Integrated interpretation of magnetotelluric and potential field data: assessing the northeast Kimberley region.

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SUMMARY

An integrated interpretation of potential field and magnetotelluric (MT) data was performed in the east Kimberley, northern Western Australia Structural interpretation of potential field data was constrained by geological field observations, petrophysics, remote-sensing and an understanding of the tectonic history of the region. Forward modelling of the potential field data located along the same survey traverse as the magnetotelluric data allowed comparison between the two datasets to assess complementarity of images and assist interpretation. Interpreted features include the presence of large-scale structures and associated electrical anomalies that indicate the presence of mineralisation deep in the crust, and guide prediction of mineralisation at or near the surface. The King River Fault is revealed to be a crustal-scale, west-dipping structure, which footwall bounds the western side of a large resistive body. A conductive anomaly is also located on the hanging wall of the King River Fault. A number of scenarios are discussed to the source of conductivity, including the presence of sulphides, saline water and graphite. Our assessment suggests that graphitic rocks, most likely with some sulphide content, contribute to the strength of this anomaly, and highlights the known potential of the east Kimberley to host graphite deposits. The conductive anomaly has a spatial and geometric correlation to Speewah Dome, a known prospective region. The depth of the conductor (c. 5km) precludes mining, but does indicate King River Fault is likely to form a mineralising conduit, and may contribute to possible Pb-Zn mineralisation where the fault reaches the surface.

Key words: geophysical interpretation, gravity, magnetic, magnetotelluric, east Kimberley.

INTRODUCTION

Interpretation of potential field and magnetotelluric (MT) data in tandem has been shown to be an effective tool to identify geology indicative of mineralisation. Nieuwenhuis et al. (2014) use a combination of MT and seismic to investigate the Vulcan Structure, a potential field anomaly buried beneath the western Canada Sedimentary Basin. The authors find the 3D resistivity model correlates well with Precambrian domain boundaries and previous interpretations of potential field data, and use these observations to suggest the origin of the Vulcan Structure is related to collision along a north-dipping subduction zone. Wannamaker and Doerner (2002) extend the capability of jointly interpreting MT with other geophysical data to investigate the relationship with Au deposits in the Carlin Trend and controls on core complex evolution in the western US. The authors find the MT data represents a large resistive block bounded by numerous discrete and linear conductive crustal 'breaks'. The conductors are interpreted to be graphitic rocks, with fluids in steeply-dipping fault zones leading to deposition of graphite. Major earthquakes thought to result in hydrothermal fluid activity, which led to subsequent graphite deposition taking place in the slip zones associated with Carlin-type Au deposits.

We take inspiration from the authors listed above to assess the mineral prospectivity of the northern Halls Creek Orogen, Western Australia (Figure 1a and b). A range of geoscientific datasets including geological field observations, remotely-sensed, potential field and MT data have been interpreted to generate a map of major and minor structures. Inverted MT data was used in combination with potential field forward modelling to develop an understanding of crustal architecture. Observations and interpretations made with these datasets provide a robust model for mineral exploration. The east Kimberley region in northern Western Australia includes the NE-trending western, central and eastern zones of the Lamboo Province (Figure 1c) (Tyler et al., 1995) and the eastern part of Kimberley Basin (Figure 1a).

The two billion year geological evolution of the region comprises four major tectonic events: the Paleoproterozoic 1865-1850 Ma Hooper and 1835-1810 Ma Halls Creek orogenies; the early Neoproterozoic Yampi Orogeny and late Neoproterozoic King Leopold Orogeny (Griffin et al., 2000; Hollis et al., 2014; Sheppard et al., 1999; Tyler and Griffin, 1990). The major tectonic units are (from the west) the Kimberley and Speewah basins, with the 1910-1805 Ma Lamboo Province, and the Southern Bonaparte and Ord basins in the east (Fig. 1a). The eastern part of the Lamboo Province, known as the Halls Creek Orogen, is inferred to be a series of northeasterly-trending Archean and Paleoproterozoic terranes (Gunn and Meixner, 1998; Hollis et al., 2014).

