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Magma dynamics of subduction zones: models of production and transport of volatile-enriched melts

David Rees Jones (2), David May (1), and Richard Katz (1)

(2) University of Cambridge, Earth Sciences (United Kingdom), (1) University of Oxford, Earth Sciences, United Kingdom (richard.katz@earth.ox.ac.uk)

Subduction zones are responsible for most of Earth's subaerial volcanism. However, previous geodynamic modelling of subduction zones has largely neglected the generation and transport of magma within the mantle wedge [1]. We previously showed that magma has a significant thermal impact by advecting sensible heat into the lithosphere beneath arc volcanos [2]. The inclusion of this effect helps reconcile subduction zone models with petrological and heat flow observations. Many important questions remain, including how magma–mantle dynamics of subduction zones affects the position of arc volcanos and the character of their lava.

Using theoretical/computational modelling, we show that melts migrate toward the surface in a heterogenous fashion. Magma flow is concentrated in a high permeability region, the geometry of which is controlled by the temperature and the rheological properties of the mantle wedge. Flow is affected by time-dependent porosity waves. We show the effect on melt migration of the mechanical coupling between the slab and the wedge, the supply of volatiles from the slab and the rheological properties of the wedge. These results clarify the fluid dynamical controls on the pattern of subduction-zone volcanism (particularly its location, magnitude, and chemical composition).

Our approach is based on the physics of two-phase flow: solving the coupled equations governing conservation of mass, momentum, energy and chemical species. The solutions are obtained numerically, in the context of finite element discretisations. The open-source code, SubMaFEC, depends only on PETSc (https://bitbucket.org/dmay/projectmagmox). The present calculations use a simple, 3-component petrological model of mantle melting that incorporates a refractory, a fertile, and a volatile species. We choose a partition coefficient between the phases to match the main features of experimental measurements of partial melting. We then calculate the migration of partial melts under buoyancy forces and dynamic pressure gradients. We account for the sensible and latent heat effect of melts.

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[2] Rees Jones, D. W., Katz, R. F., Tian, M and Rudge, J. F. (2017). Thermal impact of magmatism in subduction zones. EPSL, doi:10.1016/j.epsl.2017.10.015