The conductivity structure of the Georgina-Arunta region from magnetotelluric data

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SUMMARY

We present an updated resistivity model from inversion of the 09GA-GA1 deep magnetotelluric survey, also known as the Georgina-Arunta survey. The data were originally collected in 2009 under Geoscience Australia's Onshore Energy Security Program, together with deep seismic reflection data along the same line. The magnetotelluric data comprise broadband and long-period data. The broadband data were originally processed to a bandwidth of 0.04 s to 100 s, but have been reprocessed yielding an extended bandwidth of 0.04 s to 1000 s, which improves the resolution of deeper (>20 km depth) structures. Inversions have been carried out using the ModEM 3D inversion code given that the data indicate the presence of 3D geoelectric structure. The updated resistivity model reveals that the Casey Inlier and Irindina Province are associated with high resistivities (>2000 Ωm). In contrast, the Aileron Province, which underlies and surrounds the Irindina Province, is predominantly conductive (resistivities <50 Ωm). The Georgina Basin is associated with low resistivities, as would be expected for a sedimentary basin, while the Amadeus Basin is associated with low resistivities in the southern part of the line (where it overlies the Casey Inlier), and higher resistivities further north.

Key words: magnetotelluric, resistivity, seismic

INTRODUCTION

The 09GA-GA1 deep magnetotelluric (MT) and seismic reflection survey (Figure 1) was collected in 2009 under Geoscience Australia (GA)'s Onshore Energy Security Program. The survey, also known as the Georgina-Arunta line, extends approximately north-south across the Georgina Basin, Irindina and Aileron provinces of the Arunta Region, across the Casey Inlier and onto the northeastern Amadeus Basin (Figure 1; Korsch *et al.*, 2011).

The MT data comprise both broadband and long-period data to provide information on the shallow and deep resistivity structure respectively. In 2011, the broadband data were processed to a period range of 0.04 s to 100 s, while the long period data were processed to a period range of 10 s to 10000 s (Nakamura *et al.* 2011). Preliminary 2D inversions were carried out using the Rodi and Mackie (2001) inversion software (Korsch *et al.* 2011).

The seismic reflection data were interpreted by Korsch *et al.* (2011) providing an improved understanding of the crust in this region. The deep crust was defined in terms of five regions, the Casey Inlier, Aileron, Irindina and Davenport provinces, and the Ooratippra Seismic Province, each of which is separated by major crustal-scale faults, and overlain by Neoproterozoic – Early Palaeozoic sedimentary basins (Korsch *et al.* 2011). In some places (e.g. Casey Inlier and Georgina and Amadeus Basin) the structures identified in the seismic reflection images were well-defined by the MT inversions, in others, the correlation was less clear (Korsch *et al.* 2011).

The broadband data have now been reprocessed with an updated calibration file, to an extended bandwidth of 0.04 s to 1000 s. In addition, inversions have been carried out using the ModEM 3D inversion code. These inversions show striking similarities to the deep crustal seismic reflection profile, collected along the same traverse as the MT data.

METHOD AND RESULTS

The MT data comprise 39 broadband stations with a spacing of 10 km, and 18 long period stations spaced 20 km apart (i.e. 18 stations with broadband and long period data, and 21 stations with broadband only; Duan and Milligan 2010, Nakamura *et al.*, 2011). At each broadband station, the magnetic and electric fields were recorded in two orthogonal horizontal directions (east-west and north-south) for 30-60 hours at a sampling rate of 0.001 s. Each long period station recorded the east-west, north-south and vertical magnetic field, while the electric field was recorded in two orthogonal horizontal directions. The long period stations were recorded for 5 to 7 days at a sampling rate of 0.1 s. Detailed acquisition parameters are described in Nakamura *et al.* (2011).

The broadband data were reprocessed using the robust algorithm BIRRP (Chave *et al.* 1987, Chave and Thomson, 2004). Remote reference data were used where available (Gamble 1979). The data were processed to a bandwidth of 0.003 s to 1300 s at most stations (depending on data quality). This is a wider bandwidth than the original processing (0.003 s to 100 s; Nakamura *et al.* 2011). The reprocessed data have been merged with the long period data taken from Duan and Milligan (2010) for modelling and interpretation.

