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Probing the history of the Mathematician paleoplate using surface waves

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Abstract

This paper investigates the shear velocity structure under the northern East Pacific Rise at the latitude range of 9–18°N, using intermediate-period Rayleigh and Love waves. The selected ocean-bottom seismic records provide source–receiver paths that ideally constrain the lithospheric mantle structure beneath the southern Rivera plate and the Mathematician paleoplate. The Rayleigh wave data infer a relatively thin (~30 km) lithosphere under the eastern side of the present-day East Pacific Rise. The associated shear velocities are consistent with existing models of oceanic mantle beneath this region, and the estimated plate age of 2–3 million years agrees with results from magnetic dating. The west of the rise axis is characterized by a thicker and faster lithosphere than the eastern flank, and such structural differences suggest the presence of a relatively old Mathematician paleoplate. The discontinuous change in mantle structure across the East Pacific Rise spreading center are observed in both isotropic and anisotropic velocities. The young oceanic lithosphere east of the rise axis shows strong polarization anisotropy, where the dominant orientation of crystallographic axes roughly parallels the spreading direction. However, the western flank of the rise axis is approximately isotropic, and the lack of anisotropy suggests complex deformation mechanisms associated with earlier episodes of ridge segmentation, propagation and dual-spreading on and around the Mathematician paleoplate.

Keywords: Mathematician paleoplate; East Pacific Rise; Love wave; Rayleigh wave; Shear velocity; Seismic anisotropy; Lithosphere; Low velocity zone

1. Introduction

Transfer of active spreading centers from one location to another generally occurs as an aftermath of plate boundary adjustment through ridge jumps and reorientation of ridge propagation directions. Prior to the eventual abandonment of the old ridge segments, two or more nearly parallel spreading centers could co-exist and, depending on the geometry of the ridge–ridge interaction, trap the lithosphere between them and thereby produce oceanic microplates. Over time, these microplates can potentially evolve into paleoplates long after the cessation of spreading at one or both of the competing ridges. Hence, the combination of "dual spreading" (Mammerickx et al., 1988) and the subsequent abandonment of a key component of the ridge–ridge interaction, due to continuous or discontinuous plate boundary readjustments (e.g., Hey, 1979; Klitgord and Mammerickx, 1982; Lonsdale, 1995), can be effective means to form paleoplates.

The aforementioned plate boundary processes could play a key role in the evolution of the Mathematician paleoplate west of the present-day northern East Pacific

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Rise (from here on, EPR) ridge system. Bounded by the Rivera Fracture zone (north), the West O'Gorman fracture zone (south) and the EPR (east), the Mathematician paleoplate was strongly influenced by the Pacific–Farallon spreading and convergence at the west coast of the Americas (Klitgord and Mammerickx, 1982; Mammerickx et al., 1988; Lonsdale, 1995; DeMets and Traylen, 2000). Through seafloor spreading and subduction, parts or even entire ridge segments on the once-active Mathematician microplate have been created or abandoned (Macdonald et al., 1992). As the consequences of such adjustments, part of ridge undergoes spatially discontinuous jumps over distances from a few kilometers to over a hundred kilometers. Such jumps have been well documented by seafloor topographic, magnetic and side-scan sonar data (Lonsdale, 1985; Searle, 1989; Hey et al., 1989; Macdonald et al., 1992; Lonsdale, 1995), as have their direct imprints on the tectonic evolution of the region. The wide spectrum of seafloor-spreading rates varies from 7 cm/year north of the Clipperton fracture zone to about 13 cm/year near the Galapagos triple junction (e.g., DeMets and Stein, 1990), reflecting the complex tectonic history of dynamics in this region.

While the magnetic, topographic, and active source data place strong constraints on the northern EPR system, magnetic data suffer from the lack of spatial resolution and topographic/side-scan sonar data are limited to structures at relatively shallow depths. Broadband, passive seismic experiments using ocean-bottom seismometers (OBS) offer a viable alternative, with high lateral and depth resolutions on structures at both crust and mantle depths. In 1995, a team led by S. Webb conducted a small-scale OBS experiment called “Temporal Observation of Eruption Seismicity” (TOES), aiming at improving the overall understanding of the nature of the mantle beneath the northeastern Pacific. During this 6-month deployment, six OBS were positioned south of Clipperton Fracture Zone ($\sim 9°50'$N) along the EPR and recorded several $Mw > 5$ regional earthquakes that span the eastern and southeastern Pacific oceans. The diverse spatial sampling led to a recent study of temperature and melt content across the different ridge segments (Gu et al., 2005) that identified a high-velocity lithosphere (or lid) west of the present-day EPR axial rifts. The path-averaged Rayleigh-wave phase velocities provided preliminary constraints on the presence and effect of the Mathematician paleoplate.

This study furthers the Gu et al. (2005) analysis by providing (1) improved Rayleigh wave models, (2) qualitative error estimates, and (3) Love wave models that reveal the extent of anisotropy. The analysis in the subsequent sections highlights the substantial difference between the eastern and the western flanks of the present-day northern EPR. The Rayleigh and Love wave velocities both support a relatively normal ridge mantle beneath the eastern flank of the EPR and an older, entrapped lithosphere beneath the western flank of the ridge, as one would expect from a paleoplate. The lack of Love–Rayleigh anisotropy west of the EPR also suggests complexities in the tectonic history of the Mathematician paleoplate region.

2. Data and methods

This study focuses on the Rayleigh and Love waves generated by two earthquakes: (1) a Rivera Fracture Zone event with a strike-slip type focal mechanism and a source–receiver path that samples the Pacific side of the ridge axis, and (2) a subduction zone event near Guerrero, Mexico where the associated surface waves traverse the Cocos Plate (Fig. 1). For simplicity I will refer to them as event 1 (west of EPR) and event 2 (east of EPR) hereafter. The two event–station pairs are ideal for a direct comparison as they have nearly identical path lengths and distances from the axial rift. The seafloor bathymetric map in Fig. 1 (ETOPO5 database, Mueller et al., 1997) highlights the major fracture zones and topographic variations, among which the dormant Mathematician ridge is only visible by a series of juxtaposed, north–south trending topographic lows near 111°W.

Intermediate-period surface waves were analyzed for multiple stations, but a greater weight is assigned to a designated station that exhibits superior signal-to-noise ratios for both earthquakes (see discussions of multi-pathing in Section 3). The bulk of the surface wave energy from these two moderate-sized earthquakes is concentrated between 0.02 and 0.1 Hz, though appreciable amplitudes can be identified at most frequencies above 0.01 Hz. Fig. 2 shows a series of filtered vertical-component records with the corresponding corner frequencies specified next to each seismogram. The primary frequency range examined in this study is [0.03, 0.07 Hz], from which the final waveform is effectively a superposition of the filtered surface-wave wavelets that are sensitive to the upper 15–60 km (shaded region, Fig. 2).

The waveform modeling approach is similar to that used by Gu et al. (2005), which depends both on earthquake source mechanisms and on the elastic properties of the crust and mantle. I use Harvard CMT solutions (Dziewonski et al., 1981), obtained from global records of surface and body waves, to account for excitation at the source; solutions for both events are consistent with the expected fault orientations and plate motions. Earthquake depths and scalar moments were pre-determined by body-to-surface wave amplitude ratios (see Gu et al.,