Evolution of the East Pacific Rise at 16°–19° S Since 5 Ma: Bisection of Overlapping Spreading Centers by New, Rapidly Propagating Ridge Segments

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Abstract. Nearly complete side-scan, bathymetry and magnetic coverage documents the evolution of the geometry of the East Pacific Rise (EPR) between 16° and 19° S since 5 Ma. Lineaments visible in SeaMARC II, H-MR1 and Sea Beam 2000 side-scan data correspond dominantly to normal fault scarps which have developed in the axial region perpendicular to the least compressive stress. Except near overlapping spreading centers (OSCs), the lineament orientations are taken to represent the perpendicular to the instantaneous Pacific-Nazca spreading direction. Their dominant orientation in the axial region is 012°, in good agreement with the prediction of the current model of relative plate motion (DeMets et al., 1994). However, the variations of the lineament azimuths with age show that there has been a small (3°–5°) clockwise change in the Nazca-Pacific relative motion since 5 Ma. There is also a distinct population of lineaments which strike counterclockwise to the ambient orientation. These discordant lineaments form somewhat coherent patterns on the seafloor and represent the past migration tracks of several left-stepping OSCs. Concurrent analysis of these discordant zones and the magnetic anomalies, reveals that up to 1 Ma, the EPR was offset by a few large, left-stepping OSCs. These OSCs were bisection into smaller OSCs by new spreading segments forming within their overlap basins. The smaller OSCs proceeded to migrate rapidly and were further bisectioned by newly spawned ridge segments until the present staircase of small, left-stepping OSCs was achieved. By transferring lithosphere from one plate to the other, these migration events account remarkably well for the variable spreading asymmetry in the area. Between 16° and 19° S, the present EPR is magmatically very "robust", as evidenced by its inflated morphology, the profuse volcanic and hydrothermal activity observed from submersibles and towed cameras, the geochemistry of axial basalts, and seismic and gravity data. Since 1 Ma, all the OSCs have migrated away from the shallowest, most robust section of the ridge between 17° and 17°30’ S, which was previously offset by a large OSC. We propose that the switch from a presumed starved magmatic regime typically associated with large OSCs to the presently robust magmatic regime occurred when the EPR overrode a melt anomaly during its westward migration relative to the asthenosphere. The resulting increase in melt supply at 17°–17°30’ S has fed the migration of axial discontinuities for this section of the southern EPR since 1 Ma.

Introduction

At intermediate to fast spreading rates, lateral offsets of 1 to 30 km in mid-ocean ridge axes are accommodated by overlapping spreading centers (OSCs) rather than by the classic ridge-transform-ridge geometry (e.g. Macdonald and Fox, 1983; Lonsdale, 1983). These OSCs are unstable features of the ridge axis: their geometry evolves continuously, and in many cases they migrate along-axis at rates comparable to the spreading rates (Macdonald et al., 1984, 1987, 1988a and 1992; Lonsdale, 1985 and 1989a). Their geometry and behavior has been successfully reproduced in laboratory and numerical experiments involving two cracks propagating toward each other (Pollard and Aydin, 1984; Sempéré and Macdonald, 1986).

Several mechanisms have been proposed to explain the migration of axial discontinuities or the propagation of ridges. Based on fracture mechanics, Phipps Morgan and Parmentier (1985) and Phipps Morgan and Sandwell (1994) proposed that the shallower of the two ridge segments across a nontransform axial discontinuity will tend to propagate and prevail over the deeper one, as gravity spreading stresses concentrate near its tip. Based on similar fracture mechanics considerations, Macdonald et al. (1991) argued that the relative length of the two ridge segments is a more important factor for propagation, and that the longer ridge segment will tend to propagate. Lonsdale (1994) suggested that ridge propagation generally occurs into the plate which moves the fastest over the asthenosphere, because it would be the most stressed. Although ridge propagation provides a mechanism for ridge segments to orient perpendicular to a new spreading direction (Hey et al., 1980; Wilson et al., 1984), changes in spreading direction are not likely
causes of ridge propagation (Phipps Morgan and Parmentier, 1985). Finally, differences in the amounts of melt available to adjacent ridge segments at any given time may also explain ridge propagation.

In this study, side-scan sonar and magnetic data collected during legs 2 and 3 of the Gloria survey (Scheirer et al., 1993) are used to document the detailed evolution of OSCs for a nearly 400 km stretch of the East Pacific Rise since 5 Ma. The different models for discontinuity migration are evaluated at ultrafast spreading rates with this extensive data set.

**Epr, 16°–19° S: A Robust Magmatic Budget**

The 800-km-long section of the ultrafast spreading EPR which stretches from the Garrett transform fault to the 20°40' S OSC appears remarkably linear, with an overall strike of 009° (Figure 1). On a finer scale, the plate boundary is offset en echelon by a series of small, left-stepping discontinuities (Lonsdale, 1989b; Sinton et al., 1991). Each of these discontinuities ranges in offset from 1 to 7 km, and the intervening ridge segments consistently strike within a few degrees of 013°, normal to the spreading direction predicted by the NUVEL-1A model of current plate motions (DeMets et al., 1994).

The along-axis variations of several physical parameters in this area suggest that the melt supply to the ridge is quite robust between 16° and 19° S, reaching a maximum between 17° and 17°30' S (Figure 2). Although the axial depth is remarkably uniform from 14° to 17°30' S, it is shallower by a few tens of meters between 17° and 17°30' S, and at around 18°30' S. The cross-sectional area of the axial high describes a broad maximum between 16° and 19° S, peaking near 17°–17°30' S (Scheirer and Macdonald, 1993). The mantle Bouguer anomaly, which is the gravity anomaly corrected for the effect of bathymetry, of a constant crustal thickness and density, is at a minimum between 16° and 19° S. This residual gravity low is interpreted as due in part to the accretion of a thicker crust (0.3–0.7 km thicker than near the 20°40' S OSC), and in part to the presence of a lower density mantle beneath this section of the ridge (Cormier et al., 1995).

Both interpretations are consistent with the existence of an enhanced melt supply at the site of the residual gravity low. Also, the MgO content of axial basalts is higher between 16° and 19° S, indicating that magma supply was hotter than typical (Sinton et al., 1991). Seismic data collected along axis from the Garrett transform fault to the 20°40' S OSC show that the reflector interpreted as the top of a thin axial magma chamber is generally shallower than for the northern EPR (1.3 km versus 1.6 km below seafloor) (Detrick et al., 1993). At 17°26' S, it rises to within 1 km from the seafloor, a feature that Mutter et al. (1995) interpret as diagnostic of current eruption. There are additional lines of evidence for an enhanced melt supply between 16° and 19° S, not displayed in Figure 2. Direct observations from submersible and towed camera show that the areas around 17°–17°30' S and 18°35' S are volcanically very recently active; the volcanism is particularly profuse at 17°–17°30' S (Renard et al., 1985; Auzende et al., 1994). These surveys also document ubiquitous hydrothermal activity from 17° to 19° S, although the type of hydrothermal discharge is variable along axis (Renard et al., 1985; Bäcker et al., 1985; Sinton et al., 1985).