The mantle water valve: A melting feedback on arc magma water concentrations

Terry A Plank[1], Katherine A Kelley[2], Mindy M Zimmer[3], Erik H Hauri[4], Paul J Wallace[5]

[1]LDEO-Columbia Univ, USA, [2]Univ of Rhode Island, USA, [3]Los Alamos National lab, USA, [4]Carnegie Institution of Washington, USA, [5]Univ of Oregon, USA

E-mail: tplank@ldeo.columbia.edu

Arc magmas vary widely in the concentration of chemical tracers derived from the subduction zone, with the notable exception of H2O. Nearly all arc volcanoes are sourced with mafic magmas that contain 2 to 6 wt% H2O, based on the least degassed melt inclusions from each volcano. The average for each arc varies even less, from 3.2 (for the Cascades) to 4.5 (for the Marianas), with a global average of 3.9 wt% H2O [1]. A modulating process, either in the crust or mantle, is likely responsible for the restricted range in the H2O contents of arc melt inclusions. Although stalling of magma in the upper crust may affect some arc magma water contents, we describe here a mantle control, caused by a negative feedback in the melting process driven by water itself. A strong relationship between the water content of the source, H2O(o) and the degree of melting (F) can maintain a nearly constant water content in the melt for a restricted range in mantle temperature. This is because water is at once a highly incompatible element in mantle minerals, and a major element with a large cryoscopic effect (i.e., freezing point depression). Thus H2O(o) contents drive high F, keeping H2O in the melt similar to what would result from lower H2O(o) at low F. Magmas with 3 to 4 wt% H2O can be generated at about 50C below the dry solidus for a wide range in F and H2O(o). This result can be derived from the cryoscopic effect. 3.5 wt% H2O in the melt depresses the melting temperature of peridotite or the olivine-saturated basalt liquidus by about 110C [2,3]. On the other hand, F of 10 to 20% (typical for arc magmas) requires an increase in temperature 40 to 80C above the dry solidus, and so the two effects together lead a net depression of 30 to 70C below the dry solidus.Thus the ultimate cause of the limited range in the water contents of parental arc magmas is a combination of the negative melting feedback, and a restricted range in mantle wedge temperatures, as predicted from recent numerical models that hold upper mantle potential temperature constant [4]. Like the nearly uniform thickness of the oceanic crust, the small range in the water contents of arc magmas may be another reflection of a planet with a background uniform potential temperature of 1400 C. The characteristic mean and range of H2O contents of arc magmas has implications for both the volatile fuel for explosive eruptions and the mass balance of H2O recycled through subduction zones. References. (1) Plank, et al. (2013) EPSL, in press. (2) Hirschmann, PEPI, 2010. (3) Medard and Grove, CMP, 2008. (4) Syracuse et al., PEPI, 2010.