Volatile-rich Melts in the Earth's Upper Mantle (AGU Kuno Medal)

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The onset of silicate magma generation in the Earth's upper mantle influences the thermal evolution of the planet, fluxes of key volatiles to the exosphere, and geochemical and geophysical properties of the mantle. Although carbonatitic fluid with variable water content could be stable $\leq$250 km beneath mid oceanic ridges [1-3], owing to the small fraction (« 1 wt.%), its effects on the mantle properties are unclear. Geophysical measurements, however, suggest that melts of greater volume may be present down to $\sim$200 km [4-6] but large melt fractions is thought to be restricted to shallower depths. In this Kuno Award lecture, I will discuss the recent advancements on our understanding of deeper silicate melt generation induced by CO_2-H_2O volatiles and the relative stability of silicate versus carbonatitic melt in various tectonic settings. I will present recent experiments on carbonated peridotites that constrain the location and the slope of the onset of silicate melting in the mantle [7]. The new finding is that the pressure-temperature slope of carbonated silicate melting is steeper than the solidus of volatile-free peridotite and as a consequence the silicate melting of dry peridotite+CO_2 beneath ridges commences at $\sim$180 km. Accounting for the effect of 50-200 ppm of mantle H_2O on freezing point depression, the onset of silicate melting for a sub-ridge mantle with $\sim$100 ppm CO_2 becomes as deep as $\sim$220-300 km [7]. This melting generates a kimberlitic magma with $\sim$25 wt.% dissolved CO_2 and 1-5 wt.% dissolved H_2O. Based on the recent constraints of oxygen fugacity of the mantle in the garnet peridotite field [2, 3], we suggest that on a global scale, carbonated silicate melt generation at $\sim$250-180 km deep redox solidus, with destabilization of metal and majorite in the upwelling mantle, explains oceanic low-velocity zone and electrical conductivity structure of the mantle. In locally oxidized domains (i.e. higher than average Fe3+/Fetotal), deeper carbonated silicate melt may contribute to the X-discontinuity. Furthermore, the new experimental results along with the electrical conductivity of molten carbonated peridotite [8] and that of the oceanic upper mantle [6] suggest that if CO_2-rich melt is the only possible agent to explain the high electrical conductivity of the asthenospheric mantle then the mantle at depth is CO_2-rich but H_2O-poor; higher H_2O content in the mantle enhances melting, lowers the CO_2 content and likely the conductivity of such melts. Finally, carbonated silicate melts restrict the stability of carbonatite in the Earth's deep oceanic upper mantle and the inventory of carbon, water, and other highly incompatible elements at ridges becomes controlled by flux of the former [7].

Although the stability of carbonatitic melt may be eliminated beneath oceanic ridges at all depths, beneath continents stability of carbonatitic melt is expected. Archean cratonic mantle (geotherms corresponding to surface heat flux of 40-50 mW m−2) crosses the carbonated peridotite solidus, at a depth of $\sim$100-220 km [9]; thus considering the oxygen fugacity profile for cratons [3], carbonatitic melt is expected to be stable at 100-180 km depths, at a narrow temperature window of 1000-1100 °C. Elevated geotherms similar to those of the Proterozoic (surface heat flux of $\sim$50 mW m−2) and Phanerozoic terrains (surface heat flux of >60-80 mW m−2) would stabilize carbonatitic melt as shallow as 70-100 km [9]. A combination of geothermal and oxygen fugacity gradient with depth thus explains why carbonatitic melt is much more common on continents but rare beneath oceans.

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