Forty years of plume research

Mantle dynamics drive the formation of ocean islands and seamounts in the interior of oceanic plates. Yet the mechanisms for generating these volcanic edifices differ from chain to chain, and their material can be generated at a variety of depths.


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Steam cloud at Kilauea Volcano, Hawaii, generated by lava flowing into the ocean. The lava could have risen from great depths within the Earth.

In 1971, Jason W. Morgan sketched out a framework for understanding mantle convection, hotspots and the origin of volcanic island chains in the interior of plates (*Nature* **230,** 42–43; 1971). Forty years later, the debate over the viability of his concept has hardly lost vigour. Morgan proposed that the mantle convection that drives plate tectonics brings plumes of hot material up from deep within the Earth. He went on to suggest that the mantle hotspots that had been postulated to explain chains of seamounts and islands, such as the Hawaiian island chain, are the manifestation of these plumes. But, as yet, mantle plumes can not be observed directly. As a result, there is no end in sight to the argument over whether they exist.

In this focus issue on ocean islands, we highlight some of the active frontiers of investigation on the links between mantle composition, convection, plumes and ocean islands or seamounts. Starting with Hawaii, the archetypal plume-induced ocean island chain, the Review article on page 831 emphasises possible links between the deep interior of our planet and the mid-plate volcanic edifices that pockmark its surface. Specifically, a review of the geochemical characteristics of the two Hawaiian lines of volcanoes — the Loa and Kea trends — reveals compositional differences that have persisted for millions of years. These differences could reflect distinct sources of plume material in the lower mantle, carried up through the entirety of the mantle to erupt in the middle of the Pacific plate.

Even more intriguingly, similar couplets of volcano lines are reported on page 874 to occur at two more island chains in the south Pacific Ocean, the Samoan and Marquesan islands. Each chain consists of two parallel lines of volcanic edifices with distinct lava geochemistry. Like the Hawaiian islands, the Samoan and Marquesan island chains sit above a seismically identified boundary in deep mantle material. The two lines of volcanoes may therefore preferentially source rocks from either side of this boundary.

Without unambiguous observational evidence for mantle plumes, a direct connection between the compositional heterogeneities in the deep mantle and in ocean island lavas is just a tantalising possibility. But at least in numerical simulations, plumes that form at the edge of a lower mantle reservoir of distinct rock material can entrain small amounts of the compositionally distinct material as they rise up towards the surface, and reproduce the geochemical signatures observed in many ocean island lavas (Deschamps *et al.*, page 879). So the hypothesis seems viable in principle.

That does not imply, however, that the mantle plume framework explains the origin of all known intra-plate volcanoes. For example, the Christmas Island Seamount Province in the northeast Indian Ocean seems more likely to have originated from the melting and recycling of ancient continental material that has been preserved in the upper mantle (Hoernle *et al.*, page 883; Gibson, page 823).

So, looking at research from the past few years, it emerges that the "plume versus no-plume" debate may be ill-posed. Instead, as argued in the Feature on page 816, a more differentiated conceptual model could be more feasible, allowing for a variety of formation mechanisms for different types of seamounts and island chains. The question is not so much whether plumes exist, but in which locations they best explain the observations.

Morgan's elegant mantle plume theory has been exceptionally stimulating to generations of Earth scientists. The idea that volcanoes, such as those in the Hawaiian chain, could be anchored in some way to the deep interior of the Earth is exciting. Testable predictions are thrown up by ongoing research.

Even though there is not much agreement on the validity of Morgan's theory forty years on, it is well worth investing more time and effort into exploring what ocean island chains can tell us about the mantle near the core. ❐