Integration of regional scale geophysical data to generate a 3D geological model of the Paterson Province

Antonio Huizi
IGO Limited
antonio.huizi@igo.com.au

Nicholas Turley
IGO Limited
nicholas.turley@igo.com.au

Daniel Lindsey
IGO Limited
daniel.lindsey@igo.com.au

SUMMARY

The Paterson province is host to significant gold and copper deposits, however, deep Phanerozoic cover overlying strongly deformed Proterozoic sedimentary basins, means that it remains poorly understood, especially in 3D. IGO's early-stage exploration strategy is based on building a robust regional 3D geological model utilising the large amounts of geophysical, geological and geochemical data available in the region. The pillars of the geological model are based on building knowledge around the sedimentary hosted copper deposit model, where basin architecture, fluid pathways and metal source rocks are critical ingredients to generate a world class deposit.

A wide range of regional scale geophysical datasets have been used to assist in the creation of the model: airborne magnetics, gravity, airborne electromagnetics, ground and airborne natural source electromagnetic surveys. A combination of 1D, 2D and 3D inversions of this data were generated to provide detailed physical property models that cover all or most of the project region.

The integration of all these datasets in a 3D environment has resulted in the creation of a geological model of stratigraphy and structures. Most importantly, the model is created with the aim of developing an understanding of the timing relationships between magmatic and deformation events and the deposition of the Proterozoic sedimentary basins. The resulting model is a live resource subject of constant updates as new data is collected. Recent drilling has validated some of the interpretations generated from the "live" geology model.

Key words: Regional, Modelling, Integration, Sedimentary Hosted Copper

INTRODUCTION

The Paterson area is a remote part of Western Australia that was largely unexplored until the early 1970s when its mineral potential was demonstrated by the discovery of gold and copper at Telfer, which then became a world-class mine. Interest in the area continued and led to other significant discoveries, including copper at Nifty in 1981, and uranium at Kintyre in 1985 (Ferguson et al., 2005). The presence of the Nifty copper mine, abundant shallow geoscientific information, with an apparent absence of effective deeper data information represent a belt-scale exploration opportunity.

IGO's Exploration team is currently developing a 3D model for the Paterson region in Western Australia to improve the understanding of the regions complex structural and sedimentological setting. By reconstructing the basin from the basement up we attempt to understand the basins architecture pre-deformation. Correlation between factual geological data and regional geophysical datasets is key to interpolate our model across the basin. This work describes the way the different geophysical datasets have been processed and imaged to maximise their value in the geological model creation process.

GEOLOGICAL SETTING AND EXPLORATION HISTORY

The Paterson Orogen is defined as a 2000 km long arcuate belt of folded and metamorphosed Paleoproterozoic and Neoproterozoic sedimentary and igneous rocks that were deformed during the Neoproterozoic Miles and Paterson orogenies (Czarnota, 2009). The orogen is bounded to the west by the Archaean Pilbara craton and to the north and northeast by the Late Carboniferous to Early Permian Canning Basin (Anderson et al., 2001), as shown in Figure 1. Metamorphic rocks of the Rudall Complex from the basement, which is unconformably overlain by sedimentary rocks of the Yeneena Supergroup.

The Yeneena supergroup includes the Throssell Range and Lamil Groups. The Coolbro Sandstone is the basal unit of the Throssell Range Group. The unit is interpreted as a fluvial-deltaic succession deposited in a transitional basin (Hickman et al., 1994). The shale-dominated Broadhurst Formation conformably overlies the Coolbro Sandstone, and is interpreted to represent basin subsidence and sea level transgression. The carbonate-dominated Lamil Group overlies the Throssell Group to the northeast (Bagas and Smithies, 1995).

Paterson orogen rocks have been deformed and metamorphosed by three main events (Anderson et al., 2001). Early deformation resulted in tight to isoclinal folding of the Rudall Complex. Subsequent response to northeast-southwest compression caused reginal scale folding and cleavage development. Later events resulted in brittle deformation due to north-northeast to south-southwest compression.

