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Geophysics in greenfields regions to determine cover thickness: pre-competitive drilling in the Stavely region of Victoria

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SUMMARY

Fifteen pre-competitive stratigraphic holes have been drilled to test geological and mineral system models in the 'greenfields' Stavely region of western Victoria. Prior to drilling, seismic reflection and refraction, gravity, and airborne magnetic data were used to estimate the thickness of cover at the selected drill sites. This analysis also tested the reliability of the geophysical techniques in a range of geological conditions.

Comparisons with preliminary drilling data indicate that seismic refraction data successfully predicted cover thickness at six out of seven sites. Estimates of depth to magnetic source at the top of basement, derived from airborne magnetic data successfully predicted cover thickness at eight of ten sites. Seismic reflection was the least reliable technique with one out of four successful predictions. However, despite their success rate, neither the refraction nor the magnetic data gave reliable cover thickness estimates where cover materials were highly magnetic or had high seismic velocities.

Key words: cover thickness, depth to magnetic source, seismic refraction, seismic reflection, Stavely region

INTRODUCTION

Geoscience Australia (GA) and the Geological Survey of Victoria (GSV) have drilled fifteen pre-competitive stratigraphic holes in the Stavely region of western Victoria in order to test geological and mineral system models. The drilling was conducted in order to: (a) determine the stratigraphic continuity of the prospective Cambrian Stavely Volcanic Complex beneath diverse cover materials; (b) sample buried intrusions that are potential hosts for porphyry-epithermal mineralisation; and (c) assess key geological structures in the region. These basement sequences, although outcropping in the centre of the Stavely region, are obscured by cover sediments in the north and south of the region (Figure 1).

Prior to drilling, analysis was conducted on existing airborne magnetic data, as well as additional ground geophysics that were acquired as part of a pre-drilling geophysical data acquisition program. The aim of the geophysical analyses was two-fold. Firstly, to determine cover thickness at the drill-site locations in order to reduce the geological and financial risk for the drilling program and; secondly, to investigate a range of geophysical techniques that could provide a tool kit for explorers to reliably predict the cover thickness at the tenement-scale. This cover thickness study, in conjunction with drilling results, will add significantly to the pre-competitive knowledge base of this greenfields region.

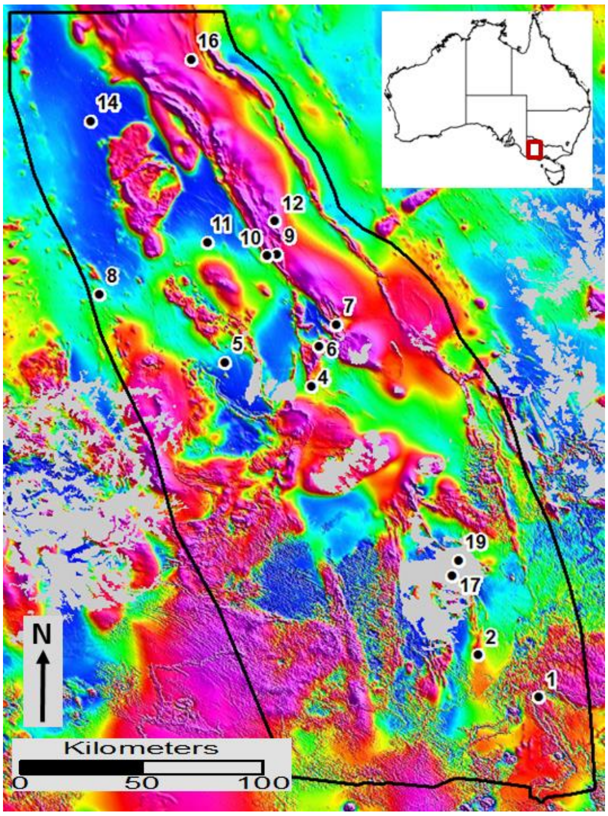

Figure 1. Total magnetic intensity (reduced to pole) image of the Stavely region in western Victoria showing the pre-drill site locations and the outline of the study area. Basement outcrop is shown as light grey polygons highlighting the degree to which the basement is obscured by cover.

