Pre-drilling geophysics in the Coompana Province of South Australia

Benchmarking magnetotelluric and active seismic cover thickness estimates against preliminary drilling results

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A.J. Meixner¹, W. Jiang¹, J. Holzshuh¹, R. Dutch², M. Pawley², T. Wise², S.R.B. McAlpine¹, J. Duan¹

¹. Geoscience Australia
². Geological Survey of South Australia
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Executive Summary

This study compares cover thickness estimates obtained from magnetotelluric (MT), reflection seismic and refraction seismic data acquired prior to drilling, to preliminary results from the Coompana Drilling Program in the far southwest of South Australia. The Coompana Project is a collaborative project between Geoscience Australia and the Geological Survey of South Australia, co-funded by Geoscience Australia’s Exploring for the Future Programme and the South Australian Government’s PACE Copper Initiative. The Coompana Project aims to provide new precompetitive geological, geophysical and geochemical data in the under-explored Coompana Province in South Australia. The pre-drilling geophysics program was undertaken to assist the drilling process by reducing the uncertainty associated with intersecting the targeted stratigraphy.

The Coompana Province straddles the South Australian–Western Australian border and is one of the least understood geological provinces of the Australian continent. The province lies under the Nullarbor Plain and the region is entirely covered by Neoproterozoic to Cenozoic sedimentary rocks of the Officer, Denman, Bight and Eucla basins, with no known basement exposures.

Prior to drilling, MT and reflection and refraction seismic data were acquired to estimate the thickness of Cenozoic cover sediments at the proposed borehole sites. The estimates of cover thickness assisted with planning the Coompana Drilling Program and reduced the technical risk for the stratigraphic drilling program. MT, reflection and refraction seismic data were acquired at eight proposed borehole sites, of which five were drilled.

A pilot MT study investigated six existing boreholes where basement depth is known. From this investigation, using the Occam 1D inversion, an electrical resistivity transition value of 10 Ωm was estimated as defining the cover-basement boundary. Three inversion methods were applied to the MT data acquired at the proposed borehole sites consisting of Occam 1D, 1D reversible jump Markov chain Monte Carlo for MT (rjMCMcMT) and non-linear conjugate gradient 2D inversion, to produce electrical resistivity models at the proposed borehole sites. Similar electrical resistivity profiles were generated by each inversion method, consisting of moderate to high electrical resistivities at the surface due to the consolidated limestones of the Eucla Basin, changing to low electrical resistivities at increasing depth due to the unconsolidated sediments of the Bight Basin, before increasing to high electrical resistivities within the basement. Applying the electrical resistivity transition value from the pilot study to the smooth models at the borehole sites generally overestimated the cover thickness by 25% on average and up to a maximum of 51%. Cover thickness estimates were also determined from the change point in histogram peaks from the rjMCMcMT inversion. This method also overestimated the cover thickness by 20% on average, likely due to the highly electrically resistive limestones of the Eucla Basin at the surface.

The reflection seismic data had low signal-to-noise ratios and lacked a high amplitude reflection at the base of the cover, resulting in reflectors that were hard to interpret. Therefore, the confidence in the cover thickness estimates derived from seismic data is low. The resulting cover thickness estimates are, in general, an overestimate when compared to the actual cover thickness determined by the drilling. Seismic data quality, and hence the confidence in the cover thickness estimates, could be improved with a larger energy source. The presence of slow-velocity unconsolidated sediments within the Bight Basin underlying high-velocity Eucla Basin limestones resulted in a poor signal-to-noise ratio and poor cover thickness estimation derived from the reflection seismic data. Cover thickness estimates were not determined from the refraction seismic data due to the great depth of basement refractors compared to the far offset shot distance, poor signal-to-noise ratio in the acquired data, and due to the presence of a velocity inversion resulting from a slower velocity layer of unconsolidated
sediments within the Bight Basin beneath a seismically higher velocity layer of Eucla Basin limestones.

The nature of the cover in the Coompana Province presents a unique challenge for estimating cover thickness using geophysical methods. Despite these findings, these new data and interpretations are a valuable contribution to an explorers' toolkit of techniques for estimating cover thickness. By trialling and benchmarking these geophysical methods in new provinces, technical risk will be reduced for the exploration industry searching for new mineral deposits in covered terranes.
1 Introduction

Geoscience Australia, in collaboration with the geological surveys of the states and Northern Territory, are undertaking regional stratigraphic drilling projects under the auspices of the National Mineral Exploration Strategy (COAG, 2017). The aim of the drilling projects is to collect samples and test mineral system hypotheses across a range of greenfields provinces in Australia in order to reduce the risk of drilling in these regions for exploration. Because drilling is a costly activity for both government and industry, Geoscience Australia is benchmarking a range of geophysical methods for different provinces and regions across the continent to determine the most cost-effective way of predicting the thickness of cover. This report is a contribution to the vision of Geoscience Australia for a region-by-region portfolio of the most effective methods for cover thickness determination.

The Coompana Province straddles the South Australian–Western Australian border, located between the western Gawler Craton to the east, the Musgrave Province to the north (Figure 1-1) and the Madura Province to the west. The province is one of the least understood geological provinces of the Australian continent and underlies the Nullarbor Plain. It is entirely covered by Neoproterozoic to Cenozoic sediments of the Officer, Denman, Bight and Eucla basins, with no known basement exposures (Figure 1-1). Previous mineral exploration in the province is limited with only 16 boreholes that intersect basement.

Figure 1-1. Location of the Coompana Province overlain on the total magnetic intensity (reduced to pole) map of Australia, 6th edition (Geoscience Australia, 2015). The Eucla (brown dashed line) and Officer (purple dashed line) basin extents are after Stewart et al. (2013). The red box indicates the study area displayed in Figure 1-2.
Pre-drilling geophysics in the Coompana Province of South Australia

Geoscience Australia and the Geological Survey of South Australia (GSSA) engaged in a collaborative study of the South Australian portion of the Coompana Province, including new pre-competitive data acquisition, leading to a stratigraphic drilling program (the Coompana Drilling Program) in 2017 to investigate the sub-surface geology and more clearly determine the history, structure and mineral prospectivity. The Coompana Drilling Program aimed to address the lack of geological knowledge in the Coompana Province and to test geophysically derived models of the geology. This was achieved by acquiring new basement diamond drill core samples from the region.

This study compares cover thickness estimates gained from new magnetotelluric (MT), reflection seismic and refraction seismic data, acquired prior to drilling, to preliminary results from the stratigraphic drilling program.

