

Lemont Magnetotellurics

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Report submitted: 24/12/24

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1. Background

The Lemont geothermal prospect, situated in central western Tasmania, is considered prospective for both geothermal energy and lithium extraction from brines due to high surface heat flow measurements and the presence of lithium-rich granites. Magnetotelluric (MT) data were collected by Moombarriga Geoscience at Lemont from 2008 to 2010, initially along three profiles and subsequently at gridded infill sites (Fig. 1). MT data should aid exploration as the saline geothermal fluids should be conductive and MT can penetrate to the depths of interest (more than 3 km). Western Geco (subsequently CGG and now Veridien) carried out 3D inversion of the MT data in 2010. In 2021, the thesis of Ostensen (2021) documented Ostensen's re-inversion of the dataset with the inclusion of new, widely-spaced, long-period AusLAMP stations (Fig. 1).

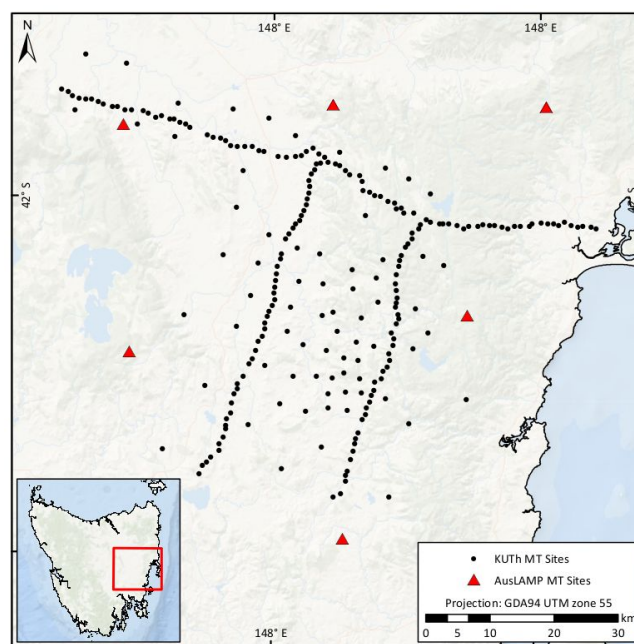


Figure 1: Location of the Lemont prospect, taken from Ostensen (2021), showing the three dense MT profiles, the infill MT grid and the AusLAMP MT sites.

There were several differences in the Western Geco and Ostensen approaches. First, they used different inversion codes - Western Geco used their proprietary code (developed from Rodi and Mackie, 2001) and Ostensen used the open-source code ModEM (Kelbert et al., 2014) - although both codes have a non-linear conjugate gradient approach to the inverse problem. Second, Western Geco included topography in their inversion whereas Ostensen (2021) did not and projected all sites to sea level. Third, the Western Geco inversions ran from a homogeneous starting model of $20 \Omega m$, whereas some Ostensen (2021) models were run from a homogeneous starting model of $100 \Omega m$ and some were run from a starting model derived from an inversion of AusLAMP data.

A comparison between the existing models (Fig. 2) highlights several important features. First, parts of the models that are not proximal to MT stations are controlled by their starting model. This is most apparent in the model that was run from an AusLAMP start (central panels), where the AusLAMP starting model has introduced a large degree of blocky structure into the inversion. Importantly, the AusLAMP data only have resolution from depths of several kilometers, so the blocky structures at these depths come only from sedimentary thicknesses

included in the starting model of the AusLAMP inversion and are not constrained by data at all. Second, the importance of topography is highlighted. The average station elevation is approximately 365 m, so Ostensen (2021) considered his -0.02 km depth slice equivalent to Western Geco's 0.36 km depth slice. However, the actual station elevations vary over a range of more than 700 m, as shown by the fact that much of the north-eastern part of the shallowest depth slice of the Western Geco model is still in air. If the stations are all assumed to be at the same elevation, features could be modelled at depths that are incorrect by up to several hundred metres. In addition, by assuming that the stations are at sea level, the conductive sea water included in the starting models of the Ostensen inversions (top left and top central panels) will incorrectly influence station data.

