AEGC
Australasian Exploration Geoscience Conference
Brisbane 2021

3D Bedrock Model Utilising Multi-channel Analysis of Surface Waves to Assist the Land Development Industry in Greater Melbourne, VIC.

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SUMMARY

A common problem across greater Melbourne's expanding land development, both residential and commercial, is encountering sites that have incredibly stiff and undulating bedrock. This is experienced on sites with Newer Volcanic Basalt which accounts for two thirds of greater Melbourne, the weathered profile of these once lava flows produces a highly variable depth and strength bedrock interface.

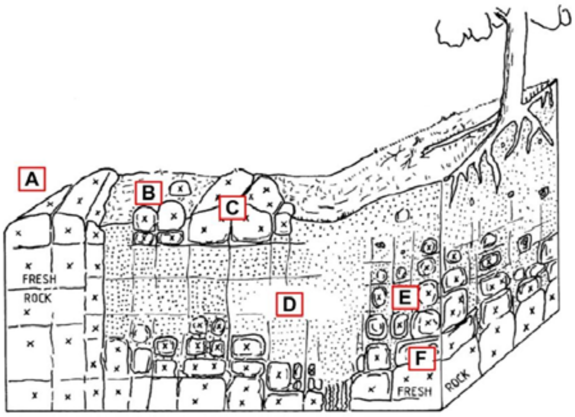
The acquisition of bedrock survey data has been shown to reduce site uncertainty, unforeseen earthwork costs and financial risk. Working hand in hand with traditional intrusive geotechnical methods, the Multi-channel Analysis of Surface Waves (MASW) method can connect the dots between boreholes generating 2D geological cross-sections of the subsurface. These 2D cross-sections when combined can create a 3D subsurface model of the bedrock.

This data can be presented in a variety of ways, including contour plots in either elevation or depth below ground level (BGL), overlying clay volumetric calculations to user friendly 3D AutoCAD files which can be encompassed with a topography model. Producing a very comprehensive site classification package, a useful tool for the investigatory stage for any land development project.

Key words: Rock Mapping, Land Development, MASW, Melbourne, Risk Mitigation.

INTRODUCTION

The problem which faces much of the land development industry across greater Melbourne is more accurately identifying the depth the basalt bedrock (Newer Volcanics), rather than relying on just traditional geotechnical boreholes. As illustrated in Figure 1, the weathered profile of basalt bedrock is varied, undulating and consists of "floaters", which have been found in the size range comparable to an average car, as Figure 2 displays.



Modified from (Unpub. Tostovrsnik, 2019).

Figure 1. Geological schematic of basalt weathering profile. Annotated by the following: (A) Interpreted top of outcropping basalt rock. (B) Moderately weathered outcropping basalt rock. (C) Floaters (basalt rock of high strength) surrounded by residual clay. (D) Sediment. Predominately residual clay / soil. (E) Slightly weathered to unweathered basalt bedrock. (F) Top of unweathered basalt rock.

Figure 2. Site photograph of the large basalt rocks / floaters encountered at a land development site in Melbourne's north.

Unlike other geophysical techniques used to map bedrock and rock strength (rippability), such as seismic refraction, Multi-channel Analysis of Surface Waves (MASW) provides the solution necessary to image this highly variable bedrock profile and velocity inversion, with regard to rock overlying clay.

Processing MASW using SurfSeis Version 6 (Kansas Geological Survey, 2017), the generated 1D S-wave velocity soundings can be compiled and gridded using Surfer version 18 (Golden Software, 2020) to produce 2D S-wave velocity profiles. Constrained and correlated with available intrusive geotechnical data, these S-wave velocity profiles can generate 2D geological cross-sections extrapolated across the site. The identified rock interface within multiple 2D geological cross-sections can be picked and gridded to produce a 3D subsurface model of the bedrock.

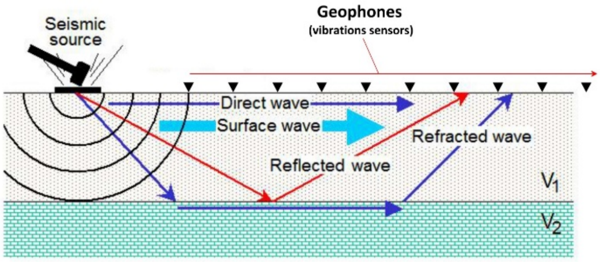
The finalised 3D subsurface model of the identified basalt bedrock can be presented in a variety of ways, which can be integrated with the client's existing survey and models. The acquisition of bedrock survey data has been shown to reduce site uncertainty, unforeseen earthwork costs and reducing finical risk, potentially saving the land development company millions, by incorporating a geophysical survey in their due diligence phase for a minute cost in comparison.

