# African hotspots and their relation to the underlying mantle

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## ABSTRACT

**Several lines of evidence indicate that Africa has been stationary relative to the underlying mantle since Miocene time. If so, it may provide a unique window to the underlying mantle convection systems. One possible hotspot population indicates a polygonal cell system that correlates with laboratory models in both plan form and scale.**

## INTRODUCTION

Most lithospheric plates appear to be in motion relative to mantle hotspots. However, Burke and Wilson (1972) have hypothesized that the African plate is stationary relative to the underlying mantle and has been so for about the last 25 m.y. Lines of evidence that support this idea are as follows.

1. The termination of the Walvis Ridge hotspot is at Tristan da Cunha and Gough, which are not on the Mid-Atlantic Ridge but instead on 25-m.y.-old oceanic crust. Similarly, recent hotspot activity has occurred at St. Helena and Meteor, again to the east of the ridge crest (Simpson and Needham, 1972).
2. Kidd and Wilson (1973), Burke and Kidd (1975), and Burke and Wilson (1976) have shown that the African plate has a greater concentration of identified hotspots than any other plate. This could be because a stationary plate is easier to burn through than a moving one.
3. Burke and Wilson (1972) and Briden and Gass (1974) noted that the amount of volcanism on the African plate increased dramatically about 25 m.y. ago. Again, this could be due to the ease of penetration of a stationary plate as opposed to one in motion.
4. Many hotspot areas of Africa have had volcanic activity over this time span (Thorpe and Smith, 1974; Black and Girod, 1970), indicating that the cause of the activity has not moved relative to the crust. Several volcanic areas do show short linear age trends, suggesting hotspot tracks (Vincent, 1970; Anguita and Herman, 1975), but the motions implied by these age trends fail to define a consistent rotation pole for the entire plate. These isolated hotspot tracks are perhaps better attributed to the relative motion of the hotspots themselves. This motion has been documented elsewhere, and its rate can exceed 2 cm/yr, as shown by Molnar and Atwater (1973) and Burke and others (1973a).
5. Africa has a distinctive basin-and-swell topography, as recognized by Holmes (1965). It has been suggested that the uplifts, many of which have associated volcanic rocks, are created by underlying mantle processes (Krenkel, 1922). This conforms quite well with the observation that the Chad and other basins have been active for 25 m.y. (Burke, 1976) and that the surrounding highlands have been rising during this time.
6. Paleomagnetic data suggest that there has been no appreciable motion between Africa and the magnetic pole over this time span (Piper and Richardson, 1972; Burke and Dewey, 1974). Although this does not preclude longitudinal motion, it does rule out any major changes in latitude.
7. Burke and others (1973b) have demonstrated that hotspot tracks on other plates are conformable with Africa at rest. Because of random motion of hotspots relative to each other, this conclusion is not definitive, and, in fact, Minster and others (1974) came to the conclusion that the best solution to all the hotspot tracks they studied requires Africa to be moving at about 2 cm/yr relative to her hotspots. In theory, their study was for the last 10 m.y. In this amount of time a plate moving at 2 cm/yr would create a hotspot track 200 km long. As this is the width of many hotspots, such a track would be hard to define. The relative motion of hotspots could also be a major factor. Therefore, in order to obtain good data on African hotspot tracks, even if Africa was moving at this rate, one would have to obtain an average rate from considerably older and longer tracks, dating back to when Africa was in motion. This procedure would yield an initial condition that Africa is in motion. Minster and others' (1974) solution is very sensitive to data from Africa and two ill-defined Antarctic tracks, which account for more than 70% of the total relative importance of all the hotspots. Conversely, the total relative importance of the well-defined hotspot tracks of the Pacific is only 1.3% for their solution. In other words, their solution is much more dependent on the data they used from the African tracks than on the data for the Pacific tracks. Because they started with an initial condition that Africa is moving, it is no great surprise that they end up with the condition that Africa is moving. Minster and Jordan (1978) ran the same calculations with a more carefully selected data set. The hypothesis that

Africa is stationary appears to fit the new plate relative-motion data and the hotspot tracks they chose essentially as well as any other hypothesis.

