Discussion of

The structure of thermal plumes and geophysical observations

by

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One way or another, the mantle convects. There is still discussion about whether the mode is whole mantle or layered and if it is driven primarily from the top. Radioactivity, secular cooling and strong plates influence convection and cause upwellings to be broad and migratory. Pressure and compositional effects cause the deep mantle to have very broad features. In any case, broad upwellings exist in the mantle, if only to replace the sinking slabs or to get rid of internal radioactive heat. These upwellings would exist even if the mantle were not heated from below and even if there were no lower thermal boundary layer (TBL). In the fluid dynamic literature buoyant upwellings are called plumes.

It was suggested that plate tectonics and normal mantle convection could not explain hotspots, melting anomalies and volcanic chains because normal mantle was too cold. A different small-scale mode of convection was proposed (Morgan, 1971). The defining characteristics of mantle plumes have changed with time but great depth, a TBL origin, high temperatures, rapid ascent rates, and low viscosity are the invariants. Initially, mantle plumes were treated as fixed, whole-mantle, chemically primitive or enriched and responsible for lifting and breaking continents and for driving plate tectonics. Plumes have been associated with anomalies in bathymetry, heatflow, gravity, chemistry, magma volume and location. An anomaly is with regard to some reference model. The reference model logically is one that has plate tectonics and normal mantle convection; anomalies are features that fall outside the ‘normal range’. Unfortunately, the reference model in discussions of plumes involves a homogeneous isothermal mantle, that has uniform depth, geoid and magma supply at ridges. All positive anomalies in elevation, geoid and magma supply are then attributed to mantle plumes. The paper by King and Redmond (this volume) provides a more realistic reference model.

There has been a tendency to regard mantle plumes as a distinct, secondary mode of convection but this has never been observed in any self-consistent numerical or laboratory experiment (Larsen and Yuen, 1997a). Plume studies have usually modeled a plume in isolation from the rest of the mantle. King and Redmond (this volume) do not do this but they use the term plume in the fluid dynamic sense, not as a distinct secondary mode of convection.

There has long been a problem of obtaining hotspot-like plumes (Larsen and Yuen, 1997a,b; McKenzie & Weiss 1975; Tozer, 1973), which must satisfy the requirements of being fast (up to

20 m/yr) and hot (> 200˚C) as compared to ambient mantle circulation and narrow (mantle plumes are usually modeled as 200-300-km-diameter vertical cylinders). There is also the issue of whether the lower boundary condition can be treated in isolation, in a self-organizing system and whether plumes can even form or survive in a convecting mantle (Nataf, 1991; Lenardic and Kaula, 1994; Anderson, 2002, 2005b).

In alternative models, hotspot and midplate volcanism are not due to a separate small-scale mode of convection; the dimensions of volcanoes and island chains are controlled by the lithosphere (cracks, rifts, dikes) and the dimensions of fertile inhomogeneities in the mantle; a partially molten asthenosphere is the source of magma.

The paper by King and Redmond (this volume) is an important contribution to normal mantle convection, not to plume theory as ordinarily understood. A TBL at the base of the mantle is inevitable but narrow, rapid upwellings under midplate volcanoes are not. If upwellings are 1000 km in radius, they are not the localized jets that Wilson and Morgan proposed, and they are not confined to the mantle just under the volcanoes. Normal mantle upwellings from internal heating are expected to be of this dimension and it is no surprise that volcanoes of all types, including midocean ridges, tend to be in these regions

If King and Redmond (this volume) endorse the idea of plate-scale convection, as their calculations indicate, as an explanation for features that others have attributed to narrow thermal plumes, then they are saying that mantle plumes as conventionally defined are unnecessary. Normal mantle convection and a partially molten asthenosphere have always been alternatives to plumes; it was the perceived narrowness and fixity of hotspots, and the assumption of a cold isothermal mantle, that motivated the idea that something other than plate tectonics and 'plate-scale' flow was going on.

It is now known that magmatism can occur anywhere, not just in extending, young, thin lithosphere or plume locales (e.g. Hofmann and Hart, 2007). These locations include old oceanic lithosphere, deep ridges, slow spreading ridges and cold mantle and near cold downwellings. If the coldest mantle can melt, then normal mantle, which can be 100˚C hotter, can melt a lot. Fertile blobs, then, with melting points 200˚C lower than peridotite, can be the source of melting anomalies. An assumption in the plume hypothesis is that the mantle everywhere is subsolidus except where there are ridges or plumes.

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