GEOPHYSICAL RESEARCH LETTERS, VOL. 31, L10615, doi:10.1029/2004GL019903, 2004

Electrical structure across a major ice-covered fault belt in Northern Victoria Land (East Antarctica)

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Received 5 March 2004; revised 30 April 2004; accepted 5 May 2004; published 29 May 2004.

[1] A Geomagnetic Depth Sounding profile was performed across the glaciated Rennick Graben and the adjacent fault-bounded terranes of northern Victoria Land in East Antarctica. Induction arrows analysis and a 2D inversion model provide a unique deep electrical resistivity window beneath these fault zones. The electrical resistivity break across the Lanterman Fault is apparently restricted to the upper crust, suggesting that this strike-slip fault may not represent a deep lithospheric suture. Further east, a westward-dipping conductor is traced to a depth of 40 km beneath the Robertson Bay Terrane. It may image a remnant of the paleo-Pacific oceanic plate, which subducted beneath the Bowers Terrane. Within the Wilson Terrane, the Rennick Graben is an upper-crust resistive block. The Rennick Graben lacks a deep crustal or upper mantle conductor, in contrast to several continental rifts. However, similar resistive lower crust underlies some other major strike-slip fault belts. *INDEX TERMS:* 0925 Exploration Geophysics: Magnetic and electrical methods; 0905 Exploration Geophysics: Continental structures (8109, 8110); 8109 Tectonophysics: Continental tectonics—extensional (0905); 8110 Tectonophysics: Continental tectonics—general (0905). **Citation:** Armadillo, E., F. Ferraccioli, G. Tabellario, and E. Bozzo (2004), Electrical structure across a major ice-covered fault belt in Northern Victoria Land (East Antarctica), *Geophys. Res. Lett.*, *31*, L10615, doi:10.1029/2004GL019903.

1. Introduction

[2] The Transantarctic Mountains are a major mountain range (Figure 1), which relates to Cenozoic continental rifting within the West Antarctic Rift System [e.g., *Behrendt*, 1999]. The NW-SE-striking dextral strike-slip fault zones cutting through the continental crust of north Victoria Land (NVL) reactivated pre-existing faults of Cambrian-Ordovician age [*Flöttmann and Kleinschmidt*, 1991] and induced the transition from orthogonal to oblique rifting in the region during the Cenozoic [*Salvini et al.*, 1997; *Rossetti et al.*, 2002]. Specifically, Cenozoic intraplate strike-slip faulting induced along strike deformation partitioning in the Rennick Graben (RG) area [*Rossetti et al.*, 2003].

[3] The deep crustal structure beneath the major fault blocks of NVL is poorly constrained, due to the lack of geophysical exploration. As part of a joint German-Italian Antarctic expedition 1999/2000 several new geological and geophysical investigations were carried out over NVL [*Bozzo and Damaske*, 2001]. We focus on the Geomagnetic Depth Sounding (GDS) profile performed as part of the expedition across the RG and the adjacent terrane boundaries (Figure 1). By comparing deep electrical resistivity signatures along the GDS profile with structural geology and with geophysical and geochemical interpretations we discuss some major fault blocks of NVL from a new perspective.

2. Geological Setting

[4] Three tectono-stratigraphic terranes of Early Paleozoic age (Figure 1) are recognised over NVL [*Kleinschmidt and Tessensohn*, 1987]: the Robertson Bay Terrane (RBT), the Bowers Terrane (BT) and the Wilson Terrane (WT). The RBT consists of Cambrian-Ordovician metaturbidites, while the BT consists of metasedimentary and metavolcanic rocks of Cambrian age [*Weaver et al.*, 1984]. Aeromagnetic [*Finn et al.*, 1999; *Ferraccioli et al.*, 2002] and geochemical data [*Weaver et al.*, 1984] suggest that oceanic crust underlies part of the BT. The WT includes magmatic arc rocks related to Cambro-Ordovician subduction beneath the East Antarctic Craton. The Leap Year Fault forms a boundary between the BT and the RBT. The Lanterman Fault (LF), is marked by a belt of mafic and ultramafic rocks, and has been interpreted as a collisional suture between the WT and the BT [e.g., *Kleinschmidt and Tessensohn*, 1987]. This inherited fault zone was reactivated as a major strike-slip fault zone during the Cenozoic [*Rossetti et al.*, 2003]. Reactivation of this terrane boundary also induced the Cenozoic opening of the RG as a localised tectonic depression along a transtensional bend of the LF [*Rossetti et al.*, 2003]. Two thrust faults of Ross-age, the Wilson Thrust and Exiles Thrust outcrop at the Pacific Coast within the WT [*Flöttmann and Kleinschmidt*, 1991] and may continue southwards in the Rennick area [*Läufer and Rossetti*, 2003].

