Have plumes been detected seismologically?

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The majority of volcanic activity can be explained by the plate tectonic theory. However hotspot regions are a little harder to reconcile to this model. In *1971, Morgan* provided the **The Plume Theory** as an explanation for these volcanic inconsistencies. This hypothesis suggests that hotspots are underlain by narrow upwelling plumes which originate from the core-mantle boundary (CMB). Over the past three decades this model has been refined and until *2000* was a popular theory with little opposition. Today, however there is increased debate as to whether plumes actually exist.

A popular way to investigate the presence of plumes is to track seismic waves through the mantle.

Methods and **limitations**:

1. **Seismic tomography:** Measures the average speed along the ray path via the use of seismometers.

Examples include:

(i) *Teleseismic*- used when analysing the upper few 100km of a particular area. Unfortunately some smearing may occur since rays are not isotropically distributed.

(ii) *Whole-mantle*- uses large global data sets, to derive 3D models of the entire mantle. However, sometimes errors occur because of uneven distribution of rays from earthquakes and seismometers throughout the world. Also, bodies under the size of 500km can not be resolved.

(iii) *Surface-wave*- can sample crust and upper mantle which body waves do not. Often used in conjunction with body-wave data in whole-mantle tomography.

2. **Receiver functions:** Detects the thickness of the transition zone by bouncing rays off the two

discontinuities at 410km and 660km depth. Upward mantle flow, such as a plume, produces thinning of the transition zone since the 660km boundary elevates and the one at 410km depth becomes depressed.

3. **Multiple ScS:** Shear waves reflected from the CMB, when observed close to epicentre of earthquakes

they have a near vertical ray path through the entire mantle. These waves are ideally suited to vertical plume detection.

4. **Plume waves:** Zones of low velocity trap energy and act as wave guides, along which waves propagate

for large distances. Plumes should therefore be ideal for supporting such waves. None have yet been discovered.

Which seismological signals do we look for when searching for plumes in the mantle?

- Large areas of unusually **low velocity**. A plume would slow down seismic waves because it is made of hot buoyant rock.
- **Bulbous shaped head** with a **thinner stem**.

However, 1)Scientific controversy exists over the definition of the plume, thus making it more difficult to detect them seismologically.

2)Various factors affect the speed of seismic waves, for example, ***temperature*, *pressure*, *rock composition*, *melting*, *anisotropy* and *anelasticity*.** Thus, anomalously low velocities in the mantle may not automatically indicate the presence of a plume.

3)**Graphical representation** of seismological data may distort the true velocity signals, e.g. colour can make some features appear more prominent than others (*Julian*).

Case studies of 3 hotspot locations

Evidence for the presence of deep mantle plumes:

- *Hawaii*: In *1998, Russell et al.* discovered an unusually **low velocity region**, indicative of a plume, nearly 1000km SE of Hawaii. They explained its distance from Hawaii as due to **"mantle wind"**. The actual location of the low velocity region was disputed by *Bréger and Romanowicz, (1998*), but the regional imaging of the area under investigation can be difficult due to its remote location. However, using a different method of receiver function, *Li et al. (1999)* found a thinned transition zone beneath Hawaii and concluded that it was due to a plume. An alternative theory, suggested by *Foulger*, is that the Hawaiian hotspot has been caused by a **tear in the plate**, but no evidence of a puncture has been found. Recent work carried out by *Montelli et al. (2004)*, using a new method of **global tomography** (finite-frequency tomography), came to the same conclusion as *Zhao (2001)* that the Hawaiian hotspot is fed by a deep mantle plume. Some investigators are sceptical of the new seismic data.
- Other examples: *Ascension, Azores, Canary, Easter, Samoa* and *Tahiti (Montelli et al., 2004).*

Evidence of the presence of shallow plumes:

- *Iceland*: *Bijwaard and Spakman (1999)* produced the first tomographic images of the entire mantle beneath the Iceland hotspot. They deduced that there was a narrow low-velocity anomaly below Iceland which went down to the CMB. *Zhao (2001)* also concurred with these findings. However, in *2000 Foulger et al.* produced teleseismic images of a low wave speed anomaly only as deep as 400km beneath Iceland and claimed that the upward flow of mantle did not extend as far as the transition zone. Using, whole-mantle tomography, *Ritsema et al. (1999)* did not uncover evidence that the Iceland hotspot was formed by a plume originating from the lower mantle. *Allen et al. (2002)* and *Montelli et al. (2004)* have used a range of seismological techniques to further this theory, and came to the conclusion that the Iceland plume can clearly be resolved only in the upper-mantle.
- Other examples: *Bowie, Eastern Australia, Eifel, Etna, Cocos-Keeling, Galapagos* and *Juan de fuca/Cobb (Montelli et al., 2004).*

Absent plumes:

- *Yellowstone*: Originally described by *Morgan (1972)* as a typical deep plume hotspot, with Yellowstone the plume head and Snake River Plains as the tail. More recent research suggests that the low velocity anomaly does not extend as far as the lower mantle. *Christiansen et al. (2002)* summarised the findings and suggested that there is no seismic evidence for a deep-mantle plume. Using teleseismic tomography they claimed that it only extended to approximately 200km depth, whilst the receiver function method revealed that there was no

thinning of the transition zone. Finally, whole-mantle tomography reveals that there is no evidence for low velocity anomalies (of greater that a few 100kms) in the lower mantle nor the lower region of the upper mantle in the Yellowstone vicinity *(Ritsema et al, 1999)*. *Montelli et al. (2004)* have gone as far as to say that there is no evidence for a substantial plume.
- Another example: *Macdonald Island* *(Montelli et al., 2004)*.

Conclusion:

Low velocity anomalies have been detected within the mantle under many hotspots, however there is still dispute over whether they can be called plume structures. Certain scientists do not accept them as plumes since they do not exactly fit the deep-mantle plume model and have developed new theories. Because there are limitations in imaging Earth's interior, new data and more effective analysis techniques are required. Perhaps by combining seismic evidence with geochemical observations, we will get a clearer picture of what exactly is happening underneath hotspots. The PLUME research project on Hawaii may provide greater insight into the debate as to whether or not plumes really exist.

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