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The tectonic evolution of the southeastern Terceira Rift/São Miguel region (Azores)

B.J. Weiß [a,*], C. Hübscher [a], T. Lüdmann [b]

[a] Institute of Geophysics, University of Hamburg, Bundesstrasse 55, D-20146 Hamburg, Germany
[b] Institute of Geology, University of Hamburg, Bundesstrasse 55, D-20146 Hamburg, Germany

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ABSTRACT

The eastern Azores Archipelago with São Miguel being the dominant subaerial structure is located at the intersection of an oceanic rift (Terceira Rift) with a major transform fault (Gloria Fault) representing the westernmost part of the Nubian–Eurasian plate boundary. The evolution of islands, bathymetric highs and basin margins involves strong volcanism, but the controlling geodynamic and tectonic processes are currently under debate. In order to study this evolution, multibeam bathymetry and marine seismic reflection data were collected to image faults and stratigraphy. The basins of the southeastern Terceira Rift are rift valleys whose southwestern and northeastern margins are defined by few major normal faults and several minor normal faults, respectively. Since São Miguel in between the rift valleys shows an unusual W–E orientation, it is supposed to be located on a leaky transform. South of the island and separated by a N120° trending graben system, the Monacco Bank represents a N160° oriented flat topped volcanic ridge dominated by tilted fault blocks. Up to six seismic units are interpreted for each basin. Although volcanic ridges hamper a direct linking of depositional strata between the rift and adjacent basins, the individual seismic stratigraphic units have distinct characteristics. Using these units to provide a consistent relative chrono-stratigraphic scheme for the entire study area, we suggest that the evolution of the southeastern Terceira Rift occurred in two stages. Considering age constrains from previous studies, we conclude that N140° structures developed orthogonal to the SW–NE direction of plate-tectonic extension before ~10 Ma. The N160° trending volcanic ridges and faults developed later as the plate tectonic spreading direction changed to WSW–ENE. Hence, the evolution of the southeastern Terceira Rift domain is predominantly controlled by plate kinematics and lithospheric stress forming a kind of a re-organized rift system.
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1. Introduction

The Azores Archipelago is located at the Mid-Atlantic Ridge (MAR) where three major lithospheric plates converge (Fig. 1): the North American Plate in the west and the Eurasian & Nubian plates in the east, the last two separated from each other by a major transform fault (Gloria Fault). MAR and Gloria Fault are linked by an oblique oceanic rift system (Terceira Rift), which is accommodating dextral transtension in WSW–ENE direction caused by the relative movement of the Eurasian and Nubian plates (DeMets et al., 2010; Fernandes et al., 2006). Northward migration of the triple point and the evolution of the present-day Terceira Rift involved increased volcanism/magmatism causing the formation of the Azores Plateau (e.g. Georgen and Sankar, 2010; Luis et al., 1998), a prominent morphological high with an abnormal low water depth of ~2000 m. The volcanic islands at the northeastern rim of the Azores Plateau represent the present-day subaerial volcanism. Hence, the Terceira Rift resembles e.g. the Spiess Ridge in the South Atlantic in terms of a volcanically active and oblique rift system linking a spreading axis with a major transform fault (Ligi et al., 1999; Mitchell et al., 2000).

Both, the jump of the triple junction and the strong volcanism are associated with the existence of a hot spot (e.g. Cannat et al., 1999; Gente et al., 2003; Schilling, 1975) or an anomalously volatile-enriched upper mantle (e.g. Bonatti, 1990; Schilling et al., 1980) which once interacted or is still interacting with the MAR. Yet, the initiation of the Azores Plateau evolution correlates with changes in the relative plate movements of Nubia and Eurasia (Luis and Miranda, 2008) and the increased volcanism is proposed to be caused by stretching of the lithosphere (e.g. Luis et al., 1994; Marques et al., 2013, 2014a; Métrich et al., 2014). Hence, it is still up for debate if the tectonic evolution of the elevated seafloor and the volcanic ridges is mainly controlled by upper mantle processes or induced by lithospheric stress due to tectonic plate kinematics.