3. Magnetovariational Data Analysis

[5] The three components of the magnetovariational field (MV) were sampled by nine fluxgate magnetometers along a profile crossing the Rennick Glacier from the Everett to the Daniels Range (Figure 1). The polar electrojet current systems (PEJ) may cause source fields which violate the uniform plane wave assumption at the base of standard data processing. Several authors [e.g., *Mareschal*, 1986; *Beblo and Liebig*, 1990] have investigated the bias induced by the PEJ. *Beblo and Liebig* [1990] argued that there is a very low-level influence of PEJ on MT apparent resistivity curves estimated in the 30–2000 s period range in NVL. *Wannamaker et al.* [1996] obtained a reliable conductivity model from MT data in the range 0.01–400 s over West

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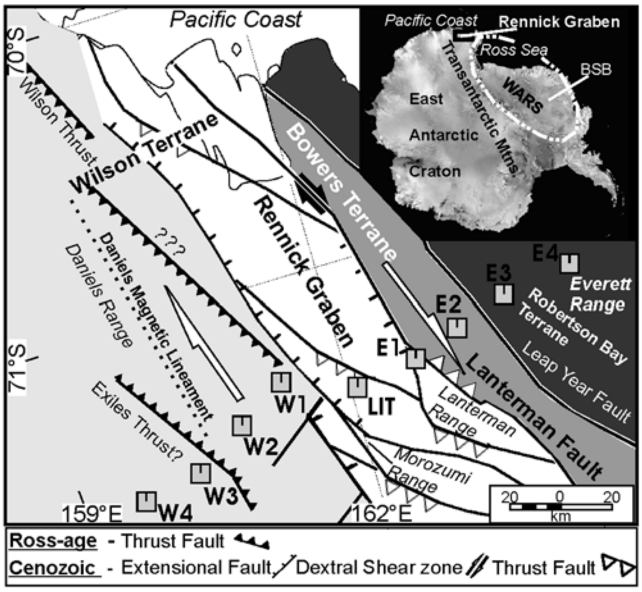

Figure 1. Location of the GDS profile across major ice-covered fault zones of northern Victoria Land. Note the investigated terrane boundaries, the Rennick Graben (white region) and the intra-terrane thrusts [*Rossetti et al.*, 2003; *Läufer and Rossetti*, 2003]. The inset shows the location of the Transantarctic Mountains at the edge of the West Antarctic Rift System (WARS). BSB: Byrd Subglacial Basin.

Antarctica. *Armadillo et al.* [2000] showed that deep electrical conductivity features can be delineated by GDS in NVL despite the PEJ. Single site Transfer Functions (TF) estimation was therefore based on the two following assumptions: (i) the bias of non-uniform sources can be removed by averaging a sufficient amount of data and excluding high contaminated intervals by a robust estimation approach [*Egbert and Booker*, 1986]; (ii) the normal vertical field varies randomly between the available data sets [*DeLaurier et al.*, 1980].

[6] The real part of TF is represented in Figure 2 as reversed induction arrows. The arrows direction is roughly perpendicular to the main faults (see Figure 1), indicating a bidimensional (2D) regional electrical conductivity pattern. Stations W4 and W3 point west at all the periods. In contrast, LIT, E1 and E2, point east. Stations W2 and W1 are at the transition between the two former groups. The observed pattern affects all periods, implying deep conductors beneath the eastern and western margins of the array and a deep resistive zone between the Daniels Range and the Bowers Mountains. A shallow (period range 20.5–41.5 s) conductor is revealed beneath the Bowers Mountains, by the facing arrows at E2 and E3. At longer periods, a deep enhanced conductivity zone is located east of the Leap Year Glacier.

4. 2D Inversion

[7] A 2D inversion technique [*Siripunvaraporn and Egbert*, 2000] was applied to the real-part dataset to image the regional electrical conductivity distribution. We assumed as starting and reference model a layered earth inferred from the averaged resistivity vs. depth curve [*Hermance*, 1995]. Our final model (RMS = 1.8) exhibits two deep electrical conductors (up to 10 ohm m), labelled Conductor 1 and 2 in Figure 3b. The former is located to the east of the Leap Year Glacier; the latter underlies the Daniels Range. The area from the Bowers Mountains to the Daniels Range shows enhanced resistivity at depth compared to the starting model (Resistive Zone). An abrupt change in the thickness of the upper resistive layers (resistivity over 400 ohm m) is apparent across the WT/BT boundary. At depths greater than 15 km forward modelling indicates that the apparently lower conductivity channel beneath the LF is likely to represent an artefact induced by the smooth inverse modelling. The upper resistive layer can be subdivided into four discrete zones (labelled A-D). A shallow conductor (100 ohm m) is located at a depth of approximately 10 km beneath the Bowers Mountains (Conductor 3).