To reliably estimate cover thickness using geophysical techniques, the cover and basement must have contrasting physical rock properties. The techniques selected were those that can potentially provide depth information from such a contrast. The cover encountered at the drill site locations varies from Murray Basin sediments in the north, Grampians

Group in the centre and Otway Basin sediments and Newer Volcanic Group in the south. The basement targeted by the drilling comprises north-trending volcanic belts of Cambrian age or older, and high-grade metamorphic rocks. Both the cover and basement exhibit a range of rock properties, and hence, a range of techniques was selected in an attempt to encompass all potential combinations of rock properties. This was done in the knowledge that some techniques will produce reliable depth estimates in certain geological environments, but not in others. The techniques investigated and the rock properties investigated were: airborne magnetics – magnetic susceptibility; gravity – density; seismic refraction – P-wave velocity; seismic reflection – seismic impedance; passive seismic – S-wave velocity; and resistivity – electrical resistivity.

In late 2013, a field party led by GA with support from the GSV acquired seismic refraction data at 11 proposed drill-sites. Seismic reflection data were also acquired at five of these sites. Basement outcrops at drill sites 17 and 19, so no analysis was conducted at these sites. The maximum cover thickness that the reflection and refraction seismic was able to resolve was limited by the strength of the active seismic source (5 kg sledge hammer). Reflection and refraction data were only acquired at drill-sites where the cover was initially estimated to be less than 200 m thick. Microgravity data were acquired on a grid of stations at four sites, and gravity profiles at two other sites. Passive seismic and resistivity data are to be acquired in future work programs. This paper provides a summary of the pre-drilling geophysical program; a detailed account is in preparation (Meixner et al. in prep.) and due for release at the end of 2014.

TARGETED DEPTH TO MAGNETIC SOURCE MODELLING

Targeted depth to magnetic source modelling on the existing airborne flight-line data was carried out to determine the depth to the top of a magnetic body. The drill-sites target magnetic rocks in the basement beneath generally non-magnetic cover. An assumption is made that the top of the magnetic body occurs at the top of the basement, and hence, the depth to magnetic source estimate provides an estimate of the cover thickness. Confidence in a depth to magnetic source estimate from a modelled body is dependent on the body's ability to simulate the geometry of the targeted magnetic body. The magnetic anomalies of these targets are generally long, linear features sourced from packages of interleaved magnetic volcanics and non-magnetic sediments, which are most readily simulated by steeply-dipping tabular (dyke-like) bodies.

Encom ModelVision V12.0 software was used to produce the depth to magnetic source estimates from dipping tabular bodies. Distinct, non-overlapping magnetic anomalies on the flight-lines that correspond to linear anomalies on the grid images were selected in order to simplify modelling. The Quick Inversion tool of the modelling software was used to iteratively modify the properties of the tabular body, including the depth to the top of the body, in order to minimise the Root Mean Square (RMS) misfit between the observed and the modelled data. Figure 2 shows an example of the match between the modelled and the observed magnetic profile. The depth to magnetic source estimate is the depth to the top of the body minus the aircraft flight-height. The targeted magnetic modelling produced depth to magnetic source estimates that are in the vicinity of the drill-site locations, but not coincident with the drill-site locations. To obtain a depth estimate at the drill-site locations a weighted average, weighted by closeness to drill-site, was calculated from the depth to magnetic source estimates.