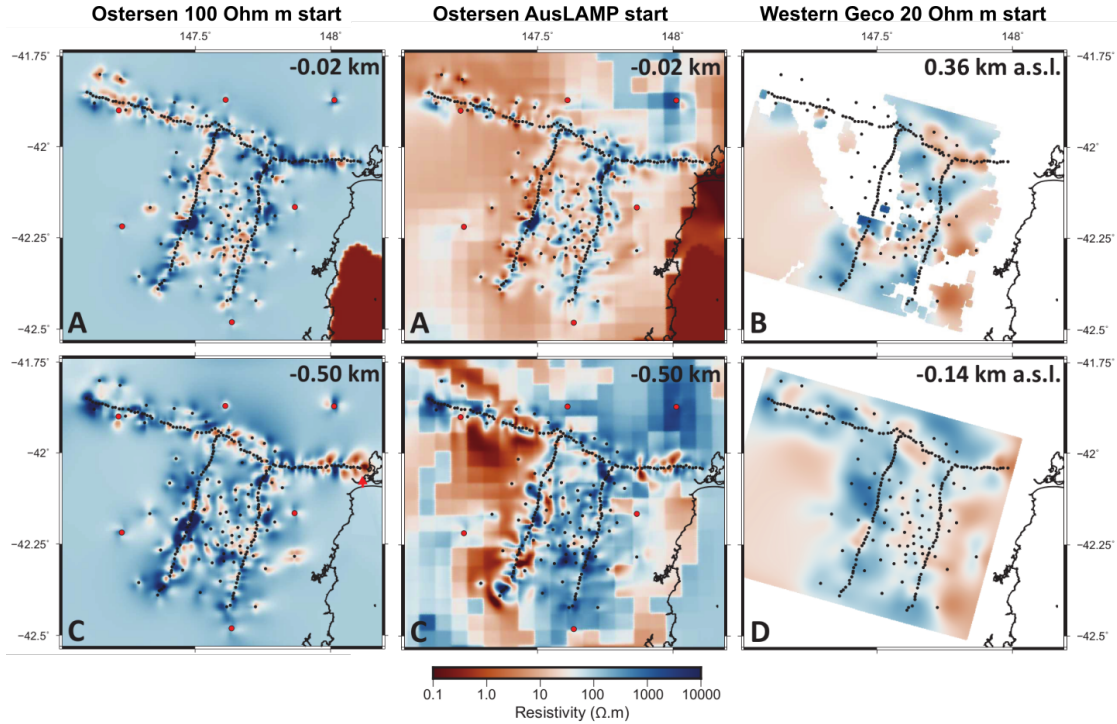


Figure 2: Comparison between previous MT models, adapted from figures in Ostensen (2021). The left panels are the Ostensen (2021) model run from a homogeneous 100 Ωm half-space, the central panels are the Ostensen (2021) model run from the result of inverting AusLAMP long-period MT data, and the right panels are the preferred model of Western Geco, run from a 20 Ωm half-space. Topography was not included in the Ostensen (2021) models but was included in the Western Geco model, and Ostensen (2021) considered these slices to represent equivalent depths.

In addition to the MT data, ambient noise seismic data were collected at 144 stations by the Institute of Mine Seismology (IMS) in 2021. The combination of MT and ambient noise tomography (ANT) models is very valuable for geothermal interpretations. For instance, low resistivity zones may be caused by saline fluid, by clay in the presence of a small amount of fluid, or by conductive minerals such as graphite. Of these options, seismic wavespeeds will be slowest in the presence of fluids, so the ANT models can be used to discriminate between potential interpretations. Two models are available from the ambient noise seismic dataset, one produced by IMS in 2021 and the second produced by IMS in 2024. The models have been provided as both absolute velocities and velocity anomalies; the 2021 model extends from -1286 to -8286 m whereas the 2024 model extends from 400 to -3400 m, assuming that the depths in the provided data files are accurate and relative to sea level. The models

contain a number of quite different features, and at the time of writing of this report the reasons for these disparities, including the apparently very different depth sensitivities, are not well understood.

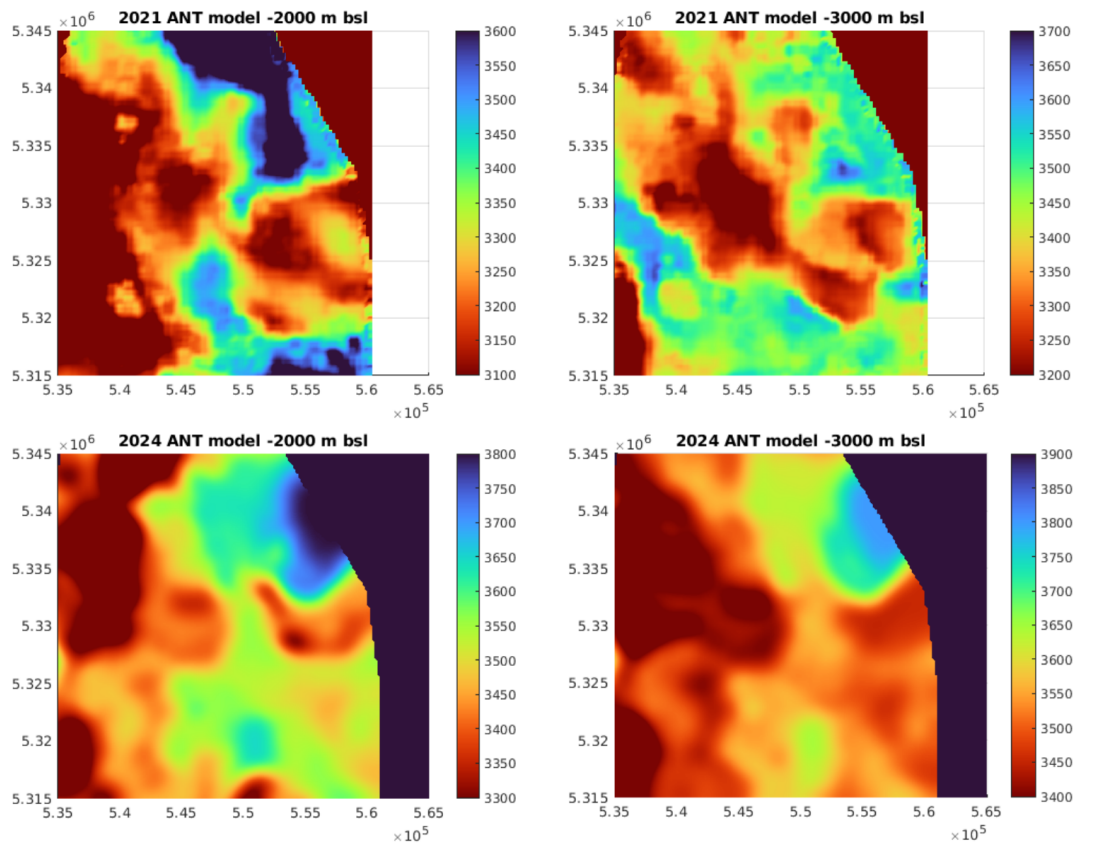


Figure 3: Comparison between the ANT models produced by IMS in 2021 and 2024 at key depth slices of 2000 and 3000 m below sea level. Note the colour scales (in m/s) are different for each model to best highlight individual features.

