Discussion of

Plate velocities in the hotspot reference frame

by

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27th January, 2007, Alan D. Smith

A difficulty arises in the plum-pudding plume model (Morgan and Phipps Morgan, this volume; Yamamoto et al., this volume) with regard to Pt-Os isotope systematics. The $^{186}Os/^{188}Os$ ratios in the MORB-source mantle, as indicated by the isotopic compositions of abyssal peridotites ($^{186}Os/^{188}Os$ = 0.119830 - 0.119838), are generally lower than in intraplate volcanic rocks (Hawaiian picrites and Gorgona komatiites; $^{186}Os/^{188}Os$ = 0.119831 - 0.119850). In standard plume models, where MORB and intraplate volcanic rocks are derived from distinct isolated reservoirs, the isotopic differences are explained by the addition of approximately 0.5 weight percent outer-core material ($^{186}Os/^{188}Os$ = 0.119870) to a plume (Brandon and Walker, 2005, and references therein).

In the plum-pudding plume model, the asthenosphere is fed by plumes generated from the D" layer at the core-mantle boundary. MORB and intraplate volcanic rocks should therefore have similar $^{186}Os/^{188}Os$ unless a core-derived Os component could be selectively removed on melting of a plume. Such a scenario would seem unlikely as MORB and intraplate volcanic rocks have lower Os content than mantle peridotites, suggesting Os partitions into the mantle on melting. A hypothetical plume comprising 30% recycled basaltic oceanic crust, 69.5% oceanic lithosphere, 0.5% outer-core material, would have an Os content of ~3.8 ppb, and would be unlikely to be depleted of Os by generation of OIB/picrites which have 0.03 to 1.0 ppb Os. The similar Os contents estimated for MORB-source mantle (~3.3 ppb Os) and plumes would fit the plum-pudding plume model, but the variation in $^{186}Os/^{188}Os$ is not consistent with such a model.

31st January 2007, Warren B. Hamilton

The fixed-plume concept—narrow buoyant jets of hot material rise from the deep mantle and burn through overpassing lithosphere plates to produce tracks of volcanoes that define the motions of the plates over the bulk Earth—was developed in large part by W.J. Morgan, and was anchored to the younging of the Hawaiian chain of volcanoes and seamounts east-southeastward from the Emperor elbow. The speculations by Morgan and Phipps Morgan (this volume) take this notion to extreme form. The material and excess heat (none is needed) of the globe-girdling asthenosphere are carried from the basal to the shallow mantle by scores of plumes. Almost all mentioned intra-plate volcanism, much intra-plate deformation, and much plate-margin volcanism is a direct or indirect product of plume-borne heat and material. The tens of thousands of small Pacific seamounts are unmentioned; and it is unclear why only a sizeable fraction of spreading-ridge magmatism is a byproduct of plumes.

The concept of globally fixed plumes has become progressively harder to defend against voluminous contrary evidence, including multidisciplinary disproof of the critical notion that the Emperor chain of seamounts tracked pre-Hawaiian-chain motion of the Pacific plate, but Morgan and Morgan (this volume) update the rationalization that plumes are approximately fixed from the deep mantle to the surface, and thus that plume tracks, as inferred from whatever surface features can be attributed to hypothetical plumes, define an absolute-motion framework for lithosphere plates. They show that the azimuths of their selection of hotspot tracks approximately accord with a fixed global frame. A temporal progression along a track is not required: many of their tracks are undated, or have ages incompatible with predicted progressions, or have reliable dates demonstrating simultaneous activity throughout their lengths. Hypothetical track velocities are assigned from a plate model that assumes the postulated fixed frame. The descriptions and rationalizations of “hotspots" in the electronic supplement summarize the substance behind the inferences.

Most of the hotspots chosen are in the oceans, where I lack the detailed familiarity needed to properly evaluate what is being done—but severe selectivity obviously is being applied. “Tracks” are identified by the fit of their azimuths to the model. Some azimuths of possible tracks that do not fit are explained by diversion of plume materials along fracture zones, spreading ridges, or lithosphere changes. Jan Mayen “is not a hotspot but rather [is] due to channeled asthenosphere flow from Iceland” (electronic supplement, p. 5). The Azores define no track but must record a plume, so a track close to the wanted direction is rationalized by assuming that some of the islands are “formed by channeled flow from the hotspot to the mid-Atlantic, and that Santa Maria is due to flow from the hotspot to a minor spreading center along the East Azores Fracture Zone” (electronic supplement, p. 4). The purported hotspot track defined by Réunion and Mauritius fits the model poorly, so its azimuth is adjusted because “Mauritius [magmatism] is ‘pulled toward’ the fracture zone at the eastern side” (electronic supplement, p. 19) Pukapuka trends in the right direction but is too fast, so it “marks a narrow ‘river’ of asthenosphere” (electronic supplement, p. 66). Adjusted and synthesized azimuths are plotted as “observed” on the figures.

