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BOOK REVIEW

G. R. Foulger. Plates vs. Plumes: A geological controversy

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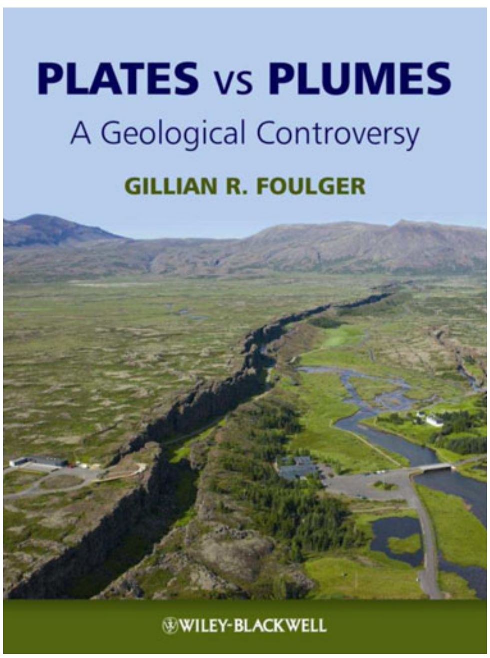

Volcanoes were always in the centre of the thinking of early natural philosophers, and remain of interest to modern scientists. Great debates in the earth sciences focused on the origin of volcanic and plutonic rocks, such as occurred between the neptunists and plutonists in the eighteenth century and the so-called granite controversy during the first half of the twentieth century. How do volcanoes work? What controls their geographic distribution and what is the triggering mechanism of melt generation? The plate tectonic theory provides rational answers to these questions, but still a significant number of volcanoes remain for which the answers are not straightforward. Most of them are located within oceanic and continental plates. They involve some very productive volcanoes, such as in Hawaii and the Réunion islands, but also the small-volume basaltic volcanoes of many monogenetic volcanic fields. The ultimate reason for the long-lasting but intermittent volcanism in the latter, for example in Arizona and Nevada in the USA, in the Michoacán-Guanajuato region in Mexico, around Auckland in New Zealand and in the Eifel and the Pannonian Basin in Europe, is still unresolved, which makes it difficult to predict any future volcanic events. A convenient explanation for the activity of all of these diverse volcanoes is deep mantle upwelling, i.e. a mantle plume.

J. Tuzo Wilson introduced the "hot spot" idea in 1963, just in the advent of the plate tectonic model, followed by the proposition of the plume concept by W. Jason Morgan in 1971. This new theory was an elegant explanation for the origin of the volcanoes, which are located away from plate boundaries. Buoyant hot solid rock has been inferred to rise from the core–mantle boundary, where remnants of ancient subducted slab material had been accumulated, and as such a cylindrical upwelling approaches the shallow depths beneath the lithosphere, partial melting begins and gives rise to mafic magmas, which feed volcanoes. Just as the plate tectonic concept has become a useful paradigm in the earth sciences, providing a strong framework for our thinking, the plume hypothesis has been also widely accepted, because it explains well the origin of intraplate magmatism. In many cases, however, it is regarded not as a possible model or hypothesis,

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which should be tested, but a fact that could serve as a starting point, a kind of basic evidence for further explanations.

