# A magnetotelluric survey across the Albany–Fraser Orogen and adjacent Yilgarn Craton, southwestern Australia

by

J Spratt[1], M Dentith[2], S Evans[3], CV Spaggiari, K Gessner, and IM Tyler

## Introduction

Magnetotelluric soundings at 163 locations across the Albany–Fraser Orogen, southwestern Australia, have provided 2D conductivity models of the crust and uppermost lithospheric mantle beneath four regional transects. Figure 1 shows the locations of stations on regional potential field datasets, and the major tectonic zones.

Magnetotellurics (MT) is an electromagnetic geophysical method that involves measuring and relating natural time-varying electric and magnetic fields, induced by the interaction between the Earth's geomagnetic field and solar winds and by worldwide thunderstorms, in order to resolve the electrical conductivity structure of the subsurface of the Earth. The relationship between these horizontal and mutually perpendicular fields recorded at each station provides amplitude (apparent resistivity) and phase lags as a function of frequency (or period, the inverse of frequency), commonly referred to as MT response curves. With increasing depth there is an exponential decrease in the amplitudes of the electromagnetic fields, the so-called skin-depth phenomenon. As the depth of penetration — or skin depth — of these fields is directly related to frequency (the lower the frequency, the greater the depth) and the resistivity of the material (the greater the resistivity, the greater the depth), estimates of resistivity versus depth can be made beneath each site.

## Data acquisition and processing

The MT data were collected by Moombarriga Geoscience over four deployments during the period 24 April 2012 to 12 April 2013. Data were acquired at 5–10 km station spacing along roads with station tracks providing information along four main MT profiles: AF3 (same location as seismic line 12GA-AF3); CUN; FR; YFB (Fig.1). Time series data were recorded for an average of 40 hours at each site in an effort to resolve apparent resistivity and phase to a period of 1000 s. In addition, time-domain electromagnetic soundings were made at each MT station comprising the traverses to quantify static shift.

Two horizontal components of the electric field (Ex and Ey) and three components of the magnetic field variation (Hx, Hy, and Hz) were measured at each site except at sites where the vertical (Hz) component was omitted because of difficult site conditions. Electric dipoles and horizontal coils were installed in magnetic north–south and east–west azimuths and the electric dipoles at all sites were approximately 100 m in length. The electric field was measured using non-polarizing (Pb/PbCl2 solution) electrodes. Electromagnetic soundings of the near surface at each station were made using a Zonge ZT20 transmitter and SmarTEM24 receiver with a three-component RVR. A 100 m-sided square transmitter loop (Tx area = 10 000 $m^2$) was used with sides oriented north–south and east–west. The receiver coil had an effective area of 10 000 $m^2$.

The MT data were processed using modern, robust, remote-referencing techniques. Prior to 2D modelling, MT data are typically analysed to determine the regional geoelectric strike direction as well as the degree of dimensionality in order to generate an accurate representation of a 2D Earth. For a 1D Earth the conductivity structure is layered and independent of the geoelectric strike direction. Within a 2D Earth model conductivity structure varies laterally so that the apparent resistivity is different along and across geological, or more correctly geoelectrical strike, therefore apparent resistivities and phases need to be calculated in both directions (or modes). The transverse-electric (TE) mode describes current flowing parallel to geoelectric strike and is predominantly sensitive to current concentration and flow patterns. The transverse-magnetic (TM) mode describes current flow perpendicular to strike and is more sensitive to charges induced on lateral boundaries. Dimensionality and geoelectric strike analysis on these data reveal variable strike directions both laterally and with depth, highlighting the need for regional 3D inversions.