I am most comfortable with the North American plate—and there it is obvious that the model is constrained only by selective use of sparse data that fit. Absolute motion of the plate is defined by Morgan and Morgan (this volume) with the supposed tracks of four hotspots, Iceland, Bermuda, Yellowstone, and Raton. Iceland tomography has failed to identify a deep-seated plume, but in their electronic supplement (p. 4) Morgan and Morgan assume the Mid-Atlantic Ridge to be moving over a plume such that the model-required 3/4 of the hypothetical motion can be assigned to the American side, and this division is termed “observed”. The purported Bermuda track is defined by several vaguely dated and widely separated on-land uplifts and minor igneous occurrences, selected because they fit the desired rough trend to end at Oligocene Bermuda (electronic supplement, p. 31). Detailed seismic tomography, by both proponents and opponents of plume hypotheses, shows the thermal effect of the purported Yellowstone hotspot to be limited to the upper mantle, but the temporally-erratic east-northeastward late-Neogene magmatic progression is used as a track by Morgan and Morgan (electronic supplement, p. 31) because it fits, whereas the temporally more uniform Brothers progression, in a different direction from the same origin over the same time span, is unmentioned. Raton, which consists of a line drawn to connect widely-separated late Neogene volcanic fields, was proposed as a track only because the line is in the desired direction. Morgan and Morgan (electronic supplement, p. 33) term it "the best track in North America" with which to define azimuth—but the many dates they report are mostly late Miocene through Quaternary in all fields along the 600-km length. The only common denominator of these four very-different purported manifestations of plumes is that each was selected, from arrays of otherwise possible candidates, because its azimuth fit fixed-plume predictions. The fact that these hoped-for tracks do fit thus is irrelevant as evidence.

Onland Africa is no better. Hoggar, Tibesti, and Jebel Marra are designated, and plotted, as tracks, even though there is no relevant age progression along any of them, because they have appropriate orientations (electronic supplement, p. 9-10). A track is assumed for Afar. The nonfit of Cameroon magmatism is given plumespeak rationalization. The large East African volcanoes are assumed to cap trackless plumes.

The whole-mantle-convection and superplume model favored by Morgan and Morgan (this volume), with its long-fixed subduction systems bounding a constant-width Pacific Ocean on both sides, is disproved by, among other features, broad global spreading patterns that are independent of inferred frameworks. The Pacific must be shrinking, by rollback of its bounding hinges, at some large fraction of the areal rate at which the subduction-free Atlantic is expanding.

31st January, 2007 Jason Phipps Morgan and W. Jason Morgan

In response to Smith's comment of 27th January, we point out that differing Re-Os isotope systematics of OIB and MORB were used by us as observational support for progressive melt-extraction from a plume-fed asthenosphere (Phipps Morgan, 1999; Phipps Morgan and Morgan, 1999). A key aspect of the Os-isotopic systems is that they imply, since Os is compatible and abundant in olivine (or sulphide micro-inclusions in olivine — a topic of much recent exploration), that the melts of low-abundance mantle components that are rich in radiogenic Os-isotopes do not re-equilibrate with the bulk Os-isotope ratios of the mantle they ascend through. This implies that both OIB and MORB are composed of a pooling of melts produced by selective melting of a heterogeneous source, and that these melts do not equilibrate, on average, with the average trace-element composition of the mantle during their ascent to the surface. If a small mass fraction of a core-derived Pt-radiogenic Os-component does indeed exist in OIB, but not MORB, then we would argue that this is a low-solidus component that is being stripped by plume-melt extraction. (Note that any residue to partial melting of this trace component may become so refractory that it doesn't melt again during later ascent beneath a MOR (Phipps Morgan, 2001), and also that any olivine crystallization during ascent of an OIB/picrite would reduce the Os concentration in the ascending magma so that Smith's mass balance conclusion is suspect.) However, we think that the detection of differences between Pt-radiogenic Os between OIB and MORB is still being assessed.

In response to Hamilton's comment about poorly defined hotspot tracks on several continents, Africa in particular, we agree these tracks are poor. We think the reason hotspot "tracks" are so poorly expressed on continents is that first, pressure-release plume melting is greatly reduced beneath thick continental lithosphere in comparison to plume melting beneath typically thinner oceanic lithosphere, and second that lateral upwards drainage of plume-fed material beneath the base of a continent may induce secondary decompression melting that is spatially removed from the plume-stem source as discussed by Ebinger and Sleep (1998).

Our model for recent absolute plate motions asks a simple question — is the observed pattern of "geologically recent" volcanic lineaments on the oceanic portions of plates consistent with known NUVEL1A relative plate motions and an assumed "fixed" source of deep plume upwelling beneath each of these oceanic lineaments? We find the hypothesis works surprisingly well, and therefore we essentially used the well-defined volcanic tracks on the oceanic portions of the plates, plus known relative plate motions, to constrain plate motions above continental hotspots such as Hoggar. This means that the inferred motion of north America is not being dominated by the few potential hotspot traces within north America, but rather by the global fit to the many better-defined azimuths on the oceanic portions of all plates. While we describe each potential continental hotspot "track" in the supplement, they have extremely little weight on the inferred pattern for recent absolute plate motions. Similarly, while we describe in the supplement a few places where we adjust azimuths by a bit for the individual geologic reasons that we describe for each of these adjustments, these corrections have very little effect on the absolute plate motions we infer, as discussed at some length in the text. (They don't change the predicted motions, just add more "noise" to the comparison of absolute motions with our estimates for the tracks.)

We hope it is clear that we do not think that intraplate volcanism only occurs above the stems of plumes upwelling from much deeper mantle. Lateral flow and drainage is an essential aspect of a plume-fed asthenosphere, and there is the potential for much melting of plume-fed asthenosphere far from the stems of the plumes in which this material first upwelled towards the surface, and even from the spreading of the buoyant hotspot-melting-created roots to hotspot swells (Phipps Morgan et al., 1995). This doesn't mean that the concept of plumes should be discarded, simply that it needs to be extended to the more complete conceptual model of slabs, plumes, and a plume-fed asthenosphere.

References

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