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Contrasting stress fields on correlating margins of the South Atlantic

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ABSTRACT

The "passiveness" of passive continental margins across the globe is currently under debate since several studies have shown that these margins may experience a variety of stress states and undergo significant vertical movement post-breakup. Of special interest is the South Atlantic, because the bounding continents have very different recent geological histories, with Africa experiencing continental rifting whereas South America is influenced by subduction on the Pacific side. It is not clear to what extent the Atlantic continental margins are subject to the same stresses and vertical motions as the main continents. To address this problem, we performed a paleostress analysis of two originally adjacent areas, i.e. NW Namibia and SE/S Brazil. Both areas are covered by the ~133-Ma-old Paraná-Etendeka extrusives that were emplaced shortly before or during the onset of the Atlantic rifting. Thus, the volcanics serve as a time marker for syn- or post-rift deformation. Collected fault slip data in the volcanics reveal remarkable differences between the two correlating areas. NW Namibia was dominated by extension in ENE-WSW and SW-NE directions, and by minor strike-slip movement with NW-SE directed compression. SE/S Brazil was mostly affected by strike-slip faulting, with compression oriented E-W and SW-NE. Similar fault systems appear widespread across SE Brazil and may be the combined result of flexural margin bending and the Nazca plate subduction. The results of NW Namibia differ from known compressional stress tensors in western South Africa, post-dating 90 Ma. The south-western African continental margin may thus have experienced a spatially variable stress history. Our results show that the tectonic evolution of the continental margins of the South Atlantic is not passive and that both margins vary significantly in structural style and stress fields, indicating that variable plate boundary forces play a major role in margin evolution.

1. Introduction

Rifting of continents and the following continental break-up leads to the development of relatively stable continental margins (McKenzie, 1978). They are generally characterized by listric normal faults, rotated blocks and down-lapping sedimentary sequences. Typical examples can be found along the eastern and western rims of the Atlantic Ocean. In terms of relative vertical motion, the initial rift is characterized by a subsiding graben and adjacent high rift flanks. During break-up, volcanic activity may lead to widespread rock and surface uplift of the whole rift and this is followed by subsidence due to cooling and thermal contraction of the underlying lower lithosphere and asthenosphere. The original rift flanks adjacent to the continental margins are thought to remain at high elevation even though they are subject to considerable erosion. However, this relatively simple history has been challenged by studies that indicate that passive continental margins may be subject to multiple rock and surface uplift and subsidence phases and are thus not completely passive. Examples of margins with such complex uplift histories include the margins of northwest Britain (Stoker et al., 2010) and western Greenland (Bonow et al., 2006). The evolution of the South Atlantic passive continental margins is also currently debated (Karl et al., 2013). These margins have been affected by rifting, hotspot activity and potentially by far field stresses and regional flexural bending. There are significantly different views on how similar or different the continental margins east and west of the South Atlantic behave. Some authors (Cobbold et al., 2001) argue that far field stresses from the Andean orogeny subjected the passive continental margin of Brazil to margin-perpendicular compression throughout the Cenozoic. Others argued that the Brazilian and Namibian margins have been influenced by flexural bending due to sediment loading offshore (e.g., Lima et al., 1997; Dauteuil et al., 2013; Reis et al., 2013). On the eastern margin of the Atlantic upwelling of the African superplume, a large thermal anomaly in the lower mantle beneath southern Africa (e.g., Ritsema et al., 2011) is thought to be responsible for the high average topography of southern and eastern Africa (e.g., Lithgow-Bertelloni and Silver,

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1998; Al-Hajri et al., 2009; Moucha and Forte, 2011). Japsen et al. (2012a) favor a model where both continental margins undergo the same multiple uplift events driven by transfer of far field stresses from one continent to another.

An understanding of the behavior of continental margins following continental breakup is vital to our understanding of plate tectonics and the effects of far field stresses across continents. Therefore, we choose to perform a paleostress analysis of NW Namibia and SE/S Brazil, two areas that were connected prior to the opening of the South Atlantic (Figs. 1, 2a). The areas are ideally suited for such a study since they are covered by volcanic rocks of the Paraná-Etendeka Large Igneous Province (Milner et al., 1995), which were emplaced just before or during the onset of the South Atlantic opening (Renne et al., 1992; Torsvik et al., 2009). Furthermore, the study areas are situated at similar distances (200–250 km) from the continent-ocean boundary (as defined by Torsvik et al., 2009). The paleostress analysis was conducted using measurements on fault planes and striations on faults within the basalts of the Paraná-Etendeka sequence in order to estimate stress fields during or post breakup and thus attain an understanding of the onshore tectonic evolution of both margins.

2. Geologic setting

The continental margins of NW Namibia and SE/S Brazil are characterized by low-to-high grade metamorphic basement rocks of Neoproterozoic age (560–530 Ma) forming the Kaoko Belt on the Namibian side and the Dom Feliciano Belt on the Brazilian side, both of which developed during the amalgamation of Gondwana (e.g., Goscombe et al., 2005; Foster et al., 2009; Oyhantçabal et al., 2011; Fig. 1). The present-day continental margins run parallel or sub-parallel to prominent shear zones and the main trends of foliation and lineation in both belts. Where the shear zones are partly covered by overlying rocks, they are thought to maintain their general trend in a NE direction in the Dom Feliciano Belt, based on interpolation (e.g., Chemale et al., 2012) and a N-NNW direction in the Kaoko Belt, based on aeromagnetic data (Corner, 2008).

