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The crustal structure of the Central Mozambique continental margin — Wide-angle seismic, gravity and magnetic study in the Mozambique Channel, Eastern Africa

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ABSTRACT

The continental margin of Mozambique formed during the initial dispersal of Gondwana about 180 Ma. Due to the lack of deep seismic and dense potential field data, many details of the timing and geometry of the early breakup in this region remained unknown to date. To close this gap, a research project (MoBaMaSis ("Mozambique Basin Marine Seismic Survey") with the French research vessel R/V Marion Dufresne II was conducted in 2007. This paper presents the results of P-wave, magnetic and 2D-gravity modelling along two parallel seismic refraction profiles between 37° and 41° E, crossing the Mozambique rifted margin. The crust shows the characteristics of normal to slightly thickened oceanic crust. A lower crustal high-velocity-body with P-wave-velocities of 7.0–7.5 km/s is observed along both profiles. Its origin is discussed in the context of upper mantle convection and thermal properties. The existing magnetic anomaly identifications have been extended to older ages. We postulate that the oldest oceanic crust near the Central Mozambique continental margin has been formed around M41n (166 Ma). Closer to the coast a pronounced negative magnetic anomaly exists that we interpret to coincide with the continent–ocean-transition. This implies that the position of the continent–ocean-transition is located significantly closer to the shoreline than proposed before.

1. Introduction

The assembly of the supercontinent Gondwana was completed around 500 million years ago (Sahu, 2001). Around 300 Ma, it merged with other continent masses, forming the supercontinent Pangaea. In the Early Jurassic, the parts of Gondwana started to disperse (for example Dalziel, 1992; Eagles and König, 2008; Grunow et al., 1991; Jokat et al., 2003; Lawver et al., 1991). This process was initiated by rifting between the western part of Gondwana (South America and Africa) and its eastern part (Antarctica, India, Madagascar, Sri Lanka, Australia and New Zealand) about 180 Ma.

Numerous publications discuss the general plate movements of the southern continents since the breakup of Gondwana using various geophysical data sets (Bergh, 1977; Eagles and König, 2008; Ghidella et al., 2007; Jokat et al., 2003; König and Jokat, 2010; Martin and Hartnady, 1986; Norton and Sclater, 1979; Roeser et al., 1996). While the Cenozoic kinematic history between Africa and Antarctica is well constrained (Bernard, 2005), the pre-breakup fit of the continents as well as the Jurassic movements after Gondwana breakup are still controversial. This is mainly because of the lack of high-quality geophysical data, which could reveal the location of the continent–ocean-transition. Closer to the coast of Mozambique only commercial seismic reflection data exist, which do not provide any constraints on the deep crustal fabric or on the position and structure of the continent–ocean-transition. Modern deep seismic sounding data are absent on the conjugate East African and Antarctic margins and potential field data characterising the oldest oceanic crust are still sparse.

The modern day geographic setting of the study area and a simplified overview over the terranes of southern Africa is shown in Fig. 1. The only stripe of seafloor providing direct evidence of the movements between Africa and Antarctica since Mesozoic times, is the Africa–Antarctica corridor (AAC). The Mozambique and Somali basins are the oldest African oceanic basins formed during the initial breakup of Gondwana. Both basins are separated by the NNW–SSE trending Davie Fracture Zone, which is considered by many authors as the fossil transform fracture zone, along which the southward drift of Madagascar from a more northerly position during Gondwana breakup occurred (Bunce and Molnar, 1977; Heirtzler and Burroughs, 1971; Rabinowitz et al., 1983; Scrutton et al., 1981; Segoufin and Patriat, 1981). In the northwest of the Mozambique Channel, south

