Regional mineral exploration targeting for gold and nickel deposits using crustal electrical conductivity variations determined using the magnetotelluric method

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SUMMARY

Current models for regional mineral exploration targeting for nickel and gold mineralisation emphasize the significance of deep penetrating geological structures and the margins of cratonic blocks as areas of greatest prospectivity. As part of a study on regional prospectivity, magnetotelluric (MT) surveys have been completed in several prospective Proterozoic and Archean terrains in Western Australia. These data, which have been interpreted in associated with potential field, seismic, geological and geochemical data, demonstrate that MT surveys can be used to identify such prospective features based on variations in the electrical conductivity of the crust and upper mantle. For example, a survey in the southern Yilgarn Craton has identified lateral changes in deep crust and upper mantle conductivity structure consistent with palaeo-cratonic boundaries inferred from studies using isotope geochemistry. The MT data allow the boundaries to be accurately located; the isotopic results being limited by the spatial distribution of outcrops of suitable lithotypes.

The areas of interest in Western Australia are geographically remote and often environmentally and culturally significant. MT surveys represent a comparatively cheap means of evaluating regional prospectivity, whilst causing minimal cultural and environmental disturbance.

Key words: Magnetotellurics, regional-scale prospectivity Western Australia, .

INTRODUCTION

Current ideas on regional prospectivity analysis emphasize the importance of major fault structures and in particular (palaeo) suture zones within and between cratonic blocks. These features represent deep penetrating zones of enhanced permeability encouraging the passage of potentially mineralizing brines and melts. Such features have been linked with the occurrence of nickel-sulfide and gold deposits; see for example Begg et al. (2010) and McCuaig et al (2010). The need to map variations in physical properties at lower crustal and mantle depths.

MAGNETOTELLURICS AS A REGIONAL TARGETING TOOL

The MT method involves minimal disturbance of the ground. Some of the areas of interest are culturally important to the indigenous peoples and, for example, seismic reflection surveys, may not be permitted. Also, the passive nature of the MT method means equipment is fairly compact and data can be acquired comparatively cheaply; this is an essential requirement given the size of the prospective terrains in Western Australia and their geographical isolation.

MT surveys in the similar geological environment of the Canadian Shield have produced excellent results, e.g. Spratt et al., (2009). Major structures usually, although not necessarily, are apparent as thin dipping conductive zones. Variations in the electrical conductivity of the lower crust and upper mantle have been correlated with differences in the geological affinity and age of the Archean crust, e.g. Jones and Garcia (2004), potentially allowing major suture zones to be located based on such changes.

Funded by the Western Australian Government's Exploration Incentives Scheme, a series of magnetotelluric (MT) surveys have been undertaken in different Precambrian terrains in Western Australia. These surveys are part of a project to provide regional exploration targeting datasets for selected terrains in the State being undertaken in the Centre for Exploration Targeting at The University of Western Australia. MT surveys have been collected in 5 distinct areas in Western Australia but for reasons of space results are described from only two areas.

Southern Yilgarn Craton

The Yilgarn Craton in southwestern Western Australia is one of the largest occurrences of Archean rocks in the world. Comprised mostly of high grade gneiss and granitoid-greenstone terranes it is host to world class mineral deposits, especially gold and nickel, e.g. Blewett et al., (2010). The southern Yilgarn Craton MT data comprise a single traverse extending from the Southwest Terrane (SWT) across the Youanmi Terrane (YT) and on to the Eastern Goldfields Superterrane (EGT). These are areas with different geochemical characteristics and which contain significant mineral deposits, notably nickel-sulfide deposits in greenstone belt rocks. A map of variations in granite Nd_{TM} produced by Cassidy and Champion (2004) shows significantly different values in the Eastern Goldfields Superterrane compared to the other terranes crossed by the MT traverse. Also, multi-isotopic analyses of zircons on whole-rock intrusive and volcanic rocks reveal how the lithosphere has evolved through time in the Yilgarn Craton (Mole et al., 2010). These data imply the presence of a palaeo-cratonic boundary in the survey area, although limited outcrop means its position is not well constrained and it is uncertain whether known apparently important structures correspond with the suture or there are major structures yet to be identified. Moreover, the position and geometry at depth of the known major structures in the study area is unknown or poorly constrained, for example the Ida Fault which separates the YT and EGTs. An improved understanding of the extent and relationships between major crustal domains/terranes and the intervening large-scale structures in the study area was the primary motivation for the MT survey.

