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RESEARCH/REVIEW ARTICLE

Electrical structure beneath Schirmacher Oasis, East Antarctica: a magnetotelluric study

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Abstract

Maitri Station (70.76°S; 11.73°E) is located in Schirmacher Oasis, a coastal nunatak in north-central Dronning Maud Land covering an area of 35 km^2. Here, we report results from the first magnetotelluric experiments and delineate the deep electrical conductivity structure under Schirmacher Oasis using the data acquired during the 24th Indian Antarctic Scientific Expedition. The magnetotelluric method has the advantage of shallow to deeper level coverage as the data acquisition covers a wide frequency band of 10^{-3}–10^{3} Hz, permitting different penetration depths depending on the frequency and conductivity of the layer under investigation. The modelling results indicate the presence of a highly resistive (8000–10 000 ohm m) upper crust, which shows a lateral variation in thickness from 20 km (below site 6) in the east to 10 km (between sites 1 and 2) in the west. It is underlain by a less resistive (500–600 ohm m) lower crust. The highly resistive upper crustal structure supports the existing notion that western Dronning Maud Land is a stable, cratonic platform. Results of free-air gravity, seismic, geomagnetic and surface wave dispersion investigations in East Antarctica also indicate a cratonic-type crust. The results of our study allow us to identify a westward thinning of the upper crust with a marked boundary between sites 1 and 2. We also find evidence for the continuity of the Mozambique mobile belt in East Antarctica on the western side of Schirmacher Oasis.

Electrical resistivity studies provide images of the deep crustal or upper mantle structure through the application of magnetotellurics (MT; Vozoff 1991; Harinarayana et al. 2003; Wannamaker et al. 2004). MT surveys have been used to tap information on primary structures such as the distribution of sedimentary units and lithologic contacts, secondary structures such as major fault offsets, geochemical fluxes including hydrothermal alteration, remobilized graphite-sulphide mineralization, thermal regimes such as prograde or melt-exsolved fluids, crustal or upper mantle melts, and mineral semi-conduction, among other aspects (Gough 1986; Constable & Duba 1990; Jones 1992, 1999). Although MT studies offer a high potential to evaluate the crustal structure of Antarctica, only a few investigations have been carried out so far in this region (Wannamaker et al. 1996; Wannamaker et al. 2004; Pedrera et al. 2012).

The Antarctic continent has been broadly divided into the eastern and western segments, separated by the Transantarctic Mountains (Gregory 1901). West Antarctica encompasses the Scotia Arc region, the Antarctic Peninsula, Ellsworth Land, Ellsworth mountains and Marie Byrd Land, while East Antarctica consists of Dronning Maud Land, Enderby and Kemp Lands (Gregory 1901; Bentley 1991; Tingey 1991). More than 95% of the surface of this continent is covered with thick (1–3 km) ice, inhibiting conventional geological investigations in the various terrains and restricting the estimation of the

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crustal architecture and mantle dynamics mostly to geophysical techniques. In this study, we report new MT data along Schirmacher Oasis, a coastal nunatak extending for about 35 km^2 in the north-central part of the Dronning Maud Land in East Antarctica. We present good-quality MT data along an east–west transect in Schirmacher Oasis in an attempt to evaluate the crustal structure beneath this region.

Geological background

East Antarctica is considered as a stable, cratonic block with a Precambrian basement and has prominently figured in Proterozoic configurations of supercontinents including Columbia, Rodinia and Gondwana (e.g., Dalziel 1991; Borg & DePaolo 1994; Rogers et al. 1995; Rogers & Santosh 2004, 2009; Meert & Lieberman 2008; Satish-Kumar et al. 2008; Santosh, Maruyama & Sato 2009; Santosh, Maruyama & Yamamato 2009; Boger 2011). Central Dronning Maud Land in East Antarctica comprises mainly high-grade metamorphic rocks intruded by voluminous igneous bodies that form coastal and inland mountainous outcrops (Dallmann et al. 1990). The Neoproterozoic evolutionary history of this region is marked by two major tectonothermal events at about 1100 million years ago (Mya) and between 560 and 490 Mya (Jacobs et al. 1999; Jacobs et al. 2003). The younger event has been correlated to the East African Orogeny and involves an early collisional event at approximately 560 Mya, followed by large-scale extension associated with voluminous granitic magmatism. The ca. 630 My ages obtained from the coastal outcrop at Schirmacher Oasis have led to the suggestion of a different evolutionary history for this area in the late Neoproterozoic compared with that of the inland mountains (see Satish-Kumar et al. 2008 and references therein).

Schirmacher Oasis is located near the Princess Astrid Coast, central Dronning Maud Land, East Antarctica (Fig. 1). This region (70°44′–70°47′S and 11°25′–11°55′E) runs parallel to the east–west trending coastline between the inland ice and the shelf ice (Tingey 1991). The coastline lies at a distance of about 100 km north of Schirmacher Oasis. The Precambrian crystalline basement of Schirmacher Oasis forms part of the East Antarctic shield with granulite facies rocks occurring as remnants within a dominantly amphibolite-facies terrane (Ravikant et al. 2004). Metapelites, exposed in central and eastern Schirmacher Oasis and the nunatak Vettiyya, contain layers and boudins of metanorite dykes. Veins of orthopyroxene-bearing pegmatite intrude both metanorite layers and metapelite. In central Schirmacher Oasis, the major rock exposed is a foliated metanorite. This mafic unit, in turn, contains enclaves of melanocratic metagabbro, metapyroxenite, and spinel-bearing and rarely garnet-bearing metawebsterite. Structurally, the main deformation was associated with the amphibolite facies metamorphism accompanied by migmatization, isoclinal folding and formation of major east–west striking overthrusts (Kampf & Stackebranwd 1985; Sengupta & Bose 1997). From a comparison of ages and geological features, Ravikant et al. (2004) proposed that Schirmacher Oasis is a possible segment of a klippen of the Lurio Belt of south-east Mozambique and a possible extension of the East African Orogen into Antarctica. Satish-Kumar et al. (2008) considered Schirmacher Oasis as an extension of the Mozambique Belt in south-eastern Africa, with the inland mountains representing part of the crust generated during the final amalgamation of East Gondwana.

Voluminous mid-Jurassic magmatic provinces characterize the Western Antarctic part of Gondwana with a probable correlation to major plume activity (e.g., Storey 1995). The influence of a modern mantle plume in Antarctica has also been invoked in various studies (e.g., Wannamaker et al. 2004) confined to the polar and western part of Antarctica. Older plume-related mafic magmatism has been widely recorded in Antarctica and correlated with the spreading of the Karoo-Maud plume (e.g., Sushchevskaya et al. 2008) which triggered the final break-up of the Gondwana supercontinent and the formation of the Indian Ocean, to the east—from Queen Maud land towards Schirmacher Oasis. Although the geochemical and isotopic characteristics of the dolerite dyke in Schirmacher Oasis suggest crustal contamination during plume upwelling and emplacement of the mafic magmas into the continental crust, it is not reflected in crustal electrical structure delineated from this study. This might suggest that the plume activity might be very old or the thermal signatures might have calmed down quickly in the polar region. Numerous dykes of lamprophyre and basalt dissect the metamorphic complex of Schirmacher Oasis. Kaiser & Wand (1985) and Wand et al. (1988) distinguished two age groups of basalts; Palaeozoic and Mesozoic. Conventional K-Ar isotope determinations yielded ages of 223 and 354 My, respectively.