Each of the Lamboo Province zones comprise rocks characteristic of their tectonic history. The western zone is dominated by the felsic to intermediate rocks of the 1865-1850 Ma Paperbark Supersuite and c. 1855 Ma Whitewater Volcanics and are linked to the Hooper Orogeny. The turbiditic c. 1872 Marboo Formation have been metamorphosed to amphibolite facies. A series of mafic to ultramafic rocks intruded post-orogenesis between 1859 and 1853 Ma (Blake et al., 2000). The central zone is characterised by the Tickalara Metamorphics, a metamorphosed group of lithologies attributed to an ocean arc formed during the Hooper Orogeny, and the felsic to mafic intrusive rocks of the 1832-1808 Ma Sally Downs Supersuite, emplaced during the Halls Creek Orogeny (Sheppard et al., 2001). The eastern zone is characterised by the 1880-1847 Ma sedimentary and volcanic rocks of the Halls Creek Group (Tyler et al., 1998). The Speewah and Kimberley Group rocks were deposited over the Kimberley Craton during and post the Halls Creek Orogeny and variably overly the western and central zone rocks in the north and south of the east Kimberley. The Hart Dolerite and Carson Volcanics rocks were respectively intruded and extruded into and onto the Speewah and Kimberley Group rocks at c. 1797 Ma. (Griffin et al., 1993). Overlying the Speewah and Kimberley Group is the <1797 Ma Bastion Group, the c. 1200 Ma Carr Boyd Group and the flood basalts of the c. 510 Ma Antrim Plateau Volcanics. The Frasnian Cockatoo Group are present in the north and east of the study area.

Our results show that a possible source of fluids for a known exploration area at Speewah Dome, an area of faulted and folded Speewah Group and Hart Dolerite rocks (Figure 2a) and for Pb-Zn hosted in the Cockatoo Group along the King River Fault (Figure 2a) can be elucidated by using the method described below.

METHOD AND RESULTS

Magnetic susceptibility and density measured from rock samples collected from the region were extensively used to constrain the structural interpretation and joint forward modelling of magnetic and gravity data. Precompetitive magnetic (400 m line spacing) and gravity data (2 to 10 km station spacing) supplied by Geoscience Australia were used in the structural interpretation to develop a regional understanding of geological architecture. Different filters and transforms (RTP, 1VD, AGC, upward continuation) were applied to each of the datasets, where appropriate, to enhance the geological signal, and support observations made between these and remotely-sensed datasets. Extensive use of geological data (lithological and structural observations) collected by the GSWA were used to constrain the structural interpretation and forward model. Moho estimates shown in the forward model were taken from Aitken et al. (2013). Forward modelling was performed with Oasis Montaj GM-SYS. Geological interpretation was conducted on the petrophysical model using geological field constraints.

A detailed description of the collection, processing and inversion of the MT data is provided in Spratt et al. (2014b). Broadband and long-period MT were acquired from 155 sites covering the entire Kimberley region, including the surrounding King Leopold and Halls Creek orogens. Station spacings were from 5 to 20 km, with smaller spacings where larger structures were predicted. Measurement times were c. 40 hours at each site. 2D inversion was performed and imaged the Earth to an estimated depth of 140 km.

Structural Interpretation

Figure 2 shows large-scale features (heavy black lines) that were identified through interpretation, or supported through previous studies (e.g. Tyler et al. 1995; Gunn and Meixner, 1998). Notably, the intersection of these features coincides with complex structures. Figure 2a - "A" exhibits an elliptical, high frequency anomaly in the magnetic data that is interpreted to be Hart Dolerite intruding into Speewah Group sedimentary rocks. This location is host to the now closed Pb-Ag-Au-Cu Shangri-La mine. Similar geometry, but a larger scale anomaly is also seen at the intersection of a north- and northwest-trending structure at Speewah Dome (labelled in Figure 2a). This region is also interpreted to be Hart Dolerite and Speewah Group sedimentary rocks. Speewah Dome is a prospective area for Cu-Au, fluorite, V-Ti and Ni-PGE.

