Tectonophysics xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

The wide-angle seismic image of a complex rifted margin, offshore North Namibia: Implications for the tectonics of continental breakup

Lars Planert [a,*], Jan Behrmann [a], Wilfried Jokat [b], Tanja Fromm [b], Trond Ryberg [c], Michael Weber [c,d], Christian Haberland [c]

[a] GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel, Wischhofstr. 1-3, D-24148 Kiel, Germany
[b] Alfred-Wegener-Institut für Polar- und Meeresforschung, Am Alten Hafen 26, D-27568 Bremerhaven, Germany
[c] GFZ Helmholtz-Zentrum Potsdam, Telegrafenberg, 14473 Potsdam, Germany
[d] University of Potsdam, Institute of Earth and Environmental Science, Golm, D-14471 Potsdam, Germany

ARTICLE INFO

Article history:
Received 24 February 2016
Received in revised form 7 June 2016
Accepted 18 June 2016
Available online xxxx

Keywords:
Wide-angle seismic
Crustal structure
Walvis Ridge
Hotspot
Rifted continental margin
South Atlantic

ABSTRACT

Voluminous magmatism during the South Atlantic opening has been considered as a classical example for plume related continental breakup. We present a study of the crustal structure around Walvis Ridge, near the intersection with the African margin. Two wide-angle seismic profiles were acquired. One is oriented NNW–SSE, following the continent–ocean transition and crossing Walvis Ridge. A second amphibious profile runs NW–SE from the Angola Basin into continental Namibia. At the continent–ocean boundary (COB) the mafic crust beneath Walvis Ridge is up to 33 km thick, with a pronounced high-velocity lower crustal body. Towards the south there is a smooth transition to 20–25 km thick crust underlying the COB in the Walvis Basin, with a similar velocity structure, indicating a gabbroic lower crust with associated cumulates at the base. The northern boundary of Walvis Ridge towards the Angola Basin shows a sudden change to oceanic crust only 4–6 km thick, coincident with the projection of the Florianopolis Fracture Zone, one of the most prominent tectonic features of the South Atlantic ocean basin. In the amphibious profile the COB is defined by a sharp transition from oceanic to rifted continental crust, with a magmatic overprint landward of the intersection of Walvis Ridge with the Namibian margin. The continental crust beneath the Congo Craton is 40 km thick, shoaling to 35 km further SE. The velocity models show that massive high-velocity gabbroic intrusives are restricted to a narrow zone directly underneath Walvis Ridge and the COB in the south. This distribution of rift-related magmatism is not easily reconciled with models of continental breakup following the establishment of a large, axially symmetric plume in the Earth's mantle. Rift-related lithospheric stretching and associated transform faulting play an overriding role in locating magmatism, dividing the margin in a magma-dominated southern and an essentially amagmatic northern segment.

1. Introduction and geological setting

A central question in the evolution of rifted continental margins is the role of magmatism in the process of crustal and lithospheric attenuation, crustal breakup and the formation of oceanic crust seaward of the continent–ocean boundary (COB). End-member tectonic models are classically known as the “active” and “passive” modes of rifting (Turcotte and Emerman, 1985). Active rifting may be associated with copious magmatism (Burke and Dewey, 1973) before and during crustal extension, and then leads to so-called volcanic rifted margins (Coffin and Eldholm, 1994). These margins are characterized by vast areas of flood basalts extruded onto the surface of the adjacent continental edges, and by large volumes of extrusive lavas at the continent–ocean transition zones as they are stretched prior to form new oceanic basins (Eldholm et al., 1989; White and McKenzie, 1989). In the lower crust beneath the extrusives high seismic velocities indicate mafic intrusions (Holbrook et al., 1994; White et al., 2008).

In the case of passive continental rifting (McKenzie, 1978) magmatism, if any, is synchronous and postdates crustal attenuation. Some examples, like the Galicia and Newfoundland conjugate rifted margins (Peron-Pinvidic et al., 2007) show that the onset of steady ocean floor basalt production after breakup is considerably delayed (Tucholke et al., 2007), resulting in broad ridges of exhumed, serpentinized mantle rocks seaward of the COB (Boillot et al., 1987; Whitmarsh et al., 2001; Reston, 2009). During the rifting no massive volcanism occurs.