The basement rocks are overlain by sedimentary rocks of the Karoo (southern Africa) and the Paraná basins (South America). They belong to a set of intracontinental basins which span South America, Africa, Antarctica and Australia (de Wit et al., 1988; Smith et al., 1993). The basin sediments were deposited from the Carboniferous to the Jurassic. The deposits are widely exposed in SE/S Brazil, whereas in NW Namibia they are mainly restricted to the Huab area (Miller, 2008, and references therein; Fig. 2).

The aeolian sandstone of the Botucatu (Brazil) and Twyfelfontein Formations (Namibia) overlies the Karoo/Paraná sedimentary rocks (Fig. 2). The age of these formations is Upper Jurassic to Lower Cretaceous (e.g., Scherer, 2000; Dentzien-Dias et al., 2007; Perea et al., 2009). The Botucatu/Twyfelfontein Formation reaches a thickness of up to 150 m (Mountney and Howell, 2000) and inter-fingers with the volcanics of the Paraná-Etendeka Large Igneous Province (Jerram et al., 1999), which covers large parts of South America and southern Africa. In Brazil, these extrusives are referred to as the Serra Geral Formation, while in Namibia they are attributed to the Etendeka Group. Today the Serra Geral Formation covers an area of about 1.2×10^6 km^2 (Melfi et al., 1988) with a maximum observed thickness of about 1700 m (Peate et al., 1990), whereas the Etendeka Group covers about 78.000 km^2 in Namibia with a maximum thickness of around 900 m (Erlank et al., 1984; Milner et al., 1992; Gallagher and Hawkesworth, 1994). The Paraná-Etendeka Large Igneous Province consists of up to 120 lava flows (Hartmann et al., 2012) which vary significantly in chemical composition ranging from basaltic lavas to massive quartz latites (Milner and Ewart, 1989; Milner et al., 1992). A stratigraphic correlation of lavas across the Atlantic was established by Milner et al. (1995). The age of the Large Igneous Province is 133 ± 1 Ma (Renne et al., 1992) and the eruption period lasted approximately 2.4 million years (Milner et al., 1995). In the northern part of the Brazilian study area, an alkaline intrusion (Lages Volcanic Field) is dated to 76 Ma (Gibson et al., 1999). About 400 km north of our

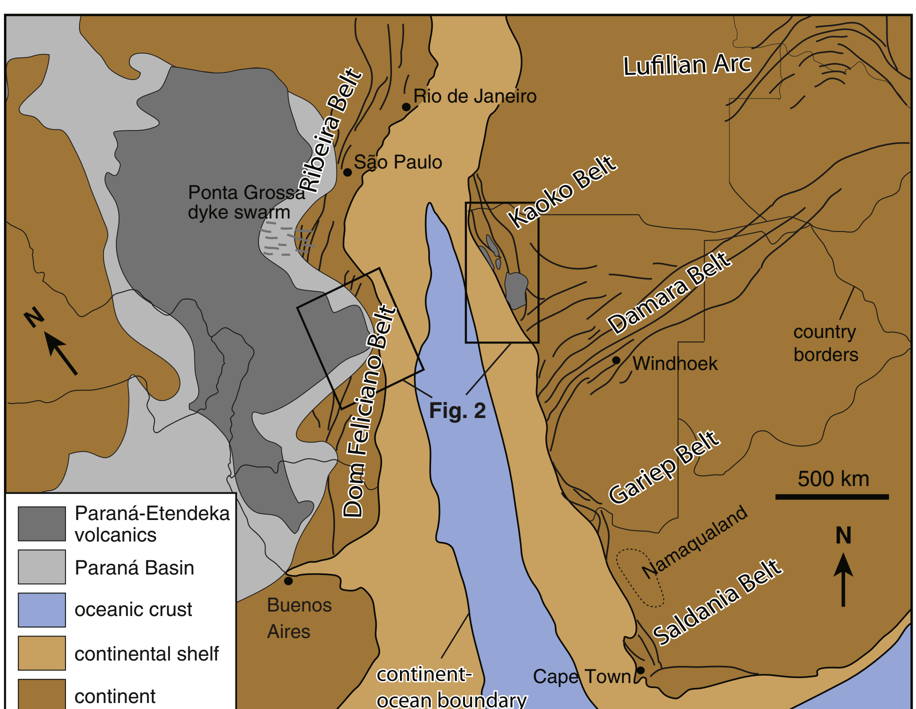

Fig. 1. Simplified paleo-geological map of southern Africa and southern Brazil at 121 Ma (sketched after Heine et al., 2013) with major Neoproterozoic structural elements (thick black lines on continents; adopted from de Wit et al., 2008) and sketched present extent of the Paraná Basin and Paraná-Etendeka Large Igneous Province (after Waichel et al., 2012).