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Effects of ridge geometry on mantle dynamics in an oceanic triple junction region: Implications for the Azores Plateau

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ABSTRACT

Plate boundary geometry can affect the nature of magmatism along a mid-ocean ridge. The Azores Plateau is located in a complex geological setting that includes a triple junction (TJ), an oblique and recently-formed ultra-slow-spreading ridge, a zone of diffuse seafloor deformation, a major fracture zone, and a postulated hotspot. The precise character of the hotspot is somewhat debated, as some lines of evidence indicate it may not be a classic deep-seated plume. However, seismic and gravity data suggest plateau crustal thicknesses of ~8 km or more, implying some mechanism for excess melting. To assess the role of ridge geometry in creating the Azores Plateau, this study uses a finite element numerical model to isolate the effects of selected aspects of plate boundary configuration on mantle flow and melt production in a TJ kinematically similar to the Azores TJ. The model focuses on the slowest-spreading ridge in the TJ, analogous to the Terceira Rift. The effect of the varying ridge obliquity observed along the Terceira Rift is also assessed using an independent 1-D melting model. In general, relatively little melt production is predicted along the Terceira Rift analogue, except for regions closest to the TJ where the proximity of a faster-spreading ridge increases temperatures within the melting zone. In the 1-D melting model with mantle temperatures of 1350 °C, melt thicknesses of ~2 km are calculated for the least oblique segments, while more oblique segments produce little to no melt. The presence of a long discontinuity (simulating the Gloria FZ) has little effect on mantle dynamics for axial distances <350 km from the TJ, although crustal production is predicted to diminish to zero within ~150 km of the discontinuity. When several ridge geometrical effects are combined (i.e., a TJ, time-limited spreading, a ridge discontinuity, and depressed spreading rates within ~100 km of the TJ point), ~2.5 km of variability in melt thickness can be produced. Overall, while these numerical experiments suggest plate boundary geometry may play a role in modifying Azores crustal accretion, additional factors such as a mantle heterogeneity are likely required to explain the full scale of the observed magmatism.

1. Introduction

The nature of magmatism at divergent plate boundaries is influenced by a number of factors, including spreading rate, mantle fertility, the presence of mantle temperature anomalies, and ridge axis geometry. This paper focuses on the latter, investigating how several aspects of plate boundary geometry may affect mantle flow and temperature patterns. The Azores Triple Junction (ATJ) has a particularly complex geological setting (Fig. 1). In addition to marking the location where three divergent plate boundaries meet, the ATJ is characterized by ultra-slow and oblique spreading along the Terceira Rift (TER), a zone of diffuse deformation near the TJ point, and relatively recent initiation of divergence along the TER. The Azores Plateau may also be influenced by a mantle thermal plume or compositional heterogeneity that results in higher than average volumes of magmatism.

The purpose of this study is to isolate selected aspects of plate boundary geometry in the TER, without invoking the addition of a plume, to determine whether these geometrical effects are likely to play a significant role in creating geophysical anomalies observed along the ridge. Earlier works exploring the effects of TJ geometry on mantle flow and temperature (e.g., Georgen and Lin, 2002; Georgen, 2008) have suggested that there may be excess crustal production along the slowest-spreading boundary in a ridge–ridge–ridge (RRR) TJ configuration. This study builds on the numerical modeling of Georgen (2008) by adding specific plate boundary geometry complexities to the slowest-spreading ridge (Fig. 2). To assess the importance of each geometrical factor, model predictions are compared to observationally-derived data such as seafloor depths. The results of this investigation may be used to infer the importance of a mantle heterogeneity in producing excess volcanism in the Azores region.

