REPORT

Parwan Lava Cave

Geotechnical Assessment

Submitted to:

Victorian Planning Authority

Level 25, 35 Collins Street
Melbourne VIC 3000

Submitted by:

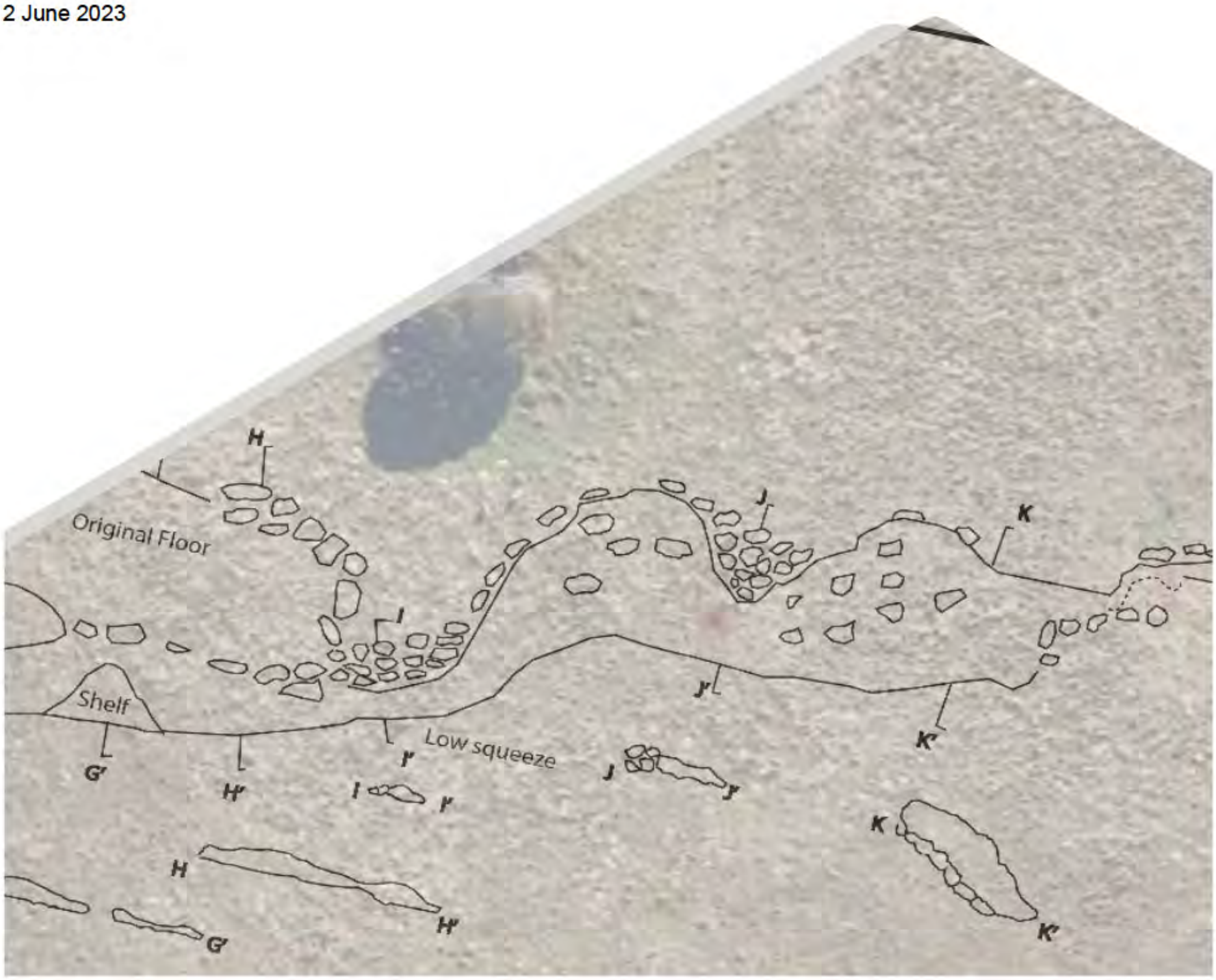
Golder Associates Pty Ltd

Building 7, Botanicca Corporate Park, 570 – 588 Swan Street, Richmond, Victoria 3121, Australia

+61 3 8862 3500

PS132605-005-R-Rev2

2 June 2023



Distribution List

Victorian Planning Authority - 1 copy (electronic)

Golder Associates Pty Ltd - 1 copy (electronic)

Executive Summary

WSP Golder were engaged by the Victorian Planning Authority (VPA) to provide geotechnical consulting services on the Parwan Lava Cave. The Parwan Lava Cave is located in the property of [redacted] which is within the proposed Parwan Employment Precinct. Based on publicly available information cave was understood to be approximately 70 m long. Potential implications of the cave for land-use planning for the Parwan Employment Precinct need to be better understood.

In addition, VPA requested a review of LiDAR elevation data in conjunction with coal mining heritage study prepared by Heritage Council of Victoria in 2008 to comment on the potential presence on additional voids elsewhere within both the proposed Parwan Employment Precinct and Parwan PSP Precinct.

As part of WSP Golder's scope of work the following investigations were undertaken:

- Desktop study of the Parwan Lava Cave
- Site Speleological Survey of the lava cave
- Site geophysical survey of the lava cave
- Review of LiDAR elevation data and coal mining heritage study

Desktop Study

The desktop assessment for the Parwan Lava Cave was submitted to VPA on the 25 July 2022 (ref: PS132605-003-L-Rev0). Key outcomes of the desktop study were:

- A previous speleological survey of the Parwan Lava Cave was provided by Wakelin Associates. The speleological study, conducted in 1969, indicates that the cave is significantly more extensive and greater than 300 m in length. The survey also indicated that the cave extended further to the west and east than what was able to be mapped.
- WSP Golder plotted the 1969 survey in real space to be understand the extent of the cave in relation to the surround property and assist in planning of the speleological survey.
- Wakelin Associates also provided a study on the cave, in this study it was found that the Geological Society of Australia, Victoria Division (GSA-V) have assessed the Parwan Lava Cave to have high level of state significance. However, currently there is no statuary requirement to protect geological sites of significance.

Speleological Survey

WSP Golder together with Wakelin visited the Parwan Lava Cave on 27 July 2022 to conduct a speleological survey. This was done using a radio direction finder device in combination with a distance laser measurer.

The chamber to the east of the cave entrance was mapped and found to be reasonably consistent with the 1969 survey. However, there were some differences. Notably the eastern most end of the mapped cave did not veer to the east as shown on the 1969 survey.

As indicated by the 1969 survey, cave was found to extend further northeast than accessible and could be surveyed. Due to access constraints and safety concerns the cave mapped to the west of the entrance was not able to be accessed and surveyed.

Geophysical Survey

WSP Golder conducted a geophysical survey of the Parwan Lava Cave on 15 September and 3 November 2022. A total of ten scan lines were undertaken across the extent of the cave mapped by the 1969 survey.

Two geophysical methods were used electrical resistivity tomography (ERT) and seismic refraction tomography (SRT). The results of the geophysical survey could also be calibrated against the RDF and Disto measurements taken by in the speleological survey.

The geophysical survey showed good correlation with the speleological survey in the section of cave to the east of the cave entrance giving confidence in the geophysical methods being used. The survey to the west of the cave entrance was broadly agreement with the 1969 survey with differences in cave alignment. In addition, the survey showed several geophysical anomalies indicating voids parallel to the cave, indicating the lava cave mapped in 1969 is part of a larger lava cave system containing parallel tubes.

Review of LiDAR elevation data and coal mining heritage study

A review of LiDAR elevation data and coal mining heritage study found no historical evidence of mining within the proposed Parwan Employment and Parwan PSP Precincts. Three locations were identified to be potential areas of localised ground subsidence or collapse. Further investigation is need to establish if these locations represent a cave system or underground void.

Key Outcomes and recommendations

Key outcomes of the above investigations are:

- The Parwan Lava Cave is much more extensive than 70 m and the accessible (by human) length is approximately 300 m. The cave however extends further to the west and east an unknown distance.
- The cave mapped in 1969 is likely is part of a larger lava cave system with parallel tubes. The width of this system is unknown.
- The cave floor is approximately 8-10 m below ground level, however, at the western and eastern ends of the area surveyed it was as little as 4 m below ground level. Geophysical survey indicated that rock cover was between 2 m and 7 m below ground level.
- Review of LiDAR elevation data identified three potential areas of localised ground subsidence or collapse.
- Considering findings of additional voids near the Parwan Lava Cave we consider it likely there are other voids underlying the proposed precincts.

The following is recommended for further investigations:

- Site walk over of the three areas identified as potential ground subsidence or collapse
- Further staged geophysical survey with rapid coverage electrical methods (i.e. Frequency Domain Electromagnetics (FDEM) and or Ground Magnetics (GM) techniques followed by stage 2 targeted ERT and SRT survey.
- Borehole drilling in select areas to confirm results obtained from ERI.

As an alternative to investigating voids across the entire precinct consideration could be given to planning controls. Planning overlays can be implemented to formally protect the Parwan Lava Cave and stipulate where the presence of voids needs to be investigated for each specific development or controls need to be in place (for example restrictions on vibration) to protect the caves.

Table of Contents

TABLES

FIGURES

APPENDICES

1.0 ENGAGEMENT

Golder Associates Pty Ltd (WSP Golder) has been engaged by the Victorian Planning Authority (VPA) to provide geotechnical consulting services at the Parwan Lava Cave, located at the property of [redacted]. This study has been undertaken in general accordance with Golder fee proposal PP137497-002-L-Rev0 dated 11 May 2022 (this is an updated fee proposal to our Response for Quotation (RFQ) attached to transmittal PP137497-001-T dated 7 April 2022). At a request from VPA (email dated 11 October) a variation of scope (refer to WSP Golder email dated 18 October 2022) was agreed upon to include review of LiDAR data in conjunction with a SMEC report on mine work subsidence in the area. As part of the scope of services outlined in the WSP Golder fee proposal, a desktop assessment for the Parwan Lava Cave was submitted to VPA on 25 July 2022 (ref: PS132605-003-L-Rev0).

WSP Golder engaged Wakelin Associates (Wakelin) for their existing knowledge of the cave and caving expertise.

As part of the geotechnical assessment WSP Golder attended site together with Wakelin on 27 July 2022 to conduct a speleological survey of the cave. WSP Golder also attended site on the 15 September and 3 November 2022 to conduct geophysical surveys of the cave.

2.0 BACKGROUND INFORMATION

WSP Golder understands that VPA plans to develop the Parwan area into an employment precinct. The proposed Parwan Employment Precinct (PEP) is located to the south of Bacchus Marsh town centre and will cover an area of approximately 2,480 ha, incorporating over 80 separate properties including the existing Bacchus Marsh aerodrome. The majority of the land within the PEP is currently used for agriculture and rural residential uses, with a limited range of commercial, recreation and utility use. The Parwan PSP (PSP) adjoins the Parwan Employment Precinct. The extent of the PEP and PSP are shown in Figure 1.

Figure 1: Extent of Parwan Employment Precinct (PEP) in yellow and Parwan PSP (PSP) in blue. These were provided by VPA (email dated 3 August 2022).

A land capability assessment (LCA) was prepared for the proposed employment precinct by SMEC in October 2021 (reference: D/20/3772). The LCA identified the Parwan lava cave within the private property of [redacted] and concluded the following in relation to the lava cave:

- The cave is understood to be located 8 m to 10 m below the level of the land surface.
- There is a single entrance that is 1.5 m wide and descends 3 m to the floor of the cave.
- The roof of the main passage averages 2 m high and allows easy movement through the cave for approximately 70 metres.
- There are few lava caves in Victoria and the Parwan cave is the only one known on the Werribee Plains. It is the closest known cave to the Melbourne metropolitan area, is a relatively large cave and is important for the occurrence of a newly described mineral.
- Although thought to be abandoned by wildlife for the last 100 years, the presence of the phosphates indicates past use by bats.
- The lava caves are considered to be of geological heritage significance by the Geological Society of Australia.
- As the lava caves are currently located on private land there is no known record of active management or preservation of the caves.
- Geological survey of the lava caves would provide valuable information to determine the condition and cultural value in their current state and requirements for their future management
- An appropriate public access and geological heritage preservation management plan may be warranted to control access and preserve this important geological feature for future generations.

Following these outcomes of the LCA, there was a need for a geological survey to be undertaken to determine the extent, condition and significance of the cave.

3.0 AIMS OF THE STUDY

The aims in of the Parwan Lava Cave Geotechnical Assessment as set out in our Response for Quotation (RFQ) are as follows:

- Discussion on the outcome of the Desktop Geological Study including:
  - comment on the basis of the geological significance of the lava cave system;
  - assessment of existing maps and mineralogical studies of the lava cave system, and;
  - any other known information of the lava caves.
- Discussion on the outcome of the site visit, including:
  - the mapped internal extent of the cave;
  - the observed internal condition of the cave, and;
  - the observed surface features associated with the cave.
- Discussion on the outcome of the geophysical investigation including:

- the extent of the caves including depth and limitations of construction/development above the cave system and how this impacts the developable area within Parwan PSP and Parwan Employment Precinct, and;
- comparison with the existing mapping of the cave system.

- An assessment of the results including:
  - Potential implications for land-use planning for the Parwan Employment and Parwan PSP Precincts.
- Recommendations including:
  - further work considered necessary to finalise this assessment;
  - requirements for ongoing protection and preservation of the lava cave system;
  - comment on potential geological hazards associated with the lava cave system;
  - recommendations for ongoing protection and preservation;
  - recommendations for future management of the lava caves.

In addition to the above a variation of scope was agreed upon to include review of LiDAR data in conjunction with a SMEC report on mine work subsidence in the area. The aims of the additional scope included:

- Review of LiDAR data in conjunction with SMEC report (to be provided by VPA) for areas that:
  - indicate surface subsidence due to mine work subsidence;
  - natural cave collapse, and;
  - other indications of potential underground voids within the proposed employment precinct .
- Commentary on the above review.

4.0 OUTCOMES OF THE DESKTOP STUDY

As part of the scope of services outlined in WSP Golder fee proposal, a desktop assessment for the Parwan Lava Cave was submitted to VPA on the 25 July 2022 (ref: PS132605-003-L-Rev0). The desktop assessment aimed to collate publicly available information together with information provided by Wakelin on the lava cave. This could then be used as a guide to for the speleological survey and provide a basis to comment on the geological significance of the cave.

Wakelin was able to obtain a previous speleological survey of the Parwan Lava Cave conducted in 1969. The Speleological survey was conducted by J.Taylor, J.Rutzou and S.Tickell of the Victorian Speleological Association (VSA). The survey indicated that the cave is significantly more extensive than the 70 m indicated by the LCA conducted by SMEC for VPA. The survey shows that the cave comprised of three main chambers linked by narrow tubes or passes (‘squeezes’). Each chamber is approximately 30 m to 70 m long and up to 10 m wide. The total mapped length of the cave is approximately 300 m and the survey also indicated that the cave may extend beyond the 300 m mapped extent in both the northwest and northeast ends. The survey also indicated the chambers have areas of historic collapse and rock piles as well as bentonite and phosphate minerals in the western most chamber.

WSP Golder plotted the VSA 1969 survey in real space using the cave entrance as a known reference point, the magnetic north and scale indicated on this plan.

Provided in Appendix C, Wakelin has also provided a study detailing the cave's:

- geological context;
- a description of the cave and its contents;
- a description of potential formation processes;
- commentary on geophysics undertaken;
- cave significance;
- high-level management recommendations for the cave.

As detailed by Wakelin's study, the cave has been assessed for its geological and geomorphological significance by the Heritage Subcommittee of the Geological Society of Australia, Victoria Division (GSA-V) to have high level of state significance. This is largely due to age of the lava cave, being between 4.03 and 3.01 million years old, making it the second oldest known lava cave in Australia. The presence of the rare mineral Parwanite also contributes to the cave's geological significance and may raise the cave to a national level of geological significance.

However, as noted by in GSA Geoheritage Policy[1] "abiotic natural environment has no standing under planning law and so cannot be protected unless it is on a heritage list". In other words, currently there is no statutory requirement to protect the Parwan Lava Cave as a geological site of significance.

5.0 SPELEOLOGICAL SURVEY

WSP Golder together with Wakelin visited the Parwan Lava Cave on 27 July 2022 to undertake a speleological survey of the cave using a combination of Radio Direction Finder (RDF) device and distance laser measuring device (Disto).

5.1 Aims of the speleological survey

The aims of the speleological survey were to:

- assess the accuracy of the speleological survey conducted by VSA in 1969;
- assess the current condition of the interior of the cave, and;
- to obtain internal measurements of the cave for use in calibrating the geophysics survey.

5.2 Methodology of the speleological survey

The survey was conducted by use of a RDF and Disto. By the joint use of these devices a cave system can be approximately mapped out and located in real world coordinates.

The RDF is a device purpose built by the VSA for speleological survey use. The device comprises of two radio phones, a transmitter and a receiver. The transmitter device is able to emit a radio frequency directionally from one circular antenna, this radio frequency can then be picked up by the circular antenna on the receiver. The transmitter device can then be taken into a cave and at agreed upon locations the operator in the cave can transmit a directed radio signal vertically up. A person on the surface can then use the receiver device to

[1] Geoscience Society of Australia Geoheritage Policy dated 16 March 2016, accessed via website www.gsa.org.au on 14 March 2023

locate this signal and thereby locate the person underground in horizontal space (real world coordinates for example by use of GPS). By doing this at regular intervals or ‘Radio Direction Finder points (RDF points)’, at each main cave chamber for example, the cave system can then be mapped out at surface level in real-world coordinates. The accuracy of this device has not been determined and depends largely on the operator of the receiver, however, when used by a skilled operator the VSA generally considers it to be accurate to within ±1 m.

Within the cave at each of the RDF points the Disto can then be used to take measurements of the surrounding cave interior. The Disto records a distance (between RDF and cave wall or feature) and an angle from vertical together with an angle from magnetic north. Intermediate measurements between RDF points can also be taken allowing sections of the cave between main chambers to be measured. The measurements from the Disto can then be plotted relative to each other in 3D space to provide a 3D map of the cave. Combined with the coordinates from the RDF points this can then be located in real world coordinate space.

While inside the cave visual observations and measurements are taken to assess the condition of the interior of the cave.

5.3 Results of the speleological survey

WSP Golder together with Wakelin visited the Parwan Lava Cave on 27 July 2022 to conduct the speleological survey of the Parwan Lava Cave. Based on the information obtained during the desktop assessment, the survey could now be guided with the use of the VSA’s 1969 detailed map of the cave and a number of RDF points at key points on the map were agreed upon prior to commencement.

The cave entrance has an approximately 6 m vertical descent onto a rocky ground (collapsed material). The 6 m descent in at the cave entrance comprises of a short 2.2 m decent on to a ledge, before a further 4 m descent on to a rock pile. This initial ledge could represent a separate flow overlying the main flow which created the lava cave. To the northeast it descends a further 4 m onto a flat dirt floor. The northeast section of the cave comprises two chambers, beyond this the cave narrowed to a point where it terminated in a historic collapse and was inaccessible. It was unclear if the cave continued past this point. In the chambers, the floor of the cave was generally flat and comprised weathered basaltic soil. The chamber ceiling and walls were a generally dome in shape (refer to section M-M’ shown in Figure 2), the first 1.5 to 2m high and 10 m wide at its center, the second chamber further away from the cave entrance was approximately 1 m high and 10 m wide at its center. The ceiling and walls consisted of slightly weathered to fresh basalt rock with some iron staining around joints in the rock mass. No evidence of recent cave collapse or instability within the cave was observed.

Due to access constraints and safety concerns the cave to the west of the entrance was not able to be accessed and surveyed. Similarly, the northeast section of cave appeared to descend down to a relatively flat dirt floor.

During the survey, three RDF points were taken, one in the center of each chamber and one at the furthest accessible part of the cave. Disto measurements were taken inside the cave at each of these RDF points in addition to intermediate locations along the cave. The disto measurements relative to the RDF points were plotted in 3D space and compared to the VSA 1969 survey. The results were generally consistent with the cave extents shown by the VSA 1969 survey for the northeastern section, however towards the end of the mapped extent the cave remained straight at a bearing of 45 degrees and did not veer to the east as shown by the VSA 1969 survey. The results are plotted in Figure 2.

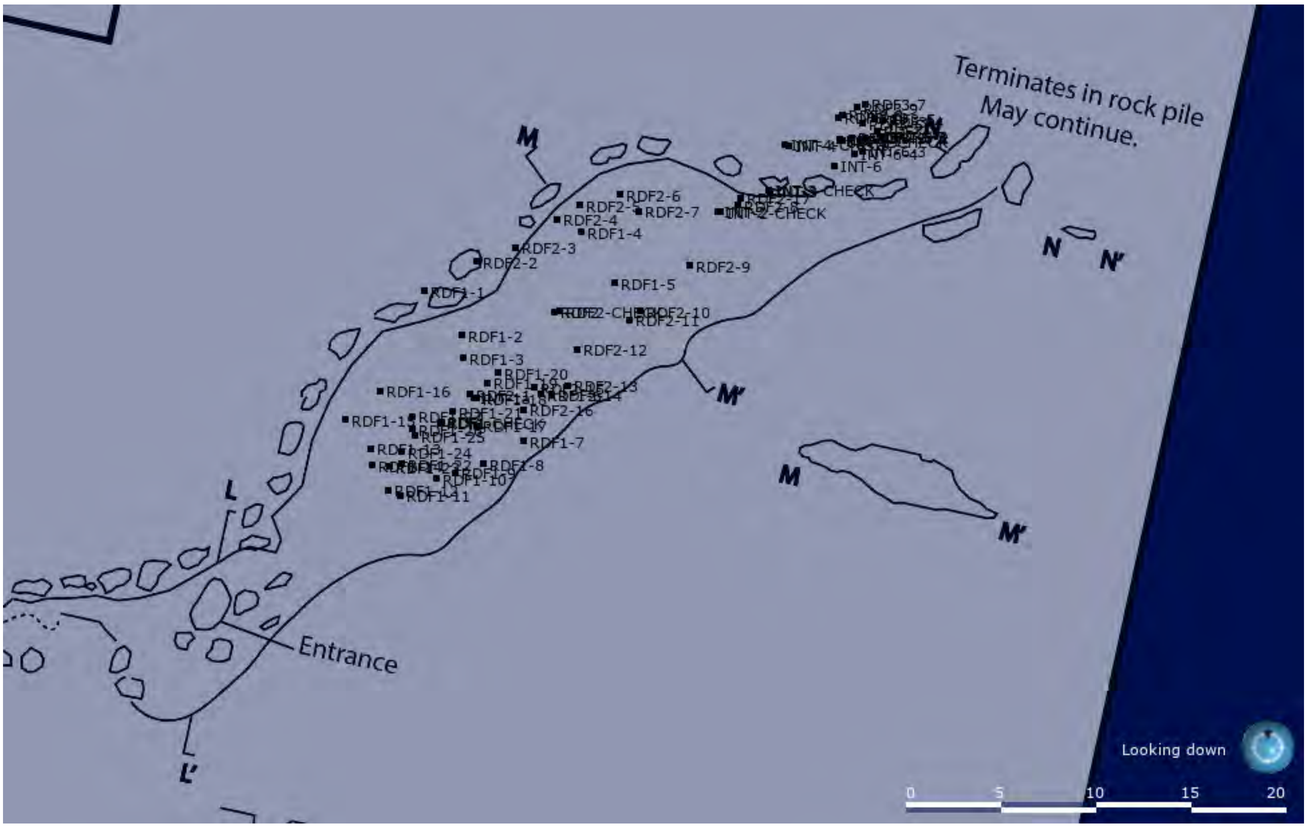


Figure 2: Disto measurements relative to RDF points plotted on VSA 1969 speleological survey

6.0 GEOPHYSICAL SURVEY

WSP Golder conducted a geophysical survey of the Parwan Lava Cave on 15 September and 3 November 2022. A total of ten scan lines were undertaken across the extent of the cave mapped by VSA in 1969. Two geophysical methods were used to detect voids within the basalt rock, electrical resistivity tomography (ERT) and seismic refraction tomography (SRT). Scan lines for ERT were 94.5 m long and scan lines for SRT were 47 m long. Five scan lines of each method were used which enabled a comparison of methods. The results of the geophysical survey could also be calibrated against the RDF and Disto measurements on the northeastern section of cave.

The geophysics report setting out the aims, methods and results of the survey are provided in Appendix B. Refer to this report for further information relating to the geophysical section which is discussed below.

6.1 Summary of Geophysical survey results

Comparison of the RDF and Disto in-cave measurements with the geophysical survey show a strong correlation between what is indicated as a void by both ERT and SRT techniques and the in-cave measurements. Figure 3 presents section PC-ERT02 compared with the in-cave measurements. The red to purple colour contrast corresponding to the resistivity contour of 750 ohm/m matches well with the in-cave measurements. Similarly, in Figure 4 the comparison between voids found by ERT and SRT techniques lines up well with the in-cave measurements. The easternmost geophysics section (Appendix B, Figure A01 – PL-SC01) confirms that the northeastern end remains straight and does not veer to the east as shown by the VSA 1969 survey. Figure 4 also shows a separate void south of the known cave.

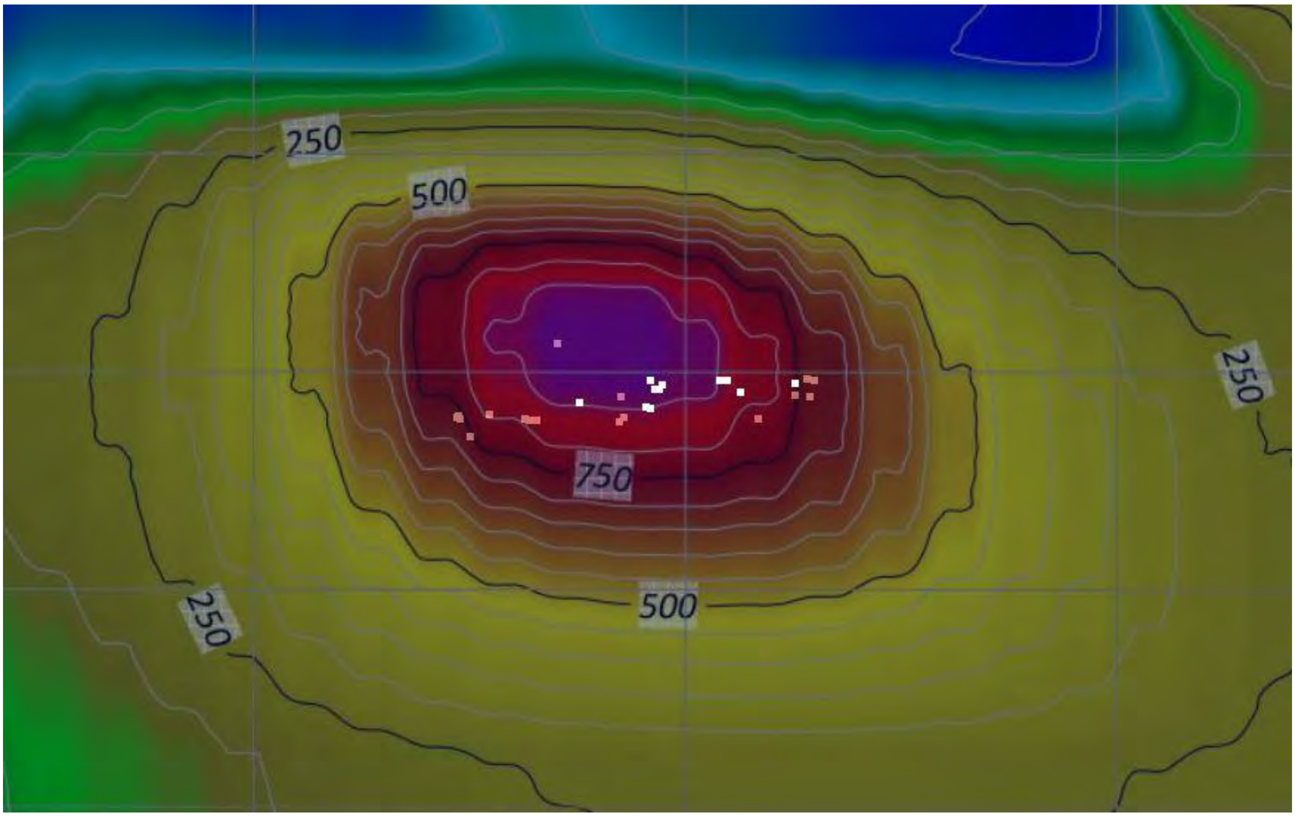


Figure 3: Comparison of in-cave RDF/Disto measurements with geophysical ERI survey

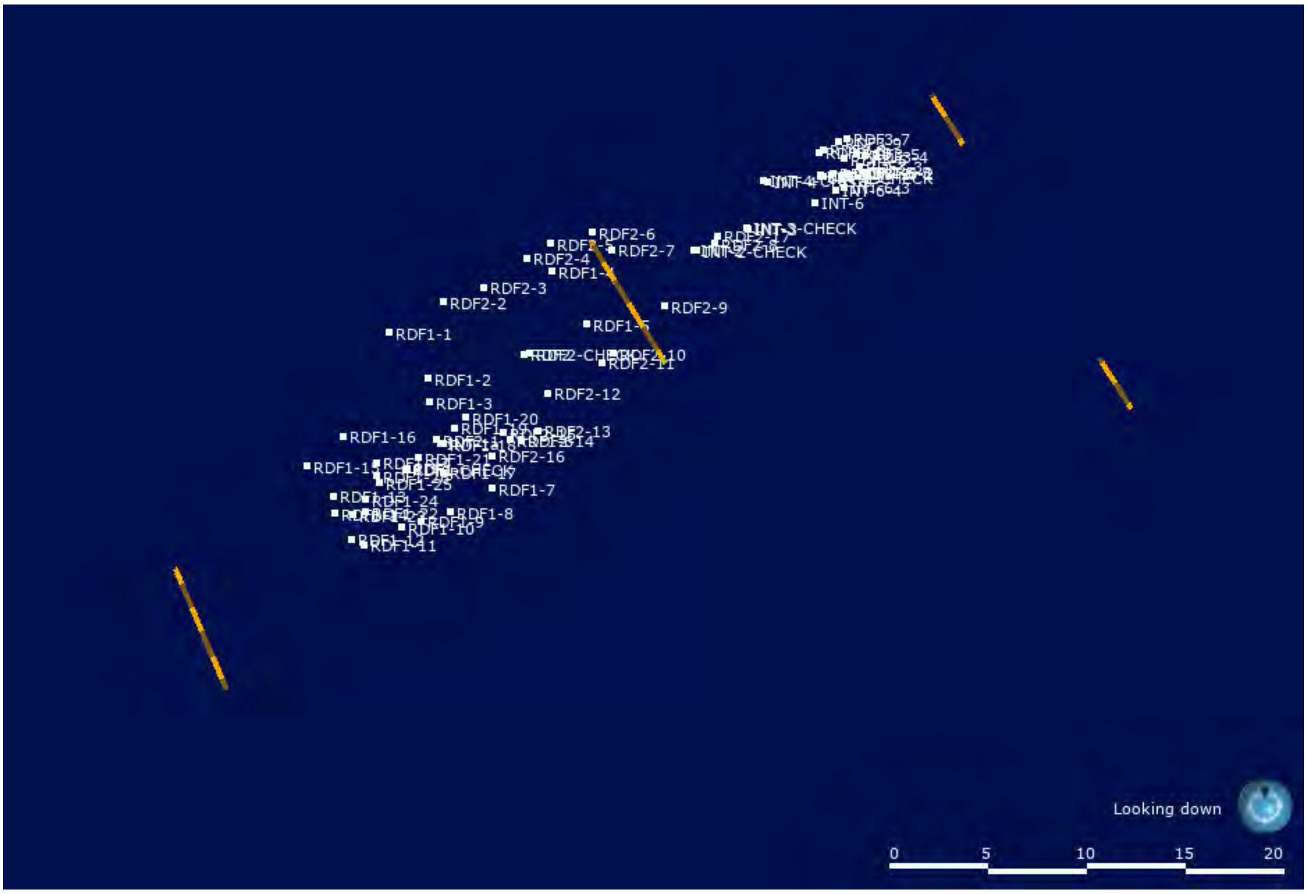


Figure 4: Comparison of in-cave RDF/Disto measurements with voids indicated by the geophyiscal scan lines (orange lines)

Comparison of the in-cave RDF and Disto measurements with the geophysical survey indicate that both ERI and RFT techniques are able to identify the cave extent. Comparing these with the VSA 1969 survey suggests there is some deviation, highlighted in Figure 2, where the VSA 1969 survey tracks off the cave alignment.

It should be noted that the spacing of the geophysical survey receivers influences the resolution of the ERT or SRT scan. For this survey a relatively coarse resolution of 1 m to 1.5 m was used. Hence the exact outline or shape of the cave may not be accurately reflected by the geophysical survey. Similarly, there will be some error in the lateral extent of any void indicative of geophysical anomalies detected. In addition, anomalies interpreted as open voids based on the geophysics survey could alternatively be caused by rock rubble or loose soil infill. ERT appears to give a better contrast in identifying voids. However, SRT is more useful to provide a relative indication of the rock competence surrounding the void.

Figure 5 shows a comparison between the location of voids interpreted by the geophysical survey and the VSA 1969 survey. Scan lines to the west of the cave entrance are in broad agreement. However, there are some noticeable differences between the cave outline shown in the VSA 1969 survey and the indications from the geophysics survey. In particular, voids interpreted from geophysics are wider near the mid section of the cave mapped in the VSA 1969 survey. This difference is likely due to voids outside the VSA 1969 survey extent in the form of rock rubble originating from historic cave collapse. These voids likely would have been inaccessible and not have been mapped as part of the VSA 1969 survey. Voids interpreted from geophysics further west indicate that the cave alignment varies from that shown in the VSA mapping.

Other voids outside of the area shown in the VSA mapping were detected by the geophysical survey. In particular, scan lines PC-SL01 (eastern most), PC-ERI06 and ERI10 (western most).

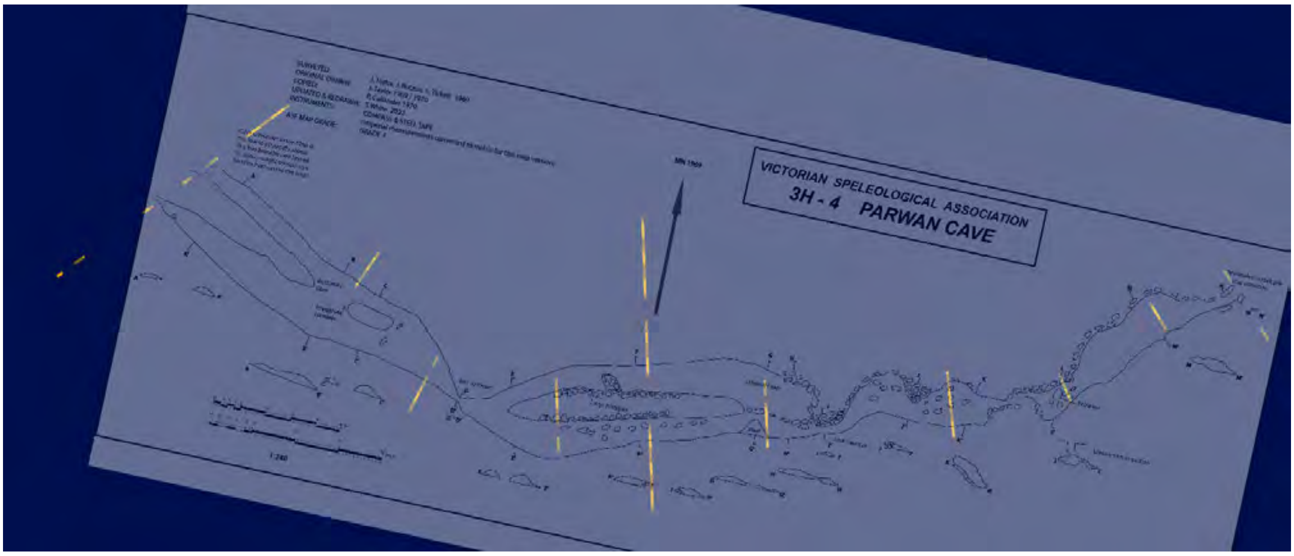


Figure 5: Comparison of voids found by WSP Golder geophysical survey and VSA 1969 survey

The geophysics survey indicates that the cave floor is approximately 8-10 m below ground level. However, at the western and eastern ends of the area surveyed it was as little as 4 m below ground level. The survey indicated that rock cover was between 2 m and 7 m below ground level.

7.0 REVIEW OF LIDAR INFORMATION AND COAL MINING HERITAGE STUDY

In discussions between VPA and WSP Golder, VPA requested that LiDAR data for the PEP be reviewed for any indications of surface subsidence that could be related to historic mine work or natural cave collapse like the cave entrance seen at the Parwan Lava Cave. VPA also provided a coal mining heritage study prepared by Heritage Council of Victoria (HCV) in 2008. The LCA prepared by SMEC also references this report.

7.1 Review of Coal Mining Heritage Study

The history of the Parwan Mine, later called the Bacchus Marsh Coal Mine, is detailed within the HCV report. Upon accidental discovery of a 30 m thick coal seam at approximately 110 m below ground level in 1927 the surrounding area was privately purchased, and a mine shaft constructed in the same location. The location of the mine shaft is approximately 3 km west of the intersection of Ballan Road and Geelong-Bacchus Marsh Road. Figure 6 is an excerpt from the HCV report showing the location of the mine shaft with the extents of the PEP and PSP overlain. It can be seen that the location of the shaft for the Bacchus Marsh Coal Mine and the open cut for the Parwan Creek mine are outside the proposed PEP and PSP.

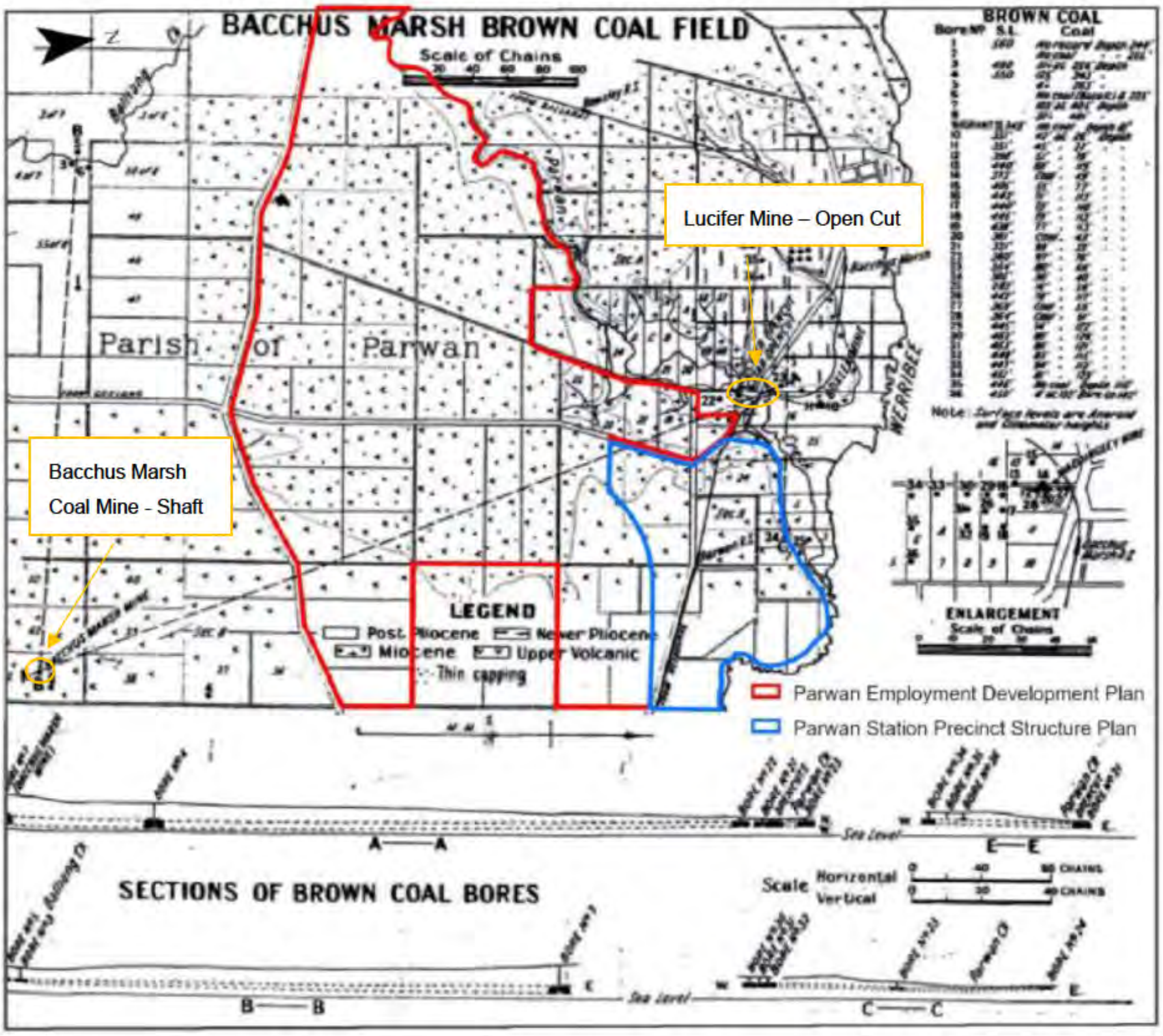


Figure 6: Excerpt from Coal Mining Heritage Study (HCV 2008 – Drawing 8.3/1 page 184) with extents of Parwan Employment Precinct and Parwan PSP Precincts overlain.

