

Separation of supercritical slab-fluids to form aqueous fluid and melt components in subduction zone magmatism

Subduction-zone magmatism is triggered by the addition of H₂O-rich slab-derived components such as aqueous fluid, hydrous partial melts, or supercritical fluids from the subducting slab. Whether the slab-derived component is an aqueous fluid, a partial melt, or a supercritical fluid persists as an open question. In general, with increasing pressure, aqueous fluids dissolve more silicate components and silicate melts dissolve more H₂O. Under low-pressure conditions, these aqueous fluids and hydrous silicate melts are divided by an immiscibility gap. The highest temperature of the immiscibility gap between the fluids and the melts is designated as a critical point. The temperature of the critical point decreases concomitantly with increasing pressure and finally reaches the H₂O-saturated solidus temperature. Under this pressure and temperature condition, no difference exists between hydrous silicate melts and aqueous fluids. This point is designated as a critical end point. Geochemical analyses of island arc basalts suggest the two slab-derived signatures of a melt and a fluid [1]. These two liquids unite to a supercritical fluid under P-T conditions beyond the critical end point.

X-ray radiography experiments [2,3] were conducted using the SPEED1500 Kawai-type multi-anvil apparatus installed at beamline **BL04B1** to examine unmixing and mixing behavior of a sediment melt and aqueous fluids, and of a high-Mg andesite (HMA) melt and aqueous fluids under high-pressure and high-temperature conditions. When we heated the sample at low pressures with various H₂O concentrations, we observed one round material in another material with different X-ray absorbance. We interpreted these to be coexisting silicate melt and aqueous fluid (Fig. 1(a)). At high pressures, we observed no such coexisting phase, but found gold powders, which was added to facilitate visualization of the boundary, falling during heating (Fig. 1(b)). Two phases were observed during heating and cooling in radiography images at pressures lower than 2.8 GPa in HMA–H₂O and 2.5 GPa in sediment–H₂O [4]. At higher pressures, only a single phase was recognized. The radiography results are also shown in pressure-temperature diagrams at constant bulk H₂O, in which critical curves and the H₂O-saturated solidus temperature meet at critical end points in HMA–H₂O and sediment–H₂O. These results show that the pressure of the second critical end point can be at 2.8 GPa (92 km depths) and 750°C for HMA–H₂O, and 2.5 GPa (83 km depths) and 700°C for sediment–H₂O.

These depths are within the mantle wedge underlying volcanic arcs, which are formed 90–200 km above subducting slabs. These data suggest that sediment-derived supercritical fluids, which are fed to the mantle wedge from the subducting slab, react with mantle peridotite to form HMA supercritical fluids. Such HMA supercritical fluids separate into aqueous fluids and HMA melts at 92 km depth during ascent. The aqueous fluids are fluxed into the asthenospheric mantle to form arc basalts, which are locally associated with HMAs in hot subduction zones. The separated HMA melts retain their composition in limited equilibrium with the surrounding mantle. The separation of slab-derived supercritical fluids into melts and aqueous fluids can explain the two slab-derived components observed in subduction zone magma chemistry.

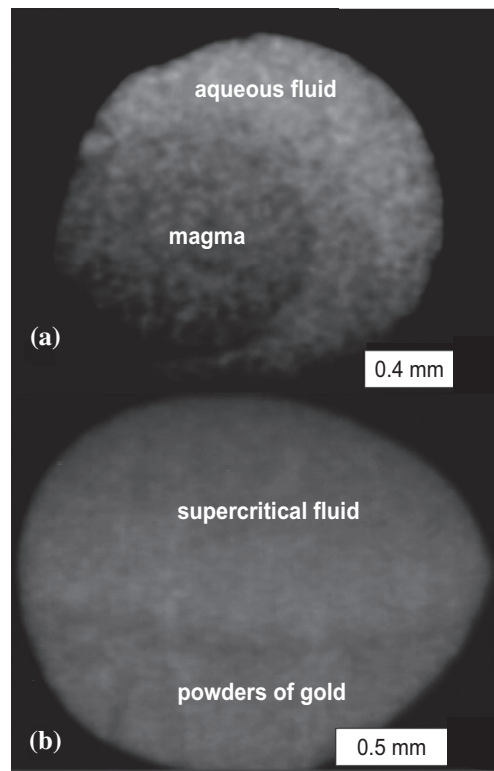


Fig. 1. Snapshots of radiography. (a) X-ray radiograph shows unmixing between HMA (dark circle) and aqueous fluid (matrix) at 1011°C and 1.5 GPa (run 2234). (b) X-ray radiograph shows the gold-powder-rich portion (lower dark half) falling in a uniform single supercritical fluid in the sediment with 50% (wt) H₂O at 953°C and 2.6 GPa (run 1536).