Vox was initially contracted to review and remodel the MT data in late 2023, motivated in part by discrepancies between the Western Geco and Ostersen (2021) modelling. The initial round of analysis and inversion is documented in 'Lemont Geolithium: MT Modelling, integration and analysis', 28/2/2024. In this work:

- The Ostersen (2021) and Western Geco (2010) inversions were compared,
- New 3D inversions were run using the inversion code ModEM (Kelbert et al, 2014), from both a homogeneous starting model and an AusLAMP starting model
- Phase tensor analysis was carried out to determine subsurface geoelectric strike and dimensionality,
- 2D inversions were run of appropriate subsets of data using the inversion code MARE2DEM (Key, 2016)
- 1D probabilistic inversions were run of appropriate subsets of data to investigate the resolution of conductors
- The 3D MT inversions were compared with the interpreted granite surface and the 2021 ANT model

While full details of this work are in the February 2024 report, the most important finding is that there is a robust conductor in the south-east of the model, constrained by 1D, 2D and 3D MT modelling, that lies beneath the granite surface and partly coincides with a low velocity zone in the 2021 ANT model (Fig. 4).

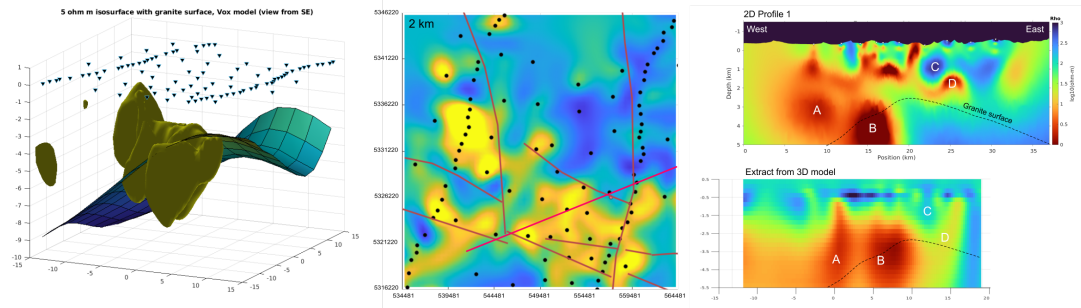


Figure 4: *Key results from previous Vox MT modelling (February 2024), showing the main south-eastern conductor that continues beneath the granite surface (left), a depth slice through the preferred MT model at 2 km, with the 2D profile line marked in magenta (centre), and the 2D cross-section and slice through the 3D model along that profile (right), showing that Conductor B is consistent between the models and continues beneath the granite surface.*

Due to limitations of the inversion code at the time, topography was not included in the Vox models in the February 2024 report; stations were instead assumed to lie at the average station topography of 365 m. This current report presents new models that include topography, and also presents updated comparisons with both the 2021 and the 2024 ANT models.

2. 3D MT inversions

A suite of four new 3D MT inversions were run using ModEM, with inversion parameters in Table 1. As for the February 2024 work, inversions were run on the subset of stations surrounding the region of interest; the southern, western and eastern extents of the dense MT profiles, where there is little 3D resolution, were not included in the inversions. This allowed for inversions to be run on a finer mesh with core cells 500 m wide laterally and 15 m thick, compared to 800 m laterally and 30 m thick for the Western Geco inversions. The core of the mesh extended 35 km laterally in both directions, and ten padding cells were added beyond this to account for edge effects. Thirty-eight vertical cells of 15 m thick, extending 570 m from the surface of the model, were included to allow topography to be modelled with good accuracy, and below this cells increased in thickness by a factor of 1.2. All four diagonal and off-diagonal elements of the MT impedance tensor were inverted, together with the two elements of the tipper tensor, with frequencies ranging from 0.05 to 320 Hz. All data points were screened and poor quality data were masked; in particular many stations had poor tipper data. In all models, error floors for the off-diagonal MT impedance elements were 5% of the absolute value of the element, error floors for the diagonal MT impedance elements were 10% of the square root of the absolute value of the product of the off-diagonal and the corresponding diagonal, and error floors for tipper data were fixed at 0.02. The key differences between the suite of models was the starting half-spaces - either 100 Ωm or 1000 Ωm - and the covariance, or smoothing, which was set to either 0.2 or 0.3, with a higher covariance leading to a smoother model.

Name	Starting model (Ωm)	Covariance	Cells x	Cells y	Cells z	Core cell width x (m)	Core cell width y (m)	min cell z (m)	Thickness (z min)	Sites	Frequencies	Iterations	Final rms
100 Ωm Cov0.2	100	0.2	90	90	80	500	500	15	570	88	26	42	1.68
100 Ωm Cov0.3	100	0.3	90	90	80	500	500	15	570	88	26	43	1.61
1000 Ωm Cov0.2	1000	0.2	90	90	80	500	500	15	570	88	26	34	2.25
1000 Ωm Cov0.3	1000	0.3	90	90	80	500	500	15	570	88	26	52	1.46

Table 1: *Inversion parameters for the suite of four model runs performed in this work*

Slices through the models at 1 km intervals from sea level to 4 km bsl are shown in Figure 5. The four models, run from different starting half-spaces and with different smoothing parameters (covariances), help to illustrate which features are robust and required by the data and which features are less robust. In general, it can be considered that features that are consistently observed regardless of starting model or covariance are the most robust, and features that differ between models are less robust. There is an overall offset in resistivity between models run from a 100 Ωm half space and a 1000 Ωm half space, where both conductive and resistive parts of the models are less resistive in the 100 Ωm half space models. This provides an indication of the range of resistivities a feature can have and still fit the data. There is a greater lateral smoothness of conductive features in the models run with a covariance of 0.3 compared to a covariance of 0.2, and some features that are discrete in the former are connected in the latter. The model run from a 1000 Ωm half space with covariance of 0.2

is the most distinct of the group, but its rms misfit of 2.25 is distinctly higher than the other models (1.68, 1.61 and 1.46, respectively), so it is considered the least reliable of the models and will not be considered in further interpretation.