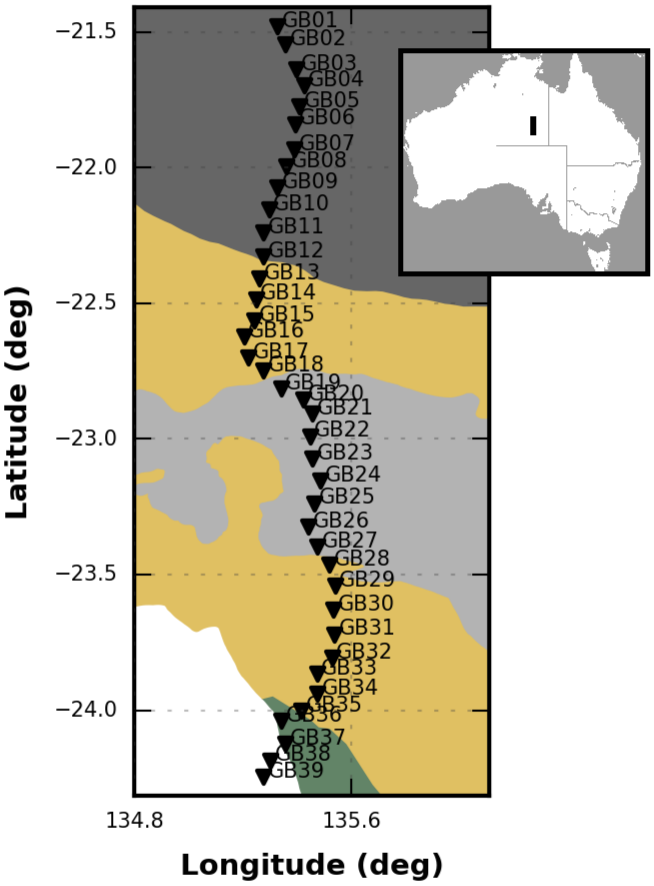

Figure 1: Magnetotelluric station locations shown with key geological provinces (from Chopping et al. 2013). Dark grey = Davenport Province, yellow = Aileron Province, light grey = Irindina Province, green = Casey Inlier, white = Warumpi Province.

Figure 2 shows all the data plotted as a phase tensor pseudosection. The MT phase tensor is defined as $\Phi = Re(Z)^{-1}Im(Z)$ and can be depicted as an ellipse (Bibby, 1986; Caldwell *et al.*, 2004). If the geoelectric structure is 1D, the major and minor axes of the ellipse are the same, i.e. the ellipse is a circle. If it is 2D or 3D, the major and minor axes are different (Bibby, 1986; Caldwell *et al.*, 2004). To distinguish between 2D and 3D geoelectric structure, the skew angle β can be introduced. The angle β is defined by the following equation:

$$\tan 2\beta = (\Phi_{12} - \Phi_{21})/(\Phi_{11} + \Phi_{22})$$

where Φ_{XY} are elements of the impedance tensor Φ. Caldwell *et al.* (2004) consider that MT data are 3D in the case where β is small, which they define as between -3° and 3°.

The non-circular shape of the phase tensors in Figure 2 indicates that there are regions of 2- to 3-dimensionality at almost all stations. We have coloured the phase tensor ellipses by the skew angle β, and these show that large parts of the data have β < -3° or β > 3°. In fact, the magnitude of β is greater than 6° in many places. Thus, the data clearly indicate there is 3D geoelectric structure beneath the Georgina - Arunta survey, and therefore a 3D inversion code is needed to adequately model the data.

