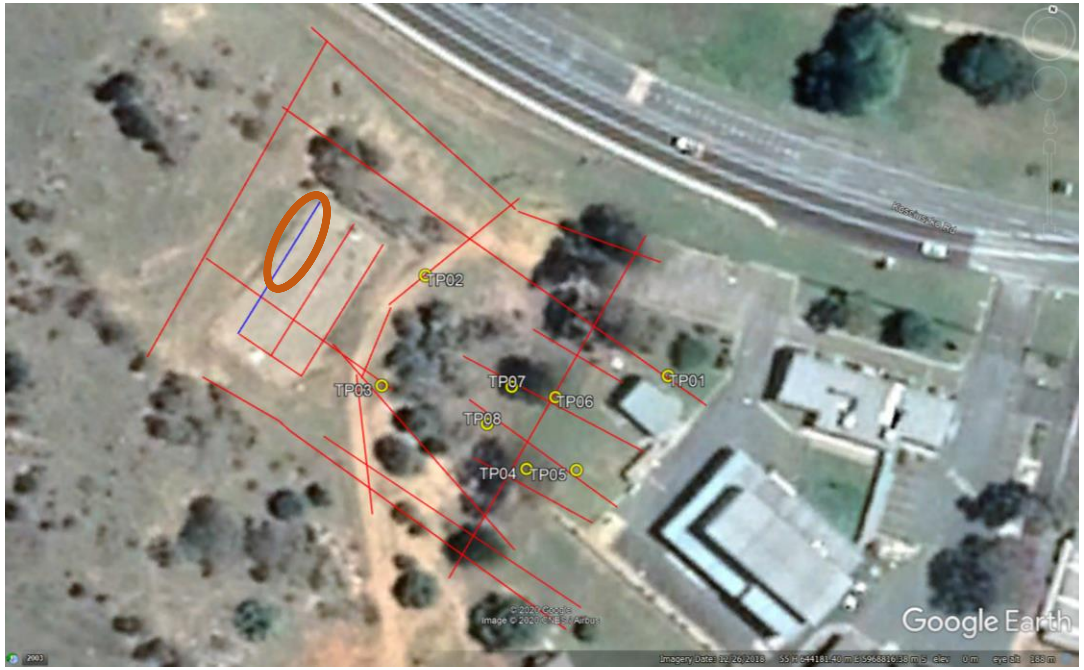
North South



GPR Line 14 (Blue Line on Plan Below): Probable boulders at 0.5 to 2.5m below ground level, highlighted in orange.

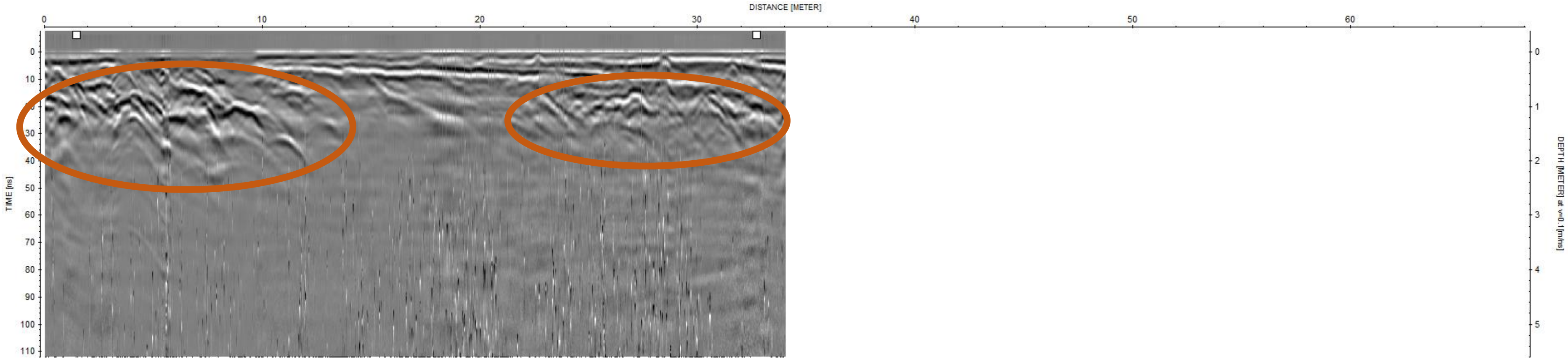
North South

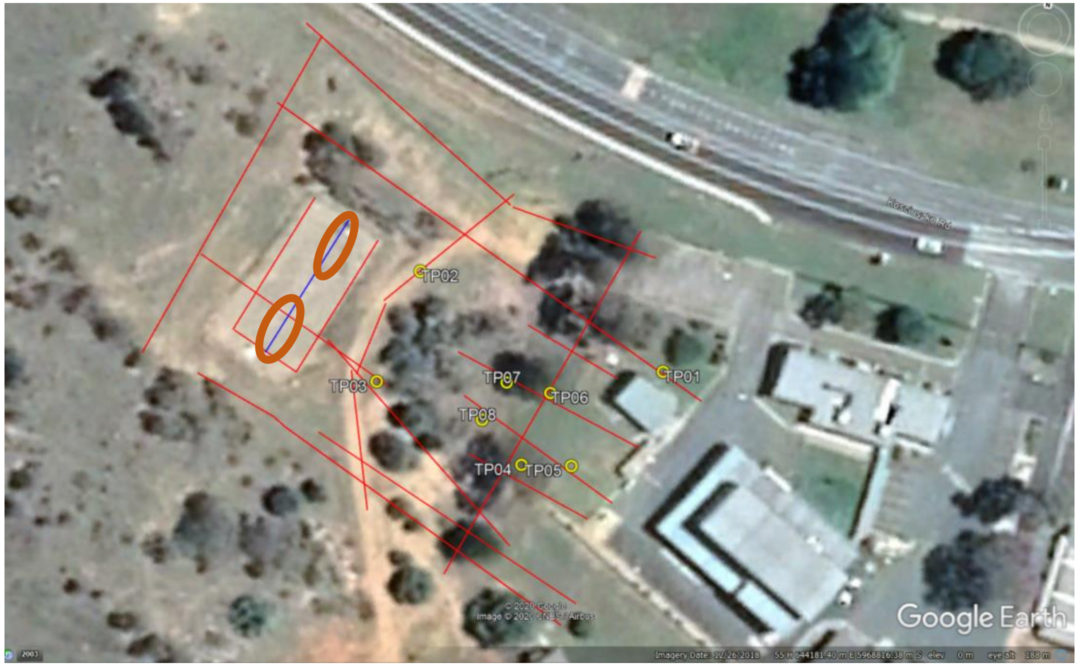




GPR Line 15 (Blue Line on Plan Below): Probable boulders at 0.5 to 1.5m below ground level, highlighted in orange.