In the 1940s and later, further open cut mining commenced in a number of locations in the north of Parwan and Bacchus Marsh. These open cut mines included the Maddingley Brown Coal Mine No. 1, Maddingley Brown Coal Mine No. 2 (which is still in operation today), the Star Collieries Bacchus Marsh and the Lucifer Colliery Bacchus Marsh. Figure 7 is an excerpt from the HCV report showing the locations of the open cut mines with the extents of the PEP and PSP overlain. It can be seen that the locations of the open cut mines are outside the proposed PEP and PSP.

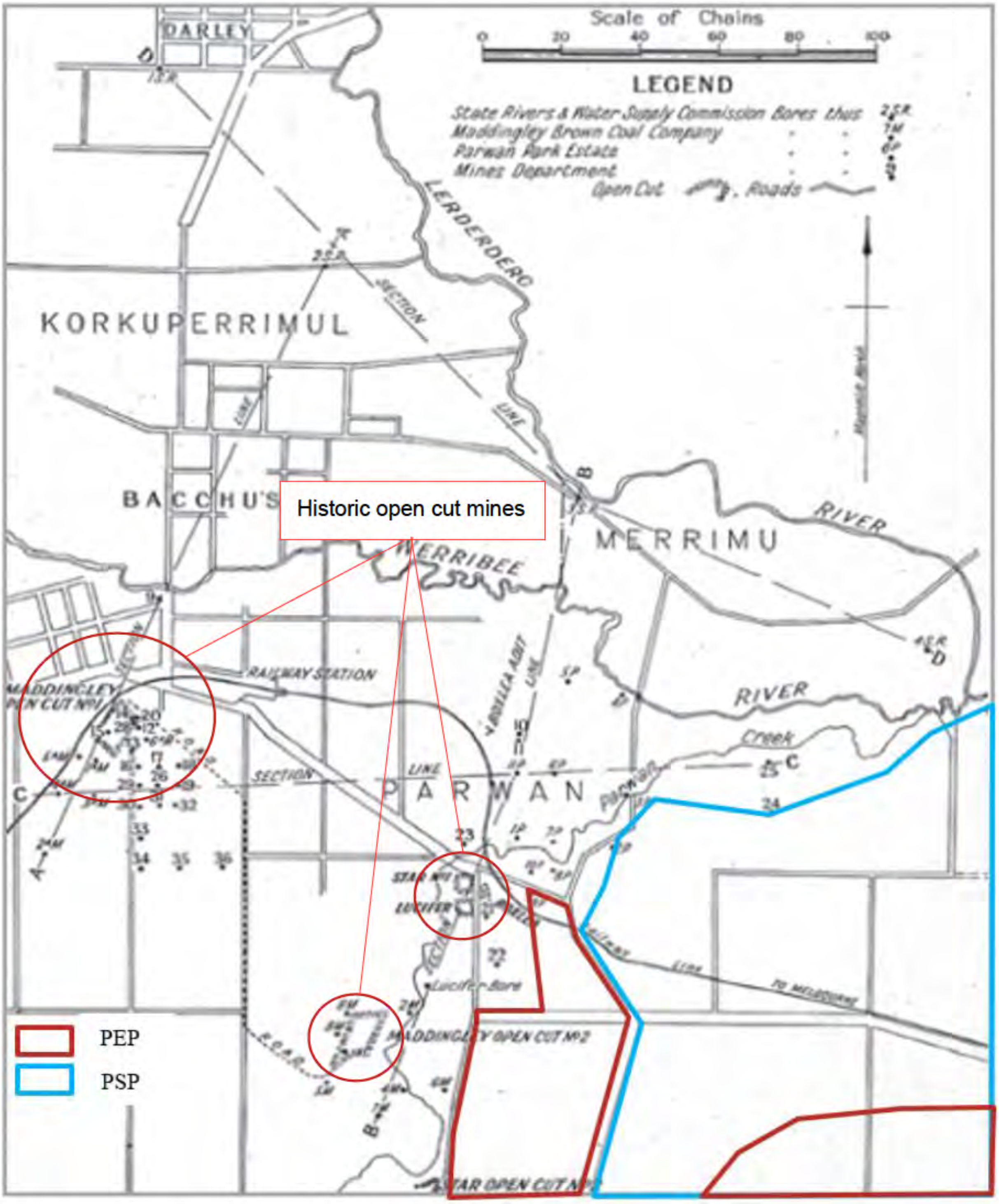


Figure 7: Excerpt from Coal Mining Heritage Study (HCV 2008 – Drawing 8.4/1 page 186) with extents of Parwan Employment Precinct and Parwan PSP Precincts overlain.

Reviewing the available information all areas of known mining activity lie outside of the proposed PEP and PSP. Therefore based on the available information it can be expected that historic mining activities will not impact the proposed developments within the PEP and PSP.

7.2 Review of LiDAR data

LiDAR derived digital elevation data for the Parwan PSP and Employment Precincts was supplied by VPA. The objective was to assess if there are any surface depressions in the precinct that might indicate collapse due to underground caves or mining shafts.

The elevation data was loaded into 3D visualization and modelling package known as “Leapfrog Works”. The software package was used to create slope angle maps from the elevation data, this could then be used to assess elsewhere in the PEP and PSP for similar slope signature as the known Parwan Lava Cave entrance (refer to Figure 8). Nearmap aerial imagery was also referred to at these locations to assess if the slope signature could potentially be subsidence and / or collapsed ground.

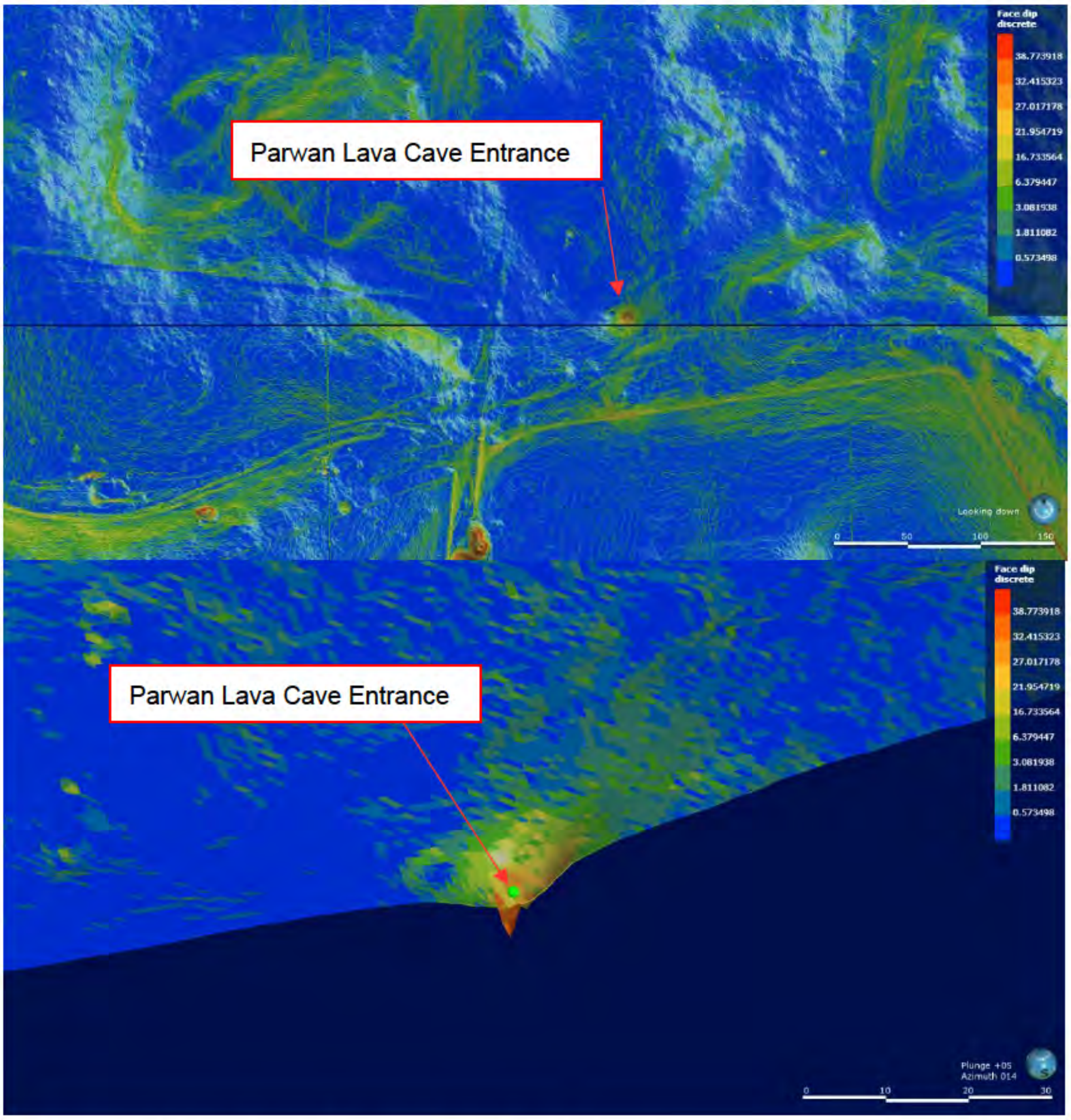


Figure 8: Slope angle signature of Parwan Lava Cave Entrance

Using this method three locations were identified as potential areas of localised ground subsidence or collapse, as set out in Table 1. In addition Nearmap aerial imagery of the locations is shown in Figure 9, Figure 10 and Figure 11. These locations in relation to the wider PEP and PSP are shown in Figure A3 of Appendix A.

Table 1: Locations of potential ground collapse

Location	Easting*	Northing*	Precinct	Property	Description
1	276033.50	5824138.50	PSP	51 Browns Lane, Maddingley	Refer to Figure 9, in paddock on southern side of property
2	276244.28	5824123.71	PSP	51 Browns Lane, Maddingley	Refer to Figure 10, in paddock on southeastern side of property
3	[redacted]	[redacted]	PEP	[redacted]	Refer to Figure 11, [redacted]ty

*Easting and Northings given in GDA2020 MGA Zone 55

Figure 9: Nearmap Aerial Imagery of location 1

Figure 10: Nearmap Aerial Imagery of Location 2

Figure 11: Nearmap Aerial Imagery of Location 3

It is important to note that these locations have been assessed on available LiDAR elevation data and aerial imagery and as such provide a high-level indication only of potential areas of localized ground subsidence or collapse. These locations are targets for further investigation. A site walkover could be undertaken to assess whether the surface depressions detected using the LiDAR imagery are related to ground subsidence or some other cause, and whether further investigation into subsurface voids within the vicinity of the surface depressions is warranted.

8.0 CONCLUSION

8.1 Summary of WSP Golder Findings

A summary of site investigations, in-cave measurements (RDF points) and geophysical scan lines, undertaken in 2022 by WSP Golder can be found in Appendix A, Figure 1A. An interpreted cave outline was developed by plotting the voids identified by the geophysics survey together with the in-cave disto measurements. This can be seen in Appendix A, Figure 2A.

While broadly consistent with the VSA 1969 survey the cave outline interpreted from geophysics and in-cave disto measurements suggests the cave extent is different in some respects to the VSA 2969 survey. Around the center of the cave (as mapped by the VSA in 1969), along geophysics scan line PC-ER106, a significant difference between the two can be seen. This difference is likely due to the presence of subsurface voids outside of the VSA 1969 survey extents in the form of rock rubble derived from historic cave collapse. These voids likely would not have been mapped as the VSA 1969 survey was conducted in-cave and these locations would have been inaccessible. Deviations in alignment can be seen between the two, particularly in the northeast corner and western end of the cave. This could be explained by inaccuracies in survey techniques and hand compass measurements used to survey the cave extent in 1969.

Other voids, likely associated with the formation of the Parwan Lava Cave, were detected by the geophysical survey. Figure 5 in Wakelin's study of the Parwan Lava Cave (included in Appendix C) illustrates a likely formation process that could have created these voids. Given the geological setting at the Parwan Lava Cave is not unique to the PEP and PSP, it is not unreasonable to assume there may be other voids present within the basalt rock in the PEP and PSP. In-cave observations and geophysics survey also show that the Parwan Lava Cave continues beyond its mapped extent, albeit not accessible by humans, in both west and east directions.

Review of LiDAR elevation data has indicated three areas of potential ground subsidence or collapse. As this review provides a high-level indication only, a site walkover would be needed to confirm if the depressions detected from LiDAR could be related to ground subsidence or collapse. Review of Coal Mining Heritage Study by HCV in 2008 found that historic mining shafts and open cut pit in the Bacchus Marsh area are outside the PSP and PEP.

Our survey of the Parwan Lava Cave itself indicates that the cave floor is approximately 8-10 m below ground level, however geophysical survey at the western end indicated the cave floor to be as shallow as 4 m below ground surface. The survey indicated that rock cover above the void was between 2 m and 7 m thick. Generally, we consider the basalt rock above the ceiling of the cave to be high strength and stable under current conditions.

8.2 Recommendations

A 10 m buffer has been applied to the interpreted extent of the Parwan Lava Cave extents and other voids identified by the geophysics survey. This buffer is labeled as a 'cave protection zone' in Figure 2A of Appendix A. The 10 m buffer is based on a 1:1 gradient from a maximum cave depth of 10 m. This 1:1 gradient is based on a geotechnical zone of influence which denotes the zone within which pressure applied at surface level will not change the ground stresses around the periphery of the cave opening and is therefore unlikely to impact upon the known section of cave. The cave protection zone would also apply to permanent works as well as construction practices such as excavation, piling and use of heavy machinery.

The potential impact to the cave from development within the 'cave protection zone' would need to be carefully assessed to ensure the cave is not damaged. The cave protection zone is not intended to indicate development is not possible in this area. Rather that development in this area needs to be scrutinized and analysed to ensure it does not affect the cave. We expect that light development could be undertaken in this area without causing an impact to the cave. Typically, it would be the responsibility of the developer to demonstrate the cave will not be impacted. Light development could include access for light vehicles such as utes and construction of lightly loaded structures such as footpaths, fencing or small buildings such as sheds.

It may need to be demonstrated that activities inside or outside the 10 m 'cave protection zone' that cause significant ground vibration will not impact the integrity of the cave. This can be achieved by monitoring the peak particle velocities (PPV) around the cave and ensuring induced vibration is kept below a pre-determined limit. A further study will need to be undertaken to determine this limit, however we note this is a typical requirement for development close to underground voids such as tunnels and critical services. Examples of activities that cause significant vibration could include but not limited to; earthworks incorporating dynamic compaction and heavy industry with processes that cause ground vibration.

Considering our findings of additional voids near the Parwan Lava Cave we consider it likely there are other voids underlying the proposed PSP and PEP. These voids could present a geotechnical risk for future construction activities and development. Should VPA wish to investigate these further, the following approach is suggested:

- Site walk over of the three areas identified as potential ground subsidence or collapse.
- Further staged geophysical survey with rapid coverage electrical methods (i.e. Frequency Domain Electromagnetics (FDEM) and or Ground Magnetics (GM) techniques followed by stage 2 targeted ERT and SRT survey.
- Borehole drilling in select areas to confirm results obtained from ERI.

We can provide a more detailed scope and indicative costing for the above items at VPA request. We are happy to discuss other approaches VPA might wish to undertake.

As an alternative to investigating voids across the entire precinct consideration could be given to planning controls requiring the presence of voids to be investigated specifically as part of each development within the precinct. Planning controls like overlays can formally protect and recognize the Parwan Lava Cave as well as stipulate where the presence of voids needs to be investigated for each specific development. A similar approach is taken in some former mining areas, for example for sites over the former Wonthaggi coal mines.

9.0 IMPORTANT INFORMATION

Your attention is drawn to the document - 'Important information relating to this report' (LEG04, RL2) which is included in Appendix D of this report. The statements presented in this document are intended to advise you of what your realistic expectations of this report should be. The document is not intended to reduce the level of responsibility accepted by WSP Golder, but rather to ensure that all parties who may use this report aware of the responsibilities each assumes in so doing.

We would be pleased to answer any questions the reader may have regarding this 'Important Information'.Signature Page

Golder Associates Pty Ltd

[redacted]

[redacted]
Senior Engineering Geologist

[redacted]

[redacted]
Technical Director

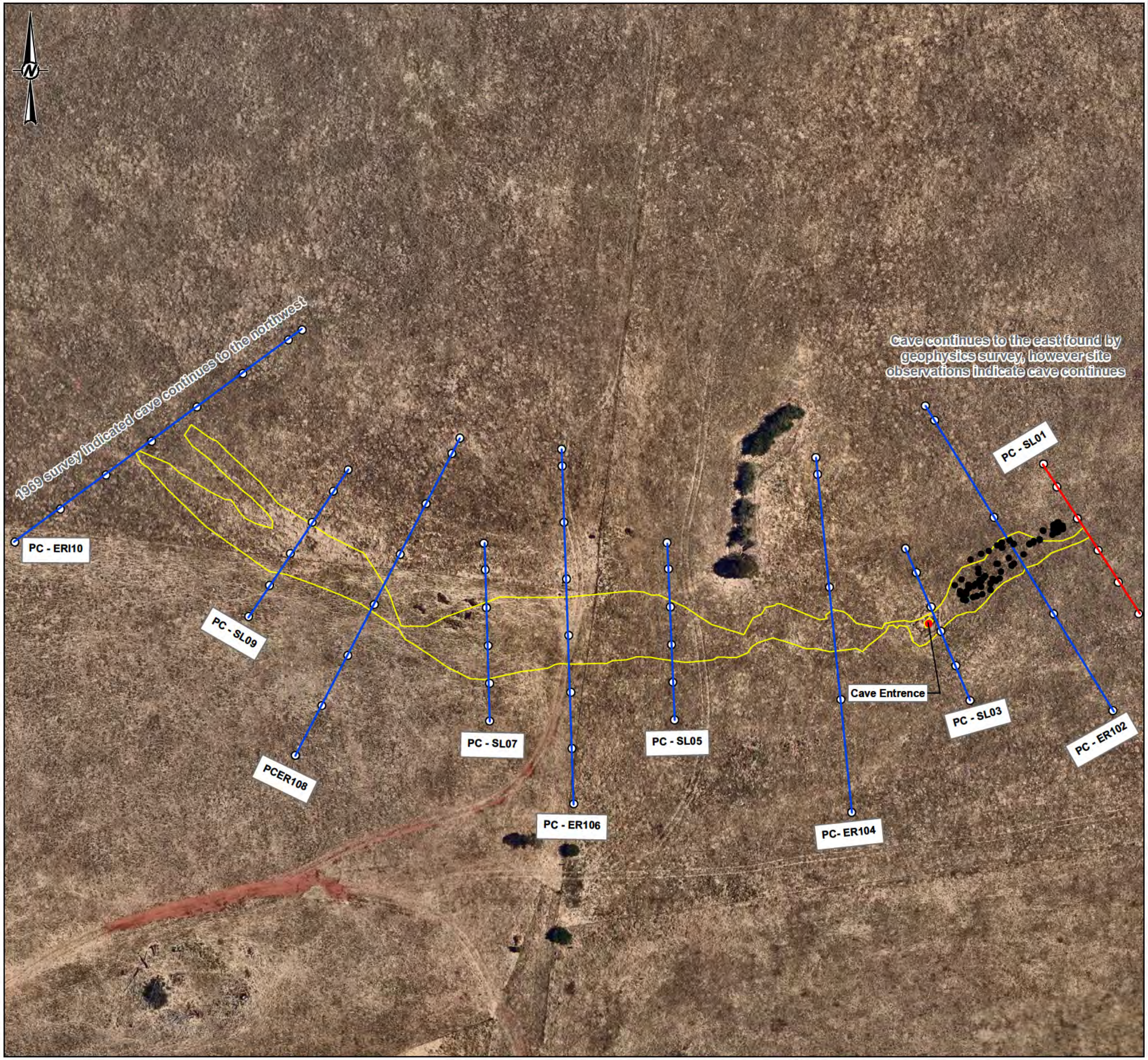
[redacted]

A.B.N. 64 006 107 857

https://golderassociates.sharepoint.com/sites/161680/project files/6 deliverables/ps132605-005-r-rev0 - parwn lava cave report/rev2/ps132605-005-r-rev2.docx

APPENDIX A

GIS Figures



Legend

- RDF Points
- Cave entrance
- Geophysical Line (red)
- Geophysical Line (blue)
- 1969 Survey - Cave outline

0 25 50
1:1,000 METRES

NOTE(S)

1. PROJECTION: GDA2020 MGA ZONE 55
2. THE MAGNETIC DECLINATION FOR THE STUDY AREA WAS NOT AVAILABLE PRIOR TO 2020 SO IT HAS BEEN CONSIDERED AS +11° 34' TO THE EAST TO MATCH WITH GRID NORTH AND ESTABLISH THE ANGULAR RELATION.
3. THIS MAP IS FOR DISCUSSION PURPOSES ONLY DUE TO LIMITATIONS OF THE DATA. GOLDER WSP CAN NOT GUARANTEE THE ACCURACY OF THIS INFORMATION AND IT SHOULD NOT BE RELIED UPON.

REFERENCE(S)

1. KEY MAP SOURCED FROM ESRI ONLINE BASEMAPS.
2.AERIAL IMAGE SOURCED FROM NEAR MAP WMS SERVISES DATED:26/04/2022.

CLIENT
VICTORIAN PLANNING AUTHORITY

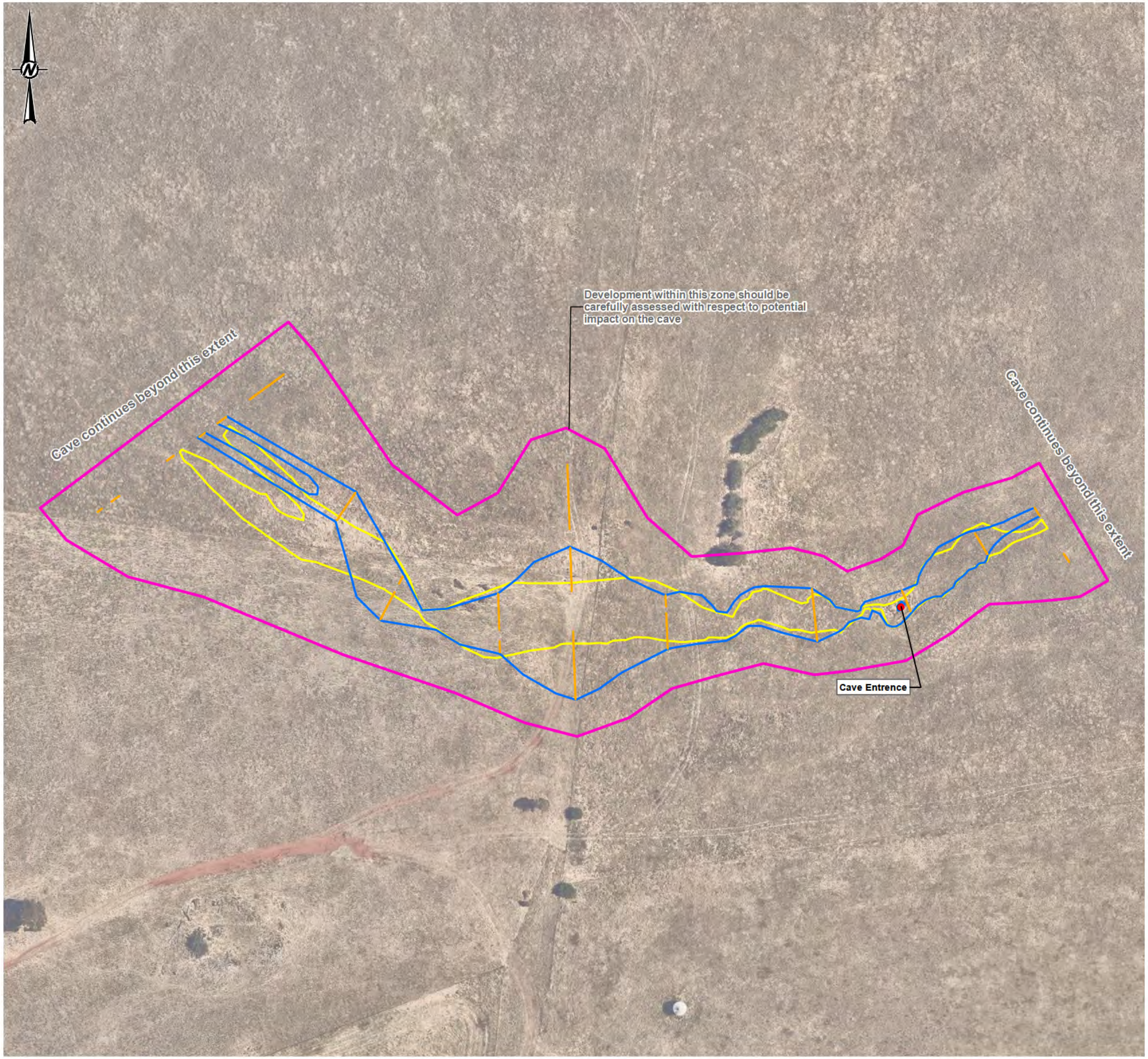
PROJECT
PARWAN CAVE PLAN

TITLE
PARWAN LAVA CAVE - SITE INVESTIGATIONS

CONSULTANT
WSP GOLDER

YYYY-MM-DD	16/03/2023
DESIGNED	AN
PREPARED	AN
REVIEWED	SFH
APPROVED	DRP

PROJECT NO.	CONTROL	REV.	FIGURE
PS132605	003	0	1A



[redacted]

Legend

- Cave entrence
- Voids identified by geophysics survey
- Interpreted 2022 cave outline
- Cave protection zone
- 1969 Survey - Cave outline

0 25 50

1:1,100 METRES

NOTE(S)

1. PROJECTION: GDA2020 MGA ZONE 55
2. THIS MAP IS FOR DISCUSSION PURPOSES ONLY DUE TO LIMITATIONS OF THE DATA. GOLDER WSP CAN NOT GUARANTEE THE ACCURACY OF THIS INFORMATION AND IT SHOULD NOT BE RELIED UPON.

REFERENCE(S)

1. KEY MAP SOURCED FROM ESRI ONLINE BASEMAPS.
2. AERIAL IMAGE SOURCED FROM NEAR MAP WMS SERVISES DATED:26/04/2022.

CLIENT
VICTORIAN PLANNING AUTHORITY

PROJECT
PARWAN CAVE PLAN

TITLE
PARWAN LAVA CAVE – 2022 SURVEY

CONSULTANT

WSP GOLDER

YYYY-MM-DD	16/03/2023
DESIGNED	AN
PREPARED	AN
REVIEWED	SFH
APPROVED	DRP

PROJECT NO.	CONTROL	REV.	FIGURE
PS132605	003	0	2A

[redacted]

APPENDIX B

Geophysical Survey

REPORT

PARWAN LAVA CAVE INVESTIGATION

GEOPHYSICAL SURVEY

Submitted to:

Victoria Planning Authority (VPA)

Level 25, Collins Street,
Melbourne VIC 3000
Australia

Submitted by:

WSP Australia Pty Ltd

Level 11, 567 Collins Street
Melbourne, VIC 3000
Australia

+61 3 8862 3500

PP137497-002

29/11/2022

Distribution List

Table of Contents

FIGURES

TABLES

APPENDICES

1.0 INTRODUCTION

WSP Golder Pty Ltd (WSP Golder) has been engaged by the Victorian Planning Authority (VPA) to provide geotechnical consulting services at the Parwan Lava Cave, located at the property of [redacted] The scope of services can be found in our fee proposal PP137497-002-L-Rev0 dated 11 May 2022 (this is updated fee proposal to our Response for Quotation (RFQ) attached to transmittal PP137497-001-T dated 7 April 2022).

The geophysical survey was conducted as a part of a geotechnical consulting services (the scope of geophysical services can be found in our fee proposal PP137497-002-L-Rev0). The geophysical survey used Seismic Refraction Tomography (SRT) to acquire P-Wave velocity measurements. The survey additionally utilised Electrical Resistivity Tomography (ERT), and shallow Seismic Reflection (SR) geophysical methods, for enhanced results.

Field data acquisition of the five seismic lines and five ERT lines (refer to Figure 1) was accomplished in two fieldwork campaigns: 1. On 15th of September 2022 and 2. On 3rd of November 2022. The surveys were completed by an experienced WSP Golder geophysics team from the Melbourne operating centre.

This report presents a brief description of the survey procedures and results. It should be read in conjunction with the geophysical methodology limitations and the other apriori information to enhance the sites understanding.

2.0 AIMS OF THE GEOPHYSICAL INVESTIGATION

The survey aimed to assist in characterising the subsurface conditions, and identify specific, localised velocity anomalies that may indicate the presence of intrusions, weak zones or increased weathering, cavities (possible cave chambers), and possible extension of the cave at the site.

3.0 SCOPE OF WORKS

The scope consisted of:

- Acquisition of five SRT survey traverses with a total combined length of 235 m;
- Acquisition of five SR survey traverses with a total combined length of 352.5 m;
- Acquisition of five ERT survey traverses with a total combined length of 472.5 m;
- Presentation of the SRT results as a series of 2D P-wave seismic velocity plots;
- Presentation of the SR results as a series of 2D reflection images in depth;
- Presentation of the ERT results as a series of 2D resistivity values in depth; and
- Preparation of a report summarising geophysical survey findings.

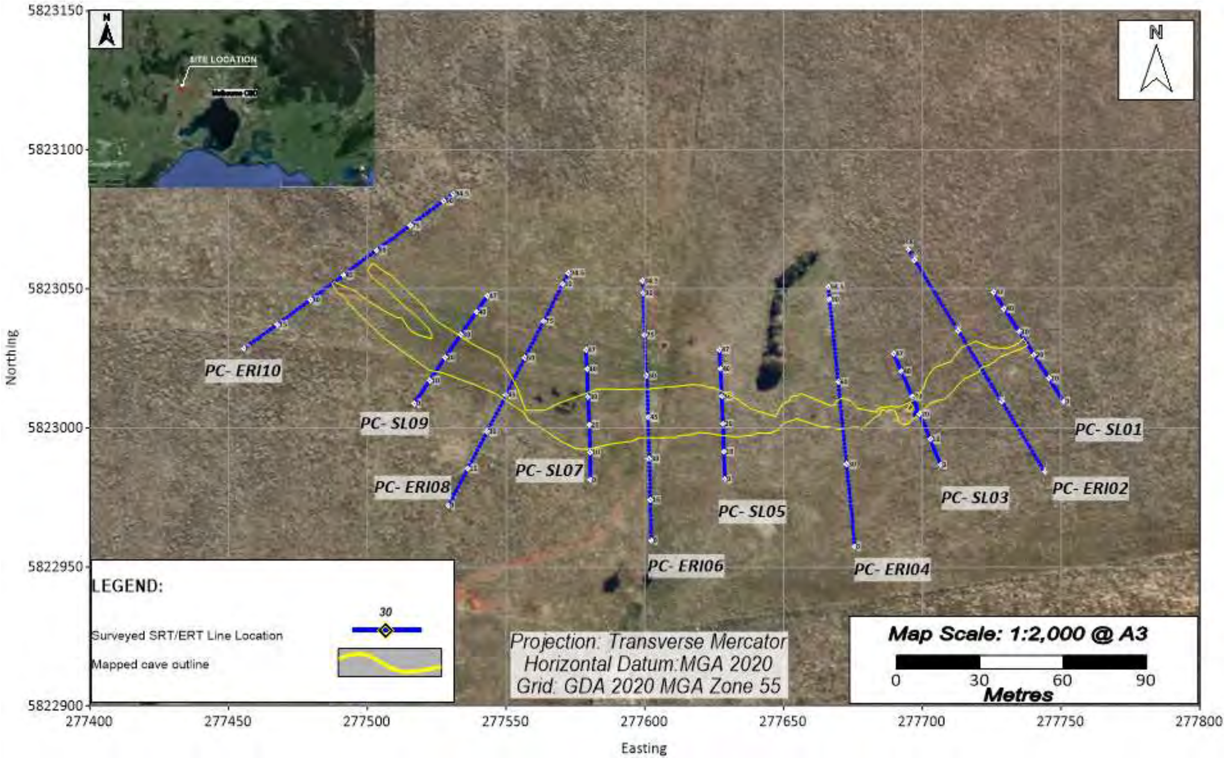


Figure 1: Seismic Survey Location Plan.

4.0 METHODOLOGY:

4.1 Seismic Refraction Tomography (SRT)

The seismic (SRT) technique measures the seismic wave velocity structure of the subsurface. Seismic wave velocity can assist in estimating subsurface differences such as ground density, which in turn can assist in identifying changes in the underlying ground profile. This includes discrimination of subsurface boundaries of contrasting density (for example, soil/rock interfaces). It can also assist in identifying abnormal low strength and/or highly fractured zones within rock masses.

The technique involves measuring the propagation of seismic body waves generated by a seismic source using a geophone array (see Figure 2). The first arrival times of the compressional (P) waves are then determined and analysed to produce the subsurface 2D P-wave seismic wave velocity profile. The process is then repeated at different locations to create a series of profiles of the seismic velocity of the subsurface conditions.

Analysis of the travel times of the direct and refracted waves provides information on the depth profile of the refractor. Following one of available velocity calculation methods (i.e. wavefront – Jones et al 1985, reciprocal, general reciprocal – Palmer 1980, Delta-t-V Gebrande and Muller 1985; Rohdewald 2011) the initial depth velocity model is generated. The initial velocity model is refined by applying the real 2D Wavepath Eikonal Traveltime Tomography algorithm (WET – Schuster et al. 1993) that allows for refraction and diffraction of seismic waves and the initial synthetic travel times which are created based on the initial velocity model. The velocity model is then refined through several WET iterations until the synthetic traveltimes optimally match the travel times as originally picked from the field measurements.

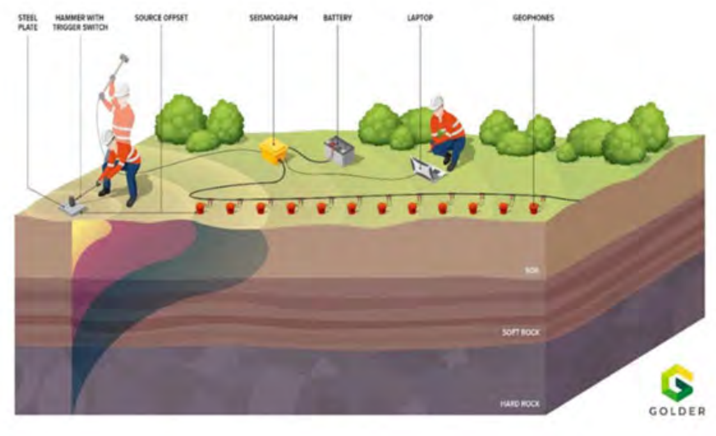


Figure 2: SRT field acquisition overview.

4.1.1 Limitations associated with SRT method

The initial velocity model may sometimes be constrained by processing artefacts caused by unfavorable seismic signal to noise ratio. The artifacts generated because of these effects are sometimes difficult to completely eliminate with the subsequent WET inversion. The resulting velocity model's competence in detecting vertical velocity inversions depends on its size, relative position, depth, receiver spacing, and shot geometry.

The main limitations of the seismic refraction method are summarised below:

- Low seismic signal-to-noise ratio (resulting in poor quality data) can create artifacts in the resulting initial P-wave velocity model;
- Subject to their size and depth and the geometry of the SRT survey, vertical velocity inversions (low-velocity layers occurring below materials having a higher velocity) sometimes may not be imaged;
- Detectability of layers with small seismic impedance contrast;
- Vertical resolution and accuracy of the P-wave velocity model decrease with depth.

4.2 Seismic Reflection (SR)

Two-Dimensional (2D) SR involves artificially generated acoustic energy traveling down from the seismic source and reflecting back to the seismic receivers (geophones) at the surface. Specialised multi-channel seismic receiver equipment records the acoustic energy back at the surface as it reflects off boundaries at depth (Figure 3). A seismic reflection occurs when the acoustic wavefront encounters change in acoustic impedance, which is a product of material density and compressional waves' seismic velocity in the subsurface. The impedance boundaries occur where the material properties change abruptly, usually due to changes in the lithology or mechanical properties of the rock.

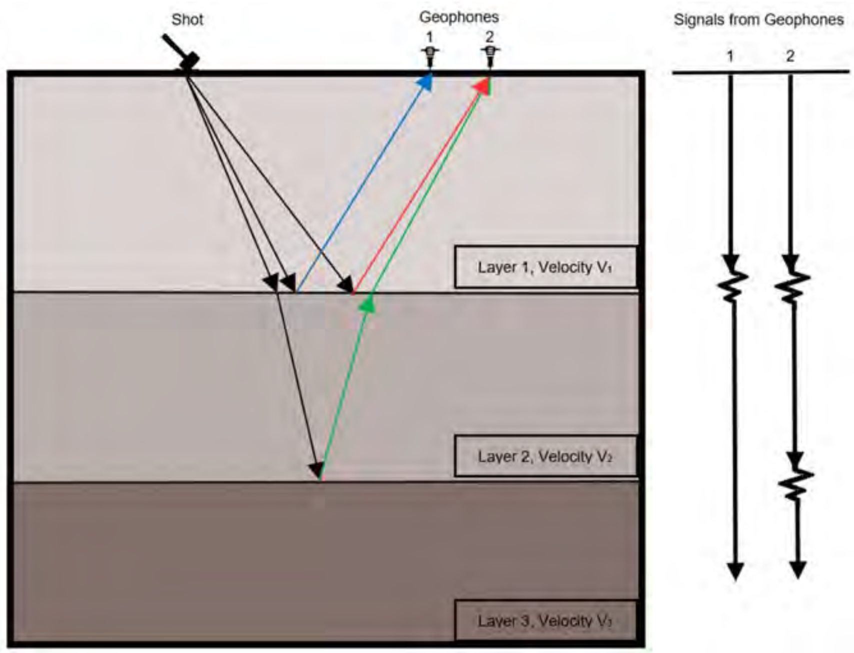


Figure 3: Seismic Reflection Principles.

4.2.1 Limitations associated with SR method

- In cases of deep weathering and/or very loose sediments on the surface, the seismic signal may be attenuated, and data resolution may suffer in areas with unconsolidated materials (i.e. sand, peat) at the near-surface.
- Seismic reflection does not provide information related to material properties (elastic moduli, Poisson's ratio, etc).
- It is often necessary to have cored borehole and velocity data (VSP) to calibrate the seismic velocity-depth profile.
- Although good in imaging faults, 2D seismic reflection surveys are limited in defining the fault orientation. In cases when the 2D seismic profile orientation is close to the fault plane orientation, the seismic image might appear smeared, and the fault may be missed or unclear.

4.3 Electrical Resistivity Tomography (ERT)

Electrical resistivity surveys have been used for many decades in hydrogeological, mining and geotechnical investigations, and more recently, have been successfully used for environmental surveys. The direct current (DC) resistivity method measures the electrical resistivity, or conversely the conductivity, of the subsurface. The electrical resistivity of soils/rocks is governed by water content, porosity, clay content, and grain size, i.e. the higher the water and clay content the lower the resistivity, or conversely, the higher the electrical conductivity.

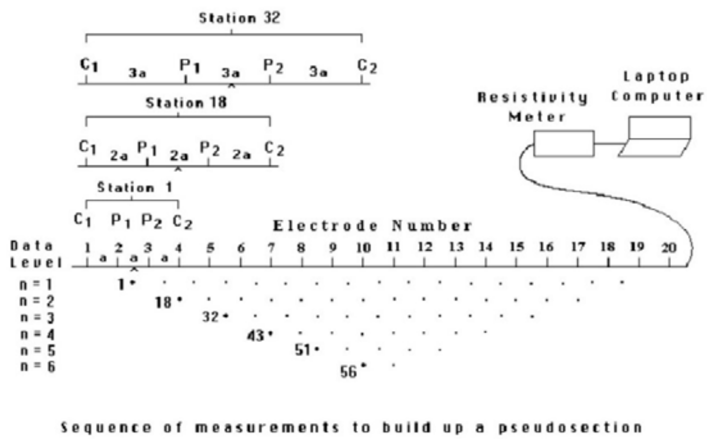


Figure 4: Typical ERT survey setup and configuration.

Resistivity measurements are normally made by injecting current into the ground through two current electrodes (C1 and C2 in Figure 4) and measuring the resulting voltage difference at two potential electrodes (P1 and P2). By collecting measurements along predetermined survey lines, profiles showing the lateral change in resistivity are generated, which are then used with other information to help identify and delineate subsurface features, such as buried pits, landfill boundaries, and soil types.

A resistivity survey collects apparent resistivity data which indicates the variation of subsurface resistivity from a homogeneous half-space. It is common practice to use the collected apparent resistivity data in a reconstruction process (inversion) to obtain an image of the true subsurface resistivity structure that provides actual resistance values and depth.

4.3.1 Limitations associated with ERT method

The resistivity method is an effective geophysical tool that exploits the fact that the resistivity of geological materials varies over several magnitudes of order (more than any other petro-physical properties). However, as with any geophysical technique there are limitations.

- The static nature of the current source limits current penetration to depths. Therefore, the resolution of a surface-based resistivity survey decreases with depth. Caution should be used in interpretation of resistivity sections at depth
- Sources of noise include: telluric currents, power lines, buried cables, earthing systems, self-potential
- Poor coupling between the electrodes and ground can occur in sandy, dry, or outcropping geology which can lead to unusually high apparent resistivity data
- The electrode polarisation effect is unavoidable when using stainless steel electrodes over porous pots. This is due to the change in mode of conduction from metallic to ionic and can be significant
- Capacitive coupling between the current and voltage channels in the multichannel cables increases with increased cable length and this can interfere with resistivity measurements. It is also increased by differing contact resistances of the takeout electrodes
- Insufficient contrast in the resistivity of the target material and surrounding material will limit the delineation of the target material.

