Perturbations to the Galápagos Hotspot due to Interaction with the Galápagos Spreading Center

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The Galápagos Islands have a number of attributes that are not readily explicable by simple mantle plume theory. The unique aspect of the Galápagos is that they lie close to, but not on, a nearby plate boundary, the Galápagos Spreading Center, which is between 30 and 300 km north of the active volcanoes. The plate boundary results in high heat flow, anomalous stresses in the Nazca Plate, and lithosphere that has large changes in thickness over short distances. Thus, the exceptional features of the Galápagos hotspot may be explained either in terms of alternatives to deeply-rooted mantle plumes, or by perturbations to the plume by the nearby plate boundary.

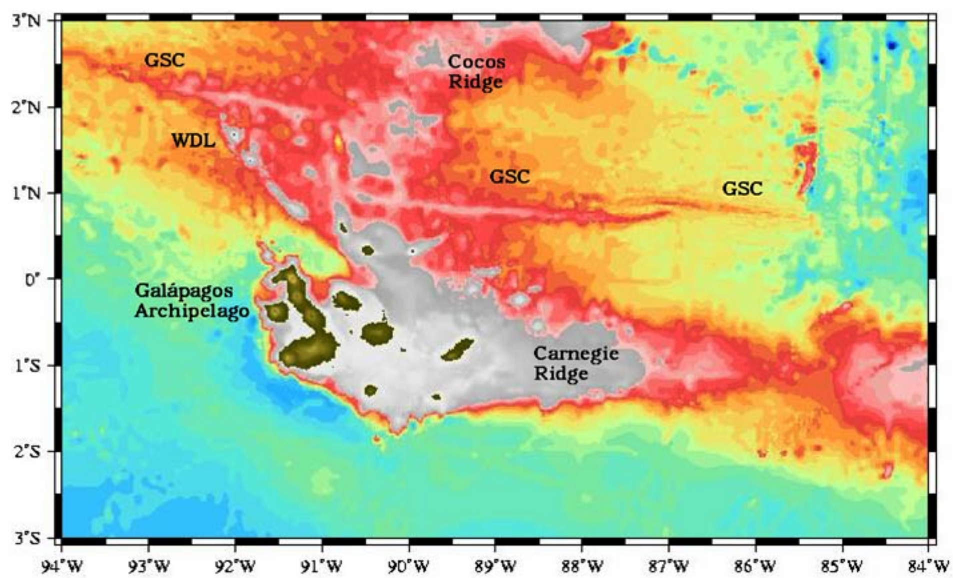

Figure 1: Bathymetric map of the Galápagos region, produced by Dr. William Chadwick. GSC = Galápagos Spreading Center, which separates the Cocos plate to the north from the Nazca Plate to the south; WDL = Wolf-Darwin Lineament (Harpp and Geist, 2002). Carnegie and Cocos Ridges are thought to be traces of the hotspot.

Some of the features that may be related to hotspot-ridge interaction are:

1. The volcanoes form lineaments (e.g. the WDL) whose orientations have no straightforward relationship to the direction of plate motion or the nearby Galápagos Spreading Center. A steadily-deepening aseismic ridge, the Carnegie Ridge, extends eastward from the islands, however. Thus, depending on the scale at which one looks, there is either no relation between the distribution of islands and plate motion, or a near-perfect relation.
2. The age progression of the volcanoes is irregular. Although the eastward plate motion of the Nazca plate would suggest that only the westernmost volcanoes

should be active, Holocene volcanism has occurred throughout the archipelago, and there is no geological or geochemical evidence that the young volcanism is comparable to posterosional volcanism at Hawaii. The vast majority of historical volcanism has been in the western part of the archipelago, however, and the oldest volcanoes are in the east. Also, sparse data indicate that seamounts on the Carnegie Ridge are progressively older to the east.

3. Some lavas from the central and northern part of the archipelago (particularly Wolf volcano on Isabela, Santa Cruz, and Genovesa volcanoes) are among the most isotopically depleted ocean island volcanoes on the planet. These lavas are indistinguishable from EPR MORB in their Sr, Nd, Hf, He, and Pb isotopic ratios. In contrast, the volcanoes from the periphery of the archipelago erupt lavas with more enriched isotopic ratios. This has been attributed both to plume-asthenosphere mixing and simply to intrinsic features of the Galápagos hotspot.
4. There is not a single enriched source. Instead, the southern enriched source is isotopically distinct from the northern one, which is in turn distinct from the western one. Whether or not the source of the magmas is a plume, the melting region is isotopically zoned.
5. Although the Galápagos is a high $^3He/^4He$ hotspot, the helium isotopes are decoupled from other indicators of an enriched source. In other words, the volcano with the highest $^3He/^4He$ is Fernandina, but those lavas possess intermediate Sr, Nd, Pb, and Hf isotopic ratios.
6. There is no Loihi-type edifice at the leading edge of the hotspot; instead, the subaerial volcanoes abruptly rise from the surrounding seafloor. The building and coalescence of large terraces (10 x 20 km in spatial dimension and up to 500 m high) appear to be the major means by which the Galápagos Platform is constructed.
7. Cocos Island, which lies on the Cocos Ridge, is millions of years younger than could have been produced at the hotspot. The Cocos ridge is essentially flat; it does not follow the subsidence path predicted for cooling lithosphere.

As an alternative to a plume origin, many of the Galápagos Islands' features might be explained by a zoned, long-lived melting anomaly that resides in the upper mantle. A critical observation, however, is that the Galápagos hotspot has produced different amounts of crust on the Nazca and Cocos plates over time, as shown by closely-spaced bathymetric profiles across the Carnegie and Cocos ridges. The most straightforward explanation for the bathymetry is that there has been differential motion between the plate boundary and the melting anomaly. Results from a recent seismic experiment indicate that the transition zone is 50 km thinner to the SW of Fernandina (Hooft et al., 2003), which appears to require a thermal anomaly of about 320° both at the transition zone's upper and lower boundaries. This anomaly in the transition zone immediately underlies a vertically-oriented, seismically-slow region in the upper mantle (Toomey et al., 2001 and in prep). At shallow depths in the mantle, the low velocity anomaly is bent to the east, as if it were being sheared by the eastward motion of the Nazca plate, which was predicted by geochemical models.