Setting aside the less robust features in the 1000 Ωm , 0.2 covariance model, the features in the remaining three models are very similar, albeit with a resistivity offset between the 100 and 1000 Ωm models. The dominant conductors emerge at a depth between 1000 and 2000 bsl, and are consistently located in the south-east (Features A and B), south-west (Feature C) and central-west (Feature D) of the model space. The north-eastern part of the model is consistently higher resistivity. With increasing depth, Feature A becomes elongated along a north-westerly trend and shifts to the north, Feature B becomes elongated along an east-west trend and shifts slightly to the south, Feature C becomes elongated along an east-north-easterly trend, and Feature D expands and shifts to the north. Conductive Feature E becomes distinct between 2000-3000 m depth and becomes more conductive with depth. The elongation and interconnection of these features is one of the main differences between the models. For instance, in the 100 Ωm models, Features A and D join at ~ 4000 m depth in the covariance 0.3 model with greater smoothing, but remain distinct in the covariance 0.2 model with less smoothing. They also remain distinct in the 1000 Ωm , covariance 0.3 model, where the default background resistivity is higher. Since all models have good data fits, this illustrates that it is difficult to resolve whether Features A and D are connected at depth with the current station spacing. Similarly, Feature C is strongly elongated to the ENE in the 100 Ωm covariance 0.3 model, but in a region where it is largely unconstrained by any overlying stations. The higher smoothing and lower starting resistivity of the 100 Ωm Covariance 0.3 model thus encourages this elongation, whereas the other models do not. In terms of resistivities, Features B and D have the lowest consistent resistivities, approaching 1 Ωm even in the 1000 Ωm covariance 0.3 model.

Figure 6 shows the 100 Ωm covariance 0.3 model from Figure 5, compared with the Vox model from the February report run with no topography but otherwise the same settings, and the Western Geco model run with topography, from a 20 Ωm starting model and using a different inversion code. The dominant features are similar. The Western Geco model (right column) is smoother overall, as is common for Western Geco/CGG/Veridien MT models. The main conductors A, B, D and E are all similar to the Vox model; Feature C is not so apparent in the 2000 m and 3000 m model slices of the Western Geco model but Feature B extends further to the east, accounting for some of the high conductance attributed to Feature C. In the Western Geco model, by 3000 m depth Features A and D have merged due to the high smoothness of the model. Background resistivities are slightly lower in the Western Geco model, likely due to the low starting resistivity of 20 Ωm . The left and central columns compare inversions run with the same inversion code and inversion parameters with topography included (left) and not included (central). Where topography was not included, all stations were assumed to lie at the average station elevation of 365 m. While most of the main features in the models are similar, features in the model with topography included are more spatially consistent. For instance, consider Feature A at 3000 m depth; the boundary of the high conductivity body is smooth in the model with topography included but it is very arcuate in the model with no topography as it shifts to include and exclude different stations. By placing the stations at their correct topographies these lateral conductivity variations are instead correctly mapped to depth. The main distinction between these two models is that Feature E is not imaged in the model with no topography. This part of the model space has the highest and most variable topography, so it is consistent that the model with no topography would be most incorrect here.

