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Subject title: Three-dimensional nature of magma plumbing system beneath Axial Volcano at the Juan de Fuca Ridge using seismic full waveform inversion

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Presentation of the subject: (Maximum 2 pages)

Oceanic crust, which covers two-thirds of the earth's surface, is formed at ocean spreading centres from melt derived from the mantle as two diverging plates move apart, and the mantle upwells. A part of the melt erupts on the surface along thin dykes, forming the upper crust, whereas the remaining of the melt stays in the crust, cools and crystalises, forming the lower crust. However, in the presence of a hot (spot) thermal anomaly beneath a mid-ocean ridge axis, the melting is significantly enhanced, leading to the storage of large amounts of melts in the crust and the development of volcanic provinces, such as Iceland and Galapagos, but what is the nature of such crustal magma reservoirs remains unfathomed by geophysical techniques. Axial Seamount (also called Axial Volcano) in the Eastern Pacific Ocean is one such volcano and is being formed by the interaction between the intermediate-spreading Juan de Fuca Ridge and the Cobb hotspot. It hosts many hydrothermal vent fields and has erupted three times (1998, 2011 and 2015) in recent years and therefore has been the subject of extensive geological and geophysical studies over the last 30 years (e.g., West et al., 2001; Arnulf et al., 2014; Arnulf et al., 2018; Carbotte et al., 2020), including setting up of a permanent, real time, wired-to-shore, multi-parameter seafloor observatory (Kelley et al., 2014). To better characterise the nature of the underlying magma reservoir, a three-dimensional (3D) multi-channel seismic survey was carried out in 2019 by US colleagues (Arnulf et al., 2019; 2020). Preliminary analyses of these data indicate the presence of at least five magma bodies beneath the volcano, with possibly one being very large (20 km long and 5 km wide). US colleagues have provided all these data to IPG Paris.

In this project, we propose to perform 3D seismic full waveform inversion (Borisov and Singh, 2015) of these data to characterise the nature of the magma bodies underlying Axial Volcano and link these results with hydrothermal vent fields and the eruption history of the volcano. The 3D seismic reflection data were acquired using four 6-km long streamers and two air gun sources (3300 cubic inch) fired in a flip-flop fashion, covering a total area of 40 km by 16 km (Arnulf et al., 2019). Unlike conventional seismic imaging, seismic full waveform inversion provides quantitative information of sub-surface structure (such as P- and S-wave velocity structures) on the scale of tens of metres, allowing to characterise the nature of magma bodies, especially melt versus mush content (Singh et al., 1998), and to pinpoint the location of fluid pathways for hydrothermal circulation etc. (Vaddineni et al., 2023). Thus, seismic full waveform inversion is a tool of choice permitting to subsequently develop a comprehensive model that includes magma plumbing, dike injection, volcanic eruption, earthquakes, faulting, and hydrothermal circulation.

To collapse the seafloor reflections and reduce scattering noise, the data will be first downward extrapolated (DC) to the seafloor, as if both sources and streamers were deployed on the seafloor (Arnulf et al., 2012). Travel times of refraction arrivals will then be picked and will be used to determine a smooth 3D velocity model using a 3D tomographic method (e.g., Arnulf et al., 2018). Then 3D elastic full waveform inversion will be applied to DC data to obtain intermediate-scale velocity information. Finally, 3D elastic full waveform inversion will be applied to surface seismic data to obtain fine-scale P- and S-wave velocity structures. The final results will be interpreted by integrating all available information at the study site: seafloor geology, petrology, earthquakes and marine geodesy.

A student with a strong background and experience in modelling and inversion, with interest in addressing fundamental scientific problems is encouraged to apply. The student will receive training in advanced seismic data analyses methods, such as downward continuation, tomography and full waveform inversion, and will work in close collaboration with our international partners at the University of Nevada (Graham Kent). He/she will also have opportunity to participate in future active source marine seismic experiments on industry and academic vessels.

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