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Book review

Gillian R. Foulger, Plates vs. Plumes: a Geological Controversy, Wiley-Blackwell, Chichester, UK, 2010, 364 pages. ISBN: 978-1-4051-6148-0 (paperback) £39.95/€47.90/US $99.95. ISBN: 978-1-4443-3679-5 (hardback) £80.00/€96.00/US $134.95

The thesis developed in "Plates vs. Plumes: a Geological Controversy" by Gillian Foulger is that the plume hypothesis, which attributes intraplate volcanism to melting in rising portions of the mantle, has run its course and should be replaced by an alternative hypothesis in which this type of volcanism is related more directly to plate tectonics. In the first chapter, entitled "From plate tectonics to plumes, and back again", she first describes the development of the plume model, then sets out what she considers to be the "predictions" of this model. After "a quick tour of Hawaii and Iceland" she describes what she calls the "Plate hypothesis" and lists its predictions. The tone of the book is exemplified by two sentences in the introduction "If the nineties was the decade of popularity of the Plume hypothesis, the subsequent decade (the naughties sic) has been the decade of scepticism". "The lengths to which the scientific community has had to go in order to cram the distorted plume foot into the glass data slipper, and the unfortunate departures from rigorous scientific practice that this has necessitated … have reinforced my conviction that the Plume hypothesis cannot be right".

The next six chapters provide summaries of subjects like vertical motions, volcanism, seismology, temperature, and petrology–geochemistry. In many respects they are very good — well written, methodically researched, comprehensive, and with numerous well-prepared illustrations. However, under no circumstances can they be considered an objective and impartial account of current knowledge on these subjects. The data are selected, the references chosen, and the arguments carefully tailored to advance Foulger's mission to disprove the plume model.

In the final chapter, "Synthesis", the approach is to attack systematically every line of evidence that has been used to defend the plume model. We are told that seismology is not capable of imaging plumes, that "hot spots" are not hot, that geochemistry provides no indication of a deep source, that convection models cannot reproduce plumes, and so on. The final conclusion is that the plume model is either "unfalsifiable" or just plain wrong, and that if only the scientific community were to refocus its research on alternative models such as "stress-driven plate-based models" the "Plate hypothesis" would prevail.

How convincing are these arguments? Throughout the book Gillian Foulger sets up fragile straw men, and then unsurprisingly brings them down. The "predictions" of the plume hypothesis are largely hers, based loosely on Jason Morgan's original paper which was written forty years ago, in 1971. Since then, this paper has stood up remarkably well. To be sure, the model has been modified, as is normal for any scientific hypothesis: we now know, for example, that plume sources are not always fixed and that their path through the mantle is not always direct. Time and again in the book we are told that plume theory predicts major uplift and that since such uplift is absent in some areas, the plume hypothesis must be abandoned. The fragility of this type of argument is demonstrated by recent modelling of inherently dense eclogite-rich plumes that produce no uplift (e.g. Sobolev et al., 2011).

As alternatives to the plume model, we are offered a bewildering smorgasbord: "…propagating cracks, internal plate deformation, membrane tectonics, self-perpetuating volcanic chains, recycled subducted slabs and continent breaking". It is difficult to fully evaluate such a wide array of alternative models, but some progress can be made if we focus on just one crucial aspect. The entire plume debate centres on the process that produces magma. Gillian Foulger, a geophysicist, does not accept that the source ascends from deeper in the mantle, perhaps because this becomes too close to the plume model. Her explanations for the generation of magma therefore differ considerably from those accepted by most petrologists. A standard diagram in all petrology texts – the phase diagram of mantle peridotite showing the solidus cut by a rising, melting source – is missing from her book and in its place we see a figure showing melts rising from the "conductive layer". Magmas are said to be "mined" from the mantle by two processes; tapping on a melt layer beneath the lithosphere, or melting of "eclogite blocks … sinking to their level of neutral buoyancy, heating to ambient mantle temperature and then rising again". The veracity of these models can be judged by their ability to explain two classical types of volcanism.