4.4 Interpretation of geophysical results and limitations

The general vertical accuracy of the seismic methods is between 10 and 20% of interpreted depth. Resolution (detectability) of the methods depends on receiver spacing and depth of interpretation, generally described in the literature as being in the range of 2 to 3 geophone spacing at depth.

NOTE: It is important to recognise that the condition of the subsurface material, including density, degree of saturation and moisture content (for soil), and degree of fracturing and strength parameters (for rocks), cannot be directly quantified by the results of the seismic survey alone. These parameters have to be considered in conjunction with the overall geotechnical investigation results, geotechnical testing and interpretation.

4.5 Survey Methodology

4.5.1 Seismic Survey set up

Seismic survey work was carried out using five lines (refer to Figure 1). The survey was conducted using a Seismic Source DaqLink 4 seismographs connected to a system consisting of multi-takeout cabling and forty-eight 4.5 Hz geophones spaced at 1 m intervals. Energy for the seismic survey was produced by impacting a metal plate with a sledgehammer. The sounding record was a transducer "trigger switch" attached to the sledgehammer. An example of a typical seismic survey line configuration on-site is presented in Figure 5.

The seismic survey was conducted in general accordance with AS1726-2017.

Figure 5: Example of a seismic line survey configuration.

4.5.2 ERT Survey set up

The ABEM Terrameter LS2 Resistivity meter was used with four 16 takeout cables, providing a total of 64 electrodes per spread. To achieve the required line and the depth of the target 1.5 increments between the electrode were chosen and used. The acquired data were exported to an ascii DAT file, which is readable by Res2DINV processing software

An electrode check was conducted before the start of the data acquisition. Electrodes found to have relatively high contact resistance were watered with saline solution to improve the electrical contact between the electrode and the soil. The test configuration set up is shown in Figure 6.

Figure 6: Example of an ERT survey configuration.

4.5.3 Survey Datum

All seismic lines in this project were acquired using the GDA2020 MGA Zone 55 horizontal Datum. The elevations were recorded in AHD.

4.5.4 Survey Acquisition Parameters and survey summary

Acquisition parameters used in the surface seismic survey can be summarised as follows:

- Sampling interval: 0.125 ms
- Record length: 1 s
- 8,000 samples / record
- Files saved in SegY and Seg2 format
- Geophone Spacing: 1 m

The total linear length of seismic data acquired and processed is 235 m for SRT and 352.5 m for SR.

The line positions were provided before mobilising to the site. The middle of the surveyed lines was positioned in the middle coordinate and the survey lines were laid down in the provided coordinates to cover the potential cave area. The provided positions are summarised in Table 1

Table 1: Parwan Cave approximate Lines Direction Coordinates.

Line Name	Start Easting (m) (GDA2020, MGA Zone 55)	Start Northing (m) (GDA2020, MGA Zone 55)	Middle Easting (m) (GDA2020, MGA Zone 55)	Middle Northing (m) (GDA2020, MGA Zone 55)	End Easting (m) (GDA2020, MGA Zone 55)	End Northing (m) (GDA2020, MGA Zone 55)
PC-SL01	277753	5823003	277723	5823052	277737	5823030
PC-ET02	277736	5822996	277705	5823045	277718	5823024
PC-SL03	277708	5822979	277683	5823035	277696	5823007
PC-ET04	277672	5822977	277667	5823032	277669	5823004
PC-SL05	277626	5822974	277625	5823033	277626	5823005
PC-ET06	277599	5822972	277597	5823034	277598	5823006
PC-SL07	277581	5822972	277580	5823033	277580	5823004
PC-ET08	277536	5822984	277564	5823041	277551	5823014
PC-SL09	277510	5822999	277542	5823055	277527	5823029
PC-ET10	277468	5823036	277516	5823078	277492	5823057

Details of the survey lines are summarised in Table 2 for SRT and Table 3 for SR, below.

Table 2: Parwan Cave SRT Survey Statistics.

Line Name	Start Easting (m) (GDA2020, MGA Zone 55)	Start Northing (m) (GDA2020, MGA Zone 55)	End Easting (m) (GDA2020, MGA Zone 55)	End Northing (m) (GDA2020, MGA Zone 55)	Number of Shots	Length (m)
PC-SL01	277751.0	5823009.5	277725.7	5823049.1	20	47
PC-SL03	277706.6	5822986.7	277689.3	5823027.6	31	47
PC-SL05	277628.9	5822981.6	277626.9	5823028.5	31	47
PC-SL07	277580.3	5822981.3	277578.8	5823028.0	29	47
PC-SL09	277543.2	5823047.4	277517.0	5823008.8	29	47
Total					**140**	**235**

Table 3: Parwan Cave SR Survey Statistics.

Line Name	Start Easting (m) (GDA2020, MGA Zone 55)	Start Northing (m) (GDA2020, MGA Zone 55)	End Easting (m) (GDA2020, MGA Zone 55)	End Northing (m) (GDA2020, MGA Zone 55)	Number of Shots	Length (m)
PC-SL01	277757.3	5823000.0	277719.7	5823058.9	20	70.5
PC-SL03	277711.0	5822976.1	277684.4	5823038.0	31	70.5
PC-SL05	277629.5	5822970.1	277626.5	5823040.0	31	70.5
PC-SL07	277580.4	5822970.0	277578.1	5823039.5	29	70.5
PC-SL09	277510.7	5822999.4	277549.6	5823056.8	29	70.5
Total					**140**	**352.5**

Acquisition parameters used in the ERT survey can be summarised as follows: Parameters used for the recording of the ERT data are:

- Array Type: Dipole-Dipole
- Total distance covered: 94.5 m
- Electrode increment: 1.5 m
- Delay Time: 0.7 s
- Acquisition time: 0.3 s
- Sample rate: 1000/1200 Hz
- Max power: 200 w
- Stack Range: Min 2, Max 5
- Output Voltage Maximum: 500 V

Details of the surveyed boreholes are summarised in Table 4 below.

Table 4: Parwan Cave ERT Survey Statistics.

Line Name	Start Easting (m) (GDA2020, MGA Zone 55)	Start Northing (m) (GDA2020, MGA Zone 55)	End Easting (m) (GDA2020, MGA Zone 55)	End Northing (m) (GDA2020, MGA Zone 55)	Length (m)
PC-ET02	277744.2	5822984.1	277694.9	5823064.2	94.5
PC-ET04	277675.5	5822957.3	277666.1	5823050.6	94.5
PC-ET06	277602.4	5822959.5	277599.2	5823052.8	94.5
PC-ET08	277529.2	5822972.2	277572.5	5823055.7	94.5
PC-ET10	277455.5	5823028.4	277531.0	5823084.2	94.5
Total					**472.5**

5.0 DATA PROCESSING AND ANALYSIS

5.1 SRT Data processing

Interpex IxSeg2SegY and Intelligence Resources Rayfract seismic processing software were used to pick the first signal arrival breaks, with signals filtered where needed using band-pass filtering and inversion techniques in the respective software.

Rayfract v 4.02 tomographic software was used in the inversion and interpretation of the acquired seismic line data.

The final P-wave seismic tomograms presented as figures in Appendix A (Figures A01 and A02) were created using Golden Software Surfer 20 Gridding software. The SRT seismic data processing involved the following steps:

1) Generation of the database files
2) Data and geometry Import
3) Correction of the trigger delay
4) Data check QA /QC – pre-processing (Bandpass filter; de spiking, signal gain)
5) Picking first arrival times
6) Checking the first arrival picks in the shot gather view
7) Creation of the initial velocity models (i.e., 1D Smooth Delta t-V velocity model);
8) The interactive parameterisation of the WET algorithm with Wavelength-Dependent Velocity Smoothing - WDVS (Zelt and Chen 2016) was applied and tested;
9) Running the inversion using the optimally parameterised WET inversion
10) Plotting the P-wave velocity model using Golden Software Surfer 20 software

5.2 SR Data processing

The gathered SEGY file generated for SRT was used as input data for 2D SR. Seismic Unix open-source software (industry standard) was used for the seismic data processing and stack imaging. The pre-stack processing was mainly focused on the suppression of the background noise.

The final migrated images overlayed by SRT results presented as figures in Appendix A (Figures A05 to A08), were created using Golden Software Surfer 20 Gridding software. The 2D SR data processing involved the following steps:

1) Conversion of SEGY to proprietary format;
2) Geometry assignment, QC & trace edit;
3) Filter tests;
4) Compensation associated with geologic effects and the propagation of seismic waves;
5) Correction for spherical divergence (amplitude correction based on offset);
6) Calculation and application of surface consistent refraction statics;
7) Muting the first arrivals;
8) Noise attenuation: Air blast elimination, Surface wave noise attenuation;
9) Velocity Analysis (Constant velocity stacks and semblance);
10) NMO application;
11) Brute stack;
12) Common Reflection Surface (CRS) processing;
13) Post-stack migration;
14) Post-stack data enhancement;
15) SEG Y file outputs;
16) Plotting the migrated section using Golden Software Surfer 20 software.

5.2.1 Refraction Statics

One of the most important steps in the 2D seismic reflection data processing is the computation of refraction statics. This was especially important in this data set due to the presence of a shallow weathered layer.

Picking the first refraction arrivals of the seismic signals travelling through regolith (i.e. the shallow overburden and variably weathered rock) is essential in determining the refraction statics. Picked first break times from SRT in Rayfract were imported to be used for this purpose.

Definition of the accurate refraction statics can influence the clarity and correct interpretation of the 2D seismic reflection horizons and determination of seismic facies.

An example shot showing the application effect of this process on the data is presented in Figure 7.

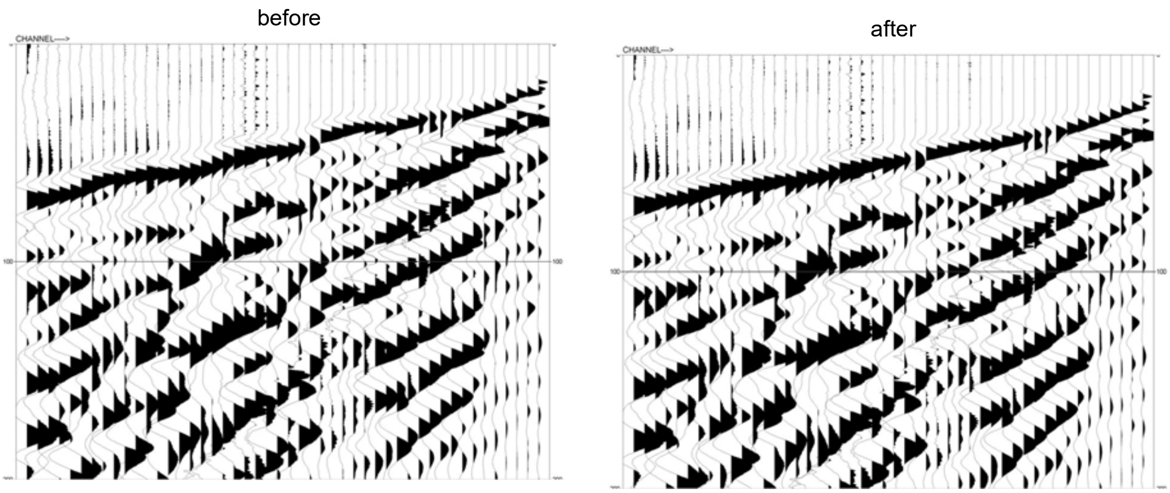


Figure 7: Example of a seismic shot before and after application of the refraction residual correction.

5.2.2 Seismic Reflection Processing Procedures

This section of the report contains series of processing images acquired in sequential order. This is to illustrate the procedure and the approach used in the processing the raw seismic data to a point where interpretation of the sub-surface layering in the ground can be undertaken.

The sections are presented in amplitudes in greyscale.

The amplitude relates to the response of the seismic wave travelling through the ground and its change as it intersects differing geological boundaries. These changes in the seismic signal can be processed and mapped to provide an image of the sub-surface conditions.

The technical processing involves several filtering and data correction steps to produce the final model output. These sequential processing steps include the initial 'brute stack', and the 'Common Reflection Surface (CRS) stack' as presented in Figure 8 and Figure 9 respectively.

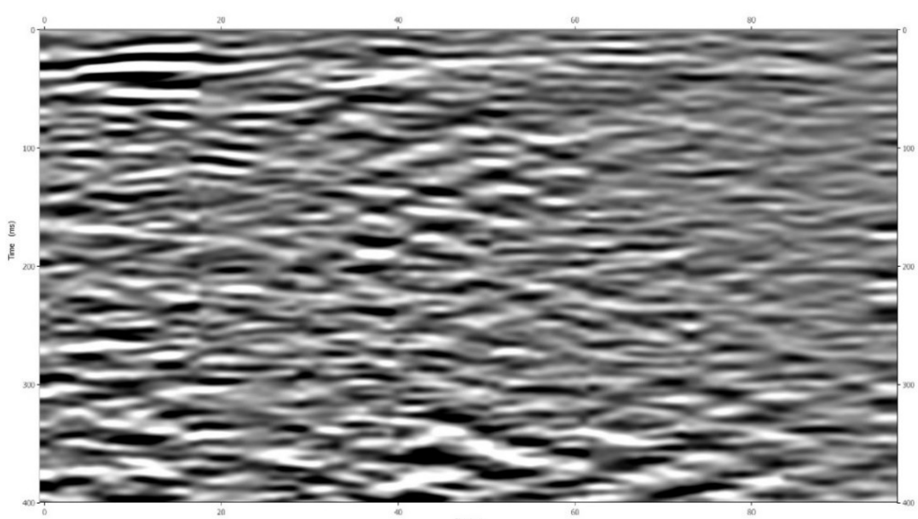


Figure 8: An example Brute stack.

Figure 8 shows initial “Brute” common depth point (CDP) or common mid-point (CMP) stack image. The CDP represents the sum of the traces of seismic reflection data, acquired from a “split spread” roll-along survey, which corresponds to the same common depth point but originates from different seismic profiles and offsets. The technique substantially reduces the amplitude of incoherent noise, multiples with their different normal moveouts, diffractions, etc.

Common Reflection Surface (CRS) Processing provides tools to bring structural information into time processing. This approach can be used for data enhancement, velocity analysis, or even residual moveout analysis. In all of these workflows, some tools are utilised by CRS to mix data across bins (i.e. CDPs) logically. The common reflection surface (CRS) stacking technique can be used in complex environments to increase the fold and, signal quality and produce reliable stacked sections with high resolution (Gierse et al. 2003; Heilmann et al. 2004). The result of the application of the CRS processing is presented in Figure 9

The horizontal axes of the stacked images are expressed in distance. The vertical axes are presented in time in milliseconds

Further steps in processing involve pre-stack and post stack migrations. The migration is undertaken to retrieve the true position of the reflectors in time and depth domain. Further processing steps included the time migration and time-to-depth conversion.

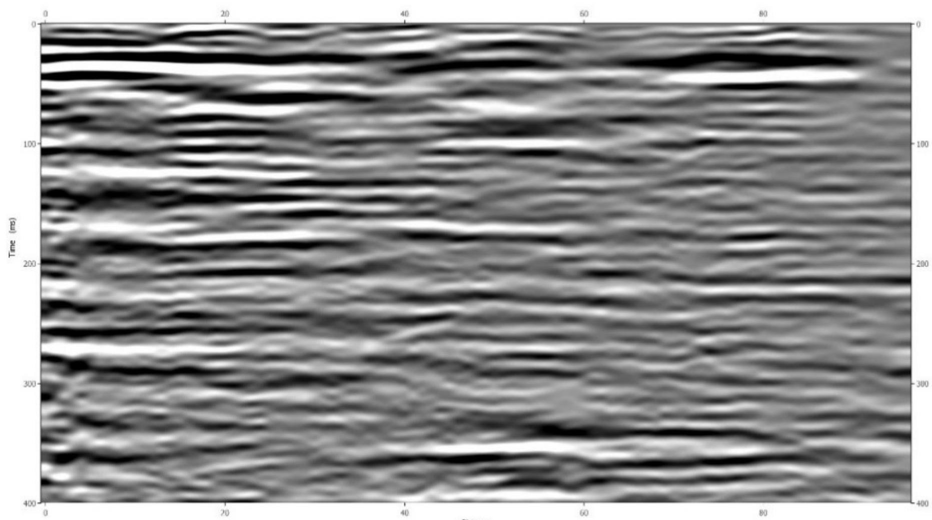


Figure 9: An example CRS stack.

The time to depth conversion is usually based on constant stacking velocity (CSV) and/or semblance velocity analyses or some externally acquired information (i.e. Seismic refraction Tomography – SRT, model downhole geophysics; Full Waveform Sonic etc.). In this report, a single velocity function derived from the velocity analysis was used for time to depth conversion. Further analyses of this step (using other information i.e. Seismic refraction Tomography – SRT, model downhole geophysics; etc.) are beyond the scope of this factual report.

5.3 ERT Data processing

The data sets were downloaded from the ABEM system and imported into Res2DINV software. Res2DINV is an industry-standard software package for the processing, inversion and interpretation of 2D and 3D electrical resistivity data. Once the data was imported into Res2DINV, the following procedures were followed:

The data was plotted and erroneously high or low resistivity values that may have affected the inversion and interpretation were removed from the data set.

Once spurious data was removed, the data was “inverted” to produce the Inverse Model Resistivity sections. The inversion process essentially determines a model (an idealised mathematical representation of a section of the earth) for the subsurface whose response agrees with the measured data subject to certain assumptions.

The data were inverted multiple times using different inversion parameters. Two different resistivity starting models were used as input to the inversion process: a homogeneous model and the resistivity pseudo-section which consists of the apparent resistivity data collected from the survey. The two inversion products (i.e. resistivity models) were compared in terms of the level of root mean square (RMS) data fit. This is a percentage value that indicates the level of agreement between the modeled (inversion resistivity section) and the surveyed data, the higher the RMS data fit the less the agreement is between the data and the model. The pseudo-section inversion provided the output with the lowest RMS (root mean square) data fit. The level of smoothing in the inversion process was also varied. Applying smoothing to the inversion, limits the amount that resistivity values may vary between model cells. It is necessary to apply smoothing to constrain the mathematical equation in the inversion process.

The processing routine has been focused on the extraction of any detectable contrast in resistivity that can indicate the potential anomalies associated with caves and cavities. Some directional filter damping was applied in the processing to minimise the influence of deeper layers and potential material anisotropy effects.

The RES2INV inversion results were plotted using Surfer 20 gridding software.

6.0 RESULTS AND CONCEPTUAL INTERPRETATION

The SRT P-Wave results for the seismic survey lines are presented as colored velocity models in Figures A01, A03, A05, A07 and Figure A09 - Appendix A.

The model figures present different seismic velocity values with the appropriate colour range from ‘colder’ or blue color representing lower velocities to the more intense or warmer color ranges (yellow, red, white). More intense (i.e. warmer) colours represent a corresponding relative increase in material density – velocity (seismic Impedance). NOTE: The color stretch in the P-wave velocity tomograms and the ERI resistivity sections (Figure A02, A04, A06, A08 and A10 – Appendix A) accentuate the physical property contrast within the imaged anomalies, and is adjusted individually for each figure.

An inferred soil /rock interface contour of 700 m/s is shown on the SRT velocity tomograms as a dashed orange line. This is a typical P-wave velocity cut-off value taken as a representing soil / rock interface in unsaturated environments. The interpretation of soil / rock interface is based on literature and the extensive experience in using the SRT method in similar geological environments. NOTE: The interpretations of soil/rock interface are not intended to be definitive. Further investigation with a review of other information such as borehole logs, core, etc, may be completed to verify that the interpretations are reasonable.

The SRT results are derived using the WET tomography inversion which follows the basic Fermat's principles of seismic energy distribution ('the seismic energy always travels via quickest paths'). Due to the nature of the true 2D wave path tomography inversion, the SRT method allows for reconstruction of seismic paths and ray coverage. This way, it is possible to reconstruct the preferred seismic energy trajectories and establish presence of weak / low velocity zones within the subsurface. Using the SRT method it is possible to image the low coverage / low velocity zones through the ray coverage images. The SRT P-Wave Ray Coverage models for the seismic survey lines are presented as a coloured image in Figures A01a, A03a, A05a, A07a and Figure A09a - Appendix A.

The SR migrated images overlayed with SRT results for the seismic survey lines are presented in Figure B01 to B05 - Appendix B.

The horizontal axes of the images are expressed in the line chainage (m). The vertical axes are presented in reduced levels (AHD - m).

The relevant survey line is shown in red on the location inset map, along with survey line chainage markers for each figure.

The mapped cave outline is presented by a yellow polyline shape within the inset figure. Generally, the seismic and ERT surveyed lines are aligned towards the north and perpendicular to the potential cave location indicated by the yellow polyline shape in the figure inset maps.

6.1 SRT Results

6.1.1 PC_SL01 results

Two relatively low velocity zones (<1400 m/s) are present at an RL between 140 m and 145 m line chaiange, which shows the possible slight discrepancy between the cave outline depicted by Yellow polyline in the figure inset. The general location of the velocity anomaly correlates well with the cave probing data collected from the recent cave inspection by WSP Godler geotechnical engineer and the client representatives.

The detailed SRT result is depicted in Figure A01 - Appendix A.

The ray coverage also correlate with the result from SRT velocity model and show the rays are traveling through the higher velocity material and the low coverage areas are due to the relatively lower-velocity zones associated with the possible location of the cave.

The Ray Coverage image for PC_SL01 seismic line is depicted in Figure A01a - Appendix A.

6.1.2 PC_SL03 results

A low-velocity zones (<1400 m/s) is present at the RL between 133 m and 138 m chaiange, which shows the entrance of the cave from the map depicted in Yellow and correlate with the data from site visit. There are deviations in the low velocity zones in the middle of the survey line whichalso correlate with the results from the site visit and the cave entrance.

The SRT Vp velocity tomogram of this line is depicted in Figure A03 - Appendix A.

The ray coverage image (Figure A03a – Appendix A)correlates with the result from SRT and show the rays 'avoiding' lower velocity material resulting in the low ray coverage areas at the possible location of the cave.

6.1.3 PC_SL05 results

Couple of relatively low velocity anomalies are present at the RL between 133 m - 143 m. The main lower velocity zone (<1900 m/s) situated at around the offset of ~20 m and depth of ~138 is most probably belong to the mapped cave, which its extension goes further north to around the offset of 30m. There is another anomaly present at the same level of the cave towards the north side of the survey area.

The resulting SRT velocity tomogram is depicted in Figure A05 - Appendix A.

The ray coverage image (Figure A05a - Appendix A)shows rays traveling through the higher velocity material and the low coverage zones coincide with possible location of the cave.

6.1.4 PC_SL07 results

A low-velocity zone (<1400 m/s) is present at the RL of ~140 m, which exist from the offset ~10 m to ~30 m. The extension of this low-velocity zone correlates with the cave shown in the map.

The detailed SRT result is depicted in Figure A07 - Appendix A.

The ray coverage also correlates with the result from SRT as the rays are traveling through the higher velocity material and the low coverage areas are due to very low-velocity zones which belong to the possible location of the cave.

The detailed Ray Coverage image is depicted in Figure A07a - Appendix A.

6.1.5 PC_SL09 results

A relatively low-velocity zone (<1400 m/s) is present at the RL between 135 m - 140 m, which exists from the offset ~20 m to ~40 m. The extension of this low-velocity zone might be the indication that the cave deviated north compared to the original map.

The SRT velocity result is depicted in Figure A09 - Appendix A.

The ray coverage image is depicted in Figure A09a - Appendix A.

6.2 ERT Results

The factual interpretation of the ERT survey results was made taking into consideration the purpose of the ERI survey; to identify and locate potential cavities related to the lava cave.

The profiles are shown with an arrow above which indicates the orientation of increasing chainage relative to the map inset in the top right-hand corner.

The electrical resistivity of soils/rocks is largely governed by water content and salinity, porosity, clay content, and grain size, i.e. the higher the moisture and clay content the lower the resistivity, or conversely, the higher the electrical conductivity.

6.2.1 PC_ET02 results

A relatively high resistivity zone (>500 ohm/m) is present at the RLs between 130-140 m, between the chainages of ~40 m and 60 m, which shows the possible location of the cave and correlates with the data from the recent site visit.

The results are presented in Figure A02 – Appendix A.

6.2.2 PC_ET04 results

A relatively high resistivity zone (>500 ohm/m) is present at the RLs between 125-140 m, between the ~30 m and 60 m chainages , which indicates the possible location of the cave.

The results are presented in Figure A04 – Appendix A.

6.2.3 PC_ET06 results

A couple of relatively high resistivity zones (>750 ohm/m) are present at the RLs between 130-143 m, between the offsets of ~20 m and 40 m and ~50 m to 90 m, which shows the possible discrepancies from the original mapped cave represented by the yellow polyline in the figure inset map.

The results are presented in Figure A06 – Appendix A.

6.2.4 PC_ET08 results

A couple of relatively high resistivity zones (>1000 ohm/m) are present at the RLs between 135-143 m, between the offsets of ~35 m and 55 m, correlate with the original mapped cave as shown in the inset map.

The resistivity tomogram of this line is presented in Figure A08 – Appendix A.

6.2.5 PC_ET10 results

A couple of relatively high resistivity zones (>500 ohm/m) are present at the RLs between 135-143 m, between ~30 m and 50 m and ~65 m to 85 m line chainages, showing possible deviation towards north from the original mapped cave shape depicted by the yellow polyline in the figure inset map.

The resistivity tomogram for this line is presented in Figure A10 – Appendix A.

6.3 SR Results

2D Seismic Reflection is commonly being used to map the differences in acoustic impedance that result in the reflection of the surface seismic source generated energy. The 2D seismic sections typically are used to image major lithological boundaries' thickness and spatial distribution and highlight geological structures such as discontinuities or faults. A change in reflector continuity, shape or frequency of seismic waves could represent a layer boundary, and the reflector discontinuity could be an indication of a subsurface geological feature such a void or cave.

The ‘breaks’ in seismic wiggles represent some kind of structural, material density, and /or geological change.

The SR results overlayed by the P-wave velocity tomograms are shown in Figure B01 to B05 - Appendix B.

Generally, the SR results correlate with overlayed P-wave results and show some reflector amplitude / frequency changes at the possible cave locations.

6.4 Discussion of Results

Both SRT and ERT results show clear evidence of the cave. The location of the cave correlates relatively well with the speleological map in the areas close to the entrance and east of the entrance. The zones west of the cave entrance show less correlation with the mapped location of the cave. This may be the product of the mapping method used. Some of the SRT/ ERT results in the western part of the cave indicate that the cave might be shifted slightly to the north of the cave’s location as shown in the map. Based on the geophysical survey results, there is a possibility that cave might be extended more towards east and west and that some more cave branches exist in the area. The P-wave velocity values measured along the SRT lines indicate variable thickness of rock cover above the cave (generally in range from ~ 2 to 5 m). The thickness of the rock overlaying the cave may vary in the areas that are not covered by the seismic lines.

6.5 Limitations

WSP Golder geophysical services are conducted in a manner consistent with the level of care and skill ordinarily exercised by the wider geophysical community currently practicing under similar conditions and subject to the time limits, and financial and physical constraints applicable to the services.

Seismic Refraction Tomography, Electrical Resistivity Tomography and 2d Seismic Reflection are remote sensing geophysical methods that may not detect all subsurface features. Depth of penetration is dependent on the nature of the subsurface, acquisition parameters, and data quality. Furthermore, interpreted features such as stratigraphic boundaries, top of bedrock, faults, voids, other geologic hazards, objects, and utilities may, upon intrusive sampling, prove to have been misinterpreted.

Seismic refraction and electrical resistivity data are analysed using an inversion method to provide a model of the subsurface conditions. This process does not necessarily produce a unique solution, i.e. a single geophysical dataset can produce multiple outputs that meet the specified constraints. Different modeling methods and software may produce different results. This inherent uncertainty in the SRT and results should be considered during the interpretation process. Accurate interpretation of geophysical data relies on the site-specific correlation of information with that obtained from borehole drilling, test pits, or other direct observation methods.

Note that for an ideal signal-to-noise ratio the resolution limit (RL) of seismic data is set to a quarter of the dominant seismic wavelet (λ), where: λ =V layer / f dominant and resolving power RL = λ/4 In practice, this limit is closer to λ/3 or for moderate signal-to-noise ratio λ/2. The dominant frequency is usually estimated from a narrow-band filter analysis but can be also estimated from the total power spectra computed across the shot record.

Your attention is drawn to the document titled - “Important Information Relating to this Report”, which is included in Appendix C. The statements presented in that document are intended to inform a reader of the report about its proper use. There are important limitations as to who can use the report and how it can be used. It is important that a reader of the report understands and has realistic expectations about those matters.

7.0 CLOSURE

We trust the above meets your requirements in this matter. Should you have any further queries please do not hesitate to contact the undersigned.

8.0 BIBLIOGRAPHIC REFERENCES

1. Birch, W. D., 2003: ‘Geology of Victoria’ Geological Society of Australia, Special Publication No.23
2. Country Roads Board Authority 1970’ – VicRoads – Materials Research Division – Interpretation of Seismic Refraction Data for Sedimentary and Granitic Rocks and Soils.
3. Dampney, CNG and Whiteley, RJ (1978). Velocity determination and error analysis for the seismic refraction method. Geophysical Prospecting, 28, pp. 1-17.

4. Fetter C.W., 1988. Applied Hydrogeology. 2nd Edition. Macmillan Publishing Co. New York.
5. Gebrande H and Muller H. 1985. Refractionsseismic. In: F. Bender (Editor), Angewandte Geowissenschaften II. Ferdinand Enke, Stuttgart; pp. 226-260. ISBN 3-432-91021-5.
6. Gierse, G., Pruessmann, J., Eisenberg-Klein, G., Caballero, A., Ballesteros, R. and Clemente, G., 2009, Improved Salt Delineation by CRS-based Depth Model Building and Depth Migration: 71st Annual International Conference and Exhibition, EAGE, Expanded Abstracts, Session Z-85.
7. Golder Associates, 2017: STAGE 2 – Report - PRELIMINARY GEOTECHNICAL AND ENVIRONMENTAL INVESTIGATION FOR 410 COOPER STREET, EPPING
8. Hatherly, P. J., Urosevic, M., Lambourne, A., and Evans, B. J., 1994, Simple approach to calculating refraction statics corrections: Geophysics, 59, 156- 160.
9. Heilmann, Z., Mann, J. and Koglin, I., 2006, CRS-stack-based seismic imaging considering top-surface topography: Geophysical Prospecting, 54, 681-695.
10. Herwanger J.V., Pain C.C., Binley A., de Oliveira C.R.E. & Worthington M.H. 2004. Anisotropic resistivity tomography. Geophysical Journal International 158, 409-425.
11. Jones G.M. and Jovanovich D.B. 1985. A ray inversion method for refraction analysis. Geophysics volume 50, pp. 1701-1720.
12. Kearey P & Brooks H. 2002 Introduction to Geophysical Exploration. Textbook.
13. MacGregor, F., Fell, R., Mostyn, G.R., Hocking, G. and McNally, G., 1994 – The estimation of rock rippability. Quarterly Journal of Engineering Geology, 27, 123-144.
14. Malovichko, L. and Urosevic, M., 2013. CRS stack based seismic imaging-a case study from St Ives mining camp, Kambalda, Western Australia. ASEG Extended Abstracts, 2013(1), pp.1-4.
15. Milsom, J. 2002 Field Geophysics. Textbook.
16. NEHRP – 2001 National Earthquake Hazards Reduction Program (NEHRP) classification (BSSC 2001).
17. Palmer D. 1981. An introduction to the generalized reciprocal method of seismic refraction interpretation. Geophysics, volume 46, pp. 1508-1518.
18. Rohdewald S. 2011. Smooth inversion vs. Delta t-V inversion with Rayfract® version 3.21.
19. Schuster G.T. and Quintus-Bosz A. 1993. Wavepath Eikonal Traveltime Inversion: Theory. Geophysics, volume 58, pp. 1314-1323.
20. Telford W.M., Geldart L.P., Sheriff R.E. & Keys D.A., 1990. Applied Geophysics. Cambridge University Press.
21. Terzic. Z 2007, Subsurface Velocity Imaging Below Street. Internet Publication.
22. Ward S.H, 1990. Geotechnical and Environmental Geophysics. Investigations in Geophysics No. 5. Society of Exploration Geophysicists.
23. Whiteley Robert J. & Stewart Simon B. (2008) Case studies of shallow marine investigations in Australia with advanced underwater seismic refraction (USR), Exploration Geophysics, 39:1, 34-40, DOI: 10.1071/EG08009
24. Zelt A.C. and Chen J. 2016. Frequency-dependent traveltime tomography for near-surface seismic refraction data Geophysical Journal International 207(1):ggw269.

Signature Page

WSP Australia Pty Ltd

[redacted]

[redacted]
Senior Geophysicist

[redacted]

[redacted]
Principal Geophysicist

[redacted]

A.B.N. 64 006 107 857

APPENDIX A

SRT and ERT Results Figures

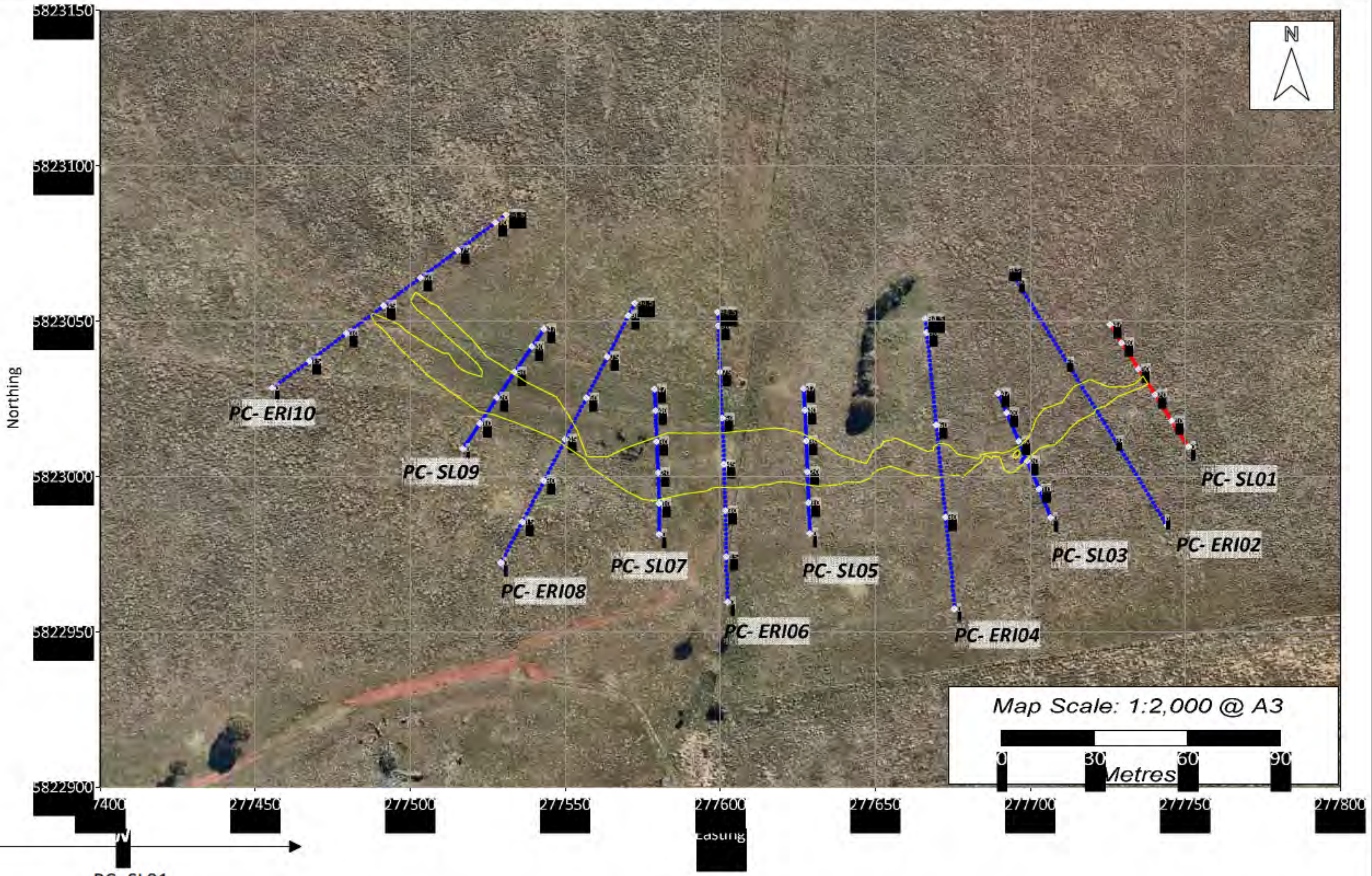
Figures:

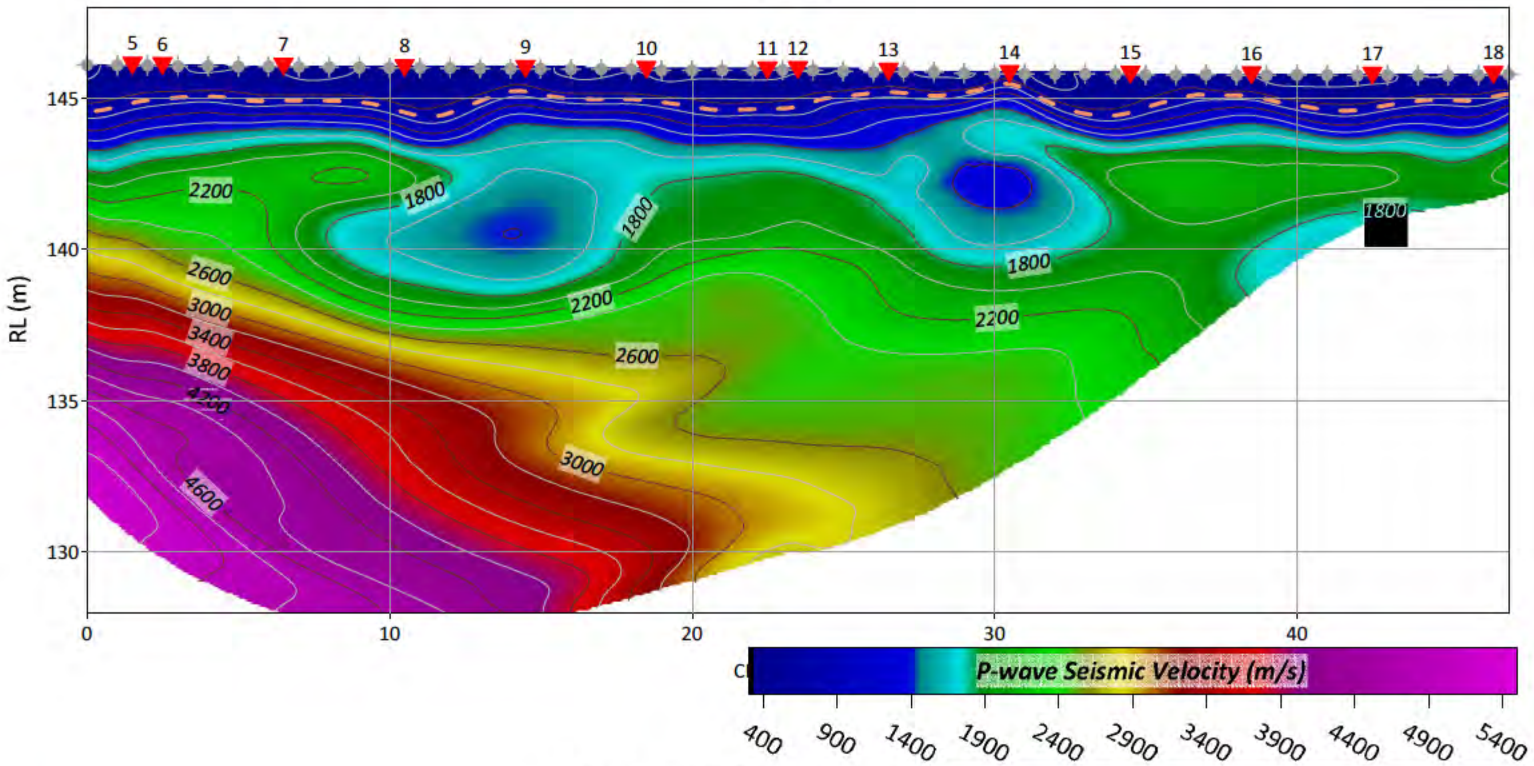
Disclaimer:

The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.





