An Electrical Conductivity Model of the Southeast Australian Lithosphere

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SUMMARY

Data from 68 broadband magnetotelluric stations were inverted to obtain a 2D electrical resistivity model beneath the Delamerian Orogen in southeast Australia along a 150 km east-west transect. Station spacing of 5 km in the west and ~2 km in the east resolved structure with changes in resistivity from 10-10,000 Ωm occurring laterally over several kilometres. To the west, the crust is generally resistive, with a more complex structure to the east involving narrow paths of low resistivity (10-300 Ωm). These conductive regions extend from Moho depths up to the surface and align with fault structures. The narrow conductive pathways possibly track mineral alterations from reactions with mantle fluids moving upwards late in the Delamerian Orogeny.

Key words: magnetotellurics, lithosphere, Delamerian

INTRODUCTION

Uncertainties exist regarding the physical state of the crust and upper mantle including the hydration of the upper mantle, the formation and deformation history of the sub-continental lithospheric mantle, and broad-scale heterogeneity of the continental lithosphere.

Knowledge of the Earth's structure at depth is sparse because xenolith/xenocryst data (O'Reilly & Griffin, 1985) and geophysical surveys are the only means of investigation. Most geophysical methods lack the ability to see much deeper than surficial depths; seismic tomography and electromagnetic (EM) techniques are two exceptions to this (Graeber *et al*., 2002; Rawlinson & Fishwick, 2011).

Magnetotellurics (MT) is a passive electromagnetic technique that records magnetic and electric field variations in the Earth due to an inducing horizontal magnetic field (Tikhonov, 1950; Cagniard, 1953). The fluctuations in the natural magnetic fields and induced electric fields are measured in orthogonal directions at the Earth's surface. Variations in resistivity could occur from changes in one or more of the following variables; temperature, melt fractions, hydration and trace mineralogy (Selway, 2012).

In this study, new and existing broadband MT data (period of 0.0064 s-81.92 s) of the Southern Delamerian transect were inverted using the smooth 2D modelling code Occam (Constable *et al*., 1987, de Groot-Hedlin & Constable, 1990). The eastern part of the existing 2D line was in-filled, to obtain the high resolution required to delineate the complex crustal structure in this region as evident from reflection seismic data.

Reflection seismics are useful in resolving major fault and structural boundaries within the crust and joint interpretation of EM data with these boundaries in mind is very effective (Jones, 1987). The results were interpreted using the 2D electrical resistivity model in conjunction with interpretations from the 2009 L193 AuScope Southern Delamerian Seismic Line, funded by AuScope, Geoscience Victoria and Geoscience Australia.

Particular items addressed in this study include; the length and resistivity-scale over which changes in the lithosphere occur, comparisons of mantle and crustal heterogeneity, and how crustal heterogeneity relates to crustal deformation imaged by reflection seismic.

Geology

The lithosphere of southeast Australia was formed during a time of Palaeozoic Orogenesis that began in the Early Cambrian, ceasing in the Middle Triassic (Glen, 2005). This new and reworked lithosphere covering the eastern third of Australia comprises the eastward-younging Tasmanides. Orogens within the Tasmanides include the Delamerian Orogen, the Lachlan Orogen, and along the east coast the New England Orogen (Foster & Gray, 2000).

The Delamerian Orogeny commenced 514 Ma (Foden *et al*., 2006), ceasing with a period of rapid uplift, cooling and extension, 490 Ma. The orogen consists of Precambrian and Early Cambrian rocks that experienced deformation and metamorphism in the Cambrian (Foden *et al*., 2006). The Delamerian Orogen separates the older Precambrian cratons to the west from the younger Palaeozoic to Mesozoic orogenic belts of eastern Australia. The Adelaide Fold Belt in South Australia, western Victoria and parts of western New South Wales and Tasmania make up the Delamerian Orogen. The MT transect involved in this study runs east-west across the Adelaide Fold Belt and the Glenelg and Grampian-Stavely Zones of the Glenelg Complex in western Victoria.

METHOD AND RESULTS

Data Acquisition

Data was collected in two stages along the Southern Delamerian seismic line in western Victoria. The first stage in 2009 consisted of 39 stations (SD01-SD39) along a 150 km east-west transect and a 50 km north-south transect, with 5 km spacing (see Figure 1). Only the east-west transect is used in

this study. Preliminary inversions of the data showed a complex resistivity structure to the east and stations east of SD24 were in-filled in June 2012 with 37 stations reducing site spacing from 5 km to about 2 km (DB24A-DB38C).

AuScope equipment recorded the two horizontal components of the electric field (Ex-north-south and Ey-east-west) using ~50 m dipoles, and the horizontal components of the magnetic field (Hx and Hy). Each station recorded for 20-40 hours at a frequency of 1000 Hz, with more than one station recording at any point in time to enable remote referencing to improve data quality (Gamble *et al*., 1979).

