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Review article

Structural comparison of archetypal Atlantic rifted margins: A review of observations and concepts

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ABSTRACT

In this study we compare three pairs of conjugate rifted margins that are often referred to as archetypes of rift systems. Despite numerous differences, a remarkable first-order structural similarity appears between the magma-poor Iberia–Newfoundland, the magma-rich mid-Norway–East Greenland and the sediment-rich Angola–Brazil rifted margins. Typical is the seaward arrangement of distinct domains (proximal, necking, distal and outer) that each present specific comparable structural characteristics. Our study also suggests that magma-rich systems may go through a stage of hyper-extension, indicating that extreme crustal thinning does not preclude a magmatic breakup.

In this contribution, we clarify the definition of a number of terms introduced recently in rifted margin studies. We review the major features constitutive of these key referenced systems, discuss their similarities and differences and examine how the related deformation modes develop in the 'life cycle' of a rift that goes to seafloor spreading. We conclude that the distinct domains observed in the margin architecture represent distinct stages in the evolution of rifted margin, independently of their later evolution into magma-poor or magma-rich environments.

1. Introduction: concepts and terminology

1.1. Introduction

Our understanding of rifting processes and rifted margin formation is undergoing a paradigm shift. Rifted margins used to be presented as a juxtaposition of continental and oceanic crusts issued from simple shear, pure shear or composite deformation mechanisms (McKenzie, 1978; Le Pichon and Sibuet, 1981; Wernicke, 1985; Lister et al., 1986). The rifting models were mainly based on the study of proximal domains, where data acquisition was concentrated in sedimentary basins with hydrocarbon potential. Most datasets and models were developed either based on onshore observations in continental rifts or in proximal offshore rift basins. As a consequence, little was known about the distal domains. The acquisition of higher-resolution geophysical data (seismic, potential field) combined with deep sea drilling and onshore analogue studies showed that the distal domains of rifted margins are different from the proximal ones. Observations from distal rifted margins led to the discovery of unexpected structural settings, such as exhumed subcontinental mantle and/or hyperextended continental crust. These results questioned the validity of some rifting models and led to the development of new concepts and approaches. Most of these ideas and models were developed along the Iberia–Newfoundland and East Greenland–mid-Norwegian conjugate margins and then later applied to the South Atlantic and other rift systems.

Numerous rift scenarios and rift geometries have been proposed to describe and explain the new observations. The end-member partitioning between volcanic and non-volcanic settings has been adjusted to magma-poor and magma-rich (or magma-sustained). New terms and concepts have been introduced and definitions have been further developed. These include morphological terms (e.g. platform, terrace, taper break, marginal high; Blystad et al., 1995; Osmundsen and Redfield, 2011; Planke et al., 2000), domain names (necking zone, transitional zone, ocean–continent transition, zone of exhumed continental mantle, ocean–continent boundary; Whitmarsh et al., 2001; Manatschal, 2004) and terms referring to geological processes (stretching, thinning, exhumation; Lavier and Manatschal, 2006). Actually, many of these terms refer to similar features or processes, although the definitions of their boundaries are often not clearly described. We need to list the similarities and differences of the entities that lie behind these terms (see Section 2). Furthermore, we need to understand if the

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differences observed between one rift system and the other are related to local variations in rift parameters, to inheritance or to fundamentally different rifting processes (see Section 3). Our aim is to better identify the similarities and differences between these rifted margins and to understand to what degree the concepts based on one margin system can be applied to another through a generic model (see Section 4).

A profound schism exists between 'ODP drilled' and 'non-ODP drilled margins'. The Iberia–Newfoundland rifted margins were penetrated by 18 deep holes drilled during DSDP Leg 47B and ODP Legs 103, 149, 173 and 210 (Groupe-Galice, 1979; Boillot et al., 1987; Sawyer et al., 1994; Whitmarsh et al., 1998; Tucholke et al., 2004) (Figs. 1 and 4). This unique dataset made the Iberia–Newfoundland margins the type example of a magma-poor rift-system that went to continental breakup, and a basis for revision of our views on rifted margins. The recognition worldwide of rifted margins that display similar first-order domains as well as structural and stratigraphic systems that resemble each other, justifies a comparison between margins with good data coverage, even if they have not all been subject to deep drilling.