1 Independent consultant, Wakefield, Quebec, Canada

2 Centre for Exploration Targeting, The University of Western Australia

3 Moombarriga Geoscience, Perth, Western Australia

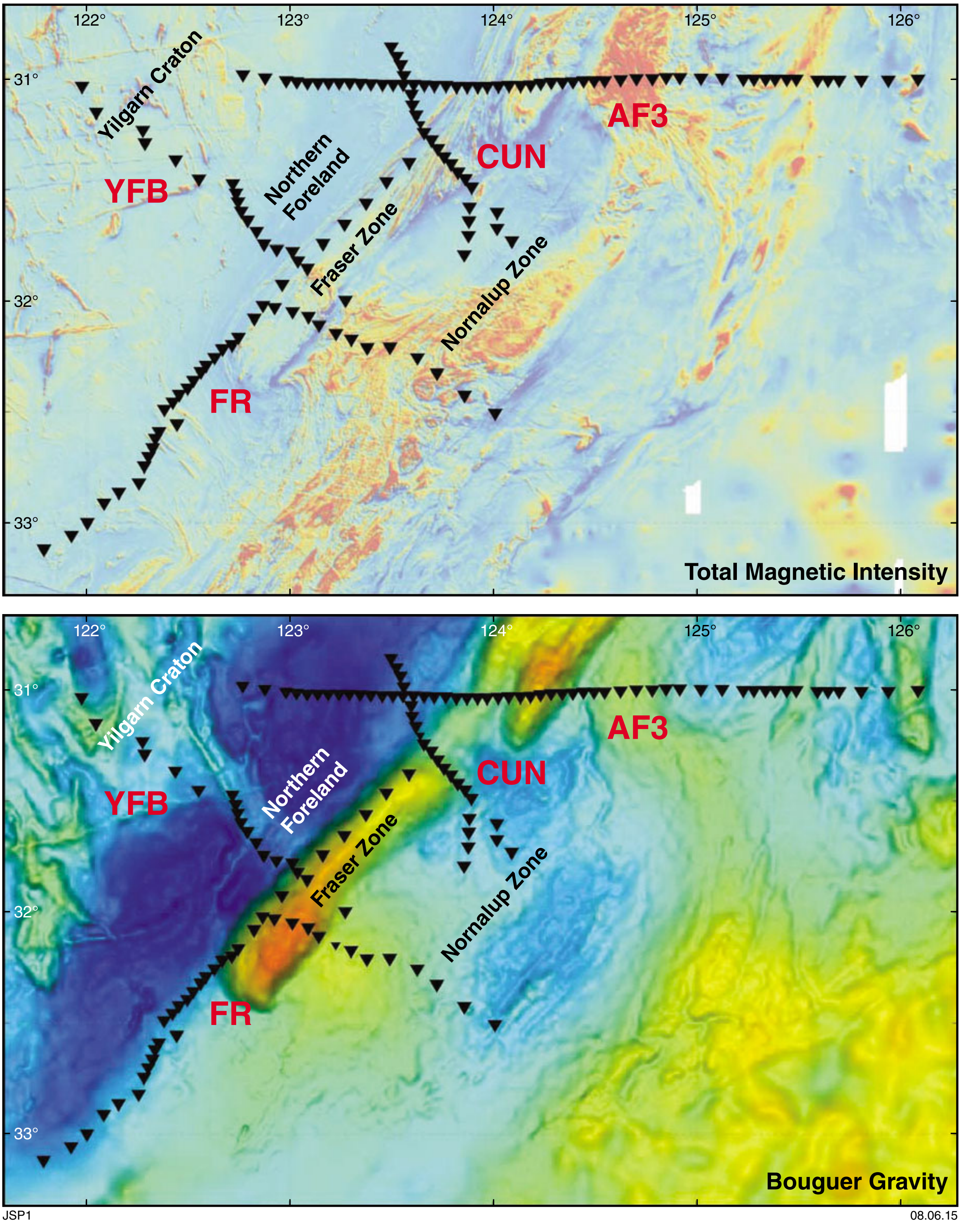


**Figure 1.** **Regional potential field maps showing the locations of the MT stations and modelled profiles**

The WinGlink™ interpretation software package, which implements the inversion algorithm of Rodi and Mackie (2001), was used to generate 2D models along the profiles. Inversions were executed from the MT responses recalculated at the appropriate geoelectric strike direction(s). The inversion program searches for the smoothest, best-fit model with the least deviation from the starting model (Mackie and Madden, 1993). The models derived, therefore, represent the minimum structure required to fit the data with an acceptable misfit.