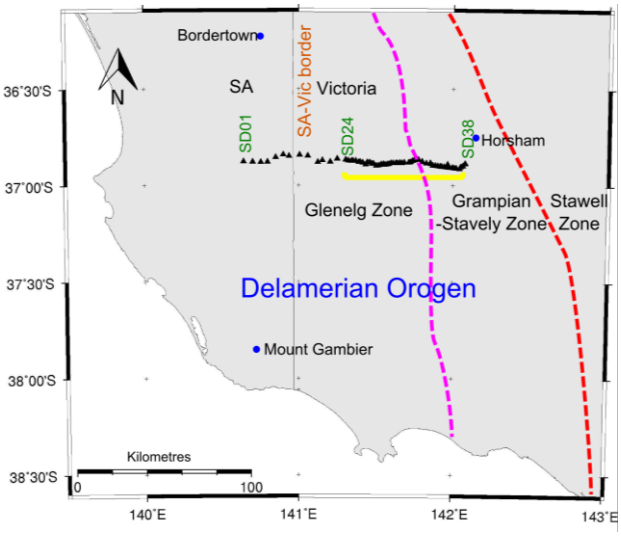

Figure 1. Map showing location of the magnetotelluric station locations of the 150 km east-west transect. Black triangles represent stations. The section highlighted in yellow was in-filled in 2012 with additional stations. The Delamerian Orogen incorporates the Glenelg, Grampian-Stavely and Stawell Zones separated by the Yarramyljup Fault (magenta dashed line) and the Moyston Fault (red dashed line) respectively.

Data Processing

A robust remote referencing code (BIRRP) (Chave & Thomson, 2004) converted time series data into the frequency domain. EDI files containing information about the impedance tensor were output from this code. A notch filter removed noise from nearby powerlines at frequencies of 50, 150 and 250 Hz.

Data quality was visually determined using plots of the apparent resistivity and phase values from the impedance tensor, and numerically using coherence plots. If plots showed noisy data or coherence of the electric and magnetic responses were low, a different time window was chosen for processing. Geological, magnetic and gravity maps show an approximate north-west regional strike and strike analysis returned a value of 49 degrees west of North. The impedance tensor was rotated by this angle prior to inversion. The 2D inversion code, Occam (Constable *et al.*, 1987, De-Groot Hedlin & Constable, 1990), was used to invert the data after 3D data points determined by having skew values (β values) outside of ±5°, were removed (see Caldwell *et al.*, 2004 and Bibby *et al.*, 2005 for theory of this value).

Occam Inversion

Figure 2 is the model resulting from the 2D inversion. The crustal resistivity is heterogeneous with much more complexity in the east. The western half is predominantly resistive (>10,000 Ωm), consisting of rift basalts and Proterozoic basement. To the east large changes in resistivity (ΔΩm > 10,000) occur in just a few kilometres. In the middle of the transect extending from an approximate depth of 10-40 km is a highly conductive region (~1-300 Ωm), C1, in Figure 2. To the east are two more notable features; C2 with a resistivity of about 1000 Ωm extending to the surface, and C3 with a minimum resistivity of ~10 Ωm. The background crust resistivity varies from about 5000-10,000 Ωm and the mantle has an average resistivity value of approximately 1000 Ωm.

Inversions were repeated with order-of-magnitude variations in starting resistivities to test model robustness. Each model showed near-identical features with the three main conductive regions appearing in every inversion with similar resistivity values, indicating confidence and robustness of the main model features.

Geological Interpretation

Seismic interpretations (currently being conducted by the Geological Survey of Victoria) show a large east-dipping fault which leads up from the Moho and through the large conductive region, C1, in Figure 2. Foden *et al.* (2006) argues for slab detachment and mantle upwelling near the end of the Delamerian Orogeny and it is possible that mantle fluids associated with the upwelling have moved up this fault, altering the surrounding rocks and drastically reducing the electrical resistivity.

The width of the conductive regions in Figure 2 appear to be about 5 km, but a combination of the smooth modelling technique and the diffusive nature of MT means that resolution at depth is poor and for this reason these low resistivity zones are very likely to have a smaller width and be much more concentrated along fault zones.

At station SD33, the MT transect is intersected by the late Delamerian structure, the Yarramyljup Fault (Morand *et al.*, 2003). The Yarramyljup Fault forms the boundary of the Glenelg Zone to the east and the Grampian-Stavely Zone to the west (Cayley & Taylor, 1998). The new seismic shows complexity around this boundary, with a number of near vertical strike-slip faults cutting the crust. From Figure 2, it can be seen that the resistivity is slightly lower in this region, possibly due to fluid movement from mantle or deep crustal levels moving up this zone of complex faulting.

When comparing the electrical resistivity model with the rock types from seismic interpretation, there appears to be a correlation between fluid alteration occurring to rocks of mafic composition, with the sediments remaining largely unaffected. An example of this is in Figure 2, above C3, a change in resistivity from 10 Ωm to 1000 Ωm approximately coincides with a change from mafic igneous (seismically reflective) rocks to sediments.