Forward Modelling

The 310 km forward model is presented in Figure 3. Large-scale differences between the Speewah/Kimberley Basin and the Lamboo Province can be seen. A 1 km layer of magnetic and dense material is modelled at 400m to 2km depths from the start of the profile in the west, to x = 230 km. Faults have been modelled in this portion of the profile, which do not have any association the geological maps, which show a paucity of faults at the surface in the western portion of this section. These faults are suggested to be blind. From 230 km, modelling suggests that the western and central zones are under cover if they extend this far north. Major faults known at the surface have been modelled (Figure 3c – e.g. the Ivanhoe, Cockatoo, and Halls Creek Fault) as well as minor ones (Dillon Springs Fault).

Comparison of MT and potential field modelling

Figure 4 shows an overlay of the potential field model (grey line) with the MT data and interpretations of Spratt et al. (2014b) shown with white dashed lines. There is some agreement in the position and geometry of the structures interpreted from each data set. Differences can be seen in penetration depth, such as the Halls Creek Fault (near station 155), where the potential field suggests only an upper crustal extent, whereas the MT suggests a middle to lower crustal extent. Some interpreted structures are either faint, or absent in one model, but obvious in the other, highlighting the usefulness of jointly interpreting datasets that respond independently to three different physical fields (magnetism, density and resistivity).

A noteworthy example is the King River fault (Figure 4 – station 125), which is interpreted as a minor, surficial structure from the forward model. The MT however, reveals a much deeper, extensive and larger-scale west-dipping structure that bounds a voluminous resistive anomaly to the east (the footwall, if this is a fault) and a strong conductive anomaly on the western side (or hanging wall). The conductive anomaly has been examined with 3D MT inversion by Spratt et al. (2014a)to find that it has a north-northeast strike, sub-parallel with interpreted orientation of the King River Fault (Figure 2a and b). The association of this conductive anomaly with the deeper extent of the King River Fault, and possible structural control bears closer for implications to mineral prospectivity. While the along-strike presence of this conductive anomaly to the south cannot be confirmed due to a lack of data, it may be that the conductor could extend under Speewah Dome. If this were the case, it could provide some insight to the processes that have led to mineralisation observed there.

Before much more speculation can be made, a feasible source for the conductive anomaly needs to be decided upon. Three options were considered: saline water; interconnect sulphides; and graphite. Spratt et al. (2014b) state long residence times and a lack of fluid regeneration mechanisms, in addition to high temperatures (125°C to 250°C) at this depth, preclude the presence of water. The presence of sulphides can provide the conductivity to produce such an anomaly, though the values obtained through inversion (4 to 10 Ω·m) likely too low (Keller, 1971). The presence of graphite, most likely with some sulphides, is the most feasible conclusion.

The presence of graphite on the King River Fault would indicate a history of hydrothermal activity and fault reactivation (Nieuwenhuis et al., 2014; Wannamaker and Doerner, 2002) and suggests it may have acted as a conduit to mineralising fluids. The surface trace of the King River Fault is juxtaposed with the Frasnian Cockatoo Group rocks, which contain a unit of dolomitised carbonaceous rocks, identified by Occhipinti et al. (2015), and present a strong possibility for Pb-Zn type mineralisation (Figure 2a and b).

CONCLUSIONS

Results of an integrated geophysical investigation of the northern part of the east Kimberley have been presented. The results show that jointly interpreted geophysical data can reveal a robust model for mineralisation with judicious use of geological constraints. Several large-scale structures have been identified from the potential field data, the MT, or both, and describe crustal architecture permissive to mineralisation, and location of a site worthy of further examination for base metals.