One look at the distribution of rift-related magmatism on both sides of the South Atlantic ocean (Fig. 1) shows that end-member models of rifting do not successfully explain divergent movements at plate scale.

* Corresponding author at: Bundeswehr Technical Center WTD71, Research Department for Underwater Acoustics and Marine Geophysics, Berliner Strasse 115, D-24340 Eckernförde, Germany.
E-mail address: lplanert@web.de (L. Planert).

http://dx.doi.org/10.1016/j.tecto.2016.06.024
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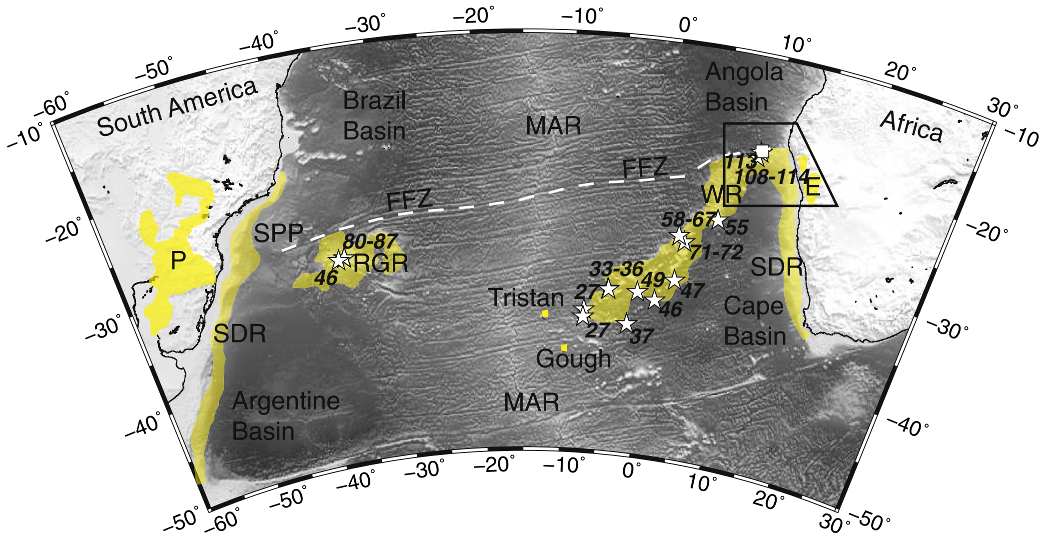

Fig. 1. Volcanic features related to the presence of the Tristan–Gough mantle "plume" and the opening of the South Atlantic (yellow-shaded areas, modified from Gladczenko et al., 1997). White stars with black numbers are locations of age-samples [Myr] from Rohde et al. (2012). The Tristan–Gough volcanic track can be traced, based on geochronical data indicating younging age-progression, from the massive Parana and Etendeka continental flood basalts (CFB) in South America and Africa (~132 Myr, Renne et al., 1996) to the conjugate Rio Grande Rise (RGR) and Walvis Ridge (WR), before becoming a more scattered and poorly defined off-axis guyot province on the African plate. The black box represents the study area of the 2010/11 amphibious seismic experiment. The white square in the Angola Basin close to the Florianopolis Fracture Zone (FFZ, white-dashed line) marks DSDP drill hole 530 (102.5 Myr; Sibuet et al., 1984). E = Etendeka CFB; P = Parana CFB; MAR = Mid Atlantic Ridge; SDR = seaward dipping reflectors; SPP = Sao Paulo Plateau. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