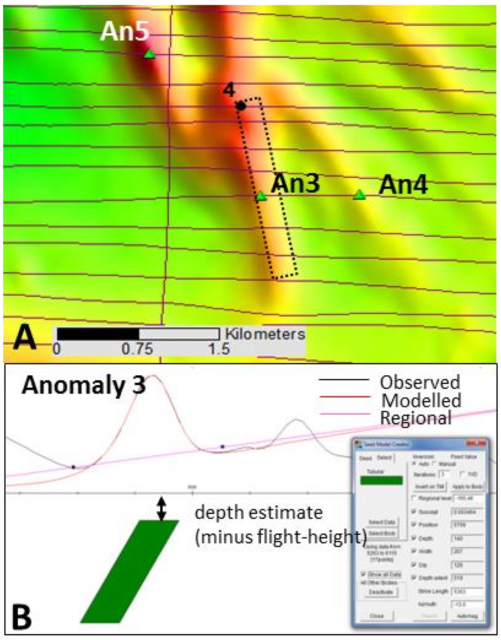

Figure 2. (A) Total magnetic intensity image (reduced to pole) at Site 4 (black circle). The top face of the modelled tabular body (dashed outline) is shown for Anomaly 3 (An3). The red lines are the airborne flight paths. (B) Plot showing the close match (RMS misfit 0.4 nT) between modelled and observed profile data for the dipping tabular body.

The depth to magnetic source estimates, and hence, cover thickness estimates, are plotted against the preliminary drilling results in Figure 3. These drilling results show that the depth to magnetic source estimates, within their error bounds (Meixner et al., 2014) has predicted the basement intersections at eight out of ten completed sites. Modelling of anomalies in the vicinity of Sites 1, 2 and 14 produced depth estimates that were interpreted to be sourced from within the cover. There were no magnetic anomalies sourced from the top of basement at these sites. Therefore, it was not possible to provide cover thickness estimates for these sites.

REFRACTION SEISMIC

Seismic data were acquired using a standard linear array of four cables comprising twelve 4.5 Hz geophones with a 5 m spacing, resulting in a 240 m spread. The seismic signal was generated by striking a plastic plate with a 5 kg sledge hammer. Multiple hammer strikes were stacked together to provide a single shot-record. Off-end shots were acquired at 50 m, 75 m and 100 m at either end of the array, with additional shots generally every 60 m within the geophone spread. A velocity model and, hence, an interpretation of the thickness of cover was produced from the refraction data by analysing first-breaks from the shot records. This analysis was carried out using intercept times and the inverse slopes of refracted arrival segments from travel time-distance plots (Gardner, 1939; Lawton, 1989).

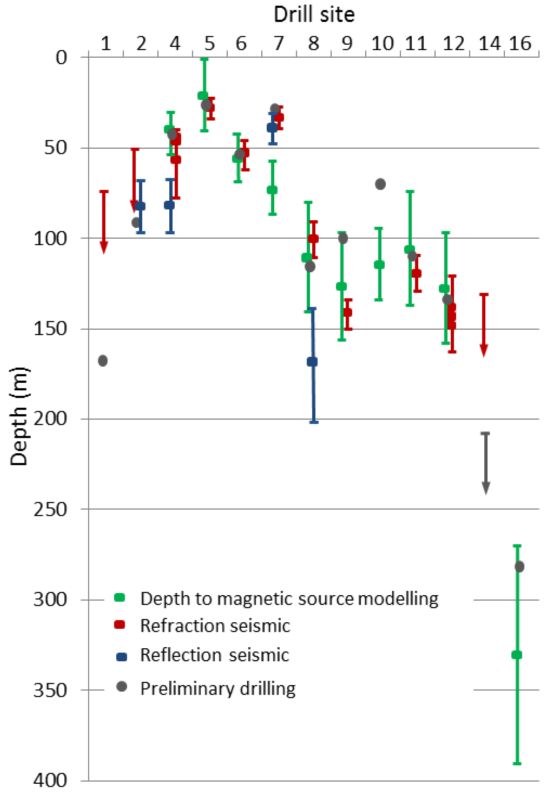

Figure 3. Plot of cover thickness estimates (including error bounds) against preliminary drilling results. Drilling is ongoing at Site 14, which is currently within the Murray Basin cover at 212 m. The down arrows indicate minimum depths.