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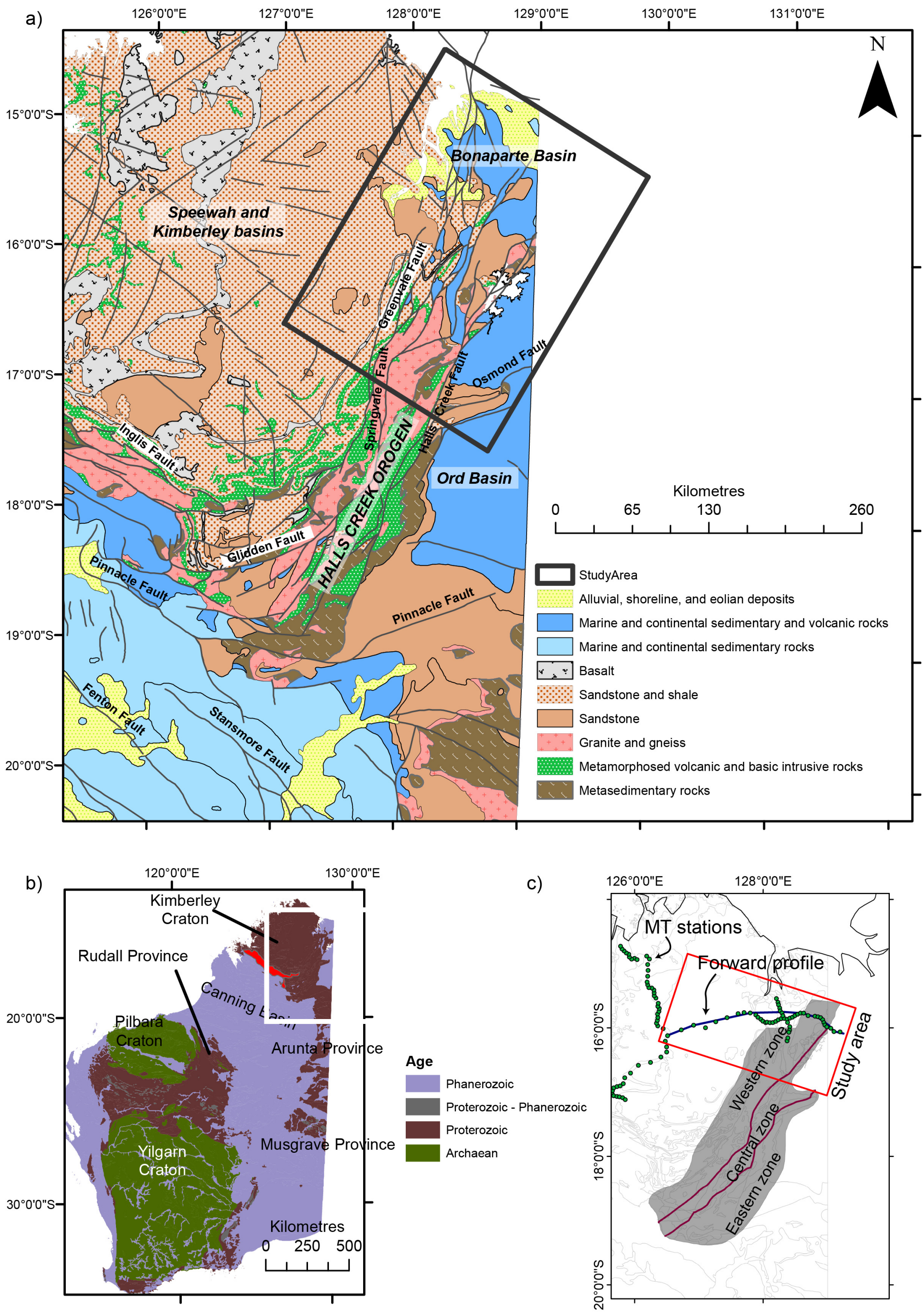

Figure 1. a) Map of the east Kimberley region showing major tectonostratigraphic units of the Lamboo Province (Tyler et al., 2005). b) Main tectonic units in Western Australia and location of study area. c) Shaded areas indicating the location of the western, central and eastern zones defined by Tyler et al. (1995) within the study area.