LEGEND:

- Inferred soil / rock interface
- Surveyed SRT Line Location / currently displayed
- Mapped cave outline
- Seismic shot points *(Profile view)*
- Seismic receivers *(Profile view)*

Map Scale: 1:250 @ A3

0 5 10

Metres

No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum:MGA 2020
Grid: GDA 2020 MGA Zone 55

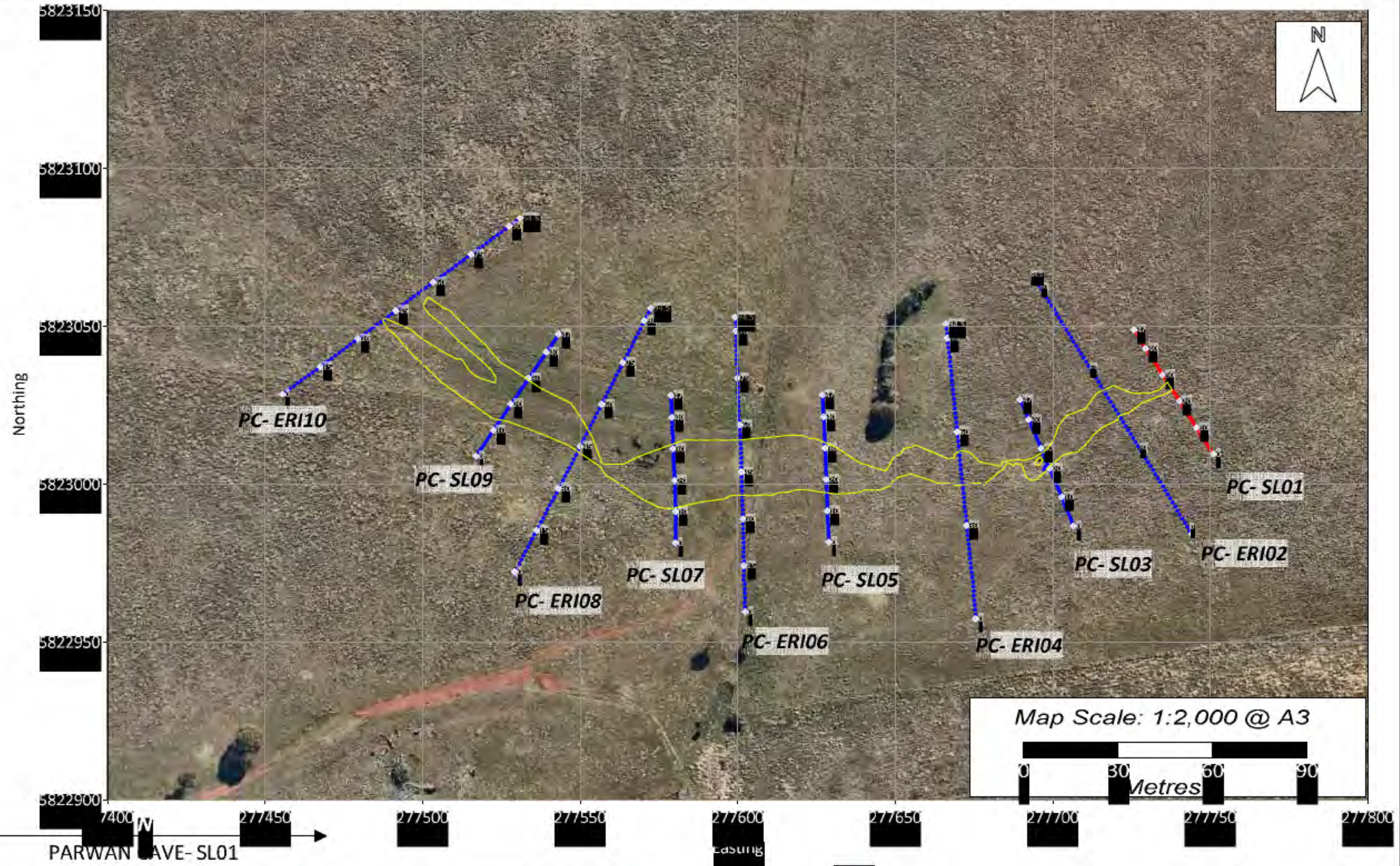
CLIENT	Parwan Cave Precinct -Victorian Planning Authority
PROJECT	Parwan Cave Development Precinct
CONSULTANT	WSP GOLDER
YYYY-MM-DD	2022-11-20
DESIGNED	ZT
PREPARED	PA&ZT
REVIEWED	ZT
APPROVED	MW
TITLE	**GEOPHYSICAL SEISMIC REFRACTION TOMOGRAPHY SURVEY PC-SL01 P-WAVE VELOCITY TOMOGRAM**
PROJECT NO.	
DELIVERABLE	---
REV.	A
FIGURE	A01

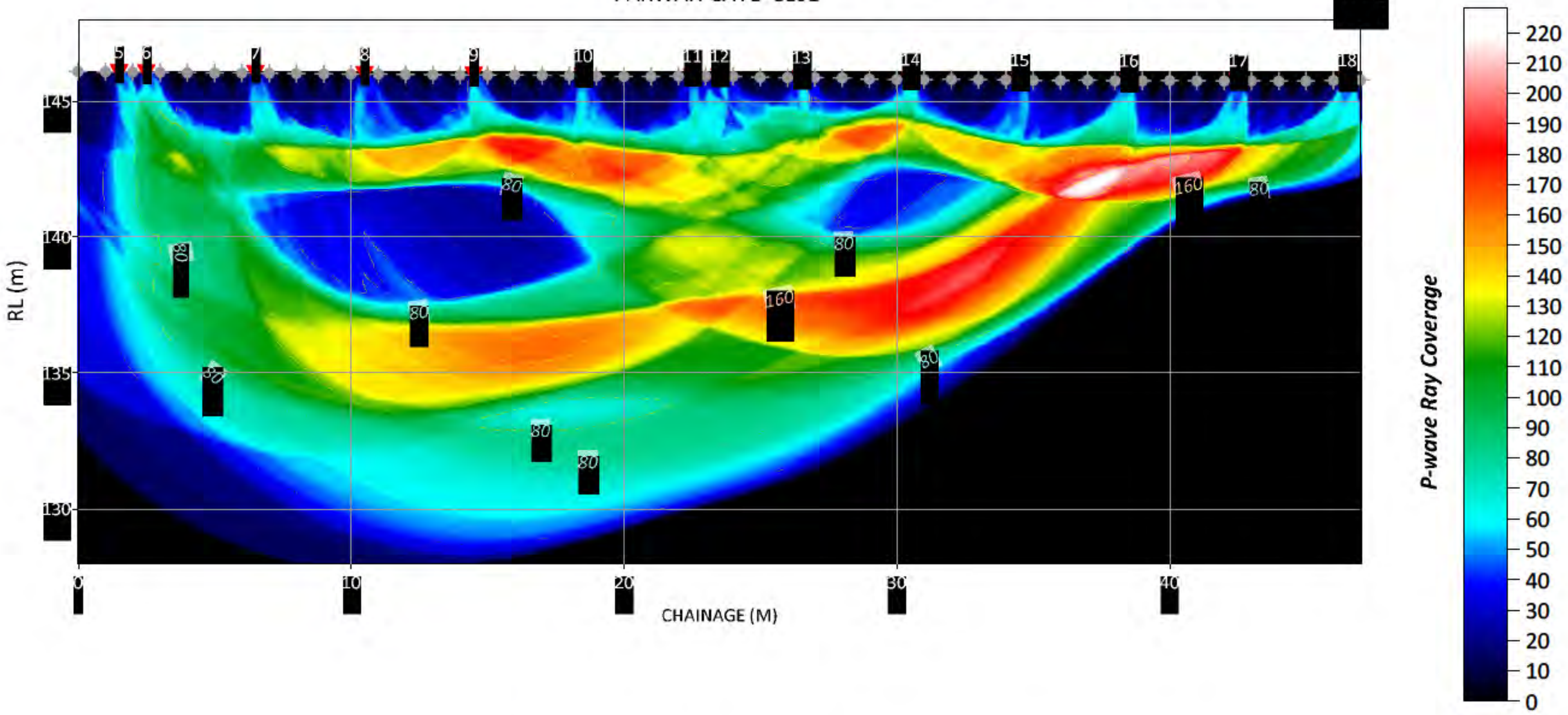
Disclaimer:

The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.





LEGEND:

Inferred soil / rock interface

Surveyed SRT Line Location / currently displayed

Mapped cave outline

Seismic shot points *(Profile view)*

Seismic receivers *(Profile view)*

Map Scale: 1:250 @ A3

0 5 10

Metres

No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum:MGA 2020
Grid: GDA 2020 MGA Zone 55

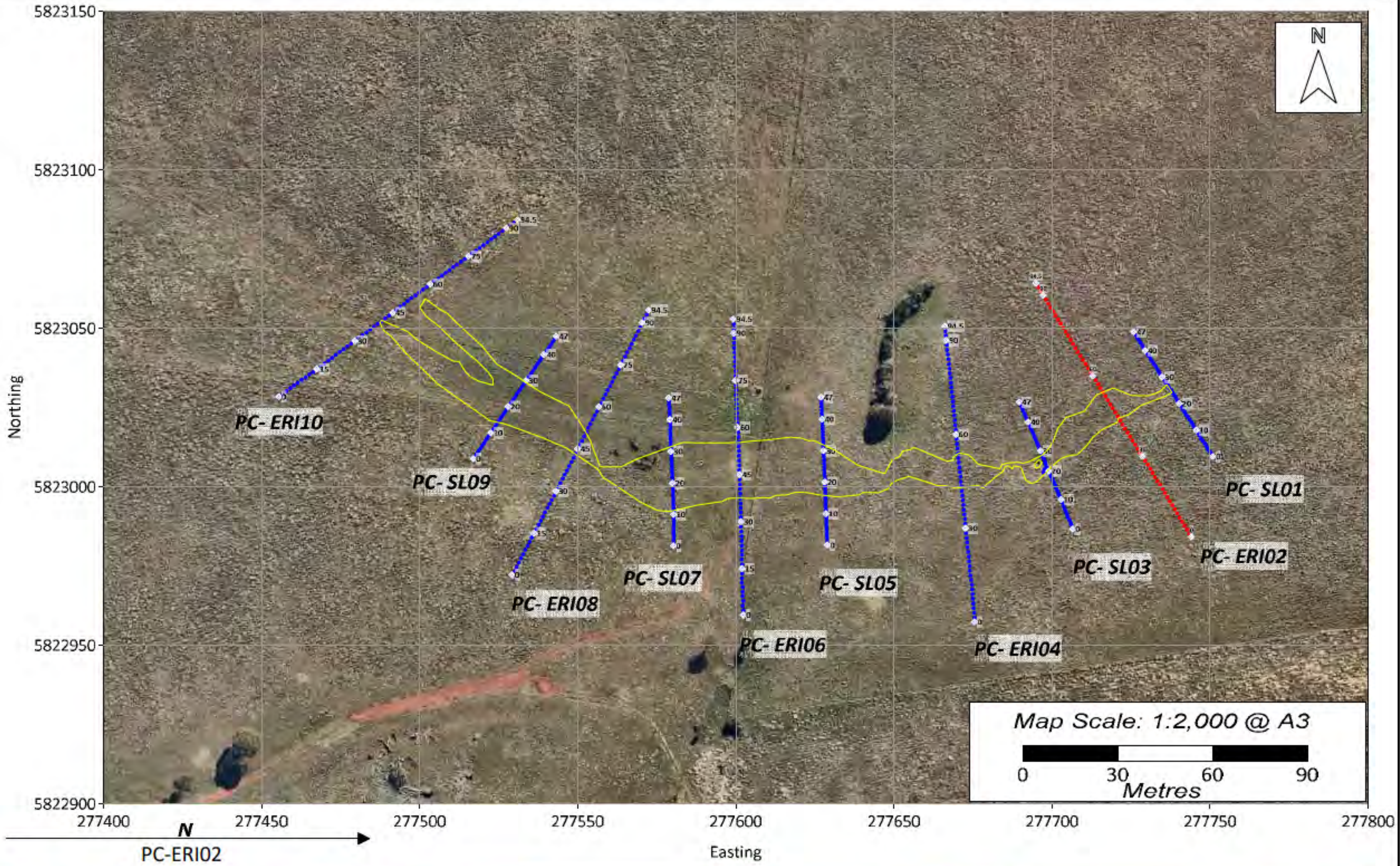
CLIENT	Parwan Cave Precinct -Victorian Planning Authority
PROJECT	Parwan Cave Development Precinct
CONSULTANT	WSP GOLDER
YYYY-MM-DD	2022-11-20
DESIGNED	ZT
PREPARED	PA&ZT
REVIEWED	ZT
APPROVED	MW
TITLE	GEOPHYSICAL SEISMIC REFRACTION TOMOGRAPHY SURVEY PC-SL01 P-WAVE RAY COVERAGE
PROJECT NO.	[redacted]
DELIVERABLE	---
REV.	A
FIGURE	A01a

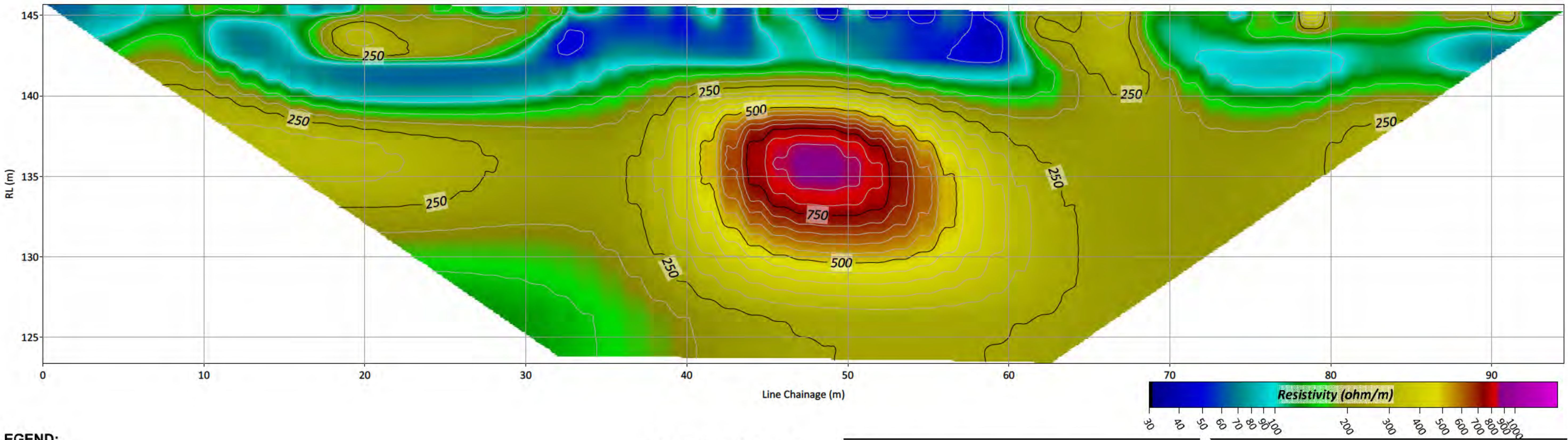
Disclaimer:

The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.





LEGEND:

Inferred soil / rock interface

Surveyed SRT Line Location / currently displayed 30 / 30

Mapped cave outline

Map Scale: 1:250 @ A3

0 5 10

Metres

0.5 Vertical axes Exaggeration

Projection: Transverse Mercator

Horizontal Datum:MGA 2020

Grid: GDA 2020 MGA Zone 55

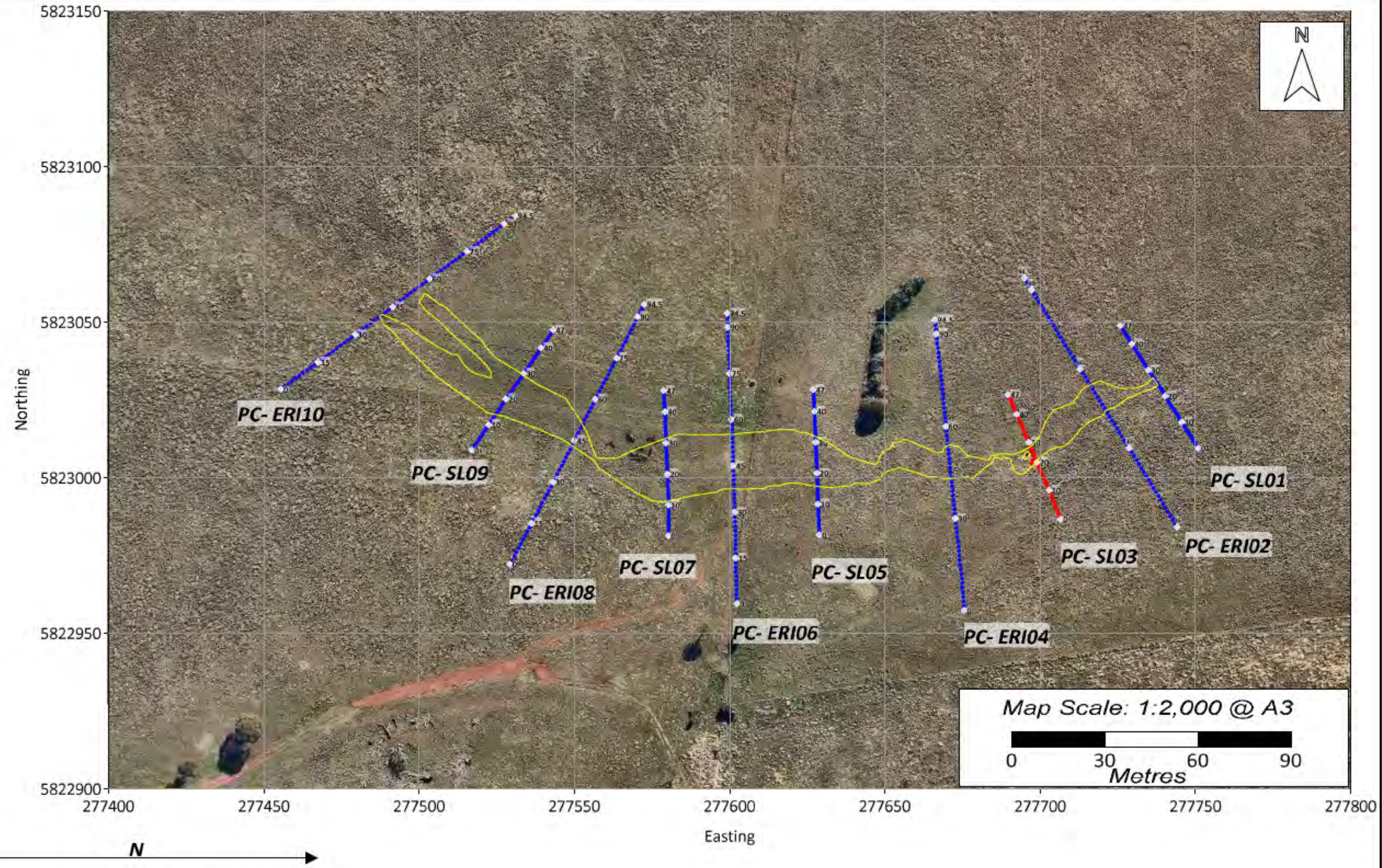
CLIENT Parwan Cave Precinct -Victorian Planning Authority		PROJECT Parwan Cave Development Precinct	
CONSULTANT WSP GOLDER	YYYY-MM-DD: 2022-11-20	TITLE **GEOPHYSICAL ELECTRICAL RESISTIVITY IMAGING SURVEY** **PC-ERI02** **ELECTRICAL RESISTIVITY MODEL**	
	DESIGNED: ZT		
	PREPARED: PA&ZT		
	REVIEWED: ZT		
	APPROVED: MW	PROJECT NO. DELIVERABLE: ---	REV.: A FIGURE: A02

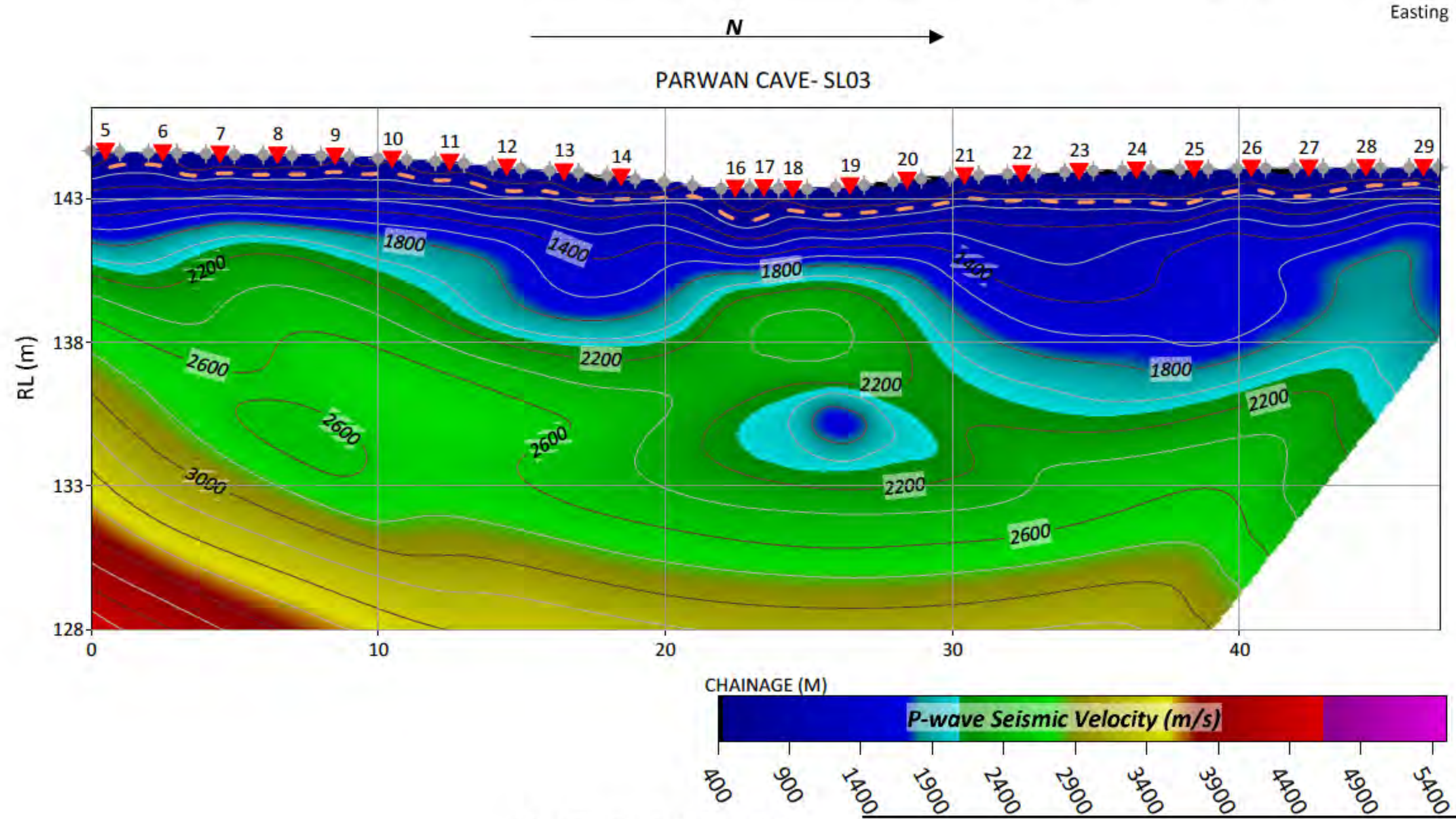
Disclaimer:

The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.





LEGEND:

- Inferred soil / rock interface
- Surveyed SRT Line Location / currently displayed
- Mapped cave outline
- Seismic shot points *(Profile view)*
- Seismic receivers *(Profile view)*

Map Scale: 1:250 @ A3

0 5 10

Metres

No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum:MGA 2020
Grid: GDA 2020 MGA Zone 55

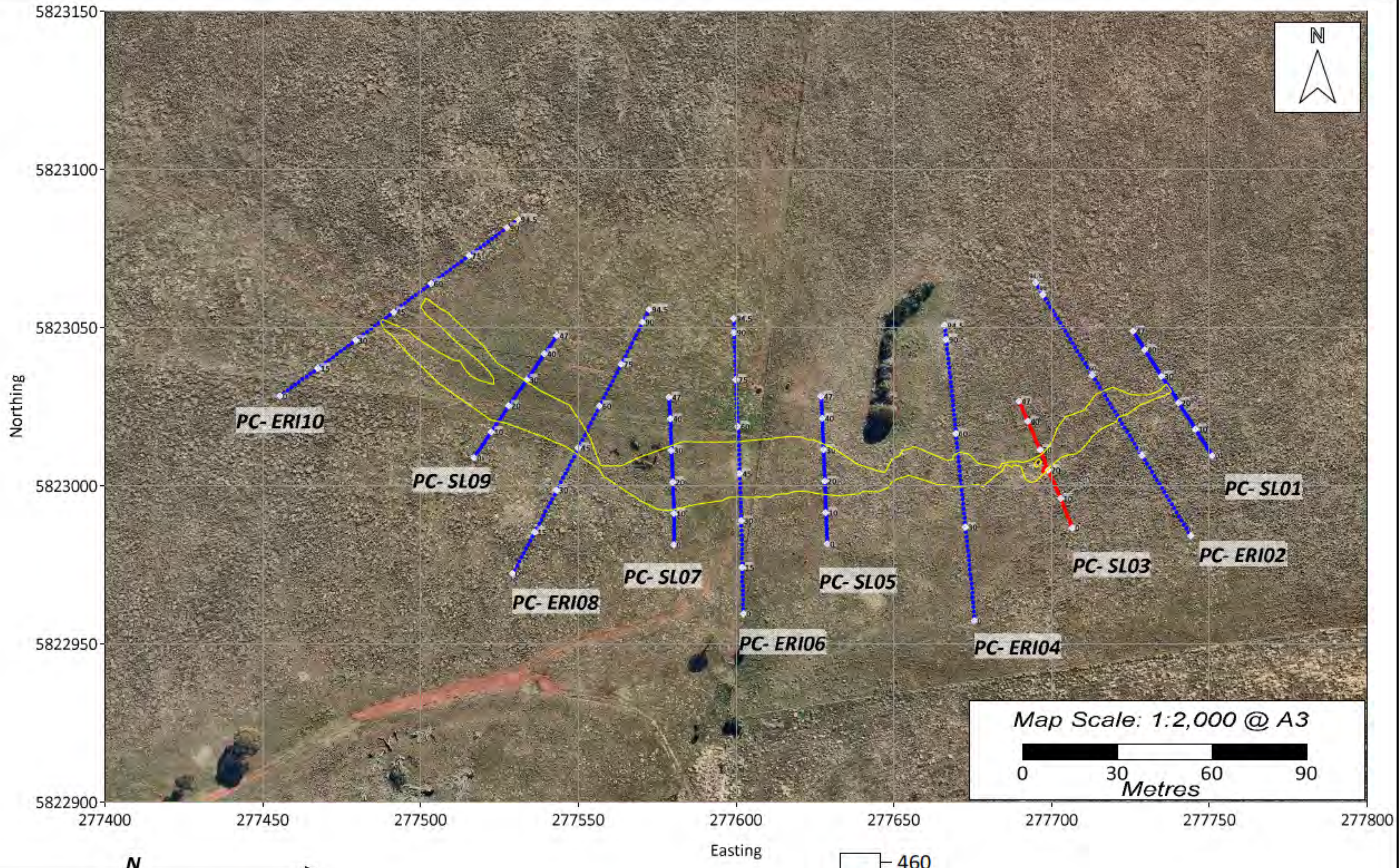
CLIENT	Parwan Cave Precinct -Victorian Planning Authority
PROJECT	Parwan Cave Development Precinct
CONSULTANT	WSP GOLDER
YYYY-MM-DD	2022-11-20
DESIGNED	ZT
PREPARED	PA&ZT
REVIEWED	ZT
APPROVED	MW
TITLE	GEOPHYSICAL SEISMIC REFRACTION TOMOGRAPHY SURVEY PC-SL03 P-WAVE VELOCITY TOMOGRAM
PROJECT NO.	
DELIVERABLE	---
REV.	A
FIGURE	A03

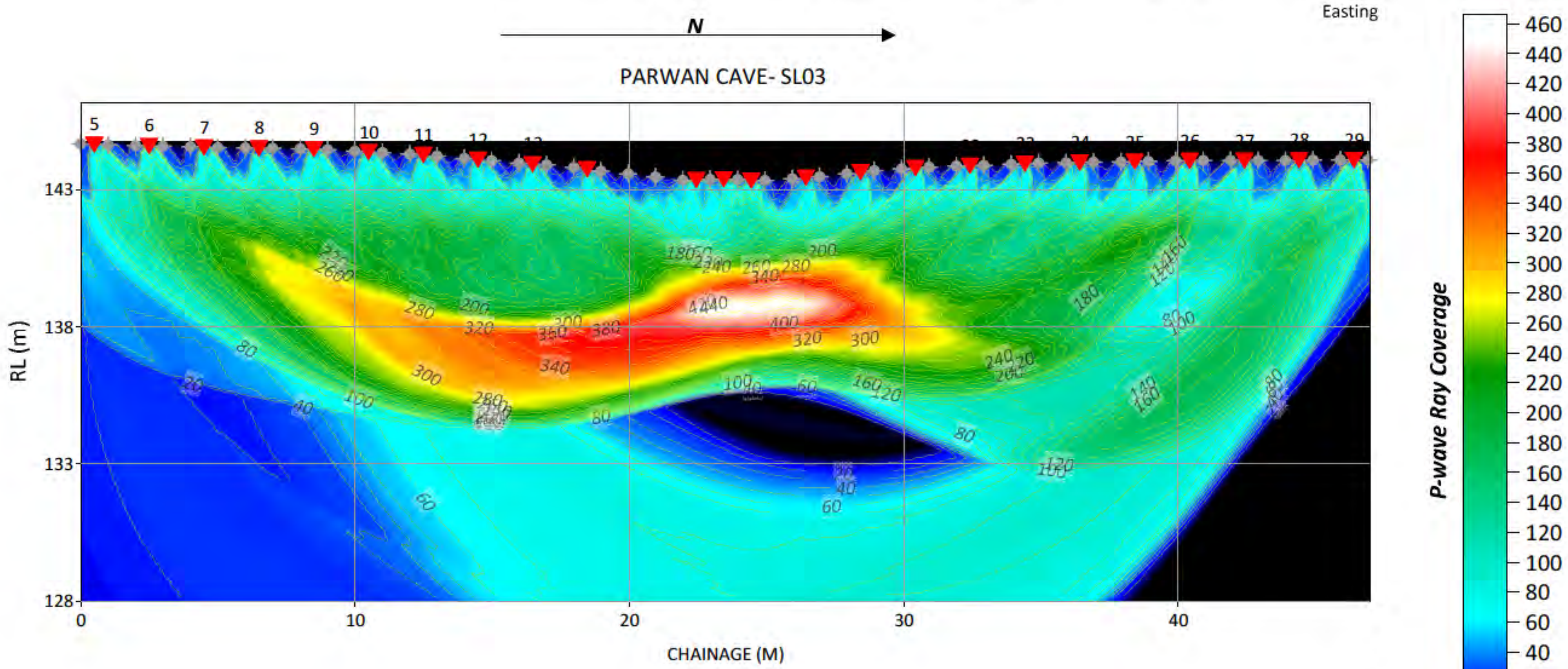
Disclaimer:

The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.





LEGEND:

Inferred soil / rock interface

Surveyed SRT Line Location / currently displayed 30 / 30

Mapped cave outline

Seismic shot points *(Profile view)*

Seismic receivers *(Profile view)*

Map Scale: 1:250 @ A3

0 5 10

Metres

No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum:MGA 2020
Grid: GDA 2020 MGA Zone 55

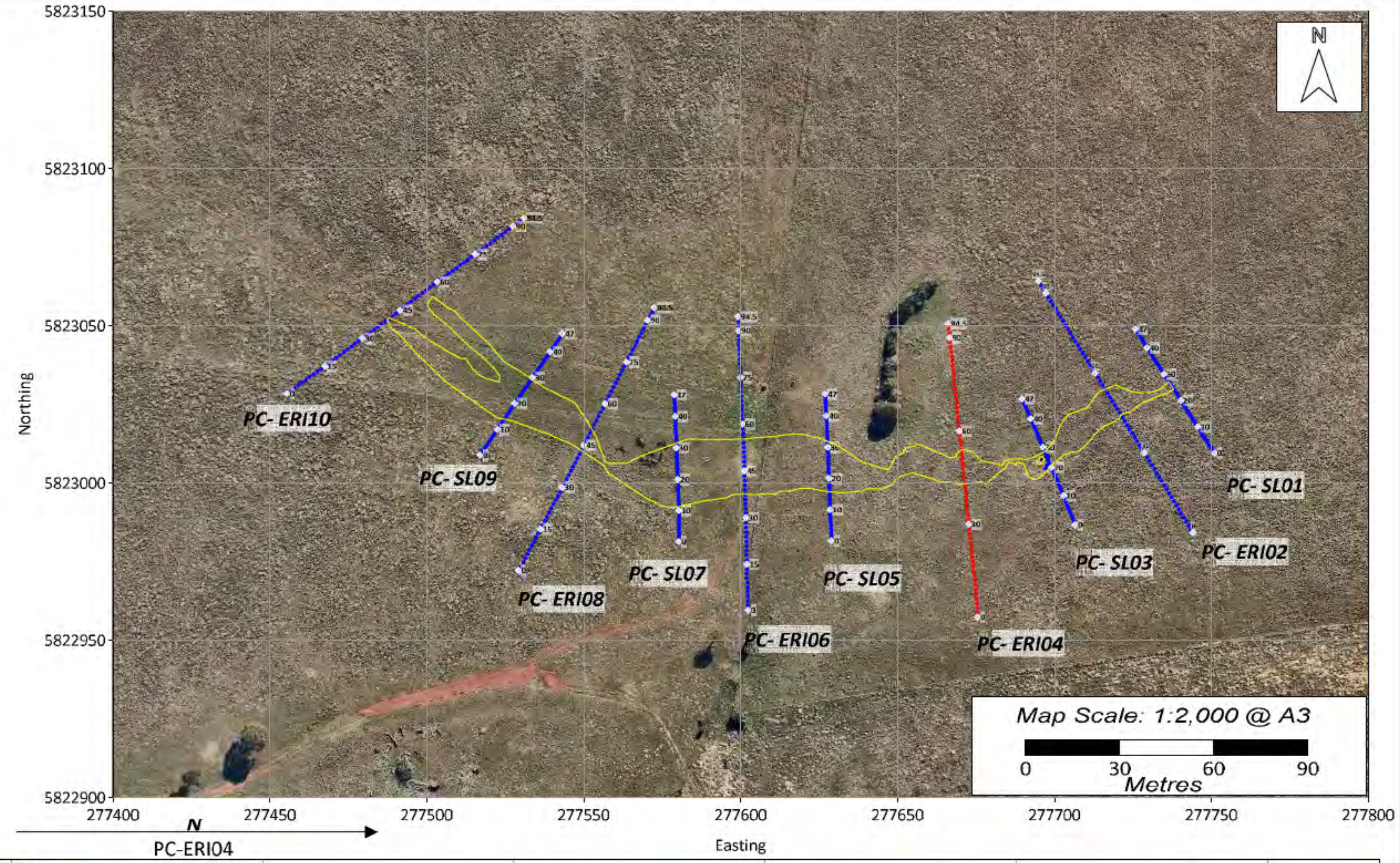
CLIENT	Parwan Cave Precinct -Victorian Planning Authority	PROJECT	Parwan Cave Development Precinct
CONSULTANT	WSP GOLDER	TITLE	GEOPHYSICAL SEISMIC REFRACTION TOMOGRAPHY SURVEY PC-SL03 P-WAVE RAY COVERAGE
YYYY-MM-DD	2022-11-20	PROJECT NO.	---
DESIGNED	ZT	DELIVERABLE	---
PREPARED	PA&ZT	REV.	A
REVIEWED	ZT	FIGURE	A03a
APPROVED	MW		

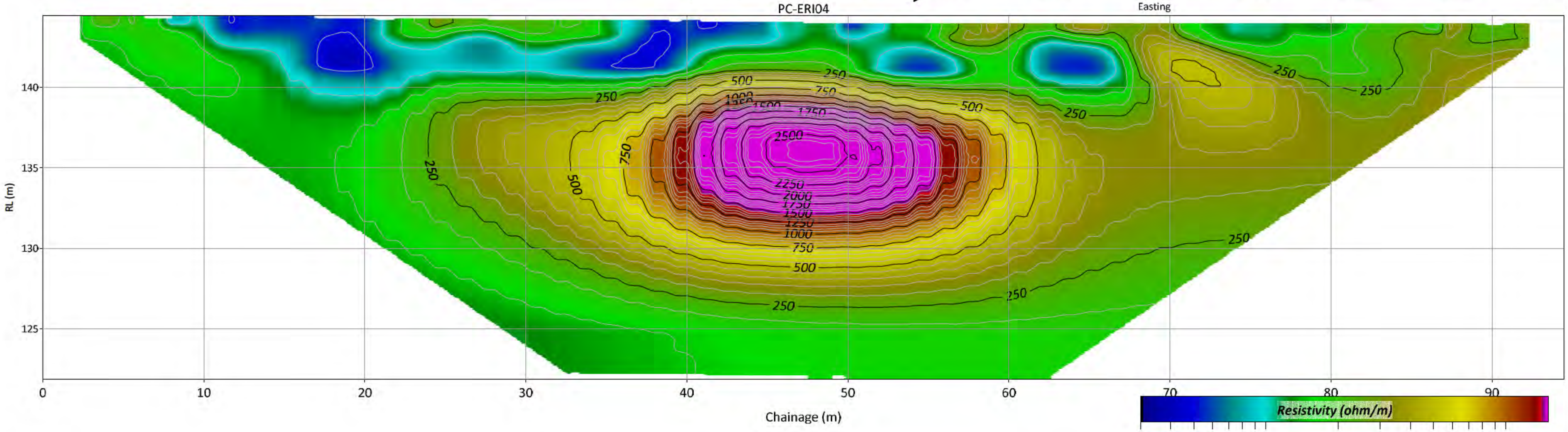
Disclaimer:

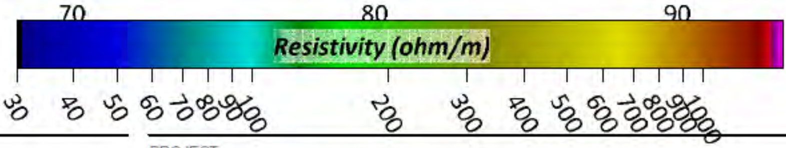
The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.







