Magnetotelluric study in northeastern Botswana

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ABSTRACT

The proposed boundaries of geological terranes in northeastern Botswana are mainly based on regional magnetic and gravity data, because there are not many outcrops available due to the thick Phanerozoic cover rocks. The extent of the Zimbabwe craton into Botswana as well as the location of the boundaries to its neighbouring mobile belts (Limpopo Belt, Magondi Mobile Belt and Ghanzi-Chobe Belt) are not very well known.
Magnetotelluric (MT) profiles of the Southern African MagnetoTelluric EXperiments (SAMTEX) are present in this area and provide information about lithospheric strike directions and the resistivity distributions as well as possible locations of terrane boundaries, which verify some of the proposed terrane boundaries and suggest modification for others (e.g., Ghanzi-Chobe Belt to Magondi Mobile Belt terrane boundary and the western boundary of the Zimbabwe craton).

Key words: Magnetotellurics, SAMTEX, Zimbabwe craton, Magondi Mobile Belt, Ghanzi-Chobe Mobile Belt

INTRODUCTION

Due to the thick Phanerozoic cover rocks the knowledge about the geological terranes in northeastern Botswana are very limited. The terranes are outlined based on only a few locations of outcrop and some regional magnetic and gravity studies. No lithospheric probing geophysics has been conducted in that area, therefore the thickness, internal structure and geometry of the lithosphere of the Zimbabwe craton and the surrounding mobile belts

(Magondi Mobile Belt, Ghanzi-Chobe Belt (often not distinguished from the Damara Mobile Belt and therefore plotted as one), Limpopo Belt) are unconstrained.

Since mid 2003 the resistivity of the subsurface structure in southern Africa has been investigated by the deep probing, electromagnetic technique magnetotelluric. The Southern African MagnetoTelluric

Experiment (SAMTEX) acquired data at over 600 MT stations across the subcontinent (Figure 1).

A data subset of 108 sites located in northeastern Botswana covers the area of the possible extent of the Zimbabwe craton in Botswana. We have processed the data to response functions, undertaken geoelectric strike analysis and initialised 2D inversion of the north-south orientated profile crossing the Zimbabwe craton (called ZIM line; red dots in Figure 1).

Although the strike direction varies along the profile and with depths, acceptable strike directions were found that match the major geological structures, e.g. the orientation of the Okavango dyke swarm and the direction of the Magondi Mobile Belt. Based on the results we suggest the modification of two terrane boundaries: the boundary between the Ghanzi-Chobe Belt and the Magondi Mobile Belt and the southwestern boundary of the Zimbabwe craton.
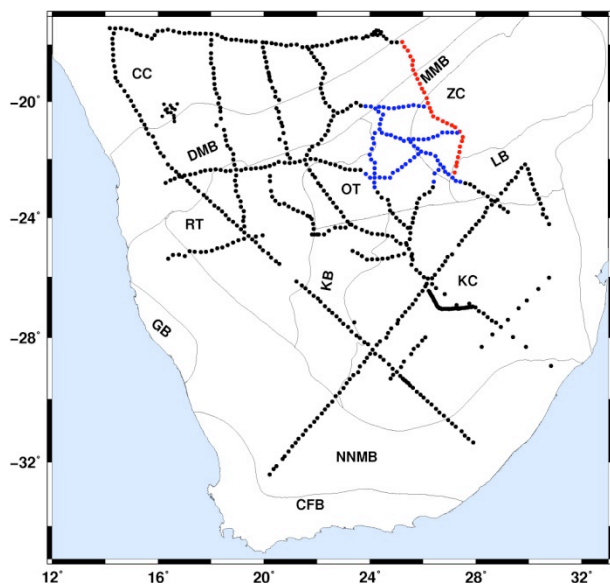

Figure 1. Outline of the geological terrane boundaries (courtesy of Sue Webb, University of Witwatersrand) based on regional magnetic data in relation to the MT sites. The ZIM profile (red dots) and sites from neighbouring profiles (blue dots) provide information about the area of the proposed boundary of the Zimbabwe craton. All other SAMTEX sites are indicated by black dots. Tectonic domains abbreviation: CC Congo Craton, CFB Cape Fold Belt, DMB Damara Mobile Belt (including Ghanzi-Chobe Belt in Botswana), GB Gariep Belt, KB Kheis Belt, KC Kaapvaal Craton, LB Limpopo Belt, MMB Magondi Mobile Belt, NNMB Namaqua-Natal Mobile Belt, OT Okwa Terrane, RT Rehoboth Terrane, ZC Zimbabwe Craton.

