The dynamics of magma storage and ascent beneath an active arc volcano (Villarrica, Chile)

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Volcanic arcs, formed along convergent plate margins, produce most of Earth's subaerial volcanic activity and are responsible for the largest and most devastating historical eruptions. At arcs, magma generated in the mantle above the subducting slab ascends through the lithosphere, where it is stored and chemically processed before feeding eruptions at the surface, typically from large stratovolcanoes. Understanding the factors that govern when and how this stored magma ultimately leaves its crustal reservoir(s) to be erupted, and what size that eruption is likely to be, remains a central goal of volcanology and should facilitate more accurate forecasts of future eruptions. The traditional view that the magmas feeding arc volcanoes reside within a melt dominated sub-volcanic 'magma chamber' has recently been superseded by a more nuanced view of magma storage and supply, whereby melts ascend through a vertically extensive series of melt-rich zones, termed a 'transcrustal magma system'[1]. Geodetic evidence has also shown that melt supply in the upper crust can also be offset laterally from the volcanic centre, requiring melts to flow through the crust towards the eruptive vent[2]. A key question that arises from these new constraints on magma plumbing is how do the dynamics of melt migration through the crust beneath large volcanic systems vary over time and is this variation reflected in the type and frequency of eruptions at the surface? A related issue is the extent to which the dynamics of magma storage and pathways of ascent are affected by lithospheric scale tectonic features, such as fault systems, and perhaps also by climate variability.

This project will employ geochemical and petrological methods to constrain pre-eruptive processes, storage conditions and/or origins of magmas erupted from an arc volcano in southern Chile (Villarrica) that has produced numerous post-glacial eruptions of varying magnitude. Villarrica is one of Chile's most active volcanoes and forms part of the southern Volcanic Zone (SVZ) group of volcanoes[3]. Volcanism along the SVZ has been strongly influenced by tectonics and Villarrica lies along a fracture system associated with a regional strike-slip fault system, the Liquine Ofqui fault zone. The volcano has also experienced extensive late-Pleistocene glaciation and its summit region remains permanently ice-covered. Postglacial activity at Villarrica has varied from small-volume eruptive events to large ignimbrite forming pyroclastic eruptions[3,4]. Despite this range in eruption magnitude, it is notable that the majority of these events involve relatively mafic magmas, typically basaltic to basaltic-andesitic in composition. Large explosive eruptions of Villarrica do not therefore involve magmas that have undergone significant extents of storage and/or fractionation compared to those feeding smaller lower-intensity eruptions. It is also notable that while smaller eruptions typically vary in composition from each other, large volume eruptions tend to be relatively compositionally homogenous, implying efficient mixing of the discrete melt batches that constitute the magma system feeding the more common smaller eruptions. In addition, geodetic studies show that maximum extents of ground deformation around Villarrica, inferred to be linked to magma movement, are offset from the centre of the volcano by several kms[6], implying that at least some of the magmas feeding the volcano move laterally through the crust.

Objectives

This research will involve a comparative study of the conditions of magma generation and storage associated with eruptions of Villarrica that vary in size between small cone forming events to large pyroclastic eruptions. You will undertake fieldwork in Chile to sample deposits from several eruptions, selected to cover as wide a range of eruption magnitudes as possible. After petrographic characterization of these samples, you will embark on an analytical programme designed to constrain the origin of these melts as well as the condition of pre-eruptive storage. This will likely include:

1) Analysis of glasses (scoria clasts and if possible melt inclusions) and crystals by electron microprobe and possibly laser ablation ICP-MS.
2) Electron microprobe and electron back-scatter diffraction imaging and analysis of olivine crystals to quantify intra-crystal Fe-Mg variations.
3) Diffusion modelling of the Fe-Mg data in the olivine crystals to extract quantitative time-scale information for magma residence in the lithosphere.
4) Other methods/approaches may also be employed depending on sample availability and preliminary results.

The interpretation of the petrological data with respect to magma storage and ascent will be informed in the context of contemporary geophysical constraints on magma plumbing (i.e. from satellite geodesy). Overall the project will seek to develop a model of magma storage that can explain how this magma system produces the observed range of eruption magnitudes and compositions.

Potential for high impact outcome

Subduction zone volcanoes typically produce Earth's most hazardous eruptions and this project will provide important insights into how the magma systems feeding these volcanoes operates. Villarrica is one of Chile's most active volcanoes and the volcano, nearby towns and surrounding area are major tourist attractions. Although recent eruptions of Villarrica have been of relatively low magnitude, the volcano is capable of producing much larger events, the deposits of which will be included in this study. In scientific terms, the recent conceptual shift in how the supply of magma to volcanoes is hypothesized to occur (i.e. the transcrustal magma system) means that this work will be very timely with respect to this new paradigm and the development of more sophisticated models of volcanic plumbing.

Training

The student will primarily work under the supervision of Dr. David Ferguson and Dr. Dan Morgan in Leeds. They will gain high-level experience and expertise in: i) field sampling in volcanic terrains; ii) preparation of samples for geochemical analysis; iii) data collection using a variety of analytical instrumentation; and iv) diffusion modelling to extract quantitative timescale information. Discussions with Dr. Susanna Ebmeier will provide important context on geophysical constraints on magma storage and help the student to integrate their results with other relevant datasets. Within SEE they will have the opportunity to engage with researchers in the volcanology and geochemistry research groups, many of whom will have overlapping interests with this work. The student will also have access to a broad range of Faculty- and University-led training courses and workshops at Leeds (http://www.emeskillstraining.leeds.ac.uk/).

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3. Stern (2004). *Rev. Geo. Chile, 31* (2)
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Villarrica volcano, Chile (Cristian Gonzalez G)