CONCLUSIONS

Smooth 2D inversions indicate a heterogeneous crust with lateral variations in resistivity of 10,000 Ωm over several km's. Despite the distinct crustal heterogeneity, the sub-Moho lithosphere contains little expression of the events that shaped the crust with regards to resistivity. Conductive regions in the model possibly correspond to pathways where mantle fluids have moved up faults concentrated along the boundary between the Glenelg and Grampians-Stavely Zones, late in the Delamerian Orogeny, altering minerals particularly in the mafic igneous rocks.

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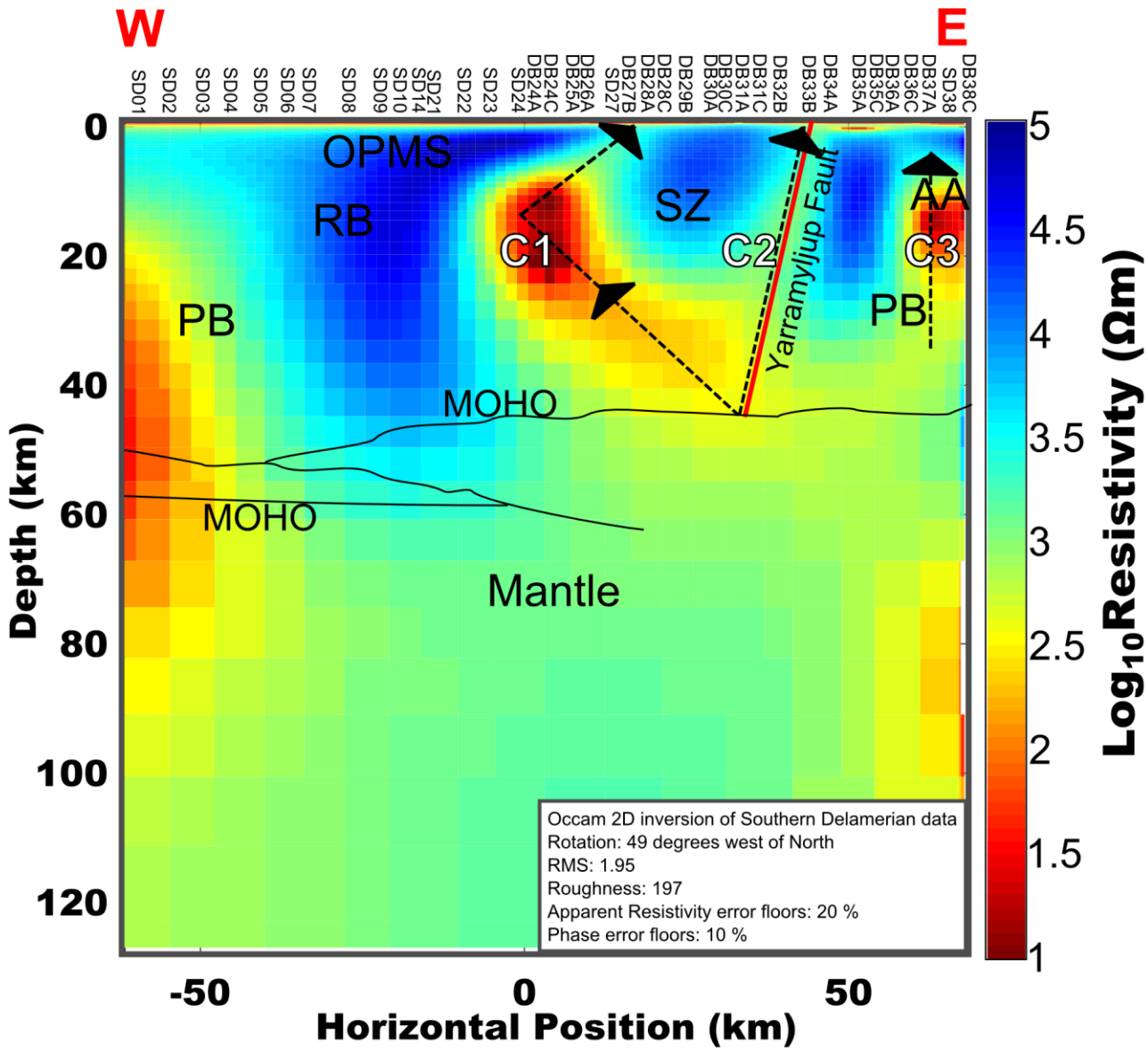

Figure 2: An Occam 2D inversion of magnetotelluric data from the Southern Delamerian transect. The data were rotated by an angle of 49 degrees west of North before inversion. The root mean squared value achieved was 1.95 with a model roughness of 197. Error floors for the inversion were 20 % for the apparent resistivity and 10 % for the phase. Red regions are conductive (i.e. low resistivity) and blue are resistive. Abbreviations: PB-Proterozoic basement, RB-Deformed rift basalt sequence, OPMS-deformed oceanic passive margin sediment, SZ-shear zone, AA-Andesite arc edifice, erupted through ophiolites. C1, C2 and C3 label conducting regions. The Moho is extracted from seismic interpretations.