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The OSCAR experiment: using full-waveform inversion in the analysis of young oceanic crust

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The OSCAR experiment aims to derive an integrated model to better explain the effects of heat loss and alteration by hydrothermal fluids, associated with the cooling of young oceanic crust at an axial ridge. High-resolution seismic imaging of the sediments and basaltic basement can be used to map fluid flow pathways between the oceanic crust and the surrounding ocean. To obtain these high-resolution images, we undertake full-waveform inversion (FWI), an advanced seismic imaging technique capable of resolving velocity heterogeneities at a wide range of length scales, from background trends to fine-scale geological/crustal detail, in a fully data-driven automated manner. This technology is widely used within the petroleum sector due to its potential to obtain high-resolution P-wave velocity models that lead to improvements in migrated seismic images of the subsurface.

Here, we use the P-wave velocity model obtained from travel-time tomography as the starting model in the application of acoustic, time-domain FWI to a multichannel streamer field dataset acquired in the east Pacific along a profile between the Costa Rica spreading centre and the Ocean Drilling Program (ODP) borehole 504B, where the crust is approximately six million years old. FWI iteratively improves the velocity model by minimizing the misfit between the predicted data and the field data. It seeks to find a high-fidelity velocity model that is capable of matching individual seismic waveforms of the original raw field dataset, with an initial focus on matching the low-frequency components of the early arriving energy. Quality assurance methods adopted during the inversion ensure convergence in the direction of the global minimum.

We demonstrate that FWI is able to recover fine-scale, high-resolution velocity heterogeneities within the young oceanic crust along the profile. The highly resolved FWI velocity model is useful in the identification of the layer 2A/2B interface and low-velocity layers that may represent zones of enhanced fluid movement. With FWI we are able to better explain the non-linear changes in velocity as the crust evolves with distance from the spreading centre and image the effects of any alteration by hydrothermal fluids. This model provides valuable insight and new constraints on the thermal processes involved, at spreading centres, setting a new benchmark for integrated multi-physics experiments at similar ocean ridge systems.

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