The key predictions of the plume hypothesis are the vertical motion of the Earth's surface due to the upward push of the uprising mantle material, the higher mantle potential temperature and as a consequence, hotter primary magma, distinct chemistry of the plume-related magmas from other basalts (e.g. mid-ocean ridge basalt), temporal and spatial change of the volcanism and the low-velocity seismic anomaly beneath the so-called hot spot areas, among others. These predictions are testable, and the outcomes of the tests can either support the hypothesis or, if not, alternative explanations are necessary. Present day plume proponents are satisfied that Morgan's concept works well, even though many changes have been made to the original idea. Now, there are different kinds of plumes, such as thermochemical plumes, fossil plumes, splash plumes, finger-like plumes and even baby plumes, all of them developed in attempts to explain why some predictions of the original plume concept have failed. Despite continued widespread support for the plume concept, the ambiguous outcomes of various tests of the plume hypothesis led a couple of people in the late 1990s to reach a different conclusion: *maybe there are no plumes in the mantle*. Although these people are often regarded as a small minority in the research community, their voices are becoming stronger and stronger, and increasing numbers of alternative interpretations have been worked out. One of the leaders of this "minority" group is Professor Gillian Foulger, a seismologist from the UK. She worked in Iceland during the 1990s, during which time she obtained data that could not be made to fit the widely accepted plume model. In 1999, she met Don Anderson from California Institute of Technology, who was already known as a strong opponent of the plume concept; this was the moment when a cross-disciplinary fight started against the plume theory. Foulger established a website (http://www.mantleplumes.org/), where growing numbers of observations, interpretations and alternative models have been collected in support of a view of the mantle without plumes.

Recently, the scientific debate about the existence of mantle plumes has become probably the most heated one in the solid earth sciences since the acceptance of the plate tectonic concept. Debates in science are an integral part of its development. They can stimulate our knowledge of how the Earth works. It is not a real fight, although the tone of the debate, as for instance about the existence of plumes, is often heated. The plume theory is widely accepted, whereas the alternative explanations are less known. "*A theory should be employed where it is useful, but not allowed to control thought*"—says Foulger. In a debate it is important to see the arguments of both groups. Therefore, Foulger's book, *Plates vs. Plumes—A geological controversy* is very welcome, and in it, readers can find an exciting summary of arguments against the plume concept. Foulger favours the so-called plate theory instead of the plume hypothesis, and suggests the neutral term "melting anomaly" instead of the targeted "hot spot" name. After reading this book, the reader has the right to decide which argument seems to work better.

The first chapter of the book deals with the history of development of the hot spot and plume theory and summarises also the alternative views that collectively represent the plate hypothesis. Hypotheses provide predictions that can be tested by detailed studies, and that is what Foulger does. She lists some fundamental predictions of both theories and examines how they work. The next five chapters analyse the five main predictions of the plume hypothesis: the precursory domal uplift caused by the rising, bulbous plume head; the associated volcanism and magma production process, i.e. the time progressive variation from initial anomalous large-volume magmatism to long-lived, small-volume activity in various tectonic settings (on ridge, near ridge and off ridge); the spatial and temporal pattern of volcanism; the seismological observations on the structure of the mantle, particularly regarding the detection of hot mantle anomalies (description of the techniques that are behind the production of spectacular seismic tomography-model images may be particularly interesting for non-specialist readers) and finally whether the hot spots are really hot, i.e. estimates of shallow sub-lithospheric mantle temperature. These five topics are completed with a chapter dealing with petrologic and geochemical characterization of the basalts. Each of these chapters has roughly the same logical structure: an introduction is followed by methodological description, predictions of the plume and plate hypotheses, observations and finally discussion of the results. Foulger always reaches a conclusion that the available data do not fit the plume theory, and therefore, this hypothesis is unsupported. As an alternative, plate tectonic and shallow mantle processes can explain well the observations, which favour the plate theory. This is reflected in the final synthesis chapter, which includes also an instructive table summarising observations and their explanations by the plume and plate hypotheses.

In summary, I found this book to be a valuable, provocative review of deep mantle dynamics, and I think that it is very useful to broaden our views on these processes as well as to learn the critical and rigorous evaluation of the data (and interpretations). Researchers searching for the reasons for melt generation beneath intraplate volcanic areas can get an impressive amount of information about possible triggering processes. I would not say that I fully agree with the author in all of her conclusions. Deep mantle upwellings might operate in some areas, whereas the plate hypothesis can be readily applied in other regions. Nevertheless I strongly recommend this book both for students and researchers. It is ideal for use in classroom discussion projects, or in "lunch time discussion" meetings. It is clearly written and well illustrated and includes hundreds of useful references as recent as 2010.