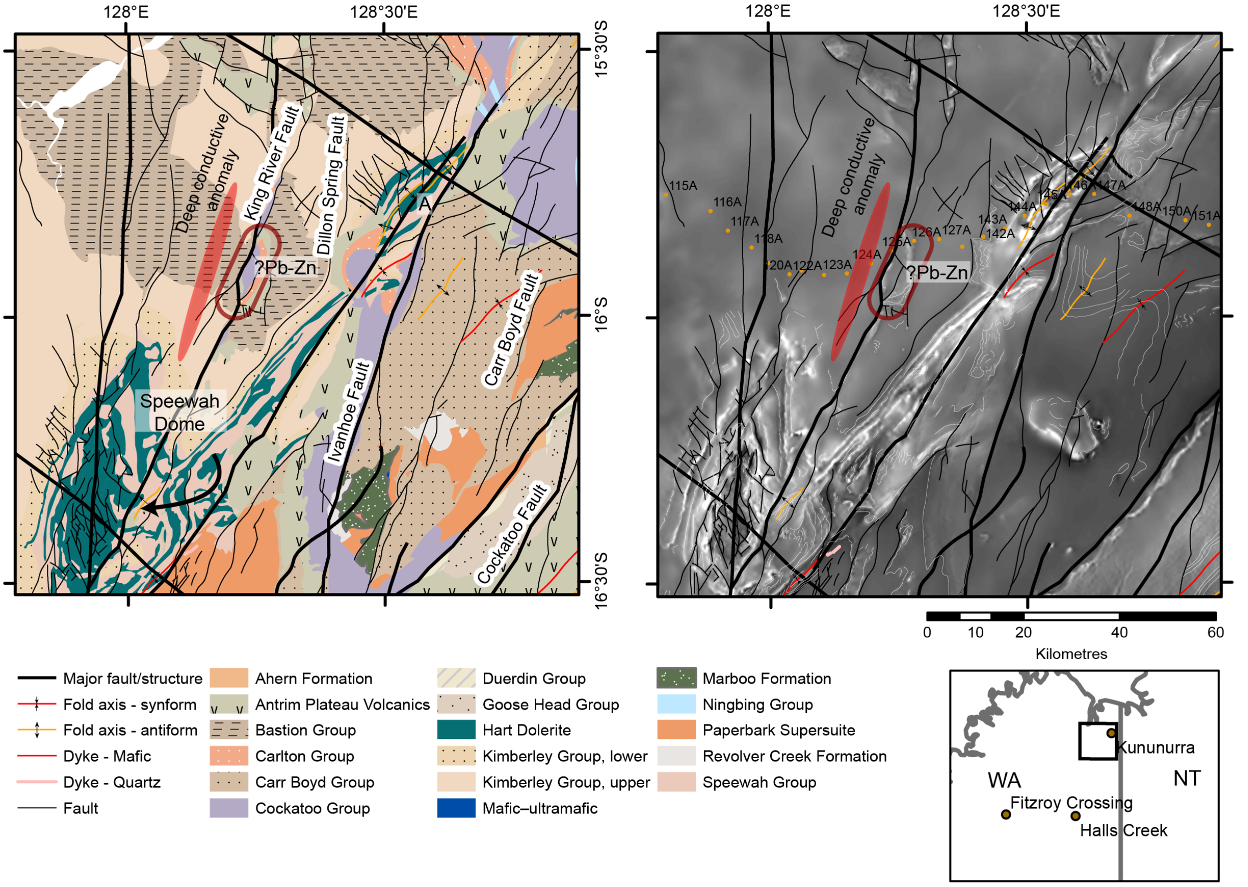

Figure 2. Detailed geophysical structural interpretation of the study area. a) Interpreted structure overlying geology. b) Interpreted structure overlying TMI magnetic data. Location of MT stations indicated with green points. The position and orientation of a deep conductive anomaly is shown with a filled red ellipse. The location of potential Pb-Zn mineralisation is shown with a hollow red ellipse.

