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Distributed deformation close to the Azores Triple "Point"

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ABSTRACT

Terceira Rift and the northern and southern branches of the Mid-Atlantic Ridge (MAR) form a triple junction close to 39°N known as the Azores Triple Junction. New swath bathymetric data are used to investigate the surface expression of faulting close to the triple junction, by the systematic mapping of MAR-generated abyssal hills. It is shown that close to the geometrical intersection between the three spreading axes there exists no single transform fault connecting Terceira Rift to the MAR but a distributed tectonic deformation area characterized by mesoscale brittle deformation close to the surface, covering approximately 90 km by 100 km, and almost no volcanism, which links Terceira Rift to the MAR, accommodating the relative displacement of the three plates close to the geometrically triple point. Magnetic chrons are used to compute the spatial variation of spreading velocity at the Mid-Atlantic Ridge and confirm the above interpretation: they show a progressive increase of spreading velocity along a single MAR segment, between pure "Nubian" at 38°30′N and pure "Eurasian" at 39°25′N, without the development of a transform fault that would integrate the Eurasia–Nubia plate boundary. The comparison of similar triple junctions where a slower axis joins two faster ridges, shows that the slower arm does not reach the "triple point" and that there is always a finite triple junction area, highly tectonized, in which size is dependent on the angle between the two faster arms and, consequently, on the relative spreading velocity of the slower arm.

1. Introduction

The Azores triple junction is formed by a northern branch of the Mid-Atlantic Ridge (MAR), with a full spreading rate of 23 mm/year, a southern MAR branch with a full spreading rate of 19 mm/year and a much slower WNW-ESE branch along Terceira Rift, with a spreading rate of ~5 mm/year. The three branches do not meet at a single point: the western Graciosa basin (see Fig. 1) which is the westernmost unit of the Terceira Rift is located ~100 km away from the MAR axial valley. Searle (1980) hypothesized that the fracture zone located close to 39°30′N could be interpreted as a dextral strike slip fault connecting Terceira Rift with the MAR, representing the northern boundary of the Nubian plate. Luis et al. (1994) challenged the conclusion, claiming that the spreading velocity north of 38°N given by the younger (C2a, C2) chrons was close to "Eurasian" and proposed that the northern limit of the Nubian plate is located close to 38°N at the latitude of Faial Island (Fig. 1).

The tectonic studies of the Azores triple junction have always been limited by the quality of bathymetric data. The first swath survey of the MAR (Needham and Sigma Scientific Team, 1991) did not include the Azores plateau. Subsequent compilations (Lourenço et al., 1998; Gente et al., 2003) still showed large limitations close to the Azores. Only in 2006 and 2007, in the framework of MARCHE missions, that high resolution bathymetric surveys were made to search for the morphological signature of the triple junction. The surveys were performed with the French vessel Le Suroît, using the EM300 swath bathymetry system that performs optimally around 1500 m water depths. Given that the water depths range between 1000 and 2000 m it was possible to compute a high resolution gridded dataset with a horizontal spacing of 50 m. It was merged afterwards into a regional digital bathymetric with 250 m resolution covering the Azores plateau. The merged dataset is used through this study (Luis et al., 2007, see Fig. 1) but the identification and quantification of fault parameters are made using the 50 m grid.

While bathymetric data are fundamental to map the surface expression of the tectonic and volcanic processes, magnetic data provide an objective way to study their spatial and temporal variations. The Azores plateau was covered by a high resolution aeromagnetic survey in the late eighties, but still suffering from the low accuracy of pre-GPS positioning systems (Miranda et al., 1991). The large number of research cruises made afterwards, particularly those in the scope of the United Nations Convention on the Law of the Sea, provided a set of very well located marine magnetic data. The combination of high quality bathymetric and magnetic data provides the opportunity to revisit the tectonics of the triple junction, at the sub-kilometer scale, to investigate the area

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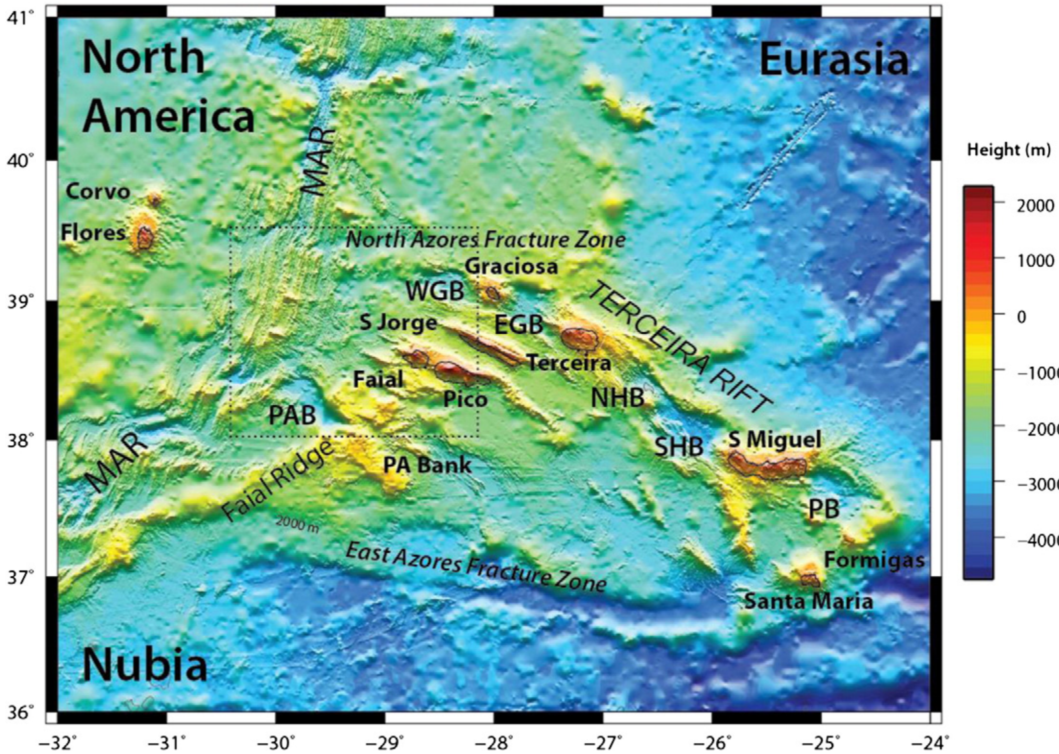