Prior to drilling, MT, reflection seismic and refraction seismic arrays were deployed to estimate the thickness of Cenozoic cover sediments at the proposed borehole sites. The cover thickness estimates assisted with planning the Coompana Drilling Program and helped to reduce the technical and financial risks associated with drilling a series of stratigraphic boreholes through the cover sequence to acquire samples of the basement rocks.

The MT method was initially applied at six pilot sites (Figure 1-2) where the cover thickness was known from nearby existing boreholes. This allowed the MT models to be compared to the known cover thickness at those locations. The MT method was then applied to eight of the proposed borehole sites, along with the reflection and refraction seismic methods. Although 18 new stratigraphic boreholes were originally planned, logistical and budget constraints meant that only eight sites were drilled, of which five were located at the pre-drilling geophysics sites (Table 1-1, Figure 1-2). The boreholes were located in close proximity to the geophysical acquisition with the exception of site CP06, where borehole CDP007 was moved 75 m to the northwest.

Table 1-1. Summary of pre-drilling geophysics sites, geophysical methods acquired at each site, and corresponding borehole ID's.

<table>
<thead>
<tr>
<th>Pre-drilling geophysics site ID</th>
<th>MT</th>
<th>Seismic</th>
<th>Borehole ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP01</td>
<td>X</td>
<td>X</td>
<td>Not drilled</td>
</tr>
<tr>
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<td>X</td>
<td>X</td>
<td>Not drilled</td>
</tr>
<tr>
<td>CP03</td>
<td>X</td>
<td>X</td>
<td>Not drilled</td>
</tr>
<tr>
<td>CP04</td>
<td>X</td>
<td>X</td>
<td>CDP002</td>
</tr>
<tr>
<td>CP05</td>
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<td>X</td>
<td>CDP006</td>
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<td>X</td>
<td>CDP007</td>
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<tr>
<td>CP07</td>
<td>X</td>
<td>X</td>
<td>CDP003</td>
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<tr>
<td>CP08</td>
<td>X</td>
<td>-</td>
<td>CDP004</td>
</tr>
<tr>
<td>CP09</td>
<td>-</td>
<td>X</td>
<td>CDP001</td>
</tr>
</tbody>
</table>

These new data and interpretations contribute to an explorers’ toolkit of techniques to help reduce the risk to the exploration industry in searching for new mineral deposits in covered terranes. This is the third pre-drilling geophysics program that has benchmarked cover thickness estimates against drilling results. The first benchmarking program, the Stavely Project, drilled fourteen stratigraphic boreholes in...
the Stavely region of western Victoria with the results detailed in Meixner et al. (2016) and Czarnota et al. (2016). The second program, the Southern Thomson Project, drilled twelve stratigraphic boreholes in the southern Thomson Orogen with the results of the pre-drilling geophysical acquisition detailed in Goodwin et al. (2017) and the benchmarking detailed in Roach et al. (2018).

![Total magnetic intensity (reduced to pole) image of the study area showing the six MT pilot sites and the nine pre-drilling geophysics sites, of which five were drilled. Note: At site CP09 no MT data were acquired, while at site CP08 no seismic data were acquired. Magnetic data are from the 2015 Coompana aeromagnetic survey (Wise et al., 2015). Map locality shown in Figure 1-1.](image)

Figure 1-2. Total magnetic intensity (reduced to pole) image of the study area showing the six MT pilot sites and the nine pre-drilling geophysics sites, of which five were drilled. Note: At site CP09 no MT data were acquired, while at site CP08 no seismic data were acquired. Magnetic data are from the 2015 Coompana aeromagnetic survey (Wise et al., 2015). Map locality shown in Figure 1-1.
2 Geological overview

The basement rocks of the Coompana Province are overlain by a range of cover rocks and regolith. A schematic section showing the relationship between the major cover rocks to the basement is shown in Figure 2-1. In the south of the project area a suite of mafic volcanics occurs directly overlying the basement, with basalt from borehole CD 1 (Figure 1-1) dated to the Neoproterozoic (859 ± 66 Ma; Travers, 2015). The extents of this suite were delineated by the 2015 Coompana aeromagnetic survey (Wise et al., 2015). In the north (Figure 1-1), the Neoproterozoic to Late Devonian Officer Basin (Drexel and Preiss, 1995) overlies the basement rocks. In the south of the project area, the intracratonic Denman Basin, a north-northwest-trending fault bounded trough filled with Permian age sediments, unconformably overlies the basement (Hibburt, 1995). This basin varies from 300 m thick in the north to 1000 m thick in the south, and sedimentary rock fill is interpreted as being glacial at the base, trending up-sequence to sedimentary rocks representing progressive de-glaciation and glacio-eustatic marine transgression. The Bight and Eucla basins overlie these older cover sequences and blanket the study area.

![Figure 2-1. Schematic section of regional basin cover overlying the basement in the Coompana Province, focussing on the stratigraphy of the Bight and Eucla basins. Figure courtesy of the Geological Survey of South Australia.](image)

The Bight Basin unconformably overlies the Denman Basin and is a large, mainly offshore basin that extends along the southern Australian margin (Hill, 1995). The basin contains a Middle Jurassic to Late Cretaceous sedimentary succession consisting of the Loongana and Madura formations. The Early Cretaceous Loongana Formation is a sandy to shaly succession with a maximum thickness of...
324 m, and is interpreted to record the initial rift phase of the basin, deposited in a terrestrial low sinuosity fluvial environment within isolated grabens of the developing rift valley (Hill, 1991; 1995). The Early Cretaceous Madura Formation conformably overlies the Loongana Formation. The Madura Formation has a maximum thickness of 474 m and consists of carbonaceous or glauconitic sandstone, siltstone, and claystone and shale, commonly pyritic. The sediments were interpreted to have been deposited in a marine environment with limited circulation suggested by low-energy lacustrine conditions (Hill, 1995).

