SHORT COMMUNICATION

MOHO FROM MAGNETOTELLURIC STUDIES IN EASTERN INDIAN CRATON AND SLAVE CRATON, CANADA

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A comparative study of the Moho from magnetotelluric studies in the Eastern Indian Craton and Slave Craton, Canada is presented in this note.

The electrical conductivity of rocks is closely related to geochemical changes than other bulk physical properties such as acoustic impedance, density and seismic velocity. Magnetotelluric (MT) methods used for the investigations of deeper structures, therefore, provide complementary, sometimes supportive but other times alternative, interpretation of geochemical characters in geological units. It has been suggested on the basis of laboratory studies that for dry rock assemblages there may be an observable difference in conductivity between deep crustal mafic and upper mantle ultramafic rocks (Haak, 1982).

A region of enhanced electrical conductivity, represents an interconnected network of fluid and/or mineral conducting phases. The enhanced conductivity of the continental lower crust (CLC) remains one of the puzzles regarding the earth about which comparatively little is known. This characteristic of the deep crust has been observed globally, using MT method, but explanations for its existence remain controversial. The enhanced conductivity of CLC can be explained either by interconnected brine below the brittle-ductile transition (Hyndmann and Hyndmann, 1968, Brace, 1971, Gough, 1986, Jones, 1986, 1992) or by interconnected, thin, grain-boundary carbon film (Duba et al. 1988; Frost et al. 1989). MT method at times becomes unsuitable in determining the exact depth of Moho due to the presence of highly conducting CLC. The presence of enhanced conductivity in CLC limits the ability to resolve the uppermost mantle conductivity structure and only a maximum limit can be placed on its value (Jones, 1999). In such cases, therefore, upper mantle resistivity and the nature of olivine as upper mantle constituent cannot also be determined. Here we report the definite identification of crust-mantle boundary due to the lack of a conducting CLC over the Eastern Indian Craton (EIC) (Bhattacharya et al. 1999; Bhattacharya et al. 2000; Bhattacharya and Shalivahan, 2002) and Slave province, Canada (Jones and Ferguson, 2001) using MT data and discuss its implications in delineating the crust-mantle boundary.

Magnetotelluric Studies over Eastern Indian Craton (EIC)

Remote reference (RR) MT measurements were carried during 1996-97 field season over a part of the southern Archaean nucleus of Eastern Indian Craton (EIC) to map the electrical conductivity of the crust and upper mantle with reference to a fixed remote site (Bhattacharya and Shalivahan, 1999; Shalivahan and Bhattacharya, 2002a). The eastern part of the Indian Precambrian shield is characterized by Archaean nucleus of Singhbhum Granite (SG) batholithic complex and ancient supracrustals surrounded by several elongate and arcuate Proterozoic belts. This Archaean nucleus is bounded by the arcuate Copper belt thrust zone (or Singhbhum shear zone) in the east, north and northwest and Sukinda thrust in the south. Geochronologically, the Archaean nucleus is at least ~3.3 Ga old (Sharma et al. 1994) represented by tonalite-trondhjemite gneiss (TTG) and amphibolites of older metamorphic Group (OMG). The OMG rocks are intruded by Singhbhum granite (SG) of ~3 Ga which occupies most of the craton. Along the southern fringes of the Singhbhum craton, outcrops of charnockites and khondalites (graphite-bearing) occur to the north and south of the Sukinda thrust respectively.

2D geoelectric model along a typical section (Bhattacharya et al. 1999; Bhattacharya et al. 2000; Bhattacharya and Shalivahan, 2002) shows 38 km thick electrically homogeneous granitic crustal layer of very high resistivity (30,000 ohm-m) below the EIC. The model fit the data to within 2.8° in phase and 0.217 in log ρ_a. A uniform layer of 8 km thickness below the granitic crust with relatively lower resistivity is found at a depth of 38 km. The resistivity of this layer is 8500 ohm-m. Keeping in view the outcrops of charnockites along the southern fringes of the Singhbhum craton north of the Sukinda thrust and of khondalites (graphite-bearing) to the south of the Sukinda thrust, these rocks may be candidates for the 8500 ohm-m layer. This implies a greater crustal thickness i.e., 46 ± 2.1 km below the craton (Bhattacharya and Shalivahan, 2002).

The resistivity of the upper mantle at a depth of 46±2.1 km (Bhattacharya and Shalivahan, 2002) is about 750 ohm-m showing a decrease in resistivity by an order from that of the lower crust of about 8500 ohm-m. Constable et al. (1992) obtained the conductivity of pure olivine to a reasonable approximation in the temperature range 720°-1500°C as:

$$\sigma = 10^{2.402}e^{-1.60eV/kT} + 10^{9.17}e^{-4.25eV/kT} \quad (1)$$

where T is the temperature, k is the Boltzmann constant and eV is the electron volt.