Fig. 1. Regional bathymetric compilation of the Azores. MAR: Mid-Atlantic Ridge; WGB: West Graciosa Basin, EGB: East Graciosa Basin; NHB: North Hirondelle Basin; SHB: South Hirondelle Basin; PB: Povoação Basin; PAB: Princess Alice Basin; PA Bank: Princess Alice Bank; GF: Gloria Fault. The dashed rectangle corresponds to the area of Fig. 2.

where the two arms of the MAR and Terceira Rift are supposed to meet and to test the different proposals that have been put forward to interpret the triple junction.

2. Morpho-structural interpretation

Fig. 2 shows the 250 m bathymetric compilation of the area. We systematically identified the main morpho-structural trends, associated with MAR-generated ridges, abyssal hill relief or extensional processes related with the Azores. In slow spreading ridges normal faulting associated with abyssal hills accounts for 10–20% of plate separation (Searle and Escartin, 2004) and their identification outside the ridge active tectonic area can be used in a way similar to isochrons, in particular they inform about the directions of the strain field associated with their development, and the existence of crustal rotations. Abyssal hill faults were identified from the original 50 m grids, considering that the steepest flank corresponded to the ridge ward direction.

Morpho-structural trends are classified into three main categories. The first one (N1) comprises MAR abyssal hill fabric. It has developed orthogonally to the spreading direction, with a trend of N10°E–N20°E, spaced 1–3 km and with hill lengths of tenths of kilometers along the axial direction. N1 is the dominant fabric west of 29°W but it can be found elsewhere in the plateau, even if dissected by N2 or N3 faulting, fault interplay between N2 and N3 sometimes defines v-shaped limits, pointing eastwards, of tectonically depressed blocks (cf. for examples in Fig. 3B, C and D). Away from the Mid-Atlantic Ridge (MAR) N1 topography keeps the same strike as the MAR valley south of 38°55′N (N11°E), but rotates up to N18°E north of this latitude. This change in strike is not present on the American plate and one must conclude that it is the result of the Azores related deformation. In all cases, it can be concluded that the underlying lithosphere was generated at the MAR and no important re-surfacing processes took place in the meantime, with the exception of those associated with the evolution of the Terceira Rift.

N2 structures with N110°E–N120°E fault direction can be found on the southern and northern flanks of the Western Graciosa Basin (WGB), and correspond to the strike of the islands located south of Terceira Rift (São Jorge, Pico and Faial). A similar strike is also found on the grabens that have developed WNW of São Jorge (see Fig. 3A) and the grabens (and volcanic ridges) that cut N1 abyssal hills close to the MAR at 38°50′N to the east of the axis. The N2 trend matches the strike of the elongated volcanic ridges that develop of the larger Azorean volcanoes (such as western Faial ridge and the eastern ridge of Pico island). Volcanic ridges are mostly associated with Pico-Faial, the largest volcanic system, and show a curvilinear shape, sub-radial to the volcanic systems in its vicinity, and are progressively aligned with the N2 direction closer to the MAR.

N3 trends can be found away from the volcanic highs associated with the small extensional basins (~N140°E) that develop NW of the West Graciosa Basin and the long faults that develop between the islands and the MAR (~N160°E). They border the younger basins that developed in the northern limb of the plateau, or the eastern and western flanks of the West Graciosa Basin. N3 trends also match the strike of the NNW-SSE mesoscale faults (see Fig. 3C and 3D) with characteristic lengths close to 30 km, and vertical offsets of hundreds of meters. There is a conjugate set of N80° faults that define with the precedent N3 faults a number of southeastward tilted lithospheric blocks, devoid of volcanic activity, except at its boundaries, with some dextral strike slip (~1 km in the case shown in Fig. 3C). These blocks are the site of the rotated N1 abyssal hills described above.

The new EM300 data provide adequate spatial and vertical resolutions to allow a quantitative analysis of the brittle strain represented by the fault scarps associated with the extension of Terceira Rift and neighboring triple junction area. We followed the approach by Escartin et al. (1999) developed for the estimation of brittle strain from fault heaves on a segment of the Mid-Atlantic Ridge, as it can also be used to study distributed tectonic strain. Apparent fault heaves were compiled from eight profiles crossing Terceira Rift along the Eurasian–Nubian spreading direction, nearly perpendicular to N3 faults