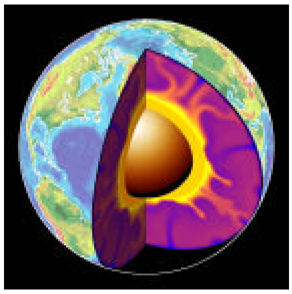
The Role of the Core in Mantle Plumes



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October 21st, 2004

Why Blame the Core?

There is an abundance of evidence from a range of fields suggesting that the Earth's core has a significant role in the initiation of mantle plumes and in many cases, the material they contain. Perhaps the most striking visual evidence is found in **seismic tomography**, which produced the image shown opposite, clearly showing large, low velocity anomalies extending from the surface to the core-mantle boundary (CMB). However, in order for seismologists to be able to test whether or not these anomalies are "plumes", great advances in tomographic technology are required, especially when wanting to resolve the plume tail (conduit).

Some other points to consider are,

1) Plumes provide a possible mechanism of **heat removal** from the core. Models of the Earth's heat budget are often short of around 20TW of outgoing energy, some of which could be transported by plumes.

2) Calculations have shown that in order for the **plume head size** to become large enough to generate large igneous provinces such as the Ontong Java Plateau and the Deccan Traps, the upwelling must originate at the CMB.

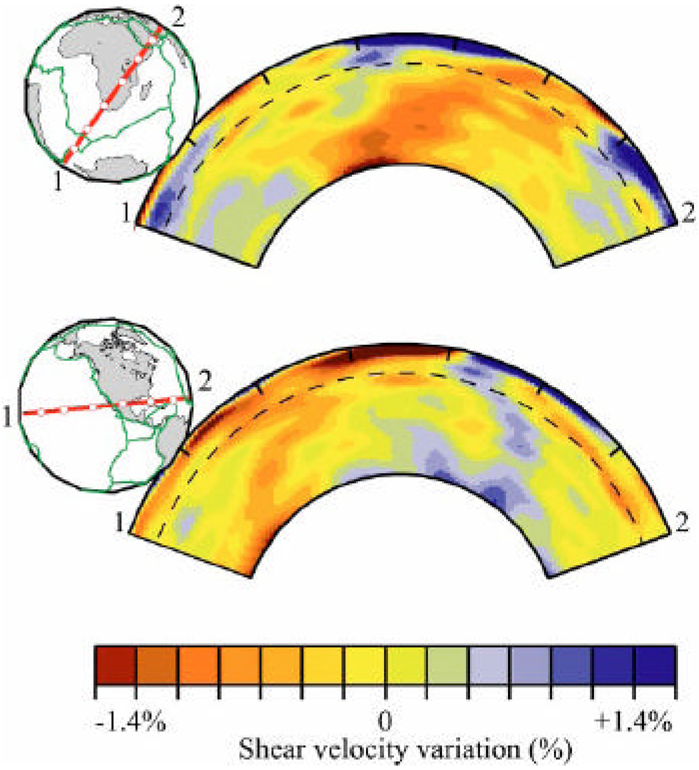


Figure 1. *Tomographic models are increasingly capable of identifying low velocity anomalies that are most likely linked with convective upwellings away from subduction zones. This figure shows cross sections through the tomographic model S20RTS (Ritsema et al. 1999) that illustrate the potential existence of deep seated anomalies that feed the African (A) and Pacific (B) hot spot regions.*

3) Extended periods of rapid, oceanic crustal production coincide with periods of no reversals of the Earth's magnetic field (e.g. Cretaceous "**superchron**"). If the rapid crustal production was the result of plume-fed flood basalt eruptions, a CMB origin for the plume could explain the prolonged period of normal polarity by removing a large parcel of heat from the core, hence destabilising convection in the outer core.

GEOCHEMISTRY - *Osmium*

During the crystallization of the inner core, Os preferentially partitioned into the liquid outer core, which is 300 times richer in Os than the mantle as a result. Therefore, if chemical exchange occurs across the CMB, any plumes which arise there should have eruptive products that are enriched in both ^{186}Os and ^{187}Os. Fig.2 shows that all OIBs have high $^{187}Os/^{188}Os$. This however, is largely the result of ancient recycled crust in the source. *Brandon* (1998) suggested that addition of <1wt.% outer core material to the plume would yield the $^{186}Os/^{188}Os$ ratios observed in Hawaiian lavas.

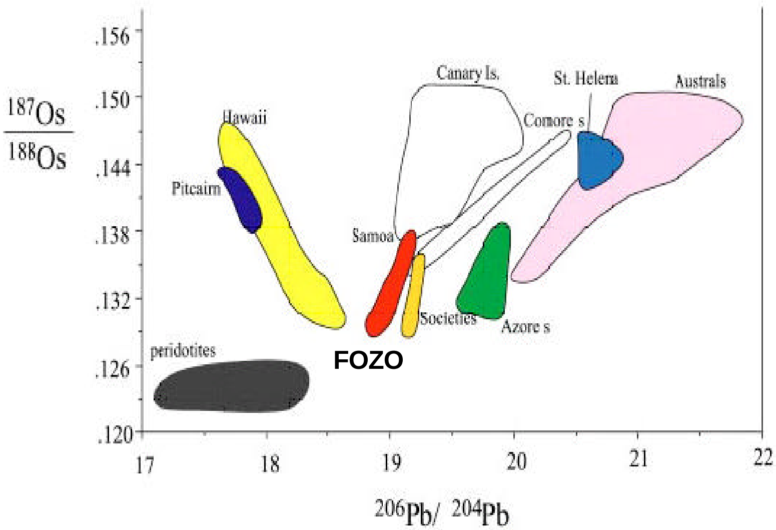


Figure 2. *Os-Pb isotope correlations for oceanic basalts. All OIB show elevated $^{187}Os/^{188}Os$ isotope ratios. Data plot shows elongated mixing arrays converging on the FOZO component. Van Keken et al. (2002).*