The Eucla Basin unconformably overlies the Bight Basin and is a widespread, thin package of marine and terrestrial sediments that were deposited on the passive margin of southern Australia during the Cenozoic and contains the following packages:

- The lowest unit is the Pidinga Formation. This is a 30 m – 60 m thick package of carbonaceous, terrigenous clastic sedimentary rocks that were deposited in topographically low settings, such as paleochannels and broader depressions (Benbow, et al., 1995)
- The Hampton Sandstone overlies the Pidinga Formation. This unit comprises quartz-rich sands that were deposited as lenses and sheets in marine, estuarine and fluvial environments (Benbow, et al., 1995)
- The Wilson Bluff Limestone overlies the Hampton Sandstone. The Wilson Bluff Limestone is <150 m thick east of the Coompana Block, increasing westwards to ~300 m thick in Western Australia (Benbow, et al., 1995) and consists of wackestone, skeletal mudstone, rudstone and minor packstone
- The Abrakurrie Limestone is a thin (generally <10 m thick) unit that overlies the Wilson Bluff Limestone. The Abrakurrie Limestone is interpreted to have been deposited on a partly to completely drowned platform (James and Bone, 1991)
- The Nullarbor Limestone is a 20 m to 35 m thick unit that overlies the Abrakurrie Limestone (Benbow, et al., 1995). The Nullarbor Limestone is interpreted to have been deposited in a shallow platform setting, with the paucity of terrigenous material suggesting river systems carried little debris to the coast (James and Bone, 1991)

The basement rocks of the Coompana Province exhibit a complex, multi-phase history beginning with interpreted Paleoproterozoic oceanic crust formation evident in the recent drilling by the Geological Survey of Western Australia (GSWA) (Spaggiari and Smithies, 2015). This crust was modified by magmatic events associated with subduction and extension crustal reworking throughout the Mesoproterozoic (Spaggiari and Smithies, 2015; Dutch, et al., 2016; Kirkland, et al., 2017). This first event was of widespread arc magmatism and recycling of the oceanic crust at ~1610 Ma, which resulted in the Toolgana Supersuite. In diamond drill core, GSWA found the Toolgana Supersuite includes locally migmatitic monzodioritic to granodioritic to monzogranitic gneisses and metadolerites that have been metamorphosed to amphibolite facies (Spaggiari and Smithies, 2015).

The Toolgana Supersuite was followed by ~1500 Ma extension and rift-related ~1490 Ma Undawidgi Supersuite magmatism in the west. This supersuite includes metagranitic and possibly bimodal metavolcanic rocks that were derived by melting of lower mafic crust and the introduction of a mantle component. In diamond drill core, the GSWA found the Undawidgi Supersuite to include: variably foliated metatonalites and metamonzogranites, which are locally gneissic and migmatitic; metamonzodiorites; and variably sheared/mylonitic felsic and mafic schists (Spaggiari and Smithies, 2015).
Major extension at ~1200 Ma to 1120 Ma resulted in crustal thinning and widespread crustal reworking. Reworking included generation and intrusion of the widespread intraplate ~1190 Ma to 1140 Ma Moodini Supersuite (Spaggiari and Smithies, 2015). In diamond drill core, the GSWA found the Moodini Supersuite to include equigranular to porphyritic, massive syenogranites, shoshonites and monzogranites that form thin sheets that cut the earlier foliations at variable angles (Spaggiari and Smithies, 2015). This widespread event, which affected the crust between the Yilgarn, Gawler and North Australian cratons has been called the Maralinga Event (Spaggiari et al., 2016).

The Coompana Province then experienced an episode of mafic magmatism, which produced three rock types (Dutch et al. 2017b; 2017c; 2017e; 2017f; Wise et al. 2015):

1. olivine dolerite-gabbro plutons and stocks
2. basalt dykes
3. vesicular olivine basalt (Mallabie Formation)

These rocks have been dated at ~1074 Ma (E. A. Jagodzinski, pers. comm.) and are correlated with the Warakurna Supersuite that can be traced across central and Western Australia.
3 Magnetotellurics

3.1 Data acquisition, processing and inversion

Magnetotelluric data were acquired at six pilot sites (April 2016) and eight proposed borehole sites (February 2017) prior to the Coompana Drilling Program (Jiang et al., 2017). The pilot study sites (Figure 1-2) were located where the cover thickness was known via existing boreholes and were acquired for two reasons: firstly, to benchmark the method against known cover thickness, and; secondly, to determine a resistivity threshold from the inversion results that defines the transition from the low electrical resistivity cover to the high electrical resistivity basement.

Geoscience Australia and GSSA undertook the pilot study using Geoscience Australia’s data acquisition units (MTU-5A), magnetic coils (MTC-150L) and non-polarisable electrodes (PE5) manufactured by Phoenix Geophysics, Canada. At each site, two sets of instruments were deployed with a separation of approximately 300 m to 500 m. Two instruments were deployed to provide redundancy in case of instrument failure (Figure 3-1). The instruments were deployed and left overnight to obtain data over a range of 10 kHz to 0.001 Hz at five sites. At site ALBALLA-KAROO (Figure 1-2), only Audio frequency MT (AMT) data (10 kHz to ~0.35 Hz) were recorded for two hours. The instruments were deployed in a cross-shaped array, aligned to magnetic north, to simultaneously acquire two orthogonal electric fields and three magnetic fields. Data was also recorded at four locations along a transect, with a spacing of ~50 m at each drill-site. In total, 32 datasets over a range of 10 kHz to 0.002 Hz were obtained for the eight proposed borehole sites. See Jiang et al. (2017) for a full description of the data acquisition procedures.

Figure 3-1. Schematic map view layout of a MT station using three magnetic induction coils and five electrodes (two electric dipoles and one ground electrode). Figure from Goodwin et al. (2017).
Data processing and quality control of the pilot study MT data were undertaken using the Phoenix Geophysics Ltd software package, which includes Synchro Time Series View, SSMT2000, and MTEditor. Data processing for the pre-drilling MT was carried out by the Zonge Engineering and Research Organisation. An example of a processed dataset is shown in Figure 3-2. Data were generally of good quality, showing smooth continuous curves over the recorded frequency range, with the exclusion of data in the Audio Magnetotelluric dead-band of 1 kHz to ~5 kHz and 0.1 kHz to ~5 Hz in the Broadband Magnetotelluric dead-band. See Jiang et al. (2017) for a full description of the data processing methods.

Figure 3-2. Apparent resistivity and phase calculated from MT data recorded at the DENMAN 1 site: resistivity $\rho_{\text{xy}}$ and phase $\phi_{\text{xy}}$ in red, resistivity $\rho_{\text{yx}}$ and phase $\phi_{\text{yx}}$ in blue.

A single inversion method, Occam 1D inversion (Constable et al. 1987), was applied to the pilot site MT data, while a further two methods, the 2D inversion algorithm of Rodi and Mackie (2001), and the 1D reversible jump Markov chain Monte Carlo for MT (rMCMcMT) stochastic inversion program (Brodie and Jiang, 2018) were applied to the pre-drilling geophysics site data. Below is a brief description of the inversion methods; refer to Jiang et al. (2017) for a more comprehensive explanation.

