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A causal relationship between a superplume and a supercontinent: which came first?

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It is generally agreed that the mantle plumes play an important role in aggregation and breakup of a supercontinent. However the timing and the location of mantle plume (or superplume) activities within the supercontinent cycle are controversial. As suggested by Gurnis (1988), a large continent affects the thermal state of the mantle. Because the continent can insulate the underlying mantle, a thermal upwelling may be generated beneath the continent, and as a result it causes the breakup of the supercontinent. However, the observed survival time of supercontinents is shorter than the time expected in the numerical model (Condie, 1988). Alternatively, a model of slab avalanches may overcome the subject of the timing. For instance, Maruyama (1994) suggested that subducted slabs around the supercontinent stagnate at and pile up on the 660km phase change. When an avalanche occurs, a large volume of the cold materials rapidly descends to the bottom of the mantle. As a part of the return flow, a broad upwelling are generated and it breakups the supercontinent. However, this model has a problem of the location of the upwelling; there is no necessity for the induced upwelling to emanate from the part under the supercontinent.

Here, based on laboratory fluid experiments, we will argue the causal relationship between generation of mantle plumes and supercontinent cycle from aggregation to breakup. We will also discuss the timing and the location of the upwelling plumes within the supercontinent cycle.

Our experiments were conducted in a transparent rectangular tank containing a fluid with stratified density and viscosity as an analogue to the upper and the lower mantle. A thermal starting plume was generated 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 2-D temperature and compositional field measurements, we introduced Thermochromic Liquid Crystals (TLCs) method and Laser-Induced Fluorescence (LIF).

As approaching the rising plume head to the density interface, the convective flow of the plume head induced the divergent flow at the bottom of the upper layer by the mechanical (viscous) coupling between the layers. This produced the downwelling flow at the center of the upper layer (= axis of the underlying plume) and the convergent flow at the surface of the upper layer. After a while, a thermal boundary layer was formed at the interface and a ring-like diapir, which had 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. This secondary plume ascended and lead to the divergent flow at the surface of the upper layer.

This experimental result indicates that if we assume the continents move with the motion of the surface flow of the upper layer, the convergent flow in the earlier stage will lead to aggregation of the continents and formation of a supercontinent. In the later stage, divergent flow by the upwelling of the secondary thermal plumes in the upper layer will result in breakup of the supercontinent. The time scale that the plume breakups the supercontinent will be shorter than the observed survival time of the supercontinent because the upwelling plumes are generated from the shallower part, the 660 km boundary.