GEOCHEMISTRY - *Helium*

During the Earth's accretion, vast amounts of ^3He were trapped in the lower mantle. This has since been diluted by radiogenic ^4He, but $^3He/^4He$ values are still estimated to be an order of magnitude higher than that of the atmosphere (1Ra, where Ra= 1.38×10^{-6}). OIBs are typically enriched in ^3He, up to 42Ra (Iceland), and the most obvious cause of this enrichment is inclusion of lower mantle/CMB material in an upwelling plume. Ancient recycled crust will have a much lower concentration of ^3He than the atmosphere (i.e. Ra<1), and hence the high ^3He recorded in OIB lava flows cannot reflect a contribution from this source.

The "endmember" in OIB geochemistry that is most commonly cited as the origin of their high ^3He values is **FOZO** (focal zone). This is a deep mantle component, but critically, does not represent CMB material as it is low in Os. (Fig.2). However, given the lack of any known thermal boundary layer in the deep mantle other than its interface with the outer core (CMB), it seems that plumes do in fact rise from this boundary.

The mixing fields of all OIBs all point toward FOZO, suggesting that the "plume" that formed them passed through the deep mantle. (Figs.2 & 3)

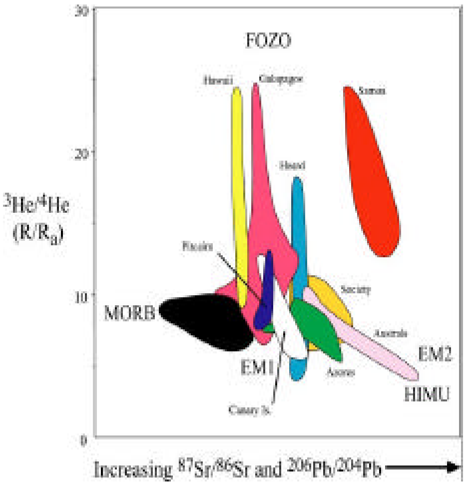
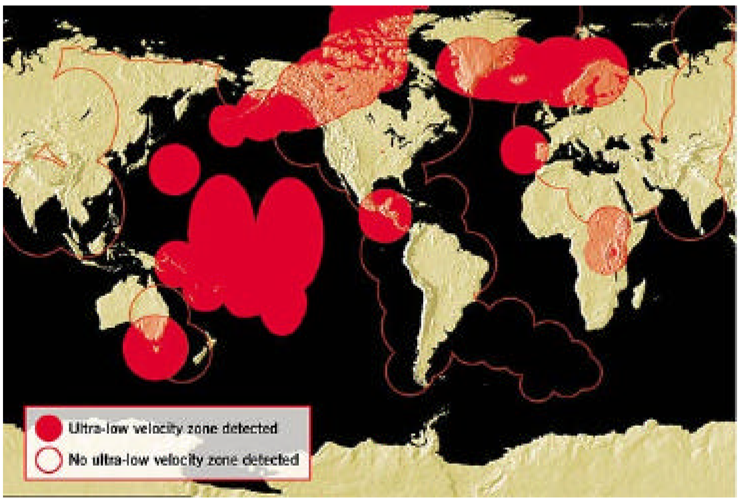


Figure 3. *Two-dimensional projection of a 3D plot of Sr, Pb, and He isotopes in oceanic basalts, viewed with the Sr-Pb plane in the horizontal. Mantle end-members from Hauri et al. (1994). The data converge toward a component high in 3He/4He (FOZO), with Sr and Pb isotope ratios distinct from MORB.*

CORE NOT MANTLE?

Basaltic magmas (i.e. the main constituent of recycled crust) tend to have Pt concentrations lower than or equal to the primitive upper mantle (PUM). Therefore, high Pt/Os ratios found in these magmas is a function of extremely low Os rather than high Pt. A shallow model therefore, not invoking the lower mantle at all, whereby ancient recycled crust mixes with PUM and produces OIBs, requires an extremely high proportion of the mixture to be recycled crust in order to produce the observed $^{186}Os/^{188}Os$ ratios in Hawaiian lavas. (*Brandon* (1999) suggests 75-90%). This requires a portion of the plume to be dominated by eclogite rather than lherzolite. Such a source would generate mainly tonalitic magmas rather than the observed tholeiitic basalts and picrites.



ULTRA-LOW VELOCITY ZONES (ULVZs)

ULVZ's are areas of layered, anomalously low seismic velocity that lie on the CMB. Areas where ULVZs have been detected correspond well with hotspots on the surface. It would not therefore, be unreasonable to suggest a link. Low velocities suggest that these areas of the D'' layer contain a large proportion of molten material (or at least, less solid), and it is hypothesized (*Garnero* 2000) that plumes are generated here because the D'' layer is less gravitationally stable due to the "molten" material.

Figure 4. *Global ULVZ distribution map. Areas in red (ULVZs) correspond well to known hotspot localities*.

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