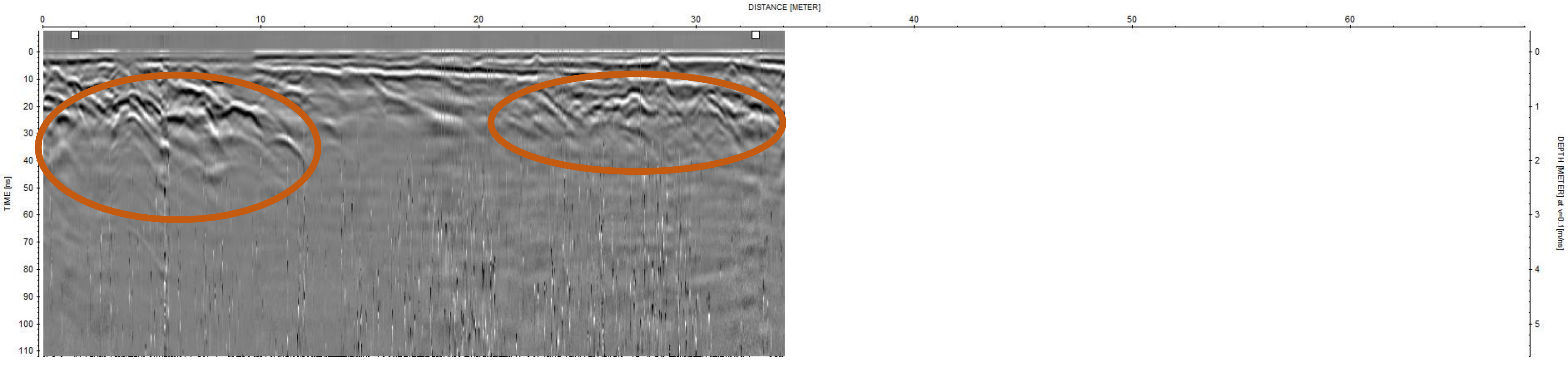
South North

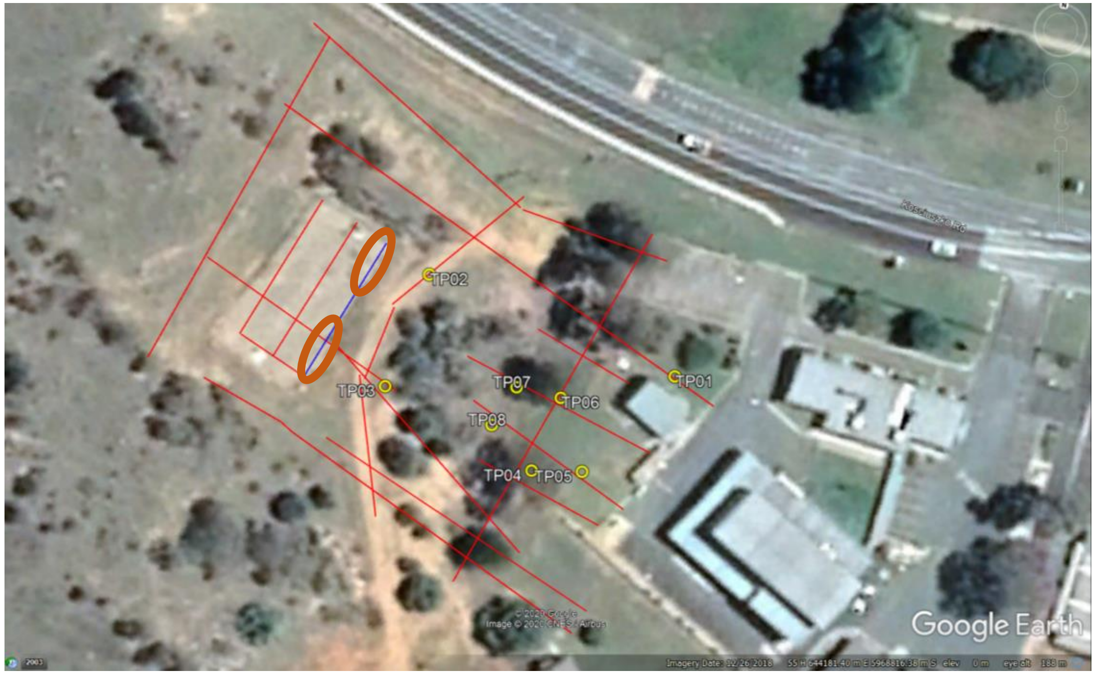




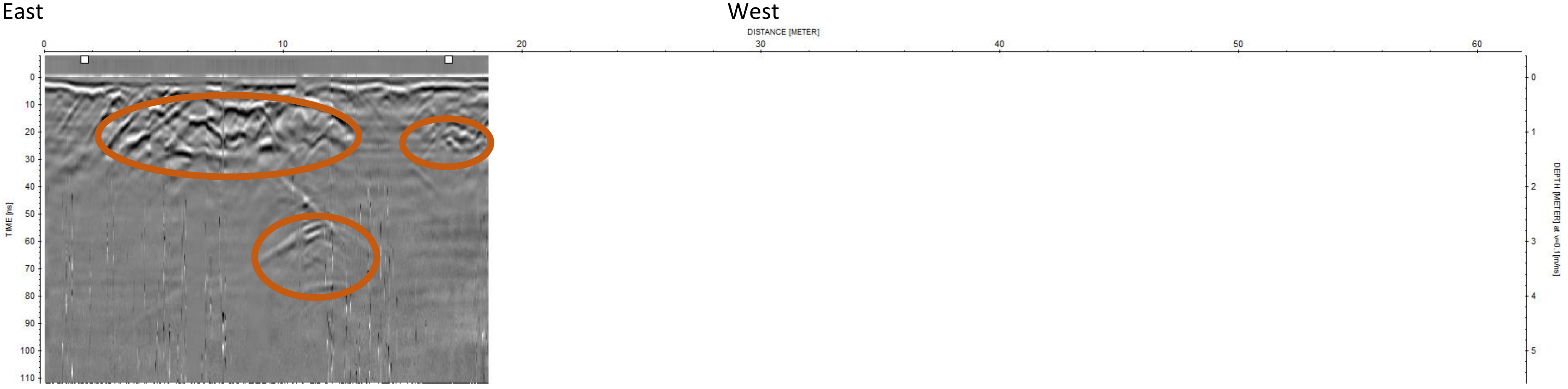
GPR Line 16 (Blue Line on Plan Below): Probable boulders at 0.5 to 1m below ground level, highlighted in orange.

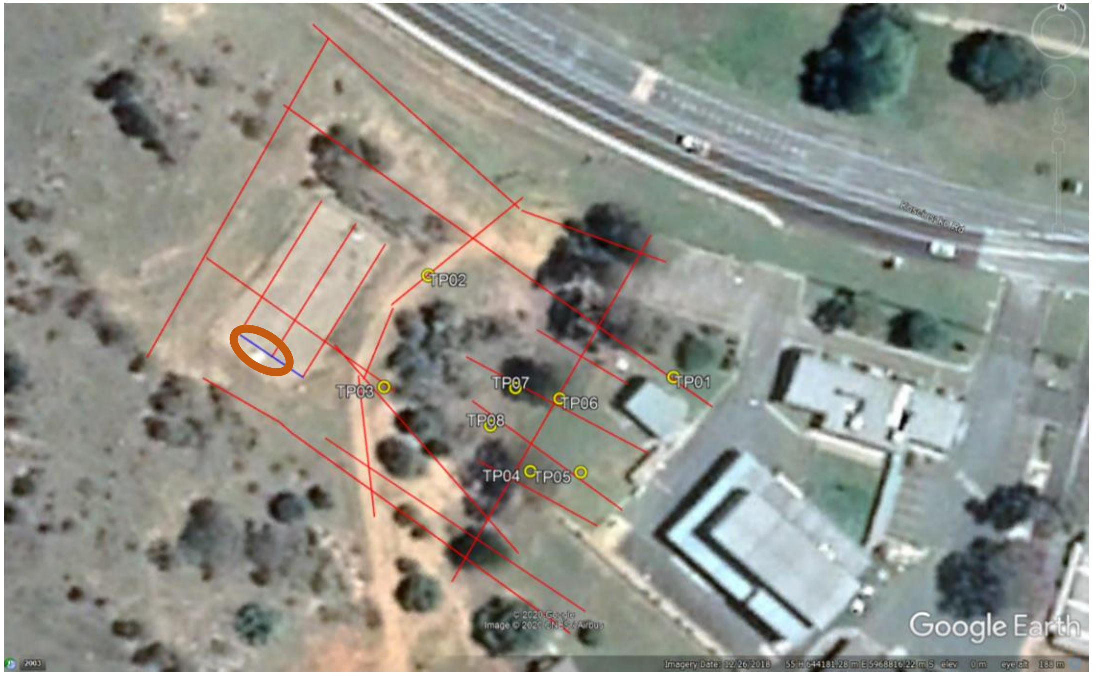
North South





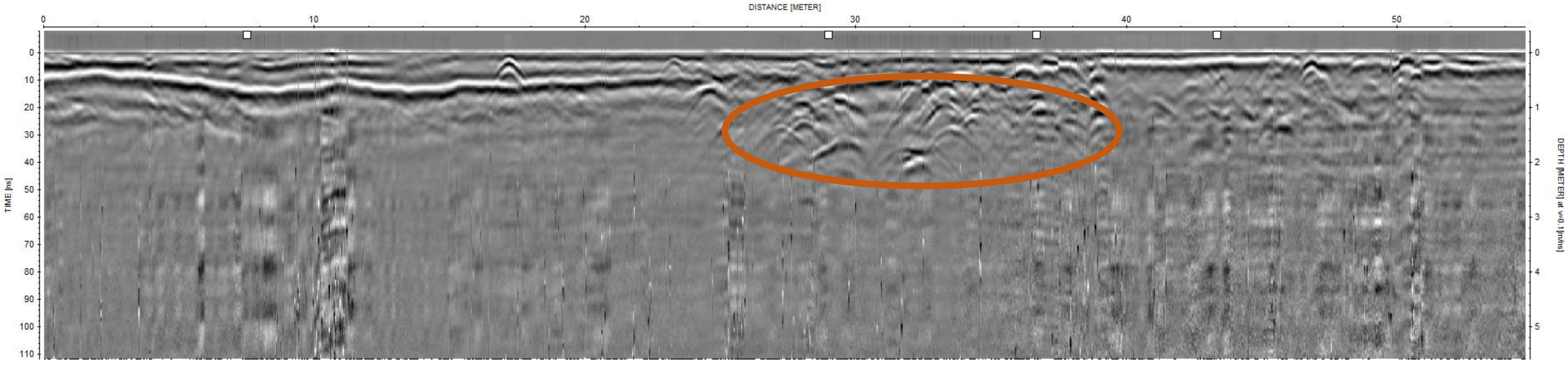
GPR Line 17 (Blue Line on Plan Below): Probable boulders at 0.5 to 3m below ground level, highlighted in orange.





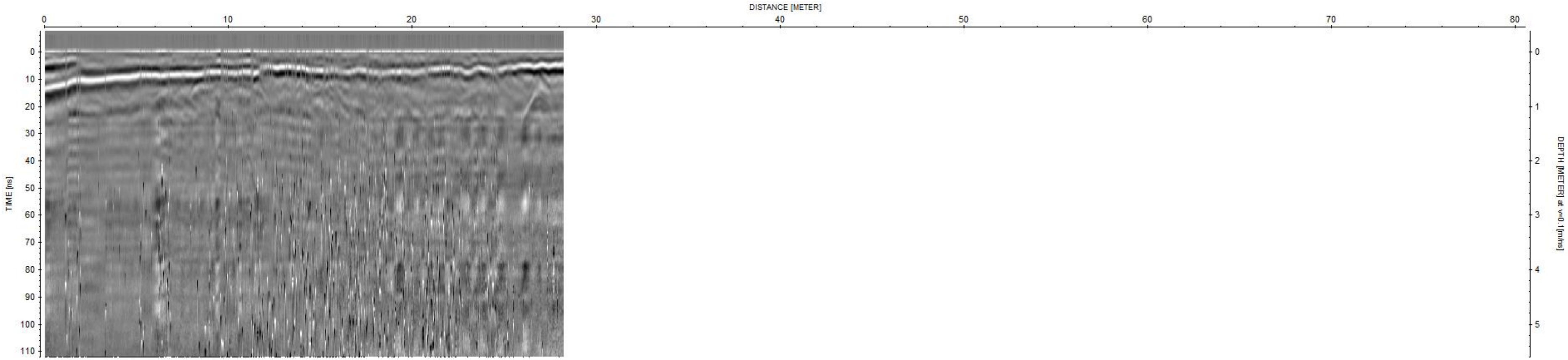
GPR Line 18 (Blue Line on Plan Below): Probable boulders at 0.5 to 2m below ground level, highlighted in orange.

