Geological Interpretation of electrical resistivity models along the SNORCLE Corridors 1 and 1A

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Introduction

Magnetotelluric (MT) soundings completed along LITHOPROBE SNORCLE transect Corridor 1 and 1A cross the Proterozoic Nahanni, Fort Simpson, Hottah, Great Bear Magmatic Arc, Hay River and Buffalo Head terranes, the Archean Slave Province and the Great Slave Lake shear zone (GSLsz). Phanerozoic sedimentary rocks overlie most of the terranes except the Slave Province (Fig. 1). The position of the GSLsz on geological maps (*e.g*., Hanmer *et al*. 1992) is between sites153 and 154, but the centre of the magnetic low with which the shear zone is correlated lies between sites 155 and 156. Examination and analysis of the MT responses (apparent resistivity and phase) has been described previously (Wu *et al.* 2000*a*, 2000*b*; Wu 2001). This paper will focus on the analysis of geoelectric dimensionality and strike and the geological interpretation of MT models.

Geoelectric Strike Angle

The determination of geoelectric dimensionality and strike involved analysis of the MT impedance tensors using Groom-Bailey decomposition and maximum phase difference methods and analysis of induction vectors. Figures 2 and 3 show summary diagrams of the geoelectric strike determined using Groom-Bailey decomposition. The results indicate the variation of geoelectric strike angle with period is remarkably similar for Corridors 1 and 1A.

The geoelectric response is approximately one-dimensional at short periods (<0.2 s), which correspond to signal penetration into the Phanerozoic sedimentary rocks. The response has a weak two-dimensionality which, considering the inherent 90° ambiguity in the determination of strike from the MT data, indicates a strike angle of either N60°E or N30°W (Fig. 2, 3). A N30°W strike angle is consistent with the gentle dip of the Phanerozoic rocks towards the southwest.

The geoelectric response indicates a two-dimensional response with a strike of ~N30°E-N35°E in the upper and mid crust, and a two-dimensional response with a strike of N60°E in the lower crust to lithospheric mantle (Fig. 2, 3). There is a suggestion that the geoelectric strike rotates closer to east-west at the longest periods (>2000 s) but this response is relatively poorly resolved by the data.

The geoelectric strike angle along Corridor 1A was re-examined using the McNeice-Jones (McNeice and Jones, 2001) multi-site, multi-frequency Groom-Bailey analysis (Fig. 3b). This analysis confirms that the strike at periods of 0.1 to 20 s averages N33°E and at 20-10,000 s averages N62°E. The transition between these two directions initiates in the period range 10-20 s, which is approximately the period range for sensitivity of the MT signals to the base of the 15-25 km thick crust. The direction in the upper crust has been interpreted to represent the local-scale (<50 km) horizontal strike of the GSLsz and the direction in the mantle is parallel to the larger-scale strike of the GSLsz (*e.g.* Wu et al. 2002). However, the similarity of the strike angles on Corridors 1 and 1A suggests the strike in the crust and mantle might reflect more pervasive structures associated with the collision of the Slave and Rae Provinces and the collision of the Hottah terrane and Slave Province.