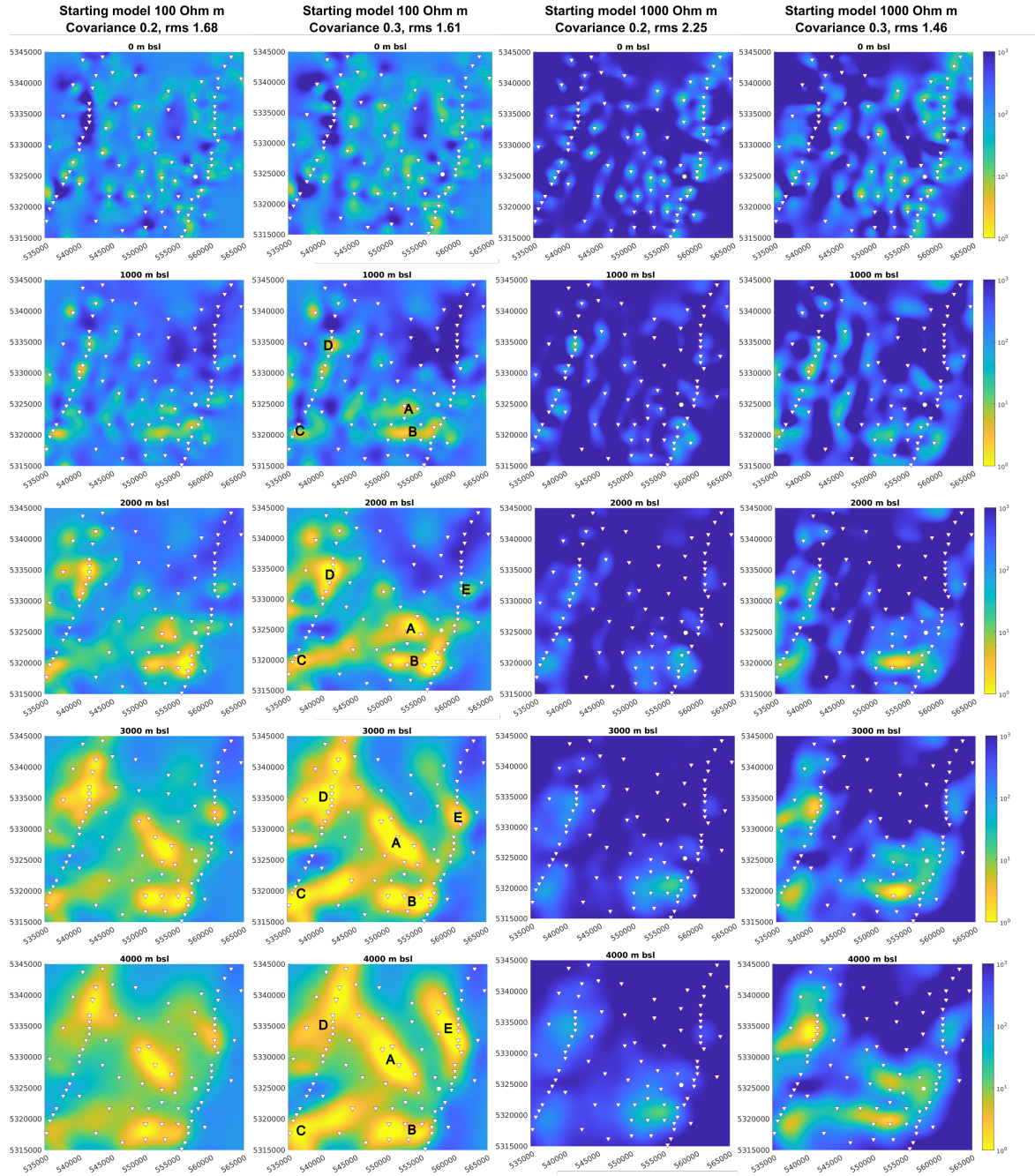


Figure 5: Slices through four inverse models at 0 m, 1000 m, 2000 m, 3000 m and 4000 m below sea level. From the left, the starting models were 100 Ω_m with a lower smoothing (covariance) of 0.2 (rms 1.68), 100 Ω_m with a covariance of 0.3 (rms 1.61), 1000 Ω_m with a covariance of 0.2 (rms 2.25) and 1000 Ω_m with a covariance of 0.3 (rms 1.46). White triangles are the locations of MT stations and the white circle is the location of the originally planned drillhole.

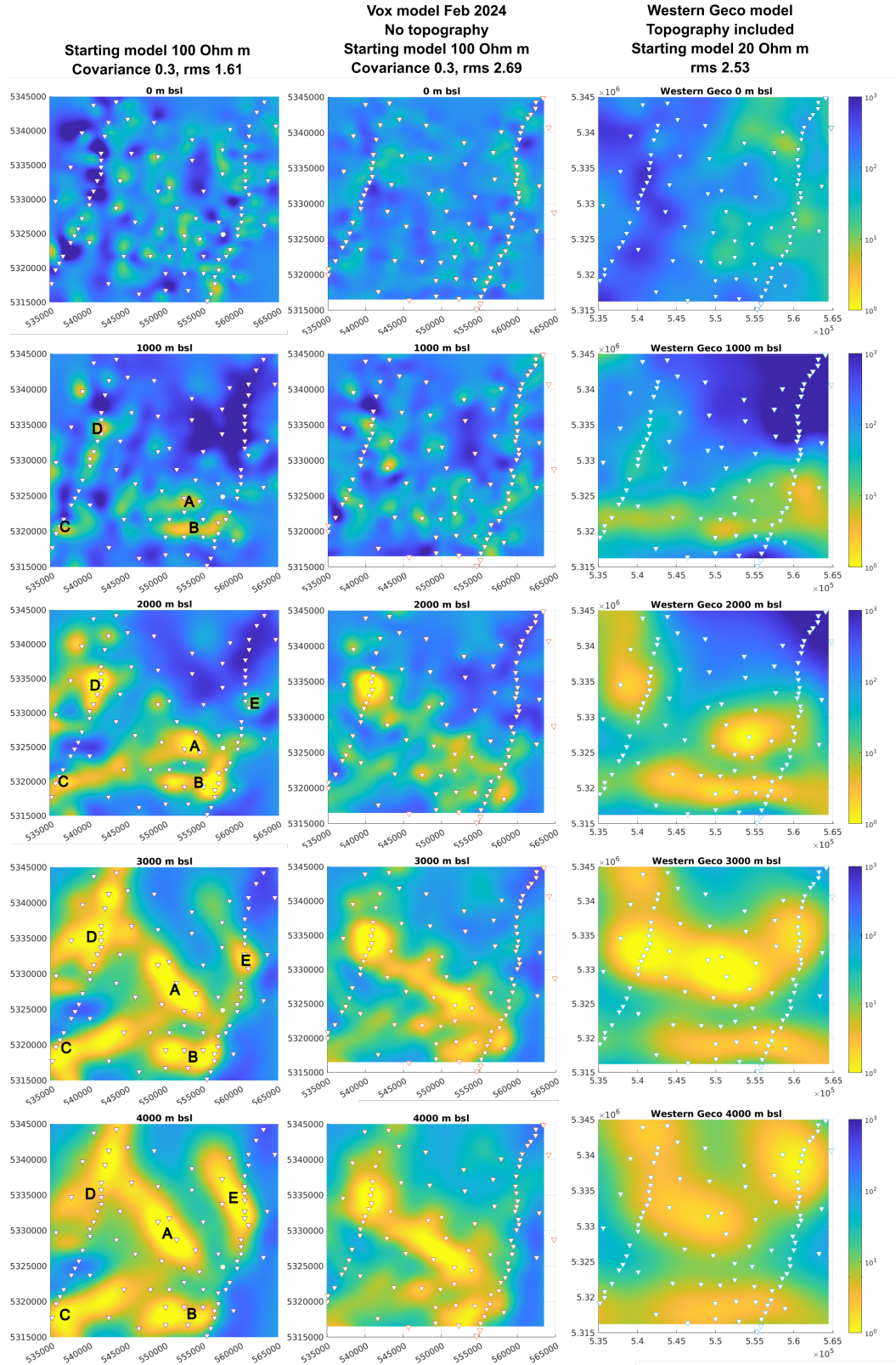


Figure 6: New model run from a starting model of $100 \Omega_m$ with a covariance of 0.3 (left), compared with the model from the February 2024 Vox report run with the same settings but no topography (centre) and the Western Geco preferred model, which was run from a starting model of $20 \Omega_m$ (right). All models have the same colour scale.