Models were generated along each profile using different components of the data, with and without the inclusion of data deemed 3D, and at differing strike angles in order to assess the change in the observed conductivity structure and resolve features that are robust in the data. A uniform grid Laplacian operator and tau value of 3 were applied. The preferred models for each profile were generated with data presumed to be affected by 3D distortion removed, have structure that appears to be robust between inversions using different data components and modelling parameters, and have the lowest overall RMS value. The reliability of conductivity variations in the models was tested with feature testing. This involves ascertaining whether the variation has a significant effect on the fit of the modelled data and hence whether it is a required component of the model.

## Interpretations and discussion

The results from 2D modelling are shown in Figure 2. Preliminary interpretation suggests:

- The Yilgarn Craton beneath the northwestern extent of the YFB profile shows anomalously low resistivities within the upper crust, compared to the high resistivities typically imaged beneath stable Archean cratons. These low resistivities may be the result of graphite or sulfide mineralization along fault planes or within metasedimentary units in greenstone belts (e.g. black shales in the Black Flag Group).
- In general, the Albany–Fraser Orogen has high crustal resistivities, with values >10 000 ohm.m, that are cut by steeply dipping or near-vertical, less resistive zones. The high resistivities are consistent with felsic granites and granulite-grade metamorphic assemblages.
- Several of the less resistive, steeply dipping or near-vertical structures show an excellent correlation with the location of known faults. These structures are not highly conductive as they are still within the range typical of crystalline rocks, with values greater than 2000 ohm.m, and are visible by MT methods due to the extremely resistive nature of the host rock. This suggests that the fault zones are dry with minimal mineralization along the fault plane. Most of the faults are shown to extend to lower crustal depths, and some may extend deeper; however, the presence of a lower crustal conductor masks their response.
- The Cundeelee Fault is imaged in profiles AF3 and YFB, and is shown to extend to at least 25 km depth. This contrasts with the interpreted flattening of the Cundeelee Fault at 4.3 s two-way time (TWT) in the seismic data, which equates to approximately 13 km (Spaggiari et al., 2014). However, the electrical structure suggests that the Cundeelee Fault does not correspond with the northwestern edge of the Northern Foreland. Although the Cundeelee Fault is currently defined to mark the boundary between the Northern Foreland and the Yilgarn Craton in this region, the boundary is in fact transitional, as the Northern Foreland represents reworked Yilgarn Craton, and is defined by a difference in strain, and locally, metamorphic grade (Spaggiari et al., 2011). Therefore, the MT data (and also the seismic data along 12GA-AF3, Plate 4), indicate that the effect of reworking on the Yilgarn Craton extends much further northwest than previously recognized. This is consistent with a northeast trending series of long wavelength, low anomalies in regional gravity data (Fig. 1) that correlate well with the MT data. Therefore, in this region, the boundary of the Northern Foreland should perhaps be considered to be further to the northwest.
- Along the FR and AF3 profiles, the Fraser Shear Zone appears to mark the northeastern (FR) and southwestern (AF3) edge of an ~25 km wide, low resistivity zone, which is likely due to the juxtaposition of lower resistivity rocks with high resistivity rocks of the Fraser Zone.
- Although the cause remains uncertain, MT studies worldwide have revealed much of the lower continental crust to exhibit relatively uniform reduced resistivities, typically 10–100 times less resistive than middle to upper crustal values. The enhanced conductivity within the crust of the Yilgarn Craton inhibits the MT data from imaging the base of the crust and model resolution is poor at 40–60 km beneath the northwestern-most extent of the YFB profile. Moderately low resistivities are observed at lower crustal depths beneath each of the four profiles impeding accurate estimates for the electric Moho depth at these locations. However, along parts of the AF3 and CUN profiles an increase in resistivity is observed between 35–40 km, which is consistent with seismic crustal thickness estimates (Kennett, 2014; Korsch et al., 2014).
- In general, where the models are found to be reliable, high mantle resistivities are imaged beneath the Yilgarn Craton. This is consistent with old colder stable lithoshere beneath the Archean Yilgarn Craton that is juxtaposed against juvenile, more fertile Paleoproterozoic upper mantle beneath the orogenic belt.
- The complex tectonic history of the Albany–Fraser Orogen has resulted in a deep electrical structure that is largely 3D. 2D models of the deep structure are, therefore, unreliable with large differences in models derived at differing geoelectric strike angles.