In this context, the presented study aims for a deeper insight in the geological evolution of the southeastern Terceira Rift and its submarine basins and highs in time and space. Based on a unique high resolution bathymetric and seismic 2D multichannel data set, we mapped the complex submarine fault systems and identified a seismic stratigraphy for the sedimentary basins in the São Miguel region. Therefore, the first objective is to describe the submarine faults and volcanic ridges

* Corresponding author. Tel.: +49 40 42838 6369; fax: +49 40 42838 5441.
E-mail address: benedikt.weiss@zmaw.de (B.J. Weiß).

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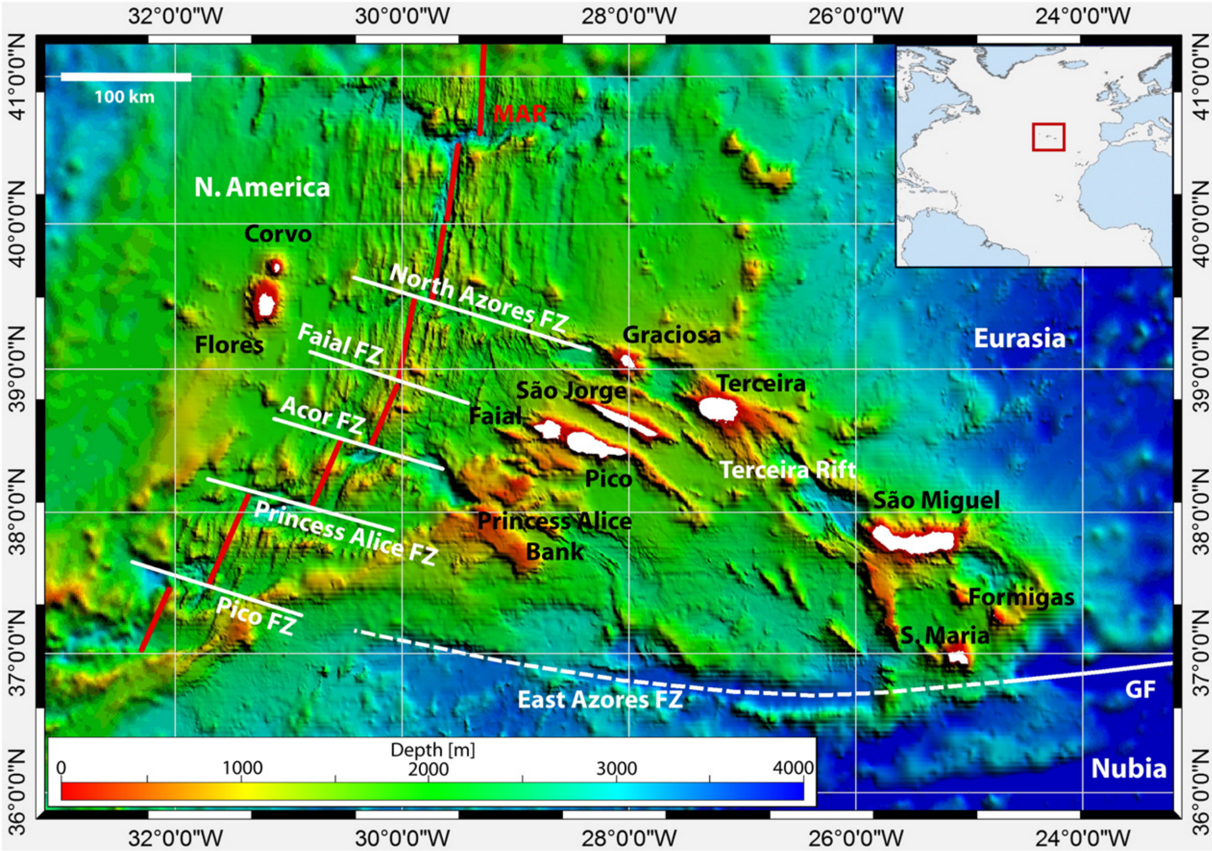

Fig. 1. Azores Plateau and corresponding structures. MAR: Mid-Atlantic Ridge; GF: Gloria Fault; FZ: Fracture Zone. Bathymetric data from Lourenço et al. (1998) and ETOPO1 from Amante and Eakins (2009). Structural features after Luis et al. (1994).

before distinguishing between different sedimentation conditions and the corresponding tectonic and/or volcanic processes. The different stratigraphic sequences then have to be correlated between the basins. This will allow us to evaluate a relative chronology of tectonic and volcanic processes in the working area, which will ultimately result in an evolutionary model for the southeastern Terceira Rift. Finally, general implications will be drawn in terms of structural development and nature of the whole Azores Plate Boundary.