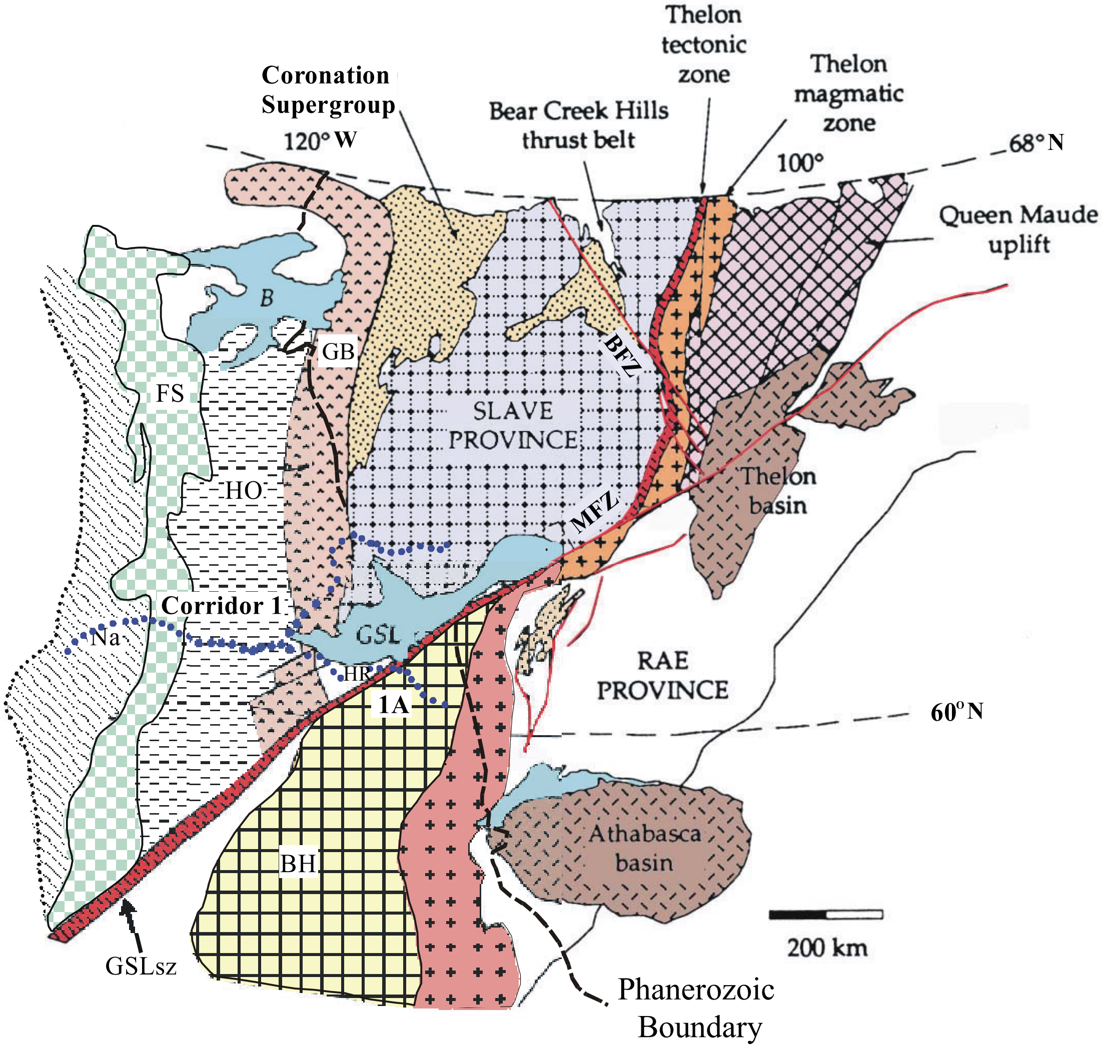


Figure 1 Selected tectonic elements and structures of the northwest Canadian Shield (after Hanmer, 1988). Na: Nahanni terrane, FS: Fort Simpson terrane, HO: Hottah terrane, GB: Great Bear magmatic arc, HR: Hay River terrane, GSLsz: Great Slave Lake shear zone, BH: Buffalo Head terrane, BFZ: Bathurst fault zone, MFZ: McDonald fault zone. The circles show the location of MT sites on Corridor 1 and 1A.