MASW METHOD

MASW data are acquired using a 24-channel seismic land streamer, which consists of 24 evenly spaced geophones attached to a Kevlar reinforced tape and metal base plates. Connected via a seismic cable to a multichannel digital seismograph positioned in the survey vehicle. Seismic energy is generated using summed impacts of an Accelerated Weight Drop (AWD) on a metal plate at one end of the MASW array (rear of the 4WD). Data points (soundings) are recorded at the middle of the array. Figure 3 depicts site photographs of this MASW field setup.

Figure 3. Site photographs of the MASW setup.

Figure 4 illustrates a schematic of the seismic waves generated from a similar seismic source, sledgehammer. The MASW method relies on measuring the seismic Surface wave by the large blue arrow, opposed to the others (Direct, Reflected and Refracted).



Modified from (Unpub. www.parkseismic.com/Whatisseismicsurvey.html)

Figure 4. Schematic of the four seismic waves paths within the upper material annotated by V1.

The MASW data are processed using SurfSeis 6 (Kansas Geological Survey) which analyses the frequency distribution against a phase velocity of the seismic record to generate seismic S-wave velocity 1D soundings. The following processing routine is applied:

1. Field geometry (geophone spacing and source offset) is applied to the acquired seismic data files.
2. Generation of overtone images giving the amplitude ratio intensity of phase velocity versus frequency are generated for each acquired seismic record.
3. The maximum intensity across the useful range of frequencies is picked for each record resulting in a fundamental dispersion curve.
4. Inversion is achieved from the initial S-wave model approximated from the measured dispersion curve, undergoing multiple iterations to reduce the root-mean-square-error (RMSE) (Park et al, 2000). The inversion algorithm in SurfSeis has been adopted from (Xia et al, 1999).
5. The number of layers (data points) undergoing inversion can be edited to produce a S-wave velocity 1D sounding. To increase vertical resolution a 20-layer model (20 data points) are selected.
6. Adjacent S-wave velocity 1D soundings along each seismic profile are compiled in order to generate a 2D S-wave velocity section.

The generated velocity profiles are constrained and correlated to generate geological cross-sections with available intrusive geotechnical borehole data. An example of a processed MASW 2D profile with an interpreted geological cross-section is displayed in Figure 5 at the end of this extended abstract.

The seismic velocity formula below illustrates the relationship between S-wave Velocity (Vs), shear modulus and in-situ material density (Rajput and Thakur, 2016). Making the correlation with identified geological units and S-wave velocity values viable.

Seismic S-wave velocity $$V_s = \sqrt{\frac{G}{\rho}}$$

where; G = Shear modulus, ρ = In-situ material density

2D S-Wave Velocity Distribution Profiles

2D MASW profiles are generated from griding 1D soundings together using the Kriging algorithm in Surfer V18 (Golden Software, 2020). Figure 6 at the end of this extended abstract illustrates an S-wave velocity distribution profile which very comparably images the known weathered profile of basaltic rock displayed in Figure 1.

The MASW method can very accurately image this unconforming and highly variable bedrock profile with the presence of floaters, which occupies two thirds of greater Melbourne. This method is particularly helpful to the land development industry is providing high accuracy subsurface information along proposed pipeline alignments, in particular, gravity fed sewer.

This highly accurate MASW profile is achieved by acquiring 1D soundings at very closed spaced intervals, such as every 2 meters. Figure 7 at the end of this extended abstract illustrates an MASW profile which was acquired at 4 metre 1D sounding intervals, annotated in vertical black lines. Figure 7 is a coarser dataset and fails to clearly identify known floaters which can occur. This is the trade off to lower the cost of an MASW survey investigation.

CONNECTING THE DOTS

This MASW survey does not remove the need for intrusive geotechnical boreholes. In fact, it relies on this information to constrain its inversion and correlated its S-wave velocities to known geological units. Figure 8 illustrates two very common limitations of relying solely on intrusive geotechnical boreholes, which are far more expensive and provide only pinpoint information. However, the combination of these two methods can connect the dots between intrusive boreholes and provide a more holistic model.

