Earth and Planetary Science Letters 362 (2013) 258–271

Contents lists available at SciVerse ScienceDirect

Earth and Planetary Science Letters

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

Mantle dynamics and characteristics of the Azores plateau

C. Adam [a,*], P. Madureira [a,b], J.M. Miranda [c], N. Lourenço [c,d], M. Yoshida [e], D. Fitzenz [a,1]

[a] *Centro de Geofísica de Évora/Univ. Évora, 7002-554 Évora, Portugal*
[b] *Estrutura de Missão para a Extensão da Plataforma Continental (EMEPC), 2770-047, Paço d' Arcos, Portugal*
[c] *Instituto Portugues do Mar e da Atmosfera, Lisboa, Portugal*
[d] *University of Algarve, IDL, Campus de Gambelas, 8000 Faro, Portugal*
[e] *Institute for Research on Earth Evolution (IFREE), Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Kanagawa 237-0061, Japan*

ARTICLE INFO

Article history:
Received 25 July 2012
Received in revised form
2 November 2012
Accepted 5 November 2012
Editor: T. Spohn
Available online 18 January 2013

Keywords:
Azores triple junction
mantle dynamics
dynamic topography
lithospheric stresses
tectonic regimes

ABSTRACT

Situated in the middle of the Atlantic Ocean, the Azores plateau is a region of elevated topography encompassing the triple junction between the Eurasian, Nubian and North American plates. The plateau is crossed by the Mid-Atlantic Ridge, and the Terceira Rift is generally thought of as its northern boundary. The origin of the plateau and of the Terceira Rift is still under debate. This region is associated with active volcanism. Geophysical data describe complex tectonic and seismic patterns. The mantle under this region is characterized by anomalously slow seismic velocities. However, this mantle structure has not yet been used to quantitatively assess the influence of the mantle dynamics on the surface tectonics. In this study, we use a highly resolved tomography model to model the convection occurring in the mantle beneath the Azores region. The convection pattern points out two distinct upwelling, thus proving that the volcanism emplacement is created by a buoyant mantle upwelling. The modeled dynamic topography recovers well the characteristics of the depth anomaly associated with the Azores plateau, except for the south-eastern most part, thus proving that most of the depth anomaly associated with the Azores plateau is created by the present-day mantle dynamics. The stresses induced by the mantle convection can account for the rifting regime observed over the Azores plateau and the Terceira Rift, and its consequences in terms of surface morphology and seismicity.

1. Introduction

The Azores plateau, a region of elevated topography (Fig. 1), encompasses the boundary zone where three major tectonic plates Eurasia, Nubia and North America meet to form the Azores Triple Junction. The plateau is asymmetric relative to the Mid-Atlantic Ridge (MAR). The eastern side of the plateau, the zone our study focuses on, has an approximate triangular shape. It is delimited by two major tectonic discontinuities: the Mid-Atlantic Ridge (MAR) to the west, and the Terceira Rift (TR) to the north-east. The East Azores fracture Zone constitutes its southern boundary. It contains numerous seamounts and seven of the Azores islands: Faial, Pico, S. Jorge, Graciosa and Terceira for the central group, S. Miguel and S. Maria in the eastern group.

Several hypotheses were proposed for the plateau formation. Some invoke only a tectonic origin. The enhanced upwelling and magmatism would then be driven by plate-boundary forces. Luis et al. (1994) show that there has been a northward jump of the Azores triple junction, during which the Azores region would have been transferred from the Nubian plate to the Eurasian plate. Luis et al. (1994) think that this mechanism is the result of small changes in the relative motion between the three megaplates. They also considered that this mechanism would be responsible for the "disturbed" topography. For Luis and Neves (2006), the elevation of the Azores plateau is mainly due to thickened crust, whereas the presence of buoyant material at the base of the crust is also required to partially account for the uplift of the plateau.