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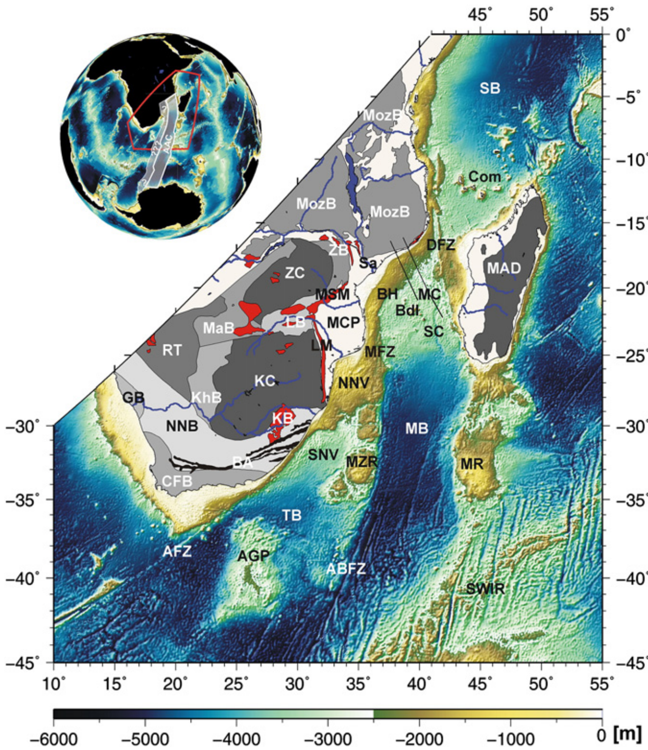

Fig. 1. Geographic and tectonic setting of the Mozambique Channel. Major terranes and physiographic features are labelled. The black lines in the Mozambique Channel mark the position of our model lines (see Fig. 2) and their magnetic profile prolongations to the south. The inset in the upper left corner shows the research area at a larger scale as well as the Africa–Antarctica Corridor. The area with question marks (?) indicates the zone that is in question to belong to the Africa–Antarctica Corridor. Red colours mark the Karoo continental flood basalts. Rivers and lakes are blue. The pronounced magnetic anomaly pattern in South Africa is drawn in black. Precambrian and Archean terranes are plotted with different grey shading. The thin black lines in the Mozambique Channel mark the MoBaMaSis seismic refraction profiles used in the study with its southward magnetic profile prolongations. Abbreviations: ABFZ: Andrew Bain Fracture Zone; AFZ: Agulhas Fracture Zone; AP: Agulhas Plateau; BA: Beattie Magnetic Anomaly; BdI: Bassas da India; BH: Beira High; CFB: Cape Fold Belt; Com: Comores; DFZ: Davie Fracture Zone; GB: Gariep Belt; KB: Karoo Basalts; KC: Kaapvaal Craton; KhB: Kheiss Belt; LB: Limpopo Belt; LM: Lebombo Monocline; MaB: Magondi Belt; MAD: Madagascar; MB: Mozambique Basin; MC: Mozambique Channel; MCP: Mozambique Coastal Plains; MFZ: Mozambique Fracture Zone; MozB: Mozambique Belt; MR: Madagascar Ridge; MSM: Mateke-Sabi-Monocline; MZR: Mozambique Ridge; NNB: Namaqua–Natal Belt; NNV: Northern Natal Valley; RT: Rehoboth Triangle; Sa: Sambesi; SB: Somali Basin; SC: Sambesi Canyon; SNV: Southern Natal Valley; SWIR: South-west Indian Ridge; TB: Transkei Basin; ZB: Zambezi Belt; ZC: Zimbabwe Craton.
Bathymetry is taken from GEBCO_08 (2003). The terranes are digitised after Hansen et al. (2009), Nguuri et al. (2001), Sahu (2001) and CGS (2000).

of the Sambesi estuary, a pronounced basement high, the "Beira high", is located (Coster et al., 1989). Oceanwards, the subsea Sambesi canyon heads east–southeast, bending to the south at the Davie Fracture Zone at 20°S.

Onshore, the geology of Mozambique (Fig. 1) can be divided into Precambrian and Phanerozoic terrains, whereby the northern and western central parts are predominantly constituted of Precambrian rocks (Jamal, 2003). This region belongs to the Mozambique Belt, which extends between the Sambesi River and northern Kenia as part of the East African Orogen (Kröner, 1977). It is composed of Meso- to Neo-proterozoic high-grade gneisses, granulites, quartzites, migmatites and granitoides (Afonso, 1976; Jamal, 2003; Kröner, 1977) and has been reworked in Pan-African times. The coastal plains covering the southern and eastern central parts of Mozambique represent — including the adjacent continental shelf regions — the largest African sedimentary basin south of the equator (De Buyl and Florès, 1986; Förster, 1975). The basin is limited to the north by the Mozambique Belt, to the north-west by the Precambrian Zimbabwe (Rhodesian) Craton and to the west by the Kaapval Craton and the volcanic Lebombo Monocline (Coster et al., 1989; see Fig. 1). These plains are blanketed by Phanerozoic sediments (Jamal, 2003).