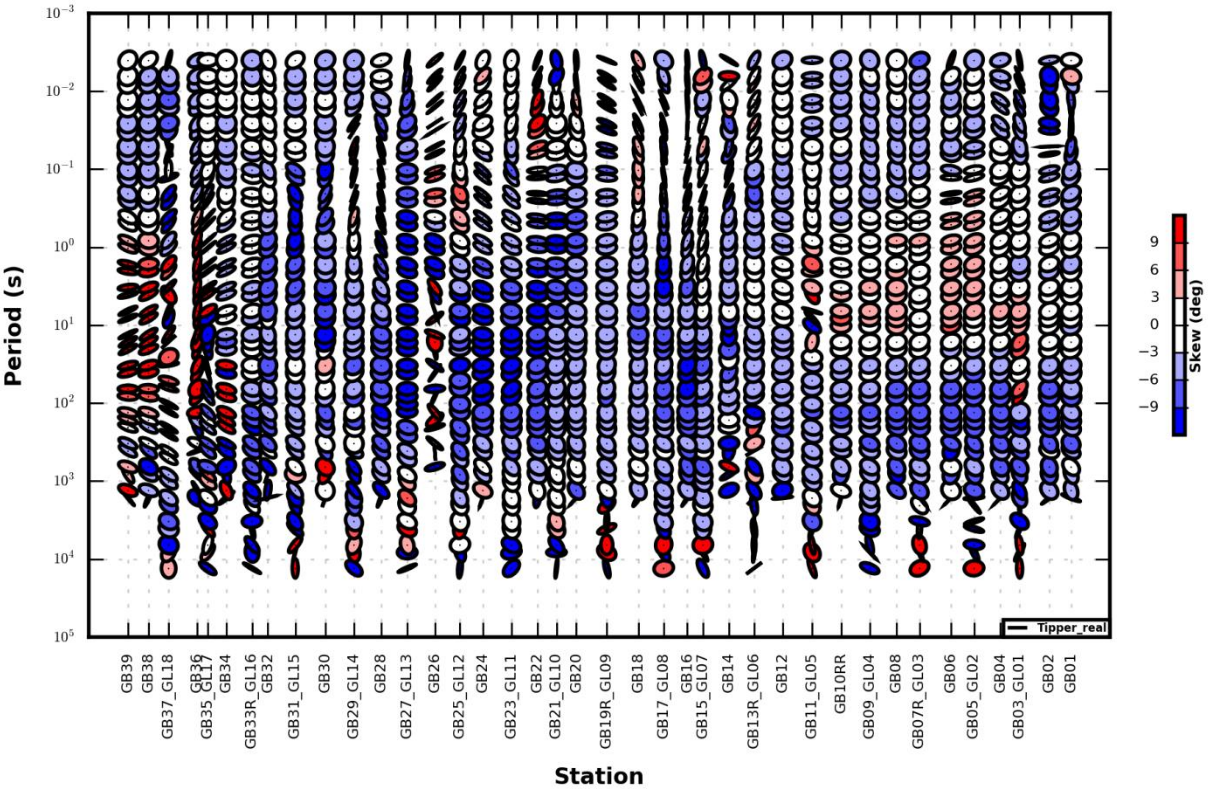

Figure 2: Merged (long period and broadband) Georgina – Arunta MT data shown as phase tensor ellipses from south to north along the line. Coloured by the skew angle β (defined in text).

Given that the data indicate 3D geoelectric structure, inversions were carried out on the full impedance tensor data using the ModEM 3D inversion code (Egbert and Kelbert, 2012, Kelbert *et al.* 2014). The horizontal cell size was 2.5 km, with seven padding cells in the north, south, east and west direction resulting in a horizontal extent of 462.5 km (east-west) and 735 km (north-south). The vertical cell size increased with depth, starting at 10 m at the surface, increasing to 10 km at 100 km depth. Error floors of 5 % of the geometric mean of the two off-diagonal impedance tensor elements ($0.05 * \sqrt{|Z_{XY}Z_{YX}|}$) were applied (after Egbert *et al.* 2012). After 239 iterations the model reached a root-mean-square (RMS) misfit of 2.04, where the misfit is defined as the absolute ratio of the difference between the data and the modelled response, and the data error.

This preliminary inversion (Figure 3) shows several notable features. South of the Casey Inlier, the Amadeus Basin is conductive (2.5 Ωm), has a limited depth extent (~2-3 km) and terminates abruptly against the southern margin of the resistive Casey Inlier (>2000 Ωm). This geometry is consistent with the seismic reflection data. North of the Casey Inlier, the Amadeus Basin coincides with a very thin conductive feature underlain by a thicker, more resistive layer (~500 Ωm). Below the Amadeus Basin in the Aileron Province, the crust is conductive (~50 Ωm to 100 Ωm). The Milly Fault, which intersects the Casey Inlier, corresponds with a small, conductive feature of limited depth extent (~5 km).

In the southern part of the Aileron Province, the seismic data indicate the presence of several shear zones. This region coincides with a resistive feature (labelled A in Figure 3), which extends to about 10 km to 30 km depth. Further north, the Irindina Province corresponds to a resistive feature (B in Figure 3) down to around 10 km to 20 km depth. The geometry of the resistive layer shows some differences to that of the Irindina Province (as interpreted by the seismic data), showing undulations that are not present in the seismic interpretation. Beneath this feature (part of the Aileron Province), resistivities are lower (~50 Ωm). Bounding this feature to the north is a northward dipping resistive feature between stations GB21 and GB16 (C in Figure 3).

The northern part of the line corresponds to the Davenport province. In this section (stations GB16 to GB01; labelled D in Figure 3), there is also a resistive layer, underlain by a region of higher conductivity, however this appears to be more flat-lying than in the Irindina Province. This layering shows broad similarities in geometry to the weakly reflective seismic package identified by Korsch *et al.* (2011) extending down to 3.0 s to 4.7 s two way travel time (TWT; upper part of the pink region in Figure 3).

