

Lithospheric structures and geometries in northeastern Botswana revealed through SAMTEX magnetotelluric profiling

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SUMMARY

Within the framework of the Southern African MagnetoTelluric EXperiment (SAMTEX) a focused study was undertaken to gain superior knowledge of the lithospheric geometries and structures of the westerly extension of the Zimbabwe Craton into Botswana, with the overarching aim to increase our understanding of southern African tectonics. The area of interest is located in northeastern Botswana, where Kalahari sands cover most of the geological terranes, and little is known about lithospheric structures and thickness. Investigation of the 600-km-long ZIM line profile crossing the Zimbabwe craton, Magondi mobile belt and Ghanzi-Chobe belt showed that the Zimbabwe craton is characterized by thick (approx. 220 km) resistive lithosphere, consistent with geochemical and geothermal estimates from kimberlite samples of the Orapa and Letlhakane pipes (approx. 175 km west of the profile). The lithospheric mantle of the Ghanzi-Chobe belt is resistive but the lithosphere is only about 180 km thick.

At crustal depths a northwards-dipping boundary between the Ghanzi-Chobe and the Magondi belts is identified, and two mid- to lower-crustal conductors are discovered in the Magondi belt. The crustal terrane boundary between the Magondi and Ghanzi-Chobe belts is found to be located further to the north, and the southwestern boundary of the Zimbabwe craton might be further to the west, than previously shown in the boundaries defined on a regional basis using potential field data.

Keywords: magnetotellurics, lithospheric structures, NE Botswana, Zimbabwe craton

INTRODUCTION

From 2003 to 2008 magnetotelluric (MT) data have been acquired at hundreds of sites in South Africa, Botswana and Namibia (see Fig. 1). The aim of this project, the Southern African MagnetoTelluric EXperiment (SAMTEX), is to improve understanding of the southern African geological framework and the history of the tectonic processes involved in the formation of the southern part of the continent. MT is being used to map lithospheric structures and geometries of various terranes. The focus of the work presented herein is an area in northeastern Botswana, where most of the geological terranes are covered by Kalahari sands. Only a few outcrops and magnetic and gravity surveys are available to allow the determination of the approximate outlines of these terranes. The only information about lithospheric mantle structure in northeastern Botswana is provided by the kimberlites of the Orapa and Letlhakane pipes ('O' and 'L' in Fig.1), which are located about 150 to 200 km to the west of the

600-km-long 2D profile (called the ZIM line, which crosses the Zimbabwe Craton, the Magondi Mobile Belt and the Ghanzi-Chobe Belt). It is uncertain which geological terrane these pipes belong to, as they are located on the boundary (based on the potential field data) between the Magondi Mobile Belt and the Zimbabwe Craton.

Prior to the SAMTEX work, northeastern Botswana has been mostly *terra incognita*, especially at lithospheric mantle depths. For none of the terranes was the thickness of the lithosphere known, nor the location or nature (e.g., sharp or smooth transition, dip, different location at crustal than lithospheric mantle depths) of the terrane boundaries at lithospheric depths. Although the terrane boundaries drawn based on the potential field data are adequate for a larger regional scale picture, they are not sufficiently accurate for local scale studies. The western boundary of the Zimbabwe Craton is of particular interest, but the boundary drawn there based on the potential field data is questionable.



Figure 1. Approximate outline of the geological provinces and main structures of southern Africa [digital terrane boundaries courtesy of Susan J. Webb, University of the Witwatersrand, Johannesburg, South Africa, and based on known geology in South Africa and Zimbabwe, and primarily on interpretation of potential field data in Namibia and Botswana, where thick Kalahari sands cover basement; Webb, 2009]. The black circles represent all SAMTEX site locations, but the ZIM line sites are numbered and highlighted in red. The Makgadikgadi salt pan complex is indicated by the white lake-like feature (M - Makgadikgadi pan, N - Ntwetwe pan, S - Sua pan), the blue star represents the location of Kubu Island and the white stars show the locations of the Gope (G), Letlhakane (L) and Orapa (O) kimberlite pipes. The giant mafic Okavango Dyke Swarm (ODS) is indicated by the gray-shaded area. (CC - Congo Craton, CFB - Cape fold belt, DMB - Damara mobile belt, GCB - Ghanzi-Chobe belt, KB - Kheis belt, KC - Kaapvaal Craton, LB - Limpopo belt, MMB - Magondi mobile belt, NN - Namaqua-Natal belt, OT - Okwa terrane, RT - Rehoboth terrane, ZC - Zimbabwe craton).