2. Geological context

2.1. Terceira Rift & Azores Triple Junction

The Azores Archipelago consists of 9 islands (Fig. 1). The two westernmost islands (Corvo, Flores) are located on present-day stable North American Plate, whereas the central (Graciosa, Terceira, São Jorge, Faial, Pico) and eastern islands (São Miguel, Santa Maria, Formigas Islets) are distributed along the Nubian–Eurasian plate boundary. The northeastern islands and intercalated basins are known as Terceira Rift, which is defined by the South-Hirondelle Basin, São Miguel Island, the Povoação Basin and the Formigas ensemble in the working area (Fig. 2).

To the South, the East Azores Fracture Zone (EAFZ) forms the southern boundary of the Azores Plateau (Fig. 1) representing the fossil trace of the Gloria Fault on the Nubian Plate (Krause and Watkins, 1970; Luis and Miranda, 2008; McKenzie, 1972; Searle, 1980). At its transition to the Pico Fracture Zone, the EAFZ originally formed the triple point with the MAR in a ridge–fault–fault (RFF) setting. Synchronously to the final stage of the Iberia–Eurasia suture between Oligocene and lower Miocene (33–20 Ma; Luis and Miranda, 2008; Srivastava et al., 1990), the triple point moved northward either in one (Gente et al., 2003; Searle, 1980) or in several steps (Luis et al., 1994; Vogt and Jung, 2004) possibly forming an interim independent Azores Micro Plate (Luis et al., 1994). However, significant extension of 4 mm/a started to occur in the Azores domain at ~20 Ma initiating the evolution of the Terceira Rift in a N50° extensional setting (Luis and Miranda, 2008). While the extension rate is still 4 mm/a (Fernandes et al., 2006), extensional direction rotated from N50° to the present-day ~N70° direction (DeMets et al., 2010) ~10 Ma ago (Luis and Miranda, 2008). Until 7 Ma, the formation of the Terceira Rift involved the accretion of large volumes of extrusives and intrusives as well as underplated material (Cannat et al., 1999; Gente et al., 2003; Luis et al., 1998). This caused the creation of thickened crust (Dias et al., 2007; Georgen and Sankar, 2010; Luis and Neves, 2006; Silveira et al., 2010) referencing to the abnormal elevated seafloor of the Azores Plateau.

Today, the triple junction is located ~150–250 km north of its former position (Fig. 1) forming a diffuse triple junction area between the Acor and North Azores Fracture Zone (Marques et al., 2013, 2014a; Miranda et al., 2014), where the MAR spreading rate increases from 20 in the south to 22 mm/a in the north (DeMets et al., 2010). Further to the east and west of Terceira, extension is mainly accommodated along N110°–120° striking linear volcanic ridges (with São Jorge and Faial/Pico representing an extreme case) and N120°–160° trending faults (e.g. Hildenbrand et al., 2014; Lourenco et al., 1998; Miranda et al., 1998, 2014), which overprint MAR related N15° fabrics. Southeast of Terceira, extension concentrates at the southeastern Terceira Rift, where N140° to N150° trending structures become abruptly prominent (Fernandes et al., 2006; Lourenço et al., 1998; Miranda et al., 1998). These different trends are assumed to be the result of plate boundary effects (Georgen and Sankar, 2010; Neves et al., 2013) and structural heritage (Navarro et al., 2009). They form a diffuse plate boundary consisting of several tectonic blocks (Lourenço et al., 1998; Miranda et al., 1998) and en échelon horst graben structures (Marques et al.,

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