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The crustal structure of Beira High, central Mozambique—Combined investigation of wide-angle seismic and potential field data

Christian Olaf Mueller [a,*], Wilfried Jokat [a,b], Bernd Schreckenberger [c]

[a] Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Department of Geophysics, Am Handelshafen 12, 27570 Bremerhaven, Germany
[b] University of Bremen, Department of Geosciences, Bibliothekstraße 1, 28359 Bremen, Germany
[c] Federal Institute for Geosciences and Natural Resources, Geozentrum Hannover, Stilleweg 2, 30655 Hanover, Germany

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ABSTRACT

The timing and geometry of the initial Gondwana break-up between Africa and East Antarctica is still poorly known due to missing information about the continent-ocean boundaries along the rifted margins. In this context, the Beira High off central Mozambique forms a critical geological feature of uncertain crustal fabric. Based on new wide-angle seismic and potential field data across Beira High a *P*-wave velocity model, supported by amplitude and gravity modelling, provides constraints on the crustal composition of this area. In the Mozambique Basin mainly normal oceanic crust of 5.5–7 km thickness with velocities of 6.5–7.0 km/s in the lower crust is present. A sharp transition towards Beira High marks the continent-ocean boundary. Here the crust thickens to 23 km at maximum. A small velocity-depth gradient and a constant increase in velocity with basal velocities of maximum 7.0 km/s are in good agreement with typical velocities of continental crust and continental fragments. The density model indicates the existence of felsic material in greater depths and supports a fabric of stretched, but highly intruded continental crust below Beira High. A gradual decrease in crustal thickness characterizes the transition towards the Mozambican shelf area. Here, in the Zambezi Delta Depression 12 km of sediments cover the underlying 7 km thick crust. The presence of a high-velocity lower crustal body with velocities of 7.1–7.4 km/s indicates underplated, magmatic material in this part of the profile. However, the velocity structure in the shelf area allows no definite interpretation because of the experimental setup. Thus, the crustal nature below the Zambezi Delta and consequently the landward position of the continent-ocean boundary remains unknown. The difference in stretching below the margins of Beira High suggests the presence of different thinning directions and a rift jump during the early rifting stage.

1. Introduction

The supercontinent Gondwana was an assembly of several landmasses consisting of a western (Africa and South America) and an eastern part (Antarctica, Madagascar, India, Sri Lanka, Australia and New Zealand). In the Early Jurassic rifting between the two parts initiated the dispersal of Gondwana (Cox, 1992; Eagles and König, 2008; Ghidella et al., 2007; Jokat et al., 2003). This process led to the formation of the first ocean basins between eastern Africa and Antarctica, the Mozambique and Somali Basin.

The reconstruction of the initial breakup was subject of numerous publications (Cox, 1992; Eagles and König, 2008; Jokat et al., 2003; Lawver et al., 1998; Leinweber and Jokat, 2012; Martin and Hartnady, 1986; Norton and Sclater, 1979; Reeves, 2014). For a consistent reconstruction it is essential to know the crustal types of the area and their present day location. In the Mozambique Basin, the reconstructions are well constrained for Late Cretaceous and Cenozoic times. However, for Early Cretaceous and Jurassic times seismic and magnetic constraints on the crustal fabric of the area are still sparse. Former deep seismic sounding surveys were limited to the use of sonobuoys, which provided only little crustal information. These wide-angle seismic data are difficult to interpret and are unsuitable for a reliable interpretation of the crustal composition. Thus, concrete evidence of the geometry and position of the continent-ocean boundary (COB) off Mozambique is lacking (Raillard, 1990; Watts, 2001). In this context, the Beira High is a critical geological feature to understand. The modelling of the geological boundaries with the help of gravity data (Watts, 2001) was a first attempt to constrain the deeper structure of this feature. Either Beira High is of oceanic origin and presents a magmatic structure, similar to Mozambique Ridge situated more to the south, or it is simply thickened oceanic crust (Watts, 2001). Conceivable is as well a continental fragment, which rifted away from the mainland along an extinct spreading centre (Mahanjane, 2012; Reeves, 2014). Furthermore, for a fundamental understanding of the driving forces of the breakup it is

* Corresponding author.
E-mail addresses: christian.olaf.mueller@awi.de (C.O. Mueller), Wilfried.Jokat@awi.de (W. Jokat), Bernd.Schreckenberger@bgr.de (B. Schreckenberger).

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essential to know details on the exact timing for the first accretion of oceanic crust and the amount of volcanism related to the breakup.

Therefore, in 2014 the MOCOM-Cruise SO230 acquired first seismic refraction data across Beira High off Mozambique (Jokat, 2014). In this study, we present the results of the deep seismic experiment, supported by an amplitude modelling and a 2.5D gravity model. The main objectives are to examine the crustal structure and origin of Beira High and the adjacent shelf area. Additionally, the location of the COB and the existence of magmatic material along the margin are investigated. Implications for the tectonic evolution of the Mozambique Basin are discussed in combination with published magnetic data.

2. Geological setting

Today, SE Africa and Madagascar are separated by the Mozambique Channel (Fig. 1). In its central area the Davie Fracture Zone divides the channel in two parts. The northern part extends to the Comoros and joins the Somali Basin. The southern part comprises the continental margin of northern and central Mozambique as well as western Madagascar. The Mozambique Basin represents the southern border. Large coastal plains and broad shelf areas characterize most of these margins. In the south-western part of the continental margin of central Mozambique the Zambezi Delta serves as the estuary of the Zambezi River and forms the shelf area of the Zambezi Coast. Here, large sediment deposits accumulated in the Zambezi Delta Depression (ZDD). About 80 km off the coast, a distinct basement high, the Beira High, borders the ZDD to the south. It makes up half of the offshore part of the continental margin of central Mozambique and forms a prominent gravity low (Fig. 2c, d).