Geological Setting

The Archaean Zimbabwe craton is mainly located in Zimbabwe and extends into Botswana, where its

boundaries are obscured by Phanerozoic cover rocks and Kalahari sands. In the south the Zimbabwe craton is limited by the Archaean age Limpopo Belt, which was built during the collision of the Zimbabwe and Kaapvaal cratons. At the northwestern margin the Magondi Mobile Belt is present, which is a product of early Proterozoic basinal sedimentation followed by deformation and associated metamorphism on the northwestern margin of the Zimbabwe craton. North of the Magondi Mobile Belt the Ghanzi-Chobe Belt follows, which is Meso- to Neoproterozoic in age and is a northeast-trending, about 500 km long and 100 km wide, elongated volcano-sedimentary basin. Another significant structure is the Okavango dyke swarm, which contains beside the Karoo dykes also a few Proterozoic dykes and is orientated ESE-WNW (about 110°E of N).

MT DATA ACQUISITION, PROCESSING AND ANALYSIS

Data Acquisition

As part of the SAMTEX project, several magnetotelluric profiles were acquired in northeastern Botswana (Figure 1). The main profile across the Zimbabwe craton (ZIM – red dots in Figure 1) runs in a north-south direction (more or less parallel to the political border between Botswana and Zimbabwe), is about 600 km long and consists of 31 broadband MT (BBMT) sites at approximate 20 km intervals. Other sites of interest for the Zimbabwe craton area (blue dots in Figure 1) belong to the BOT400, MAK, MOF, KAL, SAN and SSO profiles (also with approximate 20 km site spacing). In total 108 sites are combined into the data subset of this focused area. For political and safety reasons no MT sites were deployed to the east of the ZIM line in Zimbabwe.

Each BBMT site was composed of five lead-lead-chloride electrodes, which measure the electric field of the Earth in two perpendicular, horizontal directions. Simultaneously the magnetic field variation was recorded with two horizontal, perpendicular orientated coils. At some sites the vertical magnetic field component could be measured using a third, vertical coil. Phoenix Geophysics MTU-5A recording units were used as data loggers. All BBMT sites recorded data for 2 – 3 days in a frequency range of 250 – 0.0001 Hz.

Data Processing

The recorded time series of electric and magnetic field variations were transformed into magnetotelluric response curves, using remote referencing Phoenix processing software (based on Jones and Jödicke, 1984). Most of the sites show good quality resistivity and phase curves to periods of at least 1000 s, at some sites even up to 2000 – 3000 s.

Data Analysis

To find the most consistent geological strike direction of the data set, the distortion decomposition method by McNeice and Jones (2001) was applied. This method not only determines the strike azimuth, but also analyses the data for galvanic distortion and decomposes the distorted data. Since the penetration depth is very different at the various sites, a depth related frequency band selection was chosen to gain information at crustal and lithospheric depths.

GEOELECTRIC STRIKE INFORMATION

The strike analysis provides the azimuth angle of the geological strike and the phase difference in the two orthogonal directions of the decomposed data, which is an indicator for the dimensionality. Figure 2 shows single site strike analysis results for crustal (5 – 35 km) and lithospheric (50 – 150 km) depths. The length of the arrows represents the goodness-of-fit (the longer the arrow the better the fit) and the colour of the arrows indicates the average phase difference for each site over the whole depth band. A small phase difference (blue – turquoise) means that this area at those depths is 1D (< 10° phase difference). Larger phase differences (orange – red) indicate a strongly 2D environment (> 35° phase difference). Medium phase differences (green – yellow) indicate a weakly 2D structure.

It is important to note that the determined strike direction has a 90° ambiguity. This can be avoided by plotting the most conductive directions (Figure 3). The most conductive direction is defined as the parallel direction to a fault or terrane boundary on the more resistive side of the fault/boundary, whereas it is perpendicular to the fault/boundary on the conductive side. Therefore a 90° flip in the most conductive direction is expected at terrane boundaries. Such a flip is obvious at the northern end of the ZIM line, north of the boundary between the Ghanzi-Chobe belt and the Magondi Mobile Belt. This flip is apparent in crustal and lithospheric depths at the same location and therefore indicates that an electrical boundary is located further north than the assumed one (based on the magnetic data). It also suggests that the Magondi Moblie Belt is more conductive than the Ghanzi-Chobe Belt. A second very obvious flip can be found at the eastern sites above the Okavango dyke swarm (clearly visible as parallel magnetic anomalies at 110° angle) and south of it. This flip marks clearly the southern edge of the dyke swarm. The location of the western edge of the Zimbabwe craton is questionable, there is flip present at the location the boundary is drawn at, but the most conductive directions suggest that in this case the craton would be more conductive than the surrounding belt, which would be very unusual. Further to the west

