Going the extra mile – Julimar, a case study from Western Australia

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SUMMARY

The Julimar Complex, which is located in Western Australia, hosts the recently discovered Gonneville deposit which contains massive sulphide mineralisation (Pd, Pt, Ni, Cu and Co). The deposit was discovered by using a moving loop EM survey and follow up geophysics including AEM confirmed the find.

In this study we use a SkyTEM AEM line which was acquired as part of the AUS-AEM initiative, which cross the Gonneville deposit. The objective is to extract as much information from that data as possible to demonstrate that AEM can be used for general geological mapping in addition to anomaly detection. By using several inversion methods and analysing the results we get an understanding of the most believable model.

In addition to a deterministic full non-linear inversion of the data, we also use a stochastic reverse jump Monte carlo Markov Chain inversion on the SkyTEM data.

The results from both algorithms are comparable and correlate well with the known geological information published by Chalice mining, based on drill holes and other geophysical surveys.

Using Airborne EM for exploring for minerals under cover could provide a lot more information about the subsurface than just mapping highly conductivity sulphide mineralisation zones.

Key words: Julimar, SkyTEM, AUS-AEM, RJ-McMC, Stochastic inversion

INTRODUCTION

The demand for critical minerals including Ni, Cu, and PGE's is projected to increase by over 30% annually to beyond 2050 (Gasson et al. 2021). Consequently, the exploration for these mineral systems has become a priority among juniors and majors alike. Careful planning, the analysis of large amounts of pre-competitive data, experienced geoscientists and a little bit of luck are some of the key ingredients to being successful. One such discovery was made in 2020 – when Chalice Mining went hunting for base metals within the Julimar Complex just 70km northeast of Perth, Western Australia. Chalice Mining first staked this greenfield project located within the emerging Western Yilgarn Ni-Cu-PGE province in 2018, based on a 26km long mafic-ultramafic intrusive complex interpreted from open file aeromagnetic surveys (Paggi et al. 2021).

The Gonneville deposit itself was then discovered following a moving loop EM survey – which showed multiple EM conductors (Paggi et al. 2021). Follow up RC drilling defined massive sulphide mineralisation containing Pd, Pt, Ni, Cu and Co from 48m downhole. Additional gravity, magnetics, downhole and airborne electromagnetic data were subsequently acquired over the Julimar Complex and has assisted in identifying new anomalies as well as improving the understanding of the geology and structure of the intrusion that is a key part of the mineral system present.

Airborne electromagnetic (AEM) methods can be a great tool for discovering anomalies – i.e., highly conductive bodies within a resistive host – in this case massive sulphide sources/zones and are as such commonly used for defining targets for follow up ground geophysics and drilling. They can however also be used for general geological mapping and therefore assisting in gaining an understanding of the geology surrounding the anomaly. Understanding the broader capability of an AEM system in mapping elements of a mineral system is relevant in exploration as these may vary in relative importance depending on the setting of interest.

The motivation for this study was to examine whether AEM data could be employed for more than simply identifying conductive targets. Through a detailed analysis of AEM data across the Gonneville deposit, we consider how these data can contribute to a broader understanding of the mineral system, by mapping elements of the host sequence in addition to mapping the highly conductive sulphide mineralisation zones. We also give consideration to the careful processing and alternative inversion approaches in the analysis of AEM data to maximise the information content they contain.

METHOD AND RESULTS

AEM system

As part of the AUS-AEM (https://www.eftf.ga.gov.au/ausaem) initiative airborne electromagnetic data were acquired over the Julimar complex in WA, in 2020 using the SkyTEM system. In this study we look at one line of data that pass through the Gonneville deposit (see Figure 1 for location) with the aim of trying to gain an understanding of the geology of the prospect based on the AEM inversion results.

For the part of the AUS-AEM survey that we look at, a SkyTEM^{312} FAST system was used. The SkyTEM system is a helicopter time domain electromagnetic system, which carries the transmitter and receiver as a sling load beneath the helicopter. It uses interleaved low and high moments, which provides information of both the near surface and deeper parts of the subsurface depending in the conductivity of the ground. The low and high moments have a base frequency of 275 Hz and 25 Hz respectively and nominal peak currents of 5.9 A and 109A. The low moment has 2 transmitter turns whereas the high has 12, giving peak moments of 4036 Am^2 and 447336 Am^2 respectively.