West East



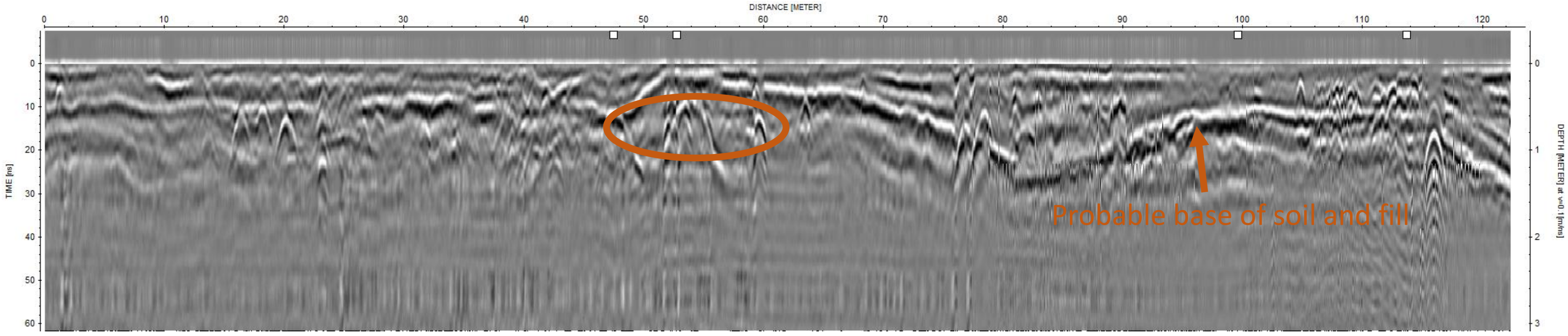
GPR Line 19 (Blue Line on Plan Below): Compacted ground along road

North South



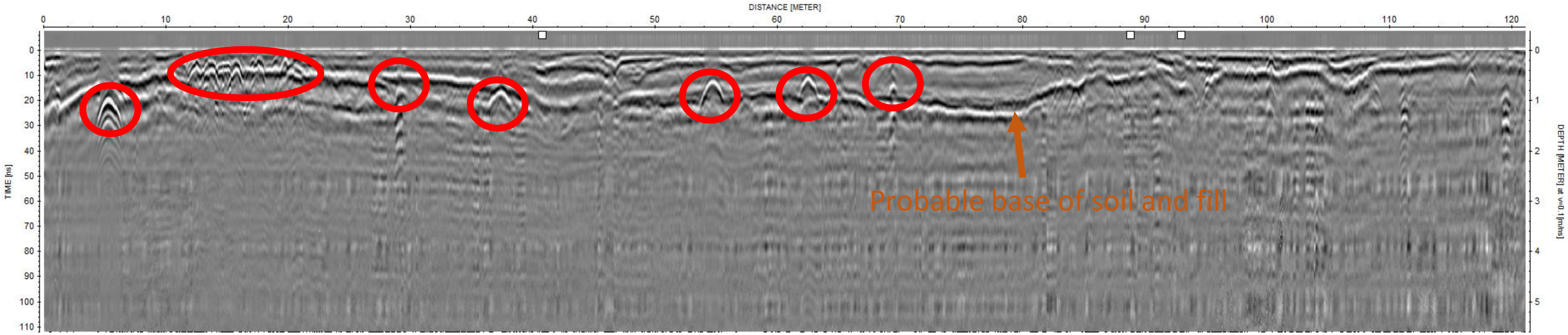
GPR Line 20 (Blue Line on Plan Below): Probable fill layer from 0.2 to 1.5m below current surface level possible boulders at 0.5 to 1m below surface

South North



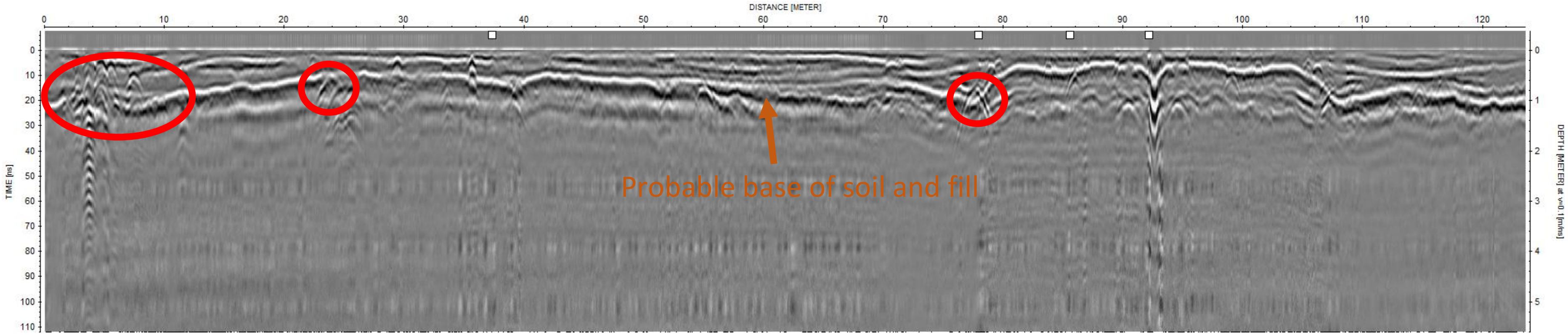
GPR Line 21 (Blue Line on Plan Below): Probable fill layer from 0.2 to 1.25m below current surface level, probable services highlighted with red ovals

North South



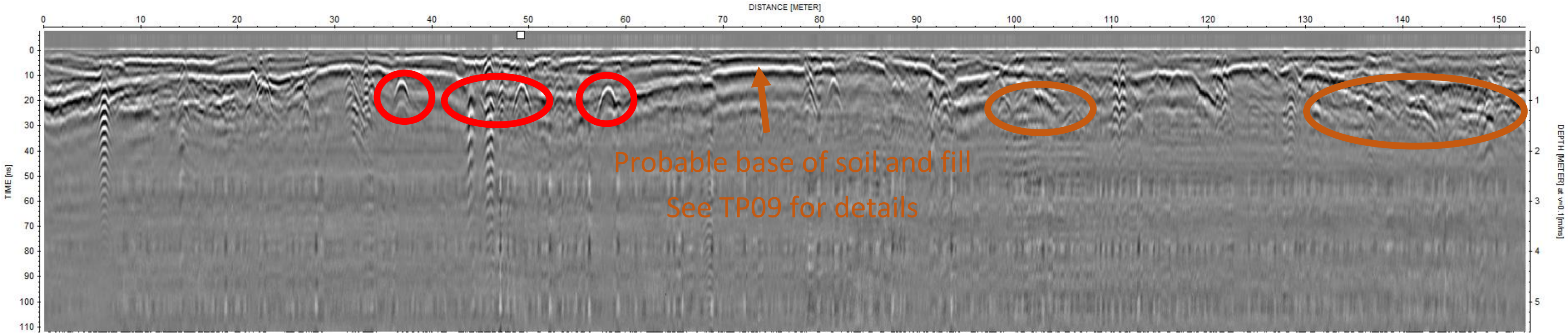
GPR Line 22 (Blue Line on Plan Below): Probable fill layer from 0.2 to 1.25m below current surface level, probable services highlighted with red ovals

South North



GPR Line 23 (Blue line): Probable fill layer 0.2 to 1.25m below current surface, probable services highlighted red ovals, possible boulders at 0.5 to 1m

