Marine and Petroleum Geology 50 (2014) 22–39

Contents lists available at ScienceDirect

Marine and Petroleum Geology

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

Segmentation and volcano-tectonic characteristics along the SW African continental margin, South Atlantic, as derived from multichannel seismic and potential field data

Hannes Koopmann [a,b,*], Dieter Franke [a], Bernd Schreckenberger [a], Henning Schulz [c], Alexander Hartwig [d,1], Harald Stollhofen [c], Rolando di Primio [d]

[a] *Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Stilleweg 2, 30655 Hannover, Germany*
[b] *Gottfried Wilhelm Leibniz Universität Hannover, Institut für Mineralogie, Callinstraße 3, 30167 Hannover, Germany*
[c] *GeoZentrum Nordbayern (GZN) der Friedrich-Alexander Universität Erlangen-Nürnberg, Schlossgarten 5, 91054 Erlangen, Germany*
[d] *Helmholtz-Zentrum Potsdam – Deutsches GeoForschungsZentrum (GFZ), Telegrafenberg, 14473 Potsdam, Germany*

A R T I C L E I N F O

Article history:
Received 31 October 2012
Received in revised form
16 October 2013
Accepted 30 October 2013
Available online 7 November 2013

Keywords:
Passive continental margin
South Atlantic
Southwest Africa
Continental break-up
Margin segmentation
Seaward Dipping Reflector Sequences (SDRs)
Volcanic rifting
Sheared margin

A B S T R A C T

Regional seismic reflection and potential field data document the South Atlantic's break-up history, between 39°S and 19°S, from the Early Cretaceous onwards. Previous maps of distribution of volcanics along the margin showed volcanics along the whole African margin based on extrapolation of data. Based on previously unpublished marine geophysical data, we found the southernmost 460 km long margin segment to be lacking huge volumes of break-up related volcanic effusives. Northwards, break-up was accompanied by the emplacement of huge volumes of volcanic material, prominently featured in seismic sections as huge wedge-shaped seaward dipping reflectors (SDRs). Detailed mapping of offsets (left- and right-stepping) and variations in structural character of the volcanics reveal the segmentation along and the break-up history of the margin. Several superimposed SDR sequences, suggesting episodicity of volcanic emplacement (divided by periods of erosion and sedimentation), are distinct along southerly lines, losing prominence northwards.

A main outcome of our study is that this passive margin is not continuously of the volcanic type and that the change from a non-volcanic to a volcanic margin occurs abruptly.

We define four distinct First-order Segments along the 2400 km section of the southwestern African margin covered by our seismic data. From south to north these First-order Segments are: Magma-poor Segment I; Segment II with enormous SDRs volumes; decreasing SDRs volumes in Segment III; Segment IV again with enormous volcanic output, likely influenced by Walvis Ridge volcanism.

Most important is that there is no systematic increase in the volumes of the effusives towards the Tristan da Cunha hot-spot. Rather there is an alternating pattern in the SDRs' volumes and widths.

The boundary between the volcanic and magma-poor margin segments in the southernmost study area is sharp (10s of km), which we propose is reflected in magnetic anomaly data as well. We suggest that this variability along the margin is mainly due to a change in stretching/rifting character from oblique during the early stages of breakup to conventional seafloor spreading from Chron M4 (~130 Ma) onwards.

1. Introduction

The southwestern African continental margin has long been interpreted as a prime example for the volcanic passive margin type (Aslanian et al., 2009; Austin and Uchupi, 1982; Bauer et al., 2000; Blaich et al., 2011, 2009, 2010; Brown et al., 1995; Corner et al., 2002; Eagles, 2007; Elliott et al., 2009; Geoffroy, 2005; Gladczenko et al., 1997, 1998; Hirsch et al, 2009; Jackson et al., 2000; Jokat et al., 2003; Martin, 1987; Maslanyj et al., 1992; Menzies et al., 2002; O'Connor and Duncan, 1990; Parsiegla et al., 2009; Séranne and Anka, 2005; Skogseid, 2001; Trumbull et al., 2007; Unternehr et al., 1988). In this regard it has also been suggested as a case location for the study of a hot-spot related break-up

* Corresponding author. Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Stilleweg 2, 30655 Hannover, Germany. Tel.: +49 511 643 3469.
E-mail address: hannes.koopmann@bgr.de (H. Koopmann).
[1] Present address: ConocoPhillips, 600 N Dairy Ashford, Houston, USA.

0264-8172/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marpetgeo.2013.10.016

history. This study questions both assumptions to a certain degree, as we present evidence that the southwestern African passive continental margin is not continuously of the volcanic type. Further, the change from non-volcanic to volcanic margin occurs abruptly. Based on 3300 km of previously unpublished BGR multichannel seismic data off South Africa along with seismic data provided by industrial partners alongside with publically available geophysical data we study in detail the margin architecture between the Agulhas Falkland Fracture Zone (AFFZ), in the south, and the Rio Grande Fracture Zone (RGFZ), in the north.

Variations in the lateral distribution of break-up related volcanics are used for a detailed investigation of segmentation along the southern African continental margin. We suggest margin segmentation as a prime feature allowing insights into the early break-up histories of continents. We show that the final extension that resulted in breakup was considerably oblique.