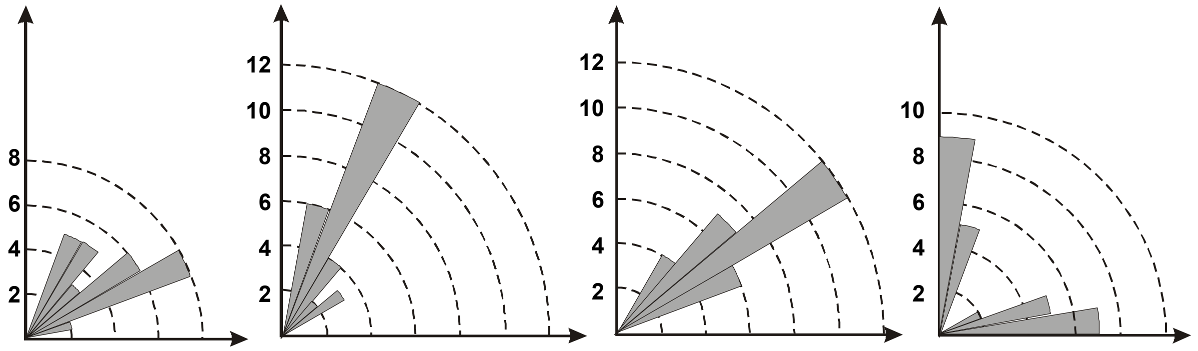


Figure 2 Rose diagram of the Groom-Bailey regional strike angle for four period ranges based on 29 sites located in Nahanni terrane to Great Bear magnetic arc along Corridor 1. The angle bin is 10°. The results for band 1 and 3 include 29 resolved strikes angles, the results for Band 2 include 27 strikes, and for Band 4 include 28 strikes.

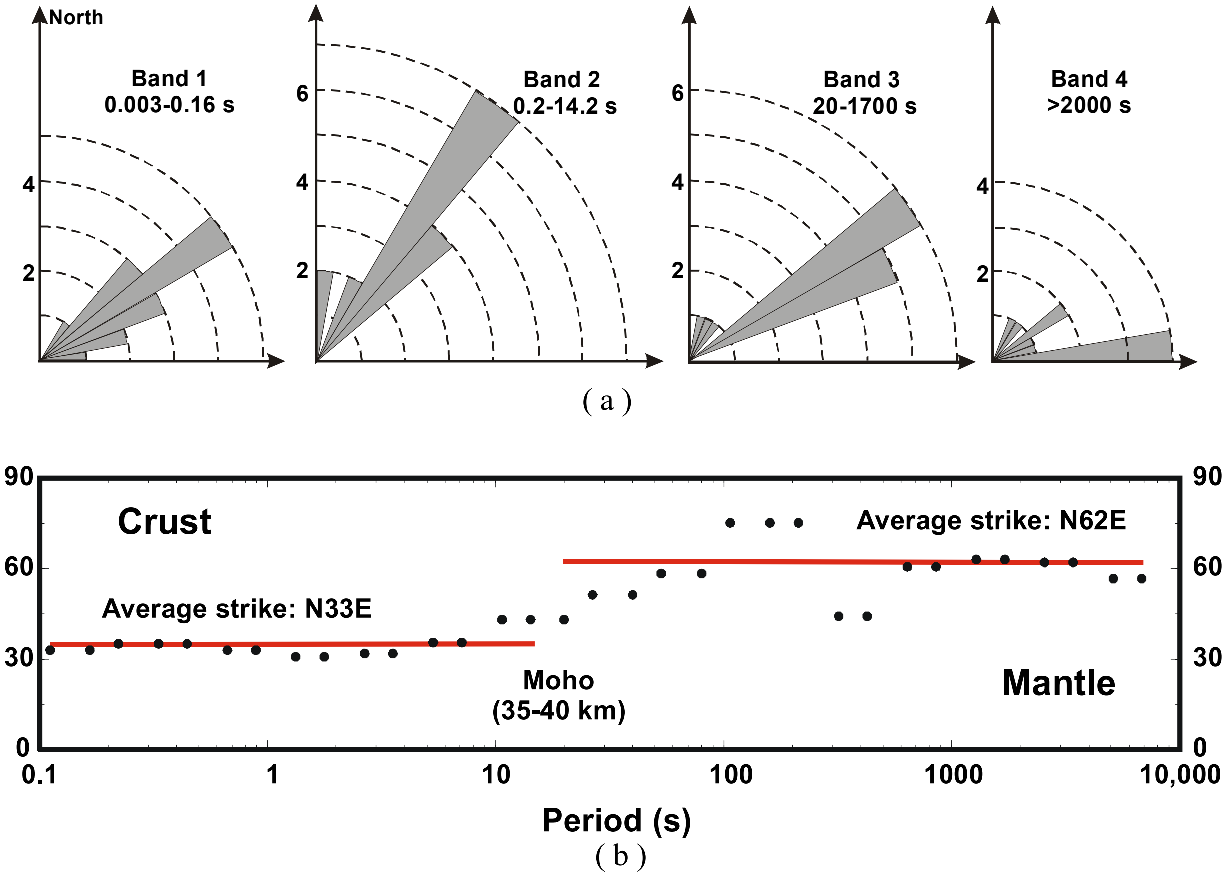


Figure 3 (a) Rose diagram of the Groom-Bailey regional strike angle for four period ranges based on 15 sites along Corridor 1A. The angle bin is 10°. The results for the first two period bands include 15 resolved strikes angles, the results for Band 3 include 14 strikes, and for Band 4 include 10 strikes. (b) Geoelectric strike angle from multi-site, multi-frequency extended GB decomposition that best fits all sites along Corridor 1A simultaneously.