Refraction models generally provide a good overview of the bulk architecture of rifted margins (e.g. Reston, 2009). The Angola margin (Contrucci et al., 2004), the Newfoundland margin (Van Avendonk et al., 2006) and the mid-Norwegian margin (Mjelde et al., 2009) are all characterized by comparable seismic refraction characteristics (Fig. 2), albeit if some controversy exists over the lithological interpretation of some seismic velocity ranges (e.g. Ebbing et al., 2006). For all three margins, a similar, first-order geometry appears with a seismic basement that thins oceanwards from >30 km thickness in proximal settings to ~0–5 km thickness at the most distal settings (Fig. 2). The Moho rises oceanwards either rapidly over short distances (e.g. Newfoundland) or more gradually (e.g. Angola), while the top of basement steadily deepens toward the distal margin. More detailed information on the architecture of these rifted margins is found in other datasets, such as seismic reflection data, potential field data and stratigraphic data obtained from exploration wells. They permit a more detailed interpretation of the basement structure and sedimentary architecture. For instance, whereas proximal margins commonly contain arrays of half-graben basins with syntectonic, wedge-shaped

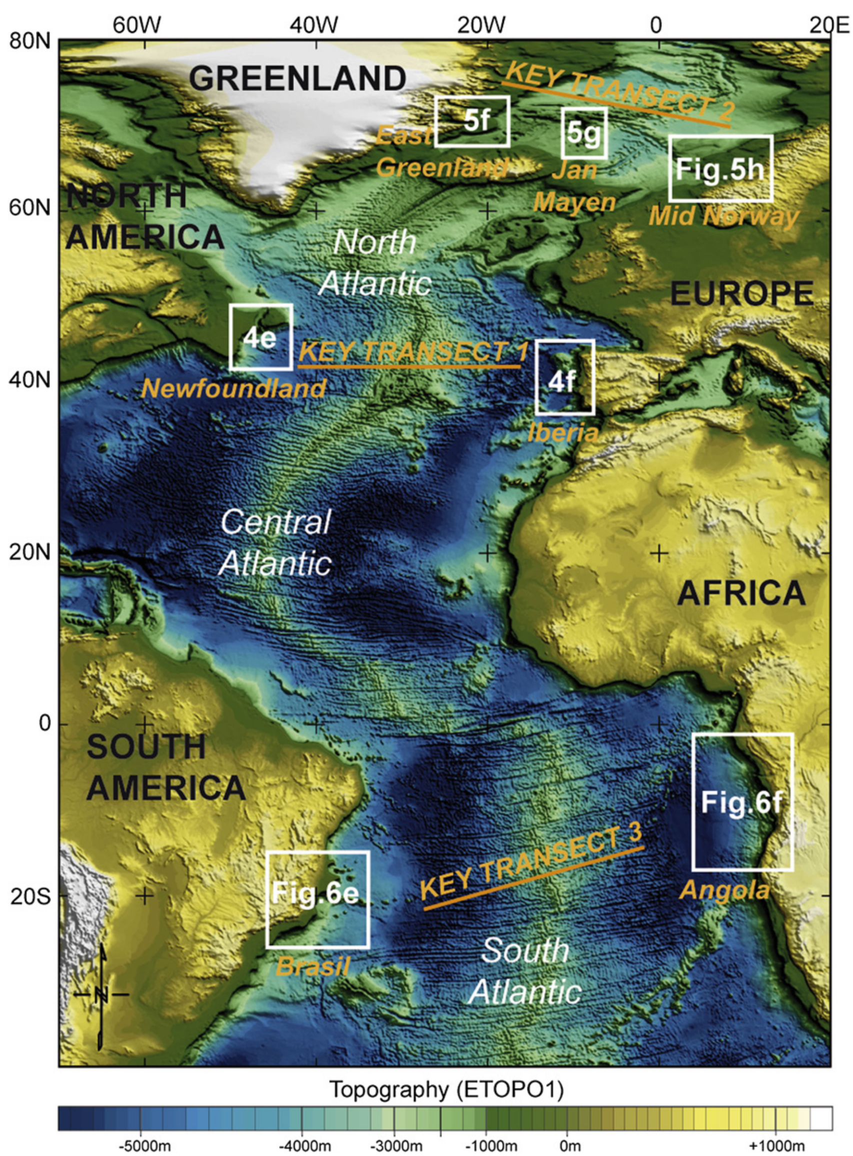

Figure 1. Topographic map of the Atlantic Ocean. The boxes show the location of the rifted areas discussed in the contribution. Topography is ETOPO1 (Amante and Eakins, 2009) presented in geographical latitude–longitude coordinates (datum WGS84).