North West | South East



SEISMIC REFRACTION

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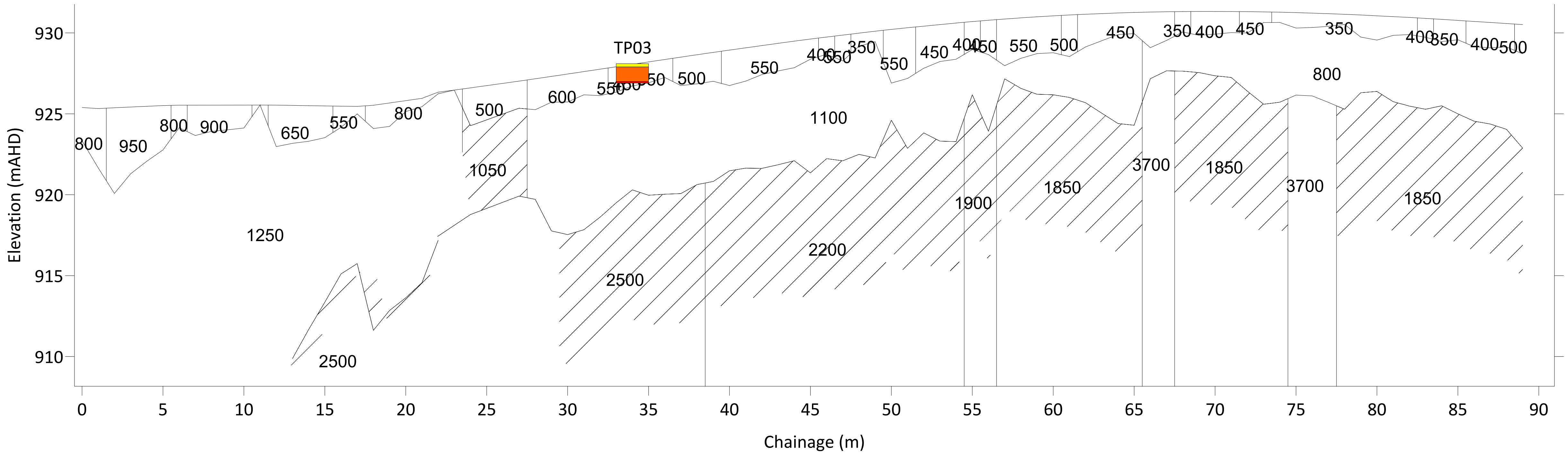
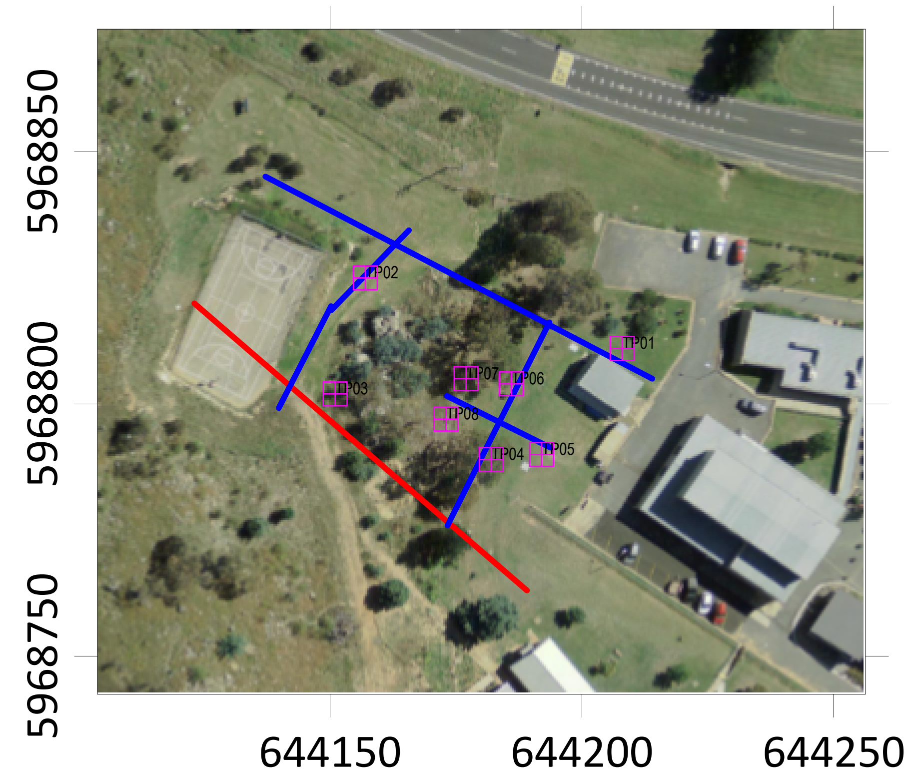
Refraction Model - Line 1



Test Pit 3

depth (m)	graphic log	classification symbol	material description **SOIL TYPE**: plasticity or particle characteristic, colour, secondary and minor components
		SM	**SILTY SAND**: fine to coarse grained, dark grey, low plasticity fines, trace roots.
		SC	**CLAYEY SAND**: fine to coarse grained, brown, low plasticity fines, trace boulders up to 0.8m in length.
0.5		SC	**CLAYEY SAND**: fine to coarse grained, red-brown, low plasticity fines.
1.0			**BOULDERS**: granite boulder from 1.3m to 1.6m depth, fine to coarse, grey, slightly weathered, inferred extremely high strength, inferred greater than 2.2m in width.
1.5			Test pit TP03 terminated at 1.2 m Refusal



Legend

- Refraction Line
- Displayed Refraction Line
- Test Pit Location
- Modelled Refractor
- Interpolated Refractor
- 800 800 Modelled P-Wave Velocity (Interpolated)

GBG Australia **Advanced Subsurface Investigations**

23 Harold Street
North Parramatta
NSW 2151
Australia

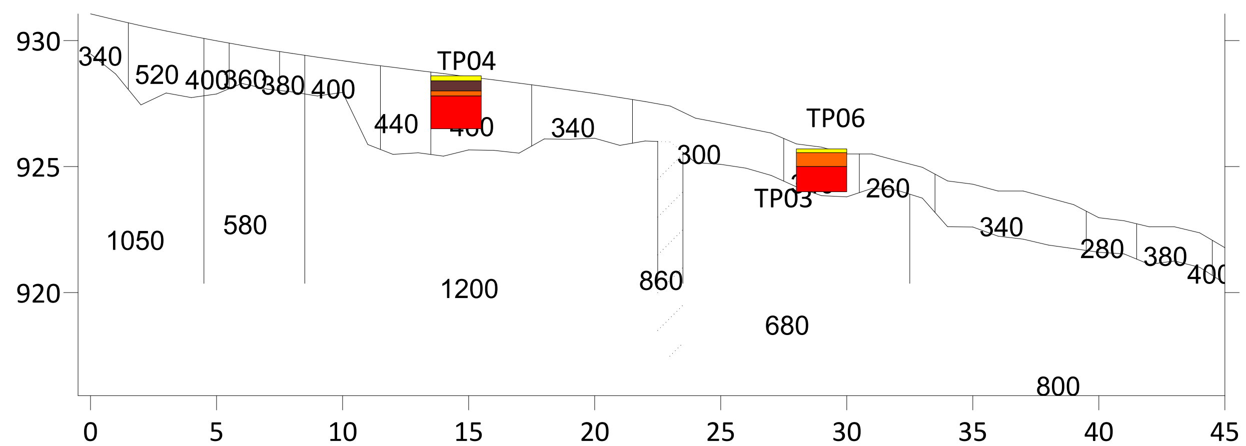
Telephone:
(02) 98902122
Fax:
(02) 98902922

Email:
info@gbgoz.com.au
Website:
www.gbgoz.com.au

CLIENT:	Munns Sly Moore Architects Pty Ltd	
TITLE:	Geophysical Investigation to Delineate Bedrock at Snowy Mountains Grammar School, Jindabyne, NSW.	
DRAWN: B.W.	PROJECT MANAGER: J.S.	DATUM: GDA94 MGA 55
SCALE: 1:300	DATE: 26/10/2020	DRG No: GBGA2386-01
		REV: A3

GBG Australia

Refraction Model - Line 2

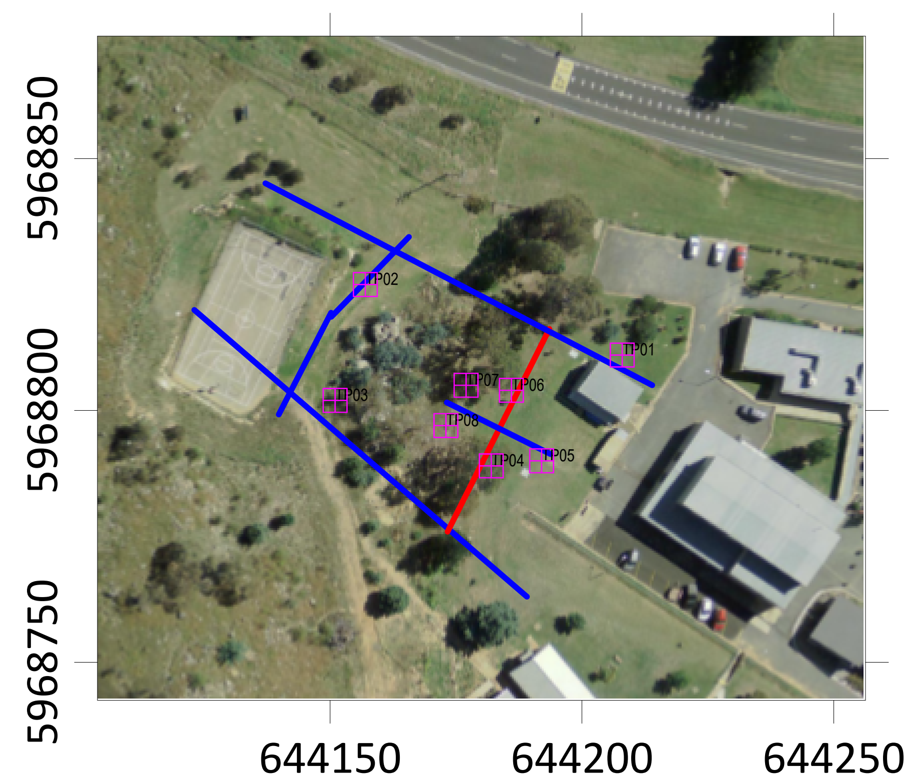


Test Pit 4

depth (m)	graphic log	classification symbol	material description SOIL TYPE: plasticity or particle characteristic, colour, secondary and minor components
		SC	**CLAYEY SAND**: fine to coarse grained, dark grey, black, low plasticity fines, trace roots.
		SC	**CLAYEY SAND**: fine to coarse grained, brown, low plasticity fines, trace roots.
0.5		SC	**CLAYEY SAND**: fine to coarse grained, red-brown, orange, low plasticity fines.
1.0 1.5			**GRANITE**: fine to coarse grained, orange-brown, extremely to highly weathered, inferred soil strength to very low strength. 1.7 m: moderately weathered, inferred low to medium strength
2.0			Test pit TP04 terminated at 1.8 m Refusal

Test Pit 6

depth (m)	graphic log	classification symbol	material description SOIL TYPE: plasticity or particle characteristic, colour, secondary and minor components
		SC	**CLAYEY SAND**: fine to coarse grained, dark grey, brown, low plasticity fines, trace roots.
0.5		SM	**FILL: SILTY SAND**: fine to coarse grained, dark brown, low plasticity fines.
		SC	**CLAYEY SAND**: fine to coarse grained, orange-brown, low to medium plasticity fines.
1.0 1.5 2.0			**GRANITE**: fine to coarse grained, orange-brown, extremely to highly weathered, inferred soil strength to very low strength. 1.7 m: highly to moderately weathered, inferred very low to low strength 2.1 m: moderately weathered, inferred low strength
2.5			Test pit TP06 terminated at 2.2 m Refusal