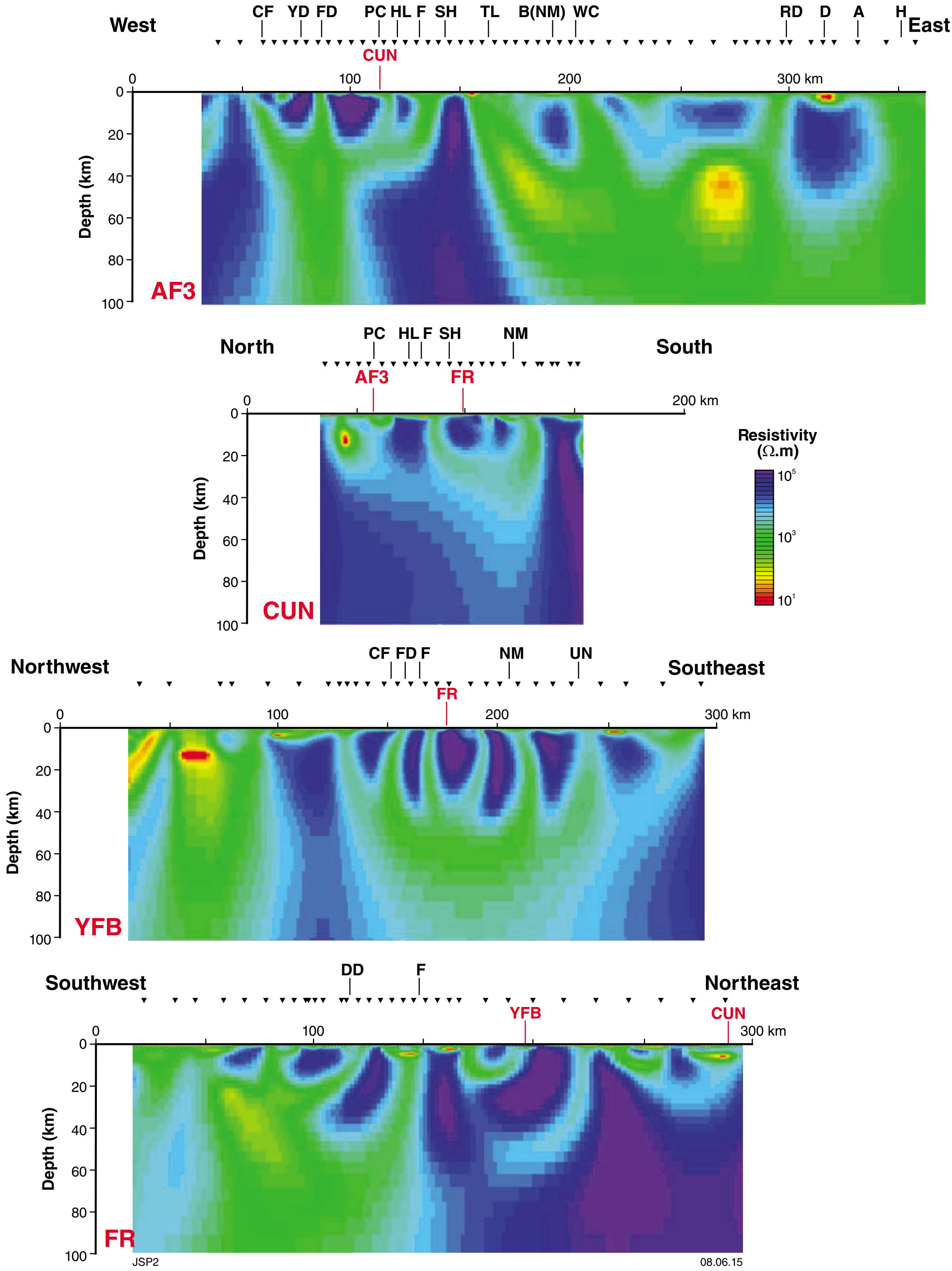


**Figure 2.** **Resistivity cross-sections. See Figure 1 for locations. Various major faults and shear zones are labelled: A – Anniversary; B – Boonderoo; CF – Cundeelee; D – Diesel; DD – Dundas; F – Fraser; FD – Frog Dam; H – Honeymoon; HL – Harris Lake; NM – Newman; PC – Ponton Creek; RD – Rodona; SH – Spy Hill; TL – Transline; UN – unnamed; WC – Woodcutters; YD – Yellow Dam.**

# References

Kennett, BLN 2014, The nature of the lithosphere in the vicinity of the Albany–Fraser seismic lines, *in* Albany–Fraser Orogen seismic and magnetotelluric (MT) workshop 2014: extended abstracts *compiled by* CV Spaggiari and IM Tyler: Geological Survey of Western Australia, Record 2014/6, p. 135–141.

Korsch, RJ, Spaggiari, CV, Occhipinti, SA, Doublier, MP, Clark, DJ, Dentith, MC, Doyle, MG, Kennett, BLN, Gessner, K, Neumann, NL, Belousova, EA, Tyler, IM, Costelloe, RD, Fomin, T and Holzschuh, J 2014, Geodynamic implications of the 2012 Albany–Fraser deep seismic reflection survey: a transect from the Yilgarn Craton across the Albany–Fraser Orogen to the Madura Province, *in* Albany–Fraser Orogen seismic and magnetotelluric (MT) workshop 2014: extended abstracts *compiled by* CV Spaggiari and IM Tyler: Geological Survey of Western Australia, Record 2014/6, p. 142–173.

