Sea-floor basement morphology: Distinguishing hotspot effects from plate tectonic effects—Examples from Iceland and the Azores

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Whatever processes create "ridge-centered" hotspots (e.g., Azores, Iceland, and Galapagoes) also modulate the oceanic crust formed by seafloor spreading. (A thicker crust and off-axis volcanism are two features commonly attributed to hotspot modulation). Much has been learned about the thickness, structure and composition of the oceanic crust where the Mid-Oceanic Ridge axis passes over or near a hotspot-generating anomaly in the mantle below the crust. However, it is the UPPER surface of this crust—the seafloor topography at the spreading axis, which becomes "basement topography" once buried under sediments—that is most readily characterized at high spatial resolution by multibeam bathymetry, sidescan sonar, or reflection seismology. (Where oceanic crust emerges above sea level, optic and radar imaging reveal this upper crustal interface at even greater resolution, but erosion by water and glacier ice (Iceland) scrape off the corresponding morphology except for recent volcanic eruptions and fault scarps).

We investigate two MOR segments (one extinct) for clues as to what morphology is due to ordinary plate tectonics and what reflects hotspot influence or modulation of this process. Basically, features which are commonly also observed on "normal" MOR segments can scarcely be "blamed" on hotspot influence. In addition, we offer an example of a rare, if not unique morphological feature near Iceland that seems still to have been created by plate tectonic processes unrelated to hotspots. We sidestep the question of whether these morphologic clues have any bearing on the question of origin depth of a possible Iceland or Azores mantle plume. We leave open the possibility that the Azores and Iceland are different "species" or even "genera" in the hotspot family.

We focus on the extinct Aegir Ridge, active ca. 55-25 Ma just north of the Iceland hotspot (1), and on the active primary accreting plate boundary on the Azores Plateau (Terceira Rift; 2,3). These plate boundaries are comparable in terms of very slow opening rates and rift valley width and depth (see below). However, the Aegir Ridge did not actually cross the Iceland-Faeroe Ridge, and should therefore be considered the equivalent of the modern Reykjanes or Kolbeinsey Ridge in relation to the paleo-Iceland hotspot. Furthermore, no dramatic central volcanic complexes (such as those forming the volcanic islands and seamounts along the Terceira Rift) were developed along the Aegir Ridge during its 30 Ma of existence (1).

Opening rates along the Aegir Ridge ranged from 8 mm/a near Iceland to 13 mm/a in the northern Norway Basin during the period 55-36 Ma, but must have decreased to lower and then zero rates by ca. 25 Ma, the probable time of extinction (1). We nominate the Terceira Rift (2,3) as the slowest opening organized spreading boundary along the modern MOR system: Although the rates are too slow to have been "recorded" by magnetic lineations, they can be calculated from plate motion closure about the Africa-North America-Eurasia triple junction. The rates calculated from NUVEL-1A (4) range from 4.4 mm/a near the triple junction to 3.7mm/a at the intersection of the Terceira Rift with the GLORIA transform.

The Aegir Ridge rift valley ranges from 40 to 50 km in width, somewhat wider than most active slow-spreading ridges. Partially sediment-filled, the basement valley is up to 3000 m deeper than the adjoining rift mountains, i.e., a greater relief than normal for slow-spreading active ridges. We attribute the wide, deep valley to slow spreading and possible slow extension after spreading ceased. The southern Aegir Ridge is oblique to the opening direction, but individual rift valley wall escarpments are normal to the calculated opening direction. None of the above features are atypical of slow and/or extinct rifts far from hotspot influence. Furthermore, despite 100% coverage by multibeam bathymetry, no diachronous basement features similar to those first reported by Vogt from the Reykjanes Ridge (5,6) and Kolbeinsey Ridge (7) are apparent in the morphology.

A remarkable, possibly unique basement ridge (Treitel Ridge) was discovered as a result of detailed mapping of Aegir Ridge. Treitel Ridge (manuscript in prep.) is a narrow (ca.100 km long; up to 1000 m basement relief), asymmetrical basement ridge on the western flank of Aegir Ridge closest to Iceland. Within the resolution of magnetic lineations, Treitel Ridge formed at the Aegir axis about Chron 18n time, and appears to be a morphological "topochron". Its narrow form and steeper inward (towards the Aegir Rift axis) slopes further distinguish it from the V-shaped (diachronous) ridges (5,6; also called "chevrons"(8)) prominent on the present Reykjanes Ridge and its flanks. The location of Treitel Ridge on the Aegir Ridge flank closest to Iceland invites attribution of the feature to some ca. 40 Ma influence of the Iceland hotspot, but we favor a plate tectonic explanation: At about anomaly 18 time, spreading between Greenland and North America ceased (9). This "forced" a change in plate motion between Greenland and Eurasia (see Foulger, these Proceedings). A new rift began to propagate along the Greenland margin, creating a separate Jan Mayen microplate (10), whose eastern margin was the Aegir rift axis. The major transform that existed at the southern end of Aegir Ridge was no longer parallel to the opening direction. We propose that Treitel Ridge registered this adjustment to the new plate motion required by the extinction of Ran rift in the Labrador Sea. We speculate that formation of this narrow volcano-tectonic ridge represents evidence that the extinction of Labrador Sea spreading was relatively abrupt.

The only feature of Aegir Ridge that seems to require hotspot influence is the relatively shallow basement depth, particularly along the southwestern rift mountains, which rise to basement depths of 2000 m (shallow for 25-30 Ma crust!) near the intersection of Aegir rift with the Iceland-Faeroe Ridge. These shallow depths are indeed on the "Iceland" side of the rift. However, the exact location of the Iceland hotspot "center" at this time (ca. 25-30 Ma) is not that certain. Furthermore, the existence and sense of rift mountain asymmetry (higher on the western flanks) is similar to that on ridges farther and even remote from Iceland hotspot influence (11).

In the case of Terceira Rift, the rift valley depth is comparable to the central MAR. The valley widths are somewhat wider than for the MAR, but this may reflect the ultra-slow spreading and therefore thicker axial mechanical lithosphere. The spacing of magmatic centers (ca. 100 km) is comparable to that found along the ultra-slow spreading Southwest Indian and Gakkel ridges, most of whose length is far from hotspot influence.

Only the AMPLITUDE of this topographic segmentation (2000-4000 m) greatly exceeds that of "normal" slow MAR segments and registers the more abundant magma supply that has created the Azores Plateau. The location of the Terceira rift near the northeast margin of the plateau suggests the plateau was formed by successive NE jumps of the rift axis. This is consistent with the existence of a relative stationary Azores mantle "hotspot" across which the Gripps-Gordon (12) model predicts a SW motion (20mm/a) of the Terceira Rift (2).

In summary, we find that most morphologic features of the Aegir Ridge and the Terceira Rift reflect plate tectonic processes similar to those at other slow-spreading segments of the MOR, far from hotspot influence. For the Aegir Ridge, only the high southern rift mountain topography appears to be of hotspot origin. For the Terceira Rift, the great along-axis volcanic center relief, and the off-axis volcanism and elevated plateau topography, is "hotspot" in morphology. However, the present "absolute" motion of the Terceira rift in a relatively fixed hotspot frame (12) is consistent with progressive northeast jumps of the rift – "attempting" to remain over the hotspot—to form the present Azores Plateau (2).

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