Julian Winter. 2004

WHAT IS A PLUME?

Definition Of A Plume

"Mantle plumes are buoyant mantle upwellings that are inferred to exist under some volcanic centres"- Davies (1999). Are they really that vague?

PLUME GENESIS & CHARACTERISTICS OF PLUMES

Head & Tail: *Whitehead & Luther* (1975) did modelling to better define *Morgan's (1971)* plume theory. Essentially heated a tank of fluids from the base. Such heating creates an adjacent Thermal Boundary Layer (TBL) at the base. This layer becomes less dense and less viscous than overlying fluid (mantle). This generates an upwelling diapir whose leading edge has a large, *spherical head* followed by a *thin trailing tail* (*fig. 1)*. Also get thermal entrainment of surrounding material into the plumes' 'head' caused by circulation within, driven by continuous arrival of hot material from the tail.

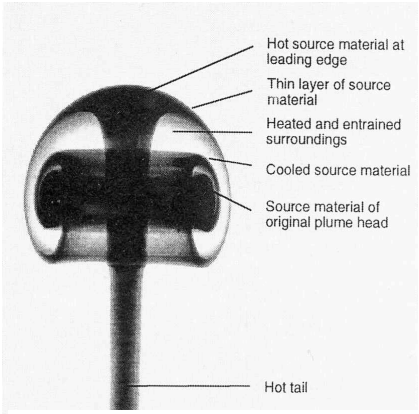

Fig 1. laboratory experiment of plume showing head & tail. *Griffiths & Campbell 1990*

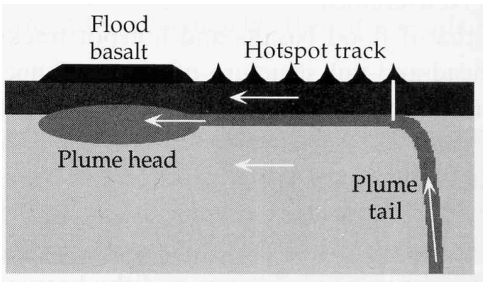

Fig 2. diagram shows island chain evolution. *G. F. Davies 2003.*

Flood basalts: *Griffiths & Campbell (1990)* went further and said that the plume head (200K hotter than surroundings) hit the base of the lithosphere, spread out and caused melting of the upper 10%. Experiments put lateral spreading to at least 2000-2500km, a dimension similar to continental flood basalts (CFB) extent e.g. *Deccan traps* and *Karoo volcanic field*. As magma supply from the plume head wanes, a narrower region (~200km wide) of plume tail melting replaces it (*fig. 2).* They proposed the surface expression of plume head melting was thus CFB's

Radial dykes: e.g. *Hudson bay.* Require point source with outward injection of magma i.e. upwelling plume. Radial pattern implies *cylindrical shape* to plume.

Their chemical make-up

A deep source for plumes has been suggested for the following reasons:

- Their lavas are more enriched in incompatible elements than in MORBs.
- Enriched in primordial Helium (He^3). The lower mantle retains its He^3 as it hasn't been able to lose it to the atmosphere.
- Isotopic data indicates that Hotspot sources don't show any mixing with or entrainment of, depleted, *upper* mantle.

HOW ARE THEY FORMED?

Morgan (1971), Whitehead & Luther (1975), Griffiths & Campbell (1990), *Hager et al (1999)* and others have suggested that plumes come from, and are a direct consequence of, the **Core Mantle Boundary** (CMB). However alternative mechanism have been put forward and are discussed below:

1) Subduction results in plumes: slab is heated as it sinks into **deep mantle** → buoyant & less viscous → melts preferentially to surrounding mantle due different chemical composition (lowers its solidus) → produces plume signature due to enrichment of radiogenic elements during initial formation of the oceanic lithosphere → thus plume material consists of re-melted oceanic lithosphere, not lower mantle. *(Ivanov 2003)*

2) A TBL exists at 1600km: → possibly formed during the earth's differentiation or from recycling of subducted mafic crust in the Archaean → *about 4% denser than overlying mantle* → the subducting slabs hits this layer → causes a high spot next to the corresponding slab's indentation → 'high' may transform into a plume → such bombardment of TBL by slabs makes its surface irregular → so plumes **depth may also vary**. *(Kellogg 1999)*

