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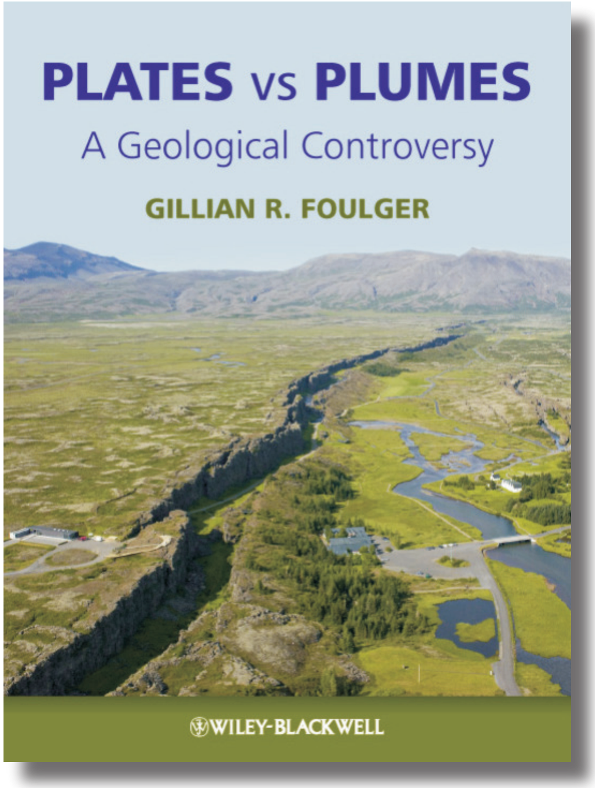

PLATES vs PLUMES: A Geological Controversy by Gillian Foulger (2010)

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The great debate between the "Neptunists" and "Plutonists" set the tone for an unintended but long-continued tradition in the development of geology as a science, with diametrically opposing schools of thought offering radically different proposals to explain a common observation. Such divergence of opinion should in principle be a stimulus to design research to validate, reject or reconcile opposing viewpoints. The reality in many of the great geological debates has often been the development of entrenched opposing camps, defending respective paradigms with the fervour of prophets of religious dogma, with little constructive dialogue, despite the potentially wide-reaching implications for our understanding of Earth processes.

Modern examples of this remarkably fitful process of advancement of geological understanding are the early debate surrounding continental drift, and the issue of extra-terrestrial impacts vs volcanism in explaining mass extensions. In the case of continental drift, the idea represented a major challenge to entrenched prejudices of the solid, dependable physical characteristics of the planet, which only collapsed long after the completely compelling geological field observations had been tabled. In contrast, in the case of the linking mass extinctions to catastrophic impacts, early widespread acceptance reflected the seeming elegance of the model in explaining a variety of associated observations – such as the widespread Ir anomaly that is broadly coincident with the K-T extinction boundary. Scientists suggesting a causative link between the coincidence of mass extinctions and major volcanic events received short shrift as modern-day heretics.

The Plume Hypothesis, initially proposed to explain the time-progressive Emperor-Hawaii volcanic chain, is a further example of an idea which received early widespread acceptance because of its apparent geological elegance. It appeared to answer a major Plate Tectonics quandary – how to account for volcanic activity in the interior of plates, well away from spreading ridges and subduction zones. Early challenges were made to the Plume model – for example the "Membrane Tectonics" concept of Oxburgh and Turcotte. These authors suggested that plates moving over a non-spherical globe would fracture to accommodate the resultant stresses, leading to deep mantle pressure release, which would trigger volatile fluxing, and in turn lower the peridotite solidus, initiating melting. Propagation of fractures linked to plate migration thus provided an alternative "topdown" or "permissive" mechanism to explain time-progressive volcanic chains. However, so entrenched was the Plume "silver bullet" that such tectonic (or Plate) models received little early support.

Almost 50 years after Tuzo Wilson suggested that the Emperor-Hawaii volcanic chain formed by the motion of the Pacific Plate over a "hot spot" in the mantle – the forerunner of the Jason Morgan's subsequent 1971 "Plume" concept, a growing group of "plume-sceptics" is voicing concerns over observations that are perceived to be at variance with the model. One of these is Gillian Foulger, who recounts how she puzzled over a low-wave-speed anomaly beneath Iceland. This terminated in the transition zone, rather than in the lower mantle, as would be envisaged by the classic Plume model. She recalls being dumbstruck with astonishment when Don Anderson (a noted Plume-sceptic) suggested that perhaps the widely assumed plume beneath Iceland did not exist. However, despite the importance for the Earth Sciences of establishing the primary cause of intraplate volcanism, "Plumists" and "Plume-sceptics" appear to have settled rather comfortably into two diametrically opposed camps, with little mutual discourse.

In order to stimulate debate, Foulger played a major role in setting up and maintaining on an ongoing basis the website www.mantleplumes.org. The aim of the website is to provide a forum for general debate and critical commentary on the origin of "anomalous" volcanism, and it is open to all interested parties. This has now been followed up by a book on the subject, providing a uniform overview of all aspects of the debate, aimed at educators, students and research scientists. This is Foulger's very timely and thoughtful book titled PLATES vs PLUMES: A Geological Controversy, published by Wiley-Blackwell in late 2010.