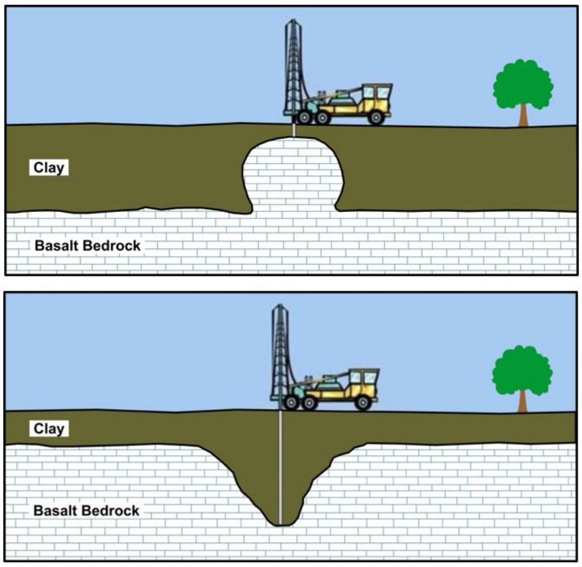


Figure 8. Common limitations with only relying on geotechnical boreholes across greater Melbourne.

3D MODELS

The data from the 2D MASW profiles and consequently interpreted geological cross-sections can be combined to create a 3D subsurface model or contour plot of the interpreted bedrock across a site. Resolution and data accuracy of this interpreted bedrock is highly dependent upon the 1D sounding spacings and spacing between interpreted 2D MASW profiles. MASW data is typically acquired across a site in a grid pattern as Figure 9 illustrates the MASW sounding locations in yellow.

The identified bedrock interface across multiple interpreted 2D MASW profiles typically follows an S-wave velocity, which is then picked and gridded, resulting in a 3D geological model of depth to basalt bedrock as displayed in Figure 10.

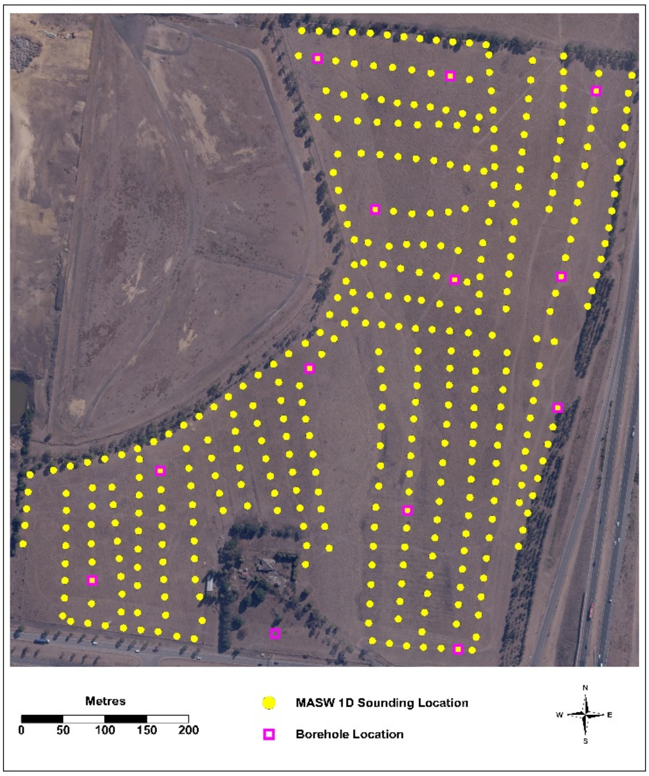


Figure 9. MASW sounding locations in yellow across an investigation site, with borehole locations in pink.

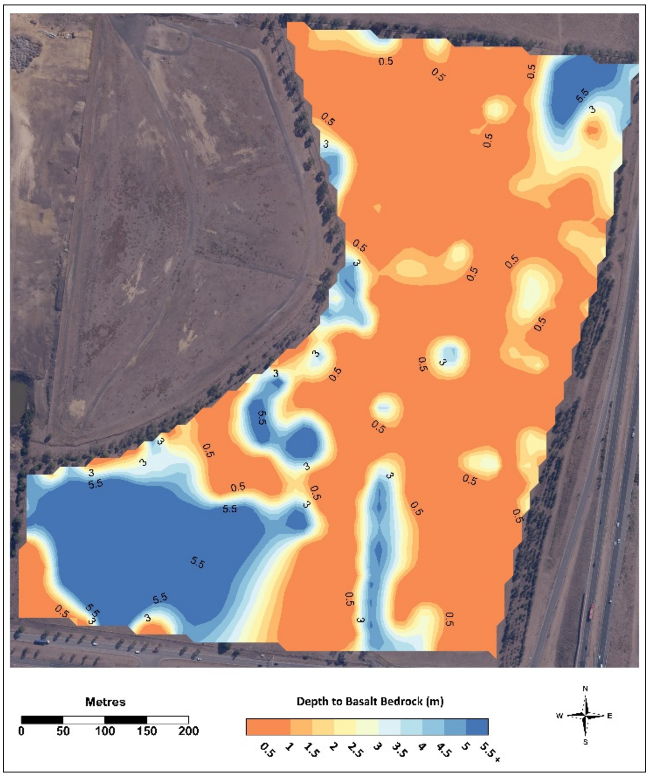


Figure 10. 3D model illustrating depth to basalt bedrock in metres below ground level across the investigation site.

