Full-waveform Inversion of Seismic Data from the Juan de Fuca Ridge: Constraints on Interactions between Magmatic, Hydrothermal, and Tectonic Processes

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I. Introduction

Mass and energy transfer at mid-ocean ridges occurs through the interplay among magmatic, hydrothermal, and tectonic processes. Our understanding of these processes has been limited by the lack of high-resolution models of the subsurface seismic structure. Here we use full-waveform inversion to obtain the highest resolution three-dimensional images, to date, of the upper crustal seismic structure of an oceanic spreading center, the Endeavour segment of the Juan de Fuca Ridge. Our results provide the first seismic constraints on the structure of the reaction zone that links the magmatic and hydrothermal systems and controls the patterns of heat transfer within a ridge segment.

II. ETOMO experiment


2. Figure 1 | (a) The Endeavour seismic tomography (ETOMO) configuration. (b) Crustal grid of the ETOMO experiment. Dark and light stars), and the approximate location of the AMC (white circles), which recorded 1673 airgun shots (black dots), are used in our analysis.

II. Full-waveform inversion

1. Isotropic and anisotropic P-wave velocity models of the upper oceanic crust, derived via travel-time tomography, are used as the starting models for FWI.

2. FWI uses an acoustic approximation to the wave equation and includes the kinematic effects of P-wave anisotropy; the velocity model is updated iteratively and anisotropy is kept constant.

3. Figure 2 | Vertical sections showing travel-time tomography velocity anomalies for the central portion of the Endeavour Ridge. (a-d) Nithia (Y = 7°), Main Endeavour (Y = 4°). High flow (P = 1.1) and Salty Chang (Y = 5°). Overlaid on the sections are earthquakes recorded between 2003 and 2004 (ref. 7), respectively.

III. Results

1. Figure 3 | (a) Comparison between travel-time tomography (a) and full-waveform inversion (b) results. Sections show the locations of the vent fields (green stars), hypocenters for earthquakes recorded between 2003 and 2004 (ref. 7), and axial magma chamber reflector (solid black line). Heat fluxes for the five vent fields are provided above each vent.

V. Conclusions and interpretations

1. This study represents the first application of acoustic anisotropic 3D FWI to an academic OBS dataset. We show that FWI is capable of recovering velocity anomalies with a resolution 2-4 times better than conventional travel time tomography when using a non-optimal, academic-sized dataset.

2. We provide the first seismic constraints on the structure of the reaction zone that links the magmatic and hydrothermal systems and controls the patterns of heat transfer within a ridge segment.

3. Along-axis variations in velocity above the AMC coincide with concentrations of seismicity and the heat fluxes of the overlying hydrothermal vent fields. We infer these variations represent fluctuations in the hydrologic permeability of the crust and may result from differing extents of cracking induced by earthquakes.

4. Our results can motivate the development of more realistic models of hydrothermal flow that incorporate complex heat sources and heterogeneous permeability with the capability of linking seismicity with fluctuations in permeability.