An anomaly measured by Magnetic Field Satellite over Schirmacher Oasis indicates a low as compared to its northern and southern sides, implying a region of weakly magnetized crust (Wagner & Lindner 1991). The nunataks close and around Schirmacher Oasis have a similar lithological set up and are probably extensions of Schirmacher Oasis (Mukerji et al. 1988). The general trend of geological features in the region is ENE–WSW with steep southern to sub-vertical dips. In the former, S-planes

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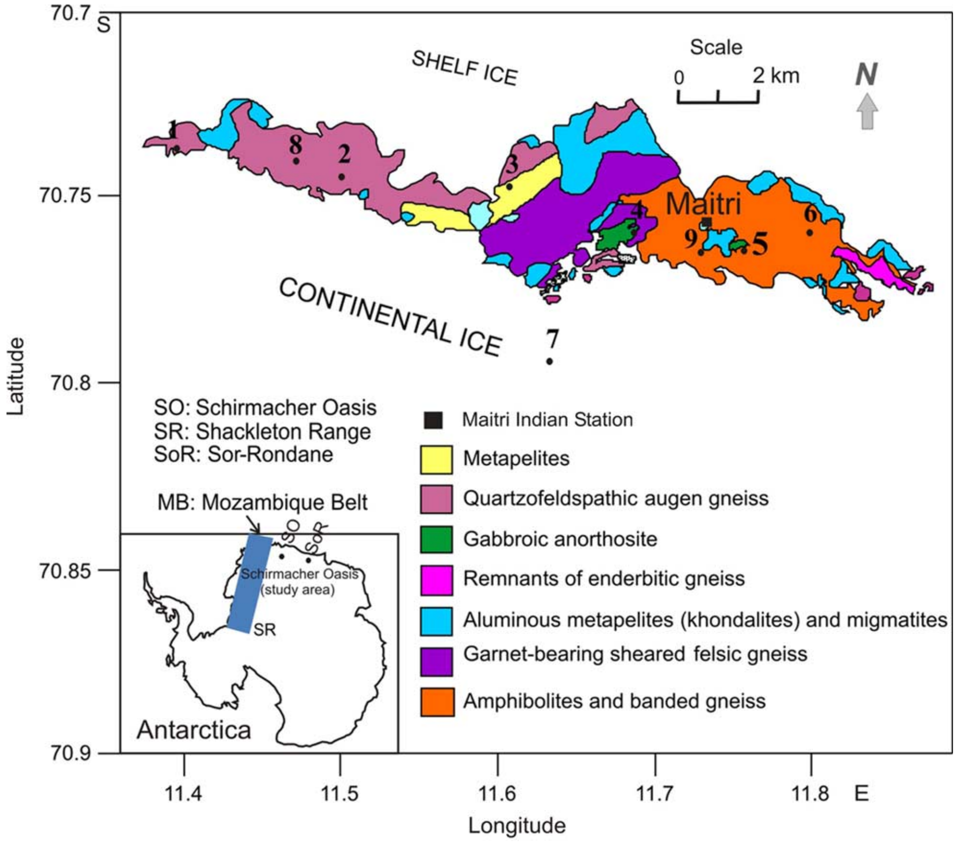

Fig. 1 Geological map indicating numbered locations of magnetotelluric investigations in Schirmacher Oasis, East Antarctica. Data acquired at sites 8 and 9 were of poor quality and could not be used for modelling studies. Experimental site 7 (over ice) is not part of the modelled profile.

defined by foliation, strike towards nearly east–west direction, the attitude varying between WNW–ESE and WSW–ENE. Foliation planes dipping at 35–50° either northwards or southwards (Mukerji et al. 1988) correspond to the east–west strike. The influence of the plume in western Dronning Maud Land is stronger than in central Dronning Maud Land (Schirmacher Oasis). Schirmacher Oasis probably was in a peripheral position in the mantle-plume region, and the western Dronning Maud Land was located close to its axis. Apatite fission-track data and the high-elevation margin morphology of central Dronning Maud Land suggest a typical passive nature for the region (Meier 1999).

MT studies

Theoretical background

By applying the MT method, naturally occurring electromagnetic (EM) fields are used as sources for imaging the electrical resistivity structure of the earth (Vozoff 1991). The incident EM waves propagate vertically downward and usually are treated as planar in geometry. In the conducting earth, EM waves at typical frequencies of the method (e.g., <1000 Hz) travel diffusively, such that high-frequency (short-period) waves penetrate a relatively short distance while low-frequency (long-period) waves can reach mantle depths. The MT method is based on recording natural variations of the earth's electric and magnetic fields (Vozoff 1991). Small variations of the magnetic field induce electrical currents in the earth. The MT signals in the lower frequencies (generally less than 1 Hz or 1 cycle per second) are caused by an interaction of the solar wind with the Earth's magnetic field. The higher frequency signal (≥ 1 Hz) is created by worldwide thunderstorms. Both of these sources of signal create EM waves varying with time.

Electrical currents are distorted and channelled by the Earth's heterogeneous conductivity structure. Horizontal electric and magnetic field components are recorded as time series at an MT site. Using this information, a period-dependent impedance tensor has been calculated. The time series is processed using robust processing methods (Egbert & Booker 1986) to arrive at the tensor impedances. A third magnetic field usually is also measured in the vertical direction to yield the tipper. The tensor impedances are decomposed into two principal impedances (orthogonal to each other) and they are usually parallel or perpendicular to the geologic strike if the structure is two dimensional. The mode perpendicular to the structure is called the transverse magnetic (TM) mode, while the mode parallel to the structure is the transverse electric (TE) mode. In the case of a horizontally layered structure (one-dimensional) the TE and TM responses overlap each other. In a two-dimensional situation, they differ from each other at least at some periods depending on the depth at which the lateral heterogeneity exists. Dimensionality analysis (Bibby et al. 2005) can be utilized to estimate the nature of the subsurface (one-, two- or three-dimensional).

Wannamaker et al. (2004) noted previous studies showing that sounding results during both low- and high-activity times of the polar electrojet were very similar, implying that non-plane-wave source effects were not a serious issue. They further processed soundings by specifically removing outliers in the tipper, which also showed basic response stability, although that is not carried out here. The high-quality broad-band MT sounding over the thick interior ice sheet of Antarctica was also obtained over the Whitmore Mountains–Ross Embayment transitional crust (Wannamaker et al. 1996).

MT survey at Schirmacher Oasis

An area covering 100 m^2 is needed to measure the two induced magnetic fields and the corresponding electrical voltages in north–south and east–west directions. Electrical signals are collected using cadmium–cadmium chloride (Cd–$CdCl_2$) porous pots, with a 90-m dipole length and induction coil magnetometers to measure the magnetic field variations. Measurements at most of the sites were done on soil cover of Schirmacher Oasis. Bentonite and salt have been used to establish a firm contact (3000–5000 ohm) with the soil. In this study, the vertical magnetic field component is very noisy so the tipper data could not be used for modelling.

A total of nine tensor soundings in the period range 0.001–1000 s were taken in a profile along the nearly east–west oriented Schirmacher Oasis (Fig. 1). The profile along which the data was acquired is 16 km in length and represents a small, but representative domain. Data from two MT sites (8, 9) were not considered for modelling because the data are dominated by noise. MT data have been recorded at only one site on ice cover (MT 7), situated 4 km south of Schirmacher Oasis, for the purpose of experimentation. Use of titanium electrodes along with bentonite and salt have helped in achieving a good contact resistance of 300 ohm (100–500 ohm) with the ice cover. Those results are presented in another publication (Murthy et al. 2012).

