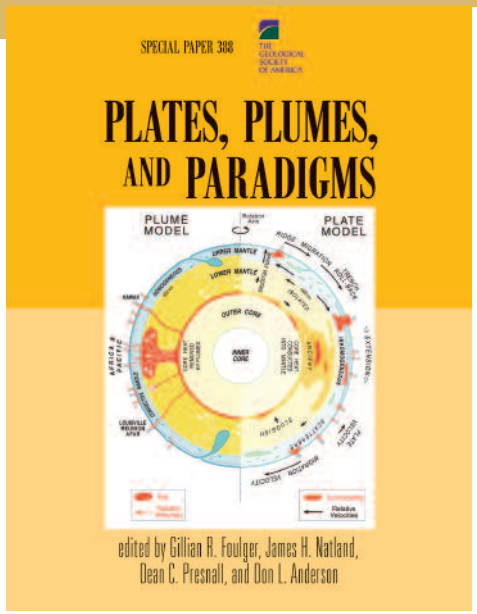
Plates, Plumes, and Paradigms[1]



Plates, Plumes, and Paradigms (PPP) is an outgrowth of a Penrose Conference ("Plumes IV: Beyond the Plume Hypothesis," 2003) held to develop alternatives to the currently dominant mantle plume model to explain the origin of melting anomalies such as Iceland and Hawai'i. The main objective of PPP is cogently stated in the volume's preface: "The fundamental question is whether plumes exist, and if they do, are they a common phenomenon in the mantle, or are they rare occurrences beneath particular localities?" With 861 pages of data, experiments, hypotheses, critiques, and historical-scientific reviews, PPP makes a powerful anti-plume case, which may be enough to shake the certainty of many who take the hypothesis for granted. As a perpetual scientific agnostic, I must admit that it is a pleasure to see so many assumptions questioned by so many and to have the alternatives to current dogma spelled out so clearly and comprehensively (PPP is weighty enough to be used for hand-to-hand combat if the debate should get too fierce). I have a vivid memory of the reaction I would typically get from my co-students (during the Early Anthropocene, 1986) whenever I questioned whether Iceland was actually the result of a plume. "What else could it be?" would be the inevitable reply. This book goes a long way towards spelling out what else Iceland could be. I could have used this book then; and I will certainly use it now.

Among the major problems with the plume hypothesis is the fact that many of the volcanic suites that are thought to be plume-derived lack the high $^{3}He/^{4}He$, large swells, large buoyancy fluxes, time-progressive volcanic chains, anomalously hot volcanism, high heat flow, or seismic signatures predicted by the hypothesis. Given these apparent inconsistencies with the model, many of which are documented in some detail in PPP, it is clear that the classical plume hypothesis can be retained only if many of its core axioms (immobility, deep enriched source) and predictions are abandoned. While the introduction of such extensive modifications to the plume hypothesis can sometimes reconcile data with theory, the adulterated hypothesis thus becomes essentially untestable, and plumes thereby become indefinable.

Many of the papers in PPP address the issues of whether or not "hotspots" are anomalously hot in contrast to normal MORB and of the relative importance of excess temperature versus fertile source composition as an explanation for the larger melt volumes of "hotspots" (or "notspots" as some would state it). For the Hawai'ian case (as for many other examples), there seems to be no compelling argument for hotter temperatures, and many geochemists have already proposed the participation of non-peridotitic source components to explain the larger magmatic fluxes and particular geochemical and mineralogical characteristics of these magmas. For Iceland, there is an ongoing debate about the temperature issue, which seems to hinge on how the composition of the "primary" melt is calculated, a matter about which there is no consensus as yet. The excess-volume argument for Iceland is addressed creatively in PPP by proposing that a large slab of Caledonian-age oceanic crust trapped in an orogenic suture zone is being recycled (i.e. the dominant Iceland source is not peridotite). That there is much discussion on this topic is no surprise, since the problem of hotspot magma genesis is extremely intractable, with the nature of the calculated melt and residue compositions being critically dependent on assumptions about source composition and melting processes. For that matter, there is little consensus on how MORB or arc magmas form either.

The basic data documenting the trends and age progressions of putative volcanic plume tracks are also considered in much detail in PPP. This phenomenological critique of the assumptions underlying the plume hypothesis is extremely effective. Data from several ocean basins and some continents show that most hotspot-type volcanism does not define coherent age-progressive tracks (contrary to popular belief), commonly exploits older linear structures (in many cases repeatedly), may occur synchronously at widely dispersed sites (right across Africa, e.g.), with age-spikes that can be correlated to documented plate-boundary reorganizations or collisional events. In a similar vein, the evidence for radiating dike swarms associated with plume-driven continental breakup is critically reexamined. Many apparent radiating patterns turn out to be composite structures, with directions controlled by an older tectonic grain or with several generations of intrusions constituting the pseudo-radial pattern.

Alternative plate tectonic explanations have been suggested for many volcanic features attributed to "hotspots," including crack propagation, reactivated and incipient plate boundaries, membrane and extensional stresses, gravitational anchors, reheated slabs, decompression melting of heterogeneous mantle, leaky transform faults, etc. Many of these models are discussed in PPP and a variety of plausible alternative explanations for the data are provided. The diversity of proposed mechanisms suggests that there is more than one way to induce mantle melting, which may thus produce a concomitant diversity in the types of hotspots seen on Earth.

One anomaly in PPP is the near-absence of debate about how plume intensity may have varied with time. Archaean komatiites are widely considered to have been hotter than modern MORB and are generally interpreted to have formed from plumes, with a minority view assigning some types of komatiite to a subduction environment. Here, too, there is a vigorous debate in the literature, which is only barely touched on in PPP. Another anomaly is the near-absence of dissenting voices. Although the pro-plume viewpoint is abundantly represented in the literature, it would have been nice to see a couple of summary papers by the most devoted defenders of the hypothesis. Despite the strong anti-plume case that is made in PPP, I can't help but feel that somewhere in the bathwater there might be a viable baby. Perhaps plumes are not as ubiquitous as is commonly assumed, but given our profound ignorance of the deep mantle it seems premature to categorically reject the possible existence of active plume-like instabilities. On the other hand, uncritical acceptance of the plume hypothesis to explain linear volcanic chains will never again be possible for anyone who takes the trouble to read PPP. Plume advocates now need to provide counter-arguments to the serious objections that are set out in PPP. Are we on the cusp of a paradigm shift? Will the students of 2056 look back on the Great Plume Debate as the moment when "modern" mantle dynamics originated? Whichever viewpoint ultimately prevails, PPP will remain an important milestone in the evolution of thought on mantle plumes by focusing and triggering debate on this important issue.

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