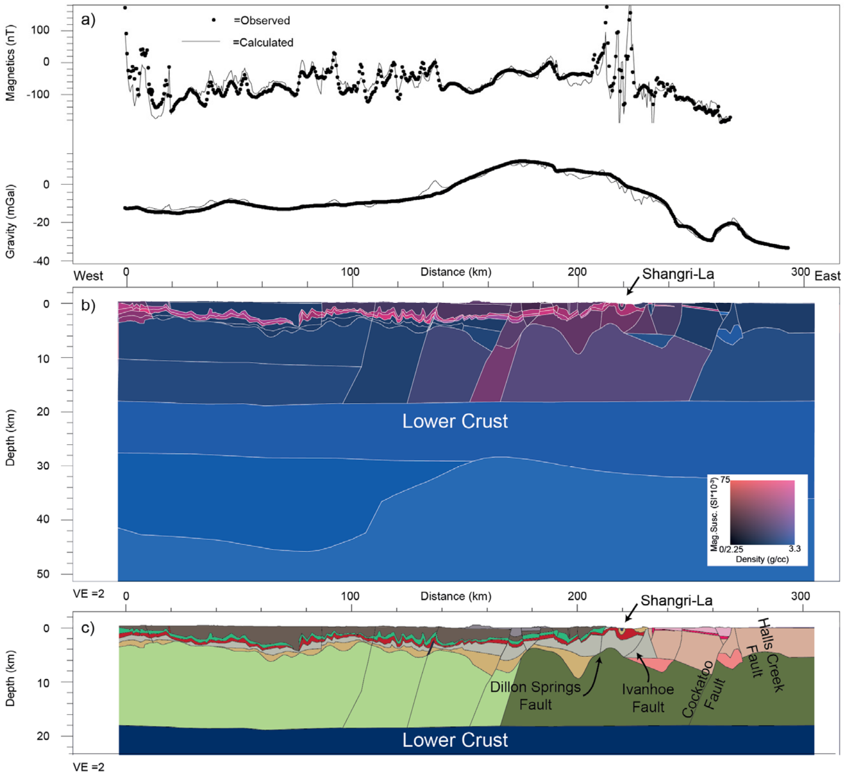

Figure 3. Combined gravity and magnetic model along the profile shown in Fig. 1c. The profile is viewed from the south, with the section starting at the left-hand side in the west, and finishing to the east. VE = x2. a) Observed geophysical single from magnetics and gravity compared with the calculated response. b) Petrophysical model used to forward model the calculated response. c) Geological section interpreted from the petrophysical model. Note section in part c) is cut off at c. 18km.

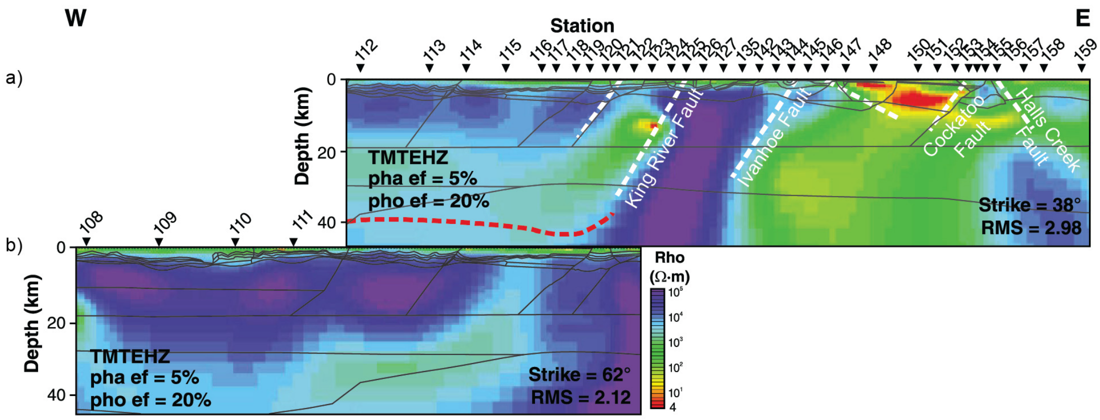

Figure 4. Comparison of the potential field and MT modelling. Two sections are shown as each have been modelled assuming different a different strike resulting in lower RMS error: a) strike = 38°; b) strike = 62° – see Spratt et al. (2014b) for details on modelling. The blue colours represent resistive areas and the warm conductive areas. The dashed white lines mark steeply dipping features observed in the upper crust; the red dashed line marks the approximate crust–mantle boundary (Spratt et al., 2014b). The thin grey lines overlying the MT sections for comparison are the boundaries modelled from the forward model shown in Fig. 6. Modified from Spratt et al. (2014b).