Structure of Phanerozoic sedimentary rocks

The Phanerozoic sedimentary rocks form an electrically conductive layer in the MT models. The sedimentary rocks have a maximum thickness of ~1000 m above the western Fort Simpson terrane and thin in a north-northeast direction. Around site 142, the conductive surface layer is thinner than in surrounding areas. This feature is interpreted to be the Liard High, a structure formed during the Cambrian and early Ordovician (Law 1971; Merjer-Drees 1975).

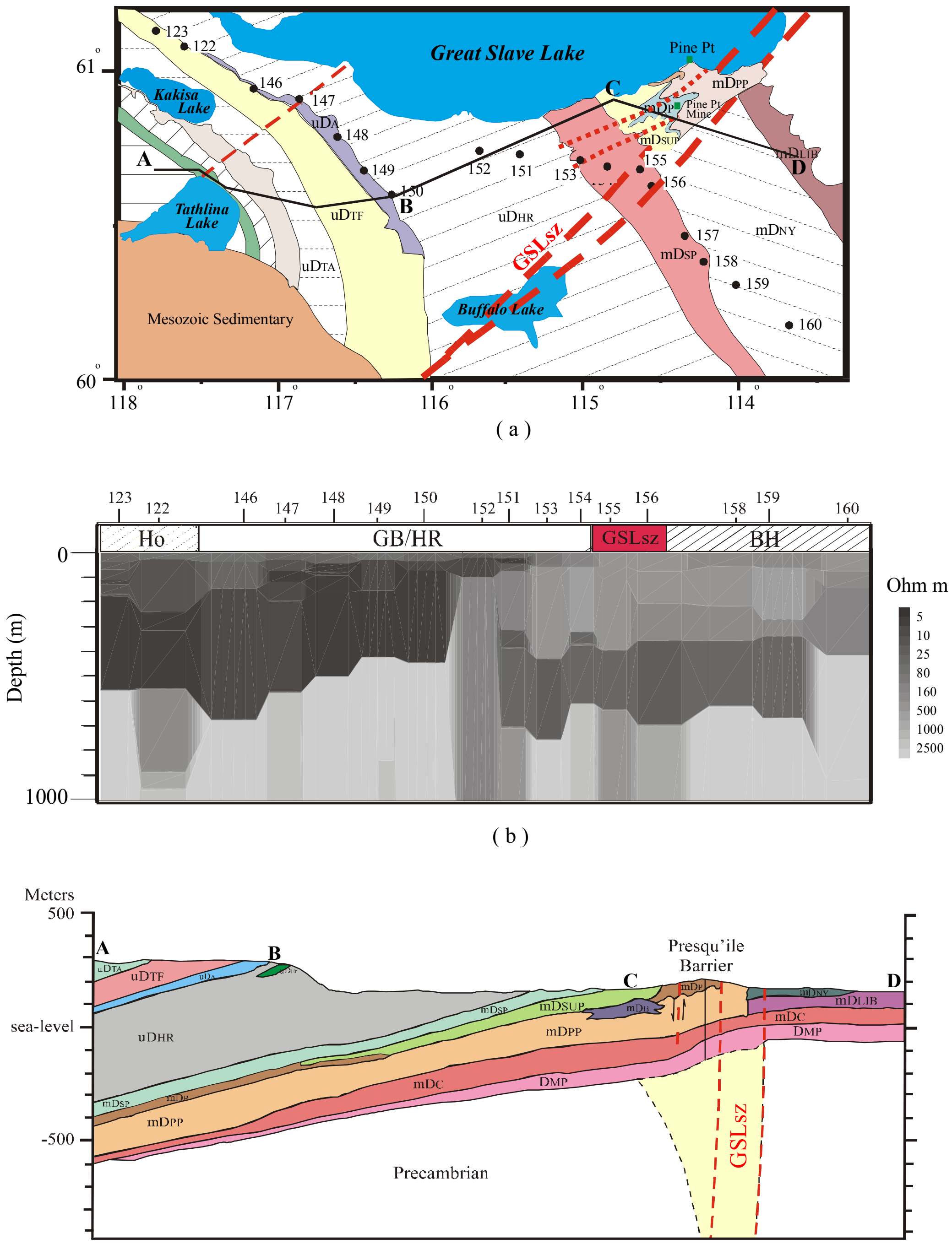
In the southeastern part of Corridor 1 and along Corridor 1A the geoelectric structure consists of three layers: a relatively resistive first layer and a conductive second layer overlying resistive basement (Fig. 4b). There is a clear resistivity boundary near sites 152-153 where the profile crosses the Presqu'ile Barrier. This structure hosts the major Mississippi Valley type (MVT) Pb-Zn Pine Point deposit.