Additional examples are displayed in Figures 11, 12 and 13 at the end of this extended abstract.

VOLUMETRIC CALCULATIONS

Additional attributes emerge with the addition of a topography survey which is typically acquired in-sync with the MASW survey or provided by the client, such as overlying clay or rock removal volumetric calculations. This is achieved through a simple math function in Surfer version 18 (Golden Software, 2020). This is a useful tool for land development engineers to determine to earthwork costs, scheduling, and reuse of onsite material.

In fact, the lots in Figure 13 which illustrate rock less than two metres BGL was calculated within 2% of the quoted to actual earthwork costs required to remove this near surface rock.

LIMITAIONS OF MASW

There are limitations to the MASW method which are inherent to the geophysics of the technique, these are:

1. MASW data cannot be acquired on an undulating surface level (Park et al, 2008).
2. Sufficient coupling between the geophone base plates is required, therefore, data acquisition cannot occur in thick grassy / vegetated surfaces.
3. MASW data acquisition cannot operate in seismic “noisy” conditions, for example, nearby excavation, drilling and / or moving machinery.

There are additional limitations related to the MASW processing capability, these are:

1. Interpolation between MASW 1D soundings, along a profile and between acquired 2D cross-section to generate a 3D model. The greater the distance between 1D soundings and 2D cross-sections decreases the accuracy of the interpreted 3D model.
2. Boulder / floater resolution is dependent on the 1D sounding spacing.
3. Within highly weathered zones it is difficult to identify the true interface between clay and basalt bedrock.

CONCLUSIONS

The MASW method has proven to be the most appropriate geophysical technique to most accurately image a very difficult geological environment. The method is not a standalone approach and requires physical data, from geotechnical boreholes to constrain and correlate the generated 2D S-wave velocity distribution profiles.

With limitations associated with the geophysics of the method and processing capability, the generated 3D models need to be taken with a grain of salt and typically represent the accuracy to what a client is prepared to pay for.

Generating both 2D and 3D bedrock models utilising the MASW approach has the ability to capture otherwise unknown information producing a comprehensive site classification package, a useful tool for the investigatory stage for any land development project, by reducing site uncertainty, unforeseen earthwork costs and financial risk to the developer.

ACKNOWLEDGMENTS

I would like to acknowledge the wider GBG Group (GBG Australia & GBGMAPS) to whom have allowed me to undertake this work and strengthen the geophysics brand within the greater geotechnical, civil and construction community.

Additionally, to the following clients who have permitted their datasets to be represented in this presentation.

- Fulton Hogan, Level Crossing Removal Project (Figure 4).
- Jacobs, Sewer Alignment MASW Survey Investigation (Figures 6).
- CMW Geoscience on behalf of Frasers Property, MASW Rock Mapping for a Proposed Commercial Land Development (Figures 9 and 10).
- Ground Science on behalf of Hume City Council, MASW Rock Mapping for a Proposed Residential Land Development (Figures 11 and 12).
- Stockland, MASW Rock Mapping for a Proposed Residential Land Development (Figure 13).