The most significant mineral deposits hosted within the Paterson orogen are the Kintyre U deposit, hosted within the Rudall complex; Nifty Cu histed in the Broadhurst formation and the Telfer Cu-Au deposit hosted in the Lamil Group. Comprehensive descriptions of the regional geology and structural history of the Paterson orogen are available from Hickman and Clark (1994) and Bagas and Smithies (1995) amongst others.

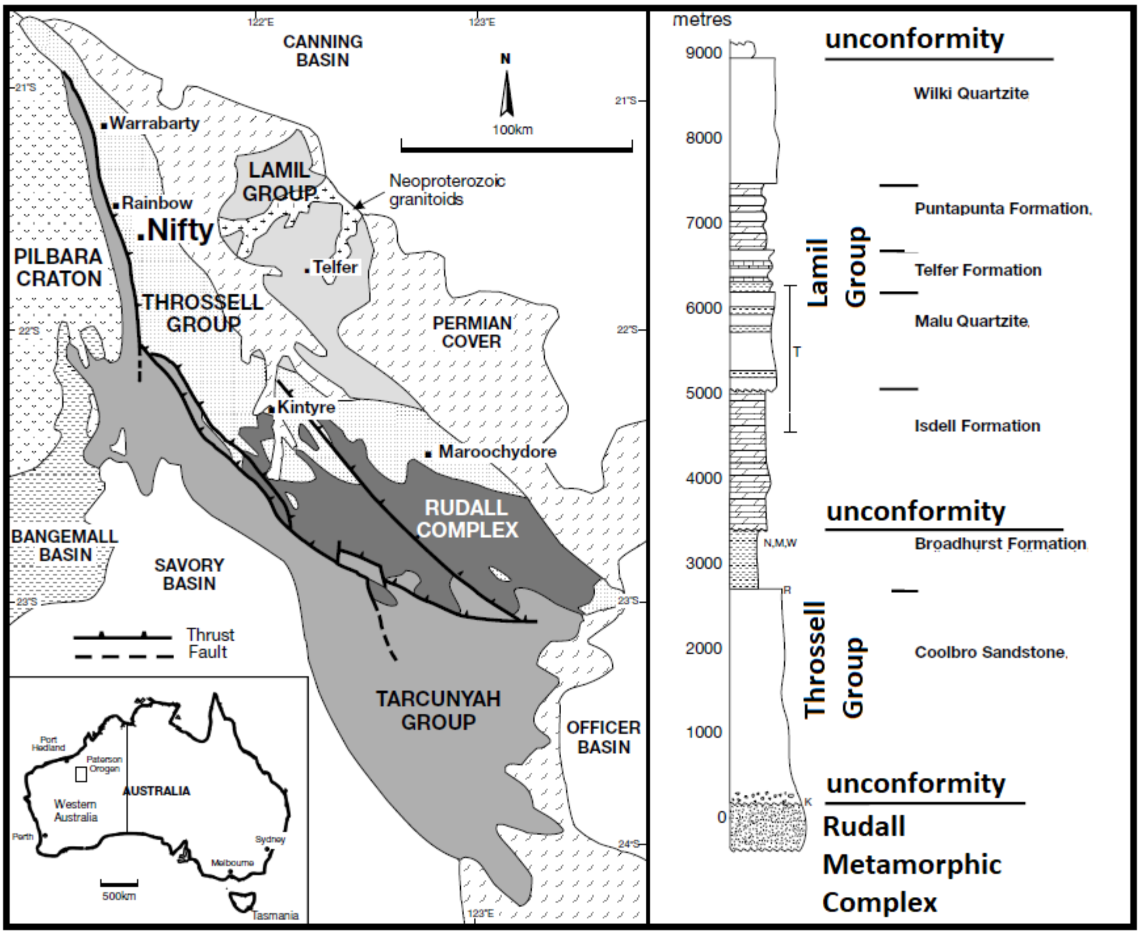


Figure 1. Left: Simplified geological map of the Paterson orogen showing major stratigraphic units and main mineral deposits (modified from Anderson, 2001). Right: Paterson orogen stratigraphic column (modified from Hickman et al., 1994) with locations of mineral deposits and prospects. Abbreviations: K = Kintyre, M = Maroochydore, N = Nifty, R = Rainbow, T = Telfer.

