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Tectonic model of the Limpopo belt: Constraints from magnetotelluric data

D. Khoza[a,b,*], A.G. Jones[a], M.R. Muller[a], R.L. Evans[c], S.J. Webb[b], M. Miensopust[d], the SAMTEX team

[a] Dublin Institute for Advanced Studies, 5 Merrion Square, Dublin, Ireland
[b] University of the Witwatersrand, 1 Jan Smuts Avenue, Johannesburg, South Africa
[c] Department of Geology and Geophysics, Woods Hole Oceanographic Institution, Woods Hole, MA 02543-1050, USA
[d] Institut fur Geophysik, Westfalische Wilhelms Universitat, Munster, Germany

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ABSTRACT

Despite many years of work, a convincing evolutionary model for the Limpopo belt and its geometrical relation to the surrounding cratons is still elusive. This is partly due to the complex nature of the crust and upper mantle structure, the significance of anatectic events and multiple high-grade metamorphic overprints. We use deep probing magnetotelluric data acquired along three profiles crossing the Kaapvaal craton and the Limpopo belt to investigate the crust and upper mantle lithospheric structure between these two tectonic blocks. The 20–30 km wide composite Sunnyside-Palala-Tshipise-Shear Zone is imaged in depth for the first time as a sub-vertical conductive structure that marks a fundamental tectonic divide interpreted here to represent a collisional suture between the Kaapvaal and Zimbabwe cratons. The upper crust in the Kaapvaal craton and the South Marginal Zone comprises resistive granitoids and granite-greenstone lithologies. Integrating the magnetotelluric, seismic and metamorphic data, we propose a new tectonic model that involves the collision of the Kaapvaal and Zimbabwe cratons *ca.* 2.6 Ga, resulting in high-grade granulite Limpopo lithologies. This evolutionary path does not require a separate terrane status for each of the Limpopo zones, as has been previously suggested.

1. Introduction

Precambrian regions hold the key to understanding the tectonic processes that prevailed during the early and middle Archaean. Many questions still remain to be answered regarding the amount of heat available at the time, the onset and dominance of early plate tectonic processes and crustal generation these processes and/or by plumes. The greatest impediment is the relative paucity of preserved Archaean rocks, compared to inferred crustal generation during the Archaean, and the identification of Precambrian structures is often masked by secondary tectonic events.

The highly complex Limpopo belt in Southern Africa provides a natural laboratory to investigate these questions and elucidate the possible geological processes taking place, where structural, metamorphic and geochemical data are available. The Limpopo belt is an Archaean-aged high-grade metamorphic complex located between the Kaapvaal and Zimbabwe cratons (Fig. 1). It has an ENE–WSW trend and comprises three zones, the Northern and Southern Marginal Zones and the Central Zone, separated from each other by major thrust faults or strike-slip shear zones. Metasediments, granitoids and gneisses comprise a significant component of the rock outcrop. Due to its Archaean affinity and relatively good surface exposure, the Limpopo belt has been a focus of a number of geological, structural, metamorphic and geophysical studies (Van Reenen et al., 1987; Roering et al., 1992; De Beer and Stettler, 1992; Rollinson, 1993; Durrheim et al., 1992). More recently, a Geological Society of America Memoir (207) on the origin and evolution of high-grade Precambrian gneiss terranes focused specifically on the Limpopo belt (van Reenen et al., 2011).

Several models have been suggested regarding the formation and deformation of the Limpopo belt and these are presented and discussed in Section 3. Seismic tomography models suggest that the lithospheric mantle beneath the Limpopo belt is generally similar to that of the Kaapvaal and Zimbabwe cratons, i.e., fast velocities, implying thick, cold lithosphere (Li, 2011; James et al., 2001). In contrast the crustal structure of the Limpopo belt is highly complex, with evidence of polytectonic events that include metamorphism, magmatism, crustal uplift and structural deformation (Kramers et al., 2011). The nature of the horizontal movements during continental accretion, including the orientation and rate of plate movements during the Archaean, is not fully described. In addition, the deep geometry of the margin between the Kaapvaal craton and