Legend

- Refraction Line
- Displayed Refraction Line
- Test Pit Location
- Modelled Refractor
- Interpolated Refractor
- 800 800 Modelled P-Wave Velocity (Interpolated)

GBG Australia — Advanced Subsurface Investigations

23 Harold Street
North Parramatta
NSW 2151
Australia

Telephone:
(02) 98902122
Fax:
(02) 98902922

Email:
info@gbgoz.com.au
Website:
www.gbgoz.com.au

CLIENT: Munns Sly Moore Architects Pty Ltd		
TITLE: Geophysical Investigation to Delineate Bedrock at Snowy Mountains Grammar School, Jindabyne, NSW.		
DRAWN: B.W.	PROJECT MANAGER: J.S.	DATUM: GDA94 MGA 55
SCALE: 1:300	DATE: 26/10/2020	DRG No: GBGA2386-02
		REV: A3

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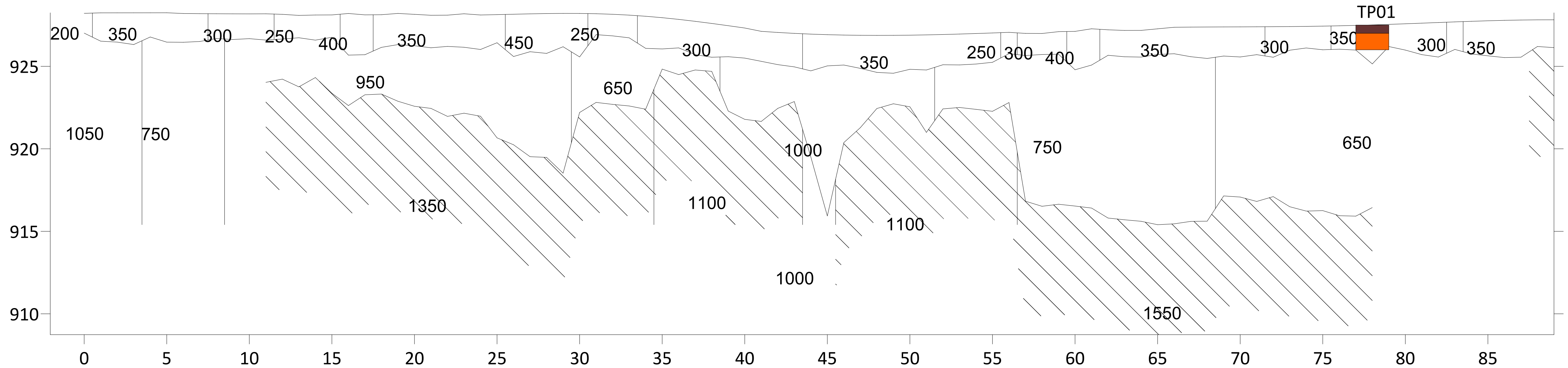
Refraction Model - Line 3



Test Pit 1

depth (m)	graphic log	classification symbol	material description: **SOIL TYPE**: plasticity or particle characteristic, colour, secondary and minor components
		SC	**FILL: CLAYEY SAND**: fine to coarse grained, dark grey, black, low plasticity fines, trace roots.
		SC	**FILL: CLAYEY SAND**: fine to coarse grained, orange-brown, mottled grey, low plasticity fines.
0.5		SC	**CLAYEY SAND**: fine to coarse grained, dark brown, low plasticity fines, trace roots to 0.8m.
1.0		SC	**CLAYEY SAND**: fine to coarse grained, orange-brown, low plasticity fines.
1.5			Test pit TP01 terminated at 1.5 m Safety reasons

Legend

- Refraction Line
- Displayed Refraction Line
- Test Pit Location
- Modelled Refractor
- Interpolated Refractor
- 800 800 Modelled P-Wave Velocity (Interpolated)

GBG Australia
Advanced Subsurface Investigations

23 Harold Street
North Parramatta
NSW 2151
Australia

Telephone: (02) 98902122
Fax: (02) 98902922

Email: info@gbgoz.com.au
Website: www.gbgoz.com.au

CLIENT:	Munns Sly Moore Architects Pty Ltd
TITLE:	Geophysical Investigation to Delineate Bedrock at Snowy Mountains Grammar School, Jindabyne, NSW.

DRAWN: B.W.	PROJECT MANAGER: J.S.	DATUM: GDA94 MGA 55
SCALE: 1:300	DATE: 26/10/2020	DRG No: GBGA2386-03
		REV: A3

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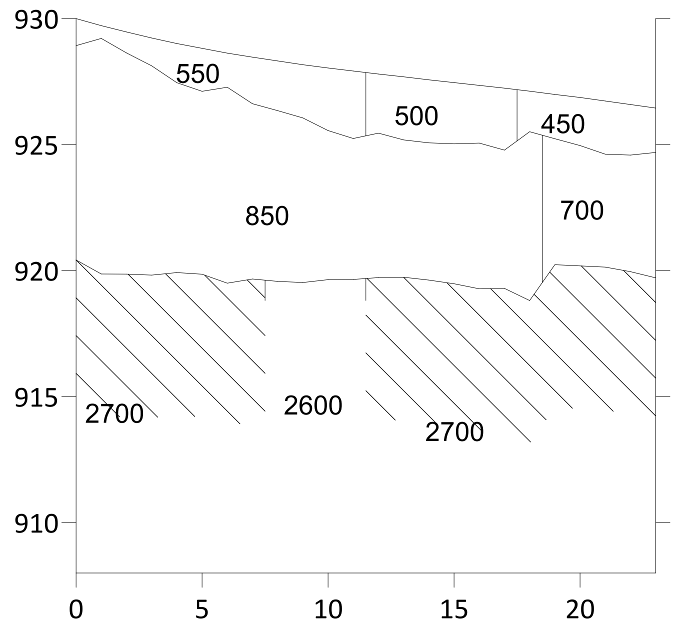
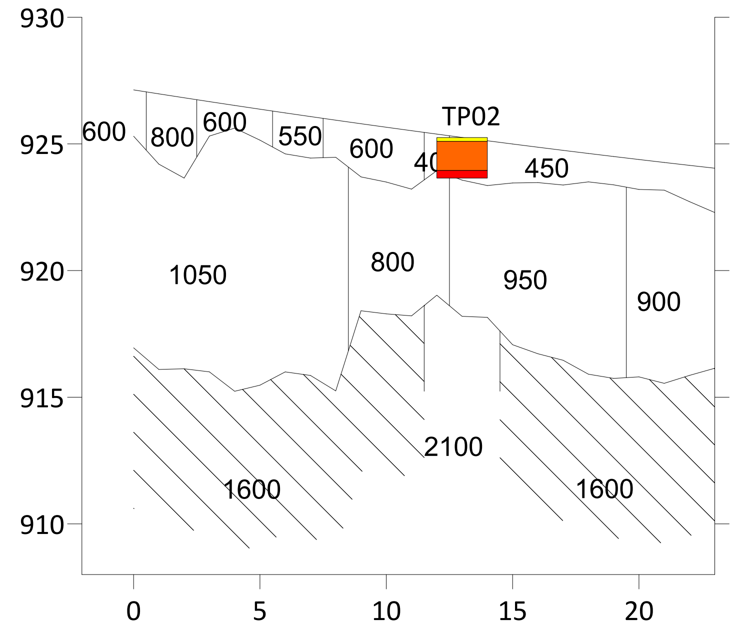
Refraction Model - Line 5



Refraction Model - Line 4



Test Pit 2

depth (m)	graphic log	classification symbol	material description **SOIL TYPE**: plasticity or particle characteristic, colour, secondary and minor components
		SM	**SILTY SAND**: fine to coarse grained, dark brown, low plasticity fines, trace roots.
0.5		SC	**CLAYEY SAND**: fine to coarse grained, dark brown, low plasticity fines, trace roolets to 0.4m.
1.0		SC	**CLAYEY SAND**: fine to coarse grained, brown, low plasticity fines.
1.5			**BOULDERS**: granite boulder from 1.3m to 1.6m depth, fine to coarse, grey, slightly weathered, inferred extremely high strength, inferred greater than 3.5m in width.
			Test pit TP02 terminated at 1.6 m Refusal

Legend

	Refraction Line		Modelled Refractor
	Displayed Refraction Line		Interpolated Refractor
	Test Pit Location	800 800	Modelled (Interp) P-Wave Velocity (m/s)

GBG Australia **Advanced Subsurface Investigations**

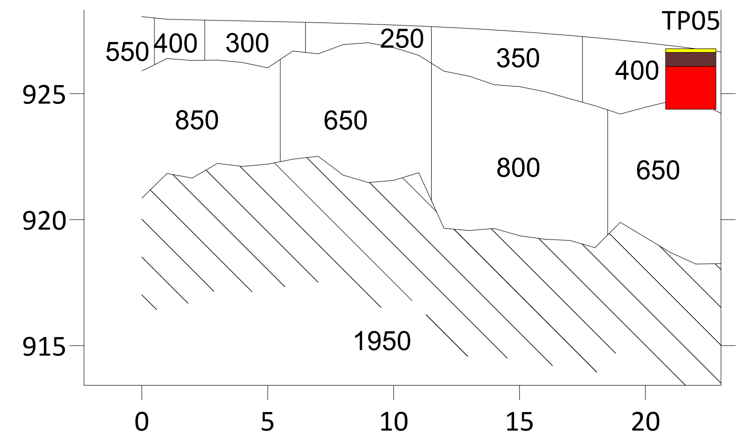
23 Harold Street
North Parramatta
NSW 2151
Australia