POTENTIAL FIELD DATA

Multiple generations of medium to high resolution magnetic and gravity surveys are available in the Paterson. Airborne magnetic surveys have been grid-stitched and imaged at a 10m cell size resolution. Gravity surveys have been integrated using variable density gridding. Figure 2 and Figure 3 show the outlines and images of merged magnetic and gravity datasets. Apart from a standard suite of magnetic and gravity image enhancements, unconstrained 3D inversions have been generated at the highest possible voxel resolution for the whole project area. By splitting the large datasets into 25km x 25km tiles, a final voxel size of 100m x 100m was achieved. For the multiple inversion tiles to merge seamlessly, a single reginal trend removal was applied to the full dataset before modelling.

Even though project wide 3D inversions of the magnetic and gravity data have been calculated and made available for the modelling team, a bigger weight is placed on more traditional imagery when interpreting structures and stratigraphy. This is important to ensure that the unconstrained inversions are not "overinterpreted" as these type of 3D products lack resolution at depth and suffer from the ambiguity of non-uniqueness.

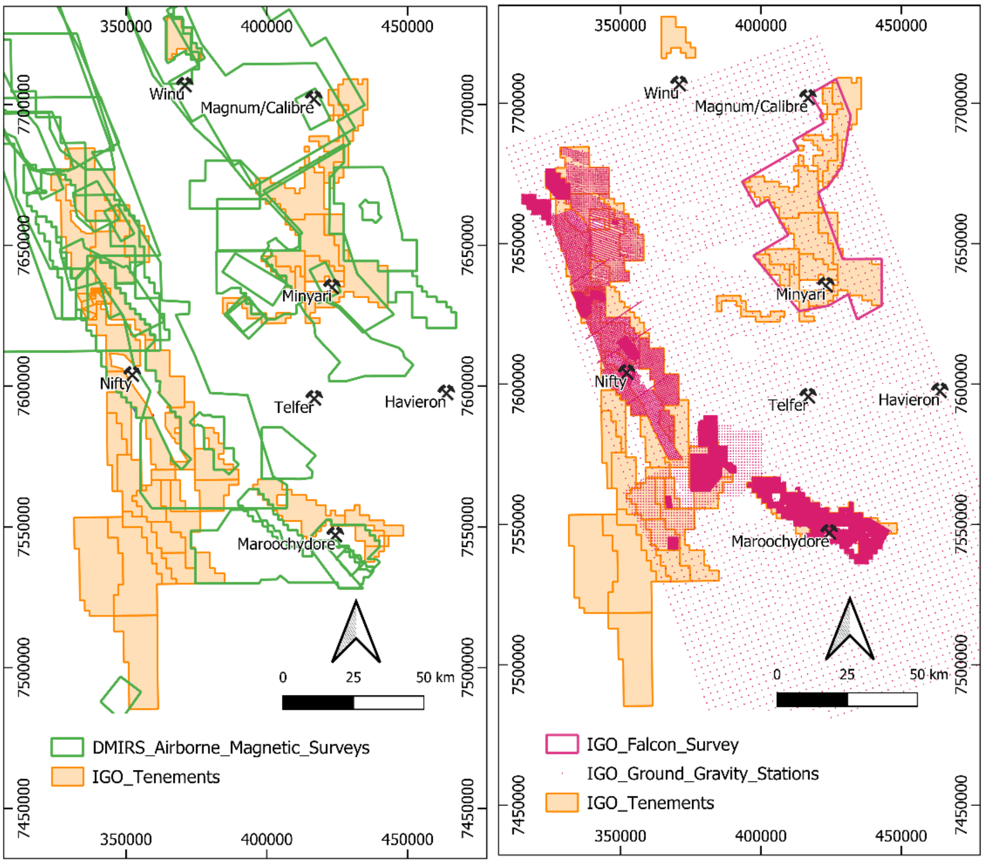


Figure 2. Left: Company airborne magnetic survey outlines over IGO tenements. Right: Ground gravity stations over IGO tenement outlines.

