Project title: The role of volatiles in controlling chalcophile element distribution in the continental crust
Project code:
Host institution: University of Birmingham
Theme:
Key words: Arc magmatism, volcanic rocks, basalt, subduction zone, ore deposits, chalcophile
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Overview: The chemical and petrological heterogeneity of arc volcanic rocks results from variability in the conditions and processes of arc-magma generation across the spectrum of modern-day subduction settings. This variability in processing extends from the slab to the surface. Studying the compositions of primitive convergent-margin magmas is particularly informative for assessing influences on the early stages of melt generation, and for investigating the controls that different primary melt compositions have on the subsequent crustal history of the cooling melt. For example, spatial variation in primary melt compositions provides constraints on fluid input from the subducting slab to the overlying mantle wedge, and how this addition of volatiles drives mantle melting. The volatile content (e.g., H_2O, S) of these mantle-derived melts, as well as their oxidation state, subsequently plays a major role in controlling when minerals such as sulphides appear on the liquidus as the melts ascend through the continental crust. Because sulphides concentrate sulphur-loving chalcophile elements such as Cu, Ag, Se and Au, understanding the cycling of volatile elements at convergent margins is key to advancing our understanding of how and why economically important magmatic-hydrothermal ore deposits (e.g., such as the major Cu deposits in central Chile) form at convergent margins.

This project will focus on a suite of arc rocks from southern Chile, across which the age of the subducting slab and the thickness of the crust varies. Some samples have already been collected, and the sample set will be extended to sites further north, where the crust thickens. The sample set includes some of the most primitive basalts known to occur in continental arc settings. Such rocks rarely reach the surface without extensive compositional modifications.

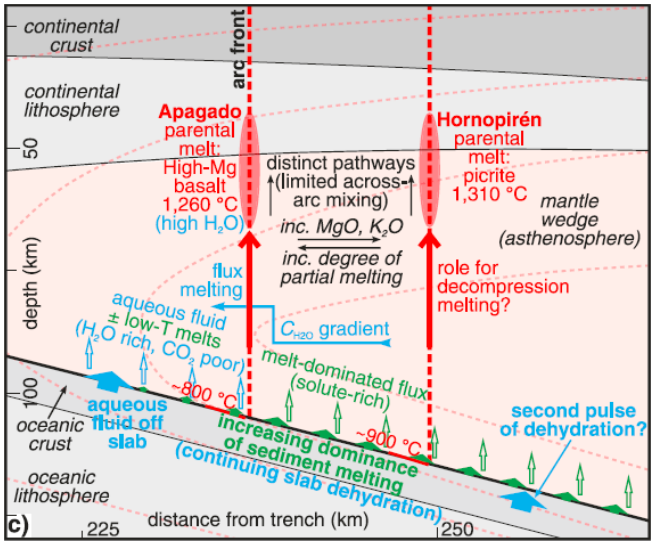

Figure 1: *Schematic diagram of melt generation processes across the S. Chile arc, inferred from primitive melt inclusions (Watt et al. 2013). This project will examine similar samples, extending along the arc and focussing on crustal processing of these melts.*

These primitive rocks contain olivine-hosted melt inclusions, which preserve a record of the early stages of magma evolution. Along with studies of whole rocks, the samples can be used to assess spatial variability in primitive magma volatile and trace (particularly chalcophile) element compositions, and how this reflects both variation in subduction

conditions and the subsequent crustal evolution of the magmas. This project will examine the relationship between the initial oxidation state, water content and chalcophile element concentrations within these arc basalts. It will assess whether systematic relationships exist between these variables, and if so, how these can be used to determine the conditions that are favourable for the formation of economically viable magmatic-hydrothermal ore deposits. Are the initial volatile and/or chalcophile element budgets of the magma the most important factors, or is it crustal processes (e.g., crustal assimilation, timing of sulphide saturation and/or timing of volatile saturation) taking place during cooling of the melt that provide the key?

Methodology:

The first part of the project will constrain the variation in trace and volatile elements in primitive melts along the arc (as the down-going slab increases in age), to assess if systematic patterns exist that reflect changes in devolatilisation or melting at the slab interface. The second part will explore the chemical modifications that take place as melts pass through the lower crust and slowly cool. The behaviour of chalcophile elements during the evolution of basaltic magmas in arc settings is particularly important in enriching elements such as Au and Cu in the magma. This enrichment is dependent on oxidation state of the magma, and associated with sulphide undersaturation. Building on earlier work (Jenner et al. 2010), the project will explore chalcophile element systematics within melt inclusions across the sample set with the aim of understanding the role melt evolution plays in aiding or hindering the ore forming processes.

This project builds on and brings together some of the most recent findings on chemical variability within arc magmas and on chalcophile enrichment in arc magmas and aims to provide new constraints for understanding elemental cycling within subduction zones.

Training and skills:

CENTA students will attend 45 days training throughout their PhD including a 10 day placement. In the first year, students will be trained as a single cohort on environmental science, research methods and core skills. Throughout the PhD, training will progress from core skills sets to master classes specific to the student's project and theme.

This project will provide comprehensive training in methods of analysing and interpreting igneous processes, including petrographic methods, whole rock geochemistry and a range of microanalytical methods, potentially including electron microprobe, laser ablation-ICP-MS, and ion microprobe. It will also provide training in modelling approaches for the assessment of melting and petrogenetic processes.

Partners and collaboration (including CASE):

The project is partly funded via a NERC consortium involving 10 UK institutions and with international reach. The consortium investigates various aspects of volatile cycling within the mantle. The student will participate in consortium meetings and have the opportunity to collaborate with project partners.

Possible timeline:

Year 1:

- Compilation of sample set from region and existing geochemical data
- Planning of fieldwork in Chile (likely early 2016)
- Sample preparation from existing and new samples
- Initial electron probe work
- Application for use of ion-probe facility

Year 2:

- Whole rock and microanalytical work across samples set, in collaboration with PDRA and others in volatile consortium.
- Development of chalcophile element analysis and assessment of along arc patterns
- Production of first manuscript based on along-arc geochemistry of primitive basalts

Year 3:

- Completion of all major analyses
- Writing up main outputs and thesis
- Production of second manuscript with focus on chalcophile element cycling and crustal processing
- Presentation of major finidgs at international conference

Further reading:

Jenner, F.E., H.St.C. O'Neill, R.J. Arculus, J.A. Mavrogenes (2010). The magnetite crisis in the evolution of arc-related magmas and the initial concentration of Au, Ag and Cu. J. Petrol 51, 2445-2464.

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Kelley, K.A. et al. (2010), Mantle melting as a function of water content beneath the Mariana arc, J. Petrol., 51, 1711–1738

Nichols, A. R. L., R. J. Wysoczanski, K. Tani, Y. Tamura, J. A. Baker, and Y. Tatsumi (2012), Melt inclusions reveal geochemical cross-arc variations and diversity within magma chambers feeding the Higashi-Izu

Monogenetic Volcanic Field, Izu Peninsula, Japan, Geochem., Geophys., Geosyst., 13, Q09012.
Watt, S.F.L., D.M. Pyle, T.A. Mather, J.A. Naranjo (2013). Arc magma compositions controlled by linked thermal and chemical gradients above the subducting slab. Geophys. Res. Lett. 40, 2550-2556