Discussion of

The Eclogite Engine: Chemical geodynamics as a Galileo thermometer

by

Don L. Anderson

2nd February, 2007, Don L. Anderson

Phipps Morgan in his comments of 31st January following Yamamoto et al. (this volume) raises "major challenges" to plate tectonic models. He favors a bottom-up, or plume, explanation for refertilizing the asthenosphere. He and his colleagues adopt a boundary-layer form of whole mantle convection, with fertile streaks introduced from below. This comment addresses these challenges, and calls attention to new publications relevant to the top-down and yo-yo mechanisms.

"Why does the MORB source have less thermal variability than that introduced into the mantle by subducting slabs…given the temperature difference between a subducting slab and the MORB source region…?" The simple answer is that slabs mainly cool other parts–deeper parts–of the mantle, while delamination from drifting continents, the yo-yo or water bucket effect, cools and removes heat from shallower areas. Neither process affects the temperatures in the surface boundary layer except at the delamination site and where the fertile blobs re-emerge to deliver their heat and magma.

Most models assume that MORB sources lie on a mantle adiabat and that variations in magma temperatures reflect lateral variations in mantle temperature. The potential temperature of a magma is calculated by cooling it by adiabatic expansion to P=0. This does not imply that the mantle has an adiabatic gradient nor does it yield the deep mantle geotherm. In the perisphere and Galileo thermometer concepts, the mantle is chemically stratified, with intrinsic density increasing with depth. It therefore has a conduction geotherm, modified by the passage of dense and buoyant sinkers. This geotherm starts out at about 10˚C/km and decreases to about 4˚C/km at 200 km depth. The adiabatic gradient is about 0.3˚C/km in a solid mantle heated entirely from below. In an internally heated mantle the gradient starts out superadiabatic and becomes subadiabatic at depth. A mantle cooled by subduction and delamination can also exhibit temperature maxima. The geotherm under these conditions will intersect the solidus but will continue to be superadiabtic to greater depth. If melting occurs at 200 km, then the temperature at 250 km, say, may be 200˚C higher. The asthenosphere can be hotter than the MORB potential temperature. Slabs mainly settle at greater depths and serve to cool the overlying mantle from below rather than internally. They displace deeper material upwards just as delaminated material is replaced by hotter asthenosphere. In steady-state boundary layer models, heated from below, one does not think in these terms. The sites of delamination and subduction cooling also migrate around the surface. They are not constantly cooling one part of the mantle.

Much of the upper mantle is cooled from below, by bottomed out slabs, and cooled from within, by delaminating blobs. These blobs are colder than ambient mantle but hotter than slabs; they may contain most of the radioactivity of the upper mantle. They are constantly sinking and rising, delivering heat to the surface. The temperature of the surrounding mantle is buffered by the melting temperatures of the low-melting constituents as well as by the near-constant temperature of the lower continental crust. A partially molten asthenosphere, or one with partially molted blobs, cannot be treated as a homogeneous subsolidus ideal fluid; melting anomalies have other causes than high absolute temperature.

"Why are there sharp transitions between volcanic and non-volcanic margins…[and] a rapid transition from OIB-like…basalts to…MORB during the initial formation of an ocean basin?"

This is addressed by Foulger et al. (2005), Foulger and Anderson (2005), and Natland (this volume). The shallow mantle along reopened sutures and collisional mountain belts is not uniform and is not the same as the mantle at mature ridges, because of trapped buoyant oceanic crust and delaminated continental crust. The mantle is not the well-stirred homogeneous fluid or marble-cake that is implied by the phrase "the convecting upper mantle".

A classic argument for deep mantle plumes involves the noble gases. I have argued that high $^3He/^4He$ ratios can be generated and preserved in shallow melt depleted mantle (Anderson, 1998). The implication is that high primordial/(radiogenic, nucleogenic) noble gas ratios ($^3He/^4He$, $^{22}Ne/^{21}Ne$…) characteristic of sources that have been attributed to plumes, can be achieved by involving a previously melted (depleted) mantle source rather than isolated, non-degassed primordial mantle. This refractory source (FOZO) can be a cumulate, or the continental or oceanic lithosphere. There is now experimental evidence in support of this trapping mechanism, for gases in general and for the noble gases in particular (Schiano et al., 2006; Heber et al., 2007). There are also new mass balance calculations in support of the delamination model from several groups (Plank, 2005; Hawkesworth and Kemp, 2006; David Scholl, personal communication, 2006). The mass flux exceeds the "hotspot" flux; the lower crust is recycled at much greater rates than the upper crust and must be an important component of the mafic blobs in the mantle.

Addendum, 8th February, 2007, Don L. Anderson

In their comment of 5th February, concerning the chapter of Sheth (this volume), Hooper and Widdowson (5th February, 2007) write that I assert that if "any one suggested result of the plume model is not obvious…the plume model is therefore void and [has] to be abandoned". I have nowhere said or implied anything like this. I *have* shown, repeatedly, that *none* of the predictions and assumptions of the plume hypothesis have been confirmed. Regarding convergence, the Deccan Traps erupted while India was converging with Asia; a plume was not splitting India or driving India away from Asia.

In his comment of 7th Feburary, 2007, on the same chapter, Widdowson defines a *mantle plume* as “a static, spatially restricted, mantle melting anomaly”. He is confusing *melting anomaly* or *hotspot* with *plume*; they are not the same (Anderson and Schramm, 2005). Except for the word “static” instead of “upwelling” or “buoyant” this definition applies to a fertile or low-melting-point blob, or delamination or rift-induced asthenospheric melting and upwelling. These are the mechanisms that best explain surface *melting anomalies*. A *mantle plume*, by contrast, is a *thermal* anomaly from a deep thermal boundary layer, for which there is no evidence.

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