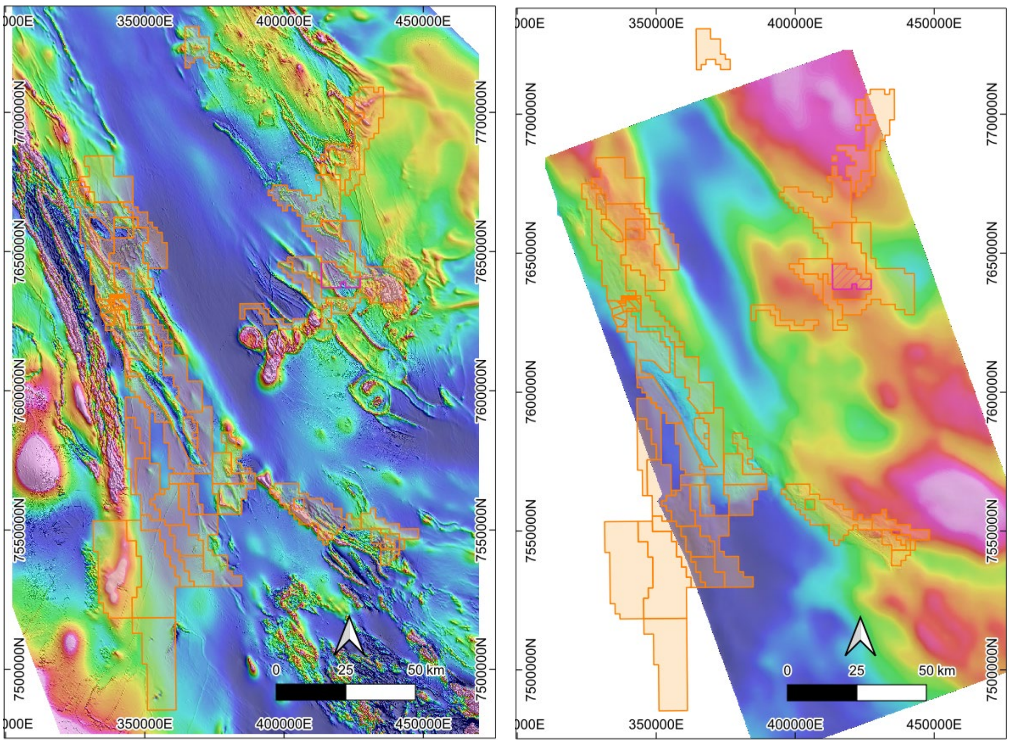


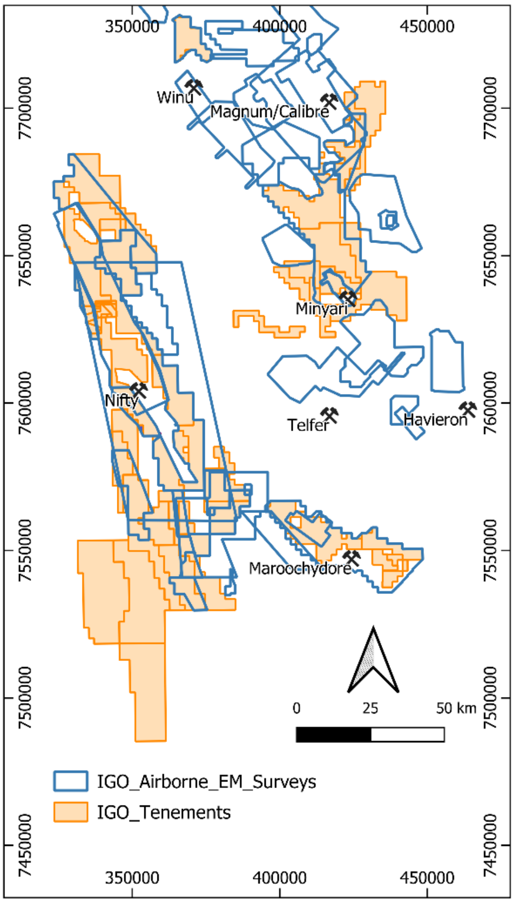
Figure 3. Left: Magnetic image of merged Reduced to Pole magnetics. Right: Image of Paterson merged Bouguer Gravity.