LEGEND:

Inferred soil / rock interface

Surveyed SRT Line Location / currently displayed

Mapped cave outline

Map Scale: 1:250 @ A3

0 5 10

Metres

No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum: MGA 2020
Grid: GDA 2020 MGA Zone 55

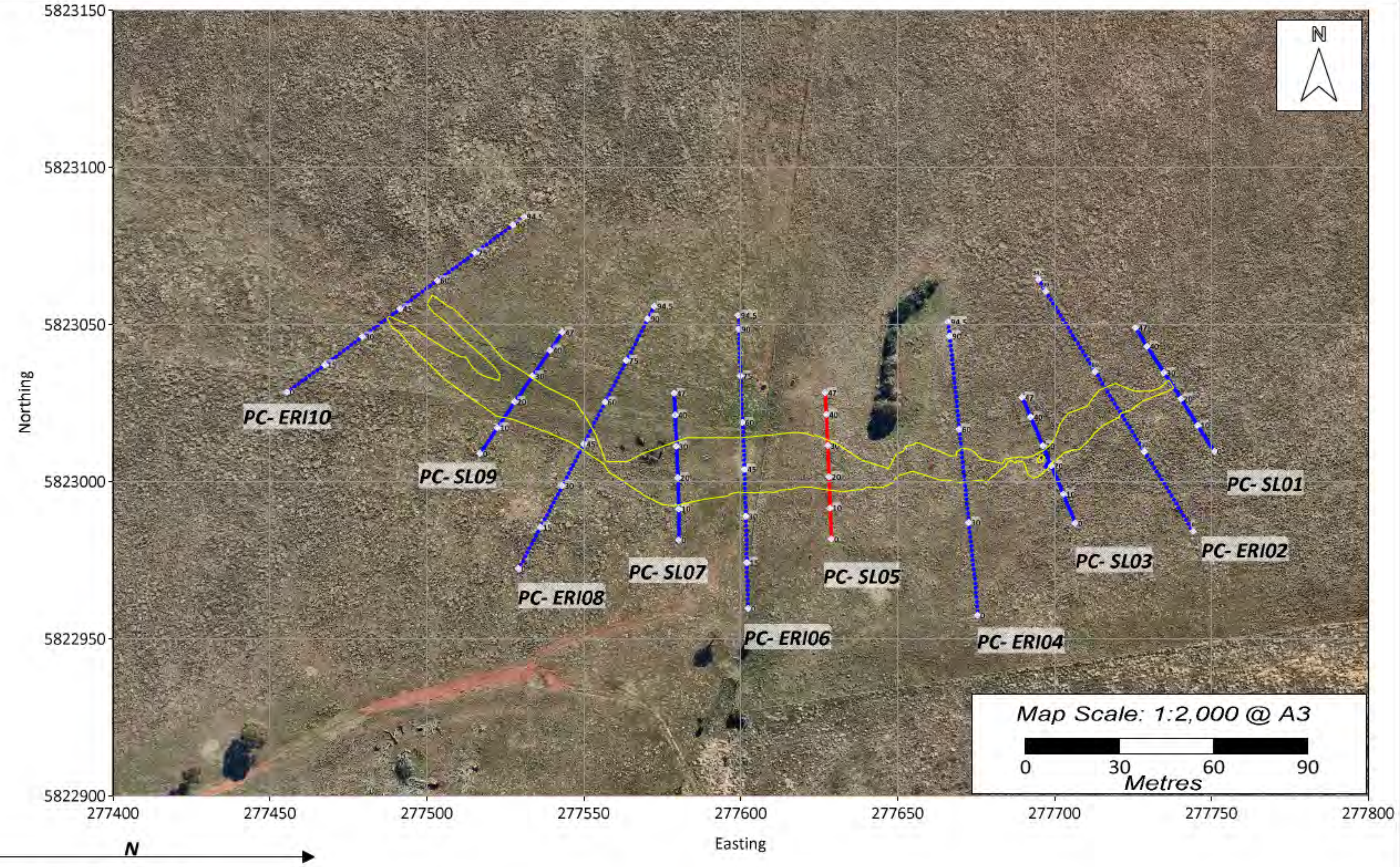
CLIENT	Parwan Cave Precinct -Victorian Planning Authority	PROJECT	Parwan Cave Development Precinct
CONSULTANT	YYYY-MM-DD: 2022-11-20	TITLE	GEOPHYSICAL ELECTRICAL RESISTIVITY IMAGING SURVEY PC-ERI04 ELECTRICAL RESISTIVITY MODEL
	DESIGNED: ZT		
WSP GOLDER	PREPARED: PA&ZT		
	REVIEWED: ZT	PROJECT NO.	DELIVERABLE: ---
	APPROVED: MW	REV.: A	FIGURE: A04

Disclaimer:

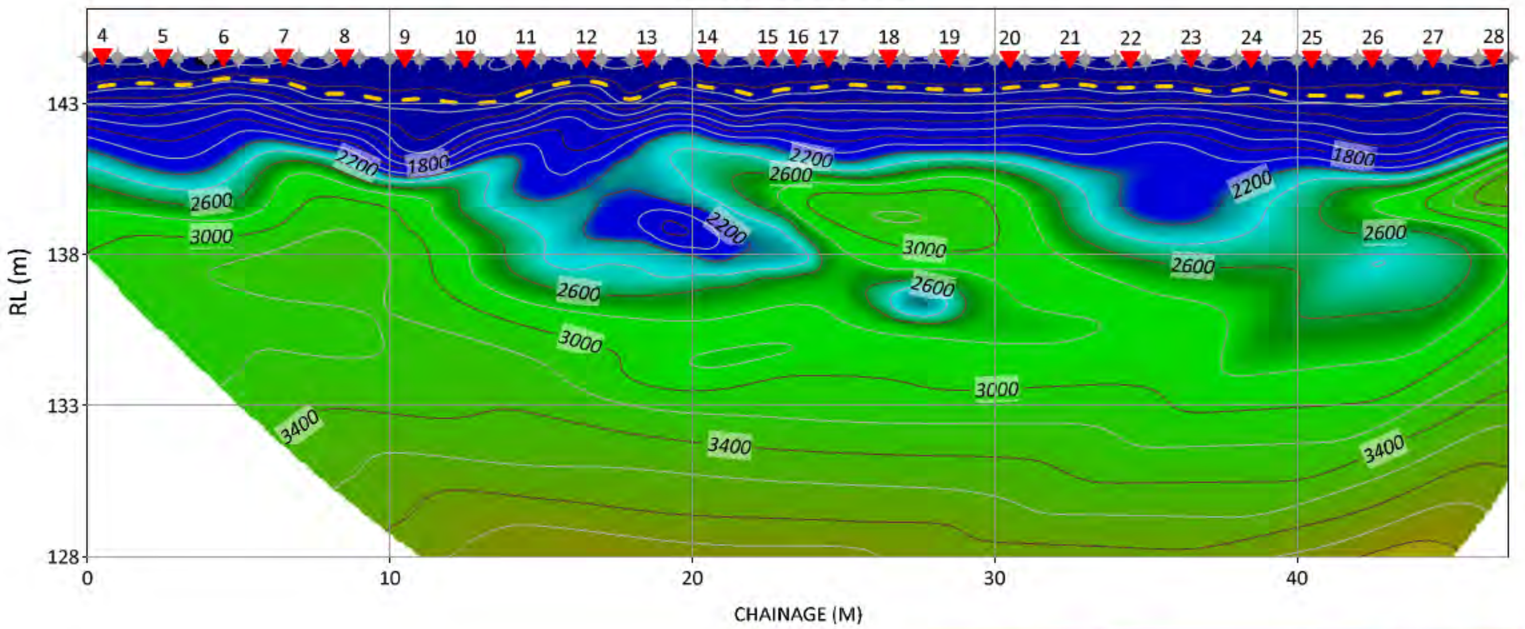
The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

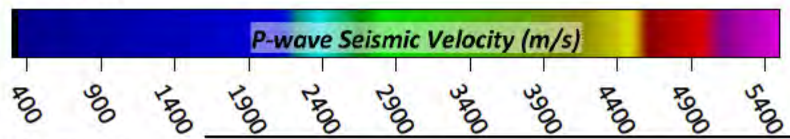
Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.



PARWAN CAVE- SL05





LEGEND:

- Inferred soil / rock interface
- Surveyed SRT Line Location / currently displayed (30 / 30)
- Mapped cave outline
- Seismic shot points *(Profile view)*
- Seismic receivers *(Profile view)*

Map Scale: 1:250 @ A3

0 5 10

Metres

No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum:MGA 2020
Grid: GDA 2020 MGA Zone 55

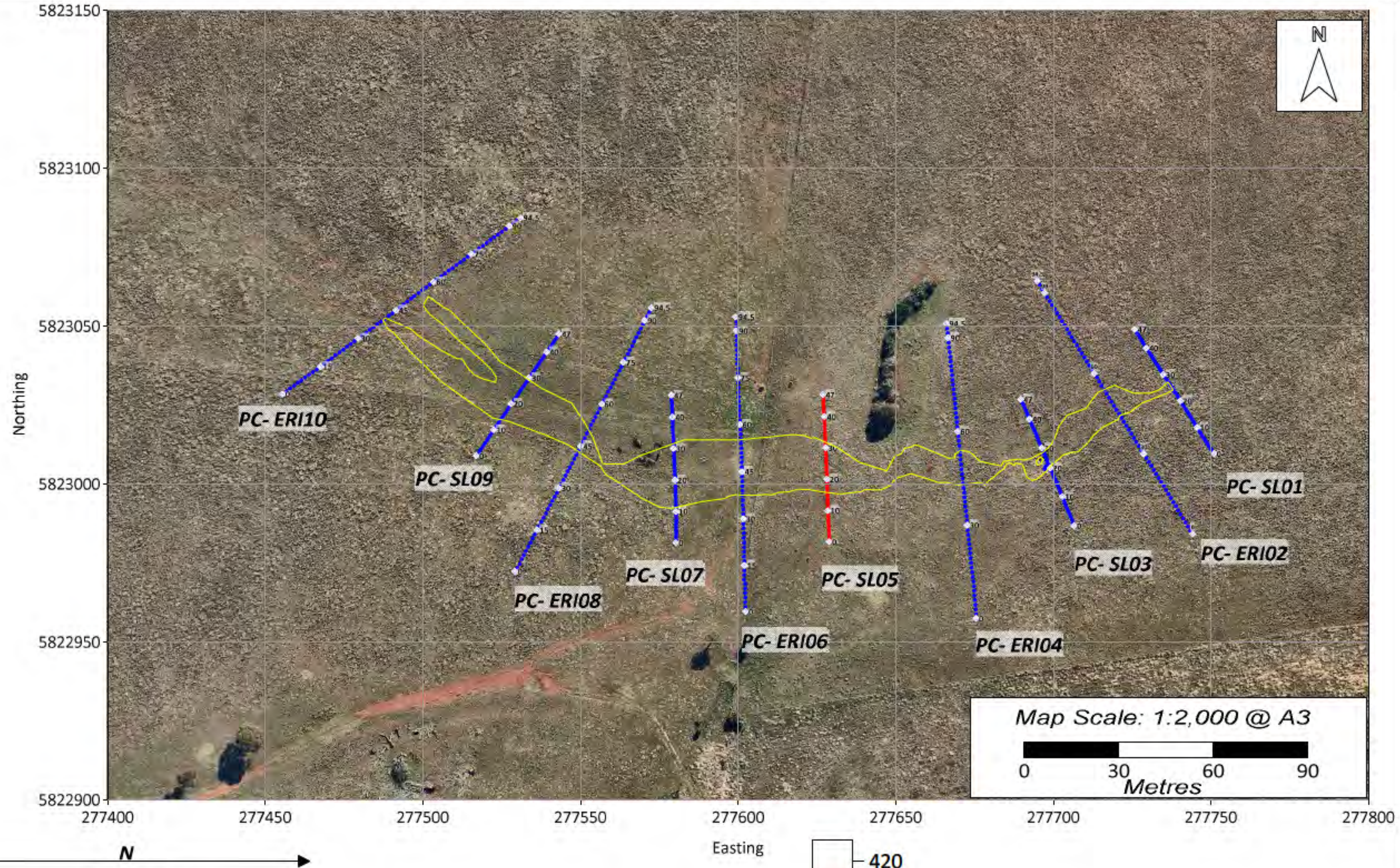
CLIENT	Parwan Cave Precinct -Victorian Planning Authority	PROJECT	Parwan Cave Development Precinct
CONSULTANT	WSP GOLDER	TITLE	GEOPHYSICAL SEISMIC REFRACTION TOMOGRAPHY SURVEY PC-SL05 P-WAVE VELOCITY TOMOGRAM
YYYY-MM-DD	2022-11-20	PROJECT NO.	
DESIGNED	ZT	DELIVERABLE	---
PREPARED	PA&ZT	REV.	A
REVIEWED	ZT	FIGURE	A05
APPROVED	MW		

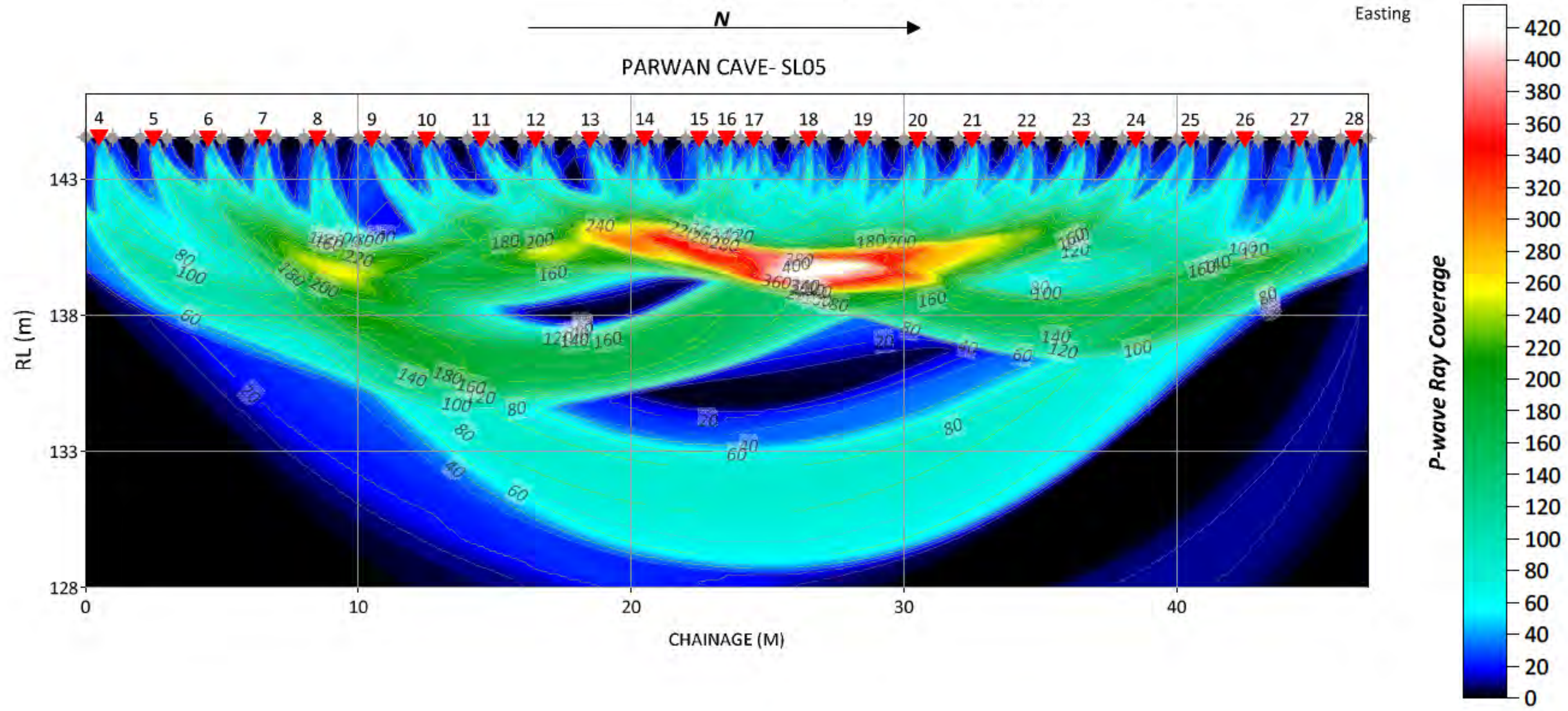
Disclaimer:

The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.





LEGEND:

Inferred soil / rock interface

Surveyed SRT Line Location / currently displayed 30 / 30

Mapped cave outline

Seismic shot points *(Profile view)*

Seismic receivers *(Profile view)*

Map Scale: 1:250 @ A3

0 5 10

Metres

No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum:MGA 2020
Grid: GDA 2020 MGA Zone 55

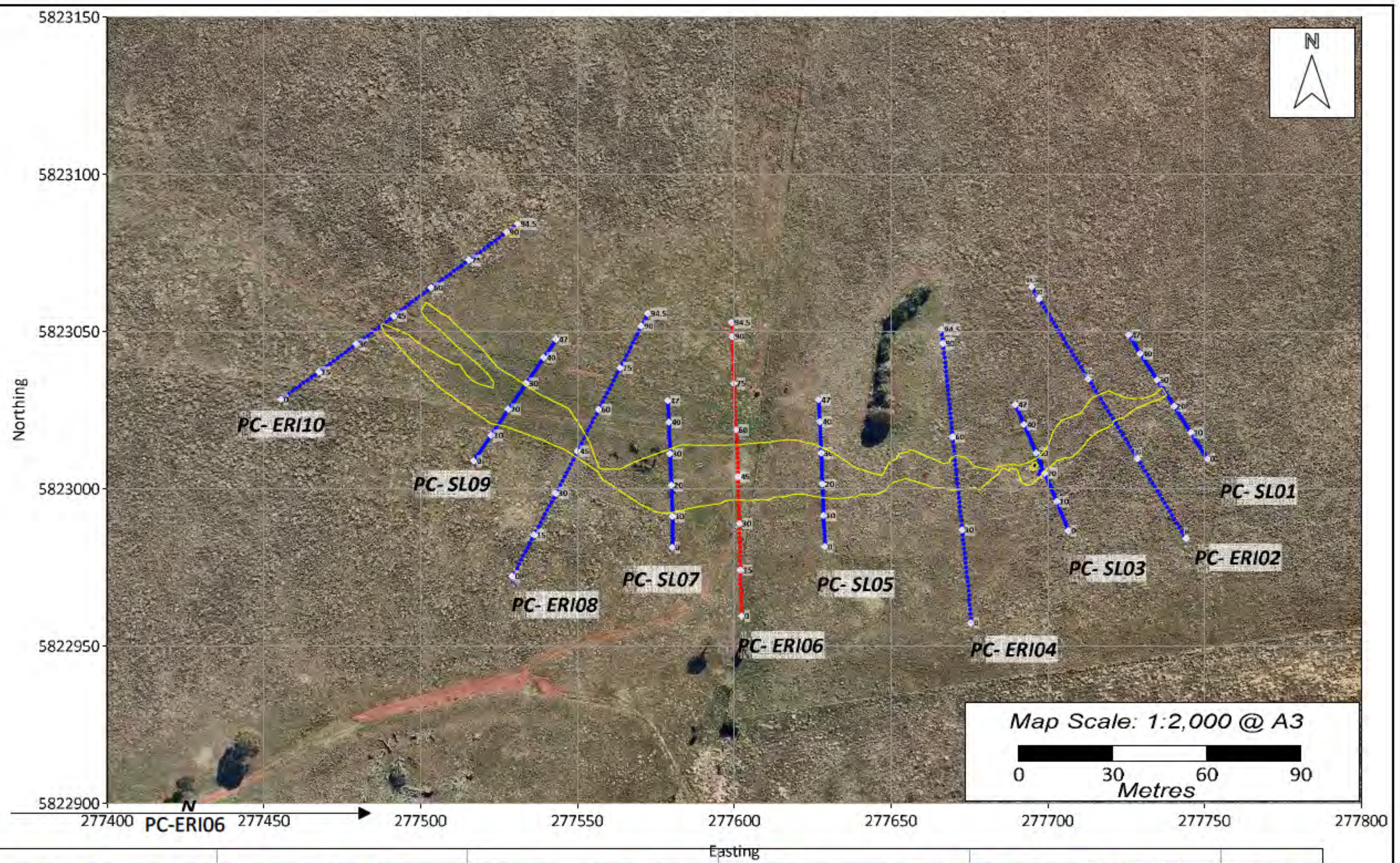
CLIENT	Parwan Cave Precinct -Victorian Planning Authority	PROJECT	Parwan Cave Development Precinct
CONSULTANT	WSP GOLDER	TITLE	GEOPHYSICAL SEISMIC REFRACTION TOMOGRAPHY SURVEY PC-SL05 P-WAVE RAY COVERAGE
YYYY-MM-DD	2022-11-20	PROJECT NO.	
DESIGNED	ZT	DELIVERABLE	---
PREPARED	PA&ZT	REV.	A
REVIEWED	ZT	FIGURE	A05a
APPROVED	MW		

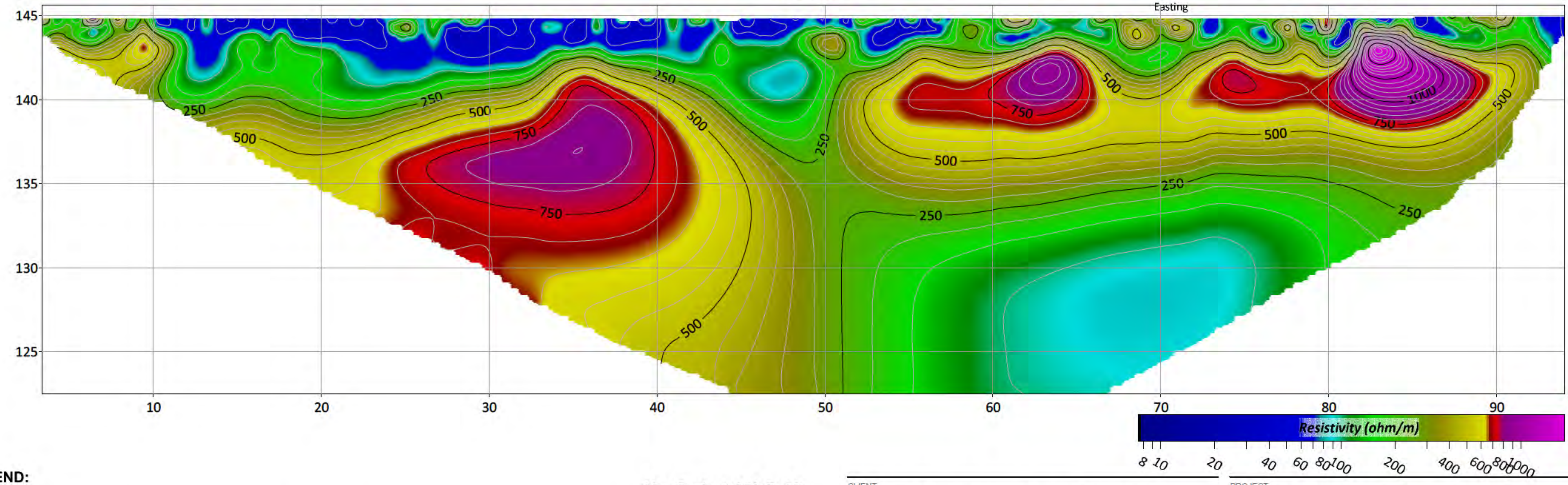
Disclaimer:

The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.





LEGEND:

Inferred soil / rock interface

Surveyed SRT Line Location / currently displayed 30 / 30

Mapped cave outline

Map Scale: 1:250 @ A3

0 5 10
Metres

No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum:MGA 2020
Grid: GDA 2020 MGA Zone 55

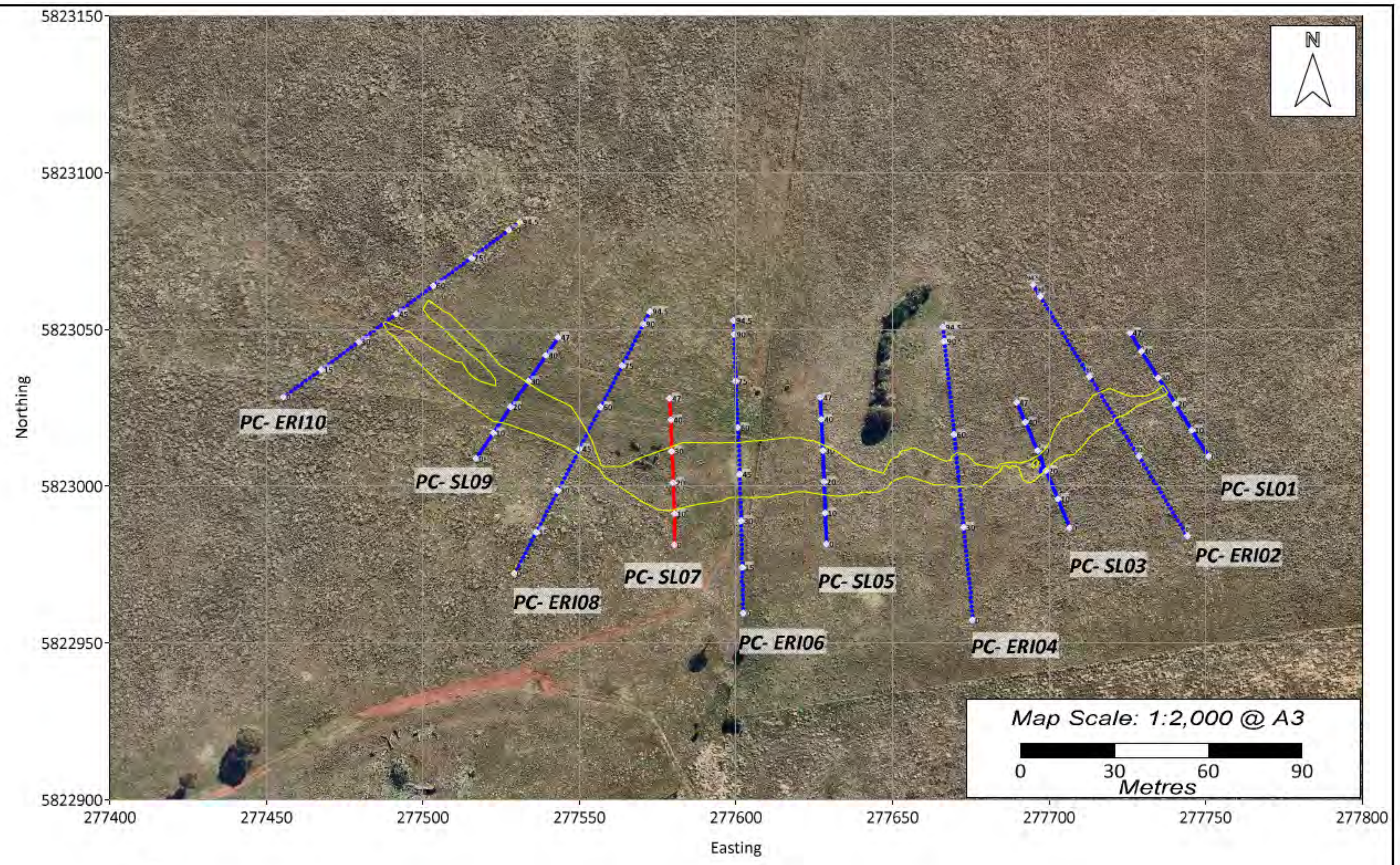
CLIENT	Parwan Cave Precinct -Victorian Planning Authority
PROJECT	Parwan Cave Development Precinct
CONSULTANT	WSP GOLDER
YYYY-MM-DD	2022-11-20
DESIGNED	ZT
PREPARED	PA&ZT
REVIEWED	ZT
APPROVED	MW
TITLE	GEOPHYSICAL ELECTRICAL RESISTIVITY IMAGING SURVEY PC-ERI06 ELECTRICAL RESISTIVITY MODEL
PROJECT NO.	
DELIVERABLE	---
REV.	A
FIGURE	A06

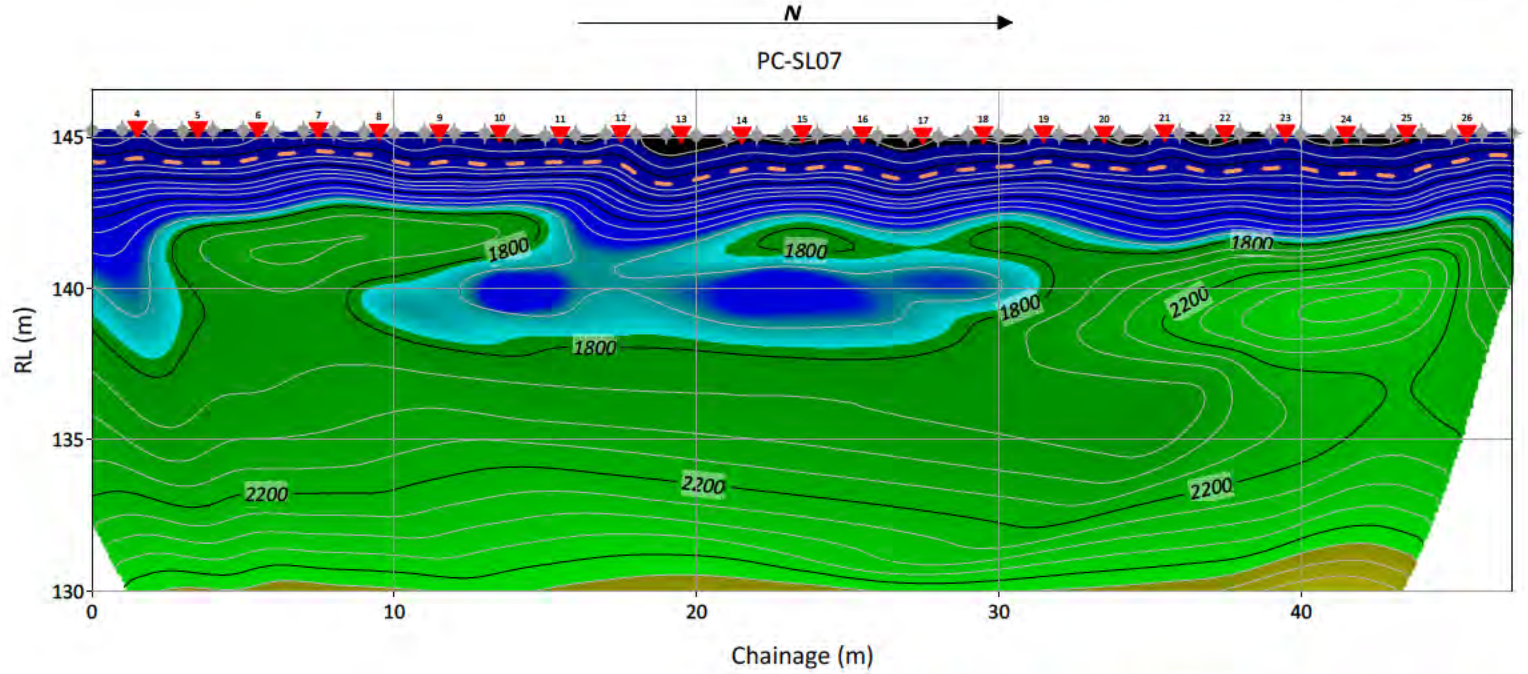
Disclaimer:

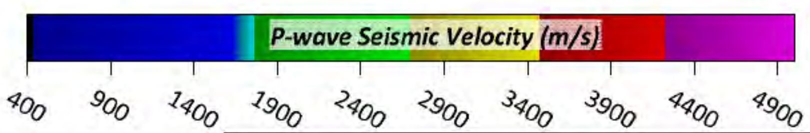
The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.







LEGEND:

Inferred soil / rock interface

Surveyed SRT Line Location / currently displayed

Mapped cave outline

Seismic shot points *(Profile view)*

Seismic receivers *(Profile view)*

Map Scale: 1:250 @ A3

0 5 10

Metres

No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum:MGA 2020
Grid: GDA 2020 MGA Zone 55

CLIENT
Parwan Cave Precinct -Victorian Planning Authority

PROJECT
Parwan Cave Development Precinct

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-11-20
DESIGNED	ZT
PREPARED	PA&ZT
REVIEWED	ZT
APPROVED	MW

TITLE
GEOPHYSICAL SEISMIC REFRACTION TOMOGRAPHY SURVEY
PC-SL079
P-WAVE VELOCITY TOMOGRAM

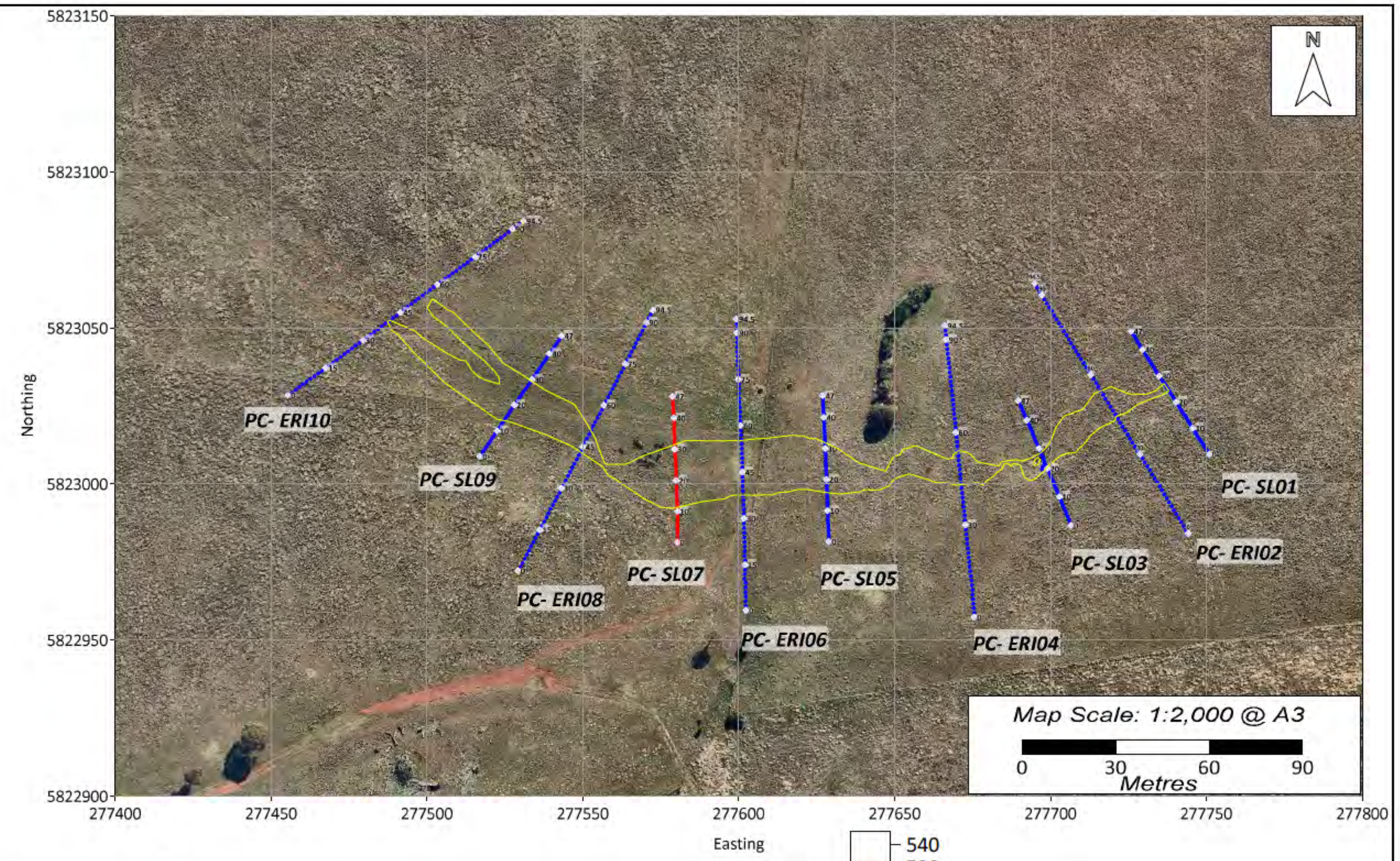
PROJECT NO.	DELIVERABLE	REV.	FIGURE
	---	A	A07

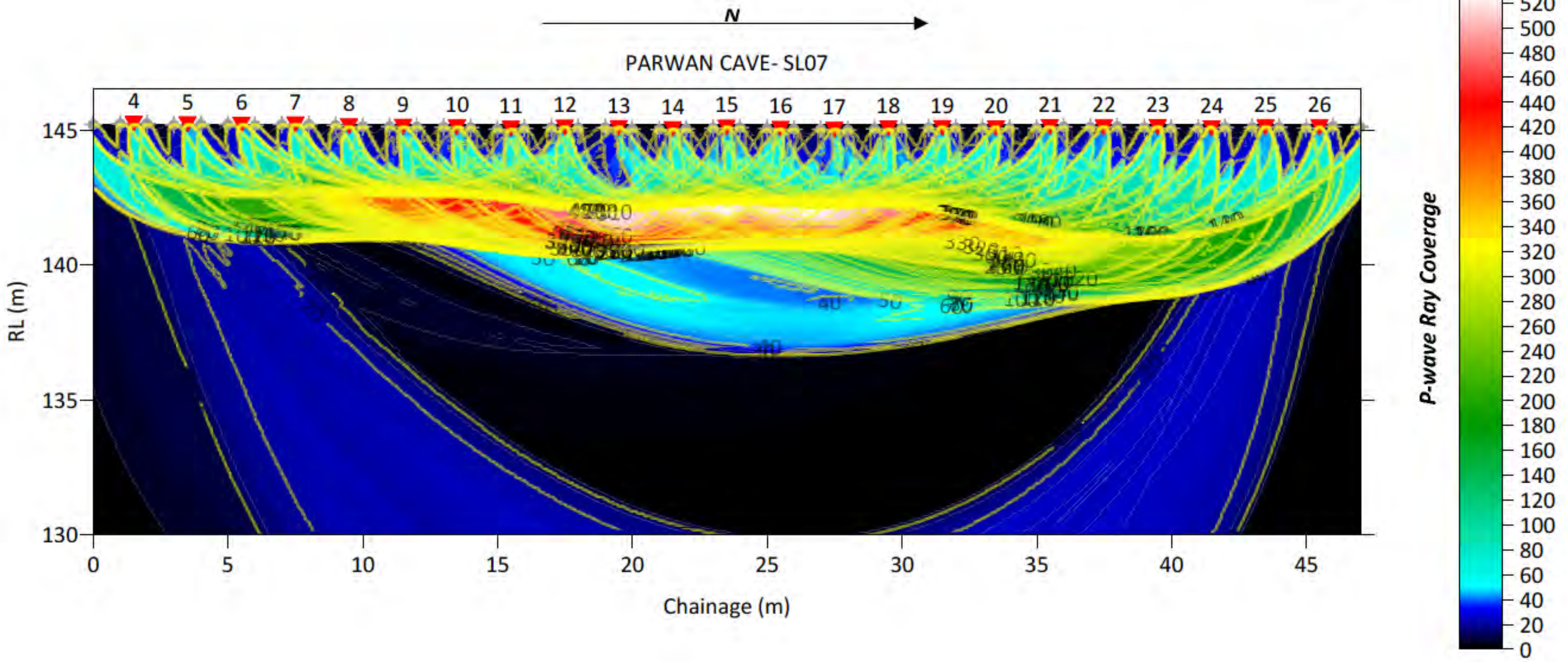
Disclaimer:

The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.





LEGEND:

- Inferred soil / rock interface
- Surveyed SRT Line Location / currently displayed
- Mapped cave outline
- Seismic shot points *(Profile view)*
- Seismic receivers *(Profile view)*

Map Scale: 1:250 @ A3

0 5 10

Metres

No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum:MGA 2020
Grid: GDA 2020 MGA Zone 55

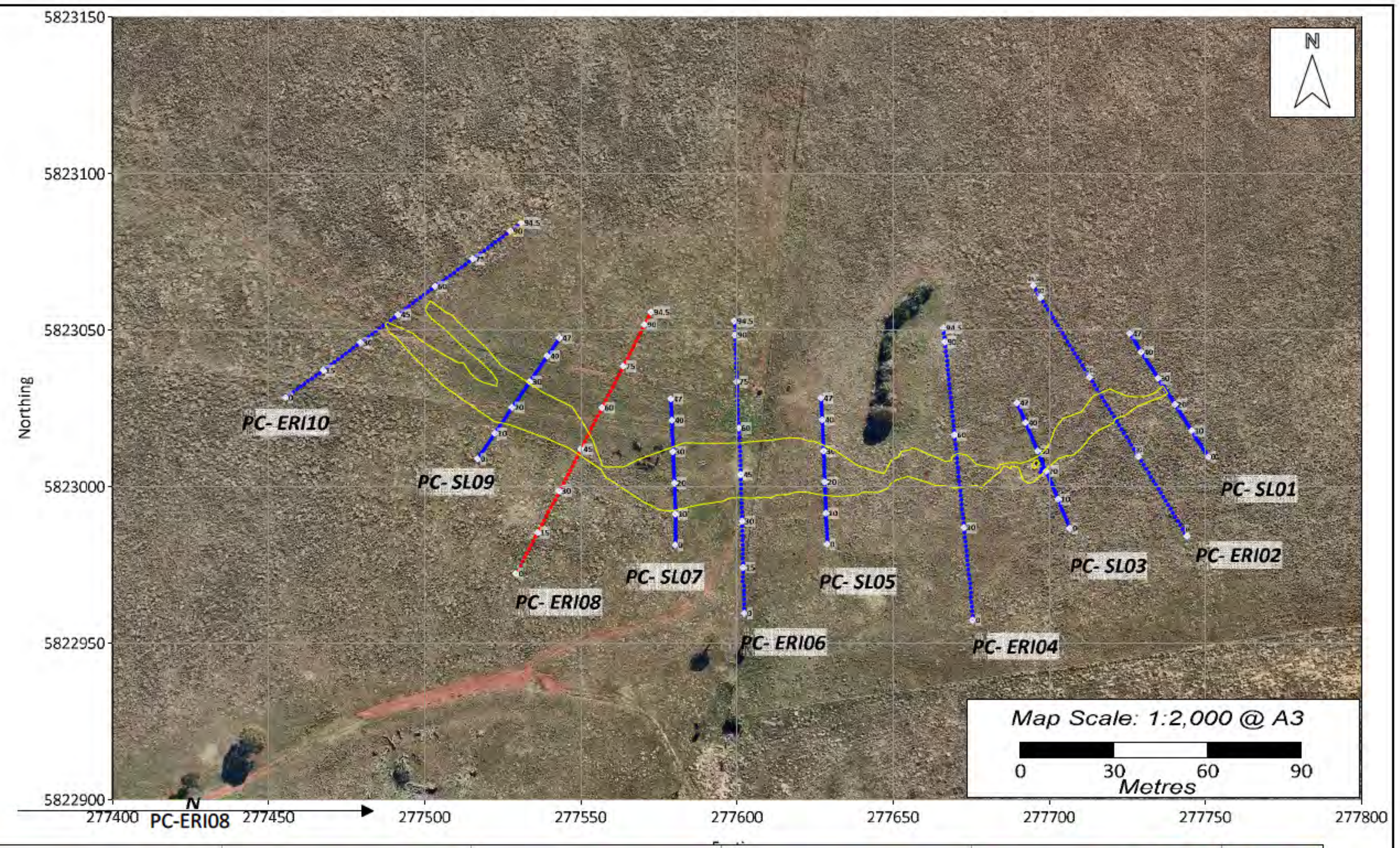
CLIENT	Parwan Cave Precinct -Victorian Planning Authority
PROJECT	Parwan Cave Development Precinct
CONSULTANT	WSP GOLDER
YYYY-MM-DD	2022-11-20
DESIGNED	ZT
PREPARED	PA&ZT
REVIEWED	ZT
APPROVED	MW
TITLE	GEOPHYSICAL SEISMIC REFRACTION TOMOGRAPHY SURVEY PC-SL079 P-WAVE RAY COVERAGE
PROJECT NO.	
DELIVERABLE	---
REV.	A
FIGURE	A07a

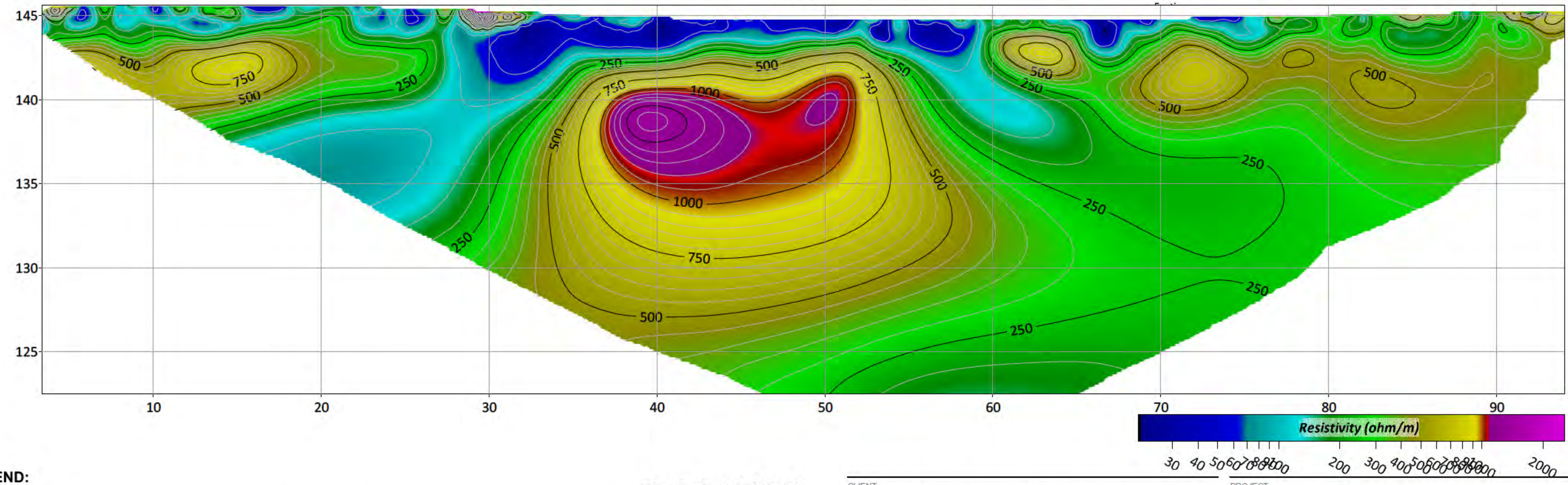
Disclaimer:

The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.