The rifting in the study area (Fig. 1) during the Gondwana breakup was accompanied by massive volcanism, which formed the continental Karoo flood basalts in Africa and the Ferrar flood basalts in Antarctica (Cox, 1992; Jourdan et al., 2005). The most prominent parts of the continental Karoo flood basalts along the eastern African margin are the Lebombo and Mateke-Sabi monoclines forming the northern and western termination of the Mozambique Coastal Plains (Fig. 1). In a smaller scale, rift related Mesozoic magmatism can also be found at the coast of central-northern Mozambique (Tectonic Map of Mozambique, Scale 1:2.000.000, 2001). Jourdan et al. (2005) report that the majority of Karoo flood basalts were emplaced between ca. 184 and 178 Ma. In Antarctica, radiometrical dating of the conjugate Ferrar basaltic province (183.6 ± 1.0 Ma, Encarnacion et al., 1996) resulted in dates, which are similar to those of the Karoo basalts, though the Ferrar basalts erupted over a shorter time interval.

Offshore, the first seismic reflection studies in the Mozambique Channel were conducted in the early 70s (Beck and Lehner, 1974; De Buyl and Florès, 1986; Fortes and Kihle, 1983; Heirtzler and Burroughs, 1971; Lafourcade, 1984; Lort et al., 1979; Mougenot et al., 1986; Virlogeux, 1987). The earliest identification of east–west-trending magnetic spreading anomalies in the Mozambique Basin was reported by Segoufin (1978) and Simpson et al. (1979) describing the seafloor spreading from chron M0r to M22. Based on a denser and extended newer ship-towed magnetic data set (Jokat, 2006), König and Jokat (2010) generally confirmed these chron identifications. They extended the chron identifications up to M26n.4n in the Mozambique Basin, and identified M22r close to 22°S 37.4°E as oldest anomaly in the area north of the island of Bassas da India (Fig. 1). However, the latter authors could not map the magnetic field closer to the coast of Central Mozambique, since their survey terminated at 21°S. Thus, the nature of around 440 km of crust between their oldest identifications and the shoreline of Mozambique remained unknown.

This paper presents the first deep seismic sounding profiles using ocean bottom receiver stations across the rifted margin of Central Mozambique. Additionally, we present 2D-gravity models along these profiles and a magnetic model based on new identifications of seafloor spreading anomalies in the northern part of the Mozambique Channel.

2. Data acquisition and processing

From 15th September to 26th October 2007, as a collaborative effort between BGR (Bundesanstalt für Geowissenschaften und Rohstoffe, Germany), IFREMER (Institut Français de Recherche pour l'exploitation de la mer, France), IPEV (Institut Paul Emile Victor, France) and AWI (Alfred-Wegener-Institut, Germany), the MoBaMaSis survey ("Mozambique Basin Marine Seismic Survey") was conducted using the French research Vessel R/V Marion Dufresne II. Two seismic refraction profiles were acquired offshore Mozambique (Reichert et al., 2008). The profile set-up is shown in Fig. 2. Both profiles were extended landwards onto Mozambique using portable land stations by the MoBaMaSis Terra team. An airgun array composed of eight G-Guns with a total volume of 67.2 l (4100 in.^{3}) was used as seismic source. In total, 2684 shots were fired with an interval of 60 s and a mean distance of 152 m between the shot points along profile 20070201. Along profile 20070202, 1268 shots were fired with the same interval and a mean shot distance of 171 m.

Three types of ocean bottom instruments and two types of land stations were used. On the profile 20070201, 11 OBS (Ocean Bottom Seismometer) and 24 MicrOBS (Micro Ocean Bottom Seismometer) were deployed. On land, four 3-channel REFTEK land stations (each with 3 strings with 6 geophones per channel, resulting in 54 geophones