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Volcano-tectonic evolution of the Santa Maria Island (Azores): Implications for paleostress evolution at the western Eurasia–Nubia plate boundary

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ABSTRACT

The growth and decay of oceanic volcanoes developed close to plate boundaries are intrinsically related to a competition between construction and destruction processes, partly controlled by tectonic strain and stresses. From morphologic, stratigraphic, tectonic and new high-precision K–Ar data, we present a comprehensive picture of the volcano-tectonic evolution of Santa Maria, and discuss its significance regarding the stress evolution and regional deformation in the Azores. Our new data show that: (1) the western flat portion of the island is mostly composed of west-dipping volcanic rocks here dated between 5.70 ± 0.08 and 5.33 ± 0.08 Ma, which we consider the remnants of an Older Shield Volcano; (2) more than half of this early volcanic complex has been removed by an east-directed large-scale sector collapse; (3) a second volcano, here coined the Younger Shield Volcano, grew rapidly on the collapse scar between at least 4.32 ± 0.06 and 3.94 ± 0.06 Ma; (4) more than half of this new volcano was removed by a second large-scale sector collapse most probably around 3.6 Ma, based on the ages of Parasitic Scoria Cones sitting unconformably on the Younger Shield Volcano; (5) the latest parasitic volcanic activity is here dated at 2.84 ± 0.04 Ma, extending significantly the known eruptive history of Santa Maria. Morpho-structural data (shape of the island, faults, dikes, and distribution of volcanic cones) show a significant control of construction and destruction along the N045° and N150° directions. The age of the lavas intruded by dikes suggests that the N045° and the N150° trends are ca. 5.3 Ma old and younger than ca. 4.3 Ma, respectively. Based on the new data, we conclude that a change in the regional stress field occurred between 5.3 and 4.3 Ma, most likely associated with a major reconfiguration of the Eurasia/Nubia plate boundary in the Azores.

1. Introduction

The evolution of volcanic ocean islands generally occurs in a complex way, as a result of a competition between volcanic construction and destruction processes. The growth of large intra-plate volcanoes, especially, is often punctuated by episodes of gravitational destabilization in the form of catastrophic flank collapses, as extensively recognized worldwide: Hawaii (e.g., Moore et al., 1989, 1995), the Canary Islands (e.g., Carracedo, 1994; Carracedo et al., 1999; Bouleisteix et al., 2012, 2013), or in Cape Verde (e.g., Masson et al., 2008; Ancochea et al., 2010). Closer to the major plate boundaries, the evolution of oceanic volcanoes may additionally be significantly influenced by regional deformation. This seems to be the case in the Azores volcanic archipelago near the present Triple Junction between the North American (NA), the Eurasian (EU) and the Nubian (NU) lithospheric plates. Recent studies on the most recent islands of the archipelago have shown that recent volcanic construction and destruction episodes have been significantly focused along major active regional structures (e.g., Lourenço et al., 1998; Haase and Beier, 2003; Hildenbrand et al., 2008a, 2012a,b, 2013a,b; Navarro et al., 2009; Quartau et al., 2012; Marques et al., 2013a, 2014a,b; Costa et al., 2014; Trippanera et al., 2014). Reconstructing the long-term evolution of such islands thus provides a unique opportunity to track the influence of deformation on the various stages of growth and destruction, especially through the analysis of strain and stresses recorded by the distribution of volcanic outputs and/or the faults and dikes cutting the various edifices. Ultimately, such markers can give valuable information on the potential changes in regional strain and stress, e.g., associated with a rapid plate reconfiguration (e.g., Hildenbrand et al., in press).

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Santa Maria is the oldest island in the Azores and is situated at the intersection between the older and the current EU/NU plate boundaries. Given this key position close to a plate boundary, the island is a suitable target to investigate the successive stages of construction and destruction, their possible relationships with regional tectonics, and possible changes of the stress field with time. Despite this key position and the importance of the age constraint, the geological evolution of the island remains not well constrained. From new morphological analyses, fieldwork, structural data, and K–Ar dating, we here constrain the volcano-tectonic evolution of Santa Maria and discuss its significance regarding regional tectonics and paleostress evolution at the western Eurasia–Nubia plate boundary.

2. Geological background

2.1. Geodynamic setting

The Azores archipelago comprises nine volcanic islands located on both sides of the Mid-Atlantic Rift (MAR). The islands sit on top of a large portion of elevated seafloor generally referred to as the Azores Plateau, which roughly coincides with the −2000 m isobath. The genesis of the plateau, the excess of magmatism and the development of the islands have been generally attributed to the presence of an anomalous mantle under the plateau. Global and regional S-wave tomographic studies show the presence of a low seismic velocity zone between ~80 and 250 km depth under the whole region (for a review, see Silveira et al., 2006). This suggests that the mantle under the Azores is presently anomalously hot and/or wet. This seems consistent with the anomalous high topography of the MAR (e.g., Schilling, 1985; Escartin et al., 2001), a thicker than average crust (Searle, 1980; Detrick et al., 1995; Luis et al., 1998; Cannat et al., 1999; Gente et al., 2003; Maia et al., 2007; Silveira et al., 2010), and the geochemistry of the lavas from the islands, which overall show a strong enrichment in incompatible elements and radiogenic isotopes (e.g., Bourdon et al., 2005). MORB from the MAR close to the Azores also has relatively high Sr, Pb, and He isotope ratios compared to normal depleted MORB (Kurz, 1982; Schilling et al., 1983; Bourdon et al., 1996; Dosso et al., 1999; Moreira and Allegre, 2002; Jean Baptiste et al., 2009). However, according to other authors, the volcanism is not due to an active hot-spot, but may rather reflect the existence of volatile-enriched upper mantle domains (Schilling et al., 1975; Bonatti et al., 1990) or a wet-spot (Métrich et al., 2014).