AIRBORNE ELECTROMAGNETIC DATA

A large number of airborne electromagnetic surveys have been flown over the Paterson region over the last twenty years, resulting in comprehensive coverage of airborne EM data over IGO's tenure, Figure 4 shows the coverage of company airborne EM surveys in the area. Even though AEM is a tool commonly used for direct detection of massive sulphide mineralisation, in the Paterson, the primary use of the AEM data is to map the prospective host rocks of the Broadhurst Formation, which are mainly fine grained, carbonaceous, sulphide bearing shales (Anderson et al., 2001) which along with carbonate rocks, host the Nifty Deposit. Given the conductive nature of these sedimentary rocks, the AEM data coupled with magnetics and gravity data, provide a powerful tool for lithostratigraphic and structural mapping within these units of the Throssell Group.

In order to merge the multiple generations of AEM data of varying systems, 1D layered earth inversions, using the GALEI code (Brodie, 2016), were completed. This results in a quasi-3D conductivity depth model that merges seamlessly, regardless of which system was used to collect the data.

Previously, Czarnota et al., 2009, utilised Euler deconvolution of magnetic data, combined with drillhole data, to produce a depth to basement surface for the whole Paterson region. Given the broad availability of AEM 1D inversions, the IGO team produced a depth of cover interpretation that integrated AEM inversions, Euler deconvolution and drilling data to produce an updated depth of cover surface. The conductivity depth sections correlate well with drilling results, while Euler deconvolution depth estimates are less reliable.



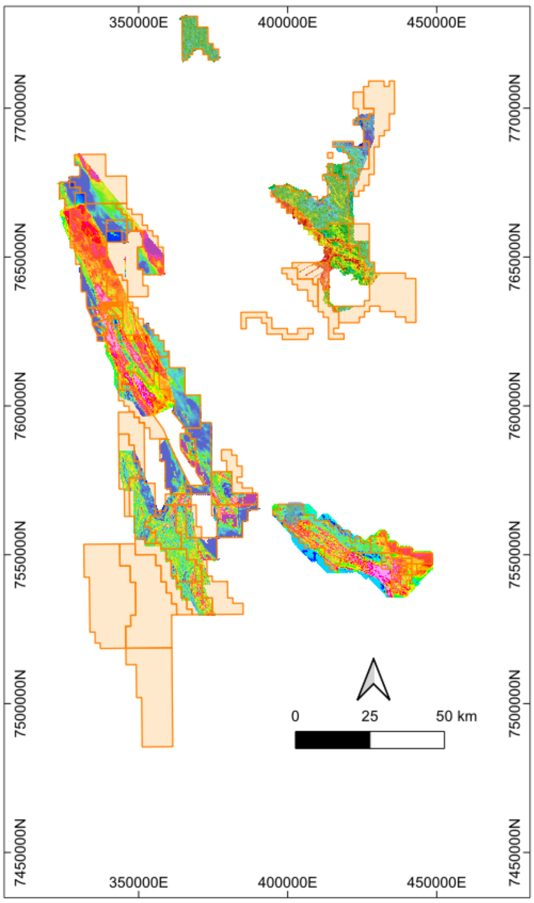


Figure 4. Left: Company AEM survey outlines over IGO tenements. Right: Image of conductivity depth slice (100m below surface) derived from layered earth inversion of multiple AEM surveys'.

NATURAL SOURCE ELECTROMAGNETIC DATA

IGO collected 11 traverses of broadband magneto-telluric data (MT) in 2020 and 2021. The MT lines are between 15 and 25 kilometres long and were designed to cover the width of the IGO tenure along the western margin of the Yeneena basin, over prospective rocks of the Broadhurst Formation, see Figure 5. The objective of the MT surveys is to provide information about the regional basin architecture and major controlling structures. All MT lines were inverted using the RLM-3D inversion algorithm from CGG's GeoTools package. The 3D inversion provides information to a depth of approximately 7-9 kilometres; however, the top 3 kilometres is where the interpretation is focused on. The sections showed useful information about the top of crystalline basement underlying the Yeneena supergroup basin sequence, boundaries of major stratigraphic packages and corroborated known major structures providing insight into the broad orientation of these major stratigraphic units.