(at about 24.5° and -22.5°) where the north-south and the NE-SW orientated profiles intersect is another flip. If this flip indicates the edge of the craton, the craton would be the more resistive terrane. Additional to that, there were diamondiferous kimberlites found in Gope, which is located very close to this location. Diamondiferous kimberlites are associated with thinner edges of cratons (rule by Clifford, 1966, modified by Griffin et al., 2004; Jones et al., 2009).
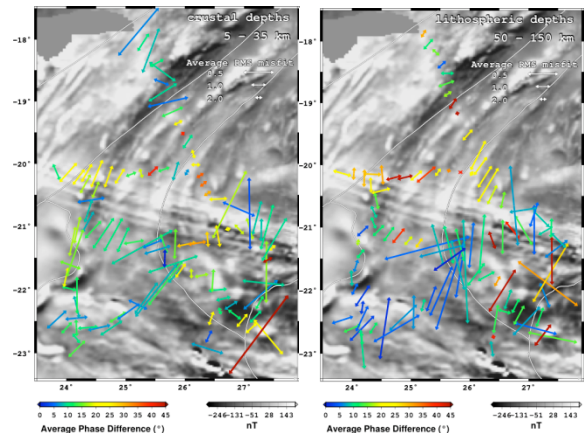

Figure 2. Geological strike directions in a crustal (5 – 35 km) and a lithospheric (50 – 150 km) depth bands. The length of the arrows indicated the goodness-of-fit (the longer the better), whereas the colour represents the phase difference in the two orthogonal directions. Magnetic image and geological terrane boundaries are shown in the background.
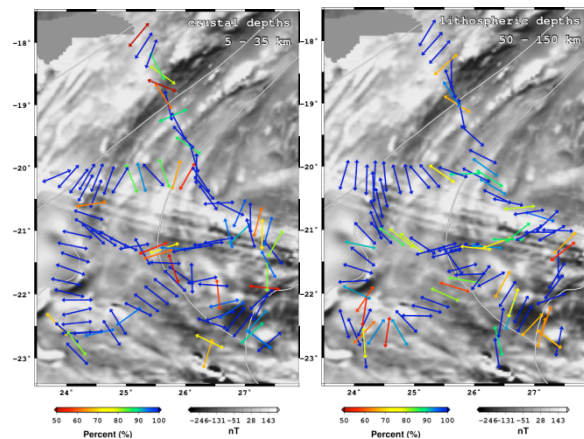

Figure 3. Most conductive directions in the crustal and lithospheric depths bands. The colour indicates how representative the plotted direction is for the whole depth range (blue/100% - all frequency have the same most conductive direction; red/50% - for half of the frequencies the most conductive direction is the plotted one, for the other half it is the perpendicular direction).

To perform 2D modelling of the ZIM profile a common strike direction must be chosen. Using multisite, multifrequency strike analysis of various groups of sites and frequencies a strike profile could be determined that is shown in Figure 4. The dominant crustal strike direction is 55°, but analysing the dyke site as a separate group results in a strike direction of 110°, which is equivalent to the dyke swarm orientation. The dominant lithospheric strike direction is 35°.
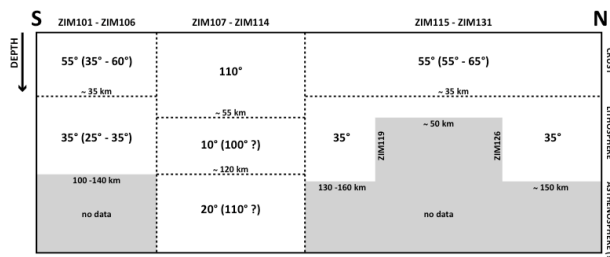

Figure 4. Sketch of the different strike directions for various parts of the ZIM line. In crustal depth a strike azimuth of 55° is dominant (strike ranges given in parentheses), but if analysed separately the sites above the Okavango dyke swarm indicate a strike direction parallel to the swarm orientation. In lithospheric depths a strike azimuth of 35° is the dominant direction.

2D LITHOSPHERIC MODELS

Since our interest lies mainly in the lithospheric structures, the lithospheric strike angle of 35° was chosen for the 2D inversion of the whole data set. Various 2D models with different parameter settings show the same major structures. One example is shown in Figure 5. There is a resistive, crustal, northwards dipping structure (R1 in Figure 5), which is related to the Ghanzi-Chobe Belt at the northern end of the profile (ZIM125 – 131). Beneath is a moderate resistive lithosphere (R2). The resistivity of the Zimbabwe craton (ZIM101 – 118/119) is not as high as found for the Kaapvaal craton, but still distinguishable from the surrounding (R3). Also all models show a conductor (C1) in the lower crust in the Magondi Mobile Belt (ZIM121 – 123).