To the east of the MAR axis, the plateau shows a triangular shape and encompasses portions of the North American (NA), the Eurasian (EU), and the Nubian (NU) plates (Fig. 1). The NA/EU and NA/NU plate boundaries coincide with the conspicuous MAR axis, whose morphology has been relatively stable over the last few Myrs (Laughton et al., 1972). In contrast, the morphology and the history of the EU/NU boundary in the Azores are more complex. Immediately to the east of the Azores region, the EU/NU boundary presently comprises a dextral transcurrent fault called the Gloria Fault (GF). Sometime in the past, the GF was connected to the MAR by an active fault called the East Azores Fracture Zone (EAFZ), bounding, in the south, the eastern Azores Plateau. However, the EAFZ seems presently seismically inactive, and thus not anymore part of the EU/NU boundary (e.g., Krause and Watkins, 1970; Searle, 1980). It is now consensual that this part of the EU/NU plate boundary has migrated to the North and is now following in part the hyper-slow oceanic Terceira Rift (TR), which bounds, in the north, the eastern Azores Plateau (e.g., Machado, 1959; Krause and Watkins, 1970; McKenzie, 1972; Searle, 1980; Vogt and Jung, 2004). A combined study of GPS, seismic and tectonic data (Marques et al., 2013a, 2014a) indicates that the EU/NU boundary presently coincides with the TR in

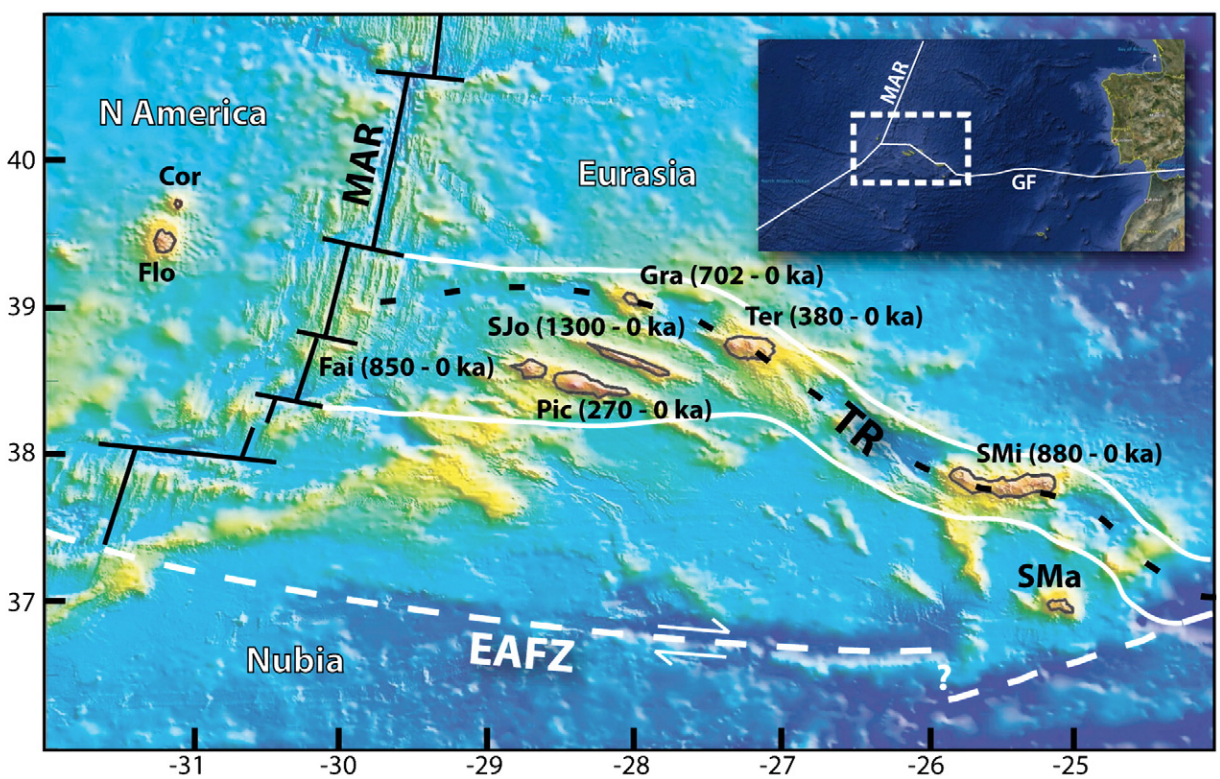

Fig. 1. Bathymetric map of the Azores (data from Lourenço et al., 1998). The thick black lines indicate the location of the Mid-Atlantic Ridge (MAR) axis, which separates the North American and Eurasian plates, and the North American and Nubian plates. The white lines mark the current Eurasia/Nubia diffuse plate boundary (after Marques et al., 2013a, 2014a). The black dashed line indicates the location of the Terceira Rift (TR), and the white dashed line the East Azores Fracture Zone (EAFZ). The black numbers show previous geochronological data on volcanic rocks from the eastern and central islands (Féraud et al., 1980; Chovelon, 1982; Johnson et al., 1998; Calvert et al., 2006; Hildenbrand et al., 2008a, 2012a; Sibrant et al., 2014). The inset shows the location of the Azores archipelago in the Atlantic Ocean. Bathymetric GF: Gloria Fault (on the inset); Cor: Corvo; Flo: Flores; Fai: Faial; Pic: Pico; SJo: S. Jorge; Gra: Graciosa; Ter: Terceira; SMi: S. Miguel; SMa: Santa Maria.