Given the success of the MT surveys and considering the relatively high costs and complicated logistics of ground surveys in the area, a broadly spaced airborne audio-frequency electromagnetic survey (ZTEM) was flown over the southwest portion of the tenement package. The ZTEM survey was flown along E-W oriented lines at a 2km line spacing, over an area coincident with the broadband MT lines collected in 2020. The objective of the ZTEM survey was to assess the amount of deep resistivity information that could be recovered in comparison to the ground MT, as the airborne survey would be significantly cheaper and logistically easier than collecting more ground MT data. In addition, the airborne MT has the advantage of providing lateral information cost effectively.

Comparison of these two datasets along with AEM, suggests that the detailed ground MT coupled with 3D inversions, provide better overall detail of the conductivity structure across deep to shallow depths. This is supported by comparing the 1D inversions of AEM data with both the MT and ZTEM sections. As shown in Figure 6, the geometry of conductive cover, mapped in detail by the AEM inversion, can be observed in the MT inverted section. The ZTEM 2D inversion maps the deeper and broader resistive bodies well but does not show the same level of detail shown in the other two methods in the top conductive layer. It is possible that additional detail can be obtained from the ZTEM data by running a 3D inversion code and this will be implemented before concluding the effectiveness of the method in comparison with the ground MT.

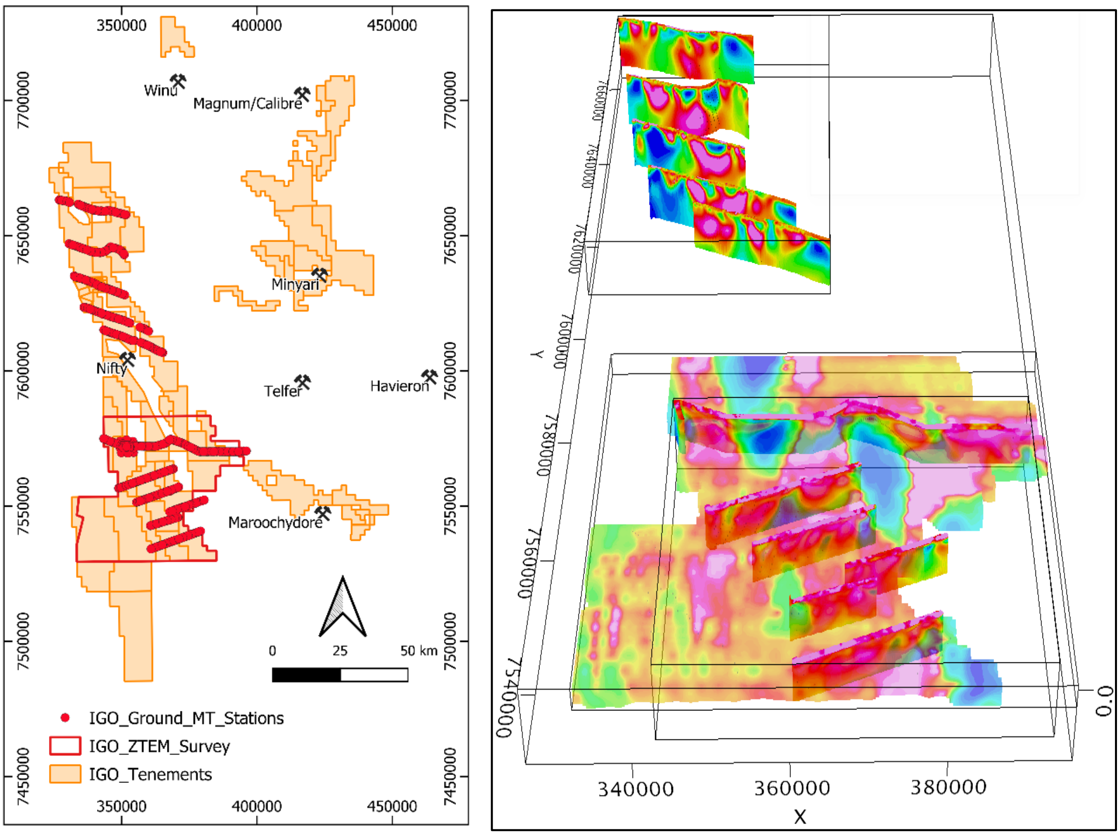


Figure 5. Left: Ground MT stations and ZTEM survey outline over IGO tenements. Right: Perspective view from the south of MT and ZTEM resistivity inversions MT and ZTEM are coloured by conductivity (mS/m).