From equation (1) the resistivity of upper mantle at a depth of 46 km (temperature gradient 25°C/km=1150°C) should have been 4000 ohm-m. However, the resistivity from MT studies at this depth is 750 ohm-m only due to impure olivine. 2-D modelling also was carried out by using Very Fast Simulated Annealing (VFSA) technique (Shalivahan, 2000). Moho depth obtained by VFSA is 46±2.6 km (Bhattacharya and Shalivahan, 2002). The models obtained by using Occam and VFSA inversion schemes are in agreement.

Bhattacharya and Shalivahan (2002) obtained the conductivity of 0.00012 S/m for CLC under EIC and is in broad agreement with the experimental results (Olhoeft, 1981). A possible explanation for the CLC below EIC is the absence of imbrication of sedimentary material and underplating of mafic crust related to subduction processes. About 8 km thick lower crustal layer occurring at a depth of 38 km, and extending horizontally for more than 40 km as revealed by this MT study will be difficult to explain by sub-horizontal disposition along a thrust. Near subduction boundary the down going slab usually becomes steeper. Plume magmatism can potentially explain the horizontal disposition and layered pattern of the crustal structure of the region (Bhattacharya and Shalivahan, 2002). Indeed Nd-isotope studies of the TTG-amphibolites of OMG rocks strongly suggest their derivation from a depleted plume source (Sharma et al. 1994).

Magnetotelluric (MT) Studies over Slave Province

Jones and Ferguson (2001) presented the result of the MT survey conducted as part of Lithoprobe's Slave – Northern Cordillera Lithospheric Evolution (SNORCLE). The RR MT data were acquired in the frequency range of 10000 Hz - 0.0001 Hz on the southwestern corner of the Archaean Slave craton – the oldest craton (~4.03 Ga).

The acquired time series data at each site were processed using a robust multi-remote-reference algorithm (method 6, Jones et al. 1989). The effect for local distortions of the electric field of the estimated responses were corrected (McNeice and Jones, 2001). The conductivity varies with depth only as the contoured MT phases for all the sites in two orthogonal directions show uniform lateral behaviour. Therefore, 1-D inversion of the processed data using Occam inversion scheme (Constable et al. 1987) was carried out by them. In this work, 27 frequencies in the range 1000 Hz - 0.1 Hz with minimum assigned errors of 3.5% in apparent resistivity and 1° in phase was used.

The model obtained over Slave craton shows a low conductivity uppermost layer of < 1 km underlain by a higher conductivity layer to a depth of 2-3 km. Below this there is a region of very low conductivity (<0.000025 S/m) to some tens of kilometres depth, beneath which is a moderately conductive (0.00025 S/m) homogeneous basal layer. The obtained moho depth was 35.8±1.5 km. The result is consistent with the obtained depth from seismic reflection, refraction and teleseismic studies. The resistivity of upper mantle at the Moho depth as obtained in the Slave craton using equation (1) (Constable et al. 1992) should be 300,000 ohm-m which is much higher than the value of 4000 ohm-m obtained from MT studies.

Discussion and Conclusions

The comparison of (i) relevant parameters and (ii) features of the geoelectric models for EIC and Slave craton is given in Tables 1 and 2 (Shalivahan and Bhattacharya, 2002b):

It is emphasised that these are the only two rare instances where the absence of conducting CLC , i.e., lower crustal conductor (LCC) is observed. This enabled to identify definite crust-mantle boundary, upper mantle resistivity and the nature of olivine as the upper mantle material.

The conductance of CLC under EIC and Slave craton are less than 1S as against the minimum conductance of 20 S generally obtained for mid- to late- Archaean cratons. MT study over Slave province, indicates that in the early Archaean rocks (~4 Ga) absence of conducting CLC suggests an entirely different dynamics than the plate tectonics process. One speculates that this difference addresses questions of early development of the earth and tectonic processes, and the applicability of plate-tectonic theory to the early-to mid-Archaean (Jones and Ferguson, 2001; Bhattacharya and Shalivahan, 2002).

Table 1. Relevant Parameters

Parameters	EIC, India (Bhattacharya et al. 1999; Bhattacharya et al. 2000; Bhattacharya and Shalivahan, 2002)	Slave Craton, Canada (Jones and Ferguson, 2001)
Age	3.3 Ga	4.0 Ga
Data	Remote Reference MT	Remote Reference MT
Frequencey (Hz)	320 Hz - 10^{-4} Hz	10^{4}Hz - 10^{-3} Hz
Frequency used for modelling	Eight frequencies in the range of 1 Hz - 1000s	27 frequencies in the range of 1000 Hz - 1 Hz
Dimensionality	2D	1D

Table 2. Features of obtained geoelectric models

Features	EIC, India (Bhattacharya et al. 1999; Bhattacharya et al. 2000; Bhattacharya and Shalivahan, 2002)	Slave Craton, Canada (Jones and Ferguson, 2001)
Crust	Electrically Homogeneous	Electrically Homogeneous
Conductivity of CLC	~0.00012 S/m	0.000025 S/m
Conductance of CLC	~1 S	~1 S
Moho depth	46 ± 2.1 km	35.8 ± 1.5 km
Upper Mantle resistivity	~750 ohm-m	~4000 ohm-m
Upper Mantle rock type	Not pure olivine	Not pure olivine

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