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A variety of plumes in the Earth's mantle: generation and morphology of thermo-chemical plumes

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The morphology of plumes in the Earth's mantle is a controversial topic. Global seismic tomography and geochemical studies show a great variety of mantle plumes, such as deep origin plumes passing through the 660-km interface, small secondary plumes rising from the top of a large upwelling in the lower mantle, plumes with or without primitive sources, deep or shallow origin plumes, and so on. In the view of the simple model of thermally buoyant plumes, it is difficult to explain the variety of mantle plume morphology. Recently we have conducted a series of laboratory experiments on the generation and behavior of thermo-chemical plumes in the density/viscosity stratification, and demonstrated many types of plume morphology are generated. We found several parameters, such as Rayleigh number, local buoyancy number of the plumes (the ratio of the stabilizing chemical buoyancy to the thermal buoyancy), and viscosity contrast between the density layers, control their behavior, and summarized them in the regime diagrams. The fate of the thermo-chemical plumes depends on the relationship between thermal and chemical buoyancy in the plume head. For example, the thermo-chemical plume cools as it ascends and disintegrates into two parts (so-called failed plume mode). The core of the plume head, which consists of hotter but heavier material, descends and a new thermal plume with the lower temperature is generated from the top edge of the heavier collapsing blobs. This gives a new insight on explaining the results of seismic tomography because low seismic velocity region can be the part of sinking, which is the contrary view of the simple thermal plume model. We will also discuss the plume behavior at the 660-km interface; the generation of the secondary plumes from the density interface. As a rising plume head approaches the density/viscosity interface, the convective flow in the lower layer induces a divergent flow at the bottom of the upper layer by mechanical coupling between the both layers. Then a thermal boundary layer forms above the interface. The centered downwelling flow in the upper layer retards the growth of thermal instabilities from the center and a ring-like diapir is formed. The ring-like diapir becomes unstable and new small diapirs are developed in a crown-like fashion. These branching plumes may explain the seismic images of mantle plumes under the south pacific region.