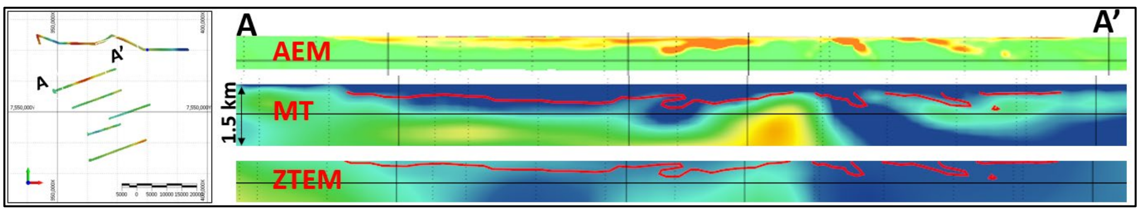


Figure 6. Comparison of ground MT 3D inversion with ZTEM 2D inversion and AEM 1D inversion. AEM section is coloured by conductivity (mS/m); MT and ZTEM are coloured by resistivity (ohm.m).

3D GEOLOGICAL MODEL BUILDING

The model was constructed using the Seequent's Leapfrog software, which allows for time efficient interpretation in a 3D space with the capability of creating surfaces constrained by few observations and more dense geophysical datasets. Regionally reconstructing the fold/thrust belt is something seldom done by exploration groups however is a powerful method when targeting on a belt scale.

Initial focus was placed on modelling the Paleoproterozoic Rudall Metamorphic complex as a basement surface. With this basement surface as a starting point, inferences can be made between what sedimentological facies are expected proximal to basement highs. Having an overall robust model of the basement is needed in predicting pleo-facies continuities. This can then be used to reconstruct the sedimentological pile; prospective horizons can then be modelled in detail to further refine where we may have rapid facies changes. These rapid changes in sedimentary facies are crucial in creating suitable redox conditions and provide rheological changes that create ideal physical and chemical trap sites to form sedimentary hosted copper deposits. These then form the basis of drill targeting and validation.

Figure 7 shows an overview of the basement surface that has been modelled at a regional scale. This has formed the basis of interpreted prospective zones that test new concepts on where the basin architecture is ideal for the formation of an economic copper deposit.