LEGEND:

Inferred soil / rock interface

Surveyed SRT Line Location / currently displayed

Mapped cave outline

Map Scale: 1:250 @ A3

0 5 10

Metres

No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum:MGA 2020
Grid: GDA 2020 MGA Zone 55

CLIENT
Parwan Cave Precinct -Victorian Planning Authority

PROJECT
Parwan Cave Development Precinct

CONSULTANT

wsp GOLDER

YYYY-MM-DD	2022-11-20
DESIGNED	ZT
PREPARED	PA&ZT
REVIEWED	ZT
APPROVED	MW

TITLE
GEOPHYSICAL ELECTRICAL RESISTIVITY IMAGING SURVEY
PC-ERI08
ELECTRICAL RESISTIVITY MODEL

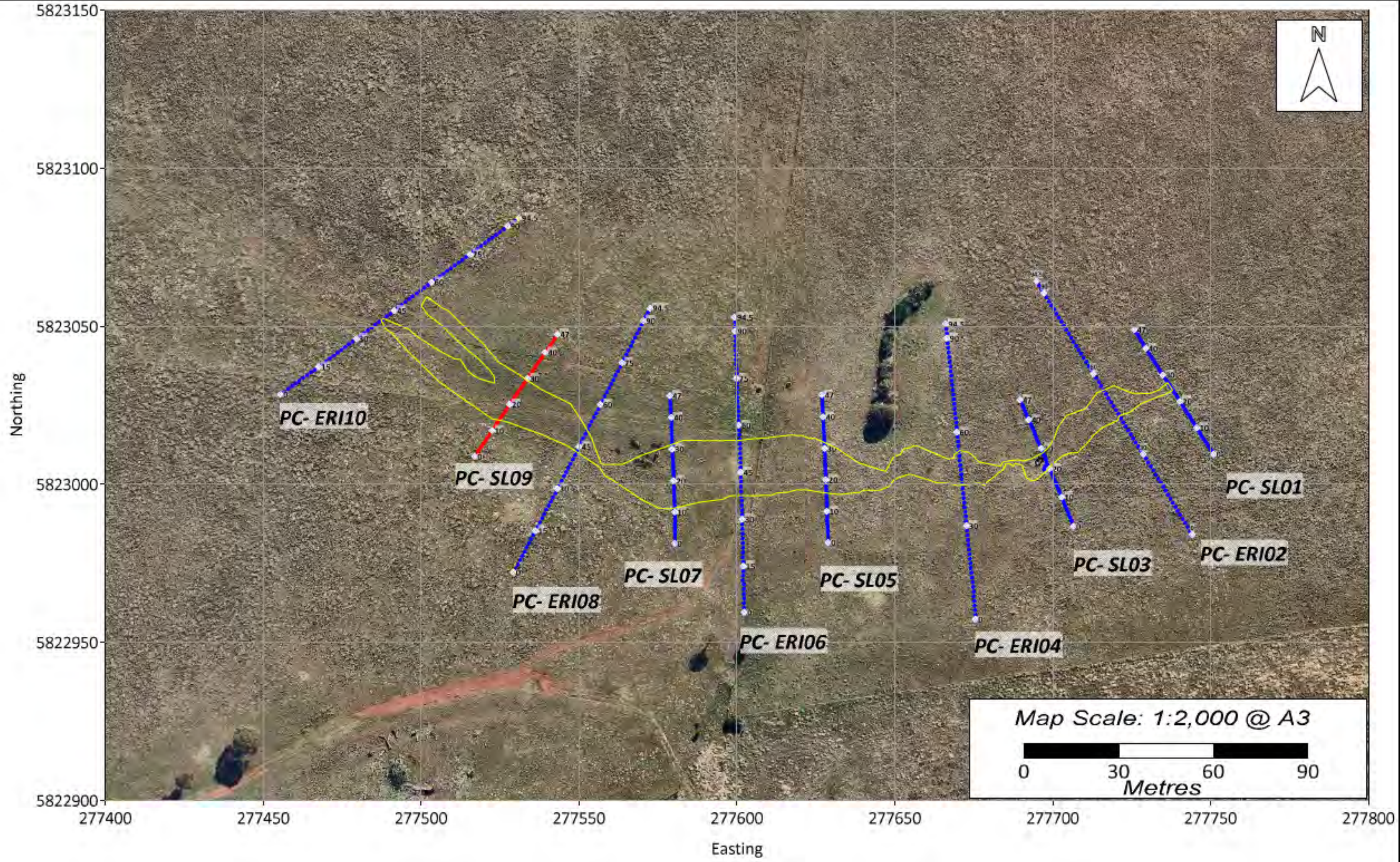
PROJECT NO.	DELIVERABLE	REV.	FIGURE
	---	A	A08

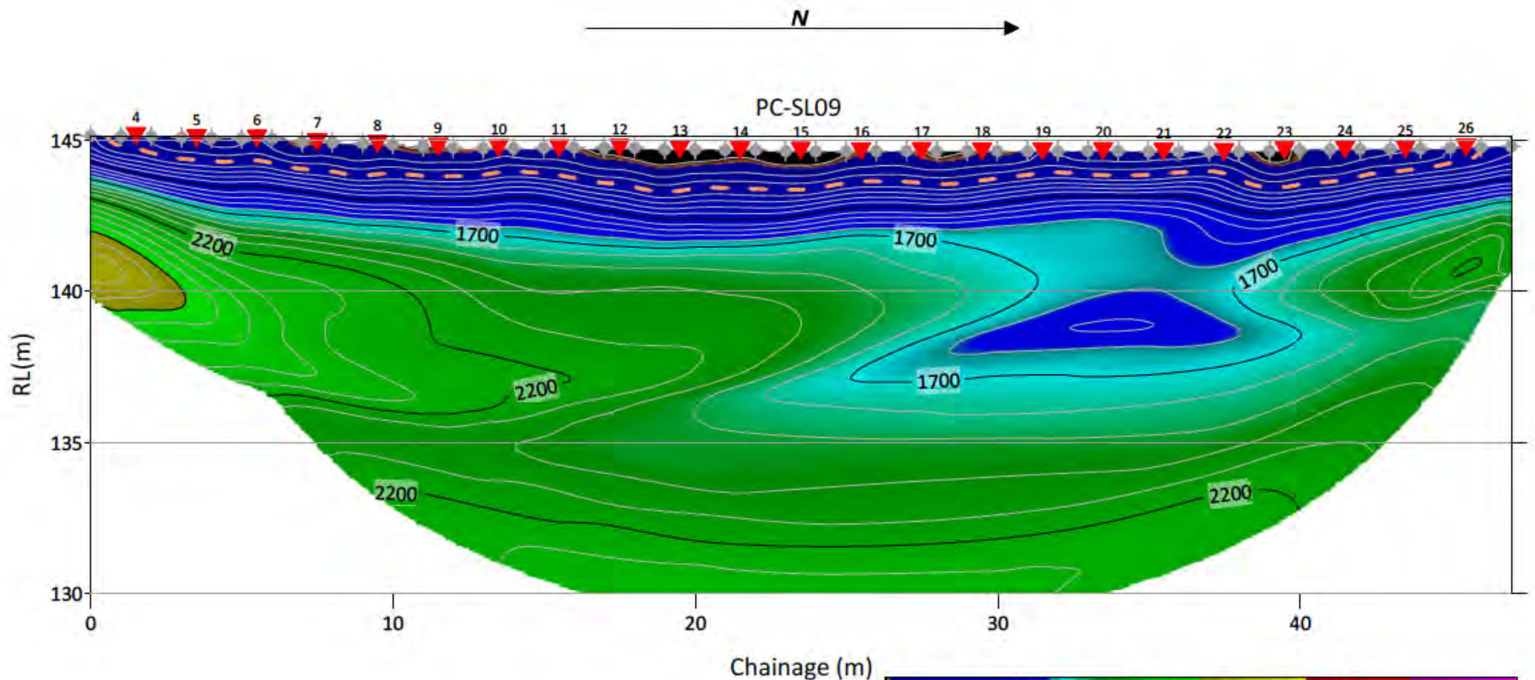
Disclaimer:

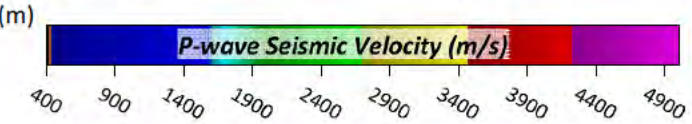
The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.







LEGEND:

Inferred soil / rock interface	
Surveyed SRT Line Location / currently displayed	30 / 30
Mapped cave outline	
Seismic shot points *(Profile view)*	
Seismic receivers *(Profile view)*	

Map Scale: 1:250 @ A3

0 5 10

Metres

No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum: MGA 2020
Grid: GDA 2020 MGA Zone 55

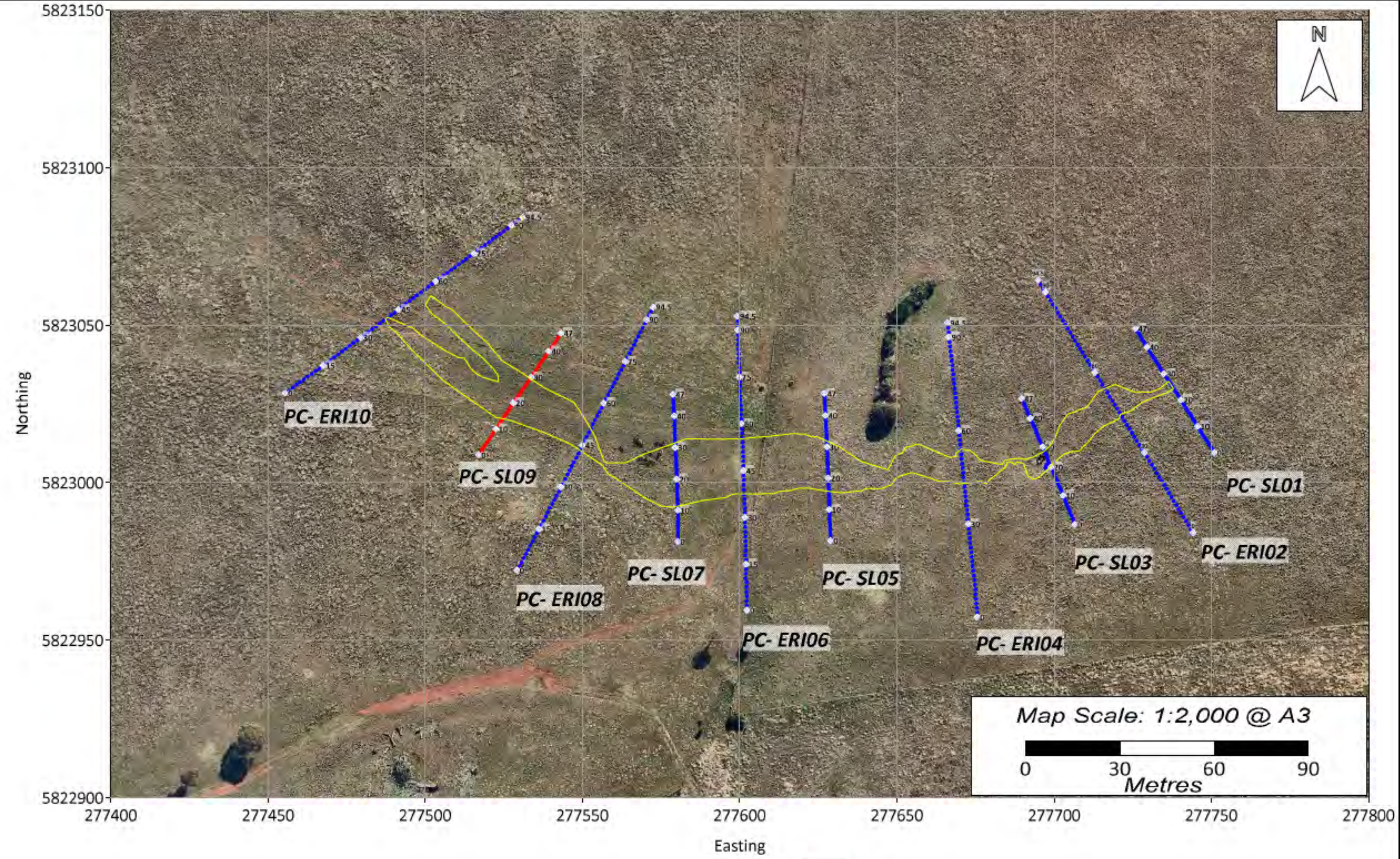
CLIENT	Parwan Cave Precinct -Victorian Planning Authority	PROJECT	Parwan Cave Development Precinct
CONSULTANT	WSP GOLDER	TITLE	GEOPHYSICAL SEISMIC REFRACTION TOMOGRAPHY SURVEY PC-SL09 P-WAVE VELOCITY TOMOGRAM
YYYY-MM-DD	2022-11-20	PROJECT NO.	---
DESIGNED	ZT	DELIVERABLE	---
PREPARED	PA&ZT	REV.	A
REVIEWED	ZT	FIGURE	A09
APPROVED	MW		

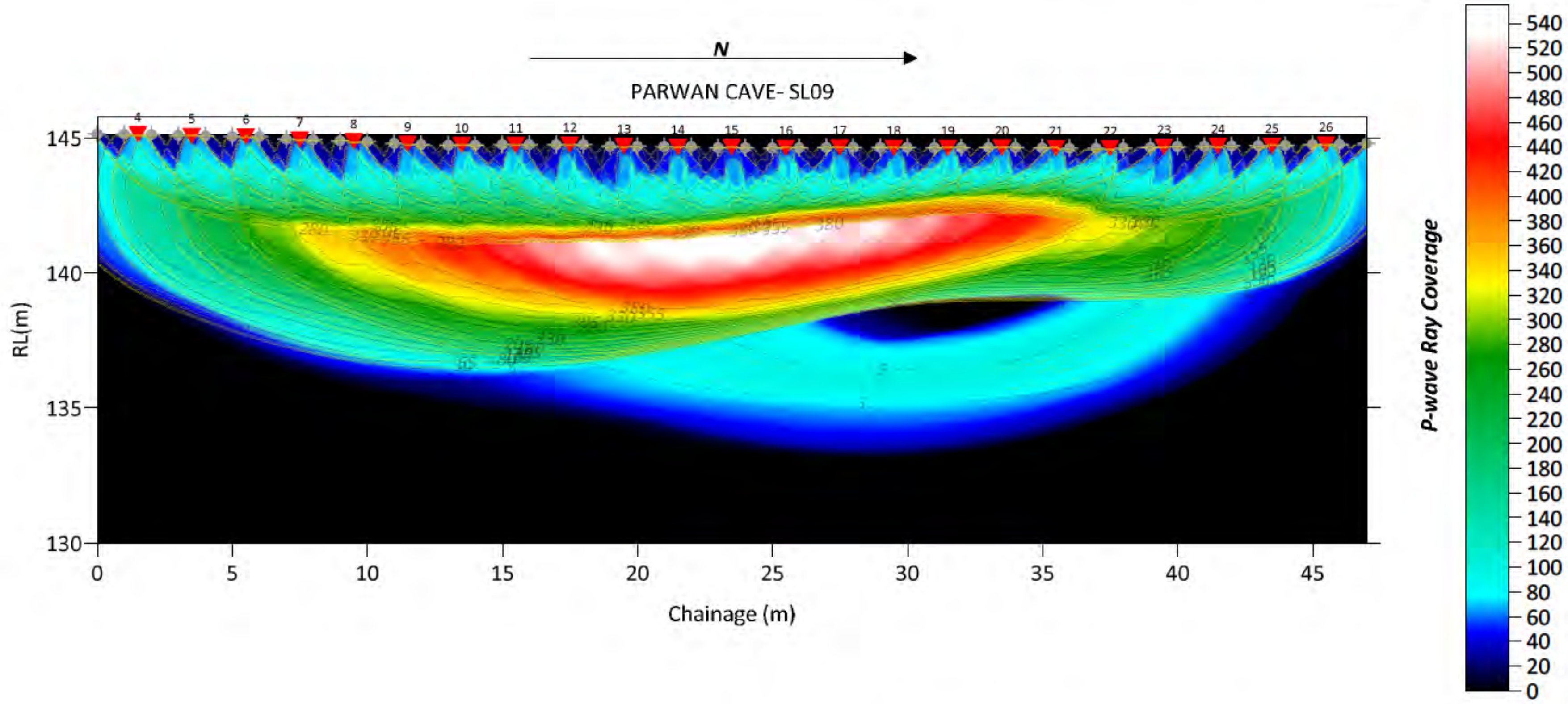
Disclaimer:

The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.





LEGEND:

Inferred soil / rock interface

Surveyed SRT Line Location / currently displayed

Mapped cave outline

Seismic shot points *(Profile view)*

Seismic receivers *(Profile view)*

Map Scale: 1:250 @ A3

Metres
No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum:MGA 2020
Grid: GDA 2020 MGA Zone 55

CLIENT
Parwan Cave Precinct -Victorian Planning Authority

PROJECT
Parwan Cave Development Precinct

CONSULTANT

WSP GOLDER

YYYY-MM-DD	2022-11-20
DESIGNED	ZT
PREPARED	PA&ZT
REVIEWED	ZT
APPROVED	MW

TITLE
GEOPHYSICAL SEISMIC REFRACTION TOMOGRAPHY SURVEY
PC-SL09
P-WAVE RAY COVERAGE

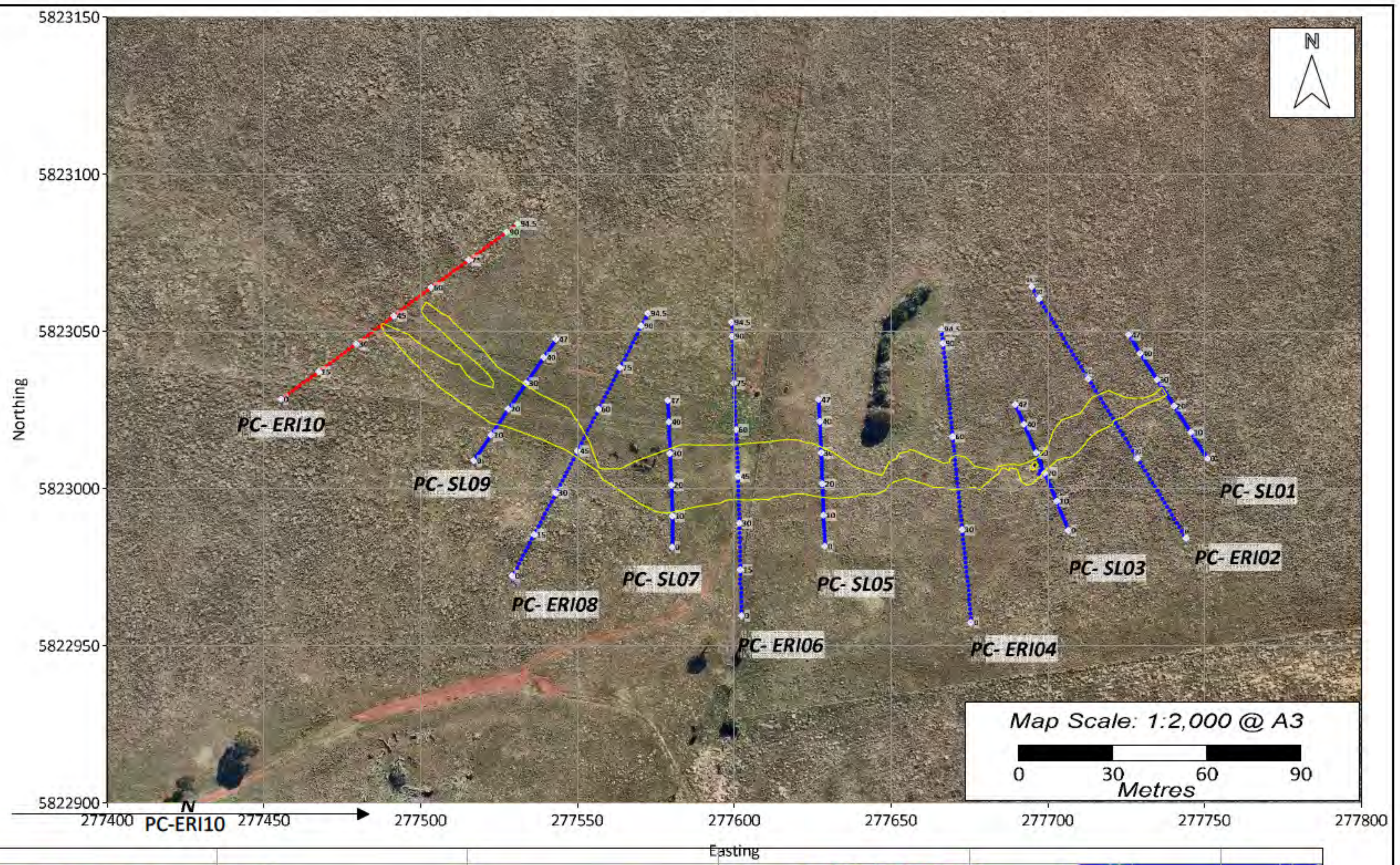
PROJECT NO.	DELIVERABLE	REV.	FIGURE
	---	A	A09a

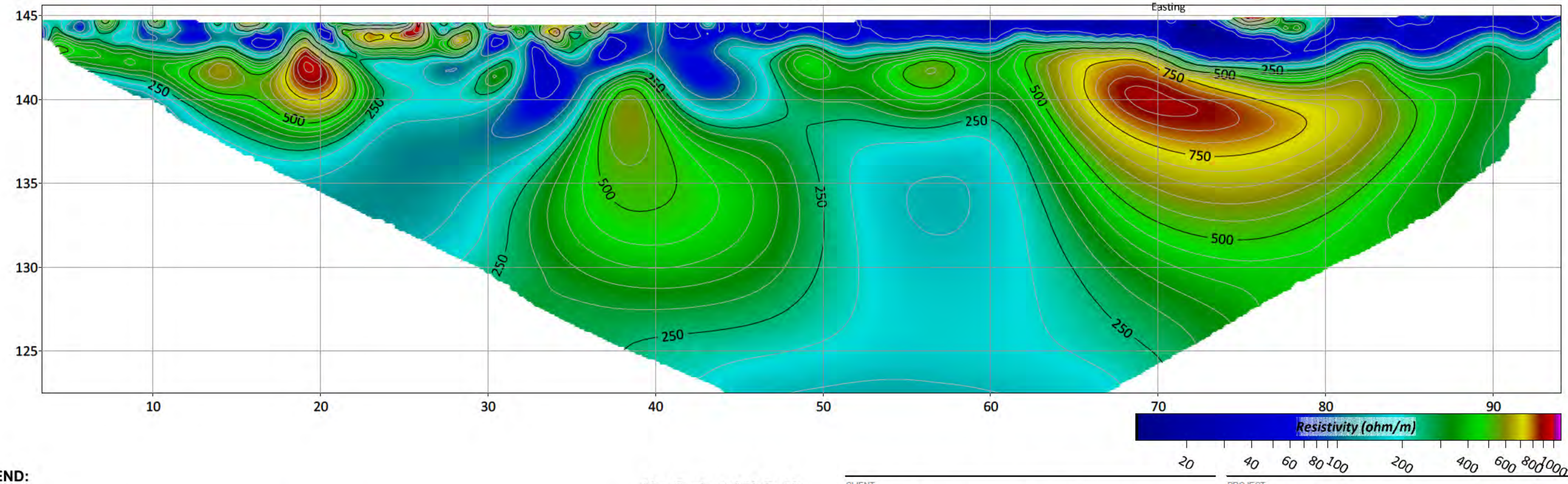
Disclaimer:

The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.





LEGEND:

Inferred soil / rock interface

Surveyed SRT Line Location / currently displayed

Mapped cave outline

Map Scale: 1:250 @ A3

0 5 10

Metres

No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum:MGA 2020
Grid: GDA 2020 MGA Zone 55

CLIENT
Parwan Cave Precinct -Victorian Planning Authority

PROJECT
Parwan Cave Development Precinct

CONSULTANT

WSP GOLDER

YYYY-MM-DD	2022-11-20
DESIGNED	ZT
PREPARED	PA&ZT
REVIEWED	ZT
APPROVED	MW

TITLE
GEOPHYSICAL ELECTRICAL RESISTIVITY IMAGING SURVEY
PC-ERI10
ELECTRICAL RESISTIVITY MODEL

PROJECT NO.	DELIVERABLE	REV.	FIGURE
	---	A	A10

APPENDIX B

SR Results Figures

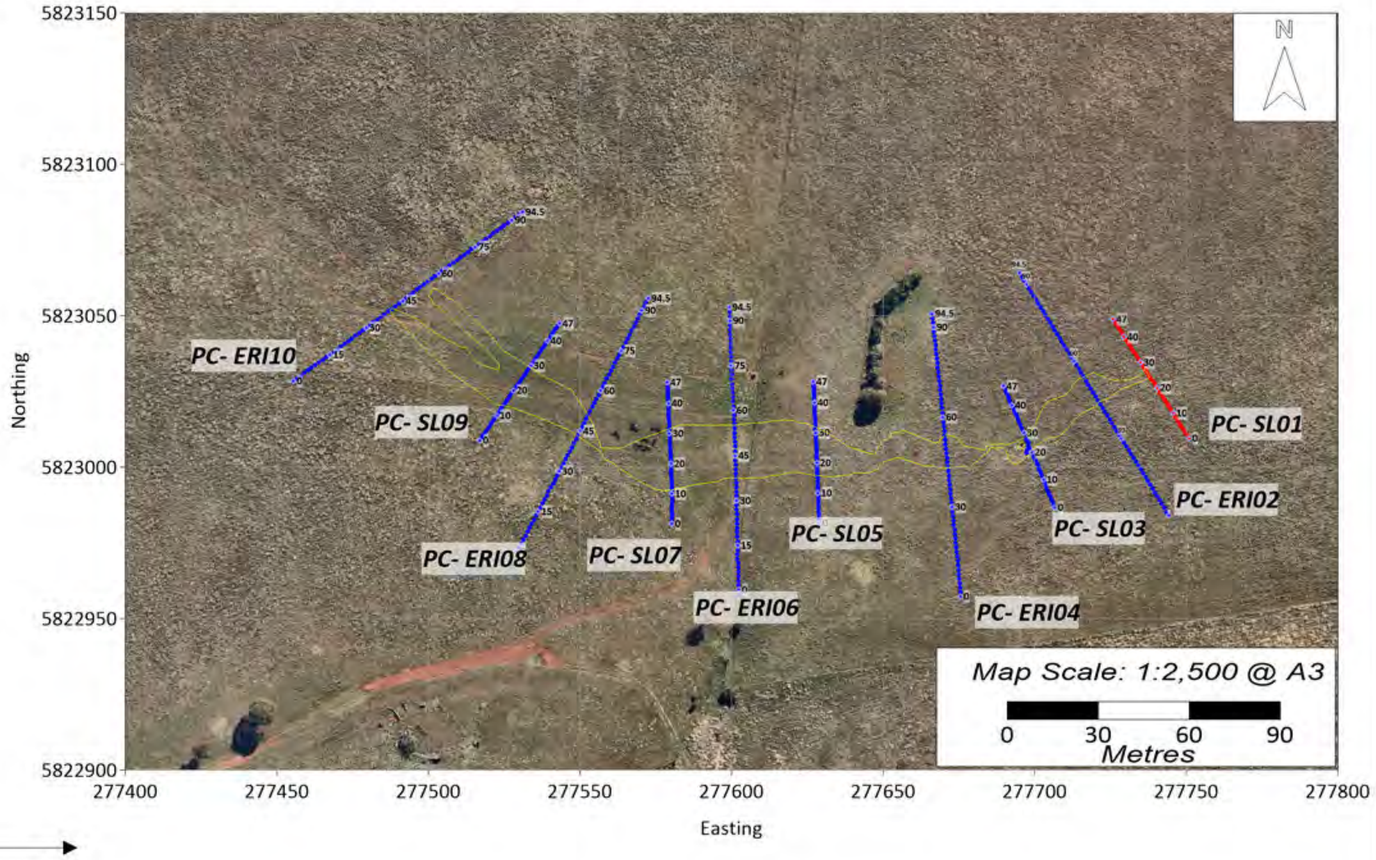
Figures:

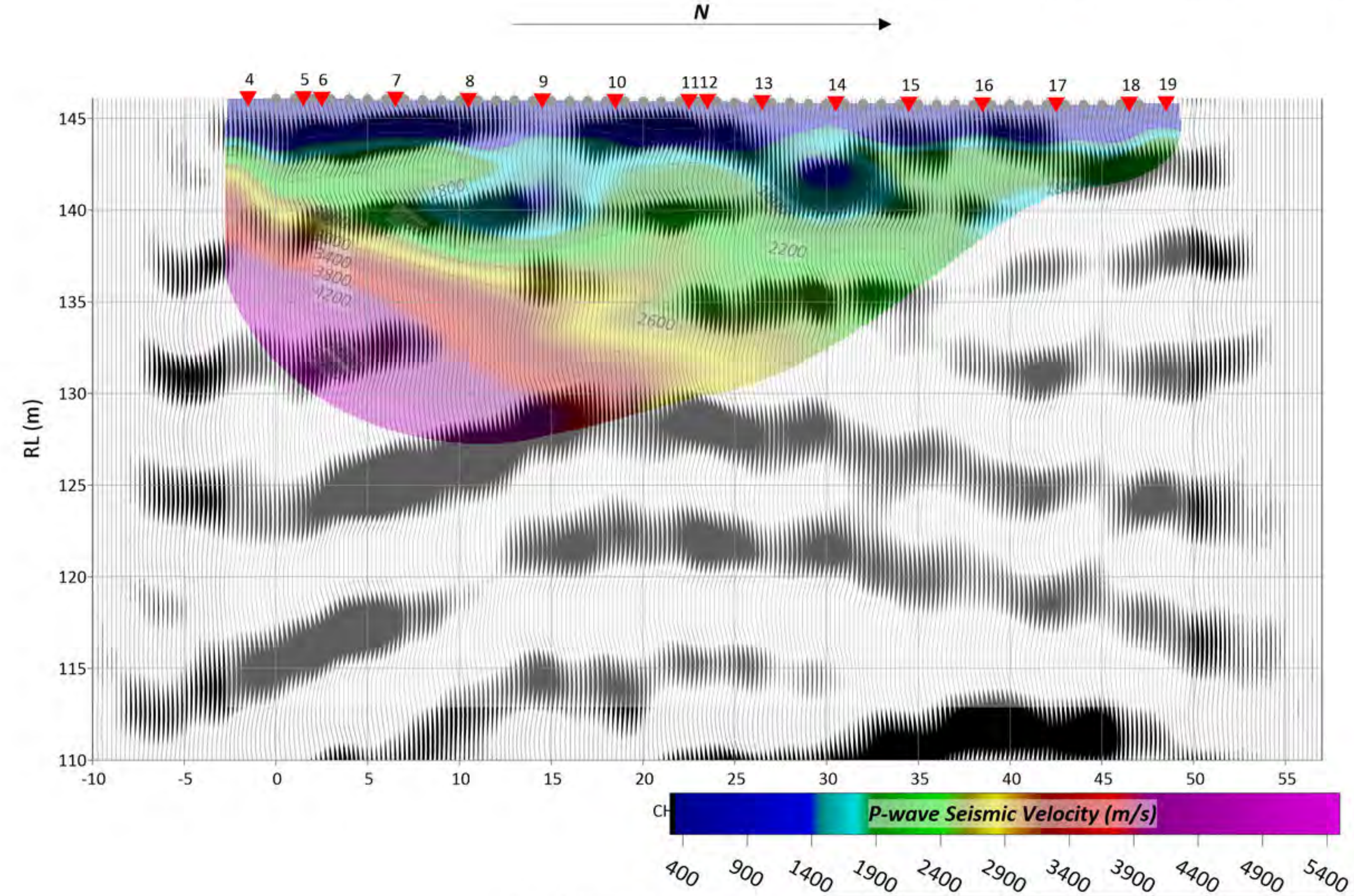
Disclaimer:

The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.





LEGEND:

Surveyed SRT Line Location / currently displayed

Mapped cave outline

Seismic shot points *(Profile view)*

Seismic receivers *(Profile view)*

Map Scale: 1:360 @ A3

0 5 10 15

Metres

No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum:MGA 2020
Grid: GDA 2020 MGA Zone 55

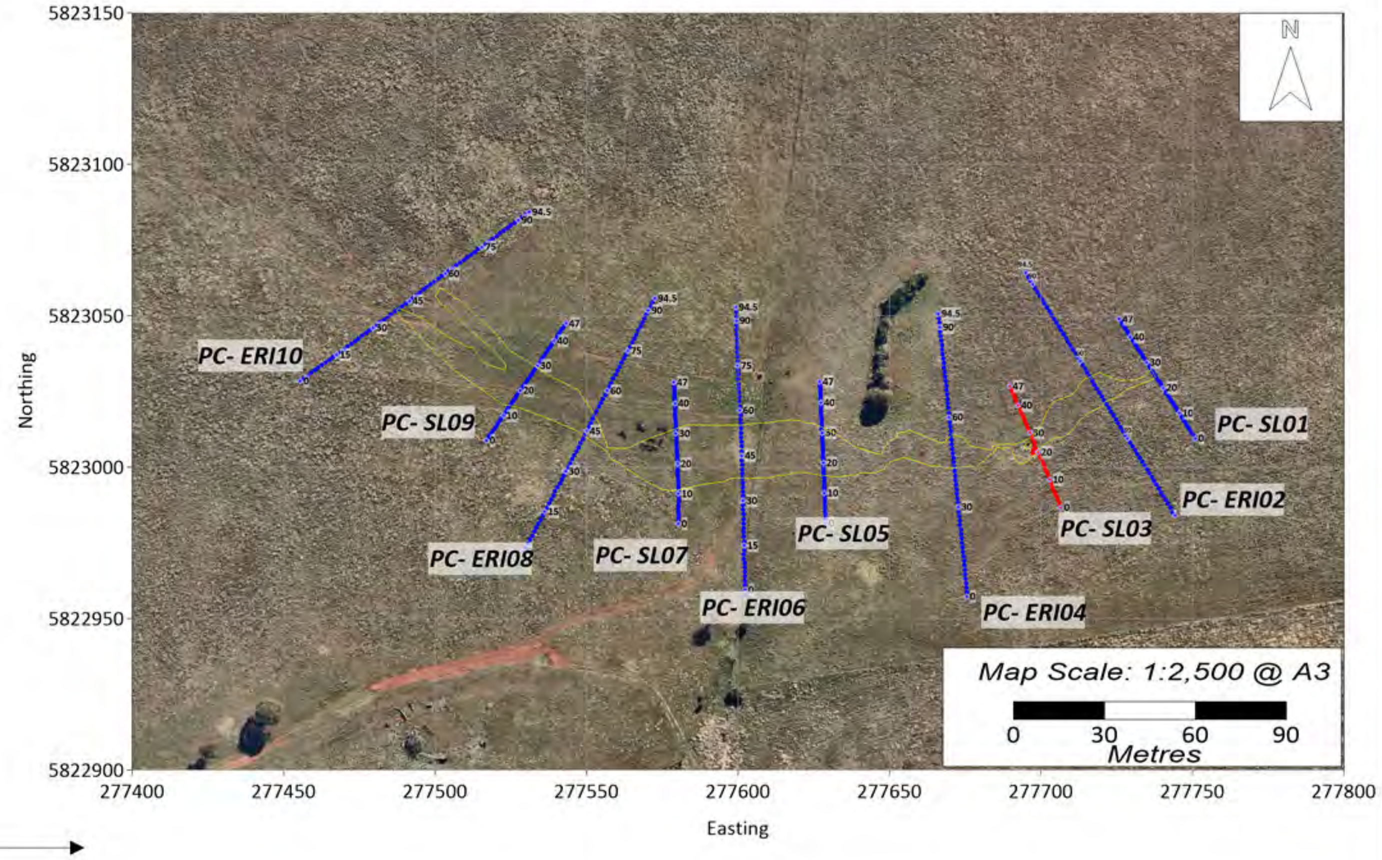
CLIENT	Parwan Cave Precinct -Victorian Planning Authority
PROJECT	Parwan Cave Development Precinct
CONSULTANT	WSP GOLDER
YYYY-MM-DD	2022-11-20
DESIGNED	ZT
PREPARED	PA&ZT
REVIEWED	ZT
APPROVED	MW
TITLE	**GEOPHYSICAL SEISMIC SURVEY PC-SL01 Vp MODEL OVER SR RESULTS**
PROJECT NO.	
DELIVERABLE	---
REV	A
FIGURE	B01

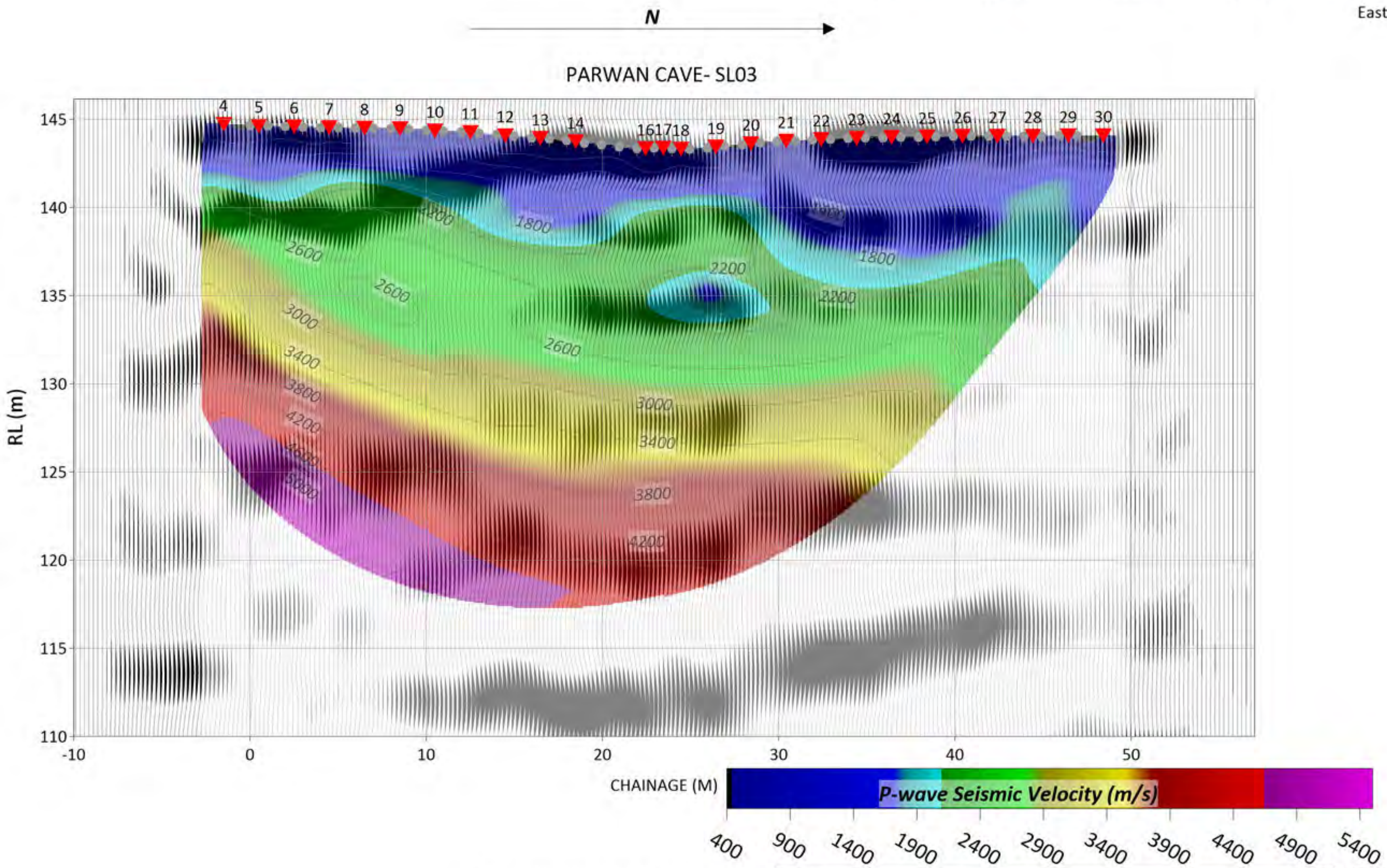
Disclaimer:

The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.