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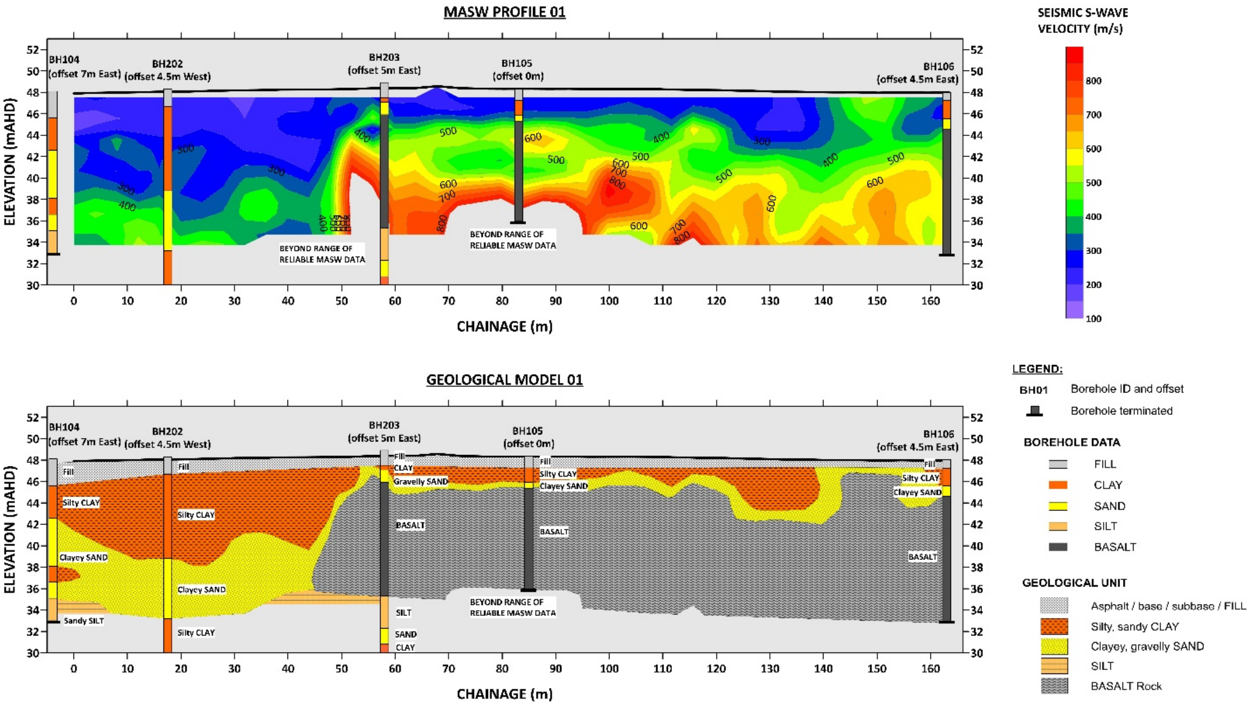

Figure 5. Top: MASW S-wave velocity distribution profile, Y-axis in elevation and X-axis in chainage (m). Bottom: Interpreted geological cross-section, Y-axis in elevation and X-axis in chainage (m). Constrained and correlated with the annotated geotechnical borehole data.

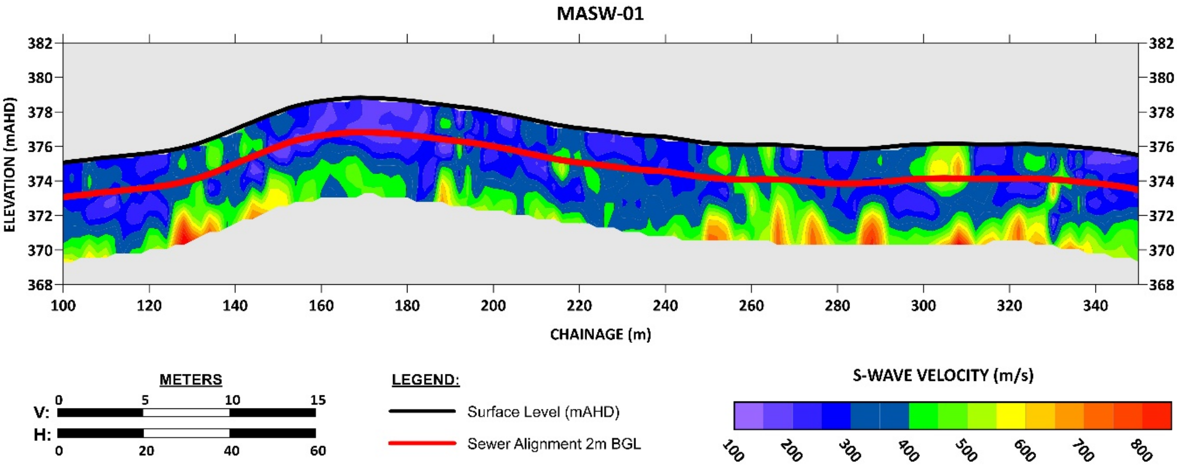

Figure 6. 2D "cross-section" of an MASW S-wave velocity distribution, with colour scale, along a proposed sewer alignment in red. Resolution of basalt floaters achieved.

