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Can plumes collapse?: Experimental results and applications to Iceland.

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Iceland has produced magma in a series of episodic events. From lava chemistry it has been inferred that the plume temperature decreased over the first 5 Myr by ∼50°C and for the next 3 Myr following continental break up it continued to oscillate by ∼25°C. Such data has been used to infer possible episodic collapse of the Iceland plume.

Collapsing plumes are not common fluid dynamical features. In thermochemical plumes it is possible to achieve collapse by varying the relative buoyancy due to chemistry and due to temperature. In thermal plumes however, with a constant heat source we would expect plumes not to collapse but to not continue to rise after reaching a point of neutral buoyancy. We expect thermal plumes, like those Earth's bottom thermal boundary layer is capable of producing, to either rise to the surface or be deflected but not to collapse.

We have designed an experimental setup to investigate the conditions that may lead to collapse in thermal plumes with constant heat sources. We used high-Prandtl number fluids with strongly temperature-dependent viscosities (Lyle Golden syrup and Liquidose 436) as analogues to Earth's high viscosity mantle in a cubic Plexiglas tank (26.5cm inner sides), heated by a circular 2cm diameter heater (flat with the base of the tank). We explored ΔTs between 3-60°C. The flow was visualized with shadowgraphs and an automated -3D Stereoscopic Particle Image Velocimetry (SPIV) system to measure velocities. In Lyle's Golden Syrup collapse occurred at ΔTs as high as 8°C, while in Liquidose 436 the 8°C ΔT run showed only partial collapse. The difference is not unexpected given the different physical properties. Partial collapse was seen even for ΔTs as high as 50°C. Both complete and partial collapse manifested themselves as downwelling flow in the central part of the conduit. Collapse stopped in the hotter plumes when the downwelling fluid met the hottest part of the conduit. The observed results suggest that diffusive time-scales are faster than the time-scales of buoyant rise. A naïve Rayleigh number analysis suggested that even a ΔT as low as 1°C is above Rayleigh critical for the size of the convecting region. We will also present preliminary 3-D velocimetry results. Our results imply a much wider range of fluid dynamical behaviours for thermal plumes, which suggests that the dynamics of Earth plumes is probably not as straight-forward as previously hypothesised.