Melt inclusions as a record of mantle heterogeneity and melt-crust interaction

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Project background:
Over the course of its history, the Earth has evolved through large scale differentiation events such as core segregation and the production of continental and oceanic lithosphere. Since the onset of plate tectonics at ca. 3 Ga, differentiated material has been mixed back into the mantle; a pre-requisite for the observed composition of many mantle plume-related ocean island basalts (OIB) erupted at the Earth's surface (Figure 1). However, the efficiency of this mixing and the distribution of compositional heterogeneity in the mantle remains poorly constrained due to (i) the inaccessibility of actual deep mantle samples, (ii) the difficulties in resolving mantle geochemical heterogeneity using geophysical imaging techniques alone and, critically, (iii) the historical reliance upon bulk-rock measurements of volcanic products to infer the complex composition of the mantle source(s)

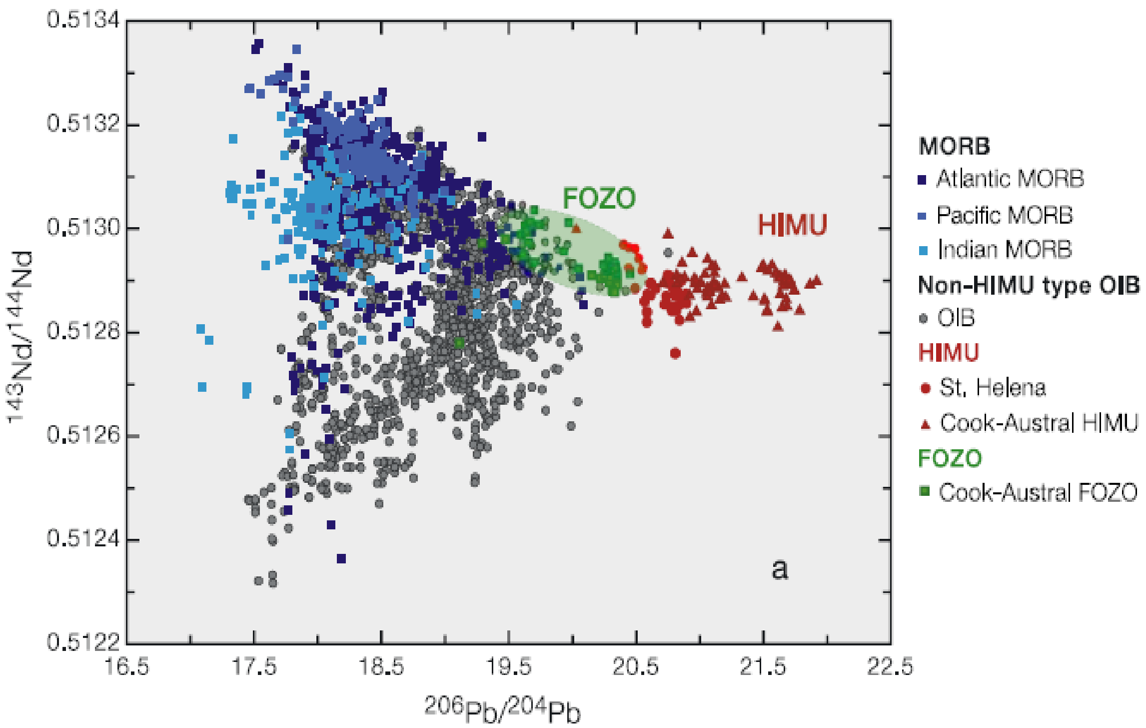

Figure 1. The "Mantle Zoo" illustrates the extent of isotopic heterogeneity in the mantle. However, superimposed upon these regional scale heterogeneities are large magnitude km to cm scale heterogeneities whose presence is masked when melt from a variety of sources is pooled prior to eruption

of magmas

It is a fundamental tenet in geochemistry that during mantle melting the isotopic fingerprint of the mantle source is faithfully recorded in the melt it produces. This information is complemented by the major and trace element signature of the erupted magma. Determining the unequivocal composition of a mantle source can, however, be problematic and the effect of mixed pyroxenite-peridotite melting, and interaction with the crust prior to eruption introduces further obstacles but may allow critical information regarding the nature of the magma "plumbing" beneath a volcano to be determined. Several studies have explained the correlations between isotopic signatures and trace element systematics of basalts as arising naturally from varying degrees of melting of a compositionally heterogeneous source. This interpretation has constituted the state of the art for decades and is firmly rooted in the bulk-rock analysis of primitive basalts. However, recent work has uncovered large magnitude isotopic and elemental variability at kilometre to centimetre scales in the mantle that are superimposed upon regional-scale compositional heterogeneity. The contribution from each of these heterogeneities to the composition of a mantle plume-derived primitive basalt, known to have originated from a mantle source that is not homogeneous, is therefore equivocal. Moreover, the distribution and magnitude of these geochemical heterogeneities are not resolvable by analysing bulk-rock samples.