To the northwest of the transition, the rocks consist of a moderately resistive upper layer (20-100 m) overlying the conductive lower layers. The resistive layer is interpreted to be associated with the overburden and/or Upper Devonian bioclastic and sandy limestone (Hills et al. 1981, Douglas and Norris 1973). The conductive lower layer can be subdivided into a more conductive (<10 Ωm) lower unit subcropping between sites 148 and 153 and a more resistive (10-25 Ωm) upper unit subcropping to the northwest of site 147. The lower unit corresponds to the thick dark grey and black shale sequences of the Upper Devonian Horn River Formation (Douglas & Norris 1973) and the upper unit corresponds to the Upper Devonian Twin Falls, Tathlina, and Redknife Formations which include bioclastic and reef carbonates as well as sandy limestone, shale and siltstone.

To the east of site 153, the two-layer structure is more resistive than to the northwest. The relatively resistive upper layer (350 m) is interpreted to correspond to the middle Devonian carbonate and evaporate dominated units including the Nyarling, Little Buffalo, and Chinchaga Formations. The conductive second layer (~300 m) corresponds to the Middle Ordovician (?)-Middle Devonian Mirage Point Formation which includes red and green shale beds, carbonate, sandy carbonate and gypsum (Glass, 1990; Rhodes, *et al.* 1984; Douglas & Norris, 1973) and the underlying Ordovician Old Fort Island Formation which consists of quartz sandstone, siltstone and shale. The greater thickness of the lower unit in the model than in the cross-section may be due in part to the divergence between the eastern end of the Corridor 1a and the location of the cross-section.

Precambrian Crustal Structure

Figure 5 shows the two-dimensional MT models for Corridors 1 and 1A which reveal a number of significant geoelectric structures. The existence and form of these structures has been confirmed using re-examination of the raw MT responses, multiple two-dimensional inversions, and one-dimensional and two-dimensional forward modelling and sensitivity studies (Wu 2001).



(a)

(b)

(c)

Figure 4 (a) Location of sites along Corridor 1A. The location of the GSLsz is shown by dashed lines and is inferred from magnetic field data. The dotted line shows the location of the Pine Point (Presqu'ile) Barrier. The mine symbol shows the location of the Pine Point. (b) Stitched 1D inversion models along Corridor 1A. (c) Geological cross-section (A-D) of Phanerozoic rocks. Modified from Douglas and Norris (1973) and Douglas (1973). Geological units: uDEr: Escarpment Member, Hay River Formation (bioclastic and reefy limestone beds), mDC: Chinchaga Formation (laminated gypsum, salt, limestone and dolomite), DMP: Mirage Point Formation (dolomite, sandy dolomite, shale and gypsum).