Throughout the book, a major theme developed is the lack of agreement as to what actually constitutes a plume, and their modern-day expressions. Morgan originally suggested that there were "about 20 plumes", sourced below the asthenosphere, that were fixed in the mantle relative to one another, although he identified only 16 of these in his original publication. The number of plumes proposed by different authors grew rapidly, achieving a world record of 5200 based on fractal arguments. A further development is that plumes have been invoked to account for volcanism ranging over eight orders of magnitude from small individual centres to large igneous provinces (LIPs). Foulger points out that it is difficult to envisage a single mechanism that can explain volcanic provinces as different as Iceland and Hawaii. Semantics present a further source of confusion, and to avoid the loosely defined concept of a "hot spot" to describe a centre of volcanism, she proposes the non-genetic term "melting anomaly."

Foulger points out that a major problem in addressing the Plume model is that the concept, as developed by different authors, has increasingly invoked a variety of ad hoc explanations to deal with inconsistencies. Thus, when it was appreciated that the putative plumes invoked to explain the Emperor-Hawaii chain and Iceland could not be relatively fixed in the mantle, it was proposed that they had been displaced by "mantle winds". Pulsing plumes (presently not pulsing) were proposed to explain away the embarrassing absence of a seismic anomaly, while channelled plumes were offered as an explanation for volcanism away from the inferred plume head. Foulger questions whether the result is a hypothesis that is intrinsically not falsifiable as a practical matter.

In order to address this problem, Foulger devotes separate chapters in the book to the predicted effects of plumes on vertical crustal motions, volcanism, time progression and relative fixity of melting anomalies, seismology, temperature and heat and petrology and chemistry. In each, she contrasts the predictions of the Plume model with those of the Plate model, and compares these with actual observations. Her conclusion is that the observations are often inconsistent with predictions of the Plume model, and more readily explained by the tectonic triggers embodied in the Plate concept. For convenience, a table in the final chapter summarizes the predictions and fits (or otherwise) of the two models with the observations.

An example of this logical treatment of the debate is that a plume head approaching the base of the lithosphere would be expected to produce surface doming a few million years prior to the onset of volcanism. Such precursory uplift is not required by the Plate model. Constraining the timing and magnitude of uplifts is notoriously difficult. Nevertheless, where there are tight geological controls – as for example provided in the Atlantic Tertiary Igneous Province by oil drilling programmes, major uplift followed rather than preceded the initial phase of volcanism. Further, the pattern of uplift in this province showed a poor fit to a domal pattern, and was centred on the coast of Greenland, over 1000 km from the postulated plume impact position. Geological evidence showed that eruption of the Eastern Siberian Traps was associated with subsidence rather than uplift, and that negligible if any uplift was related to eruption of the Emeishan basalts of southwest China.

The chapter on seismology will be particularly valuable to non-geophysicists, as it spells out many of the hazards entailed in data interpretation and presentation. Thus, numeric modelling of seismic data is faced with the problem that VP and VS seismic wave-speeds are strongly affected by the presence of a partial melt in the mantle. Chemical effects have the second largest effect, with a 1% change in olivine Fo content producing a change in seismic velocity comparable to a 70oC change in temperature. In fact, temperature has the weakest effect on seismic velocity. Simplified models, which assume (because of uncertainties in other variables) that seismic wave speed is proportional only to temperature are thus indefensible. Colour enhancements of data have to also be viewed cautiously, to distinguish between what is a strong, significant anomaly and what is merely graphics-enhanced noise or a carefully chosen cross section that is, in reality, misleading. Huge vertical exaggerations, sometimes used in cross sections, also give false impressions.

The potential pitfalls in the interpretation of seismic data can be highlighted by two major low velocity shear wave (VS) velocities just above the core-mantle interface. These are widely ascribed to anomalously hot and buoyant zones of the deep mantle, and they have been interpreted to be "superplumes", held responsible for initiating volcanism ranging in magnitude from large-volume LIPs to relatively insignificant volume kimberlite pipes. Nevertheless, the interpretation of these anomalies as "superplumes" has been called into question. They are associated with positive anomalies in the elastic bulk modulus, which like VS, will decrease with increasing temperature. Thus, they cannot be due to the effects of temperature alone, and may primarily reflect chemical heterogeneity, and be dense, rather than buoyant. Seismologists are severely challenged in teasing out the temperature component associated with these seismically-defined bodies.

In general, I found the book crisply and clearly written, easy to read, and liberally illustrated. It is also a wonderful summary of a wide range of volcanic provinces in time and space, as well as a provocative review of what we think we know and don't know of Planet Earth and deep mantle dynamics. It will be an invaluable resource for teachers of Earth science, ranging from geomorphologists to volcanologists.

Whether it will convert avowed Plumists in their views is of course an open philosophical question. What cannot be questioned, is that Foulger has unfurled the Plume-sceptic colours, and outlined issues challenging the plume paradigm, which require debate. These are multi-disciplinary, and some will undoubtedly not be easily resolved – the timing and magnitude of crustal uplift is a case in point. If such debate is stimulated, the book will have well served its purpose. At issue is whether a major paradigm-shift is required in how we interpret geological and particularly magmatic processes.

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