Telephone:
(02) 98902122
Fax:
(02) 98902922

Email:
info@gbgoz.com.au
Website:
www.gbgoz.com.au

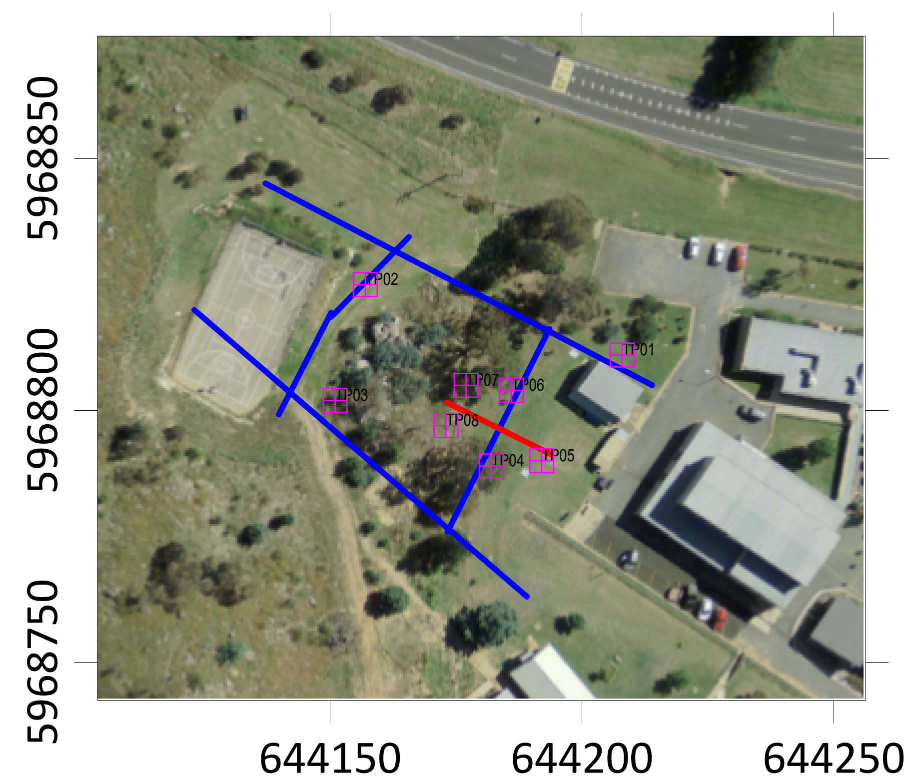
CLIENT: Munns Sly Moore Architects Pty Ltd		
TITLE: Geophysical Investigation to Delineate Bedrock at Snowy Mountains Grammar School, Jindabyne, NSW.		
DRAWN: B.W.	PROJECT MANAGER: J.S.	DATUM: GDA94 MGA 55
SCALE: 1:300	DATE: 26/10/2020	DRG No: GBGA2386-04
		REV: A3

Refraction Model - Line 6



Test Pit 5

depth (m)	graphic log	classification symbol	material description **SOIL TYPE**: plasticity or particle characteristic, colour, secondary and minor components
		SM	**SILTY SAND**: fine to coarse grained, dark brown, dark grey, low plasticity fines, trace roots.
0.5		SC	**FILL: CLAYEY SAND**: fine to coarse grained, dark grey, dark brown, red-brown, low to medium plasticity fines, trace roots and plastic.
1.0 1.5 2.0			**GRANITE**: fine to coarse grained, red-brown, extremely to highly weathered, inferred soil strength to very low strength. 2.2 m: highly to moderately weathered, inferred low strength
2.5			Test pit TP05 terminated at 2.4 m Refusal



Legend

- Refraction Line
- Displayed Refraction Line
- Test Pit Location
- Modelled Refractor
- Interpolated Refractor
- 800 800 Modelled (Interp) P-Wave Velocity (m/s)

GBG Australia Advanced Subsurface Investigations

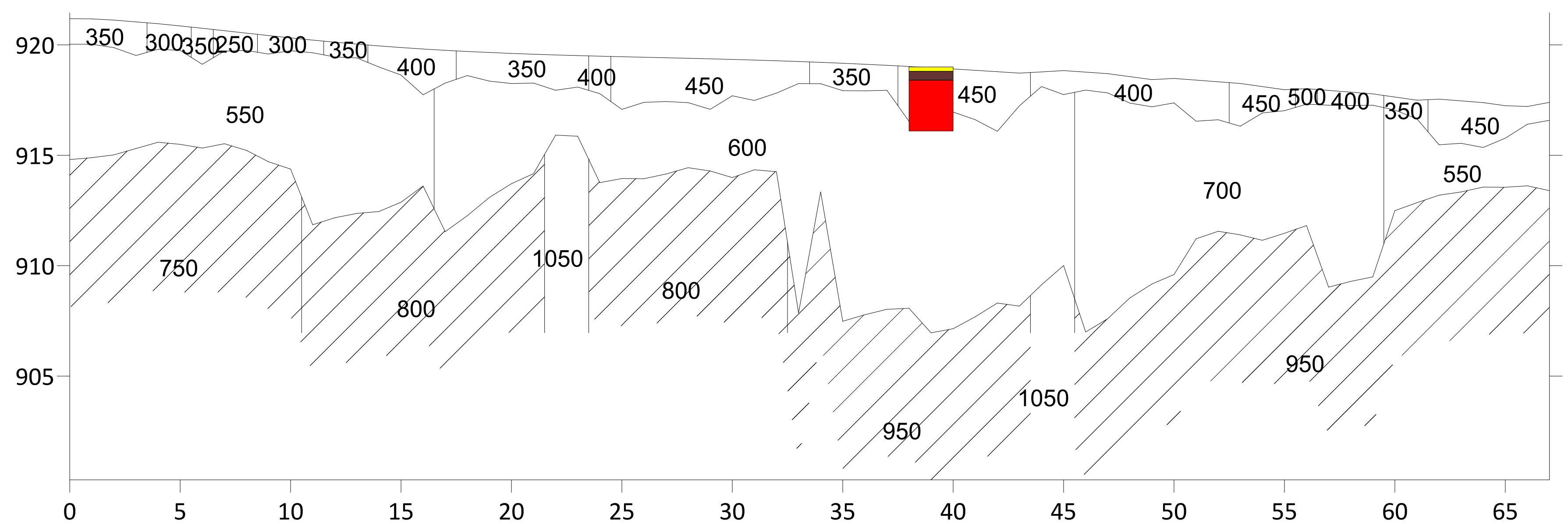
23 Harold Street
North Parramatta
NSW 2151
Australia

Telephone:
(02) 98902122
Fax:
(02) 98902922

Email:
info@gbgoz.com.au
Website:
www.gbgoz.com.au

CLIENT:	Munns Sly Moore Architects Pty Ltd	
TITLE:	Geophysical Investigation to Delineate Bedrock at Snowy Mountains Grammar School, Jindabyne, NSW.	
DRAWN: B.W.	PROJECT MANAGER: J.S.	DATUM: GDA94 MGA 55
SCALE: 1:300	DATE: 26/10/2020	DRG No: GBGA2386-05
		REV: A3

Refraction Model - Line 7



Test Pit 9

depth (m)	graphic log	classification symbol	material description **SOIL TYPE**: plasticity or particle characteristic, colour, secondary and minor components
		SC	**CLAYEY SAND**: fine to coarse grained, dark brown, low plasticity fines, trace fine, sub-angular gravel and roots.
0.5		SC	**FILL: CLAYEY SAND**: fine to coarse grained, orange-brown, low plasticity fines.
1.0 1.5 2.0 2.5			**GRANITE**: fine to coarse grained, orange-brown, extremely to highly weathered, inferred soil strength to very low strength.
3.0			Test pit TP09 terminated at 2.9 m Target depth

Legend

Refraction Line

Displayed Refraction Line

Test Pit Location

Modelled Refractor

Interpolated Refractor

800 800 Modelled (Interp) P-Wave Velocity (m/s)

GBG Australia Advanced Subsurface Investigations

23 Harold Street
North Parramatta
NSW 2151
Australia

Telephone:
(02) 98902122
Fax:
(02) 98902922

Email:
info@gbgoz.com.au
Website:
www.gbgoz.com.au

CLIENT:	Munns Sly Moore Architects Pty Ltd
TITLE:	Geophysical Investigation to Delineate Bedrock at Snowy Mountains Grammar School, Jindabyne, NSW.

DRAWN: B.W.	PROJECT MANAGER: J.S.	DATUM: GDA94 MGA 55
SCALE: 1:300	DATE: 26/10/2020	DRG No: GBGA2386-06
		REV: A3

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GROUND PENETRATING RADAR SURVEY

Legend

- POSSIBLE SERVICE
- POSSIBLE BOULDER 0.5–1m
- POSSIBLE BOULDER 1.0–1.5m
- POSSIBLE BOULDER >2.0m

Disclaimer:

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GBG Australia Advanced Subsurface Investigations

23 Harold Street
North Parramatta
NSW 2151
Australia

Telephone:
(02) 98902122
Fax:
(02) 98902922

Email:
info@gbgoz.com.au
Website:
www.gbgoz.com.au

CLIENT: GRAMMAR SCHOOL, JINDABYNE, NSW.		
TITLE: NON–DESTRUCTIVE INVESTIGATION TO DELINEATE BEDROCK AT GRAMMAR SCHOOL.		
DRAWN:	PROJECT MANAGER:	CADFILE: GBGA2386
SCALE: 1:200	DATE: 09 NOV 20	DRG No: GBGA2386-07
0 20m		REV: A3

APPENDIX B: GEOPHYSICAL TECHNIQUES.