Inversion algorithms

One of the key interests when exploring under cover, is to be able to define the depth of the mineralised zones, and the host units in which they sit. One way to achieve that might be to favour a few layer inversion model over a smooth one, as the former allows the layer boundaries to move, whereas the layer boundaries are fixed in a smooth layer model. Another option is to run a stochastic inversion where the output is a model as well as uncertainties related to that model. We examine the results of two inversion methods; a deterministic full non-linear 1D inversion (Auken et al., 2015, Auken and Christiansen, 2004), and a stochastic reverse jump Markov chain Monte Carlo inversion (Brodie and Sambridge, 2012, Brodie and Reid, 2013) and discuss the differences and commonalities between the results from the different methods and look at how they define elements of the mineral system at Gonneville.

The deterministic inversion approach finds one earth model that fits the data within the given noise level, often judged to be the best solution. The deterministic approach will usually be concerned with finding the global minimum, this process is also called an optimisation approach. In contrast the probabilistic method aims to not just settle for one model, but to collect statistics about all the models that are feasible after consideration of both data fit and prior information. The output from the probabilistic inversion is therefore an ensemble of models in the vicinity of the global extrema or possibly several local extremas.

The 1D full non-linear inversion was run using the Aarhus Workbench processing and inversion software. The data were processed in a standard way where late time noise was removed from the data before the inversion was run. Both a smooth layered inversion consisting of 30 layers and a few layer model were run. The results presented as a conductivity depth sections are shown in Figures 2A and 2B).

Results from a stochastic inversion using a reversible jump Markov chain Monte Carlo (rj-McMC) 1D inversion algorithm for the same data are presented in Figures 2C and 2D). In a stochastic inversion a suite of tens to hundreds of thousands of models are generated – which all fit the data within the specified noise levels. The reversible jump part of the algorithm means, that the number of layers for the model does not need to be specified beforehand, as the inversion explores a range of models with different number of layers but favours the models with the fewest number of layers.

Geology

The Gonneville deposit is hosted in a 1.6 x 0.8 km ultramafic-mafic intrusion within the Julimar Complex which has a >26km strike length and is up to 3km wide (Paggi et al. 2021). The Gonneville intrusion strikes NNE and covers an area of approximately 1.9 x 0.9km and is interpreted as an ultramafic-mafic sill with a maximum thickness of app 650m, with an approximate 45degree WNW dip and gentle northerly plunge. The intrusion is predominantly composed of serpentinised olivine peridotite/harzburgite with lesser intervals of pyroxenite, gabbro and leucogabbro. PGE-Ni_Cu_Co-Au sulphide mineralisation is widespread throughout these mafic and ultramafic units The main intrusion is cut by a later granite body that is parallel to the dip and strike of the mafic-ultramafic package. The intrusive complex is crosscut by a series of sub vertical NE to NW striking dolerite dykes, these contain no Nu-Cu-PGE mineralisation. The Gonneville intrusion is surrounded by a package of meta-sedimentary rocks. The regolith profile in the area extends to a depth of 30-40m below the surface with well-developed laterite and saprolite.

Primary Ni-Cu-PGE sulphide mineralisation within the Gonneville deposit is mostly found in the ultramafic harzburgite and pyroxenite domains. The mineralisation occurs as sub-parallel zones which are typically 5-40m thick and found within broader 100-150m zones of weakly disseminated sulphides. The sulphide content correlates well with the metal grade, with higher sulphide concentrations corresponding to higher metal contents (Chalice mining ASX release November 2021). PGE's are also hosted in the regolith from near surface to 25m depth (see Figure 4). In addition to the Gonneville mineralisation, further prospects to the north have been identified from an Airborne Electromagnetic survey conducted by Chalice Mining using the HeliTEM electromagnetic system (Figure 1). These are the Hartog prospect immediately to the NNE of Gonneville and extending over 6.5km, Baudin which is located 3.5km NE of the northern tip of Hartog and Jansz a further 6km NE of Baudin. While considerable knowledge has been gained on the geometry of the Julimar complex, much remains to be learned about the specific geometry of mafic intrusions, and how they vary through the region. Potentially AEM data can contribute to this understanding.

Results

The deterministic and the probabilistic inversions map a highly conductive zone that is associated with the Pyroxenite unit on the eastern side of the Gonneville intrusion. (Figure 3). The results from the different inversion approaches (see Figure 2) shows that the inverted models all map a conductive regolith profile (from surface to 30-40m). The mean model from the rj-McMC inversion (Figure 2C) suggest the regolith has a relatively uniform thickness particularly on the western side of the intrusion, conforming with the interpretation from drilling (Figure 4) A comparison between the model sections and the geological section (Figure 4) shows that the mafic-ultramafic units dip westwards corresponding well with the observed 45-degree WNW dip in the geological section. Zones of mineralisation a defined in drilling by Chalice Mining corresponds well with the zones of higher conductivity, but the AEM data does not appear to define specific high-grade zones associated with mineralisation, rather the models suggest the AEM defines an amalgamated response from sub-parallel zones.

