

## EXPERIMENTAL AND THEORETICAL CONSTRAINTS ON PERIDOTITE PARTIAL MELTING IN THE MANTLE WEDGE

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Melt generation at convergent margins occurs in what is arguably the most physically and compositionally complex environment in the upper mantle. No single model for the generation of arc magmas is universally accepted, and there is geochemical evidence to suggest that more than one mechanism is operative [1]. Pressure-release melting, the mechanism that generates partial melts beneath oceanic ridges and in mantle plumes, is thought to produce at least some subduction-related basalts. This is a process in which nominally anhydrous mantle peridotite ascends along an adiabat, eventually crossing the solidus and producing near-fractional partial melts. The depth at which melting begins is largely controlled by the potential temperature of the adiabat along which the peridotite ascends, although composition may also play a role [2]. By comparison, we know very little about the process by which *hydrous* peridotite partially melts in the mantle wedge. The base of the wedge is cooled to temperatures of  $\sim 800$  °C or less and dragged downward by the subducted slab [3]. The depth to the Benioff-Wadati zone beneath the volcanic front, which is relatively uniform in arcs worldwide ( $\sim 110$  km), corresponds with the pressure at which the breakdown of pargasitic amphibole releases H<sub>2</sub>O [4]. Geochemical tracers indicate that a substantial mass flux from the subducted slab carries a H<sub>2</sub>O-rich component into the mantle wedge, initiating partial melting of the peridotite [5]. The presence of H<sub>2</sub>O affects nearly every aspect of the melt generation process, including the composition of the partial melt, its physical properties, and the rate at which it is produced. Here I provide a brief summary of existing experimental and theoretical constraints on the nature of hydrous peridotite partial melts, and the process by which they are generated.

Experimental studies of simplified analog systems, such as Mg<sub>2</sub>SiO<sub>4</sub>-SiO<sub>2</sub>-H<sub>2</sub>O, provided important early insights into the compositions of hydrous peridotite partial melts, but also led to serious misconceptions about the origin of andesites. Enstatite (Mg<sub>2</sub>Si<sub>2</sub>O<sub>6</sub>), which is an important component of mantle peridotite, melts incongruently at pressures of up to  $\sim 0.5$  GPa under anhydrous conditions, forming forsterite (Mg<sub>2</sub>SiO<sub>4</sub>) and quartz-normative silicate melt [6]. The shift from incongruent to congruent enstatite melting with increasing pressure reflects a systematic decrease in the SiO<sub>2</sub> content of silicate melts that coexist with olivine. Experiments in hydrous systems demonstrate that the incongruent melting behavior of enstatite persists to at least 3.0 GPa when H<sub>2</sub>O is present, suggesting that olivine could coexist with hydrous quartz-normative silicate melt throughout the mantle wedge [7]. This result appeared to support the hypothesis that subduction-related andesites are direct partial melts of hydrous mantle peridotite [8,9], and subsequent experimental work carried out on both analog and natural compositions focused on the origin of andesite [10,11]. Although some of the experimentally produced H<sub>2</sub>O-bearing glasses from these studies had compositional characteristics similar to andesites, it was eventually concluded that they had been modified by the growth of amphibole and pyroxene during the quench [12]. It has since been shown that H<sub>2</sub>O-bearing partial melts are compositionally similar to those produced by anhydrous peridotite partial melting [13-16]. At a given extent of partial melting, isobarically increasing the concentration of H<sub>2</sub>O dissolved in the melt has an effect that is roughly equivalent to decreasing the pressure at which anhydrous partial melting occurs. Expansion of the olivine primary phase volume with increasing dissolved H<sub>2</sub>O, or with decreasing pressure, increases the SiO<sub>2</sub>/(MgO+FeO) ratio of the partial melt. An anhydrous-basis comparison of hydrous and anhydrous partial melts of the same silicate bulk composition demonstrates that SiO<sub>2</sub> content increases by  $\sim 1$  wt% with the addition of  $\sim 3$  to 6 wt% dissolved H<sub>2</sub>O, while the sum of FeO + MgO decreases by  $\sim 2$  wt%.

The physical properties (density, viscosity, etc.) and grain-scale distribution of partial melt are among the variables that control the efficiency of its segregation from residual peridotite. The extent to which a hydrous partial melt remains in contact with its residue during the melting process is an especially important consideration, given that segregation of the melt removes H<sub>2</sub>O from the system and hinders further melting. Experimental studies demonstrate that the presence of dissolved H<sub>2</sub>O has dramatic effects on both the density and the viscosity of silicate liquids. Due to the low molecular weight (18.016 g/mol) and relatively large partial molar volume (22.9 cc/mole at 1000 °C and 1 bar) of dissolved H<sub>2</sub>O, adding  $\sim 1$  wt% to a basaltic melt decreases its density by an amount that is equivalent to the effect of increasing

temperature by  $\sim 400$  °C or decreasing pressure by 0.5 GPa [17]. Experimental determinations of the effect of H<sub>2</sub>O on melt viscosity are limited to siliceous compositions, but they indicate that adding  $\sim 2$  wt% H<sub>2</sub>O can reduce melt viscosity by up to  $\sim 3$  orders of magnitude, which is a decrease equivalent to that produced by increasing temperature by  $\sim 200$  °C [18]. A microstructural study comparing the distribution of anhydrous and H<sub>2</sub>O-bearing partial melts in a synthetic peridotite indicates that connectivity increases under hydrous conditions, with orthopyroxene-melt dihedral angles decreasing from 70° (anhydrous), which would trap small amounts of melt at 4 grain junctions, to 52° (hydrous), which allows connectivity of even very small melt fractions [19]. The increased density contrast between partial melt and residual peridotite, decreased melt viscosity, and increased connectivity under hydrous conditions all favor a partial melting process in the mantle wedge that is near-fractional.

Melt productivity refers to the rate at which partial melt is produced, and is an especially important consideration in the mantle wedge because the length of the melting column is limited by the depth to the Benioff-Wadati zone. Isobaric productivity is the increase in melt fraction for a given temperature increase,  $(\partial F / \partial T)_P$ , while polybaric, isentropic productivity is the increase in melt fraction for a given pressure decrease,  $(-\partial F / \partial P)_S$ . Asimow et al. [20] showed that the most significant factors controlling the polybaric melt production rate during adiabatic ascent of mantle peridotite are the isobaric productivity,  $(\partial F / \partial T)_P$ , and the pressure-temperature slopes of constant melt fraction contours,  $(\partial T / \partial P)_F$ . The strong dependence of  $(-\partial F / \partial P)_S$  on  $(\partial F / \partial T)_P$  means that, although melting of hydrous mantle peridotite is likely to be a polybaric, near-fractional process, consideration of isobaric batch melting provides basic insights into melt generation processes in the mantle wedge. Calculations carried out using both olivine-liquid equilibrium [16] and a more rigorous thermodynamic model for mineral-melt equilibrium [21] indicate that  $(\partial F / \partial T)_P$  is much lower for hydrous peridotite than for anhydrous peridotite throughout partial melting by isobaric heating. This is due to the monotonically decreasing concentration of dissolved H<sub>2</sub>O in the melt with increasing extent of partial melting, which weakens the melting point depression effect. Therefore, although H<sub>2</sub>O behaves as a flux and increases the extent to which peridotite partially melts at a given set of pressure-temperature conditions, closed-system melting at H<sub>2</sub>O-undersaturated conditions is unproductive. A significantly longer melting column is required to produce a given amount of partial melt under hydrous conditions than under anhydrous conditions.

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