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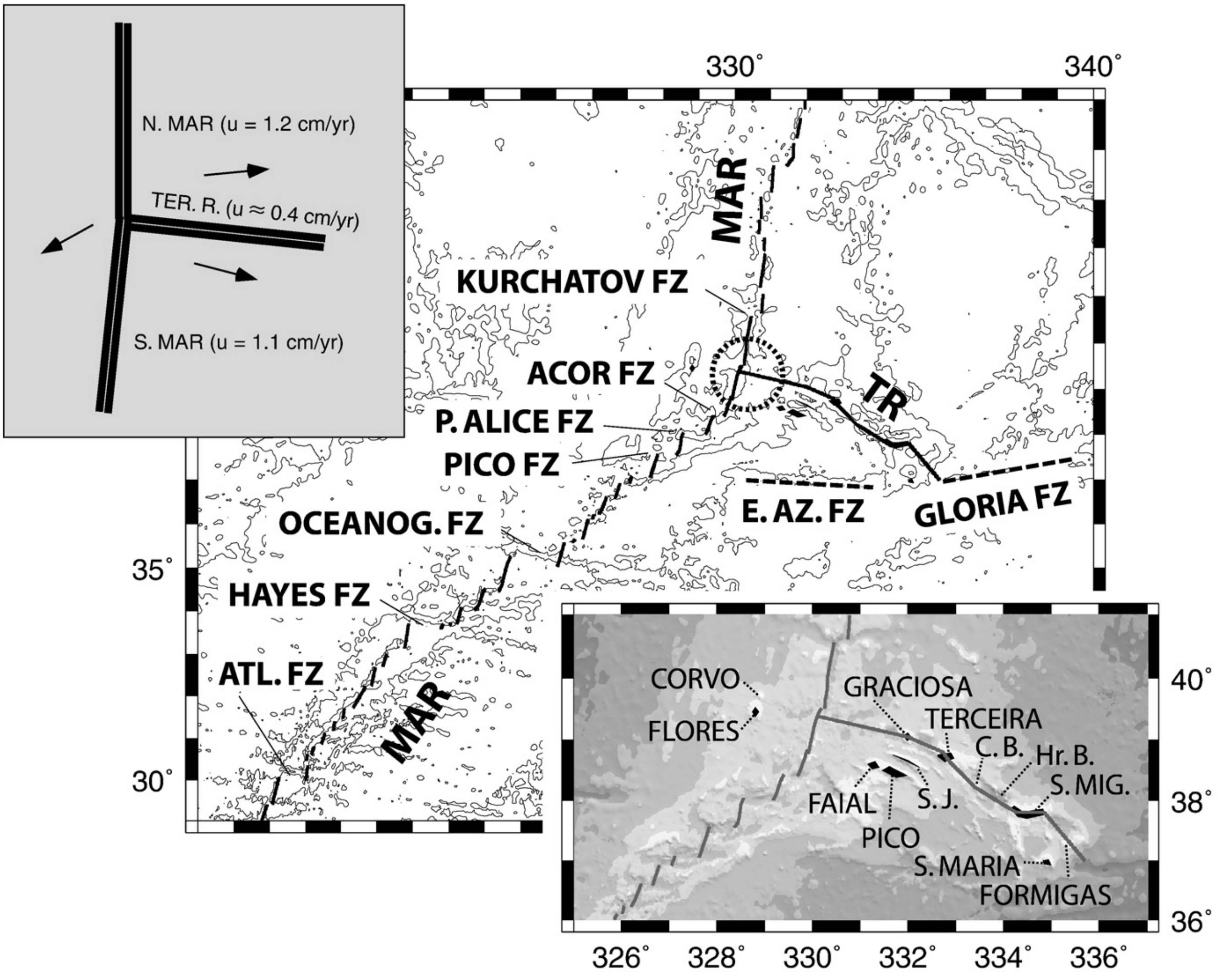

Fig. 1. (Main) Location of the Azores Triple Junction, indicated with a dashed circle. MAR = Mid-Atlantic Ridge, TER = Terceira Rift, and E. Az. FZ = East Azores FZ. (Inset, left) Schematic representation of the Azores Triple Junction, with ridges simplified into linear plate boundaries aligned along their regionally-averaged strike. Arrows show the relative motion of the North American, Eurasian, and African plates with respect to a fixed triple junction point, and the half-spreading rate for each ridge (u) is indicated. (Inset, right) Locations of prominent geographical features around the Azores Triple Junction. S.J. = Sao Jorge Island, S. Mig. = Sao Miguel Island, C.B. = Castro Bank, and Hr. B. = Hirondelle Basin.

2. Background

2.1. Location and evolution of the ATJ

The ATJ (Fig. 1) marks the intersection of the North American, Eurasian, and African plates. Two branches of the TJ are the slow-spreading MAR (half-rates of ~1.1 and 1.2 cm/yr) and the third is the ultra-slow spreading TER (half-rate ~0.3–0.4 cm/yr). Kinematic arguments suggest that the ATJ has existed since ~35–45 Ma (Krause and Watkins, 1970; Searle, 1980; Luis et al., 1994). Since this time the TJ jumped from the intersection of the MAR and the East Azores FZ to its present location between the Acor and Kurchatov FZs, and also evolved from ridge–fault–fault (RFF) to RRR configuration (Searle, 1980; Yang et al., 2006).

The nature of lithospheric extension is poorly defined in the region lying between Graciosa Island and the ATJ. High-resolution studies of seafloor deformation in the immediate vicinity of several TJs, such as the Rodrigues TJ (Mitchell, 1991; Mendel et al., 2000), the Bouvet TJ (Ligi et al., 1997), and the ATJ (Searle, 1980), suggest that the lack of a well-defined axis along one or more ridges may be characteristic of RRR TJs, and may be related to TJ migration over the asthenosphere. Most commonly, the slowest-spreading ridge terminates at a distance of ~30–100 km from the TJ point. Near the TJ, spreading is distributed over a broad region rather than organized along a linear axis.

2.2. Axial geometry of the TER and MAR

To the south of the ATJ, segmentation of the MAR is characterized by well-developed transforms that are oriented roughly orthogonal to spreading segments (Fig. 1). To the north of the ATJ, the MAR first-order segmentation pattern is less developed; the only prominent discontinuity is the short-offset Kurchatov FZ. The geometry of the TER differs considerably from that of the MAR. At ~550 km in length, the TER consists of a series of segments aligned with varying obliquities to the regional spreading direction (Fig. 1). Outside of a structure resembling a leaky transform in the eastern portion of Sao Miguel Island (Vogt and Jung, 2004), the ridge lacks distinct discontinuities. Axial profiles of seafloor depth (e.g., Vogt and Jung, 2004) reveal an alternating series of highs and lows, defined by the locations of islands and basins. The Gloria FZ marks the eastern termination of the TER.

Ultra-slow spreading makes identification of magnetic anomalies produced by the TER difficult. Although earlier studies suggested that divergence began <5 Ma (Luis et al., 1998; Vogt and Jung, 2004), more recent work finds that spreading has occurred over the last ~25 Ma