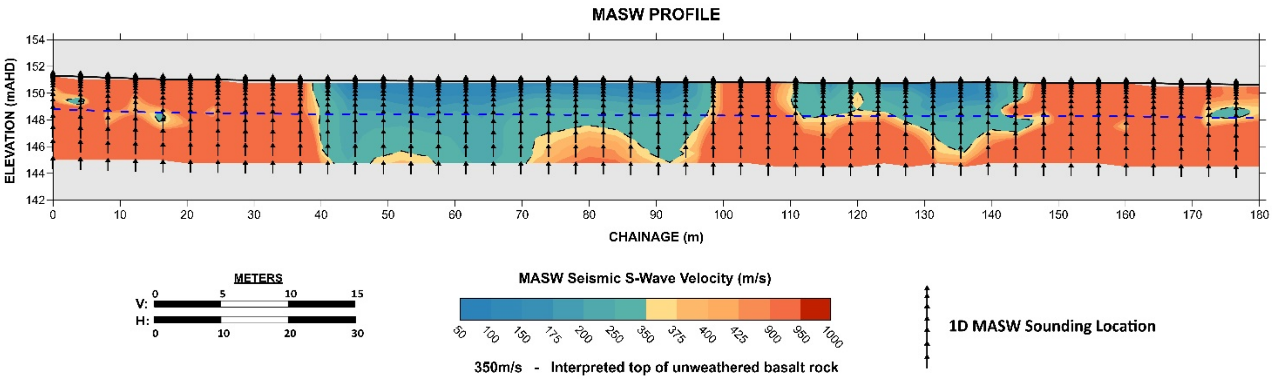

Figure 7. 2D "cross-section" of an MASW S-wave velocity distribution, with colour scale and 1D sounding locations in black.