* Corresponding author at: Dublin Institute for Advanced Studies, 5 Merrion Square, Dublin, Ireland. Tel.: +27 (0) 71 623 9168.
E-mail addresses: davidkhoza@cp.dias.ie, david.khoza2@gmail.com (D. Khoza).
[1] Members of the SAMTEX team include: L. Collins, C. Hogg, C. Horan, G. Wallace, A.D. Chave (WHOI), J. Cole, P. Cole, R. Stettler (CGS), T. Ngwisanyi, G. Tshoso (GSB), D. Hutchins, T. Katjiuongua (GSN), E. Cunion, A. Mountford, T. Aravanis (RTME), W. Pettit (BHPB), H. Jelsma (De Beers), P.-E. Share (CSIR), and J. Wasborg (ABB).

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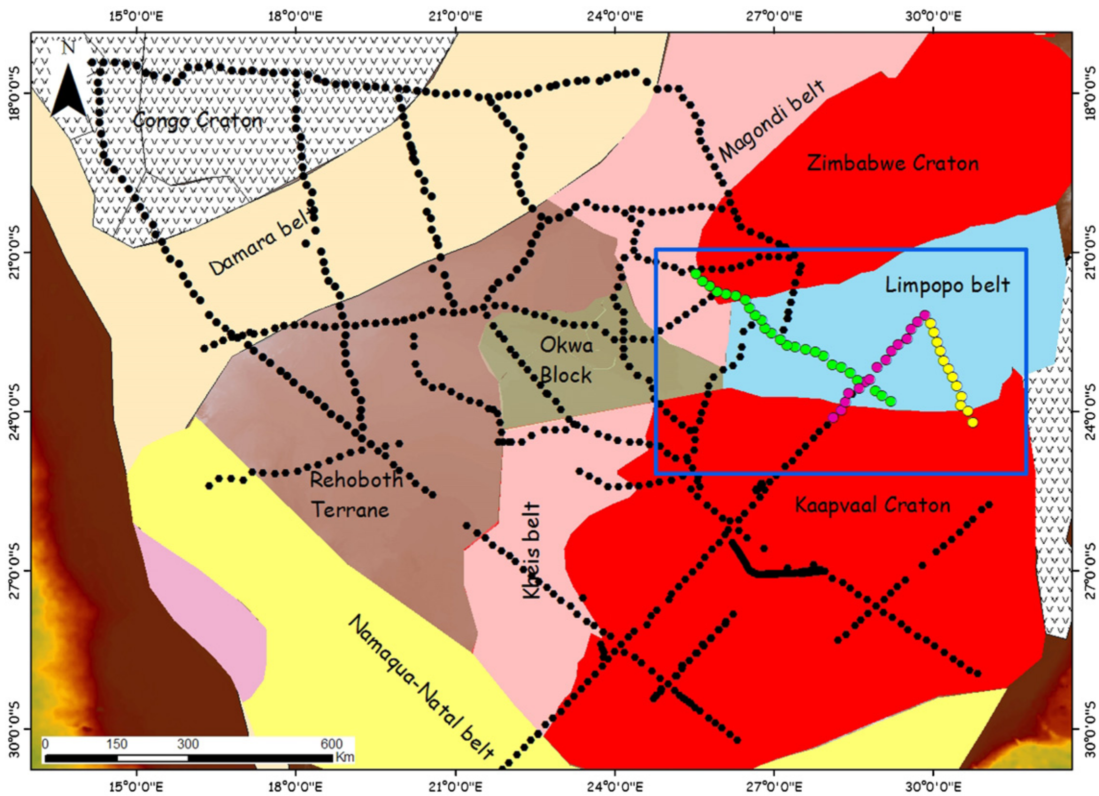

Fig. 1. SAMTEX stations (black circles) overlain on the regional tectonic map of Southern Africa, modified from Begg et al. (2009) and Webb (2009). The yellow, purple and green filled circles show locations of the MT stations for the LOW, KAP and LIM-SSO profiles respectively that are the focus of this work. The bathymetry data are from ETOPO1 courtesy of Anamte and Eakins (2009). The blue rectangle shows the area of interested, shown in Fig. 2.

the Limpopo belt, including the shear zones separating each zone, is not fully known.