The MT data were collected using GMS-05 and ADU-06 systems (Metronix, Braunschweig, Germany), with a site spacing of about 2–3 km. Field layout involving installation of GMS05 and ADU06 systems which include establishment of porous pots as electric sensors and induction coils as magnetic field sensors is shown in Fig. 2. The average recording time per site was approximately three to four days. The apparent resistivity and impedance phase response for all the soundings is shown in Fig. 3. The most striking feature is the variation of apparent resistivity in both TE and TM modes, that is, a highly resistive layer (at short periods) followed by a conductive layer at longer periods. The *yx*-component has shown higher conductivity at longer periods (>100 s) than the *xy*-component probably due to the coast effect.

Three-dimensional forward modelling

The coast is at a distance of about 100 km towards the northern side of Schirmacher Oasis. Three-dimensional modelling studies (Patro & Sarma 2009) conducted in similar situations have shown that the coast effect is stronger in the case of the TM mode than the TE mode. According to Gokarn et al. (2004), both TE and TM modes used in two-dimensional modelling show very marginal variations of 0.5–0.1 in phase and nearly 10% in apparent resistivity for the sites close (ca. 35 km) to the coast in comparison to those far off (ca. 300 km). As the present MT sites in Schirmacher Oasis are much farther (ca. 100 km) from the coast, the effects of the same are negligible. However, three-dimensional modelling has been attempted for Schirmacher Oasis region and the results are presented further below.

Three-dimensional forward modelling (Mackie et al. 1994) has been performed taking into account the preliminary resistivity and thickness parameters of different layers obtained from two-dimensional inversion. A mesh of $51 \times 48 \times 33$ cells (80 784) in north–south, east–west and vertical directions, respectively, was used to compute the forward modelling response. A minimum square error of 10^{-6} after 200 relaxations with 10 air layers and a convergence factor of 8 has been achieved for the forward model. Sea water (0.25 ohm m) at a distance of 100 km from Schirmacher Oasis has been considered in the modelling. A total of 33 layers (0 to -41 km depth) with representative resistivity values (Fig. 4a, b) derived from two-dimensional modelling have been used. The

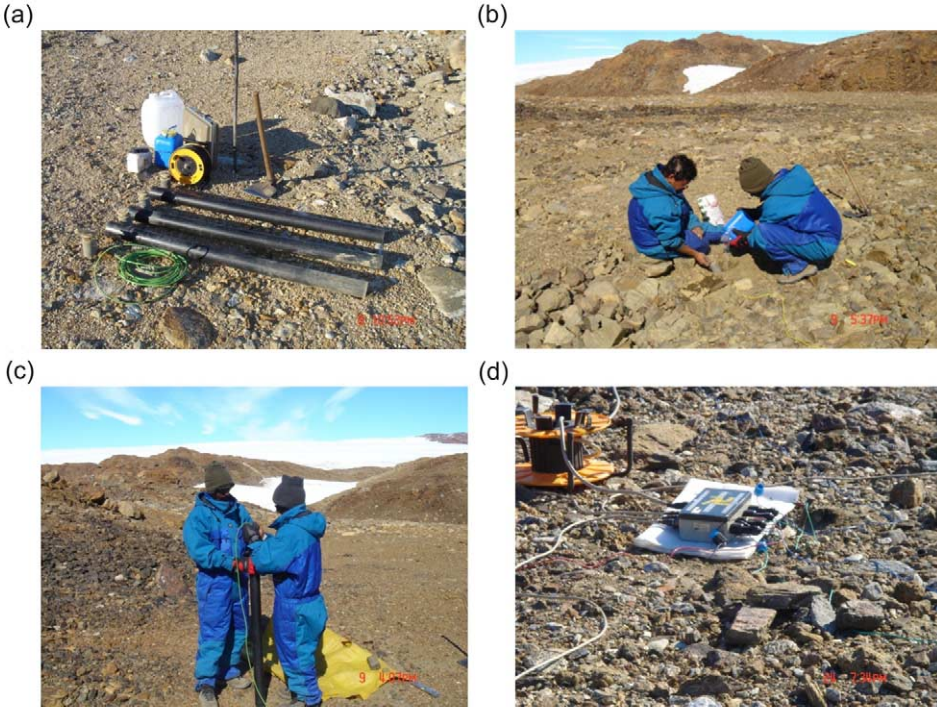

Fig. 2 (a) Induction coil and porous pot assembly; (b) conditioning of porous pot; (c) installation of induction coil at a magnetotelluric investigation site; and (d) signal detection box during data acquisition.

location of Schirmacher Oasis from the sea–land boundary is shown in Fig. 4c. The magnetotelluric response has been computed at six different locations in Schirmacher Oasis. From the response at site 3 (Fig. 4d) it is evident that the Rho(*xy*), Phi(*xy*) and phi(*yx*) components do not show much variation due to the coast effect. However, the Rho(*yx*) component shows more than 15% deviation due to the coast effect for the periods more than 100 s. Hence, two-dimensional inverse modelling has been confined up to 100 s only.

Resistivity models

Geophysical data are modelled and interpreted in terms of subsurface geology in two ways: a direct approach such as forward modelling and an indirect method of modelling through inversion. Additional constraints (Parker 1994) are needed to resolve the sharp structures and often the assumed discrete layered models are fitted in the least square way (e.g., Petrick et al. 1977). In the inversion here, a model of the subsurface is assumed as a combination of a fine grid mesh of suitable and appropriate size and the theoretical geophysical response is calculated. This is compared with the observed data and the inversion process is repeated until a minimum difference between the computed and observed response is achieved. In this study, the apparent resistivity and phase data for both TE and TM modes have been inverted. The vertical (Hz) component is, however, not considered here as reliable estimates because the component could not be obtained for all the sites due to noise caused by a strong breeze across the hard terrain.

A data set of six soundings (MT sites) has been considered here for two-dimensional modelling of the east–west oriented profile running for about 16 km. MT site 6 falls towards the eastern end of Schirmacher Oasis, close to the Russian station, Novolazareyskaya. MT site 1 is located on a nunatak on the western side. The electrical strike for the sites along the profile has been computed using the McNiece & Jones (2001) algorithm. A strike of ca. 15°E has been obtained for sites 2–6, as shown in Fig. 5 in the form of a Rose diagrams (individual and combined sites) for Schirmacher Oasis region with an ambiguity of 90°. Interestingly, site 1, which is located on a nunatak and lying in the western part of Schirmacher Oasis, shows a different strike (ca. 70°E). Distortion in the observed MT data due to conductive inhomogeneities needs to be estimated and corrected. Also, the dimensionality needs to be understood before the modelling procedure. Following the analysis of Bibby et al. (2005), the dimensionality in this particular case is more of a two-dimensional nature as observed in Fig. 6. The corrections for the distortions have been applied following Becken & Burkhardt (2004) and the corrected data set