At depths greater than about 8 km to 15 km depth in region D, the crust is more conductive (30 Ωm to 100 Ωm). The upper part of this region corresponds to a moderately reflective layer, interpreted by Korsch *et al.* (2011) to be the basement to the Davenport Province. The Lower Crust in this region (Ooratippra Seismic Province) does not appear to be resolved by the MT data. The inversion suggests that it too is moderately conductive (~100 Ωm) however it may simply be too deep to be resolved by the MT data.

At shallower levels, the Georgina Basin is resolved as a shallow (1 km to 2 km deep), conductive feature, consistent with the interpretations of the seismic reflection data.

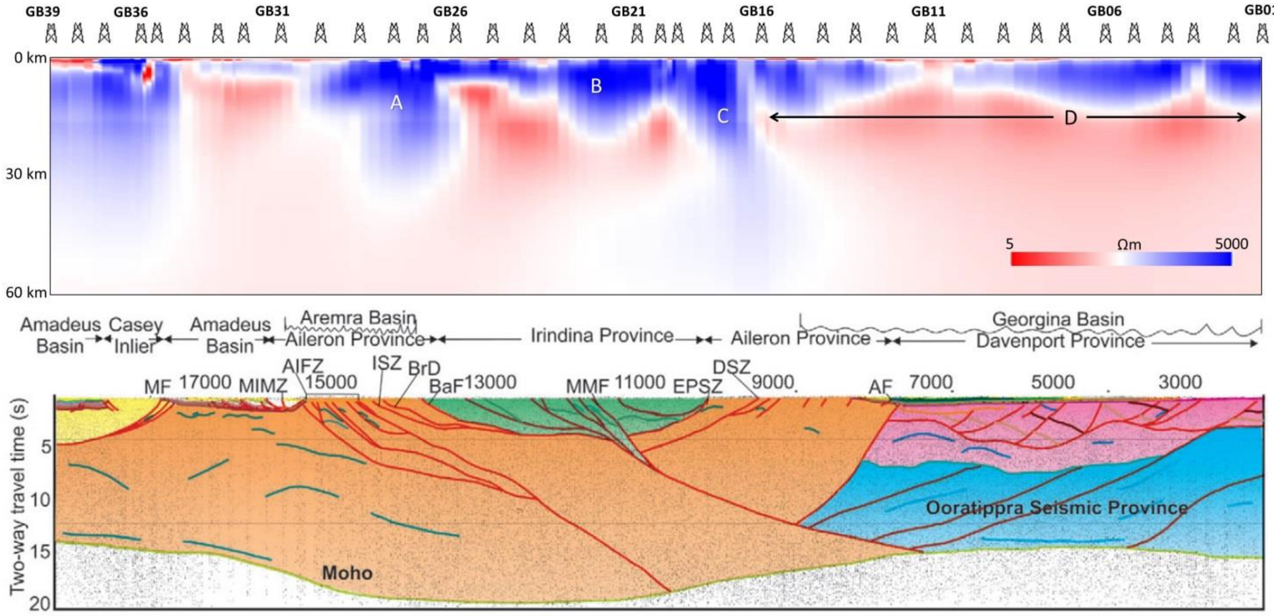

Figure 3: Preliminary resistivity model (top) and migrated seismic section for Georgina–Arunta seismic line 09GA-GA1 showing interpretation and key provinces (bottom; after Korsch *et al.*, 2011). Fault abbreviations: MF – Milly Fault; MIMZ – Mount Isobel Mylonite Zone; AIFZ – Atnarta Imbricate Fault Zone; ISZ – Illogwa Shear Zone; BrD – Bruna Detachment; BaF – Basil Fault; MMF – Mount Mary Fault; EPSZ – Entire Point Shear Zone; DSZ – Delny Shear Zone; AF – Atuckera Fault. Display shows vertical scale equal to horizontal scale (assuming crustal velocity of 6000 ms^{-1}).

CONCLUSIONS

Broadband data from the 09GA-GA1 deep MT survey have been reprocessed; yielding an increased bandwidth of 0.04 s to 1000 s (compared to 0.04 s to 100 s in the original processing). The newly processed data have been inverted using the ModEM 3D inversion code, which was not available when the data were originally collected, and allows adequate modelling of the data given that they contain 3D structure in many areas.

The updated resistivity model reveals several features that correlate with structures identified in the deep seismic reflection data collected along the same line. These include the Milly Fault, which appears as a conductive feature of limited depth extent (<10 km), the resistive Casey Inlier, and the conductive Amadeus and Georgina Basins. In the Davenport and Irindina provinces, there are some similarities between the structures identified in the MT, and those in the seismic, however there are some differences in the geometries defined by the two datasets. Further modelling and sensitivity testing will be carried out to better define some of the key features identified in the inversions and test their robustness.

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