Employing a sledge hammer as the seismic source limited the energy depth penetration. However, energy return was better than expected with basement velocities recorded at depths of up to 148 m (Site 12). An example of a combined time-distance plot is shown in Figure 4 for Site 8. At the sites where Murray Basin sediments overlie basement (Sites 4 to 14) the velocity model typically consists of four velocity layers. The upper two layers have low velocities (<~650 and ~1000 m/s respectively) and correspond to unsaturated Murray Basin sediments. Below this is a moderate velocity layer (~1800 m/s) that corresponds to saturated Murray Basin sediments. The transition to basement is marked by a high velocity layer (>~4000 m/s). Although the basement at Site 14 is too deep to be imaged, a minimum cover thickness is given and is the depth range within which a high velocity basement layer cannot occur. At Sites 1 and 2, the Newer Volcanic Group and Grampian Group sequences have relatively high velocities (~3300 m/s). No higher velocity layers beneath these sequences were imaged. As per Site 14, estimates of the minimum cover thicknesses are provided.

The refraction method successfully estimated, within error bounds (Meixner, et al., in prep), the cover thickness at six of seven sites (Figure 3). Basement has been intersected at depths below the minimum predicted depths at Sites 1 and 2, while drilling is currently within the cover, at a larger than predicted depth at Site 14. The location of drilling at Site 8 was moved approximately 1.4 km from the seismic line due to logistical considerations and may explain the mis-match at this site. The drilling intersected basement at a depth significantly shallower than predicted at Site 9.

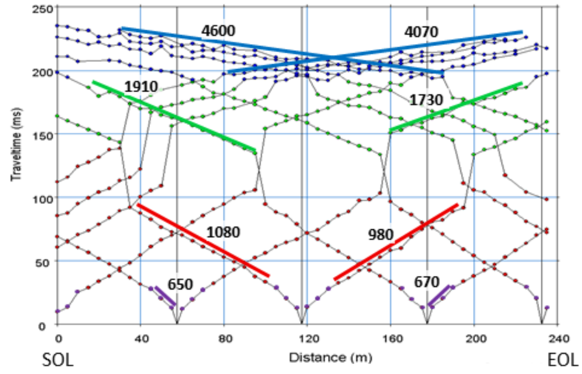

Figure 4. Combined time-distance plot of the interpreted first-break arrivals at Site 8. The coloured dots show the first-breaks assigned to each separate velocity layer. Example velocities (m/s) are shown.

REFLECTION SEISMIC

Shallow reflection seismic data was collected at five sites. The reflection seismic profiles were coincident with the refraction acquisition. Shots were spaced at 5 m intervals. Maximum fold was 48 at the centre of the spread. See Meixner et al. (in prep.) for a complete account of the acquisition parameters and processing procedures.

Depth conversion was achieved using interval velocities estimated from the stacking velocities. Uncertainty in picking the stacking velocities and difficulties in distinguishing the refractions from the reflections in the shallow data resulted in poor estimates of cover thickness. Although depth reliability is low, the depth sections are useful for assessing lateral variations in the cover/basement interface, as well as within the cover sediments. An example of a reflection depth section is shown in Figure 5. The seismic reflection data resulted in a reliable estimate of cover thickness at only one out of the four sites (Figure 3). While poor overall, reflection seismic was the only method that successfully estimated cover thickness at Site 2.

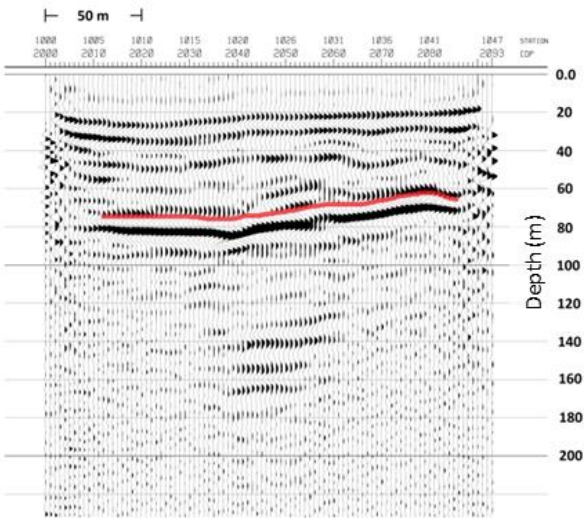

Figure 5. Depth section of the seismic reflection line at Site 4. The interpreted base of cover is shown in red.