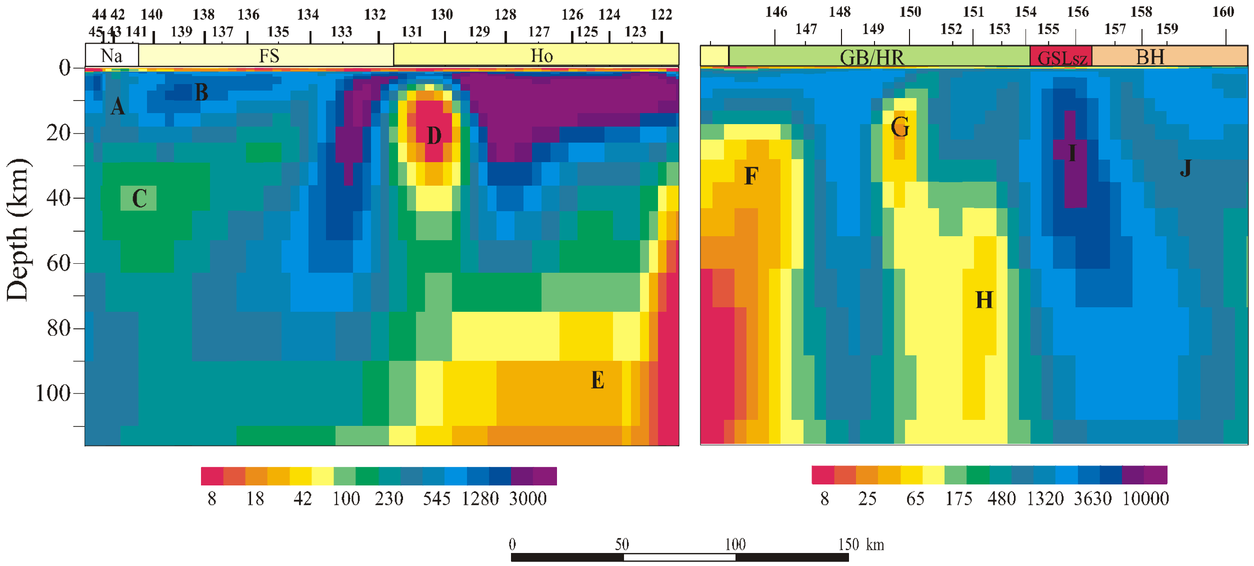
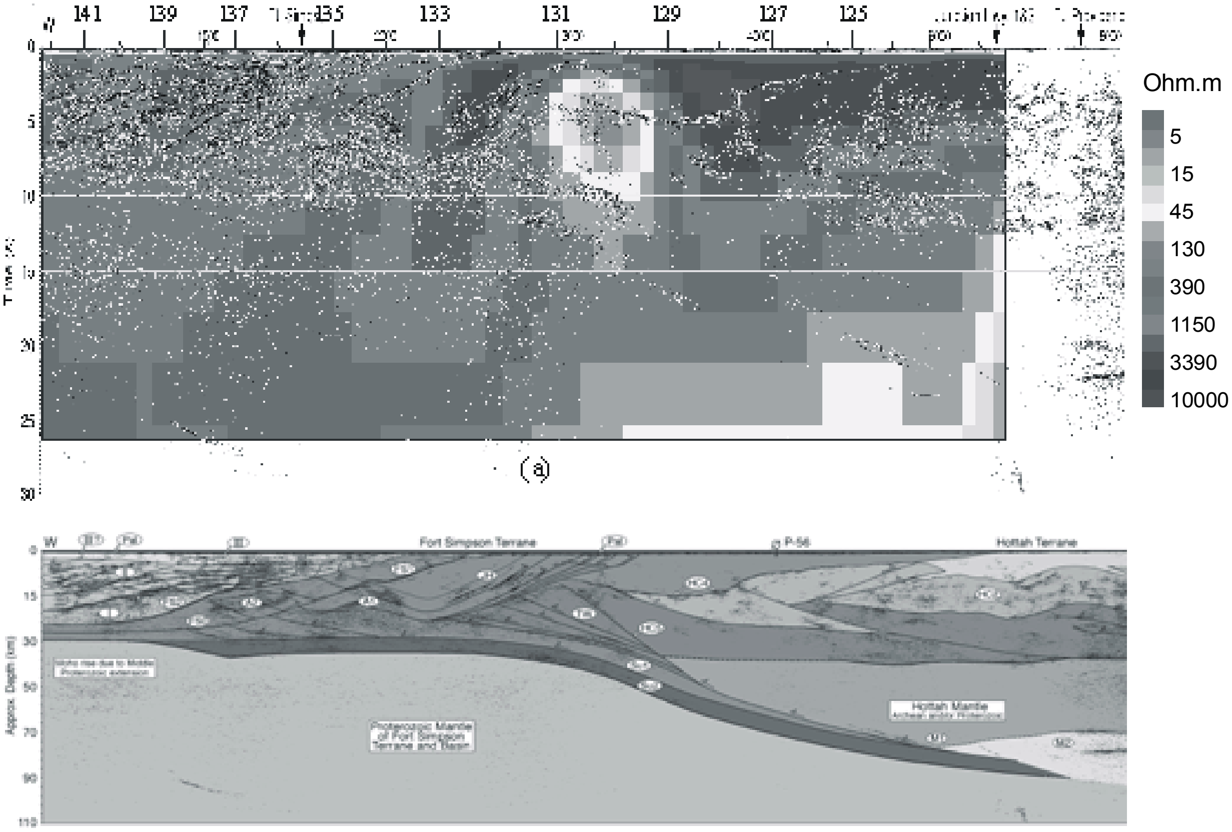