The main benefit of using a rj-McMC inversion is the possibility to explore the uncertainties related to the obtained models, and therefore also be able to establish both layer boundaries and conductivities with greater certainty. One of the many outputs of the rj-McMC inversion is the possibility to identify and visualise changepoints. These indicate the depth at which interfaces were most likely to occur in the models that were accepted into the Markov chains (Figure 2E). Although being a "busy" figure, it does provide some confidence in which layer boundaries are likely to be present, but also what areas of the model that layers are expected to be homogeneous and continuous.

DISCUSSION AND CONCLUSIONS

Both the deterministic and stochastic inversions can map the highly conductive zones associated with the Gonneville Intrusion. However, when comparing results from different inversion algorithms consideration needs to be given to whether the algorithms account for noise in a similar way, (see discussion by Mulé et al. 2019). Currently the GA-AEM code used for the rj-McMC inversion does not allow for a different number of gates to enter the inversion – i.e., removing late-time noise for individual soundings is not an option. This is an option in in AarhusInvn (the inversion algorithm used by Aarhus Workbench).

Another thing to keep in mind is that these data may benefit from running an inversion that accounts for IP effects, as they appear to be present in the data, particularly for the more resistive areas surrounding the Gonneville Deposit.

We conclude that by carefully processing and inverting the AEM data, it is possible to map a broader range of geological elements that characterise the Gonneville mineral system, rather than just sulphide mineralisation. Although the deterministic inversion provides a model, that corresponds well to the geological information – it may be beneficial to look at the deterministic and stochastic inversion in conjunction, to better establish layer boundaries and broader characteristics of the intrusion.

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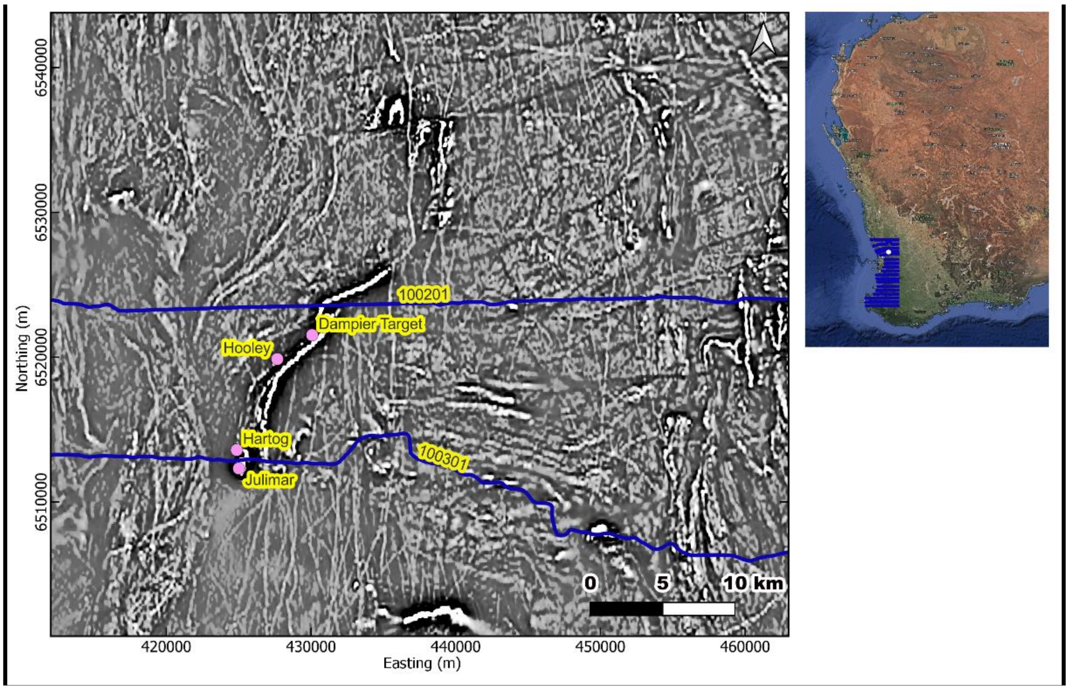

Figure 1. The location of the two AUS-AEM lines (100201 and 100301) closest to the Julimar complex, and the main targets overlaid on the TMI RTP1VD magnetic image.