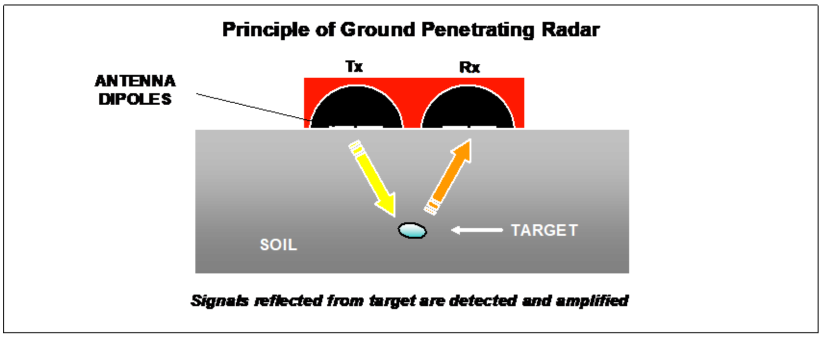
GROUND PENETRATING RADAR THEORY

APPLICATIONS

- ✓ Stratigraphic mapping including depth to bedrock
- ✓ Locating karst features, sinkholes, voids or cave systems
- ✓ Depth to water table
- ✓ Archaeology (location of graves and artifacts)
- ✓ Location of underground infrastructure, including UST's and utilities
- ✓ Assessment of internal condition and defects of engineered structures
- ✓ Assessment of road and rail infrastructure, including asphalt and ballast condition
- ✓ Slab thickness, reinforcement placement and void detection

METHOD

Ground Penetrating Radar (GPR) is a non-destructive geophysical technique for rapidly imaging the shallow subsurface. The method works by transmitting electromagnetic energy into the material being tested (most usually the ground). Very short duration radio pulses containing a wide spectrum of frequencies are used to image the subsurface material. The transmitted electromagnetic energy propagates through the subsurface as a function of the subsurface material's electrical properties, which are in turn dependent on its physical and chemical properties. Reflection of radar energy occurs at boundaries between differing layers or inclusions which have contrasting electrical properties. The reflections are detected by the receiving antenna placed adjacent to the transmitter. The depth to the target is proportional to the time (in nanoseconds) taken for the signal to travel from the transmitting antenna at the surface to the target and back to the receiver.



Schematic illustration of the principle behind ground penetrating radar

A radar-gram profile is built up of scans collected continuous along a selected line path. These form a 2D cross-sections of the subsurface showing variations in reflection amplitude as a grey (or colour) scale. The recorded reflections can be analysed in terms of their shape, travel time, phase and amplitude to provide information about a target's size, depth and orientation in relation to the material around it.

The depth of investigation achievable with the GPR method is largely a function of the antenna frequency used. Lower frequencies in the order of 100 MHz are typically used for geological mapping to a maximum depth of approximately 20 m, whilst higher frequencies in the order of 1 GHz are used for high resolution investigations of structures including building, bridges and tunnels.

Limitations inherent with SPR include:

- The ability to resolve subsurface detail is limited by penetration depth. Data may not be complete when collected over thick slabs or beams. This can be minimised by collected data from both sides of a structural member. Note that both resolution and data quality diminish with depth.
- GPR requires a sufficiently wide difference in material dielectric properties to allow signal reflection and target detection. This will also depend on the sharpness of dielectric change between materials in relation to the operating wavelength.
- Radar cannot penetrate metal and as such, a dense reinforcement layer will shadow the material directly behind the bars and reduce resolution and penetration. The density of the near surface steel layer may limit the ability to image the far side of a slab. Dense reinforcement will effectively block penetration.
- Most transducers require direct coupling with the surface. An undulating or rough surface can reduce data quality.
- The physical size of the transducer prevents information being collected close to the intersecting faces, or obstruction (typically within 150 mm).
- The methods used can penetrate through most materials, except for metals. However certain materials or conditions can adversely affect penetration depth or data quality. For example, air gaps behind plaster board, wet saturated materials, steel fibre reinforced concrete and new concrete (less than 28 days). Certain surface finishing can prevent or adversely affect

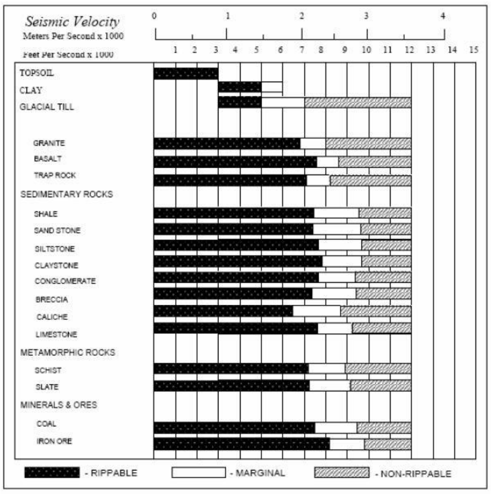
penetration. Some examples are thick carpet underlay, tiling, magnesite, terrazzo, metallic waterproof membranes and wet surfaces.

- Highly conductive soils, (containing saturated or reactive clays) will limit penetration depth and target resolution.
- The minimum void or target size that can be detected is limited by the antenna resolution. The transducer also needs to pass directly over the top of the void or target. The minimum size of the void or target that can be detected will increase with depth. Smaller voids or targets can often be detected if they are clustered close together such as occurs with extensive honeycombing.
- GPR cannot resolve individual bars if they are closely spaced. There needs to be minimum separation between the bars. It is sometimes possible to locate lapped bars by a change in amplitude associated with the greater cross-sectional area.
- GPR does not determine bar size. Where there is a large difference in bar size it is sometimes possible to differentiate a size difference, based on the amplitude of the reflected signal, provided the bars are at similar depths. Bar size can be inferred based on the difference in depth of cover between intersecting bars.
- The accuracy of depth measurements depends on the velocity of signal through the material. As velocity can vary significantly within a material due to variations in moisture and density some form of calibration is required for improved accuracy. Typically, accuracy is better than ±15% without calibration in concrete. Alternatively, cover meter for reinforcement depth or Impulse Echo for slab thickness can be used to get more accurate results.

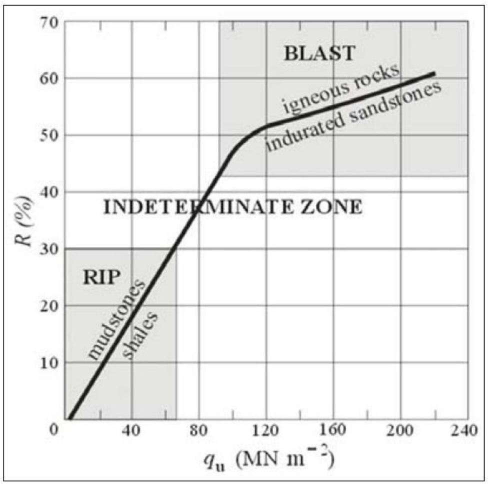
SEISMIC REFRACTION

The Seismic Refraction method involves the measurement of travel times of seismic compressional waves (P-waves). These are generated at the surface, propagate through the subsurface and return to the surface after being refracted at the interface between layers of contrasting seismic velocity. Seismic wave velocities are controlled by the fundamental parameters of elastic strength and density of the material it propagates through.

By measuring the travel times of these refracted waves from multiple source points to multiple receivers, the seismic refraction method can resolve lateral changes in the depth to the top of a refracting interface, as well as the seismic velocity within it. Furthermore, being related to elastic strength and density, the velocities calculated from a seismic refraction survey can be a useful guide to the rippability of a rock for excavation (refer to figure below).



Source: (Caterpillar, 2008)



Source: (McLean & Gribble, 1985)

The field procedure for seismic refraction investigations involve laying out a spread of geophones at regular intervals typically at 3m to 5m intervals for investigations within 10m to 30m from the surface. The geophones are connected via cables to a digital seismograph at the centre of the spread. This controls the acquisition parameters and allows the operator to view travel time records during acquisition.

Seismic energy can be generated using a variety of sources including sledgehammers, accelerated weight drops or explosives, dependent on the required depth of exploration and the subsurface conditions and composition. Source points are recorded along the spread typically starting 20m to 50m outside the spread moving through the spread and then 20m to 50m on the other side of the spread. As such a minimum 50m access is required on both sides of the spread to collect the ‘offset’ source points which are critically important to the survey. The seismic source is connected to the seismograph via a trigger switch. This records the start time of the shot within sub millisecond accuracy.

Analysis of seismic refraction data can be based on two theories of wave propagation. The first theory assumes distinct refractive boundaries. The second theory assumes gradual increases in seismic velocity with depth. The output from seismic refraction surveys are cross-sections showing lateral changes in the depth to the various refracting interfaces and the seismic velocities within them.

The use of Interpreted Seismic Sections

The results of seismic refraction surveys are presented as sections beneath the line of traverse. These sections show a two-dimensional distribution of velocities with depth, which has been interpreted by the reporting officer from first arrival travel time data obtained in the field. The following general summary is intended to assist in the understanding of interpreted seismic sections.

FIELD PROCEDURES.

Travel time data are obtained along traverses or spreads of fixed length with one or more of the following instruments and energy sources:

(i) Single channel signal-enhancement seismograph using a hammer as the energy source.
(ii) Multichannel (usually 24) seismograph using a hammer as the energy source.
(iii) Multichannel seismograph using explosives as the energy source.
(iv) Combinations of the above within a single spread.