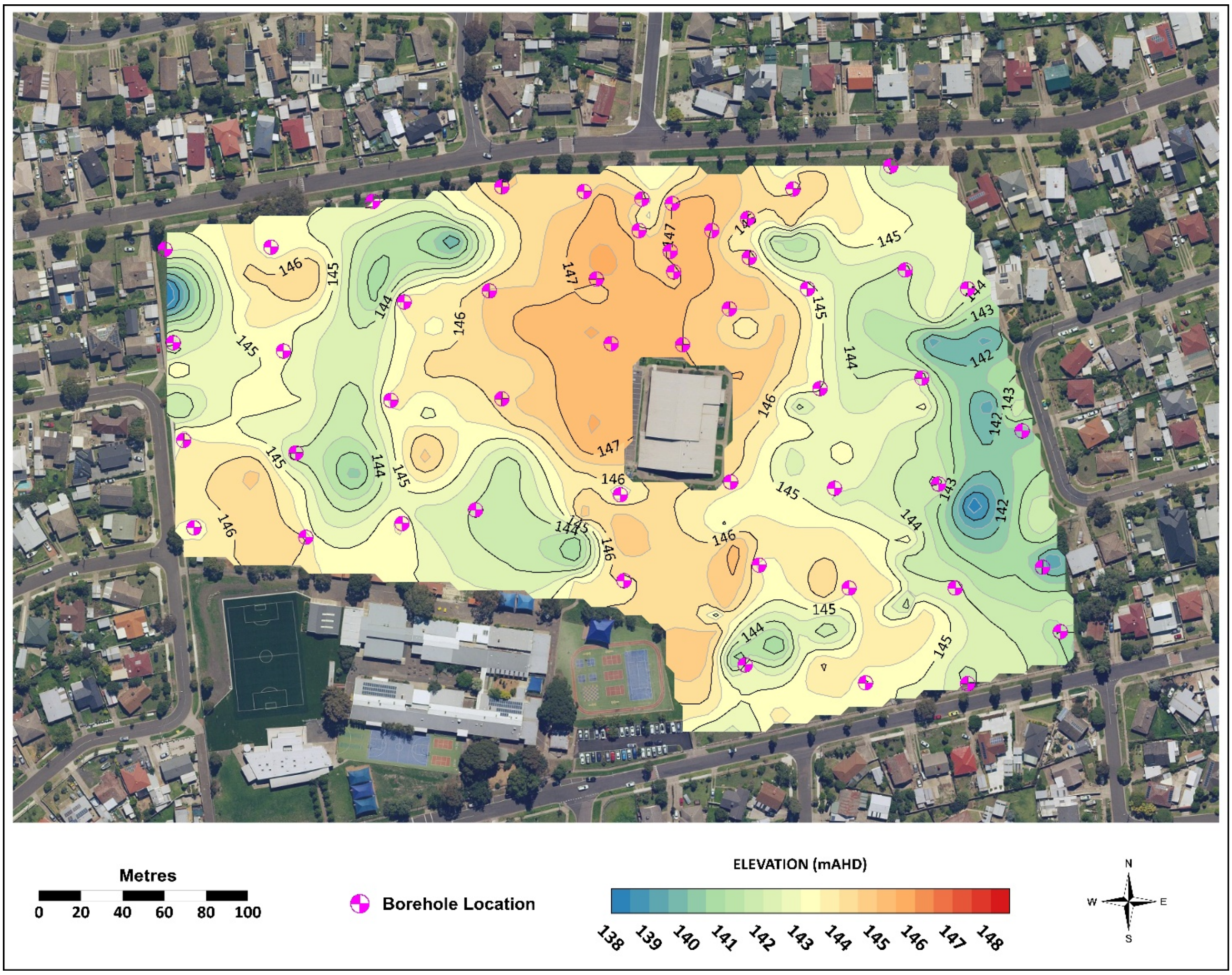

Figure 11. 3D geological model of identified basalt bedrock in elevation (level) in mAHD. Borehole data locations annotated in pink.

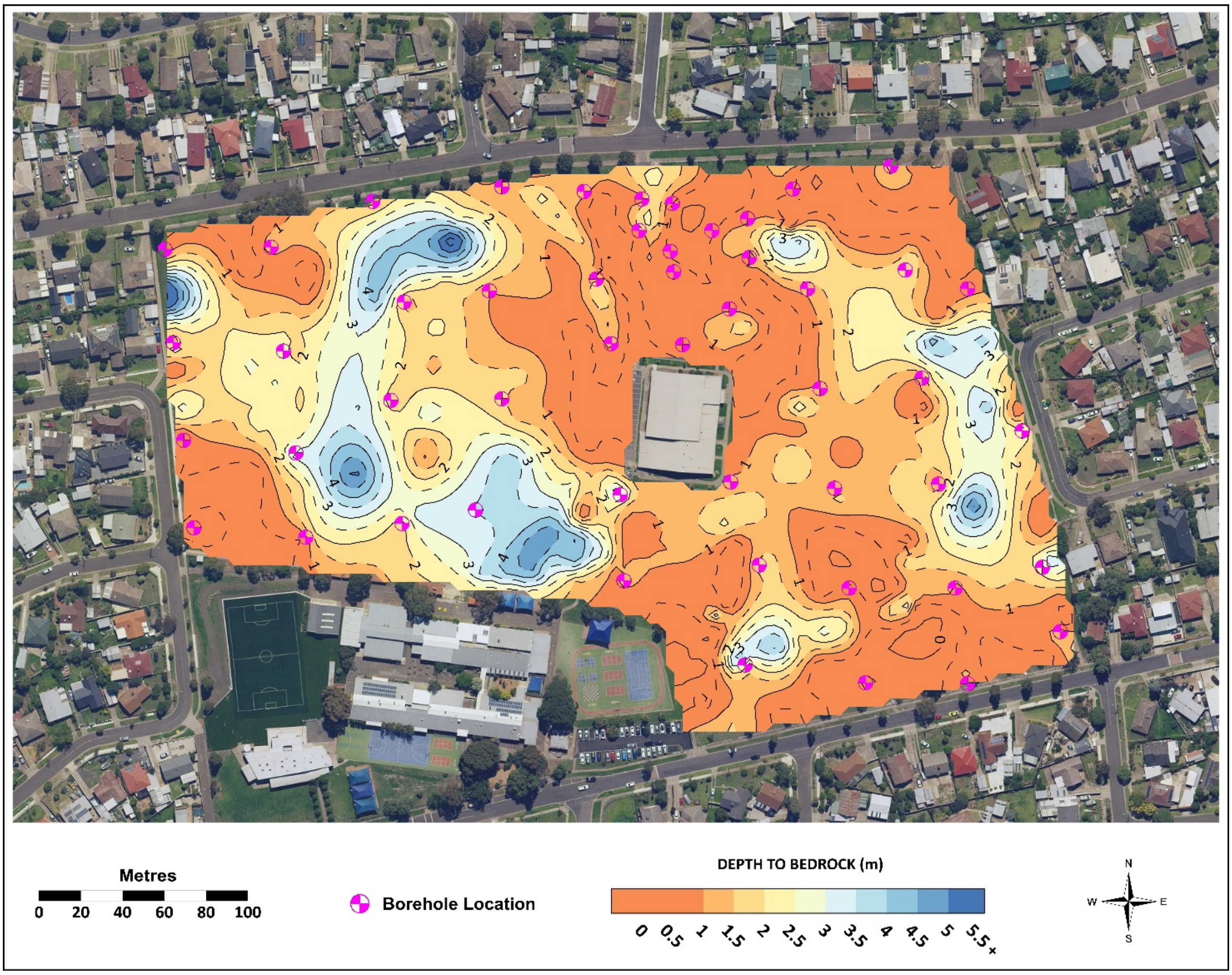

Figure 12. 3D geological model of depth to identified basalt bedrock in metres below ground level. Borehole data locations annotated in pink.