For others, the presence of the Azores plume is necessary to explain the observations. For example, Yang et al. (2006) agree with the jump of the Azores triple junction but argue that the latter is triggered by the relative motion between the lithospheric plate and an underlying mantle plume. Vogt and Jung (2004) also mention the role of the plume in the plateau formation. This later would have been formed by successive NE jumps of the oblique spreading axis, where the present TR is the latest stage. For Gente et al. (2003), the plateau results from the interaction between the MAR and the plume, followed by the progressive southward rifting of the plateau after 7 Ma. According to different authors the beginning of the enhanced volcanism occurred around 10 Ma, and ended between 3 and 7 Ma depending upon latitude (Cannat et al., 1999; Escartín et al., 2001; Gente et al., 2003; Maia et al.,

* Corresponding author.
E-mail address: adam@uevora.pt (C. Adam).
[1] Now at RMS, Inc, Newark, CA, USA.

0012-821X/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.epsl.2012.11.014

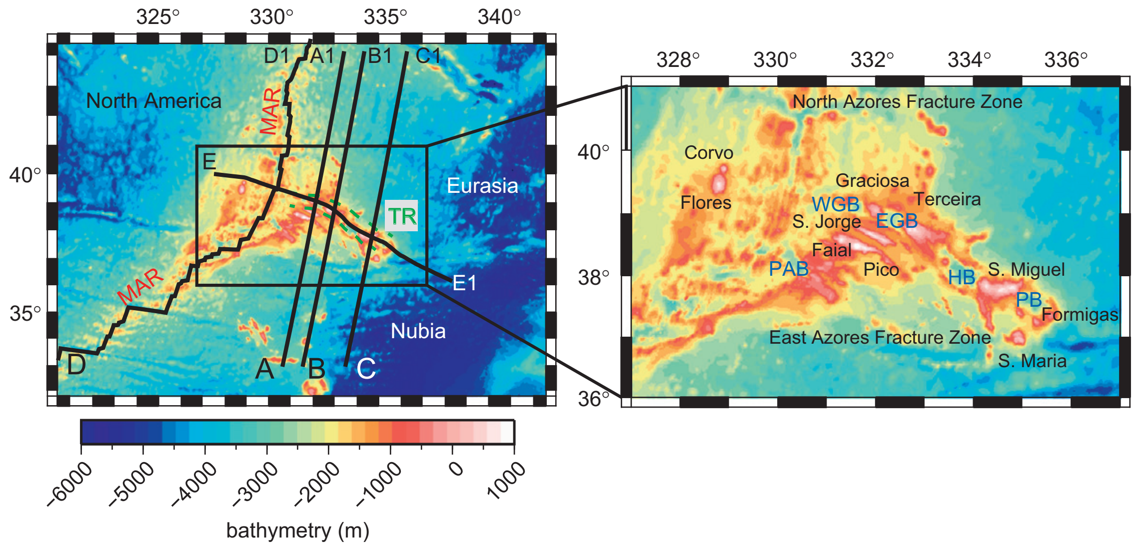

Fig. 1. Bathymetry of the Azores region. (a) global view (b) focus on the Azores islands. The volcanism is still active on most of the islands. MAR: Mid-Atlantic Ridge; TR: Terceira Rift; WGB: Western Graciosa Basin; EGB: Eastern Graciosa Basin; HB: Hirondelle Basin; PB: Povoação Basin; PAB: Princess Alice Bank.

2001). However, active volcanism is still reported near shore and on several of the Azores islands (Machado, 1959; Self, 1976; Moore, 1990; Cole et al., 1995, 2001; Gaspar et al., 2003).

Since the paroxysmal phase of plateau build-up by enhanced volcanism, rifting would have been the major process in controlling the volcanism emplacement and the shaping of the plateau. Indeed, through a careful analysis of the bathymetry, Lourenço et al. (1998) show that the tectonics of the Azores region is controlled by two sets of conjugates faults with strikes N120° and N150°, which would constrain the volcanism emplacement and thus the morphology of the bathymetric features. Two kinds of volcanic features coexist in the study area. Despite the presence of roughly circular to elliptical islands such as Graciosa and Terceira, the predominant features are volcanic ridges elongated along the N120° and N150° directions. Lourenço et al. 1998 hypothesize that such features could be explained if one considers the Azores region as a transfer zone, broadly in a tectonic transtensional regime, which accommodates the motion between the MAR and the dextral Gloria fault.

