

Convection Associated with Hotspots as Driving Force for Plate Motion

In this article, W.J. Morgan proposes that hotspots are the result of convection within the lower mantle (Morgan, 1971). This convection in the lower mantle is also the source of energy for continental drift. Morgan describes about 20 sources of upwelling (hotspots) and says that the resulting down welling is not localized in specific places as are the hotspots, but rather spread out over larger regions which makes the subsidence less obvious. Plate direction can be determined by currents in the asthenosphere as well as stresses at plate boundaries.

“Evidently the interactions between plates are important in determining the net force on a plate, for the existing rises, faults and trenches have a self-perpetuating tendency. The plates are apparently quite tough and resistant to major changes, because rise crests do not commonly die out and jump to new locations and points of deep upwelling do not always coincide with ridge crests. (For example, the Galapagos and Reunion upwellings are near triple junctions in the Pacific and Indian Oceans. Asthenosphere motion radially away from these hotspots would help to drive the plates from the triple junctions, but there is considerable displacement between the "pipes to the deep mantle" and the lines of weakness in the lithosphere which enable the plates to move apart.) Also, a large isolated hotspot such as Hawaii can exist without splitting a plate in two. I believe it is possible to construct a simple dynamic model of plate motion by making assumptions about the magnitude of the flow away from each hotspot and assumptions about the stress/strain rate relations at rises, faults and trenches. Such a model has many possibilities to account for past plate motions; hotspots may come and go and plate migration may radically change the plate to plate interactions. But the hotspots would leave visible markers of their past activity on the seafloor and on continents.”

Basaltic material found in Hawaii and parts of Iceland are distinctly different from the rocks commonly found at ocean ridges. The material found in Hawaii and Iceland suggests that it is material from deep within the mantle rather than the upper mantle material which makes up ocean ridge basalts. Different basaltic composition is used to support the claim that the convection that generates hotspot regions is providing the driving force for plate motion.

"My claim that the hotspots provide the driving force for plate motions is based on the following observations to be discussed below. (1) Almost all of the hotspots are near rise crests and there is a hotspot near each of the ridge triple junctions, agreeing with the notion that asthenosphere currents are pushing the plates away from the rises. (2) There is evidence that hotspots become active before continents split apart. (3) The gravity pattern and regionally high topography around each hotspot suggest that more than just surface volcanism is involved at each hotspot. (4) Neither rises nor trenches seem capable of driving the plates.

The symmetric magnetic pattern and the "mid-ocean" position of the rises indicate that the rises are passive. If two plates are pulled apart, they split along some line of weakness and in response asthenosphere rises to fill the void. With further pulling of the plates, the laws of heat conduction and the temperature dependence of strength dictate that future cracks appear down the center of the previous "dike" injection. If the two plates are displaced equally in opposite directions or if only one plate is moved and the other held fixed, perfect symmetry of the magnetic pattern will be generated. The axis of the ridge must be free to migrate (as shown by the near closure of rises around Africa and Antarctica). If the "dikes" on the ridge axis are required to push the plates apart, it is not clear how the symmetric character of the rises could be maintained. The best argument against the sinking lithospheric plates providing the main motive force is that small trench-bounded plates such as the Cocos plate do not move faster than the large Pacific plate⁸. Also, the slow compressive systems would not appear to have the ability to pull other plates away from other units. The pull of the sinking plate is needed to explain the gravity minimum and topographic deep locally associated with the trench system⁹, but I do not wish to invoke this pull as the principal tectonic stress. This leaves sub-lithospheric currents in the mantle and the question now is: are these currents great rolls (mirrors of the rise and trench systems), or are they localized upwellings (that is, hotspots)?

A recent world gravity map¹⁰ computed for spherical harmonics up to order 16 shows isolated gravity highs over Iceland, Hawaii, and most of the other hotspots. Such gravity highs are symptomatic of rising currents in the mantle. Even if the gravity measurements are inaccurate (different authors have very different gravity maps), the fact remains that the hotspots are associated with abnormally shallow parts of the oceans. For example, note the depth of the million square kilometers surrounding the Iceland, Juan de Fuca, Galapagos, and Prince Edward hotspots. The magnitude of the gravity and topographic effect should measure the size of the mantle flow at each hotspot.

There is evidence of continental expression of hotspot activity in the lands bordering the Atlantic: the Jurassic volcanics in Patagonia (formed by the present day Bouvet Island plume), the ring dike complex of South-west Africa and flood basalts in the Parana Basin (Tristan da Cunha plume), the white Mountain Magma series in New Hampshire (the same hotspot that made the New England Seamount Chain (Azores plume?), the Skaergaard and the Scottish Tertiary Volcanic Province (Iceland plume) and perhaps others. I claim this line-up of hotspots produced currents in the asthenosphere which caused the continental break-up leading to the formation of the Atlantic. Likewise the Deccan Traps (Reunion plume) were symptomatic of the forthcoming Indian Ocean rifting. A search should be made for such continental activity, particularly in East Africa and the western United States (the Snake River basalts?) as an explanation for the rift features found there.”

With the evidence brought forth in this article, Morgan makes a powerful claim that the convection within the lower mantle is responsible for hotspot formation as well as a driving force for plate motion.

Reference:

Morgan, W.J. (1971). Convection Plumes in the Lower Mantle. *Nature* 230: 42-43.