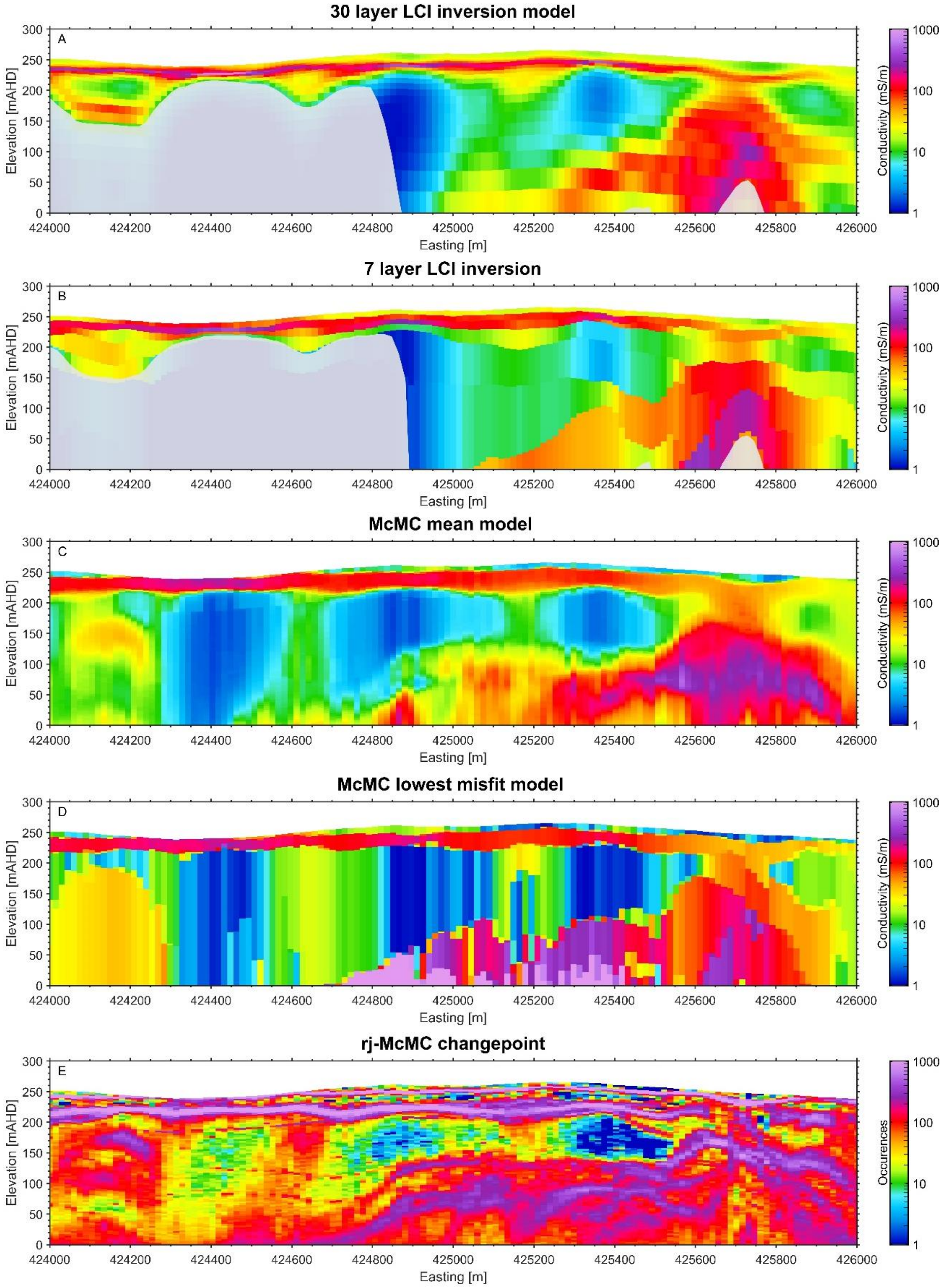

Figure 2. The results of the different inversions of line 100301 over the Gonneville prospect. A-B show the inversion result from using a 30 and 7 layer model discretization following a full processing of the data before inverting them using Aarhus Workbench. Panel C and D show the mean and lowest misfit models obtained by running a stochastic rj-McMC inversion.

Panel E shows a plot of the "changepoints" which indicate the depth at which interfaces were most likely to occur in the models that were accepted into the Markov chains.