Using a multichannel seismograph, seismic detectors (ordinarily vertical component geophones) are usually placed at constant intervals of between 1 and 10m, typically 3 to 5m, in an individual spread. The spacing may be varied according to site conditions and the objectives of the survey. A minimum of two source positions, providing travel time data in opposite directions is required for interpretation of the refraction test data. Typically, 3 to 20 sources at different locations or offset distances are used. Usually, the more source positions used, the greater the subsurface detail obtainable.

Using a single channel seismograph, the detector is placed at the end of a spread and the source position varied in increments, usually of between 1 and 5m, away from the detector. The spacing is often varied within a spread, according to the objectives of the survey. The same procedure is then followed with the detector at the opposite end of the spread.

The field procedure chosen depends on the nature of the site, the depth to be investigated and the objectives of the investigation. Details of the procedures adopted are given in the body of the report.

Where a multichannel seismograph is used permanent seismic records are taken using the recording device contained in the seismograph. This is usually not possible with single channel instruments. Where these are used travel times are picked from a screen display by the operator in the field.

METHODS OF INTERPRETATION.

Seismic refraction data collected in the field was processed and interpreted as follows:

Digital seismic records were examined on computer and first arrival times were picked using the first break pick module of REFRACT developed by the Geotechnical and Scientific Services Section of the RTA. (Leung et al 1997.)

First Break Pick Files were saved in REFRACT. (Leung et al., 1994; Walker et al., 1991).

The data were checked and edited as required.

Hardcopy and screen displays of the travel time graphs were examined. The graphs were interpreted by parallelism testing and other techniques. Segments of the graphs were assigned to appropriate layer numbers.

The data were adjusted for shot depths. Reciprocal times were then checked and the data was adjusted to bring the reciprocal errors generally to within + or - 1ms. These adjustments were kept to a minimum.

After automatic phantoming, velocity segments were defined on the velocity analysis graph for individual layers.

Seismic velocities and layer thicknesses were automatically computed by the reciprocal method, and by the intercept time method where the reciprocal method could not be applied or was considered not to be appropriate (Greenhalgh and Whiteley, 1977; Dobrin, 1976; Hawkins, 1961).

The results were checked and where necessary re- interpreted, recomputed and edited.

The results were then drafted to produce final interpreted seismic sections.

These methods of interpretation provide a simplified seismic picture of the subsurface and depend on a number of assumptions about it's nature. The major assumptions are:

(i) The subsurface essentially consists of a series of discrete homogeneous layers.

(ii) The boundaries between these layers are distinct. For the simpler methods of interpretation, these boundaries are also assumed to be planar.

(iii) The seismic velocities of successive layers increase with depth.

(iv) Each layer is of sufficient thickness to critically refract energy and to produce a refracted wave arrival, at the surface, of sufficient energy to be detected as a first arrival.

Each of these assumptions demonstrates a requirement of the interpretation procedure for an ideal condition which is unlikely to be fully reflected in reality. The extent to which each assumption is valid may vary greatly from site to site and within a site. However, at all sites the interpreted seismic sections are a simplification of the actual subsurface velocity distribution. The degree of simplification depends on the interpretative method used, the amount of data available for analysis and the extent to which the basic assumptions are violated at a site.

Because such violations may be undetectable and the interpretation process is, in any case, partly subjective, other interpretations of the data are possible and may differ considerably from that presented in this report.

The effects of common violations of the assumptions are discussed in Section 5, below. Other effects which may be relevant to the understanding of the seismic sections are discussed in Section 6.

It should be noted that, at a given site, these effects can occur in virtually any combination and that, as a result, even highly complex subsurface conditions may give rise to apparently simple seismic sections.

PRESENTATION OF RESULTS.

Drafted final interpreted seismic sections were produced using elevations and chainages provided on surface profiles of seismic lines (supplied by the division, which were generated using the surveyed position of shot holes) and depths to seismic velocity boundaries below the ground surface produced from the interpretation process.

Interpreted seismic sections are presented at 1:500 natural scale.

Precision and Accuracy of Results.

Interpreted velocities are shown on the sections to the following precision:

$v < 1000$m/s: nearest 20m/s

$1000\text{m/s} < v < 2500$m/s: nearest 50m/s

$v > 2500$m/s: nearest 100m/s

Notwithstanding this, interpreted velocities are not regarded as being accurate to better than $\pm$10% as a measure of the actual field velocities, without independent calibration from drilling or excavation.

Calculated layer thicknesses are subject to the same degree of experimental error. This has a cumulative effect on interpreted depths to velocity zone boundaries. For example, the interpreted depth to the base of the first layer defined is not considered accurate to better than ±10%. Depths to deeper layers are not considered accurate to better than ±30% (Dampney and Whiteley, 1978).

These experimental errors are inherent in the procedure and must be taken into account in any use which is made of the seismic sections eg, in estimating the volume of material represented by each layer in a proposed excavation.

EFFECTS OF VIOLATION OF ASSUMPTIONS.

This section discusses the effects of common violations of the assumptions made in seismic interpretation.

Known violations of these assumptions and any adjustments made to the interpretation to account for them are detailed in the body of the report. However, because such violations cannot be reliably detected from the seismic data alone, allowance must be made for them in any further interpretation based on the sections.

Assumption of Discrete, Homogeneous Layers.

The most common violations are:

(i) continuous increase in velocity with depth.
(ii) inhomogeneity below the scale of resolution of the survey.

The first of these occurs in many geological settings. It can be allowed for in a number of ways but contributes to the uncertainty in depth calculations. It also means that further interpretation based on the calculated velocities may give erroneous results.

As far as the second type of violation is concerned, under ideal conditions a refraction survey may be able to resolve features as small as 1.5-2 times the geophone spacing. In general, however, the limit of resolution is 2-3 times the spacing although the presence of inhomogeneity may be detectable from the travel time curves, without more detailed interpretation being possible.

The calculated velocities are averages which represent the bulk properties of the interpreted layers. It is possible for this averaging to conceal major, local variations in velocity on a scale up to at least twice the geophone spacing. The likely nature of these variations depends on the geological setting of the site.

Assumption of Distinct Boundaries.

Real geological boundaries (especially those related to weathering) are often gradational and/or irregular. The seismic method inevitably disguises gradation and smooths irregularities. The importance of this varies from site to site but it is common for interpreted seismic boundaries to appear at an intermediate level somewhere between the limits of gradation. For example, if there is an irregular boundary between fresh and highly weathered rock, the interpreted boundary frequently appears at a level some metres below the highest points at which fresh rock is found.

Assumption of Increasing Velocity With Depth.

This assumption may be violated for a number of different reasons and such violations (termed velocity reversals) often cannot be detected from the travel time data alone. It may be possible (in some, but not all cases) to infer them from the geological setting or from borehole information.

In general, it is not possible to allow for a velocity inversion in the interpretation unless there is an independent means of estimating both the thickness and the velocity of the layer. **If an undetected velocity reversal occurs all calculated depths below the reversal will be greatly in error. In particular, depths to underlying high velocity layers may be significantly overestimated (Whiteley and Greenhalgh, 1979).**

Assumption of Detectability.

Two main types of violation occur:

(i) Cases in which a layer is too thin to transmit the seismic wave.
(ii) Cases in which a layer transmits the wave but is not detected because waves from a deeper, higher velocity layer reach the surface first.

The first type of violation may occur in many geological settings and means that relatively thin, higher velocity layers may occur undetected within lower velocity materials. "Thin" in this context is defined in terms of seismic detectability and can imply thicknesses of the order of 1-1.5m. The effect cannot be detected from the seismic data alone, but may be inferable from borehole information or surface mapping. If such a layer were thick enough to be detected, it would form a velocity reversal (see Section 5.3).

The second type of violation may be inferable from the geological setting, borehole data or sometimes from the seismic data, but this cannot be guaranteed. If not detected, it also results in erroneous depth calculations in the interpreted section.

OTHER FACTORS.

There are a number of other factors which may lead to differences between the seismic model and reality. While not strictly due to assumptions made in interpretation, they must still be taken into account in any further use of the interpreted sections.

These effects are as follows:

(i) 3-D effects
(ii) Effects of water
(iii) Anisotropy

Three-dimensional effects.

The interpreted sections are two-dimensional representations and only apply to a narrow zone below the line of traverse. However the real subsurface is three-dimensional and as a result significant lateral variations in conditions can occur without being detected, even within a short distance to the side of a traverse. If signals due to such variations are detected, they may result in the interpreted sections containing features which are non-existent, displaced from their true position or shown with incorrect velocities.

In some cases this effect may be detected by cross spreads at right angles to the main traverse, or from other information.

Effects of Water.

The presence of water can greatly increase the field velocity of materials which have low velocities in the dry condition. The effect is most pronounced in soils or unconsolidated materials and is due to the difference in seismic velocity between air and water (340 m/s and 1470 m/s, respectively). It may however occur to a significant degree in materials with dry velocities as high as 2000-2500m/s. The change is not related to the normal trends of change in material properties with velocity.

Less frequently, it is possible for water saturation to cause a decrease in field velocity, most commonly in low velocity materials where highly expansive clay minerals are present and the material is unconfined.

Velocity changes due to the presence of a water table cannot be distinguished from the seismic data alone. The effect may be inferable from the geological setting and the interpreted velocities, but can only be confirmed by contemporaneous drilling.

Anisotropy.

Field velocities may vary with the direction of the seismic traverse. This is most common in steeply dipping sediments or metasediments but can occur in other settings. When measured across strike the velocity is an average for the different materials present. Along strike the higher velocity of the fresher or more competent materials is measured. This effect may be detectable from cross spreads which show a markedly higher or lower velocity than longitudinal traverses. However it may not be detected, depending on the relative orientations of the traverses and the strike of the subsurface materials.

The possible effects of anisotropy are similar to those discussed under Section 5.1, above.

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