Occam’s inversion method (Constable et al. 1987) solves the regularized problem by searching for the smoothest model that fits the data. This method generally produces smooth peaks in the model that correspond to features that are well-constrained by the data, whereas features that are not essential in matching the observations are suppressed or smoothed out (Key, 2009). An example of the Occam 1D inversion result is shown in Figure 3-3.
Data modelling and inversion of the pre-drilling geophysics site data were undertaken using the 2D isotropic modelling and inversion algorithm of Rodi and Mackie (2001) implemented in WinGLink® software. The inversion code applies the non-linear conjugate gradient (NLCG) method for direct iterative minimisation of an objective function that penalises data residuals and second spatial derivatives with respect to resistivity structures (Rodi and Mackie, 2001, 2012). The NLCG 2D forward modelling algorithm uses a finite difference numerical method for calculation. The inversion models are obtained by solving for the smoothest model using uniform-grid Laplacian regularisation and minimising the integral of the Laplacian (Rodi and Mackie, 2012). Figure 3-4 shows the NLCG 2D inversion result for drill-site CP01. The resistivity model was derived from simultaneously inverting the TE and TM mode data collected at four locations along a traverse centred over the proposed drill-site location.
Figure 3.4. NLCG 2D inversion model produced from MT data from site CP01. Warm colours represent regions of high electrical conductivity and the colder colours represent electrically resistive regions.
The 1D reversible jump Markov chain Monte Carlo for MT (rjMCMcMT) is a stochastic inversion program developed by Geoscience Australia (Brodie and Jiang, 2018) and was also used to invert the pre-drilling site data. The algorithm uses trans-dimensional Markov chain Monte Carlo techniques to solve for a probabilistic conductivity-depth model. The inversion of each station employs multiple Markov chains in parallel to generate an ensemble of millions of conductivity models that adequately fit the data given the assigned noise levels. The trans-dimensional aspect of the inversion means that the number of layers in the conductivity model is solved for, rather than being predetermined and kept fixed. Each Markov chain increases and decreases the number of layers in the model and the depths of the interfaces as it samples. Once the ensemble of models is generated, statistics for all the models are analysed to assess the posterior probability distribution of the conductivity at any particular depth, as well as the number of layers and the depths of the interfaces. The stochastic approach gives a thorough exploration of model space and a more robust estimation of uncertainty than deterministic methods. Figure 3-5 shows the result for one of the datasets at site CP01.

![Figure 3-5](image)

**Figure 3-5.** Plots summarising the results of rjMCMcMT from pre-drilling site CP01_E1. Top-left: real and imaginary impedances and error bars (red) and the best fitting model from each Markov chain (blue); bottom-left: data misfit convergence history for each Markov chain and histogram of the number of model layers; Right: the summary median, 10th and 90th percentile, mean and mode models and the change-point histogram showing the probability of where layer interfaces occur.

### 3.2 Benchmarking

Drilling was carried out at five of the pre-drilling geophysics sites where MT data were acquired (CP04, CP05, CP06, CP07, CP08; Table 1-1). A summary of the preliminary drilling results at these five sites is given in Dutch *et al.* (2017b; 2017c; 2017d; 2017e; 2017f). Figures of the preliminary field summary logs for the drilling are shown in Appendix A. Figures of the MT inversion results showing the cover thickness from the preliminary field summary logs are shown in Appendix B.
Cover thickness as delineated by the drilling (true vertical depth) at the pre-drilling sites ranges from 229 m to 441 m. All five of the boreholes intersected consolidated limestones of the Eucla Basin (Nullarbor Limestone, Wilsons Bluff Limestone) before encountering semi-consolidated and unconsolidated sedimentary rocks, mostly sands and siltstones of the Bight Basin (Madura Formation and Loongana Formation). Four of the boreholes (CDP002, CDP003, CDP006, CDP007) transitioned from the Bight Basin sedimentary rocks through a thin saprolite layer (≤21 m) before encountering basement, while CDP004, in the north of the study area (Figure 1-2; pre-drilling site CP08), encountered consolidated Proterozoic to Cambrian sediments of the Officer Basin before entering basement.

The results of the three inversion methods all show a similar resistivity profile, consisting of moderate to high resistivities at the surface followed by low resistivities before transitioning back to high resistivities in the basement (Appendix B). The moderate to high resistivities correspond to the limestones of the Eucla Basin, the low resistivities to the unconsolidated and semi-consolidated sediments of the Bight Basin, and the underlying high resistivities to the basement. Jiang et al. (2017) used the Occam 1D inversion results of the pilot study, where the cover thickness was known from existing drilling data, to determine a resistivity transition value for the smoothly increasing inversion models where the boreholes encountered basement. A transition value of 10 Ωm was used to determine the depth at which the smooth models transition from the moderate to low resistivity cover to high resistivity basement, and hence, the cover thickness at the pre-drilling geophysics sites from the Occam 1D, NLCG 2D and rjMCMcMT inversions.

The estimated cover-basement transition value of 10 Ωm holds well for most of the pre-drilling geophysics sites, except for site CP08 where the drilling encountered interpreted Neoproterozoic to Cambrian sandstones of the Officer Basin at a depth of 278 m beneath the Loongana Formation before entering crystalline basement at 444 m (Appendix Figure A.5). These sandstones are highly consolidated and are, therefore, likely to be highly resistive. The MT inversions at this site are, therefore, likely to be picking the transition from the unconsolidated Bight Basin sediments to the highly consolidated Officer Basin sediments.

The cover thickness estimates of Jiang et al. (2017) are shown in Table 3-1. Cover thickness estimates were produced from the Occam 1D, NLCG 2D and rjMCMcMT inversions using the 10 Ωm cover-basement resistivity transition value, as well as the change-point histogram peaks of the rjMCMcMT inversion. Generally, the inversion models produced cover thickness estimates that are deeper than the drilled depths, indicating that the MT results are overestimating the cover thickness by an averaged difference for each site of 25% for the Occam 1D inversion. The NLCG 2D inversion produced a closer result with an averaged difference of 16%, while the rjMCMcMT inversion (resistivity transition) sits between the two with a 21% averaged difference. The rjMCMcMT inversion, using change-point histogram peaks, produced an averaged difference of 20%. These overestimations are larger than the ±10% error margin suggested to be reasonable by Jiang et al. (2017).
Table 3-1. Cover thickness estimates from the Occam 1D, NLCG 2D and rjMCMcMT inversion results compared to the drilling results (true vertical depth). Percent differences between the inversions and the drilling results are also shown with positive values indicating an overestimation and negative values an underestimation of cover thickness.