5. Results and Discussion

[8] Faults can cause electromagnetic anomalies for a variety of reasons, e.g., juxtaposition of terranes with contrasting conductivity [*Jones*, 1998]; formation of cataclastic zones along faults enhancing percolation of fluids and therefore conductivity [*Unsworth et al.*, 1997]; fault-plane mineralisation by a conducting phase of graphite, sulphide or iron dioxide [*ELEKTB Group*, 1997]. Some major fault zones are reflected in our GDS profile (Figure 3). The change in the thickness of the upper crustal resistive layers is coincident with the surface expression of the LF, marking the transition between the WT/BT [*Rossetti et al.*, 2002]. The sharp electrical resistivity break beneath the LF is evident in the upper crust to a depth of 15 km. The LF appears to truncate Conductor 3, underlying the BT. This segment of the BT features high-amplitude aeromagnetic and gravity anomalies, associated with oceanic basement [*Finn et al.*, 1999; *Ferraccioli et al.*, 2002]. Ophiolites, presently at upper crustal levels beneath the BT, may be the source for the observed conductor, as recognised in California [*Unsworth et al.*, 1997]. At depths greater than 15 km there is no remarkable electrical resistivity contrast between arc crust of the WT and the BT. This may be consistent with recent aeromagnetic and gravity interpretations predicting that the LF was not a major collisional suture zone [*Finn et*

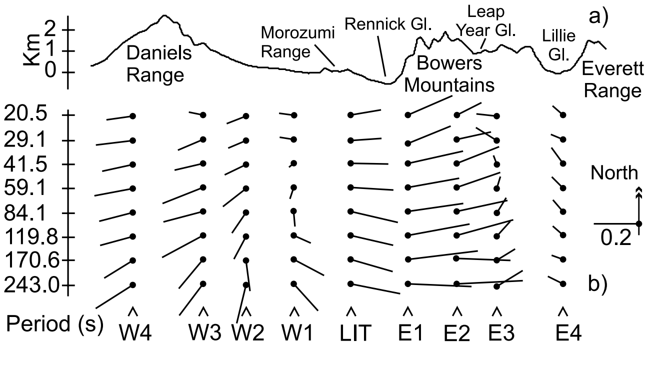

Figure 2. (a) Sub-ice topographic profile along the section; (b) Real reversed induction arrows at different periods in the range 20.5–243.0 s.

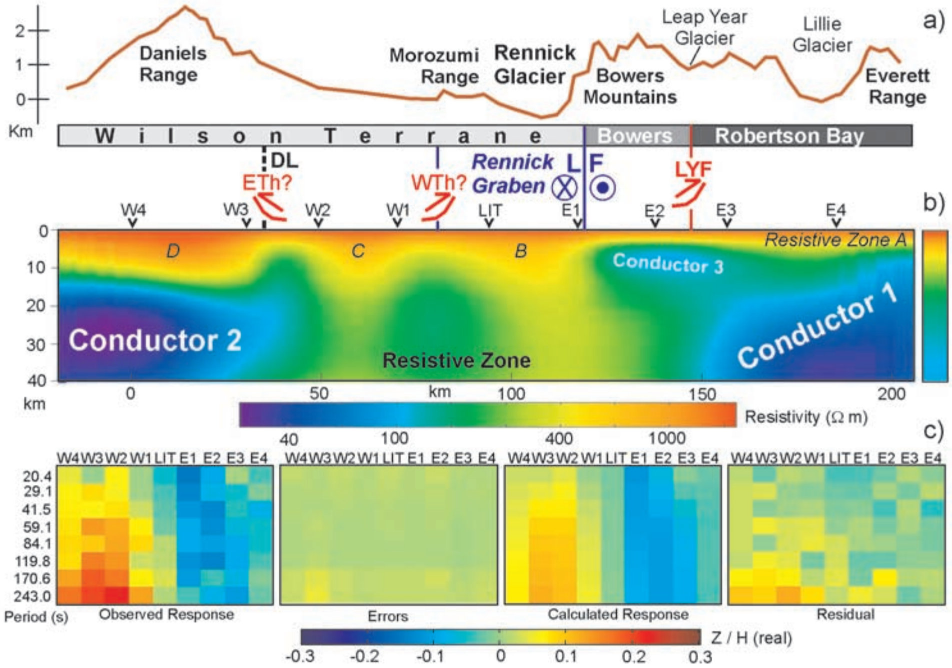

Figure 3. (a) Sub-ice topographic profile along the section; (b) 2D Resistivity model. Major terrane bounding and intra-terrane Ross-age faults [*Läufer and Rossetti*, 2003] are shown in red (LYF: Leap Year Fault; WTh?, ETh?: inferred Wilson and Exiles Thrust). Cenozoic faults [*Rossetti et al.*, 2003] flanking the RG (LF: Lanterman Fault and fault zone in the Morozumi Range) are displayed in blue. Dotted black line denotes the Daniels Magnetic Lineament (DL). The 'normal' resistivity layered earth model assumed as starting and reference model is shown for comparison on the right; (c) Observed response compared with the calculated response of the model. The estimated errors affecting the observed response and the residuals between observed and calculated response are shown.

