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Fluids and melts in subduction zones: insight from numerical modeling

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Fluid and melt transport is an important subduction zone process. Potential transport mechanisms include hydrofracture, diffusion, porous flow, reactive flow and thermal-chemical plumes generated from slabs. We use coupled petrological-thermomechanical models to investigate the dynamical effects of metamorphic reactions and melting of shallow upper mantle and subducted oceanic crust on the melt/fluid pattern and dynamics of thermal-chemical plumes beneath volcanic arcs. Plume generation is driven by the subduction of buoyant crustal rocks and expulsion of low viscosity silica-rich aqueous fluids that trigger hydration and partial melting of the mantle wedge producing water-bearing magmas of much higher viscosity. The model demonstrates two chemically distinct types of plumes: (i) unmixed plumes initiate from the melting front within the mantle that arises as a consequence of the rapid upward infiltration of slab-derived fluids, (ii) mixed plumes initiate from the slab itself and entrain both slab and mantle derived magmas. Mixed plumes explain magmas such as adakites with crustal signatures, while primitive arc tholeiites are attributed to unmixed plumes. Percolation-related mobility of liquid phase strongly depends on silica content as it affects fluid viscosity. In contrast to mobile low viscosity silica-bearing aqueous fluids stable at low temperature, water-bearing silicate melts formed within the plumes are characterized by high viscosities. Since the upward propagation rate of partially molten plumes can reach several meters per year and the volume of these finger-like and sheet-like structures can reach thousands of cubic kilometers,

we hypothesize that the plume-related transport of hydrated partially molten rock can be efficient in the hot asthenospheric part of the mantle wedge. Other mechanisms, such as hydrofracture, diffusion and porous flow, may dominate in relatively cold areas of subduction zones, for example within and immediately above the slab and in the lithospheric portion of the overriding plate. Our larger scale models show that subduction asymmetry is caused and sustained by upward fluid fluxes as these fluids lower the yield strength of the mantle above the slab creating an inherent subduction zone asymmetry (one sided subduction); in contrast, numerical models which do not account for aqueous fluids have a strong tendency to form unrealistic double-sided subduction patterns.