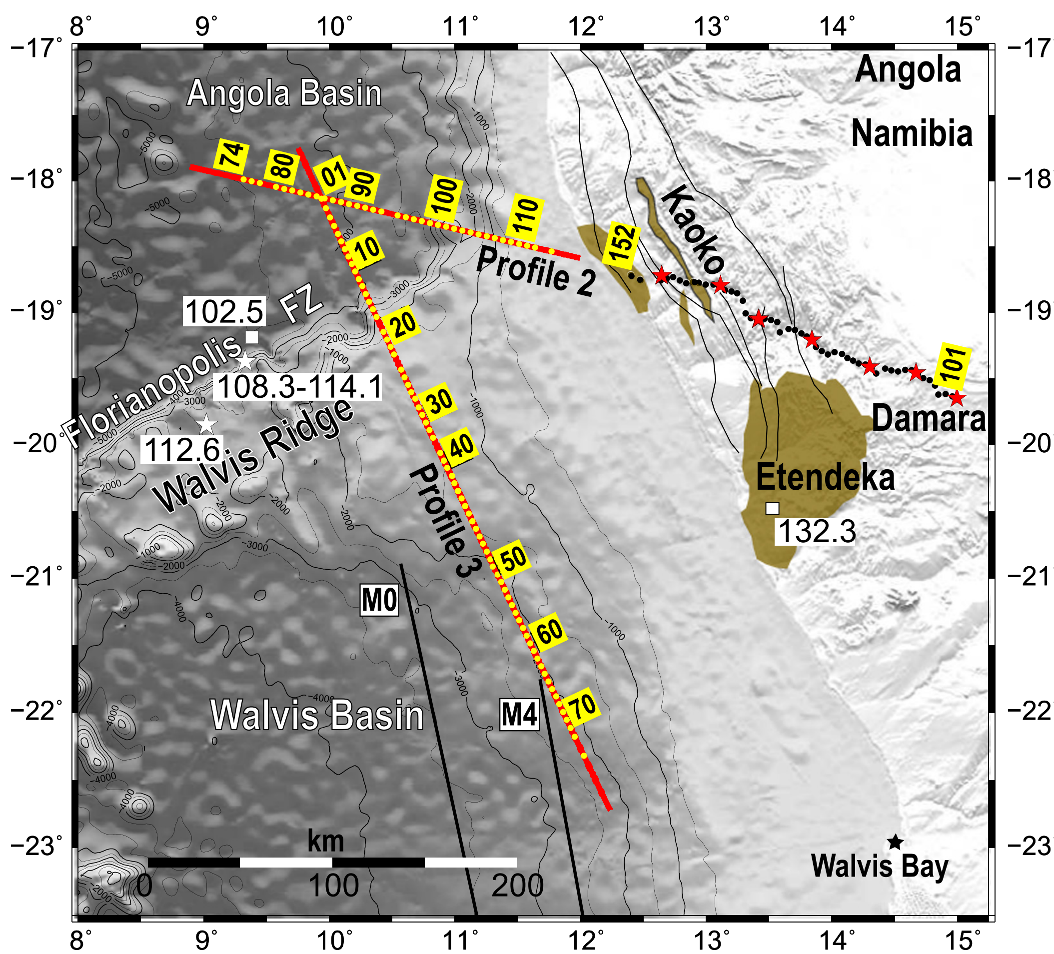

Fig. 2. Profile geometry and station distribution of seismic profiles p2 and p3. Red lines represent airgun tracks, yellow circles are OBH/S positions with instrument numbers. Black circles denote locations of the seismic land stations. Red stars mark the dynamite shots. Brownish areas represent exposed lava flows. Black lines indicate crustal faults (Foster et al., 2009). Locations of magnetic seafloor anomaly M0 and M4 are adopted from Seton et al. (2012) (M0: 120.6 Myr; M4: 125.7 Myr; Gee and Kent, 2007). Assigned ages at northern Walvis Ridge are from Rohde et al. (2012), at Etendeka CFBs from Renne et al. (1996), and at DSDP site 530 in the Angola Basin from Sibuet et al. (1984). Depth contours are drawn every 500 m. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Please cite this article as: Planert, L., et al., The wide-angle seismic image of a complex rifted margin, offshore North Namibia: Implications for the tectonics of continental bre..., Tectonophysics (2016), http://dx.doi.org/10.1016/j.tecto.2016.06.024