The MT data set comprises 45 stations spaced at between 5 and 20 km. Two (horizontal) components of the electric field and three components of the magnetic field variation were recorded, each for approximately 40 hours. Data were recorded using Phoenix Ltd MTU-5A data recorders with MTC-50 magnetic induction coils. Electric dipoles (100 m length) and horizontal coils were installed in magnetic north-south and east-west azimuths. The electric field was measured using non-polarising ($Pb/PbCl_2$ solution) electrodes. Survey sites were all relatively flat and most sites were remote from any sources of cultural electromagnetic noise. At each site electromagnetic soundings were made using a TerraTEM transmitter and receiver to allow static shifts to be estimated.

In general, data quality is very good, with useful data recorded to periods of about 1000 s. The time-series data were processed using robust remote-reference algorithms supplied by Phoenix Limited and based on the coherence-sorted cascade decimation method and the heuristic robust approach. Remote reference processing used a simultaneously recording station within the traverse. Static shifts were estimated using the time-domain (TD) electromagnetic soundings.

The geoelectric strike direction and dimensionality of the MT data was assessed using the phase-tensor method. The data not significantly affected by 3D conductivity variations were modelled using the 2D non-linear conjugate gradient inversion algorithm of Rodi and Mackie (2001) as implemented in the Winglink™ software package. This inverse modelling method minimizes an objective function consisting of the data misfit and a measure of model roughness, with the user-specified trade-off parameter, τ, defining the balance between these terms. Both TE and TM modes and the Hz transfer function were modeled over the frequency range 500-0.001 Hz.

Figure 1 shows the preferred resistivity cross section derived from the MT data, with features of significance labelled and showing aspects of the surface geology. The upper crust is mostly highly resistive (greater than about 10,000 Ω.m). Separating the resistive zones are regions, mostly narrow and dipping either to the east or west, which are more conductive (e.g. A-D). Based on comparison with equivalent data from the Canadian Shield these zones are interpreted as major fault/shear zones. The data suggest that some of these extend through the entire crust whilst others reach at least mid-crustal levels. This is consistent with the interpretation of the seismic reflection data from the region (Drummond et al., 2000). There is evidence for such structures on both sides of the Southern Cross greenstone belt , i.e. close to the SWT-YT boundary) and there are equivalent linears in potential field data. At the eastern end of the traverse, there are numerous important structures defining terrane and domain boundaries within the EGT. One of these (D) coincides with the projected location of the Ida Fault. However, the position of this feature is not geologically at all well constrained and there is no associated magnetic or gravity feature even though this is a very important structure further north.

Conductivity variations in the lower crust and upper mantle are of particular interest. To the east, feature E is consistent with a conductive lower crust and the depth to its base is in reasonable agreement with the seismic Moho. The westward limit of the conductive lower crust is near the C anomaly in the crust. To the west there is no evidence for a conductive lower crust and instead the upper part of the mantle is more conductive (F) than to the east. This zone of conductive mantle passes eastwards in a more resistive zone (G) overlain by resistive crust.

Based on the above observations, it is proposed that the MT survey has defined 2, or possibly three major ‘blocks’ of lithosphere: Units 1, 2 and 3 (Fig 2). The western block (unit 3) correlates with the SWT. The boundary between units 2 and 3 may mark the actual location, at least in the deep crust, of the western extent of the Eastern Goldfields Superterrane. This coincides with the Ida Fault to the north of the MT survey area and here the seismic reflection data suggest a coincident change in the nature of the lower crust from the Southern Cross lower crust associated with imbricated fault blocks to the Eastern Goldfields lower crust characterized by flat reflectors. If the Unit 2 and Unit 3 boundary is the equivalent structure then the position of the Ida Fault as shown on Figure 1 is too far to the east. Since numerous gold deposits occur close to the Ida Fault further north its position is of some importance. Alternatively, the terrane boundary at the surface may not coincide with the boundary in the deep crust, suggestive of para-autochthonous units in the area as has been interpreted from MT data in the Canadian Shield. Interestingly, the interpretation implies a correlation between deep electrical structure and the type of komatiites seen at the surface. Barberton- and Munro-type komatiites differ from one another primarily in the depth and degree of partial melting that produces them (Arndt et al., 2008). This is consistent with differences in the electrical properties of the mantle. Munro-type komatiites are the most nickel sulphide endowed globally and in the Eastern Goldfields Superterrane they are the only mineralised komatiites. Conversely, in the Youanmi Terrane all the mineralised komatiites are Barberton-type. Thus, deep electrical structure may provide clues regarding the origin of this type of mineralisation.