al., 1999; *Ferraccioli et al.*, 2002]. Conductor 1 underlies the RBT. It is a westward-dipping body traceable to depths of 40 km. The source of this deep conductor is enigmatic due to the lack of independent geophysical data and models. Geochemical evidence suggests that the site of westward dipping oceanic subduction of Cambrian age was located east of the LF and the BT [*Estrada and Jordan*, 2003]. Westward subduction of oceanic crust is also consistent with the magmatic arc rocks of the WT and the Ross-age intra-terrane bivergent thrust fault architecture [*Flöttmann and Kleinschmidt*, 1991]. Conductor 1 may be associated with the Cambrian subduction of paleo-Pacific oceanic lithosphere. Notably, deep conductors are known to occur over modern oceanic subduction zones such as the Juan de Fuca plate [*Kurtz et al.*, 1990] and over ancient ones [*Wu et al.*, 2002].

[9] Within the WT, the boundary between upper-crust resistive zones B–C appears to match the location of the eastern boundary of the RG [*Rossetti et al.*, 2003] and the inferred Wilson Thrust of the Morozumi Range [*Läufer and Rossetti*, 2003]. The lack of a thick upper-crustal conductive layer in the RG is consistent with gravity modelling, suggesting a relatively thin (<3 km) sedimentary infill within the graben itself [*Reitmayr*, 1997]. The boundary between resistive zones C–D corresponds to the inferred location of the Exiles Thrust [*Läufer and Rossetti*, 2003] and to the location of the Daniels Magnetic Lineament [*Ferraccioli et al.*, 2002]. Conductor 2 underlies the Daniels Range. The origin of Conductor 2 is enigmatic. *Läufer and Rossetti* [2003] proposed that the inferred Exiles Thrust marks the boundary to the East Antarctic Craton (EAC). Perhaps Conductor 2 images the leading edge of the EAC?. In contrast, a deep resistive zone is clearly imaged beneath the Cenozoic RG and the adjacent inherited Wilson and Exiles Thrust fault system (Figure 3b). Seismological data along the GDS profile suggests that thin crust (20–26 km) underlies the RG (*Agostinetti*, 2003 pers. comm.). In active extensional regimes low resistivities are expected in the deep crust due to released fluids [*Wannamaker et al.*, 1996]. However, high resistivities underlie the Byrd Subglacial Basin (Figure 1), a possible dormant rift zone within the West Antarctic Rift System [*Wannamaker et al.*, 1996]. This comparison suggests that lack of a deep electrical conductivity zone does not contradict possible rifting in the RG area. However, the Rio Grande, Baikal, East African and Rhinegraben rifts all share zones of low resistivity (<50 ohm m) in the 10–30 km depth range [*Jiracek et al.*, 1995]. The high-resistivity zone at lower crustal to upper mantle depths beneath the RG and adjacent inherited fault belts is more reminiscent of resistive zones detected from magnetotellurics beneath some major strike-slip fault zones, such as the Tintina fault in northwest Canada [*Ledo et al.*, 2002] or the Great Slave Lake shear zone in British Columbia [*Wu et al.*, 2002]. It contrasts with examples of conductive transcurrent fault belts, such as parts of the San Andreas Fault [*Unsworth et al.*, 1997] or the Alpine Fault in New Zealand [*Ingham and Brown*, 1998]. Clays associated with faulting, graphite precipitated from fluids in the fault,

fluids associated with active fault zones and serpentinite, have been cited as sources of enhanced conductivity related to some regional scale shear zones [*Wu et al.*, 2002 and references therein]. Perhaps, none of these components were available in the deep crust underlying the RG region. The hypothesis that high-resistivity in RG area relates to the deep roots of the strike-slip fault belt of northern Victoria Land [*Salvini et al.*, 1997] is attractive, because recent structural evidence suggests that Cenozoic dextral-strike motion was accommodated within the Rennick pull-apart basin [*Rossetti et al.*, 2003].

[10] **Acknowledgments.** Fieldwork was performed within German-Italian GANOVEX VIII- ITALIANTARTIDE XV Expedition. Research was funded within the BACKTAM programme. This paper is part of a collaboration between the Universita' di Genova and the British Antarctic Survey. We thank F. Rossetti for his thoughtful review.

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