Figure 5 2D inversion models along Corridor 1 and 1A.

Fort Simpson Basin: The MT models image a relatively resistive (>400 Ωm) body with a west-dipping base in the Fort Simpson terrane (labelled B in Fig. 5). The maximum depth to the base of this body, which extends at least 100 km along the survey line, is about 20 km. Seismic reflection data shows a package of west dipping (20^{o}-30^{o}) reflections beneath stations 0-2500 corresponding to the location of MT sites 142-132 (Cook et al. 1998). The MT results support the interpretation of the seismic reflection data in terms of the Fort Simpson basin. This basin is interpreted to have formed as a result of lithospheric extension following collision of the Fort Simpson terrane with the western Hottah terrane at ~1.84 Ga. The relatively high resistivity of the rocks in the basin is consistent with the presence of the Proterozoic sedimentary rocks including sandstone, siltstone and argillite deposits (Cook et al.1998; Hills et al. 1981).

Fort Simpson-Hottah conductor: The MT models reveal a clear conductive zone (<100 Ωm) under sites 132 to 130 (labelled D in Fig. 5) at the boundary of the Fort Simpson and Hottah terranes. This zone extends from several kilometres depth to ~40 km depth. It is spatially correlated with a wedge-shaped zone defined by seismic reflection results that extends from several kilometres to ~25 km depth between stations 1800 and 3200 (Fig. 6).

This zone has been interpreted to be a structural boundary between the Fort Simpson terrane with the western Hottah terrane. According to Snyder (2000), the older Hottah terrane (1.95-1.91 Ga) collided into the eastern flank of the younger Fort Simpson terrane (1.8 Ga) creating wedged shape geometry. The upper crust of the Fort Simpson terrane was detached and thrust over the Hottah terrane and the ocean lithosphere that separated the Fort Simpson terrane from the Hottah terrane was subducted beneath the crust of the Hottah terrane.



(b)

Figure 6 (a) Seismic reflection profile and 2D MT inversion model from Fort Simpson to Hottah terrane along Corridor 1. The figure shows seismic data overlying the resistivity model. (b) Geological interpretationof seismic reflection data (Cook et al., 1998).

The enhanced conductivity is spatially restricted to the crustal depths, to the point of the wedge, and to the Hottah side of the boundary. This geometry suggests the enhanced conductivity is directly related to metamorphism and deformation of Hottah rocks during the collision. Increased temperature and pressure may have produced graphitic schists and gneisses from sedimentary rocks in the Hottah crust. Fluids released by the subducting oceanic lithosphere may also have contributed to the processes that lead to enhanced conductivity.

Hottah-Great Bear Conductor: There is a conductive zone (~30 Ωm) beneath the boundary of the Hottah terrane and Great Bear Magmatic Arc with its top at about 20 km depth (labelled F in Fig. 5). The Great Bear Magmatic Arc is interpreted to have been a product of eastward subduction of oceanic lithosphere beneath the Hottah terrane at 1.84-1.87 Ga. Cook *et al* (1999) suggest the Great Bear Magmatic Arc is relatively thin (~3-4.5 km) and lies above either Hottah crust or imbricated rocks of the Coronation margin.