<table>
<thead>
<tr>
<th>Pre-drilling geophysics site ID</th>
<th>Borehole ID</th>
<th>Drilled cover thickness (m)</th>
<th>Occam 1D (resistivity threshold 10 Ωm)</th>
<th>NLCG 2D (resistivity threshold 10 Ωm)</th>
<th>rjMCMcMT (resistivity threshold 10 Ωm)</th>
<th>rjMCMcMT (change-point)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>depth (m)</td>
<td>% diff.</td>
<td>depth (m)</td>
<td>% diff.</td>
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<tr>
<td>CP08</td>
<td>CDP004</td>
<td>276(^1) 441(^2)</td>
<td>270</td>
<td>-2</td>
<td>306</td>
<td>11</td>
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<tr>
<td><strong>Average % difference</strong></td>
<td></td>
<td></td>
<td></td>
<td>25</td>
<td></td>
<td>16</td>
</tr>
</tbody>
</table>

\(^1\) top of Neoproterozoic – Cambrian sandstone  
\(^2\) top of Migmatitic Gneiss

3.3 Discussion

The cover thickness estimates using the 10 Ωm resistivity value transition between cover and basement were based on the Occam 1D results from the pilot study where the resistivity transition was determined from existing drilling data. The overestimations of cover thickness may be due to different cover geology, and hence, different cover resistivity transition values at these sites compared to the pilot study sites. The pilot study boreholes are close to some of the Coompana Drilling Project boreholes and it is likely that the pilot study boreholes contain representative cover geology. The KN 1 borehole (Figure 1-2), for example, is within 10 km of CP04, while CP05 sits in the middle of three of the existing boreholes (CD 1, ALBALLA-KAROO, KN 1). Both HUGHES 1 and DENMAN 1, both significant distances to the north, did not encounter basement and were not used to determine the resistivity transition. The four pre-existing boreholes used to determine the resistivity transition (CD 1, ALBALLA-KAROO, KN_1, GUINEWARRA) all encountered the limestones of the Eucla Basin at the surface followed by unconsolidated sediments of the Bight Basin before entering basement (Jiang et al., 2017). If the cover sequences, and hence the resistivity values, at the pilot sites are representative of the cover sequences at the Coompana Drilling Project borehole sites and assuming that the resistivity values of the basement are also similar, then the 10 Ωm resistivity transition value used for the pilot site inversions should be a valid transition value to determine cover thickness estimates at the Coompana Drilling Project borehole sites.

The Occam 1D and NLCG 2D inversions produce smooth models and, therefore, require prior knowledge of rock resistivity values in order to produce a cover thickness estimate. The rjMCMcMT inversion differs as the trans-dimensional aspect of the inversion means that the number of layers in the model is solved for, rather than being predetermined and kept fixed. The resulting models are a statistical analysis of the millions of model runs and show distinct jumps in the mode as well as corresponding peaks in the change-point histogram (Figure 3-5). Jiang et al. (2017) used the 10 Ωm resistivity transition value to determine the cover thickness estimates as the modal value of the resistivity jump to higher values. A more robust way of defining a change of resistivity is to look at the
change-point histogram. Peaks in the histogram show increased likelihood of a change of resistivity at that depth. The cover thickness estimates using this method (Table 3-1) also overestimate cover thickness by an average 20%.

Weathering of the top of the basement was thought to contribute to an overestimation of the cover thickness. The presence of saprolite at the top of basement indicates weathering of fresh rock which lowers resistivity values as evident in Figure 3-6. Analysis of the drill core identified 12 m of saprolite at the top of basement at CP04 (CDP002; Dutch et al., 2017b), 21 m at CP05 (CDP006; Dutch et al., 2017e), 18 m at CP06 (CDP007; Dutch et al., 2017f), and 3 m at CP07 (CDP003; Dutch et al., 2017c). No saprolite was identified at CP08 (CDP007; Dutch et al., 2017d). If the saprolite is included with the cover, the average percent differences between the drilled cover thickness and the MT inversion results are reduced with values of 20% (25%) for the Occam 1D inversion, 12% (16%) for the NLCG 2D, 16% (21%) for the rjMCMcMT inversion (resistivity transition) and 15% (20%) rjMCMcMT inversion (change point) where the averaged percent differences if the saprolite is not included with the cover (Table 3-1) are shown in parentheses. Although the average percent differences are reduced, indicating an improvement in the cover thickness estimates, the overestimations are still larger than the ±10% error margin suggested as reasonable by Jiang et al. (2017).

![Figure 3-6. Conductivity-resistivity values of various geological materials. Attention is drawn to the reduced resistivity values of weathered rocks (saprolite) compared to unweathered rocks. Modified after Palacky (1987).](image)

Weathering may be indicated by the presence of kaolinite. Hyperspectral mineralogy (HyLogger™) data were acquired on the diamond drill cores at the five MT acquisition sites. Shortwave infrared
(SWIR) mineralogy show elevated kaolinite sample counts (>20%) in a single diamond drill core (CDP006) at site CP05. The elevated levels occur from ~285 m to 292 m, which is within the saprolite layer (278 m to 299 m) identified in the diamond drill core. Kaolinite counts for the remaining diamond drill core, except for site CP06 (CDP007) where null values were returned, were less than 5%. The hyperspectral data confirm that the basement identified from the drill core is only slightly weathered to unweathered and cannot account for the overestimation of the cover thickness.

The nature of the cover may result in uncertainty and in the project area may be the source of the general overestimation of the MT cover thickness estimates. The moderately to highly electrically resistive limestones at the surface introduce more complexity to be solved by the inversions. In principle, the penetration depth of a given signal is deeper in an electrically resistive material than that in electrically conductive material (Chave and Jones, 2012). If the transition from electrically resistive limestones to electrically conductive formations was not solved precisely, this will result in uncertainty in the model.

There are several limitations and sources of uncertainty in applying the MT method for the purposes of cover thickness estimation. First, the propagation of the electromagnetic fields through the Earth is a diffusive process, and responses obtained are volumetric averages of the measured Earth conductivities. The diffusive nature of the energy propagation 'smears out' sharp boundaries or thin layers (Constable et al. 1987). Therefore, the MT response cannot resolve the transition between electrically conductive and electrically resistive structures precisely. Second, assumptions associated with the 1D and 2D inversion techniques lead to uncertainty in model results. For a site affected by 3D structure, a 1D or 2D assumption may not satisfy the true physical process and 3D models are required, which involves data acquisition over a grid. A third source of uncertainty includes natural and artificial (cultural) noise that affects the data quality, including sources such as powerlines, pipelines, fences, wildlife, severe weather conditions and topographic features. For the data acquired here, every effort was made to avoid cultural noise. Finally, the non-uniqueness of inversion models (Constable et al., 2015) increases uncertainty of cover thickness estimates.
4 Seismic

4.1 Data acquisition, processing and interpretation

Seismic reflection and refraction data were acquired at eight of the proposed drilling sites (Table 1-1; Figure 1-2). Seismic cables were laid out at each site and 48 geophones were placed at five metre intervals to create a 235 m spread to collect the vertical component of a primary wave (P-wave) energy source. The seismic source was a 40 kg accelerated weight drop. Source locations consisted of a shot at the centre of the spread, extending out in either direction in 20 m intervals. The last reflection shot was usually acquired 440 m from the furthest geophone unless the data were very noisy or time was limited. Refraction shots were located at 700 m and 1000 m from the furthest geophone, either side of the spread, with the exception of site CP07 where a shot was located 1300 m from the end of the spread. The geophone and source locations were recorded using a Real Time Kinematic (RTK) Global Positioning System (GPS) for accuracy.