CONCLUSIONS AND OUTLOOK

The MT data results provide new information about the unconstrained terrane boundaries in northeastern Botswana. We suggest shifting the boundary between the Ghanzi-Chobe and Magondi belts northwards, because an electrical boundary is located there. We also found indications that the Zimbabwe craton might extend further west than previously assumed based on the magnetic data.

Two-dimensional models of the other profiles and a 3D inversion of this area are desirable to gain a better overall image of the lithospheric structure and to confirm the suggested modification of the Zimbabwe craton's western boundary.

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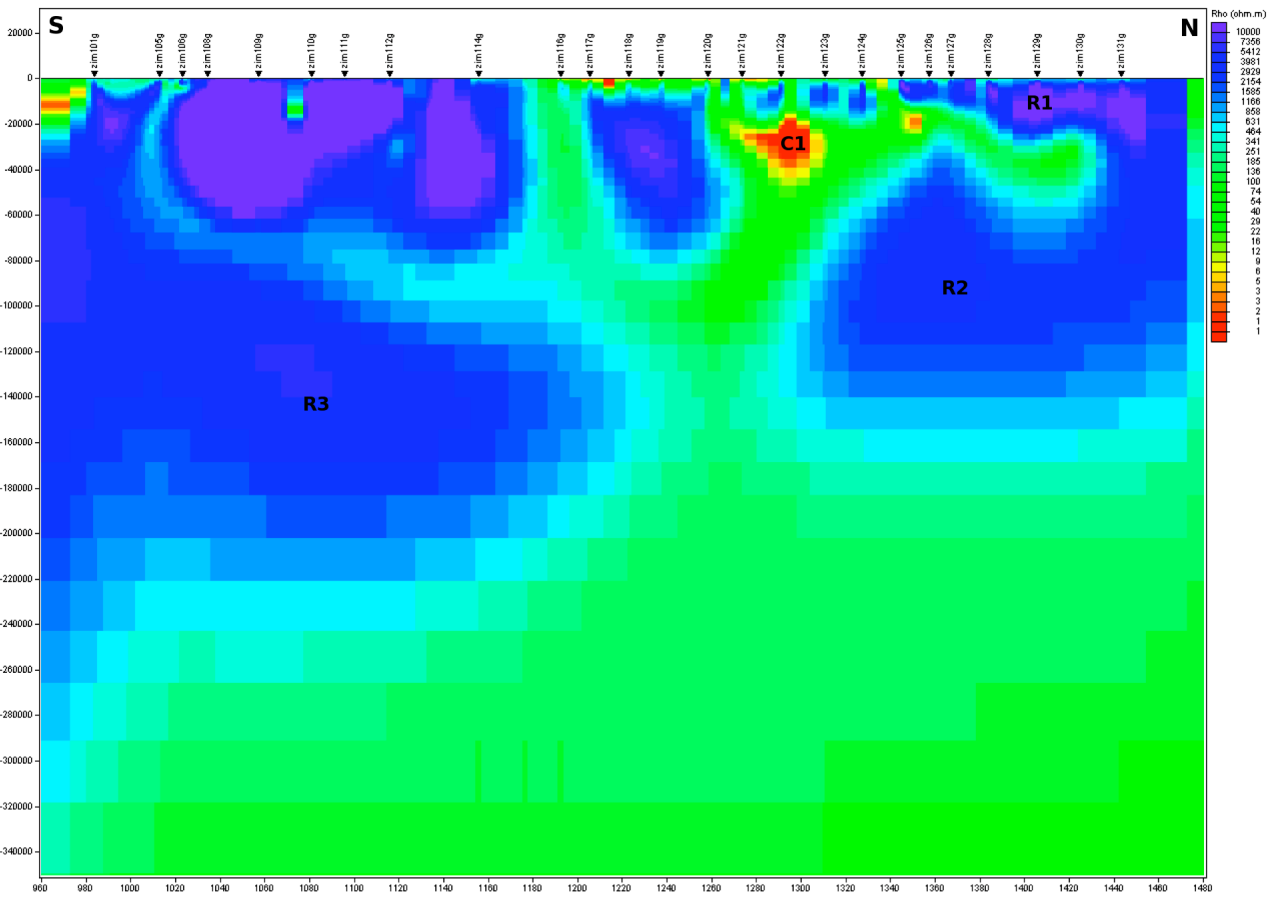
Figure 5. An example 2D resistivity model of the ZIM line using the inversion code by Rodi and Mackie (2001) implemented in WinGLink® software from Geosystem. Cold/blue colours represent high resistivity values, whereas conductors are indicated by warm/red colours.