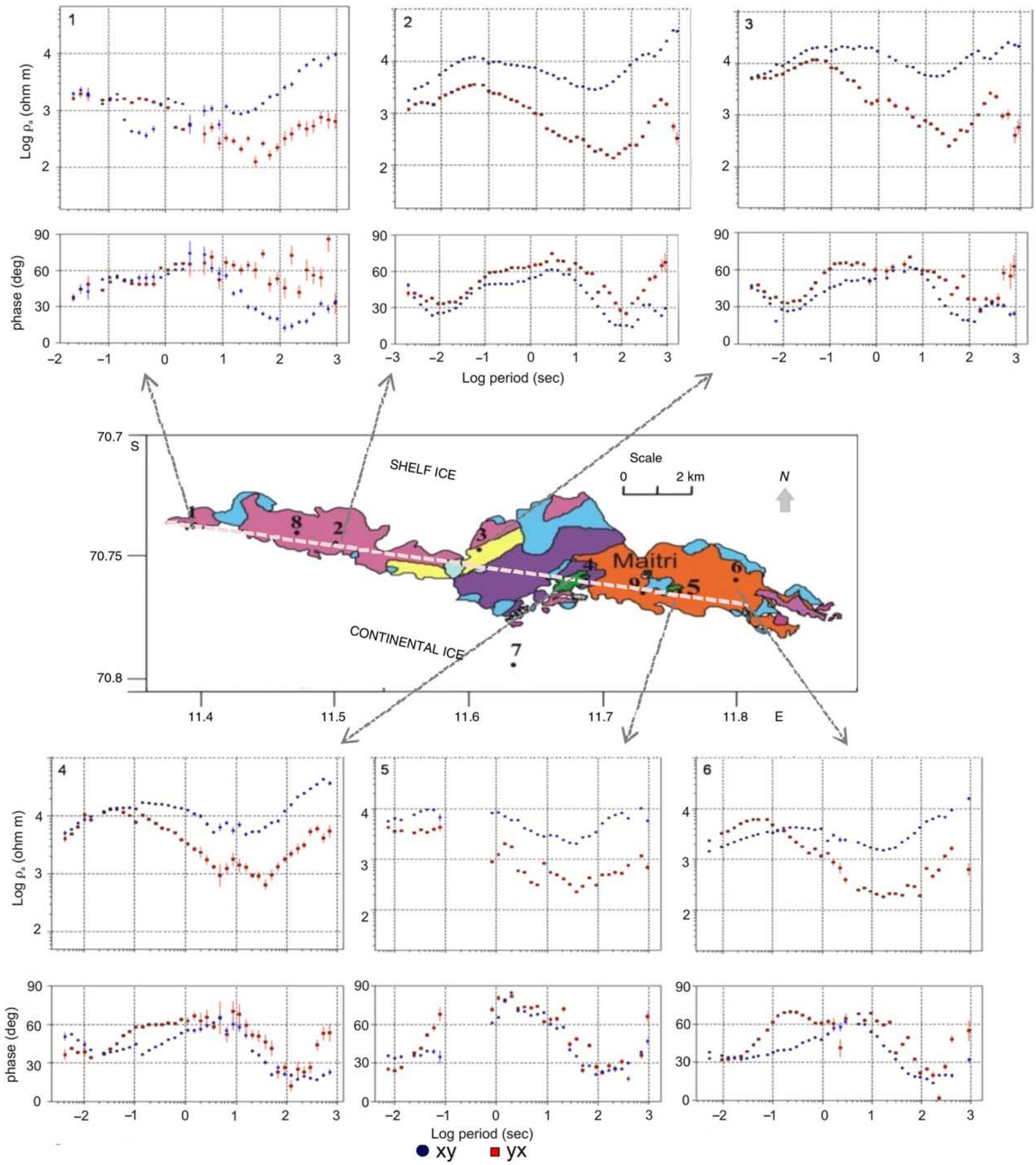

Fig. 3 Apparent resistivity and phase response for six magnetotelluric investigation sites along the profile.

subjected to inversion for arriving at the geoelectrical structure of the region.

The *yx*-component has been considered as the TE mode in the inversion, as the profile direction and geological strike are same. The MT data were inverted using the nonlinear conjugate gradients scheme implemented using the version 2.20 of the WinGlink software package (Rodi & Mackie 2001) to get a two-dimensional resistivity section. An initial model with half-space resistivity of 100 ohm m is considered and the model subjected to 200 iterations. Both TM and TE data with five decades (0.01–1000 Hz) are considered here with an error floor of 20% for resistivity and 5% for phase. A tau (τ) of 1, which indicates smoothness for the model, has been used here for the

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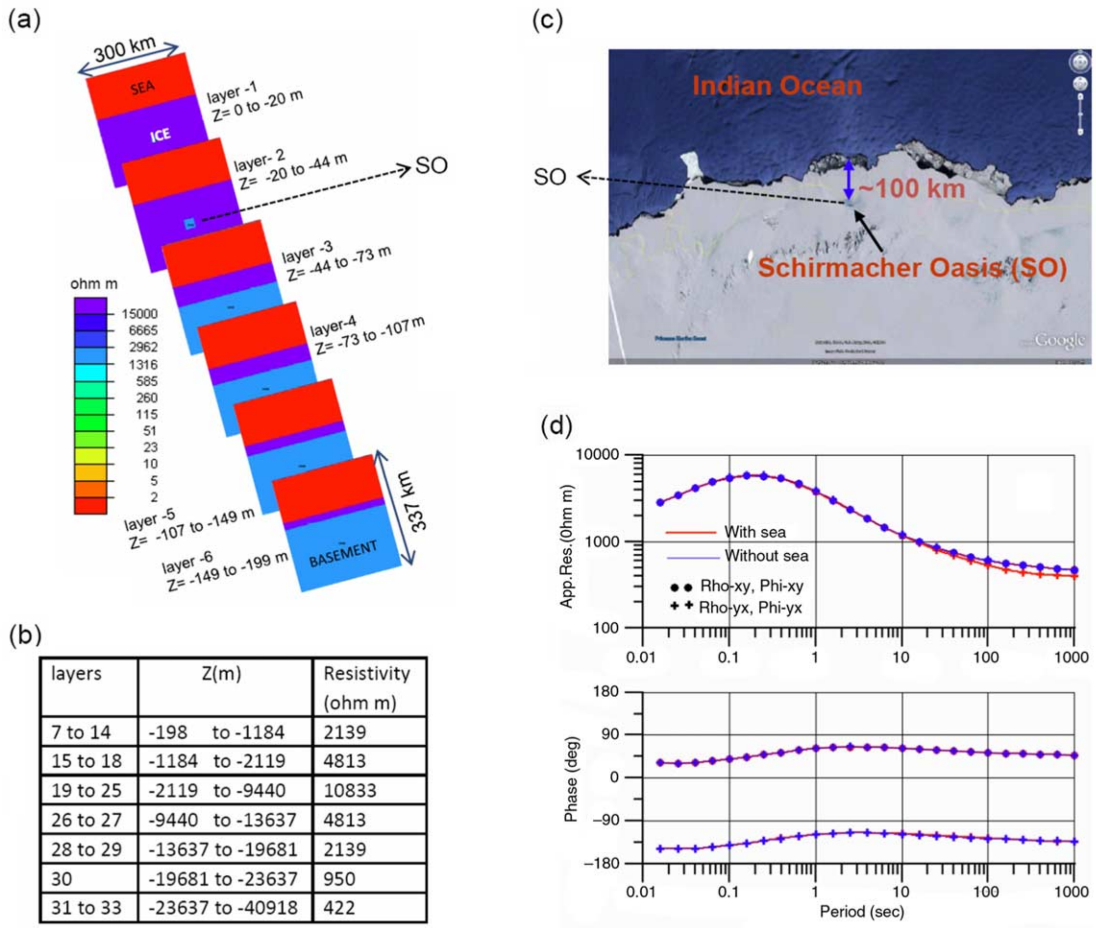

layers	Z(m)	Resistivity (ohm m)
7 to 14	-198 to -1184	2139
15 to 18	-1184 to -2119	4813
19 to 25	-2119 to -9440	10833
26 to 27	-9440 to -13637	4813
28 to 29	-13637 to -19681	2139
30	-19681 to -23637	950
31 to 33	-23637 to -40918	422

Fig. 4 (a) Three-dimensional model considered to estimate the coast effect in the magnetotelluric response in Schirmacher Oasis; (b) parameters used for layers 7–33; (c) location of Schirmacher Oasis with the Indian Ocean towards the north; and (d) magnetotelluric response derived from three-dimensional modelling at site 3.

initial inversion. The obtained model is then studied for different parameters of τ, starting from 1 to 1000. Variation of the root mean square error (RMSE) with roughness for the model is plotted and an optimum value of 8 for τ is obtained from this L curve (Fig. 7a) following Hansen's (1998) procedure. The variation in the root mean square with iterations is given in Fig. 7b, which shows that the RMSE attains a steady value after the 40th iteration. A final inversion using a τ of 8 was carried for 200 iterations and an rms misfit of 2.528 was obtained. The rms values at different locations are shown in Fig. 8a. The geo-electric section for the profile is shown in Fig. 8b.