The results highlight the strong differences between the 2021 and 2024 ANT models, including the different depth extents of the models. Both models include strong slow velocities in the western part of the model space and slow velocities extending from the north-west of the model space with a south-easterly trend at 3 to 4 km depth. Key observations of correlations between MT and seismic features include:

- Feature D is slow in both ANT models and is a robustly conductive and slow feature. The slow velocities extend to shallower depths than the low resistivities.
- Feature C is also associated with a low velocity zone in both ANT models. If the conductive feature is associated with the low velocity feature, the spatial extent of C matches more closely with the 1000 Ωm covariance 0.3 model (second column) and the 100 Ωm covariance 0.2 model (Fig. 5) than the 100 Ωm covariance 0.3 model.
- Feature A is associated with the south-east trending low velocity zone in the 2021 ANT model, but the most robust part of Feature A lies past the south-eastern extent of this low velocity zone in the 2024 ANT model.
- Feature B lies in a part of the ANT model with strong variations between 2021 and 2024. In the 2021 model, Feature B lies in a zone of considerable complexity with transitions from very slow to very fast velocities both laterally and with depth from 2000 to 4000 m, including strong east-west trends that mirror the trend of Feature B. In the 2024 model, Feature B lies in a zone of moderate to fast velocities with no strong east-west trends.
- Feature E lies to the east of the zone of resolution in the ANT models.

Figure 8 highlights the comparisons between the MT and ANT models at the depth range of interest, showing isosurfaces of 5 Ωm from the MT models and 3500 m/s from the ANT models from 3 to 4 km bsl. The MT models become progressively less conductive from the 100 Ωm covariance 0.2 model to the 100 Ωm covariance 0.3 model to the 1000 Ωm covariance 0.3 model. When compared with the 2021 ANT models, the Feature B volume enclosed by the 5 Ωm isosurface is partially to mostly enclosed by the 3500 m/s isosurface, regardless of which MT model is used. When compared with the 2024 ANT models, the Feature B 5 Ωm isosurface is mostly separate from the 3500 m/s isosurface, and for the 1000 Ωm covariance 0.3 model the two isosurfaces are completely separate. Figure 9 details the comparison between the 1000 Ωm covariance 0.3 model, which is the most conservative of the MT models in terms of the conductivity of Feature B, and the 2021 ANT model (3400 m/s isosurface). The slower velocities extend from shallower depths (here shown from 2000 m bsl) and encompass the shallower parts of Feature B.

3.2 2D MT Models and Granite Surface

A 2D inversion was previously run (Vox February 2024 report) along a south-west trending profile with data analysed to be 2D. This profile runs from 537000, 5318000 to 571769, 5330655 (Fig. 4). Figure 10 shows the comparison between this 2D profile and cross-sections taken through the new 100 Ωm covariance 0.2, 100 Ωm covariance 0.3 and 1000 Ωm covariance 0.3 models. There is more detail in the 2D inversion due to the reduced computational requirements and smaller mesh, but overall features are very similar. The granite surface plotted on the cross-sections is interpreted from gravity data and shows that in all models some high conductivity is modelled beneath the granite surface, and in the 1000 Ωm covariance 0.3 model the bulk of the high conductivity is beneath the granite surface. This high conductivity feature is Feature B.

The 3D models are further compared with the modelled granite surface in Figure 11. Five

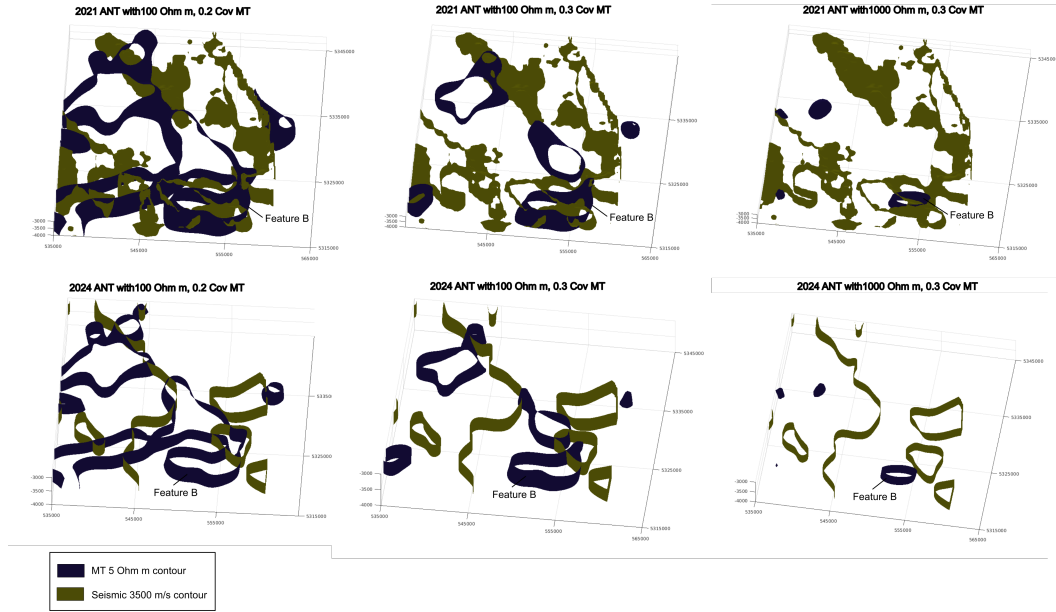


Figure 8: Comparison between $5 \Omega_m$ isosurfaces from the MT models (blue) and 3500 m/s isosurfaces from the ANT models (khaki). Top row is the 2021 ANT model and bottom row is the 2024 ANT model. Isosurfaces are shown from 3000 to 4000 m bsl; note that the 2024 ANT model only extends to 3400 m bsl.