TECTONIC AND GEOLOGICAL SETTINGS

The Archaean Zimbabwe craton is mainly located in Zimbabwe and extends into eastern Botswana, where its boundaries are obscured by Phanerozoic cover rocks and Kalahari sands. To 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 (van Reenen et al., 1987). At the northwestern margin the Magondi Mobile Belt is present, which is a product of Paleoproterozoic basinal sedimentation followed by deformation and associated

metamorphism on the northwestern margin of the Zimbabwe craton (Treloar, 1988; Treloar and Kramers, 1989). North of the Magondi Mobile Belt is the Ghanzi-Chobe Belt, which is Meso- to Neoproterozoic in age and is a northeast-trending, about 500-km-long and 100-km-wide, elongated volcano-sedimentary basin (Modie, 1996; Reeves, 1985). Two other significant structures are the Okavango dyke swarm (e.g., Le Gall et al, 2002, 2005; Jourdan et al, 2004, 2006), which contains beside the Karoo (178-181 Ma) dykes also a few Proterozoic dykes and is orientated ESE-WNW (about 110°E of N), and the Makgadikgadi Pans, a huge salt pan complex that most likely is associated with a brine aquifer.

MAGNETOTELLURICS IN NE BOTSWANA

Data Acquisition and Processing

On the ZIM profile (red circles in Fig. 1), 31 broad-band MT sites were recording time series for 2-3 days in the period range of approx. 0.004 s to 5,000 s. Only the horizontal, perpendicular components of the electric and magnetic fields were acquired (the vertical magnetic component was not recorded for logistical reason). Modern remote-reference, robust time series processing techniques were applied to these data, such as the multi-remote-referencing Phoenix processing software, which is based on Jones and Jödicke (1984). Good quality data were obtained to at least 1,000 s for most sites, and for some sites out to 2,000-3,000 s (especially at sites at the northern end of the profile). The Niblett-Bostick depth approximation (Niblett, 1960; Bostick, 1977; Jones, 1983) was applied to the data of each site to estimate the maximum depth of penetration. The maximum investigation depth was found to be highly variable between different sites but also between the two modes of each site. The data from some sites cannot be associated with depths greater than the base of the crust, whereas data at other sites have penetration depths deep into the upper mantle.

Decomposition and Strike Analysis

The distortion decomposition code developed by McNeice and Jones (2001), based on the Groom-Bailey decomposition (Bailey and Groom, 1987; Groom and Bailey, 1989), was applied to the MT response estimates for each site along the profile to analyze galvanic distortions present and to determine the most consistent geoelectric strike direction over most sites and most periods. Due to the strongly-varying penetration depths along the profile, a multi-site, multi-frequency decomposition based on frequency bands could not be applied and a depth-related method was required. This analysis showed that the geoelectric strike varies not

only along the profile but also with depth. The dominant geoelectric strike direction of 55° E of N in the crust is parallel to the direction of the terrane boundary between the Ghanzi-Chobe and Magondi mobile belts based on the SADC (Southern African Development Community) magnetic data set. Therefore, this direction was chosen for separate inversion and interpretation of the northern crustal part of the ZIM line. For the whole data set, the geoelectric strike direction was taken to be 35° E of N.

Two-Dimensional Modeling

The decomposed, regional 2D MT responses were imported into Geosystem's WinGLink interpretation software package that includes the latest 2D modeling and inversion algorithm of *Rodi and Mackie (2001)*.

Various inversion and weighting function parameter settings were tested, as well as different starting models and forward tests of modified inversion models. All these tests showed similar robust structures for both the model of the crustal, northern part and the whole profile (see Figures 2 and 3, respectively). The lithospheric mantle part beneath the Magondi belt is unfortunately located in an area of poor data coverage (lack of penetration depth) and therefore its conductive appearance cannot be falsified nor verified based on the available data.

INTERPRETATION AND DISCUSSION

Figure 2 shows the final model of the 2D inversion of the data subset from the crustal, northern part of the profile. At the northern end, the northward-dipping highly resistive structure is identified as the Ghanzi-Chobe belt, with the Magondi Belt to its south. The thin, conductive near-surface layer is related to the brine aquifer, and the two mid- to lower-crustal conductors have been found in the lateral range suggested by *de Beer et al. (1975, 1976)* and *van Zijl and de Beer (1983)*. The depth of the conductor beneath sites ZIM121/122 in the 2D inversion model (Fig. 2) matches the depth of 20 – 45 km proposed by them for their conductor. The origin of the lower-crustal conductor found remains uncertain, but a graphite and/or sulphide origin is favored.

Figure 3 shows the 2D resistivity model of the whole profile with respect to the known or postulated surface extent of the geological terranes, the magnetic anomaly due the Okavango Dyke Swarm and the estimated extent of the brine aquifer related to the Makgadikgadi salt pan complex. The crustal structures of the northern end (Fig. 2, where this area was inverted separately using its

appropriate strike direction of 55° E of N) display a very strong correlation with the lithospheric model obtained (Fig. 3). Therefore, enforcing the lithospheric strike direction of 35° E of N for the whole data set has not introduced any spurious artifacts in the resistivity structure of the crust in the northern part of the profile. The extremely high resistivity, crustal area has a lateral extent matching the location of the Okavango dike Swarm (ODS, in Fig. 3).