Although the precise nature of the rocks beneath the Great Bear Magmatic Arc is not known, it is known that they are deformed rocks of the Hottah-Slave transition (Cook, *et al.*, 1999), for example, deformed and metamorphosed Coronation Supergroup, a continental margin (back-arc) depositional prism. Therefore, the enhanced conductivity in the middle and lower crust beneath the boundary between the Hottah terrane and Great Bear Magmatic Arc may be due to either graphite or conductive minerals concentrated during the deformation and metamorphism of Coronation Supergroup rocks.

There is also conductive crust beneath the central Great Bear Magmatic Arc (labelled G in Fig. 5) with its upper surface at around 10 km depth. Because this structure is further from margin of the Great Bear Magmatic Arc its source is less clear than that of the conductor to the northwest. However, it can again be attributed to electronic conduction in interconnected metasediments of either Hottah terrane or Coronation Supergroup.

Great Slave Lake shear zone: The MT inversion models reveal that the GSLsz forms a crustal-scale resistive zone (>5000 Ωm, labelled I in Fig. 5) that is spatially correlated with a magnetic low. The GSLsz comprises greenschist to granulite faces mylonites. Its high resistivity is interpreted to be due to the resistive nature of the granitic protolith of the mylonites and the fact that the mylonites are dominated by rocks deformed in the ductile regime (Wu et al. 2002).

Buffalo Head Terrane The relatively high resistivity in the Buffalo Head terrane (labelled J in Fig. 5) is associated with the metaplutonic and subordinate felsic metavolcanic rocks, forming the terrane. The lower resistivity at mid to lower crustal depths in the east of the Buffalo Head terrane may be interpreted as the westwards extension of the Taltson Magmatic Arc beneath the Buffalo Head terrane. Additional MT soundings in the east of the Buffalo Head terrane and Taltson Magmatic Arc are needed to examine the extension of the Taltson magmatic zone in more detail.

Lithospheric Mantle Structure

The MT results show a region at enhanced conductivity at a maximum depth of 100-200 km depth across the mantle in the Hottah, Great Bear Magmatic Arc and Buffalo Head terranes. This depth is interpreted to be the base of the lithosphere. The source of the enhanced conductivity would be partial melt in the asthenosphere. High heat flow (109 mW/m^2) have been measured across the Hottah, Fort Simpson and Nahanni terranes by Lewis and Hyndman (2001) and along the Presqu'ile Barrier to the west of the study area (130-200 mW/m^2) by Majorowicz *et al.* (1989). Although there may be an influence from local topographic features and region fluid flow on these results, the values can be plausibly explained by a relatively shallow lithosphere-asthenosphere boundary.

The enhanced conductivity at shallow mantle depths beneath the boundary of the Hottah Terrane and Great Bear Magmatic Arc (labelled E in Fig. 5) and beneath the eastern Great Bear Magmatic Arc (labelled H in Fig. 5) is more localized and is therefore interpreted to represent increased conductivity within the lithosphere rather than a decrease in the depth to the asthenosphere. Seismic reflection results show delamination structures extending to 100 km depth in the mantle beneath the Great Bear Magmatic arc providing evidence that lower crustal rocks were emplaced in the mantle during subduction (Fig. 6, Cook *et al.* 1999). This subduction was associated with collision and accretion of the Hottah terrane to the western margin of the Slave craton between 1.9 and 188 Ga. The source of the enhanced conductivity in the mantle beneath the western Great Bear Magmatic Arc may be either hydrogen or carbon introduced into the mantle through the subduction process.

The truncation of the mantle conductor beneath the eastern Great Bear Magmatic Arc at the GSLsz suggests significant movement of the mantle lithosphere as well as the crust. This motion could have removed higher conducting lithosphere from the southeast side of the fault. The ductile movement on the GSLsz (2.03 to 1.95 Ga) predates most of the orogenic activity associated with the collision of the Hottah terrane and Slave Province (1.9 to 1.88 Ga). Therefore, either the high mantle conductivity beneath the eastern Great Bear Magmatic Arc cannot be attributed to processes associated with the subduction of Hottah lithosphere, or else the truncation of the conductor occurred subsequent to the ductile motion on the GSLsz. It is possible that the conductor was truncated by the McDonald Fault, which runs parallel to the GSLsz, and formed during post-collisional convergence of the Slave and Rae provinces at ca. 1800 Ma (Ritts & Grotzinger 1994).

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