The Emperor and Hawaiian Volcanic Chains

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For about 20 years there has been no serious challenge to the deep thermal mantle plume hypothesis for the Hawaiian and Emperor chains, despite the fact that many features do not conform to this hypothesis. These include:

1. The great "bend", near the Mendocino fracture zone, where the Emperor seamount chain ends and the Hawaiian chain begins does not result from a change in direction of motion of the Pacific plate [*Norton*, 1995; *Richards and Lithgow-Bertelloni*, 1996; *Raymond et al.*, 2000] (see Figure). The collision of India and Asia has been ongoing for much longer than the time taken for the bend to form, and this has little effect on the motion of the Pacific plate [*Richards and Lithgow-Bertelloni*, 1996]. The driving forces of plate tectonics are mainly thermal (ridge push and slab-pull) and the integrated effect, which dominates the direction of plate motion, cannot change rapidly, although local stresses and resisting forces can.

2. The locus of active volcanism has not remained fixed in any reference frame except itself [*Clague and Dalrymple*, 1987; *Tarduno and Cottrell*, 1997]. It moved south by ~ 800 km relative to a geographic reference frame while the Emperor Seamount chain formed [*Butt*, 1980; *McKenzie et al.*, 1980]. At the bend, the hotspot migration rate increased from ~ 7 cm/year to ~ 9 cm/year relative to the Pacific sea floor. The Hawaiian and Emperor chains may be separate and independent phenomena.

3. The Emperor chain began at or near a ridge, as shown by MORB-like ^{86}Sr/^{87}Sr values at the oldest end [*Keller et al.*, 2000], Pacific plate palinspastic reconstructions [*Engebretson et al.*, 1985; *Smith*, 2003], and the elastic thickness of the lithosphere beneath the northern Emperors [*Watts*, 1978]. This is a coincidence in the plume hypothesis. Many other hotspots are also on ridges or their tracks started on ridges.

4. There is no evidence for a Hawaiian "plume head". Oceanic plateaus are not subductable [*Abbott et al.*, 1997], and if a "plume head" had existed it would have been scraped off, accreted or obducted onto the Aleutian/Kurile/Kamchatka arc. There is no evidence for such material. Alternative hypotheses for the chain e.g., propagating cracks, stress-induced

volcanism, do not require a large igneous province at the beginning of the chain, but this association is fundamental to the plume hypothesis [*Campbell and Griffiths*, 1990; *Campbell and Griffiths*, 1993].

5. The volume flux along much of the chain has typically been ~ 0.01 km^3/yr. It dropped essentially to zero for ~ 10 Myr following the bend, but over the last 5 Myr has been an order of magnitude greater than the average rate [*Bargar and Jackson*, 1974, B. Eakins, USGS, unpublished results] which is similar to current Pu'u 'O'o eruption rates of 0.113 km^3/yr. The eruption rate correlates with the propagation rate of the melt locus, which has doubled over the last 2 Myr [*Shaw et al.*, 1980; *Clague and Dalrymple*, 1987]. Magmatic rate would be expected to be anticorrelated with migration rate for a plume source with a steady supply rate and, in the plume head-tail model, to decline with time. This is the opposite of what is observed. Thermal models do not explain the high flux rate beneath thick plates, where the top of the productive part of the melting column is missing [e.g., *Cordery et al.*, 1997].

6. Heat flow across the Hawaiian bathymetric swell shows no significant anomaly [*von Herzen et al.*, 1989; *Stein and Stein*, 1992; 1993], and the swell surrounding the southernmost part of the Hawaiian chain cannot therefore be explained as a thermal effect. In the plume model it must be attributed to compositional effects with no discernible thermal effect at the surface [*Liu and Chase*, 1989; *Sleep*, 1994]. Other models do not have this problem.

7. There is no discernable thermal rejuvenation or thinning of the lithosphere as it passes over the site of active volcanism, as predicted in the plume hypothesis.

8. Petrological estimates of the temperature anomalies beneath Hawaii compared with ridges vary from zero to a maximum of 200˚C [*Green et al.*, 2001; *Gudfinnsson and Presnall*, 2002]. This is no greater than the range observed for ridges away from hotspots relative to the mean ridge temperature. Plume models typically require temperature anomalies of 200-600˚C [e.g., *Cordery et al.*, 1997]. A small change in temperature, volatile content or fertility of the upper mantle can lead to a large change in the extent of partial melting and melt volumes [*Yaxley*, 2000; *Green et al.*, 2001; *Asimow and Langmuir*, 2003].

9. The petrology of Hawaiian lavas suggests that the melt comes from ~ 80 – 120 km depth or shallower – near or above the base of the lithosphere. No petrological data require a deeper source.

10. In addition to not requiring a hot source, the geochemistry of Hawaiian basalts does not require a deep mantle source. The ultimate origin of OIB material has been suggested to be the deepest mantle, but may also be old mantle wedge material, the asthenosphere, and a shallower layer which accumulates subduction-zone products [*Anderson*, 1989; 1994; 1995; 1996]. In the deep-plume model, subduction-zone material is carried from the surface down to the core-mantle boundary and back up in the core of the plume [*Hofmann and White*, 1982]. This is inconsistent with the widespread distribution of OIB at rifts and seamounts throughout the Pacific. The geochemistry varies geographically and temporally. *Mukhopadhyay et al.* [2003] report variations in $^3He/^4He$ ratio of up to 8 Ra during a single century in Kauai volcano, and spatially, such that different volcanoes do not appear to be fed

by the same magma source. “End-member” and principal-component interpretations require at least four different source components to explain the geochemistry of Hawaiian lavas, which suggests a spatially distributed, compositionally inhomogenous, and temporally variable source that is sensitive to shallow lithospheric features. High maximum ^{3}He/^{4}He ratios have been attributed to a lower-mantle component, but this interpretation flawed [*Anderson*, 1998b; *Anderson*, 1998a; *Foulger and Pearson*, 2001; *Meibom et al.*, 2003]. Hawaiian basalts exhibit a wide variation in helium contents and ratios and generally have low ^{3}He contents.

11. Seismic tomography reveals no plume-like low-wave-speed anomalies in the upper ~ 150 km under the big island [*Ellsworth*, 1977; *Wolfe et al.*, 2002]. Shear waves from a large earthquake there in 1973, that reflected off the core and registered on a seismometer on Oahu (*ScS* waves), indicate that the average *S*-wave speed of the mantle beneath the Hawaii region is higher than the average beneath the southwestern Pacific ocean [*Best et al.*, 1975], and that the propagation efficiency is high, contrary to expectations for regions of high temperature or partial melting (see abstract by B. Julian, this conference). Whole-mantle tomography [e.g., *Ritsema et al.*, 1999] reveals that the mantle beneath whole southern half of the Pacific ocean has low wave speeds, and on the scale of resolution of these studies (a few hundred km) Hawaii is not anomalous compared with the region as a whole. Thick pancakes of high-wave-speed material, that might be expected to characterize plume heads beneath the lithosphere or the 650-km discontinuity, have not been detected.

    Beneath the Hawaiian region, transition zone thickness [an index of mantle temperature *Anderson*, 1967] is ~ 229 km [*Gu and Dziewonski*, 2001]. This is ~ 13 km thinner than the global average of 242 km, but not significantly thinner than the transition zone throughout much of the central Pacific and other oceans.

Contrary to popular belief and countless textbooks, courses and web pages, Hawaii is poorly explained by the plume model. A fully quantified alternative hypothesis is long overdue.

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