In the absence of representative mantle samples, melt inclusions (Figure 2) trapped within early crystallizing minerals, such as olivine, provide a snapshot of primary mantle melt composition before such homogenisation occurs - the olivine crystal protects the melt inclusion from being incorporated into the pooled melt - therefore preserving evidence of the compositional heterogeneity in the mantle source. In addition, heterogeneity can be introduced through interaction of a homogeneous melt with the lithosphere while a magma is either stored within or transits through the region between its source and its eruption site.

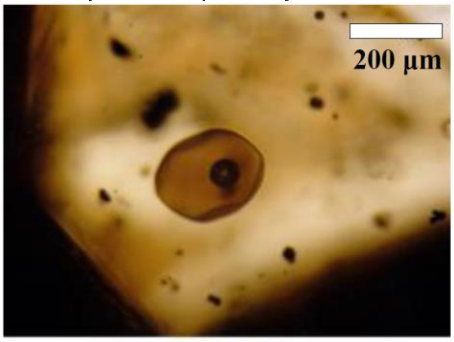

Figure 2. A typical olivine-hosted melt inclusion.

However, melt inclusions are small (sub-mm diameter) and, until recently, analysis of more than one potential tracer of mantle source in a melt inclusion has been challenging. This project, using a powerful combination of major, trace and volatile elements with Sr, Nd and Pb isotope measurements, and using methods recently developed by the supervisors and collaborators (see Harvey et al., 2009; Reinhard et al., 2017, 2018) will fingerprint the nature of the chemical and isotopic heterogeneities in individual melt inclusions that are representative of the ingredients that formed the melts erupted in the Southern Volcanic Zone of Chile (Morgado et al., 2015), the Afar Rift (Ferguson et al., 2013), and Iceland (Maclennan et al., 2008). This combination of tracers will provide a unique perspective on the scale, magnitude and distribution of mantle heterogeneities beneath these regions. The information derived will inform on processes relating to melt production and transport in the mantle sources that feed continental rifts, plumes and subduction-related magmas. The depth at which a melt inclusion becomes trapped within its host can be determined by its CO_2 and H_2O abundances; coupled with the chemical and isotopic composition of a population of melt inclusions, the chemical heterogeneity at depth and hence the complexity of magmatic plumbing within the mantle plume can also be determined.

Potential for high impact outcome

Several recent studies (Koornneef et al., 2015; Reinhard et al., 2017, 2018) have demonstrated the potential for these methods to generate high-impact publications. The methods to be employed in this project take advantage of the most recent advances in mass spectrometer technology and draw upon the supervisors' extensive chemical and petrological experience and will set a new benchmark for the nature of the information that can be extracted from individual melt inclusions. This is a field in its infancy and any high-quality data-set resulting from this study would likely generate a great deal of interest across several fields in the geological sciences

Training

In addition to the programme-wide training delivered be the Doctoral Training Programme, the successful candidate can expect to receive training in sample preparation, chemical and isotopic separation and mass spectrometric analysis of melt inclusions. The use of MELTS modelling software and diffusion modelling could also play a role in the project and appropriate training can be given in-house for these methods

Student profile

Candidates should have a good degree in an Earth Science discipline, an interest in geochemistry and volcanology, and be willing to assist with method development in a world-class geochemistry facility. The nature of this project means that a high degree of competency in sample preparation and mass spectrometry will be necessary. Given the cutting-edge nature of both the mass spectrometry and sample preparation methods that will be employed, it is unlikely that a potential candidate would have necessarily already acquired these skills, although some geochemical experience would be an advantage. This is a technical geochemical project that will require a keen eye for detail, patience and a willingness to work for extended periods in a clean laboratory. An interest in developing mass spectrometry skills would also be an advantage.

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