GRAVITY

A grid of microgravity data was collected at Sites 1, 4, 8 and 14 with station spacings of between 50 and 100 m. The grid acquisition aimed to characterise the variability in depth of the cover/basement interface around these sites. Site access for large drilling equipment may require the relocation of some drill-sites resulting in the cover thickness estimates from the refraction seismic lines that do not coincide with the location of the final drill-sites. By characterising the cover/basement interface it is possible to account for the site relocations.

Two perpendicular gravity profiles were acquired at Site 3 in order to test for the presence of a gravity low. A gravity low would support the assumption that the co-located magnetic low was the result of a demagnetised porphyry. No gravity low was evident at Site 3, resulting in the abandonment of this site.

Gravity measurements were made using a Scintrex CG5 gravity meter and an Altus APS3 Global Navigation Satellite System provided high-precision vertical positioning. Grids were acquired in short interlocking loops for drift control and tied to the Australian Fundamental Gravity Network. Field data were checked for excessive noise and instrument tilt. INTREPID™ software was used to process the data and apply latitude, free-air, Bouguer and terrain corrections.

Gravity inversion was carried out using the VPmg inversion method of Fullagar and Pears (2007) via GOCAD™ and Mira Geoscience's Potential Fields Module. The inversion takes an initially horizontal cover/basement surface that divides a 3D mesh that has been populated with typical densities for the cover and basement. The inversion deforms this surface in order to match the observed gravity data. It is not possible to produce a cover thickness estimate from the gravity data alone. An initial depth to the cover/basement interface must be provided. For this study, the estimate from the seismic refraction analysis was used. The surface was anchored at the location of the refraction profile, while the rest of the surface was allowed to move during the inversion. An example of the deformed cover/basement surface is shown in Figure 6.

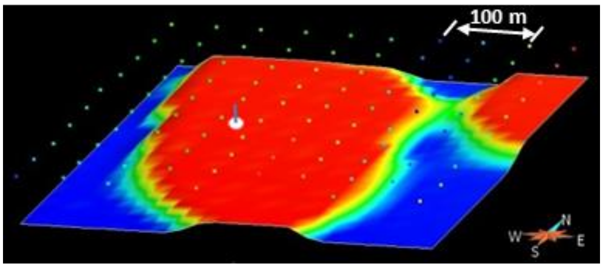

Figure 6. Oblique image of the cover/basement surface produced by the VPmg inversion at Site 4. Total vertical variability of the surface is 15 m. The grid of gravity stations is shown, along with the anchored refraction profile location. Red colours correspond to high gravity and shallow basement depths, while blue colours correspond to low gravity and deeper basement depths.

CONCLUSIONS

The geophysical data acquisition and subsequent analyses have achieved the initial objective of reducing drilling risk by providing greater confidence in the thickness of cover sequences overlying basement.

Refraction seismic was the most successful in predicting cover thickness. A stronger seismic source would increase the signal penetration allowing the tool to be used in regions of thicker cover. Depth to magnetic source modelling, although not as successful as refraction seismic, can be undertaken using magnetic data that are freely available. This data, available as flight-line profiles as well as grids, can be downloaded from the GADDS database (http://www.ga.gov.au/gadds) at data resolutions across most of Australia that are sufficient to produce reliable depth to magnetic source estimates (Percival, 2013). A full analysis of the geophysical methods against the drilling results will be reported in a later publication (Meixner et al., in prep.) once the full suite of post-drilling analysis is completed. These analyses will include down-hole geophysical logging, as well as sampling cores from the cover and basement that will include rock property measurements.

The seismic refraction and the depth to magnetic source methods represent two low cost, readily applicable tools for explorers to reduce their drilling risk at the tenement scale. Future work examining techniques such as resistivity, passive seismic and magnetotelluric data has the potential to further enhance cover thickness predictive capability in regions where cover sequences are not readily estimated using refraction seismic and depth to magnetic source modelling.

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