In this article we attempt to address several of these issues, particularly the nature of the geometry of the shear zones separating the cratonic units, and investigate the exotic terrane status of the Limpopo belt, particularly for the Central Zone. To this end we use magnetotelluric (MT) data to image the crust and the mantle lithosphere beneath the Limpopo belt and Kaapvaal craton. The deep-probing MT technique has been used successfully in Precambrian regions all over the world to elucidate their tectonic history (Heinson, 1999; Davis et al., 2003; Selway et al., 2006, 2009; Spratt et al., 2009). In Southern Africa, the MT method has been used to image Archaean and Proterozoic boundaries and to understand the tectonic history of Archaean lithosphere (Jones et al., 2005, 2009; Hamilton et al., 2006; Muller et al., 2009; Evans et al., 2011; Miensopust et al., 2011; Khoza et al., 2011). The primary physical parameter being investigated is electrical resistivity of sub-surface materials. Given its sensitivity to resistivity contrasts, the crustal models derived from MT data are very informative in mapping basement features, the location of deep seated fault blocks (Selway et al., 2006; Spratt et al., 2009) and crustal melts (Wei et al., 2001; Unsworth et al., 2004, 2005; Le Pape et al., 2012). In the Earth's crust the primary conducting mineral phases are saline waters, graphite, sulphides, iron oxides and, in active regions like Tibet, partial melt. Mantle electrical resistivity is primarily sensitive to temperature variation and water content (Jones et al., 2012; Evans, 2012) and, to a lesser extent chemical composition and pressure. As part of the highly successful *S*outhern *A*frican *M*agneto *T*elluric *EX*periment (SAMTEX) we have collected MT data along several profiles crossing the Limpopo belt and its bounding terranes: the Kaapvaal craton to the south, Zimbabwe craton to the north and the Magondi belt to the west (Fig. 1). The LOW profile (yellow filled circles, Fig. 1) crosses the northern Kaapvaal craton, over the Hout River Shear Zone, which is thought to represent the southern limit of the Limpopo belt, into the Central Zone.

The KAP profile (pink filled circles, Fig. 1), part of which was the focus of the two-dimensional Kaapvaal craton study of Evans et al. (2011), is re-modelled here using newly developed three-dimensional (3D) techniques and also to do a holistic focused study of the Limpopo–Kaapvaal boundary. The LIM-SSO profile (green-filled circles, Fig. 1) crosses the Kaapvaal craton, Bushveld complex, Limpopo belt, Magondi belt and/or southern Zimbabwe craton and terminates close to Orapa kimberlite field. The Martin's Drift kimberlite cluster (Fig. 2) is about 50 km from MT site SSO103 (Fig. 2). The Orapa and Martin's Drift kimberlites erupted about 93 Ma and 1350 Ma respectively (Haggerty et al., 1983; Jelsma et al., 2004). These profiles, crossing the Limpopo belt and its surrounding terranes, were picked to provide a spatially adequate database to perform 3D magnetotelluric inversion and to understand the nature of the crustal and upper mantle geometry of the geology along the Limpopo belt.

2. Geological background

We define in Table 1 some acronyms that will be referred to consistently in the text.

The Limpopo belt is an ENE–ESW trending high grade Archaean metamorphic complex situated between the lower-metamorphic grade granite-greenstone Zimbabwe and Kaapvaal cratons. The three geologically-defined zones that make up the complex, the Northern Marginal, Central and Southern Marginal zones, are separated from each other by variously dipping shear zones (Fig. 2).

The *Northern Marginal Zone* (NMZ), which comprises granite-greenstone material (magmatic enderbites), is separated from the Zimbabwe craton to the north by the southward-dipping North