How HOT are hotspots?

Are the predictions of the plume hypothesis borne out by observation?

What is the plume hypothesis?

•Proposed by Morgan (1971)[1]. *Hot upwellings of relatively primordial material rising from the deep mantle originating from a 'thermal boundary layer' and feed 'hotspots'.*

•Plumes were thought to rise from the D'' layer at the CMB.

•Concept of a plume allows for the return flow of material to the surface relative to subducted slabs (fig 1).

How hot is the mantle?

• Scientists are not agreed on ambient mantle temperature. Mantle plume geologists calculate that the temperature of 'normal' mantle is 1280°C +/- 20°C[2]. Geophysical estimates suggest that the temperature is closer to 1400°C +/- 200°C[3], with variations within this estimate caused by plate tectonic processes.

• >100°C difference between these estimates causes great discussion on whether the temperatures observed at hotspots are excess temperatures (compared to geologists calculations) or whether the observed values lie within the calculated geophysical range.

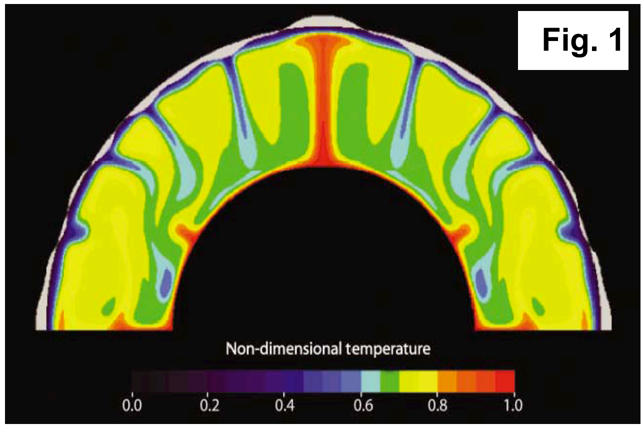


Fig. 1

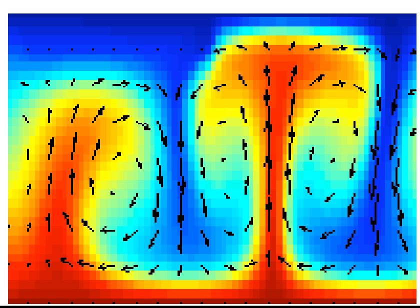
Numerical simulation of mantle plumes.
red = hot upwellings
blue=cold downwellings

Keifer and Kellogg, 1998[5]

How hot are hotspots?

• At 'normal' mantle temperatures peridotite cannot produce melt in the correct volumes or rate of that seen at hotspots[5]. High mantle temperatures are therefore required (Tp >1600°C)[4].

• Originally it was thought that plumes had a cold head and hot tail due to entrainment of mantle in the rising plume[6] (Fig.2). Recent models suggest the opposite with entrainment having little effect on plume temperature[7].



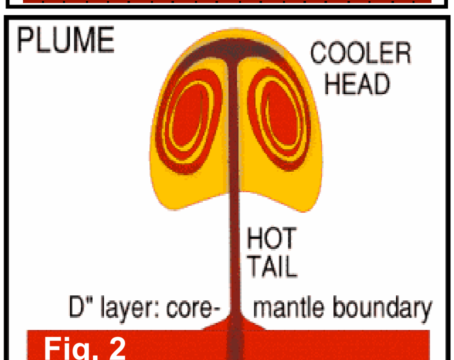


Fig. 2

Starting-plume head temperatures

• See Table 1 (overleaf) for temperature data. It should be noted that the starting plume head values of Thompson & Gibson[8] are 100-250°C hotter than the reported values for present-day Hawaiian and Icelandic plumes and 100°C hotter than even the highest geophysical estimates of 'normal' ambient upper mantle temperatures.

Contrasting present-day plume temperatures

• Hawaiian and Icelandic plumes were found to be at 150-300°C above global asthenospheric MORB-source mantle (Tp of 1450-1600°C[9]).

• Conversely it has been found that temperature of the North Atlantic Igneous Province and normal mid-ocean ridges was very similar (varying only by 20°C)[10].

• Schilling (1991)[11] inferred mantle temperatures from bathymetry to produce an excess of between 162-278°C.