Several studies have focused on the seismicity pattern in the area. The seismicity is concentrated along the MAR and the TR. The seismic pattern along the TR is quite complex. Previous research (Miranda et al., submitted for publication) reported extension perpendicular to the N120°E associated with graben subsidence and extensive volcanism, particularly west of Terceira Island. Borges et al. (2007) define two zones of distinct seismicity and stress direction, showing the existence of two different domains east and west of Terceira Island, broadly corresponding to the above strikes. None of those studies addressed the physical phenomena constraining this partitioning.

The Terceira Rift is supposed to constitute the northeast boundary of the eastern Azores plateau. It is a succession of deep basins (reaching more than 3000 m deep) and volcanic highs encompassing from the west to the east, the west Graciosa basin, the Graciosa island, the east Graciosa basin, the Terceira island, the north Hirondelle basin, D. João de Castro Bank, south Hirondelle basin, S. Miguel island, the Povoação Basin, and the Formigas islets. The wavelength separating these geological features is 60–100 km. Several hypothesis have been proposed for its interpretation: as a secondary spreading ridge in a RRR configuration developed in the sequence of a major change in plate kinematics (Krause and Watkins, 1970), as the result of oblique extension (McKenzie, 1972), or even as a leaky transform (Madeira and Ribeiro, 1990). Vogt and Jung (2004) interpreted it as one of the results of a specific hyperslow spreading regime. The TR trends WNW–ESE, a direction that also characterizes the main geologic features to the south namely the S. Jorge Island, Faial-Pico ridge and Princess Alice bank (Fig. 1).

The Azores region has been considered a classic example of a hotspot-ridge interaction. Several geophysical (Schilling, 1985; Cannat et al., 1999; Gente et al., 2003; Yang et al., 2006) and geochemical (Morgan, 1971; Schilling, 1985; White et al., 1979; Bougault and Treuil, 1980; Bougault and Cande, 1985; Dosso et al., 1999; Moreira et al., 1999; Madureira et al., 2005, 2011) studies point out the influence of a mantle plume. The plume is imaged by several tomography models (Silveira and Stutzmann, 2002; Silveira et al., 2006; Montelli et al., 2004; Yang et al., 2006). The characteristics of the plume do nevertheless vary according to the models, namely in what concerns the wavelength and amplitude of the velocity anomalies, as well as the depth of the root: is the 'Azores plume' a shallow feature of the upper mantle or does it extend to the whole mantle? However, such models of the mantle structure have not yet been used to quantitatively assess the influence of the mantle on the surface observations. The importance of this evaluation is also strengthened by the absence of correlation between the plate boundary geometry and the patterns of magmatism or the crust thickness observed over the Azores domain (Georgen and Sankar, 2010). That will be our goal in the present study. We will use the P-wave velocity model designed by Yang et al. (2006). It is derived from teleseismic body waves recorded by six broadband seismic stations on the Azores Islands and its fine resolution is able to resolve the narrow mantle plume. We will convert the seismic velocity anomalies into density anomalies and model the convection driven by these density anomalies. The approach used to model the mantle convection and the resulting stresses will be described in Section 2. We will compare the convection pattern with the volcanism emplacement in order to assess a possible link between them. We will then compare the dynamic topography to the depth anomaly characterized through a method especially adapted to the bathymetry filtering. The stresses imposed at the base of the lithosphere by the underlying mantle convection will be compared with the morphology of the seafloor and the islands, and with the seismicity pattern. We will also use the stress tensor computed from our convection model to predict the tectonic regimes. Finally, we will discuss the pertinence of our local study, and the new insights our results bring on the understanding of the dynamics and tectonics of the Azores region.