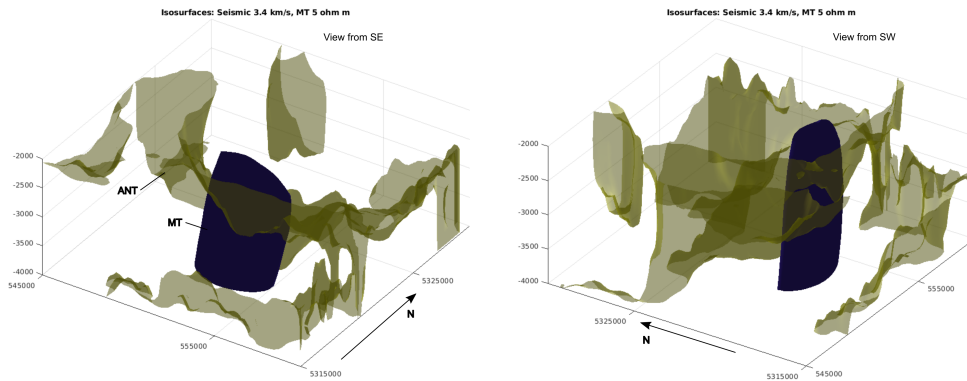


Figure 9: Comparison between $5 \Omega_m$ isosurfaces from the the 1000 Ω_m covariance 0.3 model and the 3400 m/s isosurfaces from the ANT models (transparent khaki). Isosurfaces are shown from 2000 to 4000 m bsl. The model on the left is the view from the south-west and the model on the right is the view from the south-east

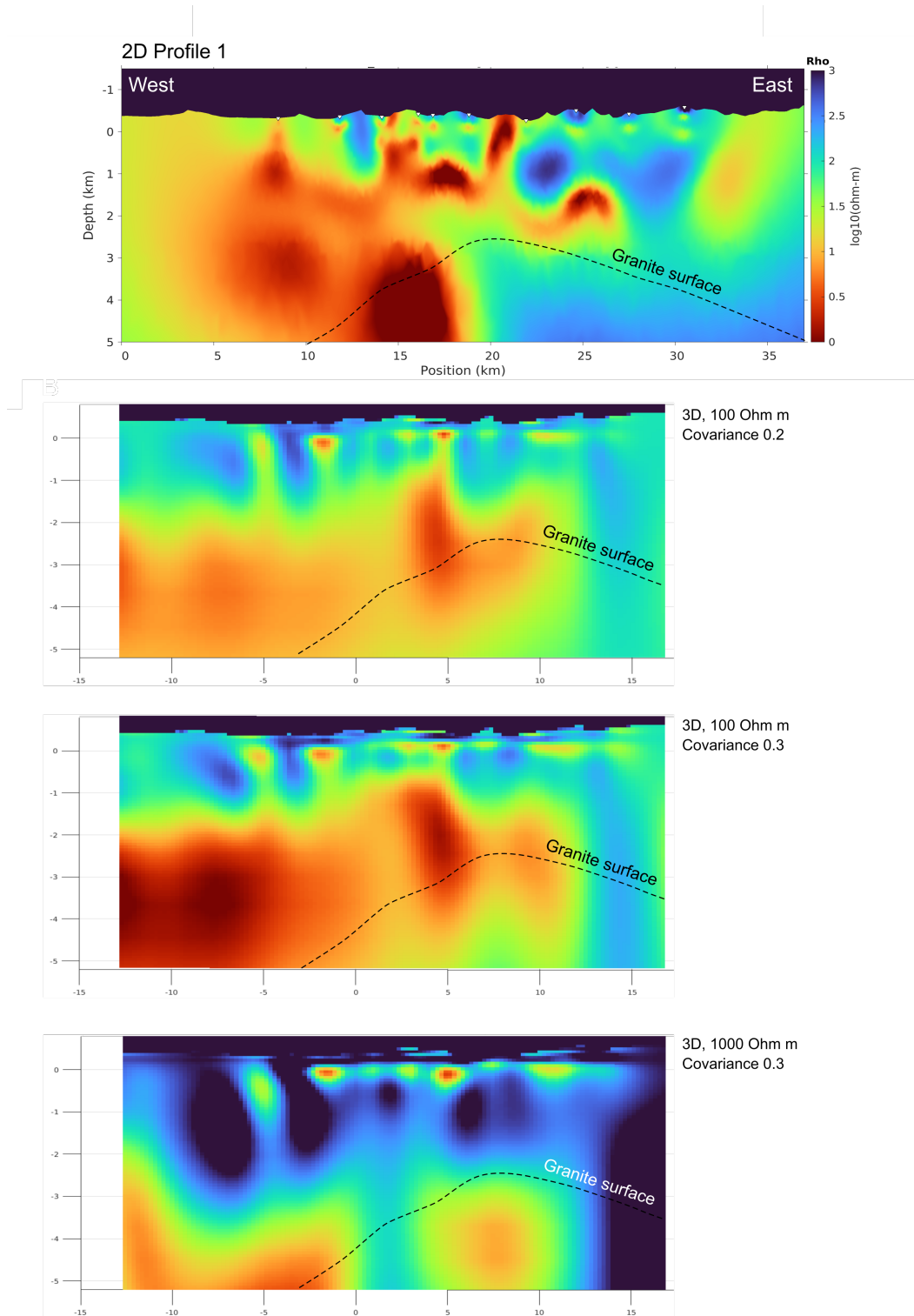


Figure 10: 2D MT inversion cross-section (see Vox February 2024 report for more details) with cross-sections through the new 100 Ω_m covariance 0.2, 100 Ω_m covariance 0.3 and 1000 Ω_m covariance 0.3 models along the same profile, with the interpreted granite surface. All models have the same colour scale.

Ωm isosurface for each of the three 100 Ωm covariance 0.2, 100 Ωm covariance 0.3 and 1000 Ωm covariance 0.3 models are shown with the modelled granite surfaces to a depth of 10 km, and isosurfaces lying beneath the interpreted granite surface are shown to a depth of 4.5 km. At the location of Feature B, all MT models have conductive bodies of Five Ωm or less extending beneath the granite surface.