The reflection seismic data were processed using the following processing stream; a detailed description of the processing steps can be found in Yilmaz (2001):

1. Geometry: station and shot locations loaded
2. Define common depth points (CDP), 5 m and 10 m spacing
3. Initially using 5 m CDP, later with 10 m CDP to improve signal-to-noise ratio
4. Read in SEG-2 shot records, convert to Echos format
5. View data to identify bad traces and ensure shot locations match observer’s logs
6. Apply notch filter: 80 Hz for vertical geophones (0 to 50 m offset); and, 73 Hz for horizontal geophones (0 to 140 m offset), to remove instrument noise
7. Edit bad traces and shot locations as required
8. View ground roll and refractor signal and calculate their linear velocities
9. Remove linear signals – test both and compare:
   a. Spectral equalisation (SPEQ) 4 to 180 Hz and F-K Dip filtering, or
   b. Apply Automatic Gain Control (AGC) and Low Frequency Array Filtering (LFAF) using the higher of the ground roll, refractor velocity or velocity of the dominant signal. Apply spectral equalisation 4 to 180 Hz
10. Velocity analysis using constant velocity stacks
11. Stack with velocity function defined from constant velocity stacks
12. Depth conversion with stacking velocities

The geophone spread was laid over relatively flat ground and little variation in weathering was expected along the spread. Geophones were often difficult to place into the hard ground and a hand drill was often used to insert the geophones. Based on this it was assumed that a seismically slow weathering layer was not present. F-K dip filtering was applied in order to remove air wave, ground roll and refraction signals from the shot records. Although the air wave was identified, it was difficult to remove this from the shot records by filtering. Low Frequency Array Filtering (LFAF) can remove
linear noise events from the shot records, such as those arising from the air wave, without introducing artefacts, and this was applied here. Despite this, the high frequency airwave noise persisted and was difficult to remove. Spectral equalisation was applied to the data after the LFAF was applied to enhance higher frequencies.

The filtered shot records were then sorted into CDP gathers in CDP and offset order and the CDP gathers were stacked over a range of constant velocities. Figure 4-1 shows a series of constant-velocity stacks for site CP09 F-K dip filtered data. A coherent event is highlighted, occurring most prominently at a stacking velocity of 3200 m/s. This event deteriorates at higher stacking velocities and is significantly diminished at 3500 m/s. Although the data are very noisy, this event is interpreted to be a coherent reflection. The approximately 50 fold data indicates that 50 CDP traces are aligning coherent signals at 3200 m/s to produce the individual traces in the stack. The final stack was depth-converted using this stacking velocity over this interval. Figure 4-2 shows a time stack with the corresponding depth-converted stack for CP04 with a five metre CDP spacing. For a comprehensive account of the acquisition and processing methods of the reflection seismic data see Holzschuh et al. (2018).

![Figure 4-1. CP09 constant velocity stacks of F-K dip filtered data, 5 m CDP spacing, showing fold and velocity at the top of each stack. The most coherent reflection event occurs with the 3200 m/s constant velocity stack.](image)

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The refraction seismic data were acquired in order to assist with reflection seismic data processing and interpretation. The far offset refraction shots were investigated for refractor layer velocity approximations. Two linear events that are interpreted as refracted first arrivals (1270 m/s and 2600 m/s) at site CP07 are shown in Figure 4-3. The values for these refractors are less than typical velocities for slightly weathered to unweathered basement rocks (which are normally >3700 m/s; Greenhalgh and Whitely, 1977) and are considered to be refractors sourced from the cover. To image a refractor at depth, the maximum source offset is generally required to be of the order of three times the depth to the refractor. At site CP07 a maximum offset of 1300 m was used, therefore, a refractor must lie at a depth of 433 m or shallower in order to be imaged by this method. At this site, the higher velocity (>2600 m/s) bedrock layer must either lie deeper than this, or is not visible in the refraction data due to inadequate power from the P-wave source.
Figure 4-3. CP07 seismic refraction and reflection data. a) A far offset refraction shot is displayed with variable area colour used to assist in identifying weak linear events highlighted in red. b) The time stack shows stacking velocities. c) The depth converted stack. Major coherent reflection events are highlighted.

Refraction seismic data may also be used to determine cover thickness independent of reflection data. This, however, was not possible due to the great depth of basement refractors compared to the far offset shot distance, as explained above, and poor signal-to-noise ratio in the acquired data. Additionally, if basement reflectors were present, the cover thickness results from refraction seismic modelling will over-estimate the true cover thickness due to the presence of velocity inversions (Redpath, 1973), which at these locations are the product of a seismically slower layer (unconsolidated sands) beneath a faster layer (limestones).

4.2 Benchmarking

Drilling was carried out at five of the pre-drilling geophysics sites where seismic data were acquired (CP04, CP05, CP06, CP07, CP09; Table 1-1). A summary of the preliminary drilling results at these five sites is given in Dutch et al. (2017a; 2017b; 2017c; 2017e; 2017f). Figures of the preliminary field summary logs for the drilling are shown in Appendix A. Figures of the interpreted reflection seismic data showing the cover thickness from the preliminary field summary logs are shown in Appendix C. Cover thickness as delineated by the drilling ranges from 229 m to 441 m. All five of the boreholes intersected consolidated limestones of the Eucla Basin (Nullarbor Limestone, Wilsons Bluff Limestone) before encountering semi-consolidated and unconsolidated sediments, mostly sands and siltstones of the Bight Basin (Madura Formation and Loongana Formation) before transitioning into basement.

