

Effect of water on magma and crustal density: Highly fractionated lavas in the Lau Basin and other wet spreading centers

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Mid-ocean ridges worldwide typically erupt basalts with approximately 8% MgO. This can be understood if eruption is primarily controlled by the density of magmas relative to the crust: high-MgO primary MORB is denser than the porous layer 2 of oceanic crust, leading to ponding and fractionation. Stolper & Walker (1980) and Sparks *et al.* (1980) pointed out the density minimum along the tholeiitic liquid line of descent at plagioclase saturation, close to typical MORB composition. Certain regions, however, erupt anomalously fractionated lavas. Hotspot-affected and back-arc ridges tend towards values near 6% MgO and a few are dominated by andesites with <4% MgO. An outstanding example is the southern end of the Eastern Lau Spreading Center, particularly the Valu Fa Ridge, sampled by the Lau II Cruise (Leg 0417 of R/V Kilo Moana) in Fall 2004. Data show a systematic trend towards highly fractionated samples with proximity to the Tonga trench, including axial andesites and dacites. As pointed out for calc-alkaline lavas by Grove and Baker (1983), water lowers the density of magma and the effect increases with extent of fractionation because water is incompatible and because it suppresses plagioclase fractionation. MELTS calculations show that these effects together eliminate the density minimum for primary MORB lavas with >0.4% H₂O. Together with increasing porosity of the upper crust (confirmed by seismic data), this effect of water provides a neat explanation for the decrease in mean MgO with moderately elevated H₂O and the rather sudden transition to highly fractionated samples at higher H₂O concentrations. This is a regional effect and results from feedback between the density of roof-rocks derived from earlier dikes and eruptions with the material in the present magma chamber.

References

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Physical and chemical controls on the viscosity of crystallizing and degassing magma

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The viscosity of magma exerts a fundamental control over the rates and styles of many geological processes: magma ascent and emplacement, mixing and mingling, and eruption style. Silicate *liquid* viscosity depends primarily on temperature, liquid composition, and dissolved volatile content, while the viscosity of natural *magmas* depends also on crystal content. Here I quantify viscosity changes accompanying crystallization due to (i) the physical effect of rigid inclusions, and (ii) chemical effects of changing composition and volatile content of the residual liquid.

Recent advances in experimental techniques have enabled the development of empirical predictive equations for non-Arrhenian liquid viscosity as a function of temperature and water content for a range of compositions from rhyolites, andesites and phonolites, to basalts and foidites. Combining published data with the Einstein-Roscoe equation for the effect of crystals leads to several important conclusions:

1. When calculating magma viscosity for modeling petrologic processes it is essential to consider the residual liquid composition, and to apply the mechanical effect of crystals separately, e.g. dacites typically have rhyolitic matrix glasses; viscosities of andesitic-dacitic liquids are lower than those of crystal-bearing rhyolitic magmas (although the difference is small at high water contents).

2. During rapid ascent and degassing, if crystallization is negligible, *liquid* viscosity remains nearly constant until volatile saturation is reached, then dramatically increases at shallow levels (typically ≥ 4 orders of magnitude increase as P decreases from ~ 400 to 1 bar). Disequilibrium degassing enhances the abruptness of this viscosity increase.

3. During crystallization, *magma* viscosity may initially decrease (as the effect of increasing volatile content outweighs that of increasing crystal fraction), followed again by a sharp increase as either water is lost (during ascent) or crystal fractions become large. Thus an initially andesitic liquid may produce a *less viscous* rhyolitic magma during closed system crystallization.

4. Various feedback relations link magma physics and chemistry via viscosity and diffusivity, which control growth and settling / ascent rates of crystals and bubbles.