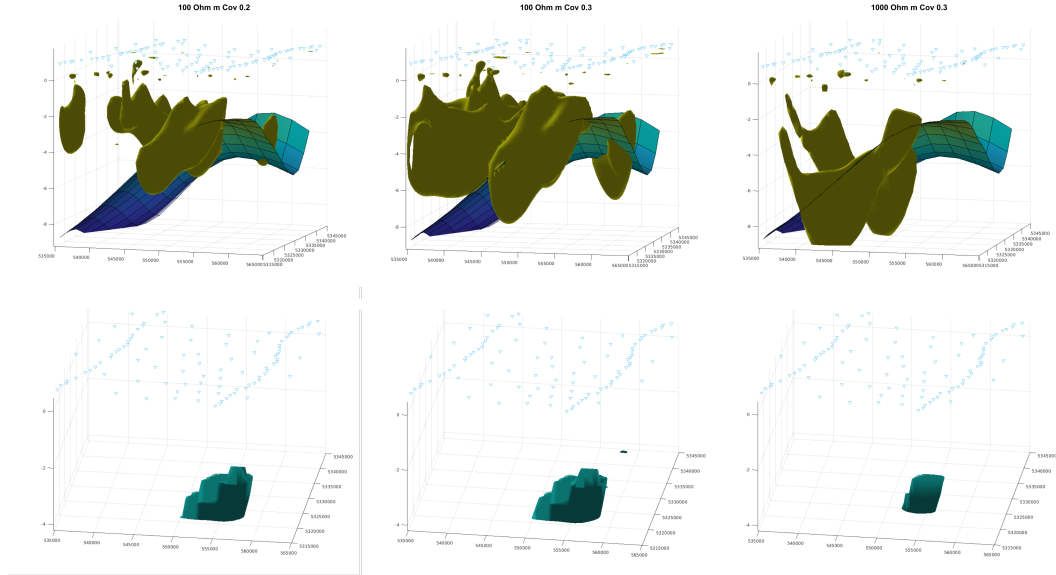


Figure 11: 5 Ωm isosurface of the 100 Ωm covariance 0.2 model (left), the 100 Ωm covariance 0.3 model (centre) and the 1000 Ωm covariance 0.3 model (right) with the interpreted granite surface. Top row shows the resistivity isosurface (gold) to a depth of approximately 10 km with the granite surface (blues), with all views from the south-east. Bottom row shows only the part of the resistivity isosurface that lies beneath the interpreted granite surface, with all views from the south-east.

4. Summary and Conclusions

The follow-up 3D MT inversion documented in this report has improved on previous inversions by incorporating topography and testing the robustness of model features through running multiple models with different inversion parameters. The conductive bodies A, B, C, D and E (Fig. 5) are considered robust. Of particular importance for the Lemont geothermal prospect, the conductive Feature B, located in the south-eastern part of the model space, is clearly imaged by all inversions as well as the previous Western Geco inversion. In all models, Feature B resistivities of $5 \Omega m$ or less extend beneath the interpreted surface of the granite. The fact that this is true even for the $1000 \Omega m$ model, which tends to higher resistivities, illustrates how strongly the data require a very low resistivity body here. Since saline fluids in fractures within the granite could be an explanation for such low resistivities, this result is encouraging for geothermal prospectivity.

The ANT models should be instrumental in helping to interpret whether the Feature B low resistivity is due to saline fluids, which would result in a low seismic velocity, or other mineralogical causes that will not produce such a low velocity. The large discrepancy between the 2021 and 2024 ANT models in the vicinity of Feature B is therefore a significant challenge for building a good interpretation. A primary recommendation would be to gain a deeper understanding of the differences in inversion approaches between the two ANT models, some measure of feature reliability, and if necessary to run additional inversions to achieve these ends.

Although all models reliably image a low resistivity body at Feature B, the spatial extent of this body differs between the models with different starting resistivities and different smoothing parameters (Fig. 5). This is partly because the stations covering Feature B have a relatively large station spacing of approximately 2.5 to 3.5 km. While this station spacing images the feature reliably, tighter station spacing would constrain its boundaries and its resistivity more accurately. If the boundaries and resistivity of Feature B were considered important for further work, a denser MT array with station spacing of approximately 1 km over and around Feature B would aid their resolution. The possible extent of such a grid is illustrated in Figure 12 and would consist of approximately 100 to 150 new MT sites, depending on the density of the array and logistical factors including ground access. One benefit of MT is that data do not need to be collected simultaneously, so any new data could be added to the existing dataset to improve the overall model

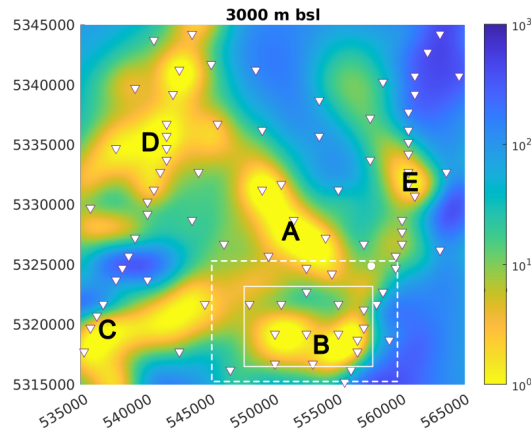


Figure 12: Possible extents of new grids of MT stations to better define Feature B. If stations were collected at a 1 km grid throughout the large box (dashed white line), approximately 150 new MT stations would be collected. It would be possible to vary station density by, for instance, collecting stations at 1 km spacing in the central box (solid white line) and 2 km spacing in the large box to reduce the number of stations to approximately 100.

5. Files Included

- Model files for each of the four 3D MT inversions run as part of this work, to a depth of approximately 10 km with lateral padding cells removed, in:
 - xyzr format, where column headings are Eastings (mE, zone 55), Northings (mN, zone 55), linear resistivity (Ohm m), log resistivity (log Ohm m)
 - UBC format, with locations in zone 55
 - ModEM format, with padding cells remaining in the model, including the appropriate data (.dat), covariance (.txt) and starting model files for each model run
- Plots of data fit for each of the four model runs
- Copies of the 2021 and 2024 IMS seismic ANT model files used in this analysis

6. Bibliography

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