Musgrave Province

The Musgrave Province is located in central Australia, straddling the border between Western Australia and South Australia and extending north in to the North Territory. That part of the Province in Western Australia is called the west Musgrave Province (WMP). The WMP was a focal point for tectonic activity from the Mesoproterozoic through to the earliest Cambrian. As a result of this activity, the region is prospective for several types of mineral deposits, principally Ni-Cu-PGE, of which the world class Nebo-Babel deposit is the major known example.

The magnetotelluric survey involved two orthogonal traverses (east-west, north-south) and was designed so as to cross major faults and also to cross a major positive gravity anomaly postulated to be associated with a large mafic magma chamber in the subsurface. An improved understanding of the extent and relationships between major crustal domains/terranes and the intervening large-scale structures in the study area was the primary motivation for the MT survey.

The survey comprises 48 stations. Data acquisition, processing and modelling was as described for the southern Yilgarn survey, except for the use of some different MT equipment, from the ANSIR national equipment pool, at some stations. Figure 2 shows the preferred resistivity cross-section along the east-west profile in relation to the surface geology and the extent of major positive gravity features. The cross-section is notable for the very high resistivities of the lithosphere, notably in the mantle. The cause of the high resistivities is difficult to determine however, because of the poor understanding of controls on electrical properties in the deep crust and mantle. The chemistry, especially iron content, of mineral species such as pyroxene and olivine, is thought to affect their electrical properties. Ultimately the high resistivities in the mantle may reflect a high degree of melting associated with the voluminous felsic and mafic magmatism, a scenario consistent with the possibility of a relationship with komatiite geochemistry mentioned above.

As is often seen in MT data in basement terrains there are more conductive areas that comprise narrow linear zones and are probably due more conductive mineral species in major fault zones. The maximum depth of such features is poorly constrained but most seem to terminate at roughly the seismically defined Moho depth. These features are a useful indicator of deep penetrating fault zones, which are important features in the prospectivity analyses described by Joly et al. (in press) due to the likelihood of their control on the movement of metal-bearing brines and magmas. The positive gravity features crossed by both MT traverses are associated with contrasting crustal resistivity characteristics. On the east-west profile (Fig.2) the source of the gravity anomaly is the mafic Jameson Intrusion and there is conductive zone 'A' which according to gravity and magnetic modelling lies below the base of the intrusion. An optimistic interpretation of this zone of greater conductivity is that it is associated with an accumulation of conductive mineral species at the base of the intrusion due to settling in the magma chamber. An interesting deep seated feature in the MT data is the zone of more resistive mantle on the east-west cross section between approximately 75 and 150 km. The western limit of the zone may be associated with the Barrow-Cavenagh corridor which is a focus for deformation mapped at the surface or possibly the Lasseter shear zone. The eastern margin coincides with the Cavenagh Fault, a major structure mapped in the near surface from aeromagnetic data. The contrast in mantle electrical characteristics may be indicative of the juxtaposition of different lithospheric blocks.