The reflection seismic cover thickness estimates compared to the drilling results are shown in Table 4-1, including the percentage difference between the seismic reflection estimate and the actual drilled
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depth. Two alternative cover thickness estimates are given at four of the five sites, due to low signal-
to-noise ratio and a lack of high amplitude reflections typically observed at the cover-basement
boundary. This results in uncertainty in picking a definitive reflector at the top of basement. The
criteria used to determine the cover thickness are also given in Table 4-1 and are based on either: a
change in stacking velocities; the deepest continuous reflector; or, a change in reflection character.
Success of the reflection seismic method in predicting cover thickness was mixed, with a general
overestimation of the cover thickness. The cover thickness estimates at three of the sites were based
on the last reflector before a change to higher stacking velocities (> 3000 m/s), with two of the sites
CP04 and CP07 picking cover thickness to -12% and 11% respectively. At site CP05 two different
stacking velocities were used to produce two different cover thickness estimates based on these
different velocities. The slower stacking velocity option for the shallower reflectors (Appendix C.2)
produced the closest cover thickness estimate (24%). A single high stacking velocity was used to
produce coherent reflectors for sites CP06 (3500 m/s; Appendix C.3) and CP09 (3300 m/s; Appendix
Figure C.5). Additional cover thickness estimates were based on a character change of reflectors for
site CP06 and consistent reflections for site CP09. The cover thickness estimates for CP09 were
within 13% for the two alternative closely spaced reflectors, while for site CP06 both reflector options
resulted in large overestimations of cover thickness.

Table 4-1. Reflection seismic cover thickness estimates against the preliminary cover thickness (true vertical
depth) from the drilling. The saprolite is included as part of the cover sequence.

<table>
<thead>
<tr>
<th>Pre-drilling geophysics site ID</th>
<th>Borehole ID</th>
<th>Drilled cover thickness (m)</th>
<th>Estimated cover thickness (m)</th>
<th>% difference</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP04</td>
<td>CDP002</td>
<td>364</td>
<td>330</td>
<td>-9</td>
<td>Change in stacking velocity</td>
</tr>
<tr>
<td>CP05</td>
<td>CDP006</td>
<td>276</td>
<td>370</td>
<td>34</td>
<td>Change in stacking velocity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>420</td>
<td></td>
<td>52</td>
<td>Change in stacking velocity</td>
</tr>
<tr>
<td>CP06</td>
<td>CDP007</td>
<td>228</td>
<td>400</td>
<td>56</td>
<td>Reflections character changes, darker below this layer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>580</td>
<td>154</td>
<td>Deepest continuous reflector</td>
</tr>
<tr>
<td>CP07</td>
<td>CDP003</td>
<td>249</td>
<td>280</td>
<td>12</td>
<td>Change in stacking velocity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>560</td>
<td>125</td>
<td>Deepest continuous reflector</td>
</tr>
<tr>
<td>CP09</td>
<td>CDP001</td>
<td>341</td>
<td>300</td>
<td>-12</td>
<td>Consistent reflector</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>350</td>
<td>0</td>
<td>Deepest continuous reflector</td>
</tr>
</tbody>
</table>

4.3 Discussion

The consolidated near-surface Eucla Basin limestones overlying the unconsolidated Bight Basin
sediments are the likely cause of the diminished seismic energy reflected from deeper horizons and
the low signal-to-noise ratio. Typically the cover-basement interface produces a high amplitude
reflection due to a large difference in the reflection coefficient between the two units. This is the result
of large velocity and density contrast between slower velocity, low density sediments and the higher
velocity, high density basement. The low signal-to-noise ratio and lack of a definitive high amplitude
reflector resulted in reflection stacks that were difficult to interpret, resulting in the low confidence in
the cover thickness estimates, as well as the alternative cover thickness estimation at four of the five
sites. Seismic data quality, and hence, confidence in the cover thickness estimates could be improved
with a more powerful P-wave energy source.
Multichannel Analysis of Surface Waves (MASW) was applied to the vertical geophone reflection data at all sites where drilling was carried out, with the exception of site CP06 (Holzschuh et al., 2018). The MASW models for sites CP04 (Figure 4-4) and C07 show high shear-wave (S-wave) velocities (>~1200 m/s) that are consistent with the high velocity limestones. Sites CP05 (Figure 4-5) and CP09, show S-wave velocity variability at the near surface with very low values on portions of the line (<~600 m/s). See Holzschuh et al. (2018) for MASW S-wave models for all sites. The sites with higher S-wave velocities at the near surface appear to have less noise and have reflection boundaries that are easier to distinguish relative to the low S-wave velocity sites. The low S-wave velocities indicate weathering or unconsolidated material at the near surface that appears to diminish the quality of the reflection data. MASW provides an indication of the likelihood of the reflection seismic method producing low-noise time stacks that result in reliable interpretations of subsurface stratigraphy.

**Figure 4-4.** MASW S-wave velocity model for site CP04 showing high S-wave velocities in the near-surface.

**Figure 4-5.** MASW S-wave velocity model for site CP05 showing very low S-wave velocities in the near-surface.
5 Conclusions

Cover thickness estimates from the Occam 1D, the rjMCMcMT 1D and the NLCG 2D MT inversions using a 10 Ωm resistivity value to pick the transition to basement overestimated the cover thickness compared to the preliminary drilling results. Cover thickness was also overestimated by the rjMCMcMT inversion using the change-point histogram method.

Confidence in the cover thickness estimates derived from reflection data were low due to a low signal-to-noise ratio and a lack of high amplitude reflections at the base of the cover. The resulting cover thickness estimates are, in general, an overestimate when compared to the actual cover thickness based on the preliminary drilling results. Seismic data quality and, therefore, confidence in the cover thickness estimates could be improved with a more powerful P-wave energy source.

The nature of the cover in the project area differs to cover that blankets much of the rest of Australia. Generally, the majority of Australian cover rocks are variably consolidated, flat lying sediments with characteristically low electrical resistivity, low velocity cover overlying highly electrically resistive and high velocity basement. It is this large contrast in physical properties that allows these methods to produce reliable cover thickness estimates. In the Coompana region, however, the physical properties of the cover are markedly different, to the generality described above. Cover here consists of the moderate to highly electrically resistive and high velocity Eucla Basin limestones over the low electrical resistivity and low velocity unconsolidated sediments of the Bight Basin before entering the highly electrically resistivity and high velocity basement. The complexity introduced by the moderately to highly electrically resistive Eucla Basin limestones at the surface is the likely cause of the overestimation of cover thickness using the MT data. The presence of the slow velocity unconsolidated sediments of the Bight Basin beneath the high velocity Eucla Basin limestones results in the poor signal-to-noise ratio and hence, poor cover thickness estimations by the reflection seismic method.

