

Active vs. passive rifting in the South Atlantic from a petrologic perspective: an upwelling controversy

Robert B. Trumbull¹, David L. Reid², Coenraad de Beer³, Rolf L. Romer¹

1. GFZ German Research Centre for Geosciences, Telegrafenberg, Potsdam, Germany

2. Dept. of Geological Sciences, University of Cape Town, Rondebosch, South Africa

3. Council for Geoscience, Bellville, South Africa

ABSTRACT

The Atlantic margin of southern Africa is a classic example of a volcanic rifted margin, but the strong gradient in the intensity of magmatism from north to south challenges a conventional plume model. A petrologic study of breakup-related mafic dikes from the northern and southern margin was undertaken to provide data on magma compositions and P-T conditions of mantle melting with which to test the plume (excess heat) hypothesis. The results demonstrate not only more magma but greater diversity of magma types and stronger crustal influence in the dikes from high-flux northern margin in Namibia. Some of these dikes have picritic bulk compositions (>12 wt.% MgO), and olivines Fo₉₀₋₉₃, indicating about 200°C excess mantle temperature. Dolerite dikes from the Cape peninsula derive from a single tholeiite series and yield petrologic temperature estimates in favor of a passive upwelling model.

Key words: South Atlantic, mantle plume, Etendeka Province, dike swarms

INTRODUCTION

The continental margin of southern Africa is a classic example of a volcanic rifted margin and its first-order feature is a strong decrease in magmatic intensity from north to south along the ca. 2000 km from the Walvis Ridge to the Cape Peninsula. The N-S gradient shows up in the amount of lavas and intrusive rocks preserved onshore, and also in the varying thickness of underplated igneous crust inferred from geophysical records. On the other hand, the seaward-dipping reflector sequences continue with no change in width or thickness along the entire margin.

This contribution discusses these features with respect to the hypothesis that a mantle plume was instrumental in continental breakup and opening of the South Atlantic. Our focus is on information obtained from ongoing petrologic and geochemical studies of the magmas produced during breakup and still preserved as on the uplifted margins.

Fortunately, breakup-related mafic dike swarms of contemporary age occur along the entire margin, from the high-flux Etendeka province of Namibia in the north, to the Cape peninsula at the southern end of the margin. These dikes bear witness to the timing of magma emplacement and the composition of magmas produced, and they give insights on the conditions and causes of mantle melting that are directly relevant to the mantle plume issue.

METHOD AND RESULTS

This study is based on chemical compositions (major, trace elements and radiogenic Sr, Nd, Pb isotope ratios) and olivine compositions from representative samples of dolerite dike swarms in NW Namibia and the Western Cape Province (Trumbull et al., 2007).

Dolerite dikes in the Cape Province (False Bay dike swarm) formed from a single tholeiitic magma series which differentiated to produce the range of compositions observed (SiO₂ = 50-58 wt.%, maximum MgO = 8 wt.%). The incompatible trace element ratios and Sr-Nd-Pb isotopic compositions (⁸⁷Sr/⁸⁶Sr_i = 0.7064, εNd_i = -2 and ²⁰⁶Pb/²⁰⁴Pb_i = 18.72) suggest a lithospheric mantle source. Petrologic temperature-depth estimates of these magmas show no evidence for excess heat and we infer that magma generation involved passive upwelling of the upper mantle as a consequence of the breakup process.

The mafic dikes emplaced in the northern part of the margin in Namibia have the same age as those in the Cape but they differ in terms of composition and magma genesis. Three distinct magma series are recognized among the Namibian dikes (a) crustally-contaminated tholeiites (with ⁸⁷Sr/⁸⁶Sr_i = 0.710-0.712, εNd_i = -2 to -7, and ²⁰⁶Pb/²⁰⁴Pb_i = 18.74-19.10), which are similar to the main flood basalts series of the Etendeka province (b) MORB-like tholeiites with with

$^{87}\text{Sr}/^{86}\text{Sr}_i = 0.704\text{-}0.705$, $\epsilon\text{Nd}_i = +2$ to $+6$, and $^{206}\text{Pb}/^{204}\text{Pb}_i = 18.00\text{-}18.83$ indicating an asthenospheric mantle source, and (c) alkaline OIB-like basalts with $^{87}\text{Sr}/^{86}\text{Sr}_i = 0.7055\text{-}0.7059$, $\epsilon\text{Nd}_i = 0$ to -2 , and $^{206}\text{Pb}/^{204}\text{Pb}_i = 18.30\text{-}18.61$ similar to rocks from the Tristan da Cunha hotspot and the Walvis Ridge.

Among both the alkaline and the tholeiitic dikes from Namibia are examples with picritic bulk compositions (maximum 16 wt.% MgO), and extremely Mg-rich olivine phenocrysts Fo₉₀₋₉₃. Geothermometry calculations for the Mg-rich rocks indicate excess temperatures on the order of 200°C relative to normal asthenospheric mantle (MORB model). Thus, high mantle temperatures are associated with the high-flux magmatism of the Etendeka province, in accord with the plume hypothesis.

The main conclusion of this study is that continental breakup in the South Atlantic and the intense mantle melting event which formed the Etendeka Province are two separate processes. The nature of the southern margin conforms to a passive rift scenario whereas plume-enhanced, active rifting took place only in the north.

REFERENCES

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