Mackie, RL and Madden, TR 1993, Three dimensional magnetotelluric inversion using conjugate gradients: Geophysical Journal international, v. 115, p. 215–229.

Rodi, W and Mackie, RL 2001, Nonlinear conjugate gradients algorithm for 2D magnetotelluric inversion: Geophysics, v. 66, p. 174–187.

Spaggiari, CV, Kirkland, CL, Pawley, MJ, Smithies, RH, Wingate, MTD, Doyle, MG, Blenkinsop, TG, Clark, C, Oorschot, CW, Fox, LJ and Savage, J 2011, The geology of the east Albany–Fraser Orogen — a field guide: Geological Survey of Western Australia, Record 2011/23, 97p.

Spaggiari, CV, Occhipinti, SA, Korsch, RJ, Doublier, MP, Clark, DJ, Dentith, MC, Gessner, K, Doyle, MG, Tyler, IM, Kennett, BLN, Costelloe, RD, Fomin, T and Holzschuh, J 2014b, Interpretation of Albany–Fraser seismic lines 12GA-AF1, 12GA-AF2 and 12GA-AF3: implications for crustal architecture, *in* Albany–Fraser Orogen seismic and magnetotelluric (MT) workshop 2014: extended abstracts *compiled by* CV Spaggiari and IM Tyler: Geological Survey of Western Australia, Record 2014/6, p. 28–51.