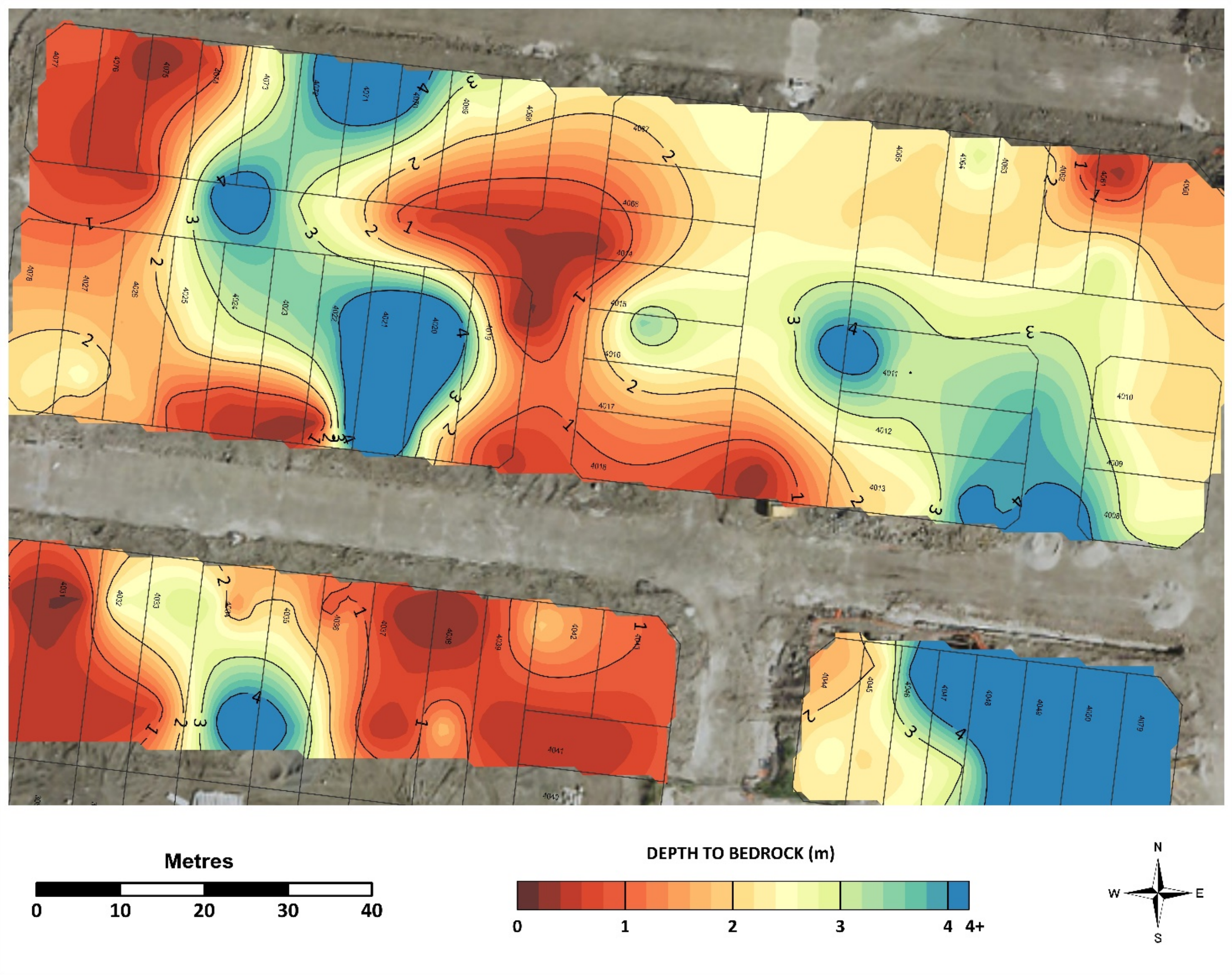

Figure 13. 3D geological model of depth to identified basalt bedrock in metres below ground level, overlaid on lot boundaries of a recent residential land development.