LEGEND:

Surveyed SRT Line Location / currently displayed

Mapped cave outline

Seismic shot points *(Profile view)*

Seismic receivers *(Profile view)*

Map Scale: 1:360 @ A3

0 5 10 15

Metres

No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum:MGA 2020
Grid: GDA 2020 MGA Zone 55

CLIENT	Parwan Cave Precinct -Victorian Planning Authority	PROJECT	Parwan Cave Development Precinct
CONSULTANT	YYYY-MM-DD: 2022-11-20; DESIGNED: ZT; PREPARED: PA&ZT; REVIEWED: ZT; APPROVED: MW	TITLE	GEOPHYSICAL SEISMIC SURVEY PC-SL03 Vp MODEL OVER SR RESULTS
PROJECT NO.	DELIVERABLE: ---	REV.: A	FIGURE: B02

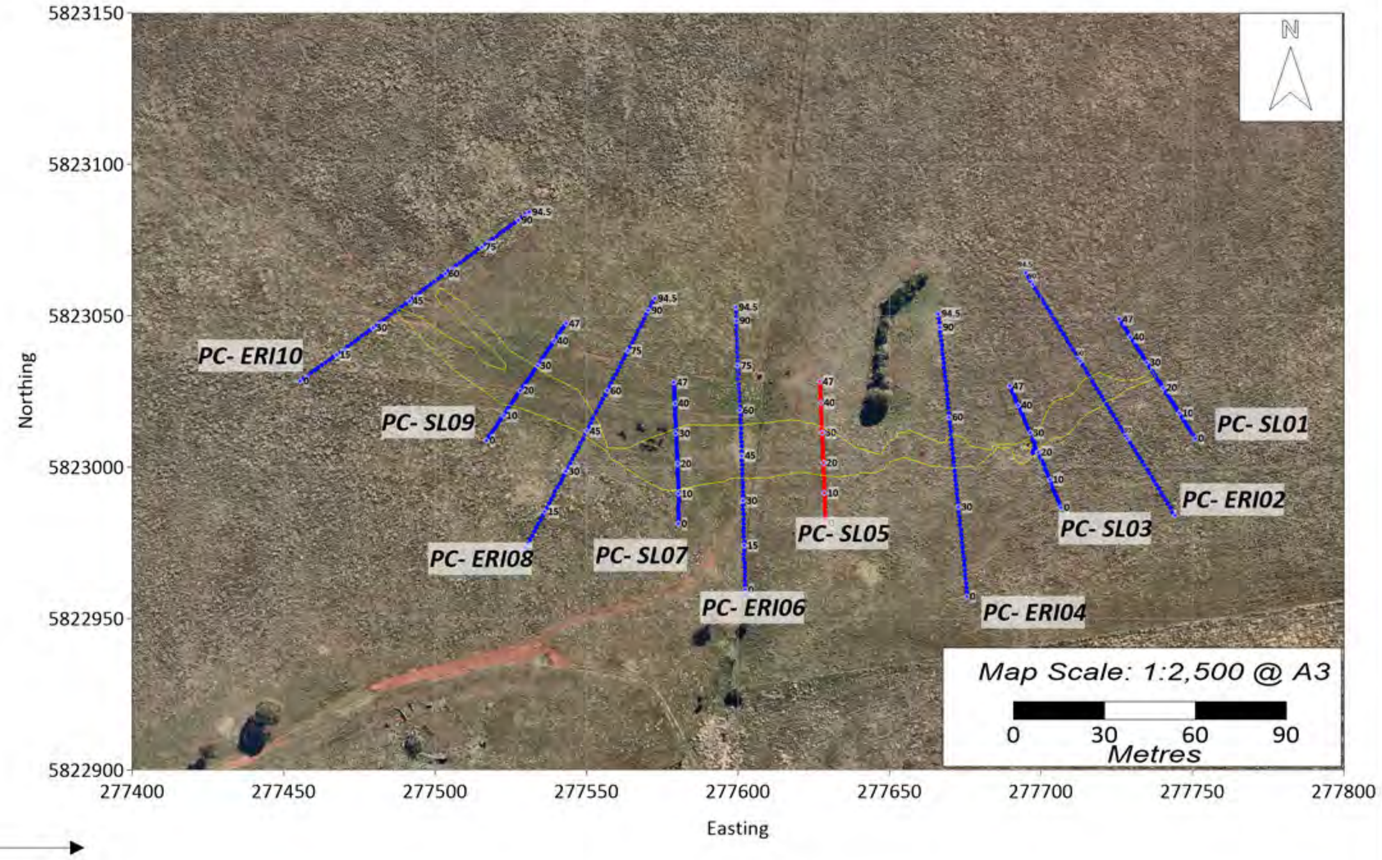
WSP GOLDER

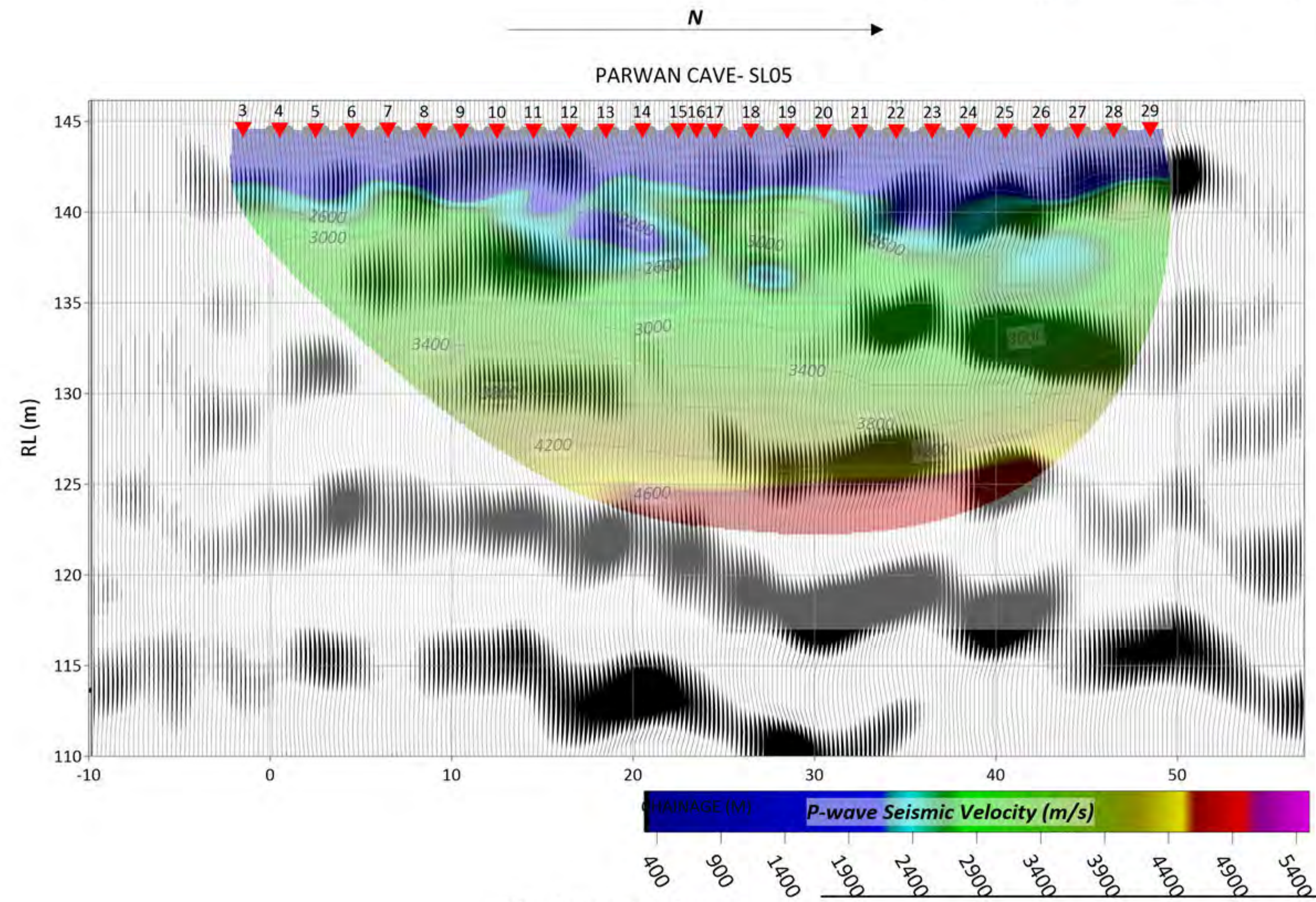
Disclaimer:

The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.





LEGEND:

Surveyed SRT Line Location / currently displayed	30 / 30
Mapped cave outline	
Seismic shot points *(Profile view)*	
Seismic receivers *(Profile view)*	

Map Scale: 1:360 @ A3

0 5 10 15
Metres

No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum:MGA 2020
Grid: GDA 2020 MGA Zone 55

CLIENT
Parwan Cave Precinct -Victorian Planning Authority

PROJECT
Parwan Cave Development Precinct

CONSULTANT

WSP GOLDER

YYYY-MM-DD	2022-11-20
DESIGNED	ZT
PREPARED	PA&ZT
REVIEWED	ZT
APPROVED	MW

TITLE
GEOPHYSICAL SEISMIC SURVEY
PC-SL05
Vp MODEL OVER SR RESULTS

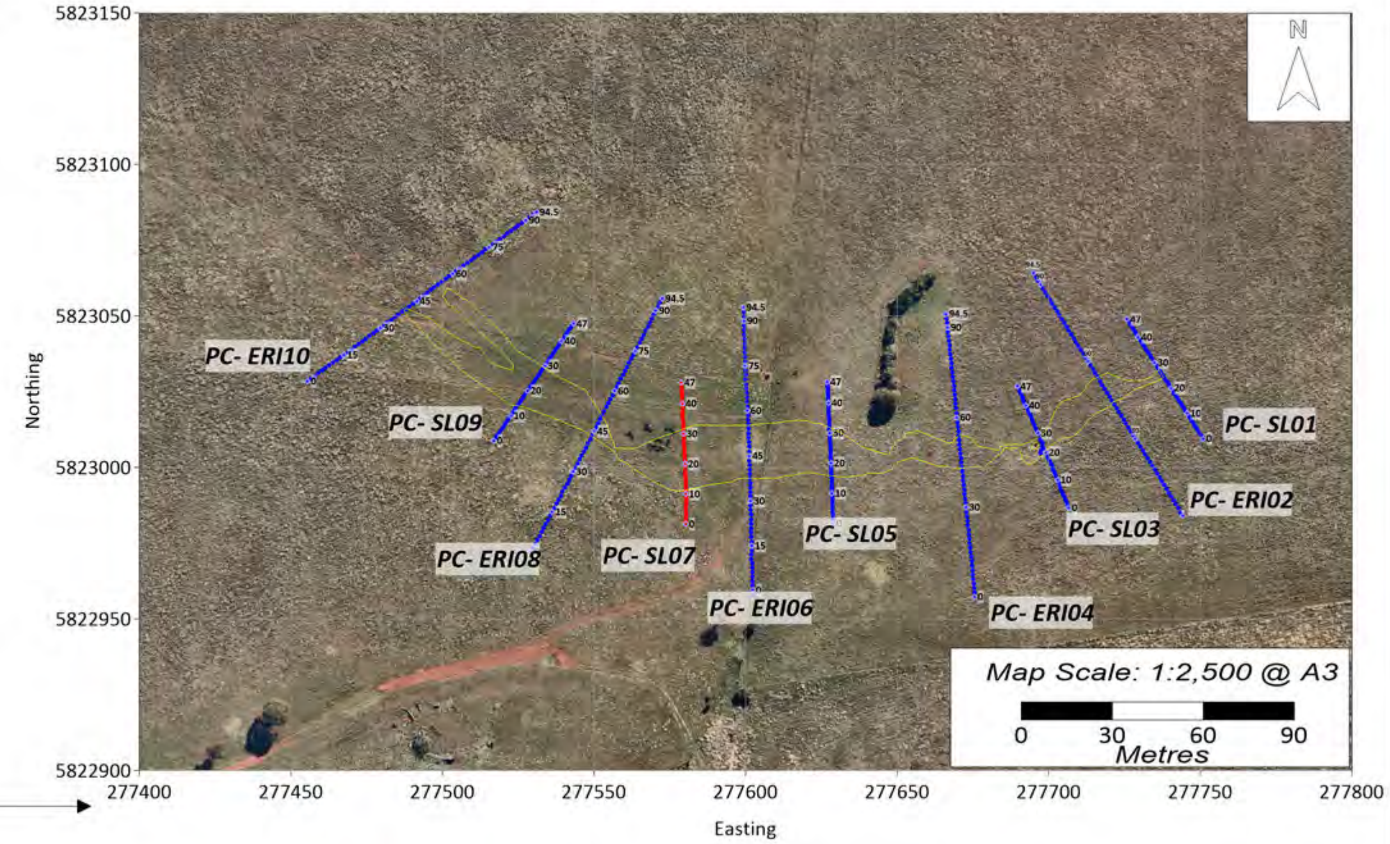
PROJECT NO.	DELIVERABLE	REV	FIGURE
	---	A	B03

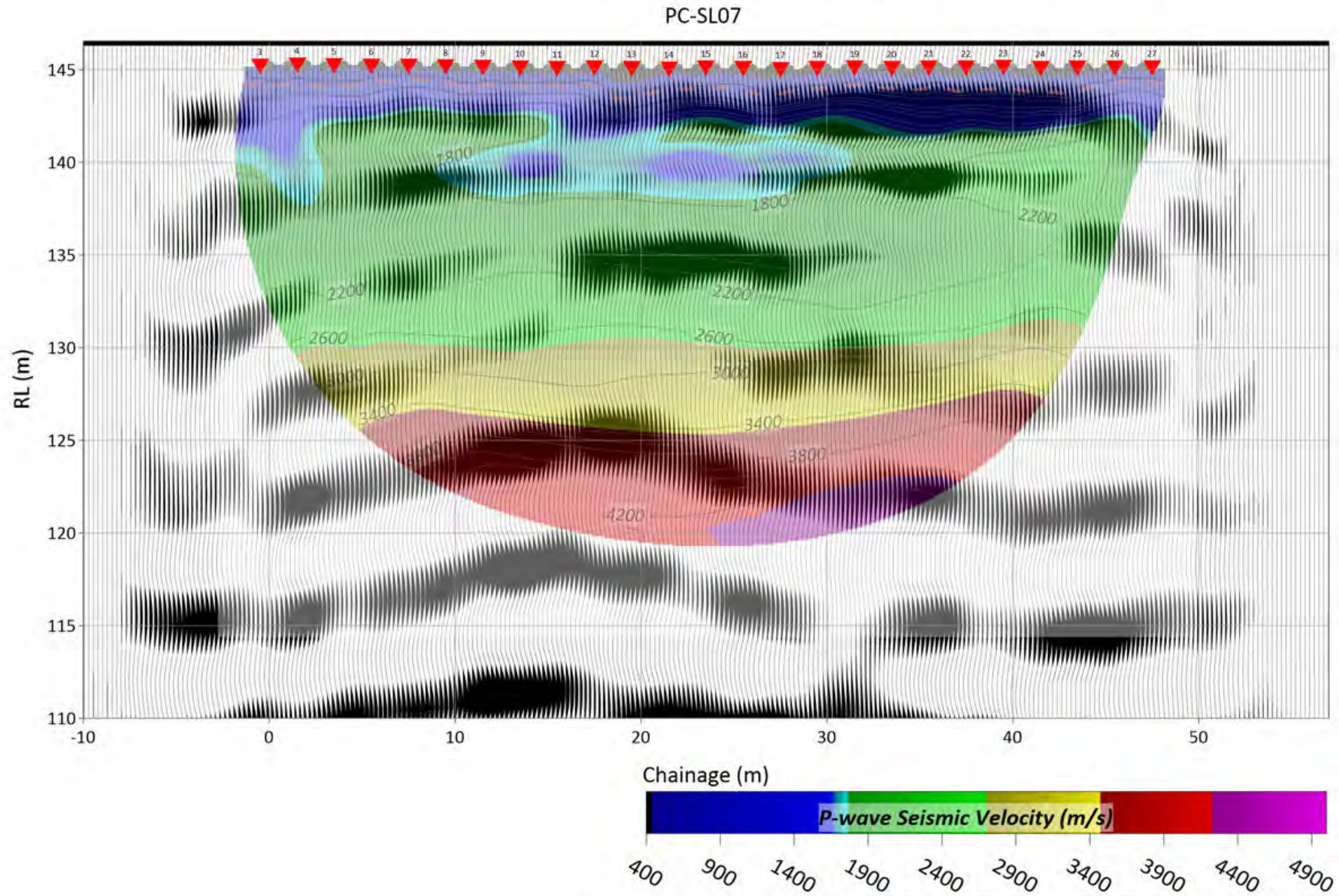
Disclaimer:

The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.





LEGEND:

Surveyed SRT Line Location / currently displayed 30 / 30

Mapped cave outline

Seismic shot points *(Profile view)*

Seismic receivers *(Profile view)*

Map Scale: 1:360 @ A3

0 5 10 15
Metres

No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum:MGA 2020
Grid: GDA 2020 MGA Zone 55

CLIENT	PROJECT
Parwan Cave Precinct -Victorian Planning Authority	Parwan Cave Development Precinct

CONSULTANT: WSP GOLDER

YYYY-MM-DD	2022-11-20
DESIGNED	ZT
PREPARED	PA&ZT
REVIEWED	ZT
APPROVED	MW

TITLE
GEOPHYSICAL SEISMIC SURVEY
PC-SL07
Vp MODEL OVER SR RESULTS

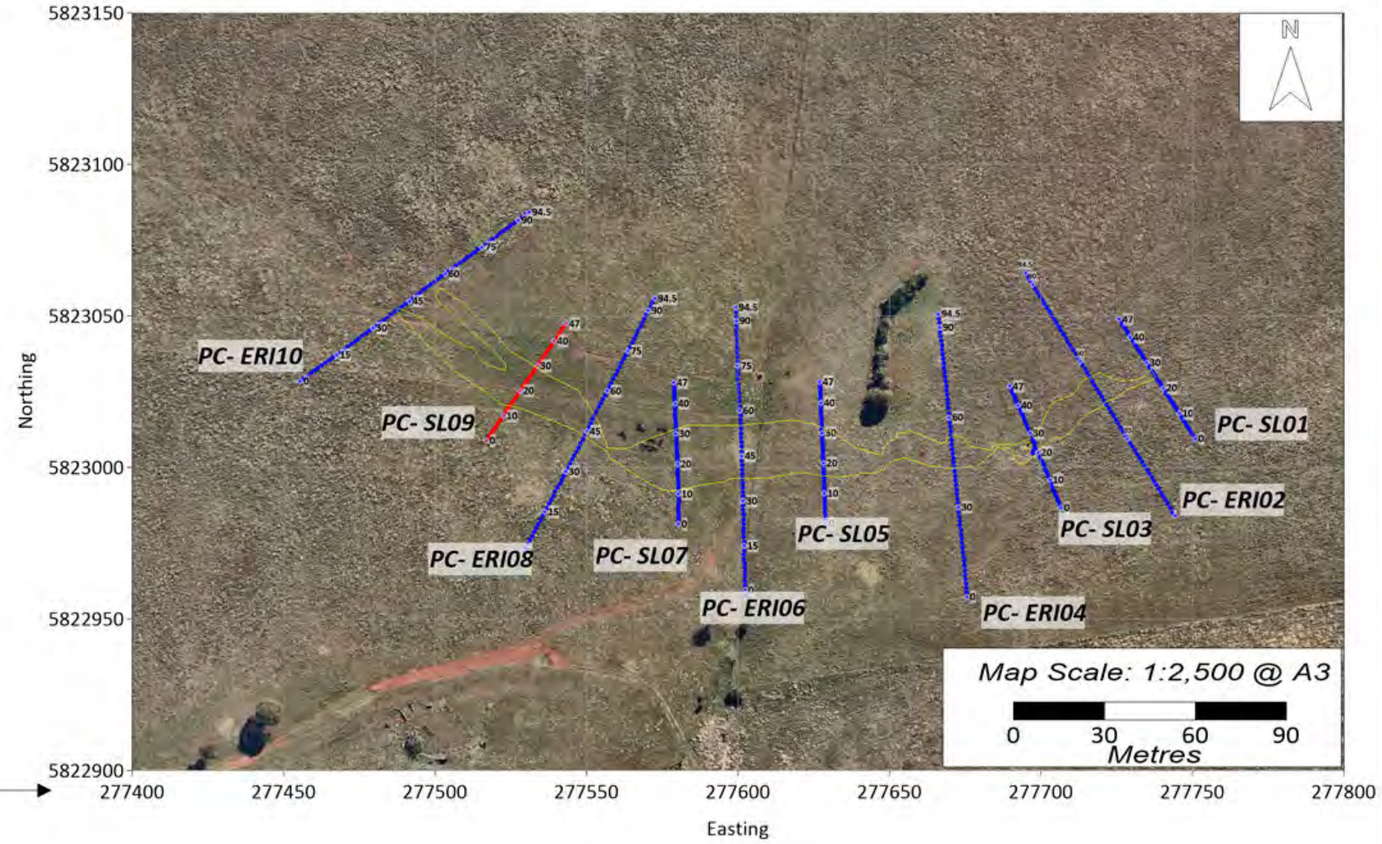
PROJECT NO.	DELIVERABLE	REV	FIGURE
	---	A	B04

Disclaimer:

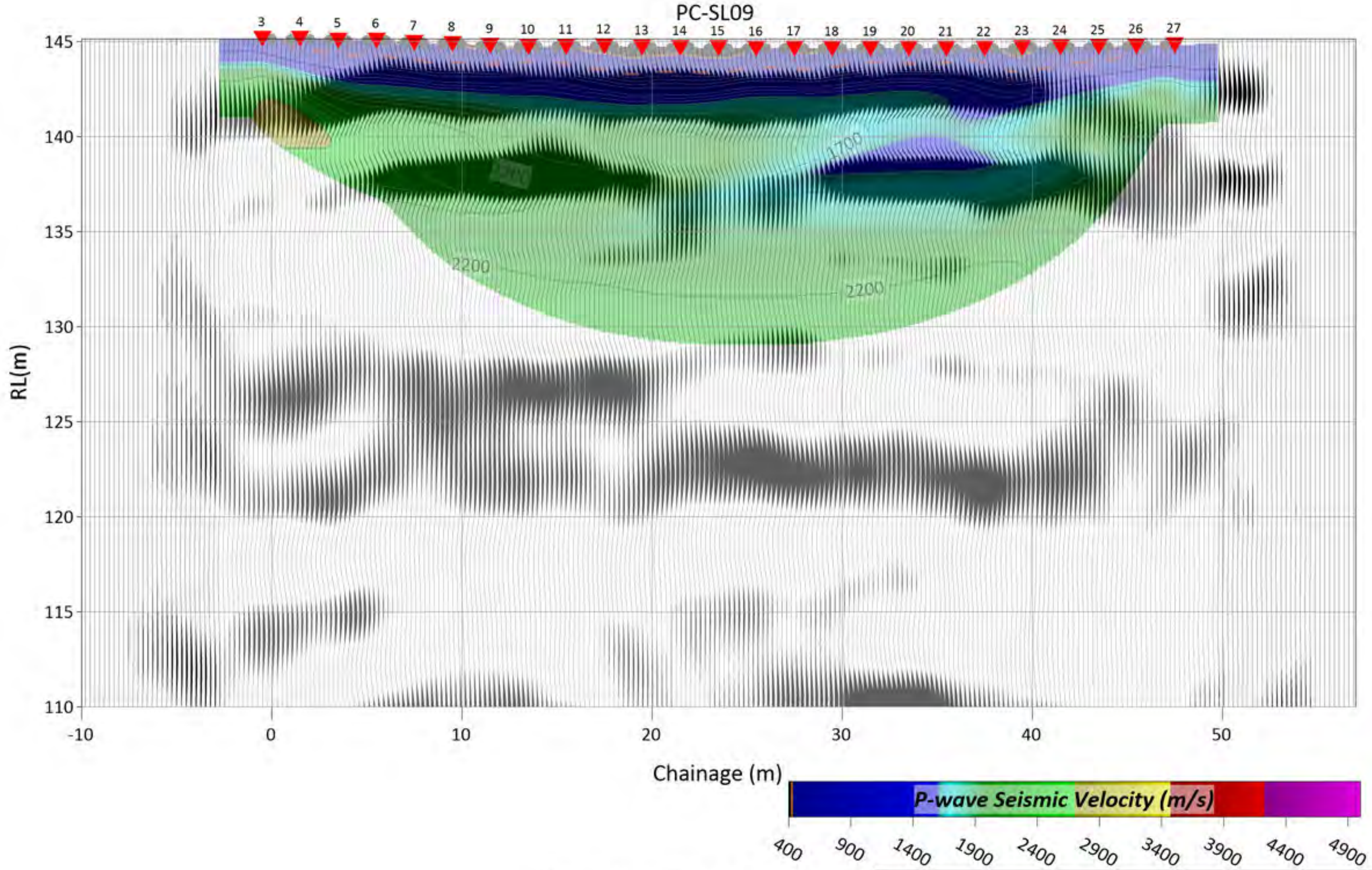
The seismic refraction method is sensitive to ground vibrations (time-variable noise) from a variety of sources. Geologic and cultural factors additionally may produce unwanted noise.

Seismic velocity models are subject to uncertainties due to ist dependancy upon the levels of noise and the geometry and spacing of the geophones and source used in the survey.

Due to the inherent limitation, a seismic refraction velocity models provide somewhat idealised representation of a site's geological reality. Properly integrated with other geologic information, seismic refraction survey is an effective, accurate, and cost-effective method of obtaining more complete subsurface information.



N →



Map Scale: 1:360 @ A3

Metres
No Vertical axes Exaggeration
Projection: Transverse Mercator
Horizontal Datum:MGA 2020
Grid: GDA 2020 MGA Zone 55

LEGEND:

Surveyed SRT Line Location / currently displayed	30 / 30
Mapped cave outline	
Seismic shot points *(Profile view)*	
Seismic receivers *(Profile view)*	

CLIENT
Parwan Cave Precinct -Victorian Planning Authority

PROJECT
Parwan Cave Development Precinct

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-11-20
DESIGNED	ZT
PREPARED	PA&ZT
REVIEWED	ZT
APPROVED	MW

TITLE
GEOPHYSICAL SEISMIC SURVEY
PC-SL09
Vp MODEL OVER SR RESULTS

PROJECT NO.	DELIVERABLE	REV	FIGURE
	---	A	B05

APPENDIX C

Important Information Relating to this Report

The document (“Report”) to which this page is attached and which this page forms a part of, has been issued by Golder Associates Pty Ltd (“Golder”) subject to the important limitations and other qualifications set out below.

This Report constitutes or is part of services (“Services”) provided by Golder to its client (“Client”) under and subject to a contract between Golder and its Client (“Contract”). The contents of this page are not intended to and do not alter Golder’s obligations (including any limits on those obligations) to its Client under the Contract.

This Report is provided for use solely by Golder’s Client and persons acting on the Client’s behalf, such as its professional advisers. Golder is responsible only to its Client for this Report. Golder has no responsibility to any other person who relies or makes decisions based upon this Report or who makes any other use of this Report. Golder accepts no responsibility for any loss or damage suffered by any person other than its Client as a result of any reliance upon any part of this Report, decisions made based upon this Report or any other use of it.

This Report has been prepared in the context of the circumstances and purposes referred to in, or derived from, the Contract and Golder accepts no responsibility for use of the Report, in whole or in part, in any other context or circumstance or for any other purpose.

The scope of Golder’s Services and the period of time they relate to are determined by the Contract and are subject to restrictions and limitations set out in the Contract. If a service or other work is not expressly referred to in this Report, do not assume that it has been provided or performed. If a matter is not addressed in this Report, do not assume that any determination has been made by Golder in regards to it.

At any location relevant to the Services conditions may exist which were not detected by Golder, in particular due to the specific scope of the investigation Golder has been engaged to undertake. Conditions can only be verified at the exact location of any tests undertaken. Variations in conditions may occur between tested locations and there may be conditions which have not been revealed by the investigation and which have not therefore been taken into account in this Report.

Golder accepts no responsibility for and makes no representation as to the accuracy or completeness of the information provided to it by or on behalf of the Client or sourced from any third party. Golder has assumed that such information is correct unless otherwise stated and no responsibility is accepted by Golder for incomplete or inaccurate data supplied by its Client or any other person for whom Golder is not responsible. Golder has not taken account of matters that may have existed when the Report was prepared but which were only later disclosed to Golder.

Having regard to the matters referred to in the previous paragraphs on this page in particular, carrying out the Services has allowed Golder to form no more than an opinion as to the actual conditions at any relevant location. That opinion is necessarily constrained by the extent of the information collected by Golder or otherwise made available to Golder. Further, the passage of time may affect the accuracy, applicability or usefulness of the opinions, assessments or other information in this Report. This Report is based upon the information and other circumstances that existed and were known to Golder when the Services were performed and this Report was prepared. Golder has not considered the effect of any possible future developments including physical changes to any relevant location or changes to any laws or regulations relevant to such location.

Where permitted by the Contract, Golder may have retained subconsultants affiliated with Golder to provide some or all of the Services. However, it is Golder which remains solely responsible for the Services and there is no legal recourse against any of Golder’s affiliated companies or the employees, officers or directors of any of them.

By date, or revision, the Report supersedes any prior report or other document issued by Golder dealing with any matter that is addressed in the Report.

Any uncertainty as to the extent to which this Report can be used or relied upon in any respect should be referred to Golder for clarification

golder.com

APPENDIX C

Wakelin Associates Parwan lava Cave Study

Wakelin Associates Pty. Ltd.

Parwan Employment Precinct

Lava Cave (Parwan Lava Cave: 3H-4)

Geology and Geophysical Assessment

report by report by [redacted]
Wakelin Associates to

WSP/Golder for the Victorian Planning Authority

30 November 2022

Graffiti in the most trafficked part of the cave

Wakelin Associates Pty Ltd. ABN 11 002 971 262
PO Box 271, Clifton Hill Victoria, Australia 3068. Ph 03 9482 4584
www.wakelinassociates.com.au

Table of Contents

List of figures and Tables

Executive summary

The development of the Parwan PSP requires information on the nature, the geological and geomorphological significance of the Parwan Lava Cave and suggestions regarding its future management. Then cave is located 1km south-east of Parwan Railway station.

This report:

- Describes the cave, its features and contents in the geological and geomorphological context of the eastern section of the Victorian Western District Volcanic Province
- Provides a more up to date map of the cave
- Discusses and explains the speleogenesis and processes of formation of lave tubes in relation to this cave
- Comments on the geophysics used to determine the extent of the cave and the potential presence of other tubes nearby
- Discusses the state significance rating for its geology and geomorphology in the context of the cave's age (3-4 Ma) and rarity in the eastern part of the Western District Volcanic Province
- Provides information on appropriate management including issues of risk and safety during any construction work

Four appendices are attached which give more detail to these matters.

Abbreviations

~	approximately
ASF	Australian Speleological Federation Inc.
et al	and others
GSAV	Geological Society of Australia (Victoria Division)
H-4	3H-4; the Australian Karst Index \unique number for the cave entrance
ID	Identification number
K-Ar	Potassium /Argon (dating)
km	kilometre(s)
m	metre(s)
Ma	Million years
MIC	Minimum Impact Caving (Code)
Mm	millimetre(s)
Mt	Mount
VSA	Victorian Speleological Association Inc
VPA	Victorian Planning Authority

Introduction

The Minister for Planning has appointed the VPA as the planning authority to lead the planning for the Parwan Employment Precinct (PEP) and the Parwan PSP. The plan will guide future urban development of these areas.

The existence of a single lava tube (cave), Parwan Cave (3H-4), has been known for many years at [redacted] but only limited knowledge of the cave existed outside speleological circles. Information in the public arena is neither accurate nor up to date (see 2021 SMEC Desktop Land Capability Assessment). The potential for extension of Parwan Cave, the existence of other lava tubes in the area, updated information on the geological and geomorphological significance and suggestions on appropriate management are needed to understand the geology and geomorphology of the Parwan PSP.

Caves from the Victorian Western District Volcanic Province are numbered in the Australian Karst Index with a "3H" prefix, e.g. 3H-4 abbreviated to H-4. This Australia wide system ensures each cave entrance has a unique ID. The GSAV uses a ID numbering protocol based on the 1:250,000 geological map series and the GSAV ID for Parwan Cave is ML-162. The ID (L 13) used by Rosengren (1986) is a legacy system and this online material is of limited use as it is often out of date. (https://vro.agriculture.vic.gov.au/dpi/vro/portregn.nsf/pages/port_lf_sig_sites_l13).

Qualifications

[redacted] is a geologist, geomorphologist and speleologist with specific understanding of caves and karst, including the many lava caves of the Western Victorian Volcanic Province. She has over 45 years' experience of the geomorphology of caves in Victoria and similar areas elsewhere in Australia and overseas. She is a long-term member of the Victorian Speleological Association (VSA) and is currently VSA's Documentation Officer. She chairs the Heritage subcommittee of the Geological Society of Australia (Victoria) (GSAV) and maintains the Victorian database of Sites of Geological and Geomorphological Significance for GSA(V). She has knowledge of stability issues in caves. She has visited and explored the cave several times over the years.

Methods

Google Earth was interrogated for landscape features. The Records of the Victorian Speleological Association Ltd (VSA) were checked, personal notes of previous field visits and specialist references were consulted. The GSAV Sites of Geological and Geomorphological Significance database was consulted. The GSAV protocol (Appendix 1) for assigning significance to sites had been used to assign significance.

A more accurate map of the cave and its survey were located, and an updated map produced. The previously published one was incorrect. VSA has commenced resurveying the cave using more precise instrumentation and cartography, but this is not completed and the remapping of the cave is not part of this project.

A visit to the cave occurred and the entrance area was investigated for changes. The VSA radio Direction Finding (RDF) equipment cross checked the easily accessible areas of the cave including the passage east of the entrance. The main passage was not entered.

The images for the geophysical survey undertaken by *wspGolder* were checked for potential voids.

Location

The Parwan lava cave (3H-4) is situated on privately owned grazing land approximately 1 km south-east of Parwan railway station and 5 km south-east of Bacchus Marsh, Victoria (Figure 1). The locality has coordinates 37° 42.8' S, 144°28.6' E. While known for about a century, the cave was first surveyed only in 1959 (Rees and Gill, 1959) and a more accurate survey was made by John Taylor and others from the

Victorian Speleological Association (VSA) in December 1969. It has not been resurveyed since, although the VSA map has been annotated and updated (Figure 2).

The cave is located on relatively flat (very low gradient slope) farm land currently used for grazing. A small intermittent stream flows on the south side near the entrance after sufficient rainfall but is neither a permanent nor reliable water source and has not been used much for stock watering.

[redacted]

Figure 1 Location of Parwan Cave (3H-4) Parwan South Rd, Parwan. The approximate sample site for sample of basalt dated by K- Ar method (Aziz-ur Rahman & McDougall, 1972).

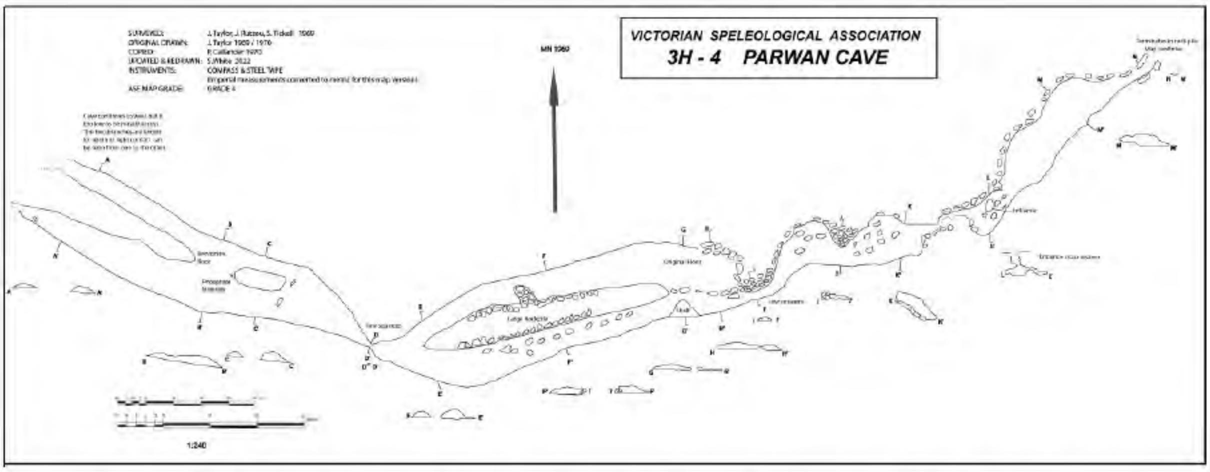


Figure 2 Plan map of Parwan Cave (3H-4) S. White 2022 after J. Taylor et al 1969 (for larger version see Appendix 4).

Geological Context

The cave is one of over 131 known lava caves on the Victorian Western District Volcanic Province. This relatively flat basaltic lava plain has small scattered central vent eruption centres locally aligned along inferred basement lineaments. The flat topography reflects the flat surface of the underlying late Cenozoic sediments and the topography-filling nature of the lava flows. Lava caves are found scatted across the plain for Clifton Hill in inner Melbourne to west of Hamilton. Although basalt lava caves are not rare in Victoria, they are very rare world-wide in older basalts.

The area is at the northern edge of the Werribee Plains, a flood basalt lava flow field (Hare et al 2007). The preserved vent structures are considered to be the youngest feature of the flows and many of the flows are possibly the products of fissure eruptions rather than from the later more explosive pyroclastic eruptions that resulted in the scoria cones e.g. Mt Bullengarook. However it more probable that the flow is the from Mt Bullengarook to the north, as basalt from that vent flows south. The basalt flows south but the Werribee River has subsequently incised across the flow east of Bacchus Marsh separating the southerly section of the flow from the main flow. Details of the nature of the separate flows south of the Werribee River are very limited and separate flows have not been identified.

The lava flows in this part of the province are relatively old, and dates between 1.41 and 4.03 Ma have been published (Aziz-ur Rahman & McDougall 1972, McDougall et al 1966, Hare et al 2007). The Bullengarook flow is Pliocene in age, between 4.03 and 3.01 Ma (Roberts 1984) and a date of 4.03$\pm$0.04 Ma is from a site 1 km SW of Bacchus Marsh (Aziz-ur Rahman & McDougall, 1972).

Cave description

Parwan Cave is one of 131 numbered lava caves in Victoria. There are several more known that still have to be documented and lava caves are not rare on the Western District. However this cave is in a much older lava flow than others known in Victoria.

The known cave comprises three elongated interconnecting chambers, which run approximately E-W for about 200 m and are up to about 20 m wide (Figure 2). However the cave extends to the west beyond the current mapped area and possible extends to the east as well. Currently human access beyond the extent of the existing cave is not possible. The geophysical investigations undertaken for this project indicate that more voids exist and further geophysical investigations are highly likely to show more.

The cave floor is 8 -10 m below ground surface and the maximum ceiling height is ~3 m. This means that the roof thickness is estimated as between 5 - 7 m. However roof heights are notoriously difficult to measure/estimate prior to the use of digital range finders. The only entrance is a subvertical tunnel-like aperture about 0.6 m across and ~5 m deep that drops to the tube floor (Figure 2). The walls and ceiling show some excellent examples of lava stalactites, formed as drips as the lava cools. Unlike stalactites in limestone caves, these form at the same time as the host rock solidifies.

The generally flat floor is either banded brownish clay deposits up to at least 30 cm thick, with associated organo-phosphate minerals or relatively stable piles of collapse rubble. The rock piles are the remnants of previous collapse events. These collapse events occurred a very long time ago and no collapse activity has been documented since the cave was first explored by Europeans.

Several low mounds of white to off-white earthy material that have been identified as several organo-phosphate minerals, represent strongly altered bat guano from the interaction of guano and basalt. This bat guano/basalt interaction has resulted in a range of organo-phosphate minerals. Parwanite has a general appearance of minute roseate clusters of very thin, platy pseudohexagonal crystals encrusting surfaces within taranakite-clay matrix (Figure 3). Clusters are 50-100 um in diameter, crystals about 2-5 um thick (Birch et al 2007). These deposits are more common further from the cave entrance and are often located below small ceiling alcoves. They are up to 10 cm high and may cover an area of several square metres, as well as extending up to 15 cm below the floor surface as thin bands within the clay. The white material may also coat some fallen rocks on the floor.

Australian caves host 44 such minerals and Victorian lava caves host several of these; Skipton Lava Cave (3H-1) and Parwan Cave (3H-4) are the type localities for some minerals. Parwan Cave, is the type locality for Parwanite [$(Na,K)(Mg,Ca)_4Al_8(PO_4)_8(CO_3)(OH)_7.30H_2O$] and has good examples of Taranakite[$(K,NH_4)Al_3(PO_4)_3$ $(OH).9H_2O$], Gordonite [$MgAl_2(PO_4)_2(OH)_2.H_2O$] and Montgomeryite [$Ca_4MgAl_4(PO_4)6(OH)_4.12H_2O$]. Whilst not of known economic value, these minerals are of scientific interest and value.

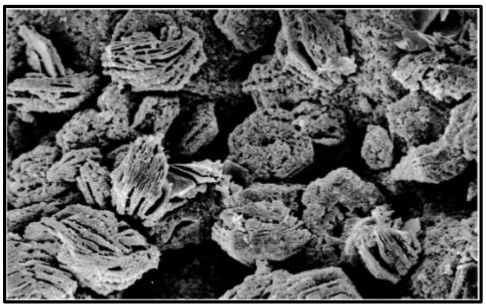


Figure 3 Scanning electron microscope photomicrograph showing minute clusters of parwanite crystals. Clusters are ~0.1 mm across. Chemical formula $(Na,K)(Mg,Ca)_4Al_8(PO_4)_8(CO_3)(OH)_7.3H_2O$.

