

Probing the roots of volcanoes: Mantle heterogeneity and magma evolution revealed by experimental petrology

Primary supervisor:	Elena Melekhova (www.earth.ox.ac.uk/people/elena-melekhova)
Co supervisor(s):	Jon Blundy (www.earth.ox.ac.uk/people/jon-blundy)
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Research theme(s):	• Geophysics and Geodynamics • Geodesy, Tectonics, Volcanology and related hazards • Planetary Evolution and Materials • Earth Resources
Eligible courses for this project:	• MSc by Research in Earth Sciences (2-3 years) • DPhil in Earth Sciences (3-4 years) • Interdisciplinary Life and Environmental Science Landscape Award (ILES�A)

Overview



Figure 1 Photo by Lee Siebert, 1998 (Smithsonian Institution)

Volcán Popocatepetl rises to the SE beyond the Sierra Chichinautzin. More than 150 small cones formed across the Chichinautzin range; many of these are of Holocene age.

What lies beneath volcanoes? Can the diversity of erupted magmas reveal variations in the rocks and minerals that make up their mantle sources?

The Earth's mantle is commonly represented as a relatively uniform peridotitic reservoir, yet growing evidence suggests that mantle sources can be heterogeneous in both their composition and mineralogy. Understanding how this heterogeneity influences magma generation is fundamental to explaining the chemical diversity of volcanic rocks and the evolution of the Earth's crust.

One of the major challenges in igneous petrology is determining the pressures, temperatures and mineral assemblages with which magmas equilibrated before eruption. Conventional mineral-based thermobarometers commonly record conditions of crystallisation during magma ascent, rather than those associated with deeper magma generation.

This DPhil project will investigate this problem using **multiple saturation thermobarometry**. By combining high-pressure and high-temperature experiments with numerical and machine-learning methods, the student will investigate the conditions at which volcanic magmas last equilibrated with their source assemblages and explore whether these constraints can reveal variations in mantle source lithology and mineralogy.

The research will focus primarily on the **Chichinautzin Volcanic Field in the Trans-Mexican Volcanic Belt**, investigating compositions ranging from relatively primitive basalts and basaltic andesites to more evolved andesites. This compositional diversity provides an opportunity to test whether different magmas record equilibration with distinct mantle mineral assemblages, potentially reflecting lithological heterogeneity within the underlying mantle.

An important aspect of the project will be distinguishing signatures inherited from mantle sources from those produced by subsequent magma differentiation and equilibration within the crust.

Depending on the student's interests and research outcomes, the investigation may be extended to selected volcanic systems in other tectonic environments, including the Cascades, Aleutians or Main Ethiopian Rift.

Experimental results will be integrated with petrological, geochemical and geophysical observations to develop a more complete understanding of mantle heterogeneity, magma generation and transcrustal magmatic evolution.

The project offers an opportunity to address fundamental questions about the Earth's interior while developing expertise in experimental petrology, quantitative modelling and machine-learning approaches to magma thermobarometry.

Methodology

The project is rooted in high-pressure and high-temperature experiments using the well-equipped piston-cylinder and cold-seal laboratories in Earth Sciences. Experimental run products and natural samples will be analysed using electron microbeam techniques. Experimental results will be combined with numerical and machine-learning approaches to multiple saturation thermobarometry to investigate magma equilibration conditions and mantle source mineralogy. Some fieldwork to collect volcanic samples is anticipated. The project will suit a numerate student with a strong interest in igneous petrology, thermodynamics and volcanology. Previous experimental or field experience would be advantageous but is not essential.

Timeline

Year 1: Training in high-pressure experimental techniques. Selection and characterisation of volcanic samples from the Chichinautzin Volcanic Field (Mexico). Initial experiments and introduction to numerical methods for multiple saturation thermobarometry.

Years 2 and 3: Experimental investigation of basaltic to andesitic magmas to constrain equilibration conditions and explore mantle source heterogeneity. Application of numerical and machine-learning approaches. Potential extension to other volcanic settings.

Year 4: Integration of experimental results with petrological, geochemical and geophysical data. Interpretation of mantle source mineralogy and magma evolution. Thesis completion and preparation of publications.

Training & Skills

Training will be provided in high-pressure and high-temperature experimental petrology, electron microbeam analysis and phase equilibria. The student will also develop skills in numerical modelling, data analysis and machine-learning approaches to thermobarometry, as well as the integration of experimental results with petrological and geophysical observations.

References & Further Reading

- [1] Blundy, J., 2022. Chemical differentiation by mineralogical buffering in crustal hot zones. *Journal of Petrology* 63, egac054
- [2] Melekhova, E., Blundy, J., 2024. Generation of mantle-derived basaltic andesites in volcanic arcs. *Earth and Planetary Science Letters* 641, 118791
- [3] Weber G., Blundy, J., 2024. A machine learning-based thermobarometer for magmatic liquids. *Journal of Petrology* 65, egae020
- [4] Cashman, K.V., Sparks, R.S.J., Blundy, J., 2017. Vertically extensive and unstable magmatic systems: a unifying view of igneous processes. *Science* 355, 1280
- [5] Asimow P.D., Longhi J. 2004. The Significance of Multiple Saturation Points in the Context of Polybaric Near-fractional Melting. *Journal of Petrology* 45, 2349-2367
- [6] Becerra-Torres, E., Melekhova, E., Blundy, J. D., & Brooker, R. A. (2020). Experimental evidence for decompression melting of metasomatized mantle beneath Colima Graben, Mexico. *Contributions to Mineralogy and Petrology*, 175(11), 101.

Further Information

Contact: Elena Melekhova (elena.melekhova@earth.ox.ac.uk)