Experiments on the interaction of a thermal starting plume with a compositional boundary: effect of a viscosity step

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Seismic observation indicates that there are two major seismic discontinuities in the mantle transition zone caused by phase change. This phase transformation affects the rising of mantle plumes. As well, depth dependence of viscosity has a significant effect on the penetrating behavior of mantle plumes. Kumagai & Kurita (2000) showed from the results of laboratory models of the compositionally buoyant plumes that the mode of penetration depends on the degree of entrainment and that of the viscosity reduction across the interface. Here, we have examined the case of the thermally buoyant plumes based on laboratory experiments in order to understand the behavior that a thermal starting plume might interact with a compositional boundary.

Our experiments were conducted in a transparent rectangular tank containing a fluid with stratified density and viscosity. Buoyancy in the form of heat was injected into the fluid by operating a heater placed at the bottom of the tank. The flow was marked with small tracer particles and analyzed their motion by using Particle Image Velocimetry (PIV). For temperature field measurements, we introduced Thermochromic Liquid Crystals (TLCs) method.

For the situation that buoyancy ratio of compositional density anomaly to the thermal density anomaly was large, the rising plume head was slowed and flattened as approaching to the interface, and a thermal boundary layer was formed over the plume head. The arrival of the plume head also led to uplift of the interface and radial shear-induced flow in the boundary layer, which was caused by mechanical (viscous) coupling between the layers. After a while, a ring-like diapir, which had a same axis of the flattened plume beneath the interface, was formed. Then, the ring-like diapir became unstable and new small diapirs were developed in a crown-like fashion. These circular aligned diapirs moved towered the center of the axis and finally merged into a large plume because of thermal coupling with the underlying thermal plume. We will discuss the dependence of thermal and mechanical couplings on the generation and motion of small plumes emanated from the interface.

In this presentation, we will also argue the differing effects of buoyancy ratio, of the viscosity contrast between the layers, and of the structure of the plume head with respect to the entrainment phenomena. Our understanding of the interaction behavior allows us to connect with geological observations such as the number, the size and distribution of small plumes emanated from the interface.