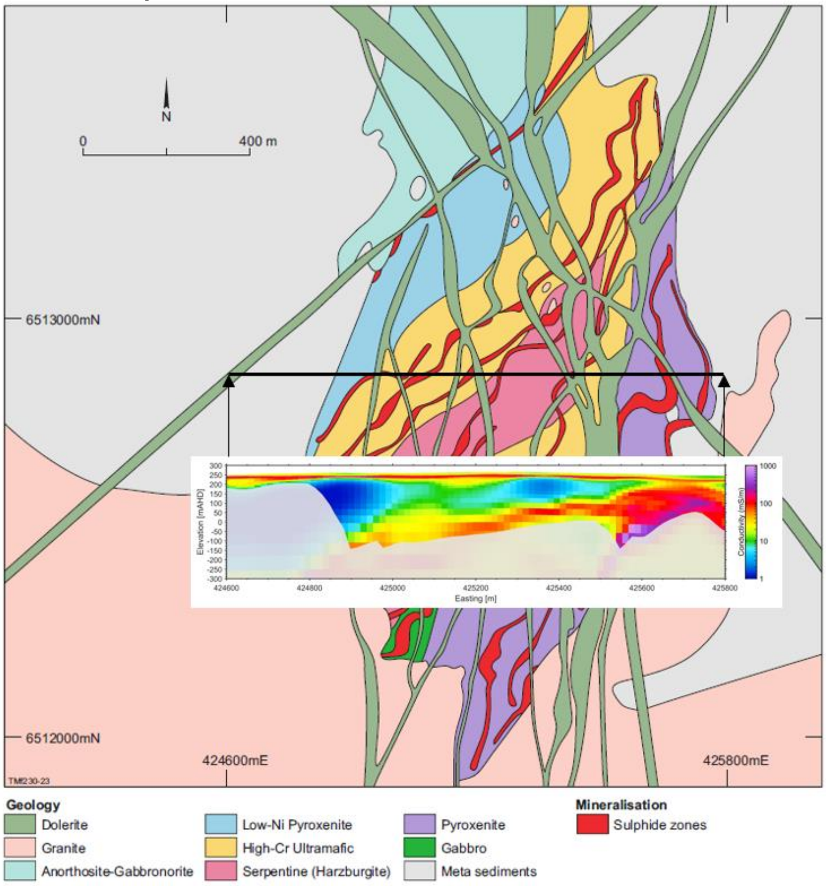

Figure 3. (Adapted from Chalice) shows the Gonneville intrusion plan view along with the location of the AUS-AEM SkyTEM line (shown by black line) and the inverted model section.

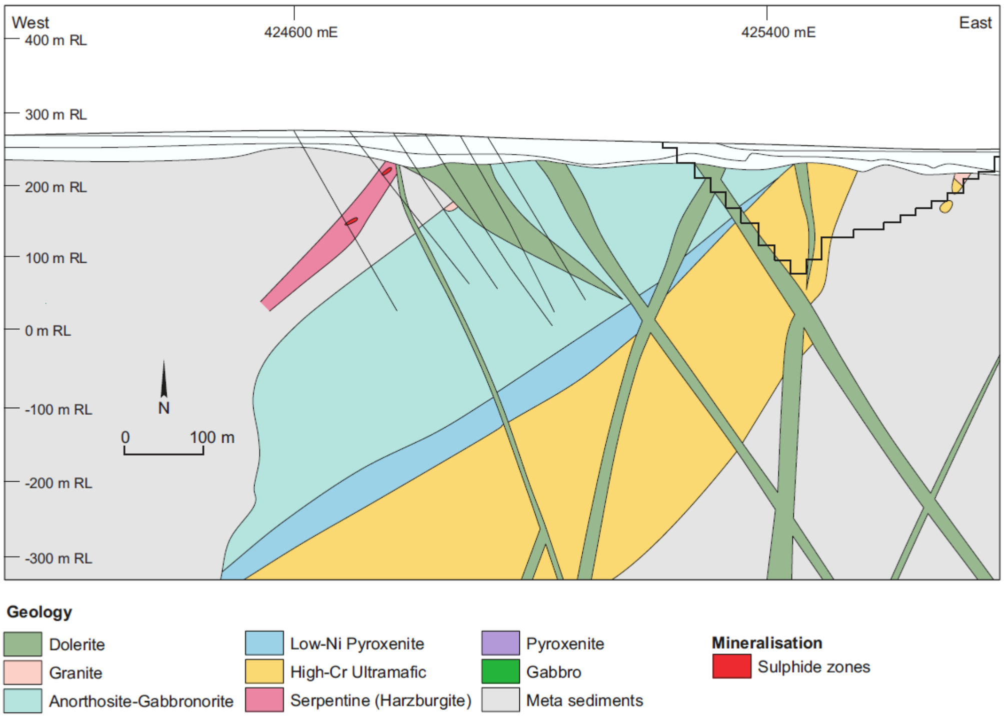

Figure 4. Geological cross section (adapted from Chalice), showing the resource pit, the mineralisation zones as well as the geology.