Most parts of the lithospheric mantle are resistive, but its thickness and resistivity vary along the profile. The Zimbabwe Craton (on the southern end of the profile) is characterized by very thick (approx. 220 km, consistent with geochemical and geothermal estimates from kimberlite samples of the Orapa and Letlhakane pipes - approx. 175 km west of the profile) and very resistive lithosphere, whereas the lithosphere beneath the Ghanzi-Chobe Belt is significantly thinner (approx. 180 km thick) and less resistive.

CONCLUSIONS

The MT data results provide new information about the unconstrained terrane boundaries in northeastern Botswana. The lithospheric mantle of the Zimbabwe craton was found to be of similar thickness than the Eastern Block of the Kaapvaal craton in South Africa. The terrane boundary between the Magondi and Ghanzi-Chobe belts is dipping northwards and located further to the north than previously defined on a regional basis using potential field data.

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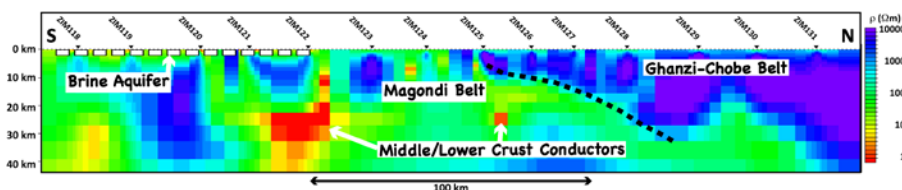


Figure 2. Figure showing the crustal inversion model (vertical exaggeration = 1.0) with geological interpretation. The black dashed line indicates the northward dipping boundary between the resistive Ghanzi-Chobe Belt to the north and the Magondi Belt to the south. Two major mid- to lower-crustal conductors are identified. The brine aquifer is indicated by the approximately 600 m thick conductive (about 1 - 5 Ωm) layer beneath the southern sites (white dashed line).

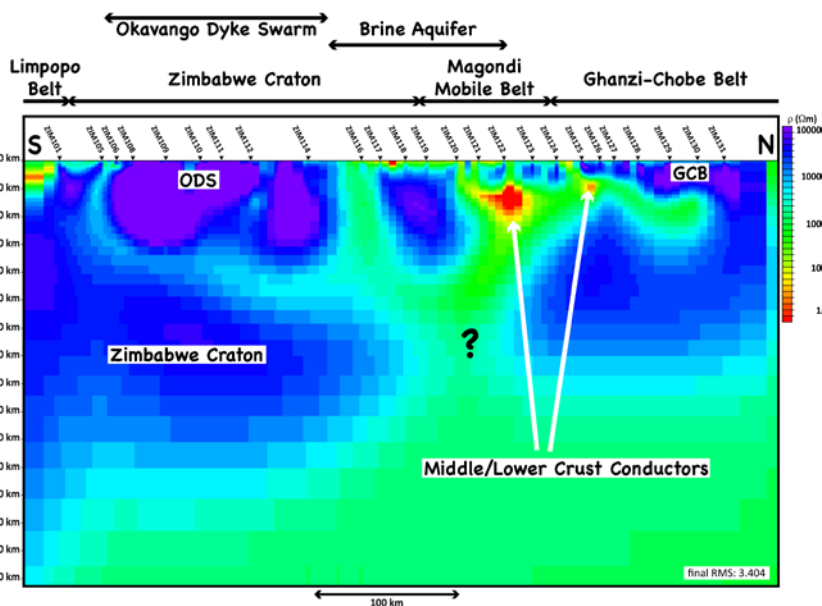


Figure 3. The inversion model (vertical exaggeration = 1.0) of the whole profile in relation to the known surface extent of geological terranes. The arrows above the image of the resistivity structure show the crustal extents of the Limpopo Belt, Zimbabwe Craton, Magondi Mobile Belt and Ghanzi-Chobe Belt (GCB) with respect to MT sites of the ZIM line, adapted from the geological terrane boundaries drawn based on potential field data Webb, 2009. The extent of the Okavango Dyke Swarm (ODS), known from magnetic data, is indicated, as well as an estimated extent of the brine aquifer related to the Makgadikgadi salt pan complex. The dominant resistivity features related to the main geological terranes are labeled and the question mark indicates the area of missing data coverage. Two dominant mid- to lower-crustal conductors are also apparent (compare with inversion results from the northern crustal part of the profile, Fig. 2).