Structures that compartmentalize a propagating rift at high angles have long been recognized. Rosendahl (1987) defined a zone, transferring displacement or strain from one rift-graben segment to another with opposite sense via oblique shear along an inter-basinal ridge as accommodation zone. Morley et al. (1990) developed a classification of extensional fault displacement zones and introduced the term “transfer zones”. According to Lister et al. (1991), major transfer faults are required to accommodate a switch in dip of the master detachment fault(s) when the resulting rift-basin segments are alternatively located on either side of the developing margins. The terms transfer zone or segment boundary were widely used in the following, particularly where cross-margin structural elements on the shelf are spatially related to onshore zones of strike-slip faulting. In this work we use the term “segment boundary” to describe linear areas (rather sharply-defined fault lines) localizing major structural differences along the margin, e.g. an offset in the extent of volcanic effusives or the disappearance of intrusive and effusive features.

As deeper structures within the crust along the volcanic-rifted margin are masked by thick wedges of volcanic material (Blaich et al., 2011), volcanic effusives are considered as an important clue in understanding the early break-up and segmentation history of a margin. These effusives are imaged in seismic data as Seaward Dipping Reflector Sequences (SDRs). Offsets and variations in the character of the SDRs have previously been shown to indicate margin segmentation along the southern South American margin (Blaich et al., 2009; Franke et al., 2007). This study investigates the width, architecture and regional distribution of volcanic effusives (SDRs) along the 2400 km of the continental margin between the Agulhas-Falkland Fracture Zone (AFFZ) at 39°S and the Rio Grande Fracture Zone (RGFZ) at 19°S along the African margin of the South Atlantic. We incorporate previous investigations on SDRs (Gladczenko et al., 1997, 1998) and provide an update on an earlier segmentation model for the Namibian part of the study area (Clemson et al., 1997). This results in a consistent and conclusive description of margin segmentation along the entire eastern margin of the southern South Atlantic.

2. Regional geological setting

The South Atlantic continental margins (Fig. 1) resulted from the break-up of Gondwana, with Antarctica separating from Africa and South America at around 155 Ma, forming the Mozambique Basin and Weddell Sea prior to the South Atlantic opening (Jokat et al., 2003). The opening of the South Atlantic took place in the Early Cretaceous with suggested opening ages ranging between 137 and 126 Ma (Gladczenko et al., 1997; Jokat et al., 2003; Nürnberg and Müller, 1991; Rabinowitz and LaBrecque, 1979; Unternehr et al., 1988). The South Atlantic likely opened from South to North in a zipper-like succession along individual rift zones (Austin and Uchupi, 1982; Jackson et al., 2000; Rabinowitz and LaBrecque, 1979; Uchupi, 1989). Just before and during the opening of the ocean basin, large volumes of volcanic effusives were emplaced both on Mesozoic intracratonic basins onshore (Paraná-Etendeka Large Igneous Province (LIP)) and on the incipient rifted crust onshore and offshore (Bauer et al., 2000; Franke et al., 2010, 2007; Franke, 2013; Gladczenko et al., 1997; Hinz et al., 1999; Jackson et al., 2000; Jerram et al., 1999a,b; Moulin et al., 2010; O’Connor and Duncan, 1990; Trumbull et al., 2007).

The presence of magnetic anomalies Chron M4 (~130 Ma; Gradstein and Ogg, 2004) and younger anomalies is widely accepted offshore South Africa, marking the onset of conventional

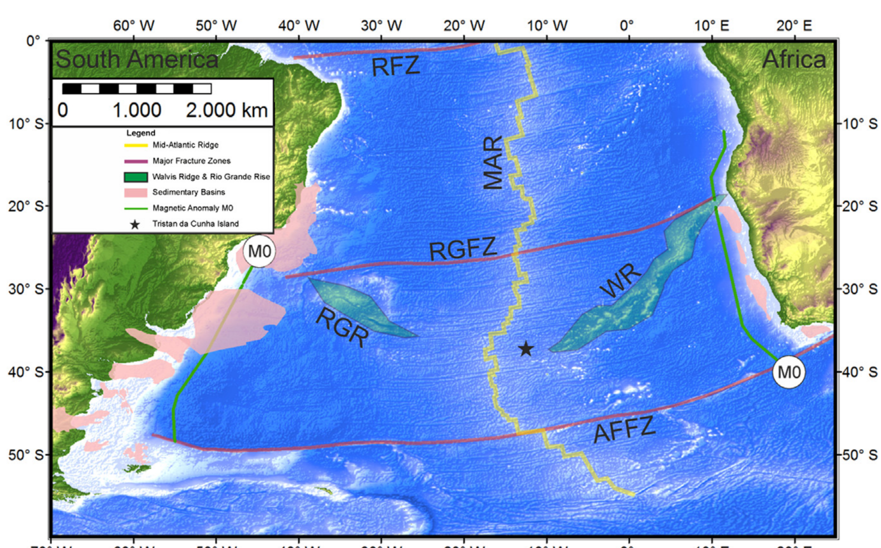

Figure 1. Regional map of the South Atlantic. In this work, we study the volcano-tectonic characteristics along the Namibian and Southern African margin between the Agulhas Falkland Fracture Zone (AFFZ) and the Rio Grande Fracture Zone (RGFZ). The map shows the distribution of the sedimentary basins in the study area on the Namibian and Southern African margin (South to North: Outeniqua Basin; Orange Basin; Lüderitz Basin; Walvis Basin) and on the conjugate South American margin (South to North: North Falkland Basin; San Julian Basin; San Jorge Basin; Rawson Basin; Valdez Basin; Colorado Basin; Salado Basin; Pelotas Basin; Campos Basin; Santos Basin). Further shown: Magnetic Anomaly M0, Mid-Atlantic Ridge (MAR; the spreading axis of the Atlantic Ocean); Walvis Ridge (WR) and Rio Grande Rise (RGR); Tristan da Cunha volcanic Island and the Romanche Fracture Zone (RFZ).