Table 1. Examples of starting-plume head potential temperatures

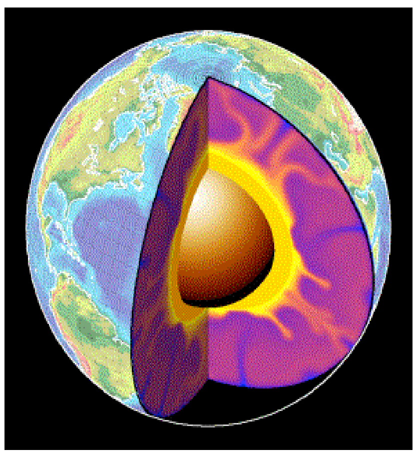
Tp (°C)	Location	Method	Reference
1550-1600	Iceland starting-plume	Forsteritic olivine in picrites. West Greenland/Baffin Island	Gill et al. (1992)[12]
1600	Galapagos starting-plume	Komatiites	Nisbet et al. (1993)[13]
>1500	Ontong Java Plateau starting-plume	Crustal thickness	Fitton and Godard[14]
1700	Tristan starting-plume	Olivine phenocrysts in komatiites (Namibia)	Thompson and Gibson (2000)[8]

What is the source for hotspots?

- Farnetani and Richards (1994)[7] produced the correct volumes of melt typical at flood basalt regions with a model relying on high plume temperatures (1600-1700°C). This produced picritic melt from a pyrolitic source. Picrite is not the observed rock type at hotspots.
- Flood basalts have higher FeO for a given amount of SiO2 compared to MORB's.
- Hoffman and White (1982) first proposed from trace element and isotopic data that plumes require a more basaltic source than that predicted for MORB and that this component may come from subducted ocean crust which would represent an eclogitic source.
- Eclogite has a lower solidus and thus would enhance melt productivity if present as a component of plumes. This means that melting can occur at lower temperatures (see Fig. 3).

Summary

- There is disagreement over ambient mantle 'normal' temperature.
- 1300 +/- 20°C OR 1400 +/- 200°C.
- There is also disagreement over how to measure plume temperatures.
- Starting-plume head temperatures can be inferred by crustal thickness, phase equilibria and bathymetry data to calculate starting-plume head temperatures.
- Present-day plume temperatures can be measured from heatflow and petrology.
- Finally, there is disagreement over source composition.



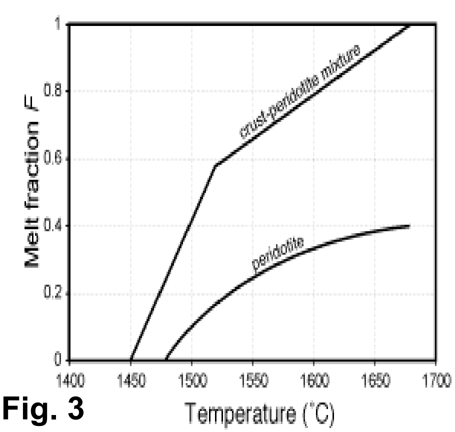


Fig. 3

1. Morgan, W.J. (1971). *Nature*, 230, 42-43. **2.** McKenzie, D., and Bickle, M.J. (1988). *Journal of Petrology*, 29 (3), 625-679. **3.** Anderson, D.L, and Bass, J.D. (1984). *Geophysical Research Letters*, 11. 637-640. **4.** Cordery, M.J., Davies, G.F., and Campbell, I.H. (1997). *Journal of Geophysical Research*, 102 (B9). 20179-20197. 5. Kiefer, W.S., and Kellogg, L.H. (1998). Phys. Earth Planetary International, 106. 237-256. **6.** Griffiths, R.W., and Campbell, I.H. (1990). *Earth and Planetary Science Letters*, 99. 66-78. **7.** Farnetani , C.G., and Richards, M.A. (1994). *Journal of Geophysical Research*, 99. 13813-13833. **8.** Thompson, R.N., and Gibson, S.A (2000). *Nature*, 407, 502-506. **9.** Watson, S., and McKenzie, D. (1991). *Journal of Geophysical Research*, 83. 5989-6004. **11.** Korenaga, J., and Kelemen, P.B. (2000). *Earth and Planetary Science Letters*, 184. 251-268. **12.** Schilling, J.G. (1991). *Nature*, 352. 397-403. **12.** Gill, R.C.O., Pederson, A.K., and Larsen, J.G. (1992). In: Magmatism and the Causes of Continental Break-up (eds Storey,B.C., Alabaster, T., Pankhurst, R.J.) 335-348 (Special Publication 68, Geological Society, London). **13.** Nisbet, E.G., Cheadle, M.J., Arndt, N.T., and Bickle, M.J. (1993). Lithosphere 30, 291-307. **14.** Fitton, G.J., and Godard, M. In: Origin and evolution of the Ontong Java Plateau. (Geological Society Special Publication).

Natalie Starkey