Subject title: Dynamics of magma reservoir before and after volcanic eruptions at the Axial Volcano in the Eastern Pacific using time-lapse seismic imaging method

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Presentation of the subject: (Maximum 2 pages)

Magma reservoirs (mixture of liquid melt, crystals, and gases) are normally present beneath most active volcanoes from where dikes initiate, and magma erupts to the surface. Depending upon the thermal state of the reservoir, magma may be in a pure melt state if supplied by fresh melt from below, or in a mush state because of cooling by hydrothermal circulation, which increases the crystal fraction in the magma (Singh et al., 1998). The magma is most likely to erupt when it is in a pure melt state, less likely when it is in a mush state. Thus, the nature of the magma reservoir (pure melt versus mush) plays a crucial role in the occurrence of volcanic eruptions and the intensity of the hydrothermal circulation above. Whereas it has been difficult to characterize the nature of magma reservoirs on land due to poor imaging conditions, the marine environment allows more favorable imaging conditions.

The Axial Volcano in the Eastern Pacific Ocean is a large submarine volcano, like a mini-Iceland, which 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), and a three-dimensional (3D) multi-channel seismic survey (Arnulf et al., 2019; 2020). Interestingly, 2D seismic reflection data were acquired in 2002, 2012 and 2019 before and after the 2011 and 2015 eruptions, hence these data could be used to characterize the dynamic behaviour of magma reservoir before and after the eruptions in a time-lapse sense.

The time-lapse signal could be due to the change in depth of the top of magma reservoir and/or a change in the state (melt versus mush) of the magma. For example, inflation (caused by fresh melt supply) and deflation (following an eruption) would lead to changes in the depth of the magma lens. Singh et al. (1998) have shown that the amplitude versus offset (AVO) behaviors of pure melt and mush are very different and could be used to characterize the state of the magma reservoir and possibly quantify the amount of crystals present in the magma reservoir.

In this project, we propose to use these techniques to monitor the state of a magma reservoir over time, before and after eruptions. The work will include a component of data analysis as well as AVO modelling. Data analysis will start by loading these data vintages on a processing workstation; then the effect of the data acquisition footprint will be removed, and differences between the two data vintages will be computed, allowing to quantify the influx and out flux of melt in the reservoir. The AVO modelling work will be carried assuming both a simple interface (upper crust/magma lens) and multi-sills where the P-wave and S-wave reflection coefficients as a function of incidence angle will be calculated for different states of magma lens ranging from pure melt (where the S-wave velocity is zero) to fully crystallized magma. The P-wave and S-wave velocities with different melt fractions in the magma reservoir will be computed using an effective medium theory (Taylor and Singh, 2002). The theoretical AVO curves will be compared with the AVO behavior of the magma lens reflection for all the data vintages. Theoretical modelling indicates that a pure melt region in a thin melt sill is likely to become mush in 10-15 years (Singh et al., 1999), and therefore, these results will be used to quantify the percentage of crystals in the magma reservoir in 2002, 2012 and 2019, and hence shed light on the evolution of the magma reservoir through time and its eruption potential as of 2019.

A student with an interest and experience in seismic data analysis, modelling and inversion, with interest in addressing fundamental scientific problems is encouraged to apply. The student will receive training in advanced seismic data analysis methods and modelling 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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