

Melting in the sub-arc mantle: the effects of H₂O on primary magmas and the spinel-to-garnet transition

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Introduction

In subduction zone settings H₂O plays an important role in the melt generation process. The effects of H₂O are likely to be complex in a dynamic melting environment, because H₂O contents will vary continuously with increasing degree of melting. In order to model the melting process, a quantitative understanding of the role of variable H₂O content and variable mantle residue composition must be developed. The model must be capable of recovering liquidus temperatures and compositions of melts saturated with a mantle residual assemblage of olivine + orthopyroxene + clinopyroxene ± spinel ± amphibole ± garnet (primary magmas) as a function of pressure and H₂O content. Equally important is understanding the effect of H₂O on the stability of mantle phases under various pressure-temperature conditions. Recent experimental work indicates that the presence of H₂O stabilizes garnet to lower pressures in mantle peridotite (Gaetani and Grove, 1993). Here we report the results of H₂O-undersaturated melting experiments performed at 10–16 kbar. These experiments were designed to determine the temperature of the H₂O-undersaturated liquidus of primary magmas over a range of pressures, and the compositions of mantle melts containing 6 wt% H₂O. Further, the results can be used to constrain the pressure at which the spinel-to-garnet transition occurs in the mantle under hydrous conditions.

Experimental and analytical methods

Experiments were performed in a piston cylinder apparatus. Starting materials consisted of a basaltic glass containing ~6 wt% H₂O to which either San Carlos olivine, Kragero orthopyroxene, or a fertile peridotite mix, made of mineral separates from a Kilbourne Hole spinel lherzolite xenolith, was added. Starting material was packed into an Au₈₀Pd₂₀ capsule that had been pre-conditioned to minimize Fe-exchange with the sample. The sample capsule was welded shut and placed into a larger diameter Au₈₀Pt₂₀ capsule,

along with powdered graphite, and the outer capsule was welded shut. The use of a double capsule fabricated from Au-based alloys minimizes diffusive loss of hydrogen during experiments. Experimental duration ranged from 24 to 36 hr. Experiments performed by melting mixtures of hydrous glass and fertile peridotite differ from sandwich experiments in the higher proportion of basalt to peridotite used (from 70:30 to 90:10), and in the fact that they are mechanically mixed, rather than layered, to promote equilibration between co-existing phases. The use of hydrous glass as a starting material allows the amount of H₂O in each experiment to be controlled, so that a series of experiments can be run at H₂O-undersaturated conditions with a constant H₂O content. The hydrous glass was prepared by melting a high-MgO, high-Al₂O₃ basalt from Medicine Lake volcano, CA (Sample 82-72f; Bartels *et al.*, 1991) at 2 kbar, H₂O-saturated, in a rapid-quench gas pressure vessel. All experimental run products were analyzed using the five-spectrometer JEOL 733 electron microprobe at MIT.

Results and discussion

As peridotite in the mantle wedge is dragged down by corner flow, it is fluxed by fluids released during breakdown of hydrous minerals in the subducted slab. Fluid fluxing either induces melting directly or metasomatizes the mantle, forming hydrous phases such as pargasite or phlogopite. The point at which the mantle begins to melt, and the amount of melt produced, will depend on temperatures in the inverted geotherm above the slab, the amphibole-buffered peridotite solidus and the H₂O-undersaturated peridotite solidus. In order to estimate the depression of the mantle solidus associated with melts containing 6 wt% H₂O, we used the predictive expression of Kinzler and Grove (1992) to determine the liquidus temperatures for anhydrous melts saturated with a spinel lherzolite assemblage. These melts have the same TiO₂ contents, Mg/(Mg + Fe), or Mg#, and (Na + K)/(Ca + Na + K), or NaK#, as our hydrous melts at 10–16 kbar. A comparison of these

temperatures with the ones determined from our experiments indicates a depression of the 6 wt% H₂O peridotite solidus of between 75°C and 115°C relative to the anhydrous solidus. This is significantly less than the liquidus depression expected under H₂O-saturated conditions (~350°C–380°C) over the same pressure interval. The slope of the 6 wt% solidus is roughly to parallel the anhydrous solidus in pressure-temperature space.

The SiO₂ (47–49 wt%), FeO (6.8–8.3 wt%) and MgO (10.7–11.6 wt%) contents of our 6 wt% H₂O spinel lherzolite-saturated melts are similar to anhydrous equivalents, predicted using the expressions of Kinzler and Grove (1992). They have higher Al₂O₃ (18.5–19.0 wt%) and slightly lower CaO (11.0–11.2 wt%), due to an increase in the size of the clinopyroxene stability field. This results in lower CaO/Al₂O₃ ratios for the hydrous primary magmas (0.580–0.604) relative to anhydrous ones (0.625–0.661). The compositional variations with increasing pressure for 6 wt% H₂O primary magmas with a constant Mg# are similar to those for the anhydrous case, with significant increases in FeO and MgO and a decrease in SiO₂ (i.e., they become more olivine normative).

A recent determination of the pressure at which the spinel-to-garnet transition occurs with melt present under anhydrous conditions is 23 kbar at a temperature of 1440°C (R.J. Kinzler, pers. comm.). Our H₂O-undersaturated melting experiments constrain the transition to begin at approximately 15 kbar over the temperature range of 1250°C–1290°C. The depth of the spinel-to-garnet transition will play an important role in determining the composition of mantle melts. 6 wt% H₂O primary magmas saturated with both spinel and garnet at 16 kbar show some systematic differences from H₂O-bearing melts saturated with a spinel lherzolite assemblage at 14 kbar. There is a sharp increase in MgO (from 11.6 wt% at 14 kbar to 12.8 wt% at 16 kbar) and a slight decrease in Al₂O₃ (from 18.5 wt% at 14 kbar

to 18.0 wt% at 16 kbar). The fact that the spinel-to-garnet transition occurs at shallow depths in a hydrous mantle (~50 km) relative to anhydrous conditions (~75 km), such as beneath mid-ocean ridges, means that the major element composition of hydrous primary magmas accumulated from a mantle wedge melting column will be more heavily weighted toward melts formed in the garnet stability field.

A recent study of the rare earth element (REE) geochemistry of Central American arc lavas shows regional differences in the modal abundance of garnet in the mantle source region (Feigenson and Carr, 1993). Specifically, lavas erupted from volcanoes in Guatemala and Costa Rica have REE abundance patterns consistent with a high modal abundance of garnet in their mantle source, while those from Nicaragua appear to have little or no garnet in their source region. Ion microprobe measurements of H₂O contents of mafic glass inclusions from the 1974 eruption of Fuego (Sisson and Layne, 1993) demonstrate the existence of lavas with high pre-eruptive H₂O contents (up to 6.2 wt%) in Guatemala. Taken together with our experimental results, the REE and H₂O content data is suggestive of variations in the modal abundance of garnet in the mantle source region being related to regional variations in the flux of H₂O coming from the subducted slab.

References

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