Whilst this study has shown MT and seismic methods generally overestimate cover thicknesses in the Coompana Province due to the nature of the cover, these new data and interpretations contribute further knowledge to an explorers' toolkit of techniques for estimating cover thickness. By trialling and benchmarking these geophysical methods in new provinces, technical risk will be reduced for the exploration industry searching for new mineral deposits in covered terranes.
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Appendix A Preliminary drilling field summary logs

A.1 Site CP04 (CDP002)

Appendix Figure A.1. Summary graphic log of drillhole CDP002 (pre-drilling geophysics site CP04). Abbreviations; CALC calcrete, CLYU clay unit, LMST limestone, CLST clay stone, SLST silt stone, SDST sandstone, SAPT saprolite, GBNR gabbro/gabbro norite, MCGB microgabbro. From Dutch et al. (2017b).
Appendix Figure A.2: Summary graphic log of drillhole CDP006 (pre-drilling geophysics site CP05). Abbreviations: LMST limestone, CLYU clay unit, MDST mudstone, SILT silt, SAPT saprolite, BREC breccia, MTHH metasomatic/thermal/hydrothermal rock, GNSS gneiss, GRNT granite, MTEX metatexite, QZRU quartz rock (undifferentiated). From Dutch et al. (2017e).
A.3 Site CP06 (CDP007)

Appendix Figure A.3. Summary graphic log of drillhole CDP007 (pre-drilling geophysics site CP06). Abbreviations; LMST limestone, MDST mudstone, SAPT saprolite, DOLR dolerite. From Dutch et al. (2017f).
A.4 Site CP07 (CDP003)

Appendix Figure A.4. Summary graphic log of drillhole CDP003 (pre-drilling geophysics site CP07). Abbreviations: CALC calcrite, LMST limestone, CLST clay stone, SDST sand stone, SLST silt stone, SAPT saprolite, GRNT granite, LCGR leucogranite, FBRC fault breccia, MCGR microgranite, DOLR dolerite. From Dutch et al. (2017c).
A.5 Site CP08 (CDP004)

Appendix Figure A.5. Summary graphic log of drillhole CDP004 (pre-drilling geophysics site CP08). Abbreviations: LMST limestone, CLYU Undifferentiated clay unit, SILT silt, SAND sand, SLST silt stone, MZGR monzogranite, GRNT granite, DIOR diorite, MDIO monzodiorite, FPEG felsic pegmatite, DTEX diatexite, MTEX metatexite. From Dutch et al. (2017d).
A.6 Site CP09 (CDP001)

Appendix Figure A.6. Summary graphic log of drillhole CDP001 (pre-drilling geophysics site CP09). Abbreviations: BREC breccia, CLYU Undifferentiated clay unit, GNSS gneiss, GRNT granite, LMST limestone, SAND sand, SAPT saprolite. From Dutch et al. (2017b).
Appendix B MT inversion models against drilling logs

B.1 Site CP04 (CDP002)

Appendix Figure B1. Occam inversion results at pre-drilling geophysics site CP04 compared with drilling log (CDP002). The purple line delineates the cover/basement boundary.
Appendix Figure B2. rjMCMcMT inversion results at pre-drilling geophysics site CP04 compared with drilling log (CDP002). The purple line delineates the cover/basement boundary.
Appendix Figure B3. NLCG 2D inversion at pre-drilling geophysics site CP04 compared with drilling log (CDP002). The black line delineates the cover/basement boundary.
B.2 Site CP05 (CDP006)

Appendix Figure B4. Occam inversion results at pre-drilling geophysics site CP05 compared with drilling log (CDP006). The purple line delineates the cover/basement boundary.
Appendix Figure B5. rjMCMcMT inversion results at pre-drilling geophysics site CP05 compared with drilling log (CDP006). The purple line delineates the cover/basement boundary.
Appendix Figure B6. NLCG 2D inversion at pre-drilling geophysics site CP05 compared with drilling log (CDP006). The black line delineates the cover/basement boundary.
B.3 Site CP06 (CDP007)

Appendix Figure B7. Occam inversion results at pre-drilling geophysics site CP06 compared with drilling log (CDP007). The purple line delineates the cover/basement boundary.
Appendix Figure B8. rjMCMcMT inversion results at pre-drilling geophysics site CP06 compared with drilling log (GDP007). The purple line delineates the cover/basement boundary.
Appendix Figure B9. NLCG 2D inversion at pre-drilling geophysics site CP06 compared with drilling log (CDP007). The black line delineates the cover/basement boundary.
B.4 Site CP07 (CDP003)

Appendix Figure B10. Occam inversion results at pre-drilling geophysics site CP07 compared with drilling log (CDP003). The purple line delineates the cover/basement boundary.
Appendix Figure B11. rjMCMcMT inversion results at pre-drilling geophysics site CP07 compared with drilling log (CDP003). The purple line delineates the cover/basement boundary.
Appendix Figure B12. NLCG 2D inversion at pre-drilling geophysics site CP07 compared with drilling log (CDP003). The black line delineates the cover/basement boundary.
B.5 Site CP08 (CDP004)

Appendix Figure B13. Occam inversion results at pre-drilling geophysics site CP08 compared with drilling log (CDP004). The purple line delineates the cover/basement boundary.
Appendix Figure B14. rjMCMcMT inversion results at pre-drilling geophysics site CP08 compared with drilling log (CDP004). The purple line delineates the cover/basement boundary.
Appendix Figure B15. NLCG 2D inversion at pre-drilling geophysics site CP08 against drilling (CDP004). The black line delineates the cover/basement boundary. Reflection seismic inversion compared with drilling log.
Appendix C Reflection seismic against drilling logs

C.1 Site CP04 (CDP002)

Appendix Figure C1. Reflection seismic results at pre-drilling geophysics site CP04 compared with drilling log (CDP002). The purple line delineates the cover/basement boundary.
C.2 Site CP05 (CDP006)

Appendix Figure C2. Reflection seismic results at pre-drilling geophysics site CP05 compared with drilling log (CDP006). See Appendix Figure C3 for alternative results using different stacking velocities. The purple line delineates the cover/basement boundary.
Appendix Figure C3. Reflection seismic results at pre-drilling geophysics site CP05 compared to drilling log (CDP006) using alternative stacking velocities to Appendix Figure C2. The purple line delineates the cover/basement boundary.
Appendix Figure C4. Reflection seismic results at pre-drilling geophysics site CP06 compared with drilling log (CDP007). The purple line delineates the cover/basement boundary.
Appendix Figure C5. Reflection seismic results at pre-drilling geophysics site CP07 compared with drilling log (CDP003). The purple line delineates the cover/basement boundary.
Appendix Figure C6. Reflection seismic results at pre-drilling geophysics site CP09 compared with drilling log (CDP001). The purple line delineates the cover/basement boundary.