This MT study has revealed a well-defined layer with an average thickness of 15 km and a highly resistive (8000–10 000 ohm m) upper crust below sites 2–5 along the profile (Fig. 8b). The thickness of this layer varies over the length of the profile, with 20 km on the eastern side of Maitri and a thinning (ca. 10 km) towards the western side. A less resistive (500–600 ohm m) lower crust has been delineated all along the profile. The same layer approaches shallower depths (ca. 6–8 km) between sites 1 and 2.

The fit between the observed and computed data for this profile in the form of apparent resistivity and phase pseudo-sections is presented in Fig. 9a and b for TE and TM modes, respectively. A reasonably good fit is observed for all sites. The conductive features in the geoelectrical section are well resolved as shown in the sensitivity map (Fig. 10) for the profile. As the strike at site 1 is different from the other five sites, the inversion has been attempted with and without site 1 to estimate the robustness of the subsurface structure. The contribution of site 1 is insignificant on the geoelectrical structure as seen from Fig. 11a (with site 1) and Fig. 11b (without site 1).

There are some limitations to our findings. (1) Even though Schirmacher Oasis represents a three-dimensional situation, the modelling has been confined to two-dimensions due to a limited data set (i.e., six stations in a

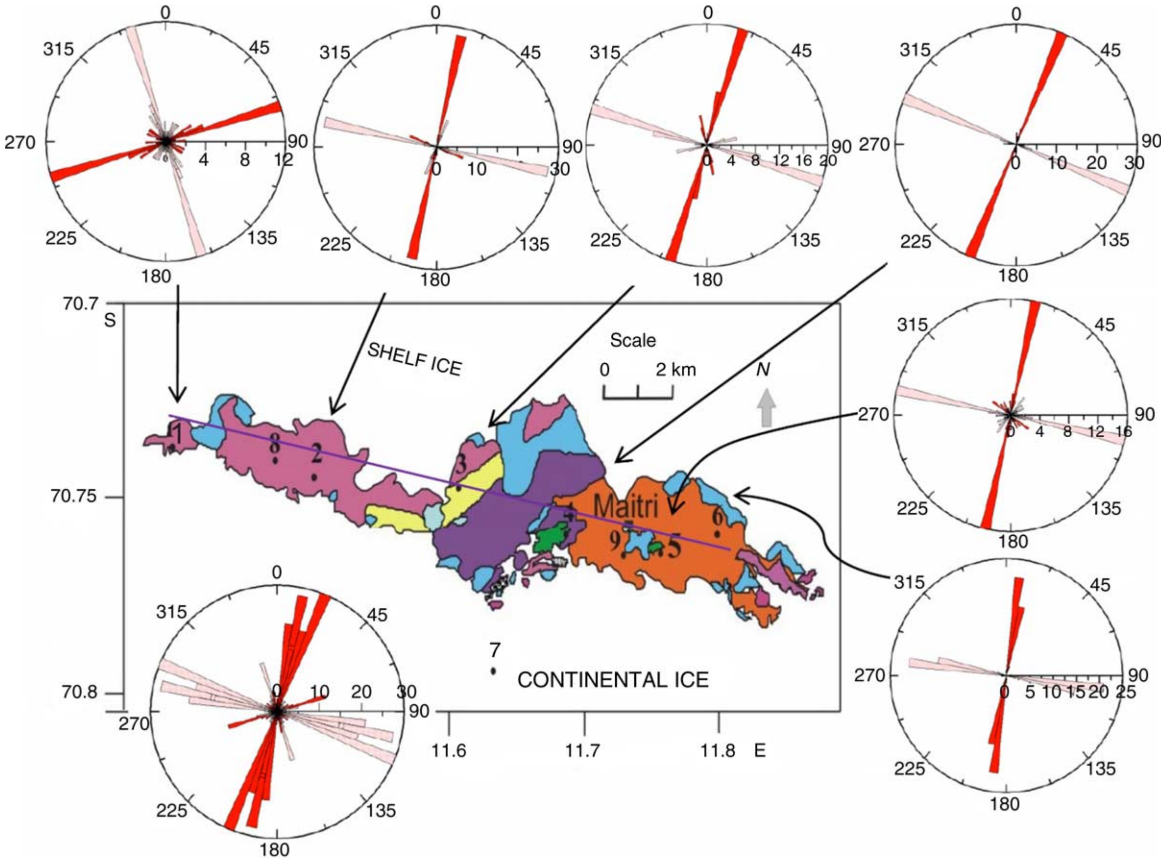

Fig. 5 Rose diagrams with petals at 90° showing geo-electric strike (individual and combined sites) for Schirmacher Oasis region. Considering 90° ambiguity, the strike has been taken as east–west while inverting the results.

line with 2- or 3-km spacing between stations). (2) A vertical magnetic field that yields tipper values could not be considered due to large noise from winds. (3) Due to accessibility problems, data could not be collected in a north–south oriented profile (i.e., strike perpendicular). Hence, the resistivity section shown here will indicate along-the-strike a lateral heterogeneity in resistivity in east–west direction over Schirmacher Oasis.

Geological implications

Previous studies have established that the crustal thickness in West Antarctica varies between 20 and 30 km in contrast to the crust that is ca. 40 km thick in East Antarctica, derived on the basis of seismic refraction profiles near the north–east coast, coupled with regional gravity interpretations (Bentley 1991). However, according to Wagner & Lindner (1991) the Moho depth in Schirmacher Oasis region has been interpreted to be ca. 35 km on the basis of geomagnetic data. Surface wave studies confirm a distinct contrast between the East and West Antarctic blocks, with the former showing more craton-like velocities on an average and with the highest lateral gradient in model velocities (Bentley 1991; Danesi & Morelli 2000; Ritzwoller et al. 2001; Harley 2003). Seismicity throughout Antarctica is generally low, which is consistent with a slowly moving plate almost entirely surrounded by mid-ocean ridges. However, the western part is ca. 10 times more seismically active than the east (Bentley 1991; Hole & Lemasurier 1994). Electromagnetic measurements conducted for bed rock investigations (Bhattacharya et al. 1987; Bhattacharya & Majumder 1987) have identified basement rocks below an ice cap 200–400 m in thickness south of Schirmacher Oasis.