Photo by D. Vince from Vince, et al 1993

Although a few bats (possibly *Miniopteris sp.),* have been observed in the cave area around the entrance, none have been observed in the main parts of the cave beyond the first squeeze. As these minerals are the result of the interaction of bat guano and basalt, bats must have inhabited the cave at some time in the distant past. This must have been prior to the collapse that blocked the tube and is now the first squeeze. It is assumed that as there are no evidence of bats, including remains, in the main part of the cave, the bat presence was a very long time ago perhaps some thousands of years and may be tens of thousands of years. No bat remains were found in the cave despite several attempts to find them over the years.

Lava Cave Speleogenesis (formation) and processes

The cave is interpreted as forming part of a tube system in a basaltic valley flow on the southern section of the Bullengarook Basalt Flow. As the cave forms as part of the lava flow it is of the same age i.e. between 4.03 and 3.01 Ma (Roberts 1984). As such this is the oldest known lava cave in Victoria and one of the oldest in Australia. Holy Jump Lava Cave (4BM-1), in Southeast Queensland is the known oldest in a 22-24 Ma old Late Oligocene-Early Miocene basalt (Webb et al 1982, Webb 1967).

The Newer Volcanics Province basalt has several types of caves: **lava tubes** which include subcrustal **lava caves, proto-tubes,** and **blister caves**. A specific technical term (***pyroduct***) for these features has been used by volcano-speleologists and geologists for some years although the use of *lava tube* is still known. Nevertheless, some technical literature will use pyroduct.

Lava tubes form in two main ways. Firstly, by roofing of narrow surface lava channels, which happens in several ways and secondly by draining from beneath the crust of a set of spreading lava lobes near the leading edge of a lava flow. The first type tends to form linear and simply-branched or anastomosing tubes. The second tends to form smaller, but more complex mazes of shallow, low-roofed chambers and passages. Over time these may evolve by solidification of the more stagnant areas and erosional enlargement of the fastest moving routes to form simpler linear tubes that are difficult to distinguish from the roofed channels. Both types of tube contain liquid lava flowing beneath a solid crust. At the end of the eruption some of that lava drains out to leave empty caves, but many tubes remain filled with solidified lava. Many lava caves end at solid undrained lava sumps. Subcrustal lava caves is a broad term for all the small shallow caves that form by drainage from beneath a broadly crusted lava flow (Figures 4 & 5).

Entrances to lava caves are generally the result of collapse although vents are known e.g. The Shaft at Budj Bim (Mt Eccles) but these are relatively rare and only 3 are known in Victoria despite the 131 caves documented.

In any discussion of lava tubes and lava caves and their genesis, it is important to distinguish between active (lava-filled) cavities and the drained tubes and chambers (i.e. caves which appear at the end of the eruption. Proto-tube is a term introduced by Grimes (2008) for the very small tubes that seem to be the earliest stage in subcrustal drainage. In Victoria, speleologists have previously used the term blister cave for the small, simple, isolated chambers found under the stony rises. However, this theory is now discredited, and the cavities are **not** small chambers formed by gas pressure but are lava blisters inflated by liquid lava and later drained (Grimes 2010).

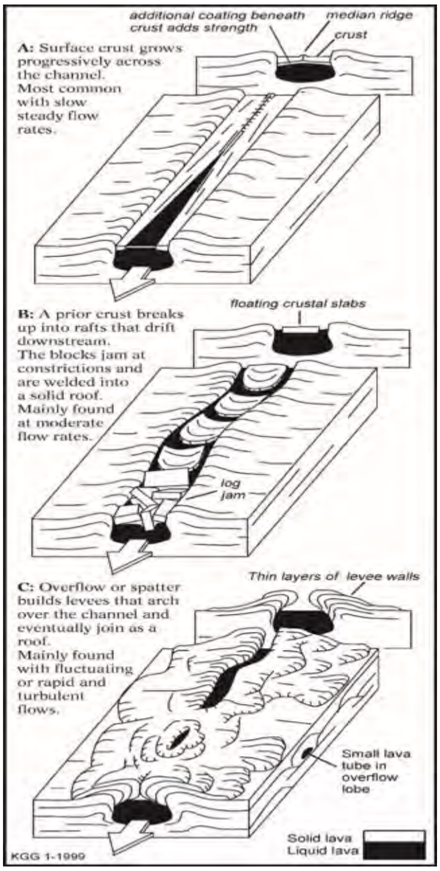


Figure 4. Three ways to make a lava tube by roofing a lava channel. (KGG).

It is difficult to determine specifically which of these 3 processes is the most likely formation process for Parwan Cave due to the age of the flow. A is probably the most likely as no evidence of features within the cave related to B or C. Such features can be seen in other lava tubes in Western Victoria. However linear feeder tubes are possible.

Source Grimes 2010

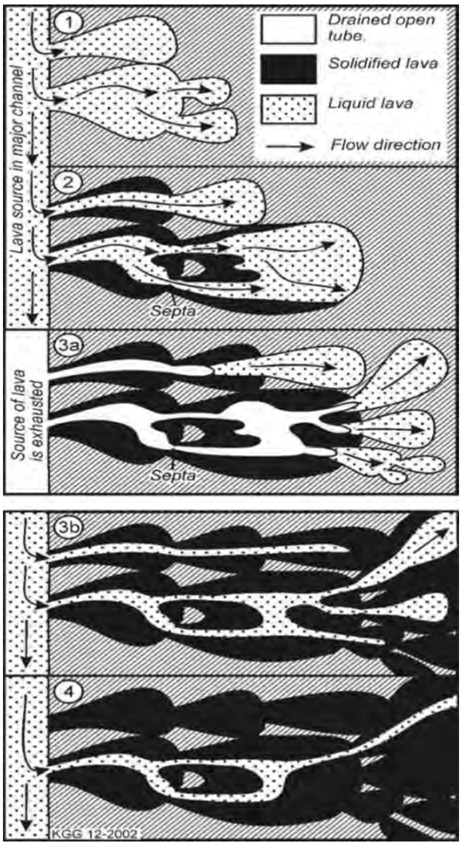


Figure 5 Stages in the formation of lava tubes by draining of lava lobes. (KGG)

***Step 1:** Thinly crusted lobes of lava expand by breakouts through ruptures and budding of further lobes.*

***Step 2:** Stagnant areas of the older lobes solidify, but flow from the source keeps the feeder conduits liquid.*

***Step 3**a: If the source flow ceases some of the conduits may drain to form air-filled cavities.*

***Steps 3b and 4** indicate the further evolution into more linear feeder tubes as lava continues to flow through the system.*

Source Grimes 2010.

Parwan Cave appears to be a drained linear lava tube drained during the eruption period and solidification of the basalt flow (Figure 4) by the draining from beneath the crust of a set of spreading lava lobes near the leading edge of a lava flow. It is probably longer than the known cave, but exactly how much longer is not known. The existence of further voids and tubes can be identified by geophysical methods across the flow, but these may be a complex pattern of voids (Figure 5).

Geophysics analysis

Geophysics is useful, especially with respect to identifying voids that do not have entrances. However, it is not particularly precise and gives little evidence as to whether the void has loose fill or is a significant void that in theory (if there were an entrance) could be traversed. It is also expensive to obtain more precise characterisation of the subsurface.

The 10 slices of geophysical data indicate that the cave map relates well to the geophysics but not precisely. However it is important to check the map cross sections as this gives measured information regarding the presence of rockpiles.

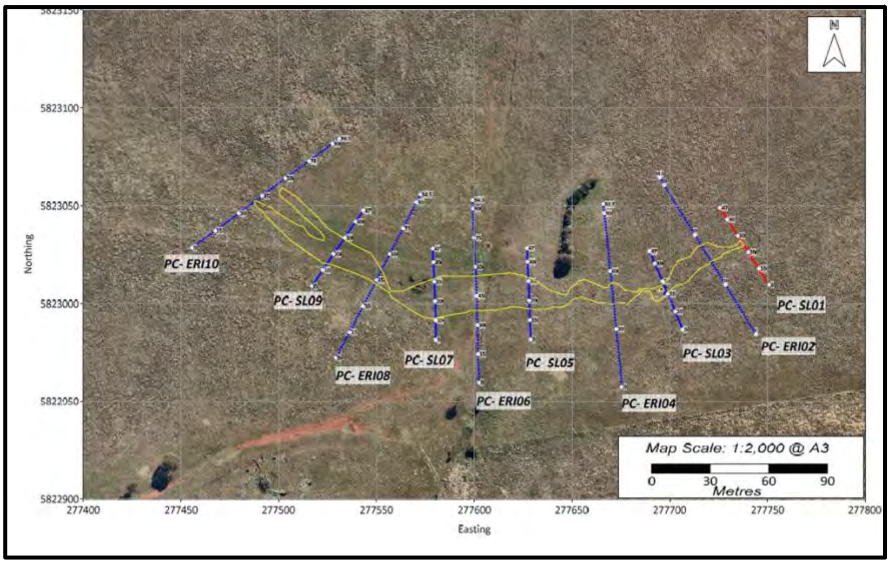


Figure 6 Location diagram for geophysical data slices.

The geophysics generally indicates the main part of the cave, but it is not precise as is the case usually when comparing natural voids (caves). Where voids are known it can be seen to validate them, but the outline is rarely if ever precise compared to a surveyed map; neither the shape nor precise dimensions and struggles with rockpiles. It therefore is useful to indicate significant voids but not their precise dimensions or even shape. The caution with using geophysics is its lack of precision in terms of the size and shape of the void and the limited ability to distinguish rockpiles (collapse material) that may partially fill a void. This is confirmed here especially with regard to transect line A6 (PC-ERI06) where comparison with the map indicates that the total width of the two voids (red & purple) is approximately the width of the cave and the yellow shading between the two is the large rockpile which reaches nearly to the ceiling. This rockpile is not solid rock but consists of pebble to small boulder sized clasts with limited fine material, in a big rockpile that reaches almost to the ceiling. The cross sections on the map indicate this, see cross section E-E’, where annotations on the map indicate that there is a large rock pile. Details of the presence of voids along the transects is detailed in Table 1.

Table 1 Comments regarding void presence detected by geophysical techniques.

Transect Line	Line ID	Comments
A01	PC-SL01	Void (blue) around the collapse area where there is a passage. Tube is assumed to extend to the east. Not explored as yet. Second similar sized void to the south; no known entrance.
A02	PC-ERI02	Void around 750 contour. Lines up well cave survey data. Resistivity gives a more 'averaged' circular shape which is not the true shape of the void
A03	PC-SL03	Cave indicated in blue. The passage here is relatively narrow.
A04	PC-ERI04	Definitely the cave. There is some collapse material around in this area that is not marked on the map. This may confuse the geophysics. There may be a low section on the east side of the cave where the void pinches out rather than a more vertical wall.
A05	PC-SL05	Yes, approximately where the cave is but again the cave has collapse material which will confuse the signal.
A06	PC-ERI06	The cave is wide here (see the map and cross check the scale). The two on the right are the large chamber and the yellow in between indicates the rock pile which goes nearly to the ceiling. The one on the right is certainly a new void. The map cross section (F-F') also indicates the rockpile.
A07	PC-SL07	This also is across the rock pile although the passage here is lower and the rockpile lower as well. Check the map and the cross sections e.g (E-E')
A08	PC-ERI08	Both purple shading are voids. I think the cave has a low roof here somewhere. Certainly there is a bifurcating or rock pile section at cross section C-C'. Which is near where this slice is.
A09	PC-SL09	Yes the dark blue is the void and this is before the passage bifurcates. This is approximately where the minerals are. On the southern edge there is a hint that there might be something but is may be a tube still filled with lava (see speleogenesis information above)
A010	PC-ERI10	This is more complex. The 2 small green sub circular features may be the 2 low passages but there are 2 other rather large voids on either side and another one to the south which may be tube filled with solidified lava.

The geophysics appears to indicate where voids exist reasonably accurately, and these outside the known cave conduit. There are no other known entrances, but the area obviously has problems for major construction. The voids, whilst some metres below the surface, do not appear to be at depth and heavy earth-moving machinery is at risk of causing collapse.

However, as we have known from field observations in the cave, the tube does extend beyond the extent of a light beam at the western end of the current passage. The collapse at the eastern end of the known cave also has excellent potential to have a passage behind it. No detailed exploration has been made at the eastern end of the known cave by experienced cave explorers.

Cave Values

Caves have intrinsic worth not only for their visual aesthetics but also for their scientific, economic and cultural values. As well as their fragile and sensitive ecosystems, they contain repositories of information about past environments that can date back millions of years. Lava caves are the same age as the basalt as they form as the lava solidifies, in this case during the Pliocene, between 4.03 and 3.01 Ma ago (Roberts 1984).

Geological and Geomorphological heritage, significance and values are poorly protected in Victoria as there is no formal Heritage protection in Victoria for such sites except under local planning schemes. There is no state-wide database managed by a state government department and this task is voluntarily undertaken by the Geological Society of Australia (Victoria Division). Several reports by Neville

Rosengren from the 1980s and 1990s are available on the Victoria Resources Online website (https://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/vrohome) but these do not cover the entire state and are not updated and many sites are now seriously out of date. VEAC has produced a limited number of reports (https://www.veac.vic.gov.au/) related to more recent investigations but these are restricted to public land. The GSA(V) does provide **limited** information from its updated data base free of charge when requested, but for larger enquiries, especially for development projects, consultant fees are required. For details on geological significance see Appendix 1 and White et al 2003.

The cave has been assessed for its geological and geomorphological significance by the Heritage Subcommittee of the Geological Society of Australia (Victoria Division) (Appendix 1) as at a high level of State Significance. This is currently under review and may be raised to National level due to the presence of the cave minerals, being the type locality for Parwanite and its very old age. As a cave in a flow between 4.03 and 3.01 Ma (Roberts 1984) Parwan Cave (3H-4) is the second oldest known in Australia. Lava caves weather relatively quickly (in geological time) and most lava caves are in younger flows e.g. Mt Eccles/Budj Bim flow is about 40,000 years.

Lava caves are relatively common in the Western District Volcanic Province; there are currently 131 numbered and several unnumbered still to be documented by VSA. However, this is by far the oldest known in Victoria and is the most significant cave at the eastern end of the Newer Volcanic Province. There are only two others known further east; Gisborne Bone Cave and a small cave in Clifton Hill, neither of which are as large nor show the range of features seen at Parwan. It shows the classic features of a lava tube such as lava stalactites and drip features on the ceiling and walls as well as the geometry of the cave passage. The cave is the type locality for the phosphate mineral Parwanite, and contains other organo- phosphate minerals (Taranakite, Montgomeryite and Gordonite).

This study indicates that there are other voids in the vicinity of Parwan Cave and the cave does extend beyond the known passages, both to the west and the east.

Management

The cave is a robust relatively feature and contains no delicate or sensitive decorations. The main deterioration of cave quality is the appearance of graffiti on some of the cave walls. It is not a particularly dangerous cave for normal caving activities by appropriately qualified groups. Appropriate management of the cave should be undertaken especially in the light of this major development.

In the situation of rezoning and redevelopment of the property, the area of the cave with an appropriate relatively generous buffer zone should be excluded from the redevelopment appropriate management be established (See Appendix 3) and the site should revert to public ownership and e.g. establishing a Crown Land reserve with a Committee of Management which should include appropriate speleological membership. Just blocking off the cave is not a sensible option. Regular access for appropriate parties should be provided. The Victorian Speleological Association Inc (Corporate Member of ASF) would be in a position to assist (GPO Box 5425, Melbourne 3001).

The geophysical assessment indicates that there are probably other lava tubes present and a much more extensive geophysical investigation is needed before any development occurs at this site and its surrounds. In fact the whole area needs to have a risk management plan for the potential to uncover other lava tubes in the whole precinct.

No drilling, road works, excavations or buildings should be permitted over the area of the cave. The use of heavy machinery and major earthworks close to the cave has a relatively high risk as collapse due to the weight of such machinery. The vibrations caused by such operations nearby may be also cause collapse. Although the extent of this cave is currently known, extension of tubes which may not be accessible and other such tubes of varying dimensions may occur in the locality and contractors should be briefed on this possibility and procedures to follow is this occurs (Appendix 2). Such collapse poses real industrial and OH&S risks to personnel working on the site.

For recreational caving and scientific research, the cave is not particularly difficult, fragile or dangerous as long as the appropriate risk management and Minimum Impact Caving (MIC) protocols for cave exploration are undertaken. Access to the cave should only be to suitably qualified groups following these protocols (Australian Adventurous Activity Standards (https://australianaas.org.au/read/caving/) or Australian Speleological Federation Inc. Codes and Standards (https://www.caves.org.au/administration/codes-and-standards).

Land management of sites of geological significance is important and significant damage can occur with inappropriate actions. Information on appropriate revegetation and other land management matters is available from the Geological Society of Australia (Victoria Division) (gsavictoria@gmail.com) or (www.gsavic.org) (See Appendices 2 and 3).

References

Aziz-ur-Rahman, A. and I. McDougall. I. 1972 Potassium-argon ages on the Newer Volcanics of Victoria. *Royal Society of Victoria Proceedings* **85**: 61-69.

Birch W.D., Mills, S.J., Schwendtner, K., Pring, A., Webb, J.A., Sebnit E.R. and Watts, J.A,   2007 Parwanite: a new hydrated Na-Mg-Al-phosphate from a lava cave at Parwan, Victoria, Australia. *Australian Journal of Mineralogy* **13** (I) 2007:

Grimes, K.G.(Ed), 2010 *Field Guide to the Volcanic Caves of Western Victoria 14th International Symposium on Viulcanospeleology August 2010*: 16.

Grimes, K.G., 2008: Subcrustal Lava Caves: examples from Victoria, Australia. Proceedings of the 10th Volcanospeleological Conference, Iceland, 2002. in Espinasa, R., & Pint, J., (eds, 2008) *Proceedings of the X, XI and XII International Symposia on Volcanospeleology. Association for Mexican Cave Studies, Bulletin*, **19**: 35-44. PDF Online at <http: //www.vulcanospeleology.org/sym10/ISV10p2.pdf> (4.3 Mb)

Hare, A.G., Cas, R.A.F., Musgrave, R. and Phillips, D. 2005. Magnetic and chemical stratigraphy for the Werribee Plains basaltic lava flow-field, Newer Volcanics Province, southeast Australia: implications for eruption frequency, *Australian Journal of Earth Sciences*, **52** (1), 41-57.

McDougall, I., Allsopp, H.L. and Chamalaun, F.H. 1966 Isotopic dating of the Newer Volcanics of Victoria, Australia, and geomagnetic polarity epochs. *Journal of Geophysical Research* **71** (24): 6107-6118.

Vince, D., Hall, P. and Birch, W. 1993: Phosphate minerals in cave deposits. In Birch, W. D. and Henry, D. A. (Eds), *Phosphate Minerals of Victoria. Special Publication No. 3, The Mineralogical Society of Victoria Inc*.

Rees, D. J and Gill, E. D. 1959. The Parwan Caves, Bacchus Marsh district, Victoria. *The Victorian Naturalist* **75**, 159- 160.

Roberts, P.S. 1984. Explanatory notes on the Bacchus Marsh and Ballan 1:50,000 Maps *Geological Survey Report No 76,* Department of Minerals and Energy, Victoria.

SMEC, 2021 *Desktop Land Capability Assessment, Parwan Employment Precinct*: 21-22.

Webb, J.A., Joyce, E.B. and Stevens, N.C. 1982. August. Lava caves of Australia. In *Proceedings, Third International Symposium on Vulcanospeleology*: 74-85.

Webb, J.A., 1967. Morphology and origin of Holy Jump Lava Cave, Southeastern Queensland, *Helictite*, 17: 65-74.

White, S., King, R. L., Mitchell, M. M., Joyce, E. B. Cochrane, R. M. Rosengren, N. J. and Grimes. K. G. 2003. Conservation and heritage registering sites of significance. IN Birch W. D. (Ed) *Geology of Victoria. Geological Society of Australia Special Publication 23.* Geological Society of Australia (Victoria Division): 703 – 711.

Appendices

Appendix 1: GSA(V) Protocol for assigning or reviewing geological significance.

The assigning or reviewing geological significance is undertaken in Victoria by the Geological Society of Australia Inc (Victoria Division), Heritage subcommittee. The GSA is a volunteer learned society. The GSA has developed a methodology and protocol for assigning or reviewing geological significance (White et. al 2003), which has been accepted as reliable and repeatable by organizations such as the former Australian Heritage Commission (now Australian Heritage Council). This methodology has been used is assessing significance of the various sites around Victoria and has been used by VEAC with regard to sites on public land. It is regularly updated.

The following information is reviewed from personal experience, fieldwork, literature review and consultation with other geologists with specific knowledge and expertise. The GSA subcommittee has members with a wide range of geological experience and expertise. Significance rating is achieved by consensus after considerable discussion on the merits of the site. This is particularly the case for sites of International and National significance where an extensive understanding of comparable sites outside Victoria is desirable.

The international and national significance discussed here does **not equate** to World Heritage status or National Heritage Listing for these sites.

It is important to note that geological, including geomorphological, significance may not necessarily relate to the aesthetics of a landscape. Some sites of very high significance may not be at all aesthetic, e.g. quarry faces or road cuttings whereas aesthetically pleasing views may not always be assigned a high *geological* significance. If processes are involved these can be active or relict.

Geological sites should possess at least one of the following attributes to be considered for assessment on their significance:

- a type section of a geological unit,
- a fossil locality,
- exposures of a range of features characteristic of the rock unit, or exposures of features which are unusual in the rock unit,
- an unusual occurrence of a particular feature or mineral,
- an illustration of tectonic and/or volcanic processes,
- features which enable palaeoclimatic reconstruction,
- demonstration of the effects of weathering, erosion and/or deposition on landform evolution,
- a representative example of a landform type.

The criteria for significance is related to whether a site can be regarded as important with regards to it being representative or outstanding. A choice often has to be made between the most outstanding or unusual example and an excellent representative example from a group of very similar ones.

The representative approach (McRae-Williams et al., 1981; King, 1985; Davey & White, 1986; Joyce, 1995) has been found to be the most appropriate in assessing significance but outstanding examples must be considered. Criteria used in such assessment include:

- how representative is the feature?
- how adequately is each type of feature represented over a particular scale?
- which feature is the most appropriate to represent a particular type?
- how many representatives are justified?
- How far is travel with an interstate or international visitor interested in for that type of site?
- How does it compare with other similar sites regionally, state, Australia, internationally?
- Is it under threat and if so, what is the nature of that threat?
- How common or rare is the feature? National? State? Regional? or Local? Level
- Replication? Representation?

- Is it a particularly good example?
- Is it a type section or type example (for landforms).
- What use ? e.g. education, geotourism, research, recreation.

Other aspects of the site such as present and past land use, diversity of features present, access, and vulnerability to damage are also considered. Features or areas are also described according to size, physical and/or geological type and age.

The level of geological significance is classified at local, regional, state, national or international level by documentation, assessment and comparison. The significance rating assigned to a site is periodically reassessed in the light of new information and/or site condition.

More detailed criteria for classification are:

- **International Significance:** These sites are landforms, structures, rock formations or fossils which are rare in the world, and/or by the nature of their scale, state of preservation or display, are comparable with examples known internationally. They may be global type examples and are widely known as reference sites by the international geological community. A site may be included in an international register of sites of scientific significance and would rate listing on the National Heritage List. Tower Hill is an example of an internationally significant site due to the well-preserved evidence of phreato-magmatic volcanic processes.
- **National Significance**: Sites that are rare in Australia or are important nationally by virtue of their scale or state of preservation are assigned national significance. Widely used as reference sites by the Australian geological community, they should be included in a national register of sites of scientific significance and may be considered for listing on the National Heritage List. An example is Mount Buffalo.
- **State Significance:** These sites are important in defining the geology and geomorphology of Victoria and may be rare in Victoria, reference sites or type examples. An example is Mount Kororoit, Diggers Rest.
- **Regional Significance:** These sites include landforms or geological features representative of regions of about 60km radius. An example is the Royal Park railway cuttings in Melbourne.
- **Local Significance**: These are features representative of smaller areas in a region, e.g. the Ovens Valley. Such sites are usually related to an area of a local municipality or an area with a radius of 20km. A typical example is the Stony Creek Road cuttings at Halls Gap where there is a good exposure that shows the relationship of igneous rocks to the main body of the Grampians Group sediments.
- **Unknown Significance**: Sites are assigned this rating if there is insufficient data to allow a complete assessment to be made. Typically, these sites are either under investigation or subject to continual change e.g. active quarry faces.
- **Destroyed Sites:** These sites are documented as they may be locations for important geological materials lodged in museums or referred to in published material.

Documentation of sites

Sites are chosen after recommendation and assessed. However, many sites are large, and we have found using subsites is a satisfactory way of dealing with smaller sites within a larger one. The Site ID is based on the names of the 1:250000 geological map sheets e.g. The Organ Pipes site on the Melbourne 1: 250000 sheet is ML 016. This is chronological as new sites are added. The data base is being gradually added as volunteer time permits. Some larger and more complex sites have subsites e.g. National rated Port Campbell NP CL 020, has 33 subsites 3 international, 4 National, 8 State, 13 Regional and 5 Local; but Dinosaur Cove (CL 020.28) is International.

GSA(V) maintains a data base with over 2500 entries for the state. This has the following main data fields:

- Site ID and Alpha-Numeric Reference Number:
- Feature name
- Location (Nearest Town)
- Municipality
- Mapsheets (1:100000 & 1:250000)
- Site size
- Description
- Location data
- Significance
- Significance Statement
- References

For enquiries regarding information from the database and for any other enquiries contact the convener of the GSA Victoria Heritage subcommittee and database manager, Dr Susan White OAM, <susanqwhite75@gmail.com>.

Appendix 2: Protocol regarding potential discoveries of cave & karst features during construction.

Cave and karst features are not as rare in Victoria as many people think. Many are small but still may result if very real issue during construction. In particular the carbonate rich dunes (Bridgewater Formation and other limestones) that are common on the Mornington Peninsula, Geelong, Surf coast and central Gippsland areas host small caves. The extensive Newer Volcanic basalts also have volcanic caves.

1. Detailed use of the relevant Geological Survey of Victoria's maps and geological reports of the area in the design and construction phase of the project.
2. **All** site workers and contractors need to be briefed that these features may exist and that the geological issues are important.
3. Caves and vents are often bigger than the initial entrance and the surface expression indicates; this needs to be understood. The surface expression is seldom equivalent to the subsurface bedrock boundaries.
4. Minimum buffer width from a cave or vent needs to be at least 10m. It may be advisable to increase this.
5. Make sure that suitable and adequate procedures and facilities are in place for fuel storage so that leaks do not spill into either the highly porous scoria or any larger natural holes.
6. If a feature/ deposit is found it should be immediately reported to the site supervisor and the following institutions contacted so that immediate assessment can occur. Make sure that up to date contact details are available at or near the site.
   - Mineral or fossil deposits Melbourne: Museum Geosciences Unit, Carlton.
   - Caves and vents: Victorian Speleological Association Inc (Mr Nicholas White, Conservation convenor)
   - Groundwater: Geosciences Victoria or the local Catchment Management Authority.
   - The Geological Society of Australia, (Victoria) can assist with the assessment of a site's significance.
7. Particularly **do not** fill caves in with concrete on the mistaken assumption that the problem will then go away!!! Such hollows often take very large volumes of concrete and so do not fill satisfactorily. Also someone is sure to find out about it and it could become a Public Relations problem.

Appendix 3: MANAGEMENT OF SIGNIFICANT SITES—WHAT IS THE ROLE OF VEGETATION?

Management of geological sites is often confused with other conservation ideas. This paper is to assist managers of geological sites with suggestions of what to do and what not to do that might make things worse.

INTRODUCTION

Although there has been a growing recognition of the value of natural heritage in the last few decades, the importance of conserving geological features is still frequently overlooked. Yet Victoria has a rich diversity of sites that are geologically significant, ranging from massive landmarks of great beauty to inconspicuous outcrops of a few square metres.

Often perceived as robust features, these outcrops and landforms are in fact vulnerable to a number of threats. One concern that is becoming increasingly apparent is that of re-vegetation and associated land rehabilitation works on both public and private land. Rock faces in cuttings and quarries that have long provided valuable exposures for excursions, scientific reference and research are increasingly being obscured by plantings or destroyed altogether in accompanying landscaping. Tree planting around lookouts and viewpoints is interfering with previously expansive views of surrounding landforms and landscapes. Landforms that have been identified as geologically significant are being concealed beneath a mantle of trees and shrubs. In some parks the very features that were cited as reasons for creating the reserve are now scarcely visible.

The benefits of re-vegetation are wide ranging, and with careful planning it should be possible to enhance the biological, aesthetic and safety values at geologically significant sites without compromising the geological values.

A set of principles, standards and guidelines which may help both government and non-government land managers address re-vegetation and associated rehabilitation issues at sites of geological significance is discussed below.

WHAT ARE SITES OF GEOLOGICAL SIGNIFICANCE?

Geological heritage sites are places where the rocks, landforms and landscapes have special value in letting us understand the composition of the earth's crust, the processes, past and current, that shaped it, and the evolving flora and fauna that occupies it.

Key rock exposures and landforms have been identified throughout Victoria and range in size from thousands of square kilometres to less than a hundred square metres. Sites may be important because of their fossil, rock or mineral content or their landscape. They may reveal unusual or outstanding sedimentary or igneous structures or are type sections that define particular geological units. In some, cases the relationships between different rock units are well displayed. Some have associated cultural interest, perhaps mining relics or a well-known geological identity.

Many sites of geological significance result from human activities, not natural processes. Road and railway cuttings and quarries often provide the best exposures, particularly in areas where natural outcrop is scarce. Landforms may be the result of natural processes or reflect differing degrees of human interference with the landscape. Some sites are lookouts or viewpoint from which aspects of regional geology and active geomorphological processes can be best appreciated.

THE VALUE OF GEOLOGICAL SITES

Geological heritage sites are important for many reasons. Professional geologists in both the private and public sector use the sites for reference and research. For geology teachers and general science teachers in primary and secondary schools, accessible field areas are an invaluable educational resource. Amateur geologists, field naturalists and members of the public are also interested in visiting and understanding sites. Tourist trails with interpretive signage and geological guides are in increasing demand at geologically interesting areas. The more spectacular geological settings such as the Port

Campbell National Park and the Grampians have long been popular tourist destinations for their aesthetic, recreational and historic experiences. Many landforms have particular spiritual or cultural significance to Indigenous people.

THE REGISTER OF GEOLOGICAL FEATURES OF SIGNIFICANCE

The Geological Heritage Subcommittee of the Geological Society of Australia (GSAV) has an inventory of sites of geological and geomorphological significance within Victoria. The project records sites of interest on a database if they are an outstanding or unusual example of a feature or if they provide a useful representative example of a widespread phenomenon. Once identified and documented, the sites are assessed by a panel of geologists as being of international, national, regional or local significance. A statement of significance records why the place is important. The register, which currently contains over two thousand sites is continually updated with new sites added or existing details modified to reflect changed circumstances or new information.

The Victorian Environment Assessment Council (and its predecessor, the Land Conservation Council) as well as various state government departments, local councils and organisations have also commissioned limited inventories of sites of geological significance within specific geographic boundaries. However there is no current formal Victorian government based database of sites that is managed and updated. GSAV is the **only** organization in Victoria that currently manages and updates a database of geological and geomorphological sites of significance. This has been the situation for over 25 years.

These valuable data resources are all too often overlooked when planning and land management strategies and being developed. As a consequence, irreplaceable exposures and landforms are being lost. Current quarrying and engineering practices do not generally favor the creation of new sites. Pits and quarries are more often progressively backfilled during the course of operations or are soon reused as waste disposal sites. Road cuttings are typically cut back to a low slope and re-vegetated or reinforced. Railway lines are being decommissioned and cuttings allowed to become overgrown. It is important therefore to conserve those geological sites that have particular value.

THREATS TO GEOLOGICAL SITES FROM LAND REHABILITATION

Whilst rehabilitation work is just one of the activities that can destroy or diminish the value of geological features, its impact is increasingly being noticed and needs to be addressed. It is not just small sites that are vulnerable, large landforms too can be substantially affected. Sometimes the impact is immediate and obvious but other times the disturbance is incremental over a long period.

Rehabilitation work can impact on geological sites in a number of ways:

- The plants themselves may obscure the feature itself or views of the feature, either as a result of inappropriate height, bushiness or density of planting.
- Engineering works may be implemented to re-contour the land thereby destroying existing exposures.
- Soil may be added to a site as a substrate for planting thereby burying outcrops.
- Stricter management measures may be adopted on re-vegetated sites, which prohibit the removal of rock specimens from sites that have traditionally been accessible for collecting.
- Human traffic may be confined to delineated pathways or restricted by fencing so that close inspection of outcrop is no longer possible.
- Uncontrolled weed growth may obscure features of interest.
- Engineering structures such as sound walls and concrete retaining walls can obscure exposures.
- Engineering works or large-scale plantings may irreversibly affect drainage patterns thereby altering existing geomorphic features. This is of particular concern in limestone (karst) areas and sites where active geomorphic processes contribute to the site's significance.

PRINCIPLES

Some suggestions and principles for the management of sites of geological significance.

- Sites that have been identified as geologically significant should be managed in such a way that those features that contribute to its geological value are retained or enhanced and not obscured, damaged or destroyed. Within the boundaries of a large site, the components that have special value may not be distributed uniformly so that practices that are acceptable or desirable in one part may not be in another.
- Where sites have a range of heritage values then conservation should be based on respecting all the differing values of the place without unwarranted emphasis on any one aspect at the expense of others.
- Conservation planning and management should make use of all disciplines and experience that can contribute to the study and safeguarding of the place.
- Re-vegetation and associated land rehabilitation operations that adversely impact on geological values should only be undertaken for essential purposes where no other alternative strategy is available.
- Some sites may have specific vulnerabilities to damage form inappropriate actions. These include fossil sites, mineral sites, caves and karst, coastal dunes and cliffs for example. Information on how to minimize the issues with particularly vulnerable sites may be available from the GSAV.

REVEGETATION GUIDELINES FOR LAND MANAGERS OF SITES OF GEOLOGICAL SIGNIFICANCE

These guidelines are intended to assist both government and non-government planners and land managers to identify sites of geological significance and to protect those locations from inappropriate re-vegetation strategies.

Ascertain whether or not the site has geological significance. This information may already be available in the GSA's database (see below for contact details), in regional listings or excursion guides. If not it may be necessary to undertake further geological research to identify any significant geological components of the site.

Develop a management plan in which all special geological values are described and ensure that these geological components and viewing lines are clearly identified on a site analysis plan. Specific objectives and rehabilitation proposals must be consistent with the overall rehabilitation plan.

The type and density of re-vegetation should not obscure significant outcrops, exposures, landforms or views. Species selection should have regard to height of the mature plant, canopy spread and density of growth.

Conservation works should be sympathetic to both biological and geological values. Where a conflict arises between these values, experts in all relevant fields should examine the site, make recommendations and together work towards an acceptable solution.

Educational and tourism values of a site can be enhanced in certain situations by the provision of appropriate roadside stops, walking tracks and interpretive material.

Some sites of geological significance include unstable or hazardous rock faces. If these need to be stabilized or made safe, alternatives to vegetation cover that would maintain visibility should be investigated e.g. meshwork.

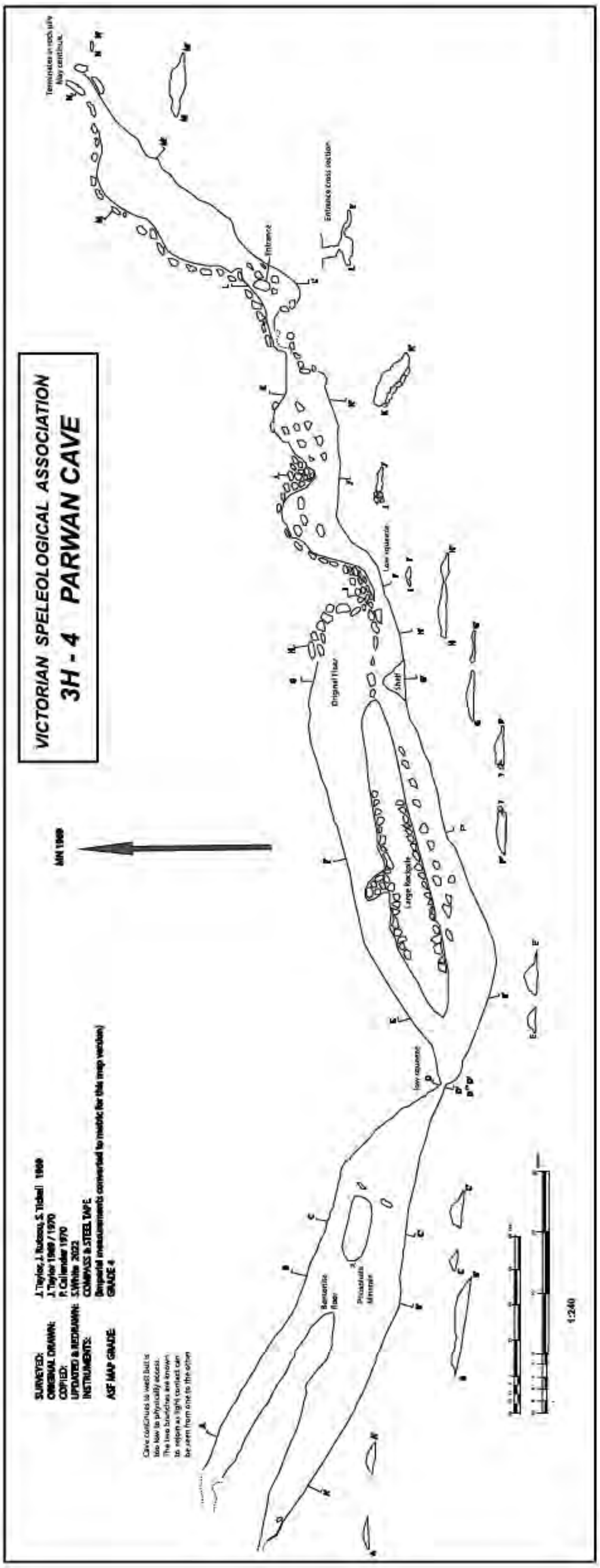
Ongoing monitoring should be undertaken routinely to ensure that geological values are not being interfered with as plants grow and reproduce. In areas where the geological feature has been obscured, appropriate trimming or judicious removal of vegetation should be carried out.

The GSA heritage subcommittee is willing to work with individuals and groups who need assistance.

For enquiries contact the convener of the GSA Victoria Heritage subcommittee and database manager,

[redacted]

Appendix 4 Map of Parwan Cave 3H-4



APPENDIX D

Important Information

The document ("Report") to which this page is attached and which this page forms a part of, has been issued by Golder Associates Pty Ltd ("Golder") subject to the important limitations and other qualifications set out below.

This Report constitutes or is part of services ("Services") provided by Golder to its client ("Client") under and subject to a contract between Golder and its Client ("Contract"). The contents of this page are not intended to and do not alter Golder's obligations (including any limits on those obligations) to its Client under the Contract.

This Report is provided for use solely by Golder's Client and persons acting on the Client's behalf, such as its professional advisers. Golder is responsible only to its Client for this Report. Golder has no responsibility to any other person who relies or makes decisions based upon this Report or who makes any other use of this Report. Golder accepts no responsibility for any loss or damage suffered by any person other than its Client as a result of any reliance upon any part of this Report, decisions made based upon this Report or any other use of it.

This Report has been prepared in the context of the circumstances and purposes referred to in, or derived from, the Contract and Golder accepts no responsibility for use of the Report, in whole or in part, in any other context or circumstance or for any other purpose.

The scope of Golder's Services and the period of time they relate to are determined by the Contract and are subject to restrictions and limitations set out in the Contract. If a service or other work is not expressly referred to in this Report, do not assume that it has been provided or performed. If a matter is not addressed in this Report, do not assume that any determination has been made by Golder in regards to it.

At any location relevant to the Services conditions may exist which were not detected by Golder, in particular due to the specific scope of the investigation Golder has been engaged to undertake. Conditions can only be verified at the exact location of any tests undertaken. Variations in conditions may occur between tested locations and there may be conditions which have not been revealed by the investigation and which have not therefore been taken into account in this Report.

Golder accepts no responsibility for and makes no representation as to the accuracy or completeness of the information provided to it by or on behalf of the Client or sourced from any third party. Golder has assumed that such information is correct unless otherwise stated and no responsibility is accepted by Golder for incomplete or inaccurate data supplied by its Client or any other person for whom Golder is not responsible. Golder has not taken account of matters that may have existed when the Report was prepared but which were only later disclosed to Golder.

Having regard to the matters referred to in the previous paragraphs on this page in particular, carrying out the Services has allowed Golder to form no more than an opinion as to the actual conditions at any relevant location. That opinion is necessarily constrained by the extent of the information collected by Golder or otherwise made available to Golder. Further, the passage of time may affect the accuracy, applicability or usefulness of the opinions, assessments or other information in this Report. This Report is based upon the information and other circumstances that existed and were known to Golder when the Services were performed and this Report was prepared. Golder has not considered the effect of any possible future developments including physical changes to any relevant location or changes to any laws or regulations relevant to such location.

Where permitted by the Contract, Golder may have retained subconsultants affiliated with Golder to provide some or all of the Services. However, it is Golder which remains solely responsible for the Services and there is no legal recourse against any of Golder's affiliated companies or the employees, officers or directors of any of them.

By date, or revision, the Report supersedes any prior report or other document issued by Golder dealing with any matter that is addressed in the Report.

Any uncertainty as to the extent to which this Report can be used or relied upon in any respect should be referred to Golder for clarification

golder.com