CONCLUSIONS

Based on changes in electrical conductivity, MT surveys in two geologically distinct terrains in Western Australia have successfully mapped what are interpreted to be major crustal fault structures and boundaries between different tectonic crustal and mantle blocks. Such features are key indicators of regional prospectivity analysis for nickel sulfide and orogenic gold deposits. Thus the MT method, with its advantages of low cost and minimal environmental disturbance, is potentially a useful tool in the early stages of mineral exploration when selection of the most prospective ground is vital to exploration success

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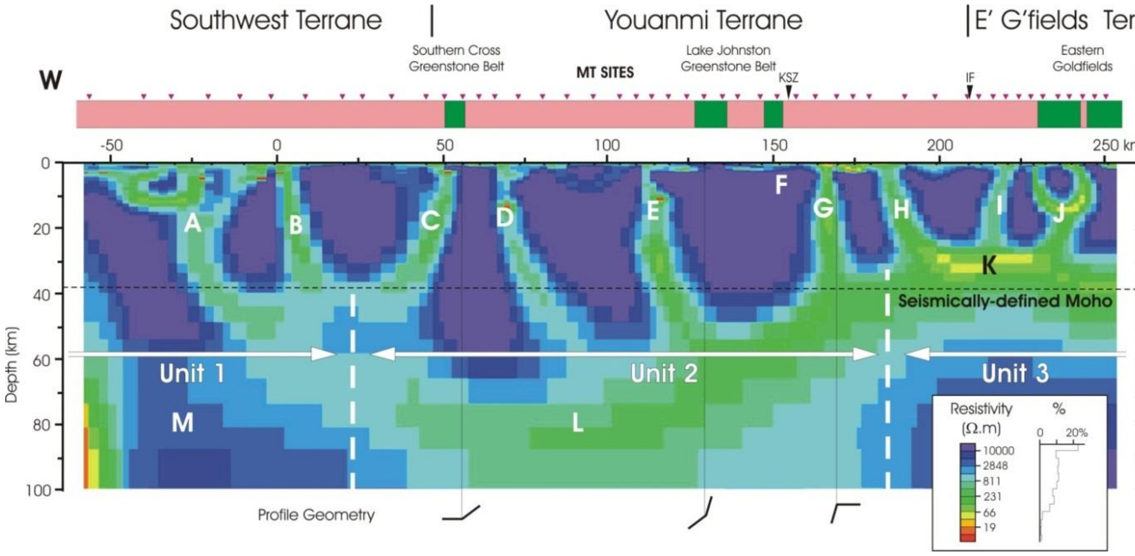

Figure 1. Resistivity cross section, southern Yilgarn Craton, Western Australia. Dentith et al. (in press). KSZ – Koolyanobbing shear zone, IF – Ida Fault.

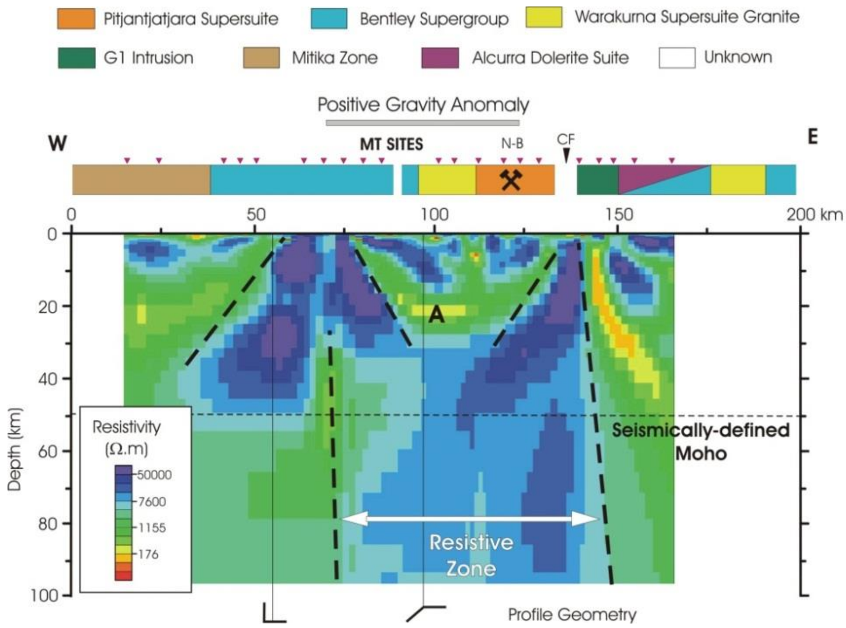

Figure 2. Resistivity cross section, West Musgraves Province, Western Australia (Aitken et al., in press). CF – Cavenagh Fault, N-B Nebo-Babel.