A substantial and widespread sedimentary section with significant porosity or matured organic content has also been inferred below the ice sheet in previous regional MT studies in East Antarctica and has been correlated with similar results from seismic refraction data pertaining to the South Pole region (Wannamaker et al. 2004). Sedimentary basins ca. 6 km thick were also identified below the ice cover by Fournier (1994) from MT studies on Seymour Island and James Rose Island in the

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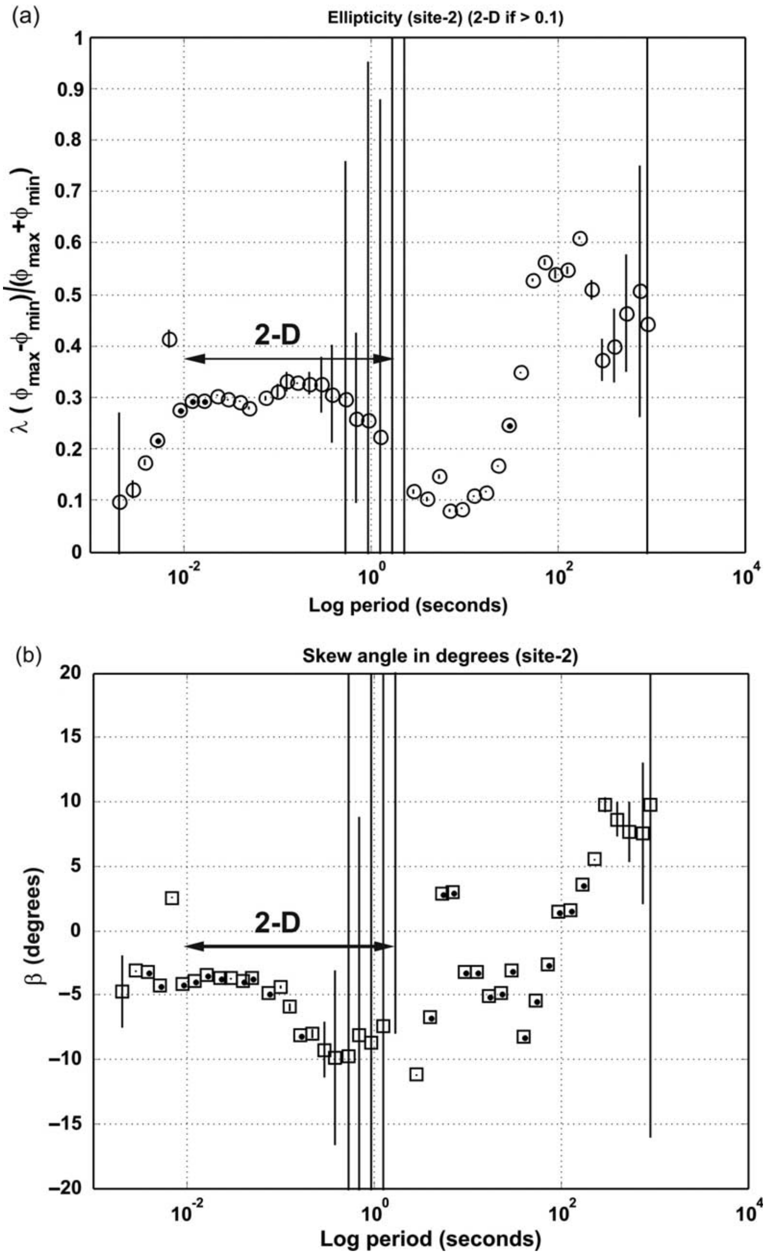

Fig. 6 Parameters of the phase tensor for site 2. (a) The dimensionality parameters ellipticity (λ) and (b) skew angle (β) indicate a two-dimensional (2-D) electrical structure for the region.

north-eastern part of Antarctica. Our traverse in Schirmacher Oasis reveals a thinning of the upper crust from ca. 20 km in the east to less than 10 km to the west within the short distance of 16 km.

Wannamaker et al. (2004) observed that the present-day deep resistivity structure of the South Pole region is markedly different from the typical cratonic lithosphere worldwide in exhibiting a low resistivity in the lower crust and upper mantle. They correlated this feature with a thermal anomaly generating high-temperature fluids or melts. Siegert (2000) proposed that heat flow through much of the East Antarctic lithosphere is in the order of ca. 50 mW m^{-2} or more. As the degree of extensional activity in Antarctica today is limited, perhaps related to its being surrounded by oceanic ridges, the thermal anomalies are hypothesized to stem from mantle plume processes (Hole & Lemasurier 1994). Regional plume-related dynamics in the deep lithosphere have been postulated as the dominant trigger for this thermal activity, with a possible contributing influence from the adjacent West Antarctic

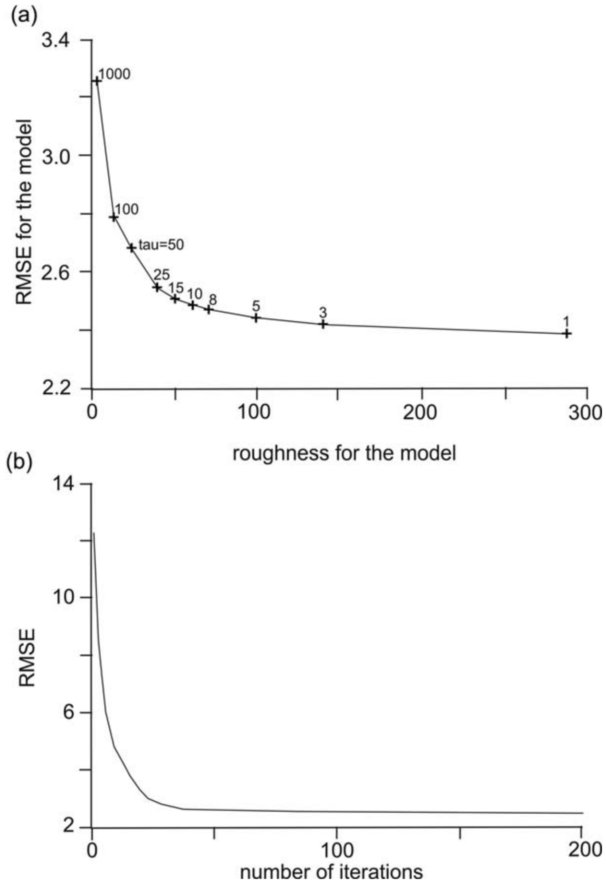

Fig. 7 (a) L curve for arriving at optimal trade off parameter tau (τ) value (Hansen, 1998), with τ of 8 chosen for two-dimensional inversion here and (b) variation of root mean square error (RMSE) values with number of iterations. From this diagram, it is clear that RMSE attains steady value after 40 iterations.

Block, a process that has also been invoked in earlier studies to account for the regional uplift in East Antarctica such as in the Gamburtsev–Vostok areas (Studinger et al. 2003; Bell et al. 2006). However, a recent study by Ferraccioli et al. (2011) negated this hypothesis and interpreted the feature to be a compositional Airy compensation.

Continental flood basalts are known from western Dronning Maud Land and the Transantarctic Mountains which are regarded as manifestations of the Karoo–Maud mantle super-plume activities at about 180 Mya (e.g., Bormann & Fritzsche 1995), which enabled subsequent Gondwanaland break-up (e.g., Storey 1995; Raval & Veeraswamy 2003). Sushchevskaya et al. (2008) reported olivine-bearing dolerites and gabbro dolerites from the Dronning Maud Land originating in Jurassic trap activity. Otherwise, there is no evidence so far for Cenozoic igneous activity in this region. In relation, the Farrar era volcanics are quite old. Although thermal causes have been invoked locally elsewhere in Antarctica, solid phases can also generate such anomalies, as displayed in the data set from the Canadian lithoprobe programme, where values of a few 100 ohm m seem easily achievable without the presence of thermal anomalies. Wagner & Lindner (1991) suggested magnetization all the way to the Moho, implying a cool regime. Thus, the lower resistivity of the lower crustal layer observed in our MT traverse is consistent with a cratonic nature and solid-phase conductors (Wannamaker et al. 1996).