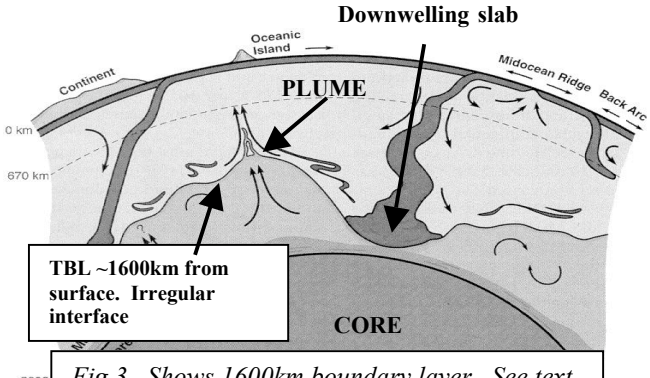

Fig 3. Shows 1600km boundary layer. See text for discussion. Kellogg *et al* 1999.

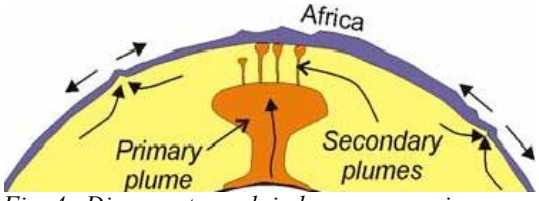

Fig. 4. Diagram to explain how some regions have a greater concentration of hotspots e.g. Africa. Ritsema et al, 1999

3) Have heterogeneous & chemically stratified mantle: → lower mantle's stratification results in focusing of heat from the CMB → results in doming into upper mantle and/or transition zone (**Superswell**) → This shallower TBL results in plumes issuing from the tops of the 'Dome'→ e.g. *French Polynesia* (Pacific) & under *Africa* (*fig. 4*). *(Davaille 1999)*

4) Top down Models: → stresses at plate boundaries → transmitted to intra-plate regions → cracking/stretching within plates → allows exploitation by upper asthenosphere i.e. upwelling from **shallow source**.

SUMMARY

Characteristic	Not…
❑ Thermal Swell	❑ always e.g. *Canary Islands*
❑ Radial dykes	❑ associated with *all* Flood basalts
❑ Flood basalts	❑ at all supposed plume regions e.g. Hawaii
❑ Age progression of island chains	❑ at *Austral-Cook islands* –multiple plumes?
❑ Linear chain of islands	❑ At *Cape Verde* for example
❑ Deep, intermediate or shallow source	❑ possible to confirm, seismic tomography can't penetrate deeper than transition zone

CONCLUSION

Not all these features are found at every flood basalt province or island chain. *Courtillot (2003)* suggests that not all the criteria needs to be met to suggest a plume mechanism. Is this reasonable? With such a 'grey definition of the word 'plume' it maybe used better as a generic term for any anomalous melting *within* plates.

References: Courtillot V., Davaille A., Besse J., Stock J. Three distinct types of hotspots in the Earth's mantle. *Earth. Planet. Sci. Lett.*, Vol 205, p295-308, 2003. Griffiths, R. W, Campbell, I. A. 1990. stirring and structure in mantle plumes. Earth Planet. Sci. Lett. Vol 99, p66-78. Kellogg, L.H. Hager, B.H. Van der Hilst, R.D. 1999. Compositional stratification in the deep mantle. *SCIENCE*. VOL 283 p19-22. Morgan W.J. 1971. Convection plumes in the lower mantle. *Nat ure*, **230**, 42-43. Ritsema J., van Heijest H.J., Woodhouse J.H. 1999. Complex shear velocity structure imaged beneath Africa and Iceland. *Science*, Vol **286**, 1925-1928. Whitehead, J.A. & Luther, D.S. 1975. Dynamics of laboratory diapir and plume models. J. Geophy. Res. Vol 80, p705-15. **WEB**: Ivanov A.V. (2003) Plumes or reheated slabs? HotSlabs.html. Ernst, R.E (2004). Characteristics and Origin of Giant Radiating Dyke Swarms; http://www.mantleplumes.org . **FUTHER READING**- Davies, G. 2003. Dynamic Earth: plates, plumes & mantle convection.