The main tectonic units onshore SE Africa consist of Archaean crust of the Kaapvaal Craton in the south-west and the Zimbabwe (Rhodesian) Craton in the west (Fig. 1). Around 2.6 Ga the collision of these two cratons caused the formation of the Limpopo Belt (Kröner, 1977). In the north-eastern part of Mozambique, the Lurio Belt is the result of the Kibaran Orogeny (assembly of Rodinia in the Mesoproterozoic) (Grantham et al., 2003). Today it acts as a prominent north-east to south-west trending boundary dividing the basement of northern Mozambique in two parts, which were affected by different metamorphic events in the Neoproterozoic (Ueda et al., 2012). Around 800–500 Ma the Pan-African Orogeny (assembly of Gondwana) led to the emplacement of the Zambezi Belt in the west and the Mozambique Belt in the north (Grantham et al., 2003). Both belts are composed of Archaean material, reworked in Meso- to Neoproterozoic ages (Kröner, 1977).

At the initial stage of the Gondwana breakup massive magmatism accompanied the rifting and emplaced the Karoo flood basalts onshore

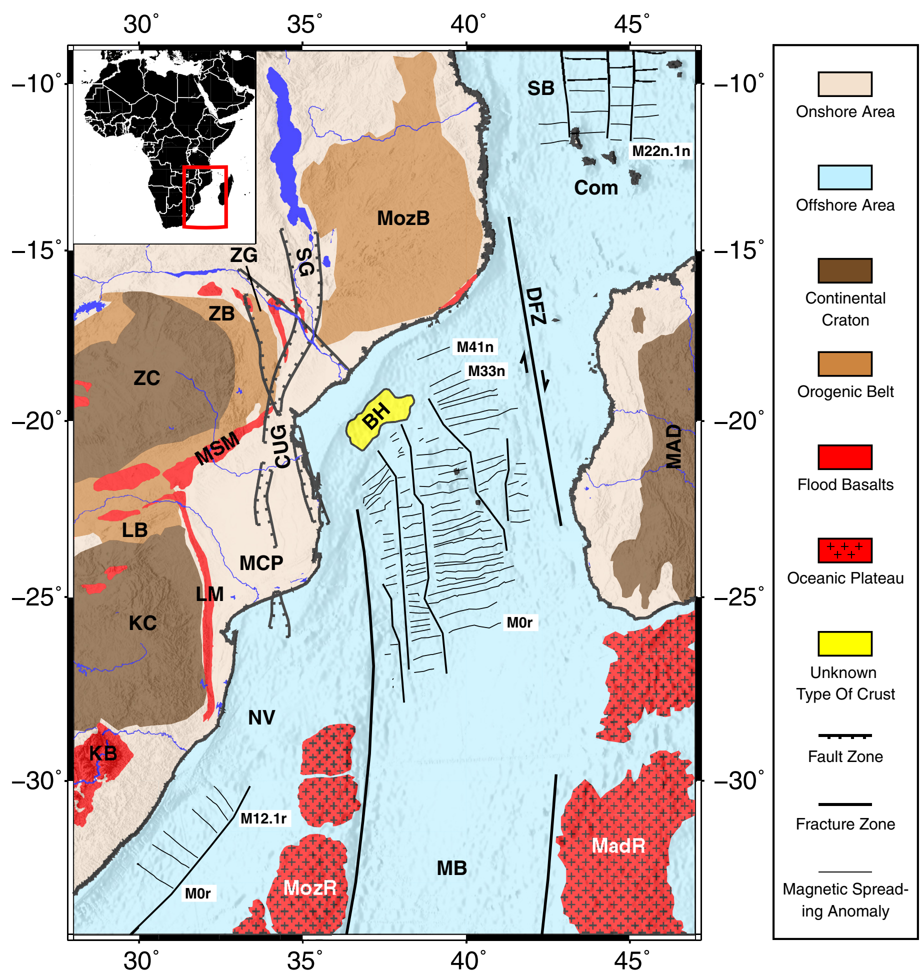

Fig. 1. Tectonic overview of the Mozambique Channel. The major tectonic provinces and identified magnetic spreading anomalies are labelled. Abbreviations: BH: Beira High, Com: Comoros, CUG: Chissenga-Urema Graben System, DFZ: Davie Fracture Zone, KB: Karoo Basalts, KC: Kaapvaal Craton, LB: Limpopo Belt, LM: Lebombo Monocline, MAD: Madagascar, MadR: Madagascar Ridge, MB: Mozambique Basin, MCP: Mozambique Coastal Plains, MozB: Mozambique Belt, MozR: Mozambique Ridge, MSM: Mateke-Sabi Monocline, NV: Natal Valley, SB: Somali Basin, SG: Shire Graben, ZB: Zambezi Belt, ZC: Zimbabwe Craton, ZG: Zambezi Graben. Onshore the terrenes are digitized after Leinweber et al. (2013) and the fault systems after De Buyl and Flores (1986). The outline of Beira High is taken from Mahanjane (2012). For large igneous provinces the outline follows the 2500 m isoline of the bathymetry of the GEBCO, 2014 grid. The locations of the magnetic spreading anomalies in the Somali Basin are taken from Cochran (1988), in the Mozambique Basin and northern Natal Valley from Leinweber and Jokat (2012), and in the southern Natal Valley from Goodlad et al. (1982).