Southward extension of the Mozambique Belt

The Mozambique Belt is one of the largest Neoproterozoic orogens associated with the assembly of the Gondwana supercontinent (e.g., Meert & Lieberman 2008; Santosh, Maruyama & Sato 2009; Collins et al. 2014). One of the outstanding issues of the Mozambique Belt is its southern continuation into East Antarctica (Jacobs et al. 1998). Rifting in the Mozambique basin contributed to rifting between India and Antarctica probably between 127 and 118 Mya (Lawver et al. 1991). According to Shackleton (1996), the eastern margin of the Mozambique Belt seems to continue from Madagascar–India–Sri Lanka towards Antarctica and enters the Lutzow-Holm Complex, and the western margin, after crossing the south-east corner of South Africa, enters Antarctica towards the western side of western Dronning Maud Land and goes up to the Shackleton Range in the south (Fig. 12). The model given by Jacobs et al. (1998) combines these two ideas: they propose that after passing through Sri Lanka the Mozambique Belt enters Antarctica on the western side of western Dronning Maud Land and goes up to Shackleton Range in the south. Yoshida et al. (2003) also inferred the southward extension of Mozambique Belt after its passage through Madagascar, India and western Dronning Maud Land into Shackleton Range. The southward continuation of the Mozambique Belt from South Africa to western Dronning Maud Land has also been proposed by Ravikant (2006) and Ravikant et al. (2004). Our results broadly match the model proposed by Jacobs et al. (1998), as Schirmacher Oasis preserves a cratonic nature and a conductive anomaly has been inferred towards west of Schirmacher Oasis. However, we can only speculate about the trace of this suture between Sri Lanka and Antarctica as it passes through the offshore region.

Our study in Antarctica is limited to a small profile (ca. 16 km), limited to a nunatak in the coastal region by

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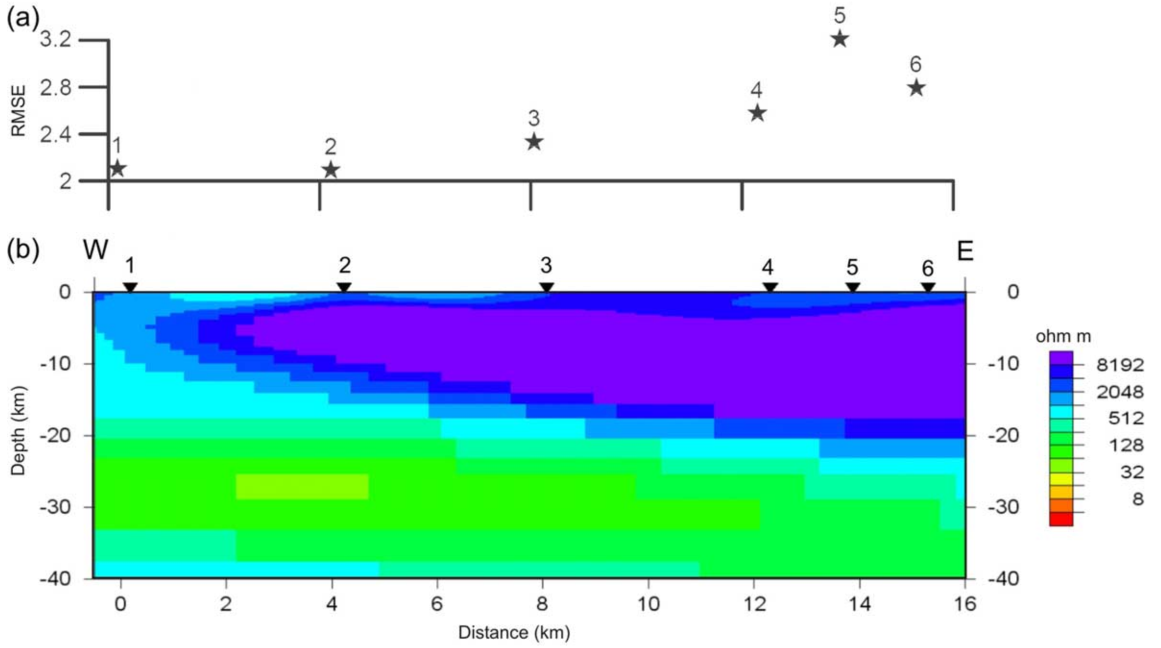

Fig. 8 (a) Root mean square error (RMSE) for the sites along the profile after 200 iterations and (b) two-dimensional geo-electric resistivity section for Schirmacher Oasis. Transverse electric and transverse magnetic modes have been considered for inversion with TE = YX and τ of 8. The final RMSE obtained for the profile is 2.528.

logistical limitations. We interpret the crustal resistivity section beneath Schirmacher Oasis to represent that of a craton. In order to better understand the resistivity structure of the upper mantle, MT sites over a longer transect are required.

Conclusions

The MT study in Antarctica, as reported here, is the first of its kind under the Indian Expedition programme. Two-dimensional modelling of the data has delineated a

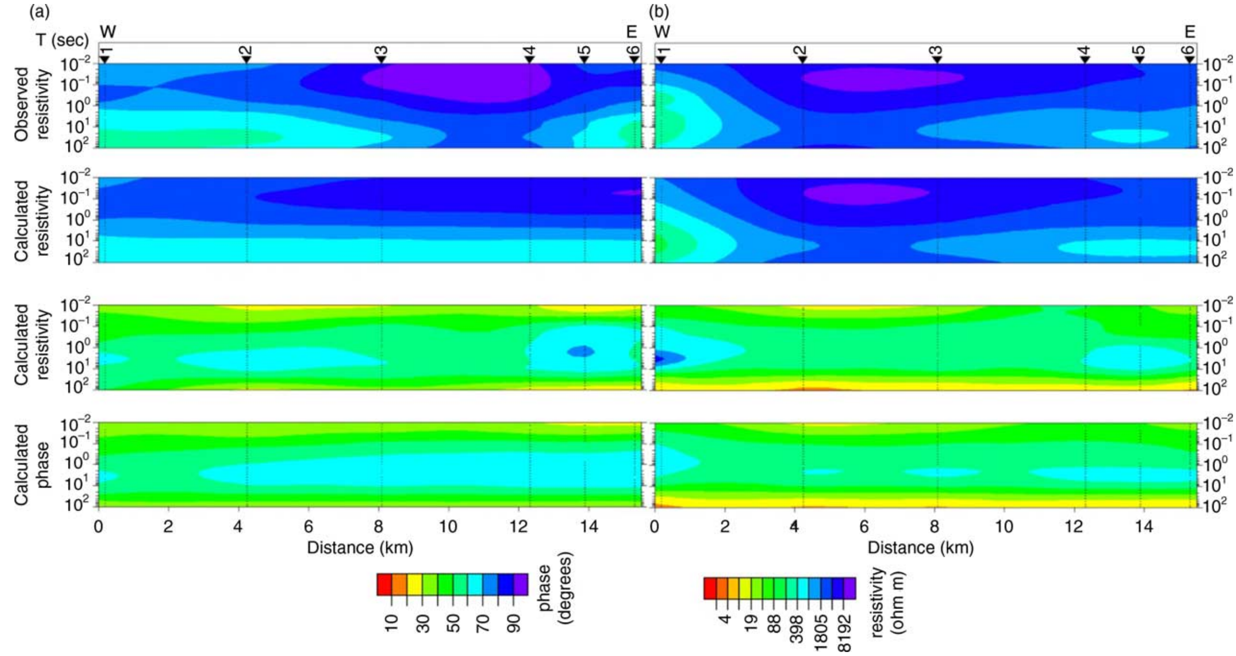

Fig. 9 Observed and modelled apparent resistivity and phase pseudo-sections for data for (a) transverse electric and (b) transverse magnetic modes.