In the plume model, the volcanoes in the Hawaii–Emperor chain are attributed to melting in a mantle plume that rises from its source deep in the mantle. In the "Plate hypothesis", they erupt when a fracture that opens parallel to Pacific plate motion taps a layer of melt that broods below the oceanic lithosphere. To explain the alkali–tholeiite–alkali progression of Hawaiian volcanoes, proponents of the "Plate hypothesis" argue that progressively deeper layers are sampled: the melt sheet apparently was stratified and, to produce voluminous shield-building tholeiites, we can infer from phase relations that the central layer must have contained 10–15% of melt. The magmas are said to be CO_2-rich and would therefore have had low density and extremely low viscosity. Rather than resting meekly in place until released by a propagating fracture, such melts would have escaped towards the surface as soon as they formed. To explain the distinctive isotopic composition of volcanoes of the Hawaii–Emperor chain, the melt layer must have had a composition like that of Hawaiian volcanoes, but different from that of other Pacific islands, along a narrow, 6000 km-long, dog-legged corridor aligned fortuitously in the direction of plate movement.

We are told in the book that "the only model currently proposed that can explain the volume of the Ontong Java Plateau … is enhanced fertility near a mid-ocean ridge". "Although eclogite is dense, small blocks … can be entrained without sinking …". These blocks are said to be bought up in upwelling mantle and melt almost completely to produce the volcanic plateau. Although such a model is marginally more plausible than tapping of a stratified melt sheet, it would surely fail if subjected to the severe examination that, in this book, is reserved solely for the plume hypothesis.

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The one-sidedness extends to the references. On almost every page we find one or more footnotes with links to www.mantleplumes.org, the anti-plume website, but never a mention of other, more balanced websites (e.g., www.largeigneousprovinces.org). Papers by plume sceptics are systematically preferred over those of other scientists. Twenty-one papers of Don Anderson are cited and he is accredited the well-known diagram illustrating element abundances in the mantle, a diagram developed by Ringwood (1979), O'Neill (1991) and others. Natland is cited as the authority on basalt genesis; eight of his papers are listed in the references versus only one each by Langmuir and Asimow. A diagram illustrating calculation of the compositions of basaltic parental magmas is taken from papers by Claude Herzberg, a plume protagonist, with no mention of his name, neither in the figure caption nor in the accompanying text.

Errors abound. To cite just three examples, which all favour the anti-plume case: (1) on several occasions it is said that "Although the experiments (to model plume behaviour) were conducted using fluids with compositional density differences, it is assumed in nature the buoyancy of plumes would be thermal in origin". Campbell and Griffiths simulated plumes using fluids of differing temperatures but strictly the same composition, and Farnetani and Tackley, in their numerical experiments, modelled both compositional and thermal plumes. (2) It is said "there is little evidence for major uplift preceding the onset of (Ethiopian) flood volcanism". In the cited reference by Menzies et al. (1992), the authors are equivocal, but in a subsequent paper, not referred to by Foulger, we read "surface uplift was initiated immediately prior to volcanism" (Menzies et al., 1997). (3) In Table 6.1, the potential temperature of Gorgona lavas is given as 1460 °C; in the cited reference, Herzberg et al. (2007), the potential temperature is 1550 °C for komatiite and 1800 °C for picrite.

What should we make of Gillian Foulger's claim, made many times throughout the book, that the plume model will soon be abandoned? There seems little evidence that this is soon to happen. Some twenty years have now passed since Don Anderson started to agitate against the hypothesis and although he has recruited a loyal group of supporters, theirs is far from the majority view. At two recent meetings, one in Prague that attracted over 3000 geochemists and another in Potsdam for numerical modellers, anti-plume arguments were ignored. Most geoscientists appear to accept that the plume model currently provides a far better explanation of most intraplate volcanism and related phenomena than any of the alternatives.

Should anyone buy "Plates vs Plumes?" It might be useful to provoke discussion in a graduate-level class on the philosophy of science, but it has little to no value as a general reference book or as an undergraduate text on mantle processes and global geodynamics.

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