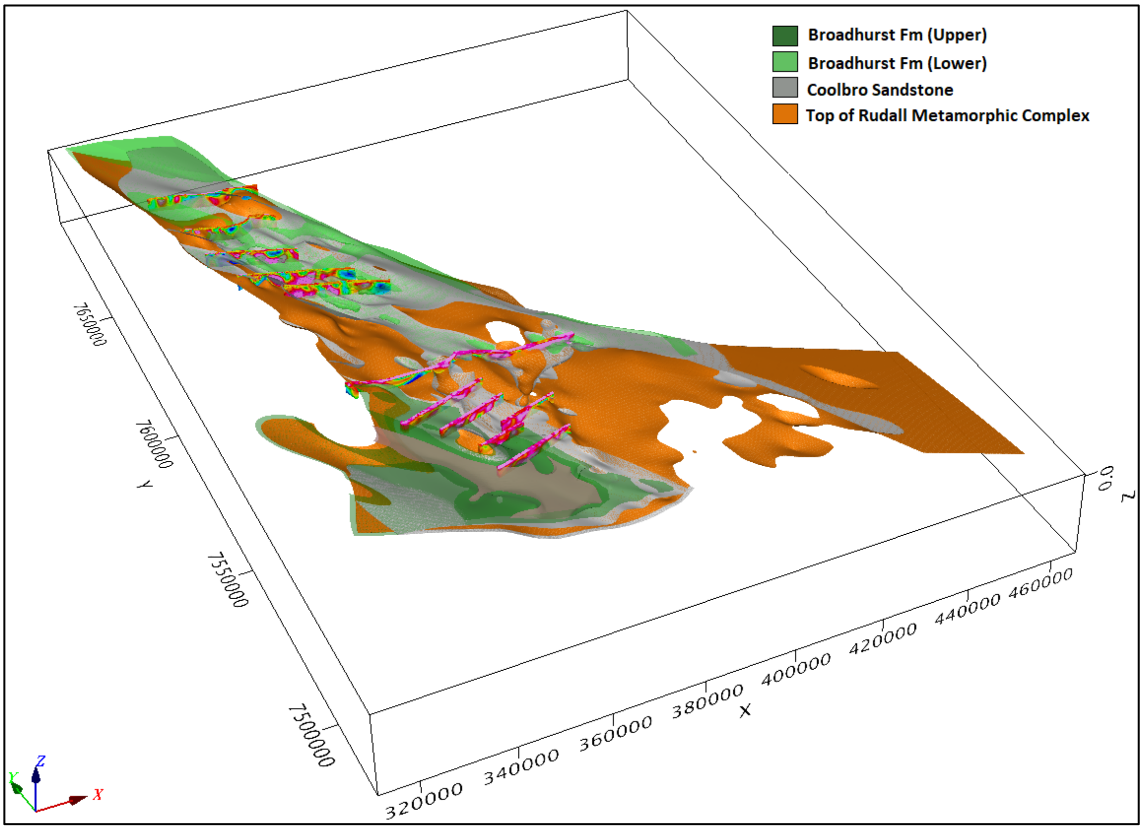


Figure 6. Perspective view of Trossell RangeGroup geological units 3D model with ground MT sections.

.

CONCLUSIONS

Since embarking on copper exploration in the Paterson, IGO has focused on compilation of a variety of historical geological and geophysical datasets, as well as collection of new regional scale surveys. Processing, merging and inversion has been applied to the multiple datasets in order to produce imagery and 3D models. These images and models have been important foundations in the construction of the geological model that provide an insight into the sedimentary basin architecture during deformation events, from which prospective target zones can be defined and further investigated. Active and passive EM methods have proven to be very valuable in mapping conductive basin stratigraphy and the crystalline bedrock underlying the Yeneena Basin, while potential fields datasets provide detailed structural information.

Detailed 3D geological model using geological and geophysical data can be time consuming and involves a number of very specific skills, and is critical for exploring for mineralised deposits undercover, where direct detection tools are lacking. A practical, qualitative approach to geological interpretation in three dimensions allows for relatively quick updates to the model, which remains a very dynamic tool that stimulates a mineral systems approach to targeting.
.

ACKNOWLEDGMENTS

IGO and JV partners in the Paterson, Cyprium Metals, Encounter Resources and Antipa Minerals for allowing the presentation of this work. Clemens Augustein from Absolute Geoscience for providing structural and geological modelling expertise and his mentorship to the Paterson team.

REFERENCES

Anderson, B. R., Gemmell, J. B., and Berry, R. F., 2001, The geology of the Nifty Copper Deposit, Throssell Group, Western Australia: implications for ore genesis.

Bagas, L., and Smithies, R. H., 1997, Palaeoproterozoic tectonic evolution of the Rudall Complex, and comparison with the Arunta Inlier and Capricorn Orogen: Western Australia Geological Survey, Annual Review 1996–97.

Brodie, RC., 2016 User Manual for Geoscience Australia's Airborne Electromagnetic Inversion Software. Geoscience Australia.

Czarnota, K., Gerner, E., Maidment D. W., Meixner, A. J., and Bagas, L., 2009, Paterson area 1:250,000 scale solid geology interpretation and depth to basement model.

Ferguson, K. M., Bagas, L., and Ruddock, I., 2005, Mineral occurrences and exploration potential of the Paterson area: Western Australia Geological Survey, Report 97.

Hickman, A.H., Clarke, G.L., 1994. Geology of the Broadhurst 1:100,000 sheet, Western Australia. West. Aust. Geol. Surv. 1:100,000 Geol. Series Explan. Notes.

Katona L.F., 2017., Gridding of South Australian Ground Gravity Data, using the Supervised Variable Density Method, Report Book 2017/00012. Department of the Premier and Cabinet, South Australia, Adelaide.