Anatomy of mantle plumes

Ichiro Kumagai[1]

[1] Inst. Geotherm. Sci., Kyoto Univ.

Laminar entrainment of starting plumes with a compositionally buoyancy has been explored based on laboratory experiments. Two types of starting plumes are identified in viscosity ratio 10.4 to 856 of the ambient to the buoyant fluids. The first is "vortex ring" type for a small viscosity ratio (11). The plumes entrain the ambient fluids and form a multi-layered and swirled structure within their heads. This is similar to the well-known structure as observed in the thermal starting plumes with the fluids having a strong temperature-dependent viscosity. In contrast, the second one, "chaotic mixing" type is observed for a higher viscosity ratio (104-856).

Recent developments of seismological studies have a great success in detecting much smaller structure of geological units such as mantle plumes. For example, the seismic images for P- and S-waves under Iceland show a cylindrical region of low velocity, extending from the surface to the core-mantle boundary. Not only a silhouette (external structure) of the plumes but their anatomy (internal structure) are focused because geochemical studies about mantle plume products have revealed that they consist of more than two components of geochemically distinct sources. This multi compositional structure is generally interpreted as a product by the entrainment and mixing between plume sources and ambient mantle materials.

Here, laminar entrainment of starting plumes with a compositionally buoyancy has been explored based on laboratory experiments. Two types of starting plumes are identified in viscosity ratio 10.4 to 856 of the ambient to the buoyant fluid. The first is "vortex ring" type for a small viscosity ratio (11). The plumes entrain the ambient fluids and form a multi-layered and swirled structure within their heads. This is similar to the well-known structure as observed in the thermal starting plumes with the fluids having a strong temperature-dependent viscosity. In contrast, the second one, "chaotic mixing" type is observed for a higher viscosity ratio (104-856). No report has been published on this type. At the earlier stage, the plume head forms a double-layered structure by the entrainment, having a buoyant fluid as the upper layer and an entrained fluid as the lower. Thereafter, the shear-flow at the interface between the layers promotes the shear instability and produces a mixing layer between them. This mixing layer grows with time and finally all fluids in the plume head mingle together. Depending on the viscosity ratio, the resultant internal structure of the plume head is different: layered structure preserving the initial compositions vs. chaotically mixing tending to homogenize everything. The anatomy of the plume heads presented here will provide a new point of view for the spatial and temporal variation of the geochemical data obtained from mantle plume products.