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Vertical structure of time-dependent currents in a mid-ocean ridge axial valley

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Abstract

Velocity measurements with high vertical resolution, and a two-dimensional linear quasianalytic model for subinertial oscillatory flows, are used to analyze the vertical structure of flow in the axial valley at Endeavour Segment, Juan de Fuca Ridge. At a site away from hydrothermal vents, observed semidiurnal flows are independent of depth, rectilinear and parallel to the valley axis, while subinertial flows are intensified and re-aligned along-valley toward the bottom. This behavior is consistent with solutions from the model, which show attenuation of subinertial across-valley flow with depth. This cross-flow attenuation is most pronounced for valleys with widths less than the internal Rossby radius of deformation. Reduction of across-valley flow with depth results in a weakened Coriolis force that cannot fully balance the along-valley pressure-gradient force. The resulting force imbalance yields a directly accelerated bottom-intensified along-valley flow. The importance of this physical process in other submarine valleys depends on their geometry, stratification and latitude. If active, this mechanism provides a dynamic background environment for the axial valley to which hydrothermal venting would add complexity. The strong vertical shears and spiraling flows observed within the axial valley for diurnal tidal and lower-frequency flows have important implications in the transport of hydrothermal vent fluid and the dispersal of larvae of vent organisms by bottom currents.

Keywords: Flow–topography interaction; Current observations; Mid-ocean ridges; Tidal currents; Larval dispersal; Hydrothermal fields; NE Pacific; Juan de Fuca Ridge; Endeavour Segment

1. Introduction

The Juan de Fuca Ridge lies along the divergent boundary between the Pacific and Juan de Fuca plates, approximately 400–500 km off the coasts of Washington and Oregon (Fig. 1). This 400-km long submarine mountain range is oriented 20° east of north (020°N) and is divided into several linear offset segments. The present study focuses on the central portion of the Endeavour Segment, in the northern Juan de Fuca Ridge. Here, the 10-km wide axial ridge rises to a depth of ~2100 m at its crest, above the regional baseline depth of ~2400 m. A 1-km wide median rift-valley with an average depth of 100 m dissects the axial ridge crest lengthwise. Several major hydrothermal vent fields lie along this axial valley, among them the well-studied Main Endeavour Field (MEF), at 47°57′N, 129°6′W

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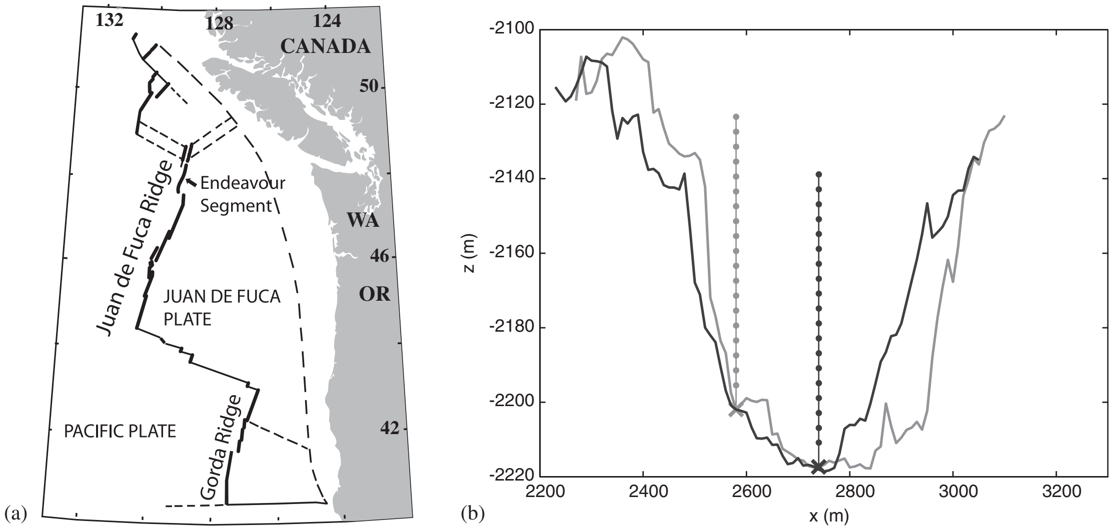

Fig. 1. (a) Location of Endeavour Segment on map. (b) Two cross-sections of the axial valley in the Endeavour Segment from SM2000 bathymetry (Johnson et al., 2002) at the locations of the ADCP deployments (x) and ADCP bin distribution (4 m intervals in dots). The black (gray) symbols and lines correspond to the 2002 record in the central valley (2003 record in Easter Island, Main Endeavour Field).

(Tivey and Delaney, 1986, 1985; Delaney et al., 1992; Johnson and Holmes, 1989).

Ridge axis hydrothermal systems have been the subject of numerous investigations over the last two decades, in part motivated by the presence of a rich and diverse ecosystem thriving under extreme environmental conditions, and the potentially important contribution of hydrothermal fluid to the heat and chemical budgets of the deep ocean. A major component of understanding these unique systems involves characterizing near-bottom currents at mid-ocean ridges and determining the flux of heat and the dispersal of biological/chemical species associated with hydrothermal fluid.

Certain aspects of currents near the Juan de Fuca Ridge have been well-studied by a considerable number of observational efforts mostly focused on flow above the ridge crest (e.g., Thomson et al., 1990; Cannon et al., 1991; Cannon and Pashinski, 1997), specifically, at the level of the neutrally buoyant plume, approximately 200 m above bottom (Baker and Massoth, 1987; Thomson et al., 1992). At the Endeavour Segment, mean flows above the ridge crest are about 5 cm s^{-1} and generally directed southward, although significant variability of the cross-axis component exists (Thomson et al., 2003; Veirs, 2003). Current variability is dominated by semidiurnal tidal, inertial (~16 h), diurnal tidal (which at this latitude is subinertial), and low-frequency (4–8 days) flows. The latter broad spectral band (also known as the "weather band") has been associated with ridge-trapped subinertial waves generated by storm systems (Cannon and Thomson, 1996). Above the ridge, near-inertial and semidiurnal current variations are comparable in magnitude and slightly more intense than subinertial currents (Allen and Thomson, 1993; Thomson et al., 1990). Subinertial motions are trapped to the ridge and experience an amplification of their clockwise rotary component that Allen and Thomson (1993) attribute to the generation of anticyclonic vorticity by vortex squashing over the ridge. Near-inertial currents are also intensified immediately above the ridge (Thomson et al., 1990).

Currents within the axial valley are not as well-documented as flows above the ridge crest. However, the few observations that do exist agree that currents above the ridge are not representative of motions within the valley (Allen and Thomson, 1993; Franks, 1992; Thomson et al., 1990). Mean flows within the valley are typically northward with speeds of 1–5 cm s^{-1} (Thomson et al., 2003; Veirs, 2003). Superimposed on these mean flows are predominantly along-valley oscillatory motions. Semidiurnal tidal flows of several cm s^{-1} dominate, while diurnal and 4-day oscillations are weaker (Thomson et al., 2003). Inertial currents are particularly dampened within the valley, presumably too narrow to support rotary motions (Thomson et al., 1990). These previous conclusions were