The newly determined critical end points suggest that slab-derived fluids are expected to be under supercritical conditions in the slab sediment layer and at the base of the mantle wedge, where HMA-bearing supercritical fluid is presumably formed by a reaction between sediment-derived supercritical fluids and peridotite, beneath the volcanic arcs. Therefore, no isolated fluid/melt phase exists, but there is a single supercritical fluid phase (with a continuum characteristic between aqueous fluid and hydrous melt in the downgoing sediments) at least > 83 km, and the base of the mantle wedge (underneath volcanic arcs) at least > 92 km.

Elliott *et al.* [1] recognized two slab-derived components in basalt chemistry: a partial melt from the subducting sedimentary layer and an aqueous fluid from the subducting basaltic layer. In our hypothesis (Fig. 2) [4,5], the melt and the fluid components can coexist in the mantle wedge if the supercritical slab-fluids supplied from the downgoing slabs separate into a melt and an aqueous fluid. Two such distinct slab-derived components have also been suggested to explain the chemistry of many arc basalts. Separation of slab-derived supercritical fluids into melts and aqueous fluids can commonly occur in most subduction zones.

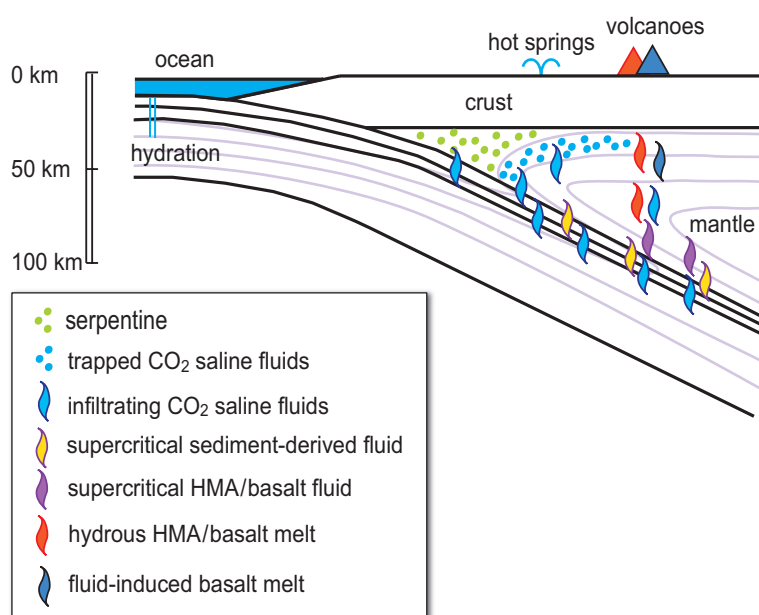


Fig. 2. Schematic illustration showing separation of supercritical fluids into aqueous fluid and hydrous melt. When a sediment-derived supercritical fluid enters the overlying mantle, the fluid will react with the peridotite to become HMA-bearing supercritical fluid. This HMA-bearing supercritical fluid migrates upwards and meets the critical end point. Then it will separate into a melt phase and a fluid phase. The HMA or basalt melt will continue to react with mantle to form a melt-derived magma or a Mg-rich andesitic magma. The fluid will trigger hydrous partial melting of the ambient mantle peridotite to form a fluid-derived magma. [4,5]

Tatsuhiko Kawamoto^{a,*}, Masami Kanzaki^b and Kenji Mibe^c

^a Graduate School of Science, Kyoto University

^b Institute for Study of the Earth's Interior, Okayama University

^c Earthquake Research Institute, The University of Tokyo

*E-mail: kawamoto@bep.vgs.kyoto-u.ac.jp

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