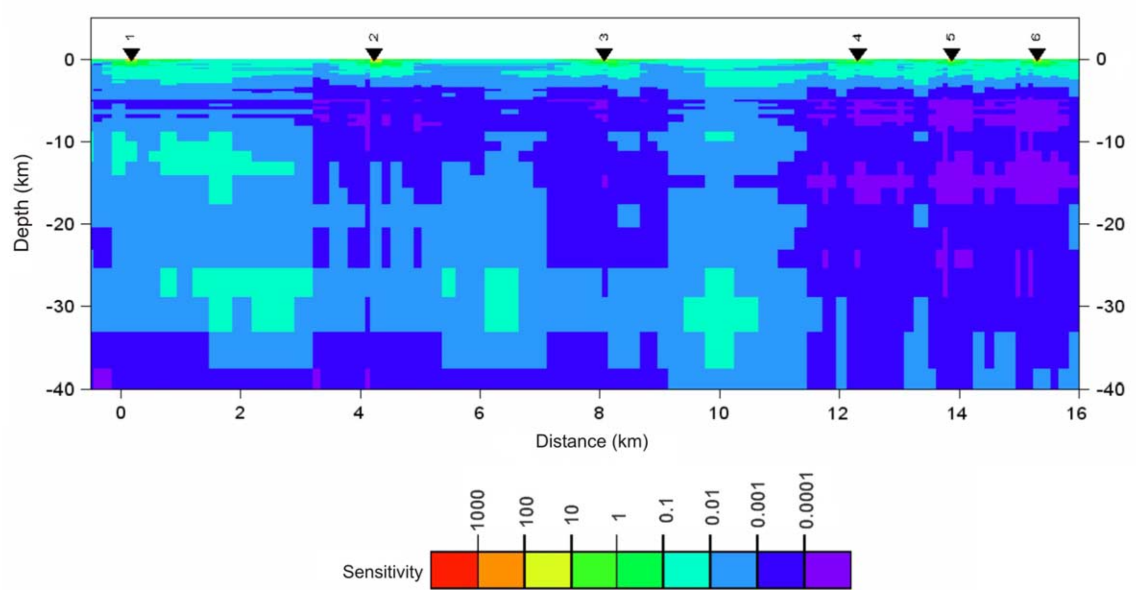

Fig. 10 Sensitivity matrix values for the geo-electric section. It represents the influence of data for small changes in resistivity in each model cell.

laterally varying upper crust (10–20 km) with a resistivity of more than 8000 ohm m. This is underlain by less resistive (500–600 ohm m) lower crust. The resistive upper crust, which thins towards the west, appears terminated between sites 1 and 2. The geoelectrical structure of the Dharwar craton shows a highly resistive (3000–10 000 ohm m) upper crustal layer of 10 km followed by a relatively low (200–1000 ohm m) resistive layer down to

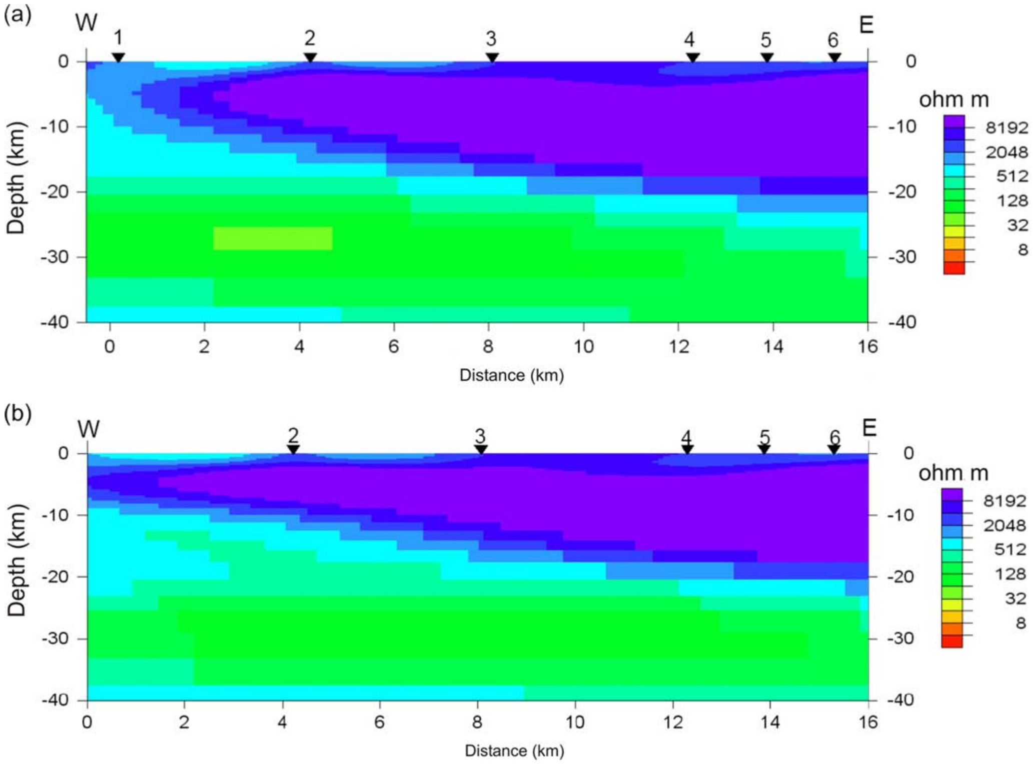

Fig. 11 The inversion results with and without site 1 indicate that there is no significant change in the geo-electric section. Note that site 1 is situated on a nunatak while the other sites are part of Schirmacher Oasis.

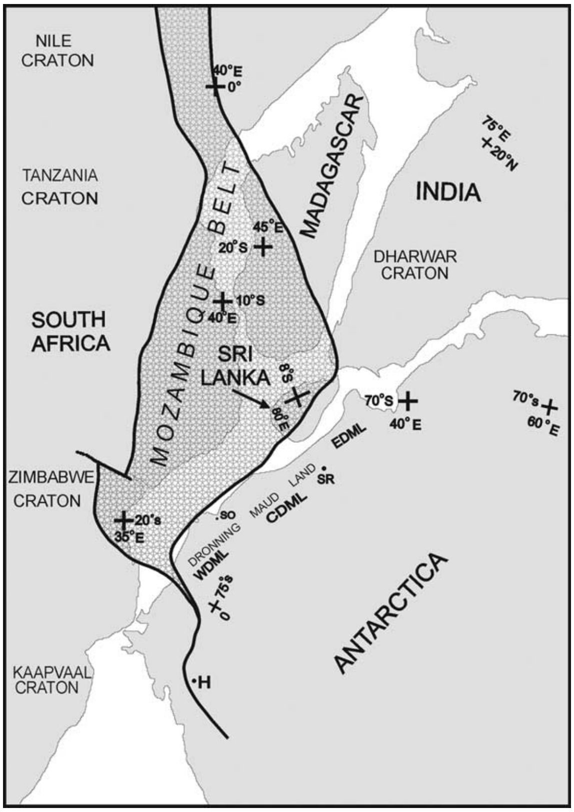

Fig. 12 Gondwana reconstruction (modified after Shackleton 1996). Regions between the sutures (represented by shaded zone) seem to be part of the Great Mozambique mobile belt. The following place names are abbreviated: Heimefrontfjella (H); Schirmacher Oasis (SO), Sør Rondane (SR); and western (WDML), central (CDML), and eastern (EDML) Dronning Maud Land.

depths of 30 km (figure 7 of Gokarn et al. 2004). The geoelectric structure obtained from Schirmacher Oasis resembles the same pattern with a highly resistive (> 8000 ohm m) layer down to depths of 10–20 km followed by a low resistive (500–600 ohm m) layer down to depths of 40 km (Fig. 8b). In view of the similarities between Schirmacher Oasis and the Dharwar craton, Schirmacher Oasis may also be considered as a craton (stable).

It is also noted that the Mozambique Belt which runs along the east coast of South Africa, Madagascar, Southern India and Sri Lanka might extend into East Antarctica along a corridor which lies to the west of Schirmacher Oasis and whose eastern boundary appears to be controlled by the fault delineated in this study.

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