Africa being stationary relative to the underlying mantle plumes may explain the rifting of Africa. It also may be the cause of the general high elevation of the continent and certainly the high relief, which has led to the more rapid progradation of the Niger and other river deltas in the last 25 m.y. (Burke, 1972).

## AFRICAN HOTSPOTS AND CONVECTION

Morgan (1971) has suggested that hotspots are the surface expression of hot, upwelling mantle convection currents, or plumes. This type of secondary convection is superimposed on the mass-movement system of the moving lithospheric plates and mantle return flow. In the case of Africa, the lithosphere is stationary, so the secondary plume convection system and other local motions will be the only mass-movement systems at work. The type of convection pattern that occurs with the hotspots can be inferred, as shown in Figure 1. This schematic convection layer extends from the base of the lithosphere down to some lower convection boundary. The hotspots lie over the hot, upwelling areas, while downwelling occurs in some unspecified form approximately midway between hotspots. It is apparent that a random distribution of hotspots should have associated with it polygonal convection cells, as shown by dashed lines in Figure 1. Any point within any particular cell will be closer to that cell's hotspot than to any other hotspot. This convection pattern of polygonal cells is conceptually the simplest convection pattern that could produce mantle plumes, because the plumes are just the upwelling centers of the convection cells.

On a map of hotspots, the construction of polygons that meet these criteria is quite simple (Fig. 2). To generate a polygon around any hotspot, one first draws lines to it from the neighboring hotspots (solid in the example). The perpendicular bisectors of these lines are then drawn (dashed) and are extended so that they cross one another. The smallest area enclosed by the intersecting bisectors that contains the original hotspot is then the convection polygon of that hotspot. This area is shaded in Figure 2. Notice that one should actually do this on the surface of a globe, as was done in this study, to avoid errors caused by the curvature of the Earth.

This type of polygon, mathematically described as above, was first used by Thiessen (1911) to analyze rainfall data. These polygons are used extensively in computer cartography, where they are known as Thiessen polygons (Kopec, 1963). They also provide a convenient description of nearest neighbors, which are simply two points (hotspots) whose polygons share a common boundary (Rhynsburger, 1973).

Figure 3A shows the distribution of Neogene and Quaternary volcanic rocks and areas of high elevation and/or relief. Figure 3B depicts one possible scheme of grouping these areas into hotspots and highspots, along with the corresponding polygonal pattern. The groupings are in many places conjectural, and choice of the exact centers may be off by several degrees. The highspots are defined as uplifted areas with no associated volcanism. The most obvious fact about the pattern is that it consists of randomly shaped polygons and not of squares, hexagons, or elongate rectangles. If such shapes did exist, the polygonization process described above would have produced them. This convection pattern is quite similar to those obtained by Richter and Parsons (1975) and McKenzie and Richter (1976) in experimental models of mantle mass convection. They generated polygonal cells in oil layers heated from below, with Raleigh numbers in excess of 100,000. The upwelling centers of the experimental polygons would be the analog of plumes in the Earth. They produced this type of pattern when using a stationary upper layer on their experimental apparatus. When the upper layer was moved to simulate the lithosphere moving relative to the mantle, the pattern evolved into one of elongate rolls. Marsh and Marsh (1976) and Bonatti and others (1977) have suggested that there is evidence for this roll pattern under the fast-moving Pacific plate. However, McKenzie and Richter (1976) theorized that the low-velocity zone may act as a shear decoupling layer, and so the lower parts of the mantle may not be affected appreciably by this shearing. If this is so, then the polygonal pattern may persist even under moving plates. This speculation is supported by the pattern of the Polynesian hotspots and also Menard's (1973) depth anomalies in the northeastern Pacific.

It is apparent that the hotspots and highspots of Africa can be used to define a possible convection pattern that is consistent in plan form with what we would expect under a stationary plate. The question is then whether the Africa cells and the experimental ones have comparable widths when the depths of convecting layers are properly scaled. Richter and Parsons (1975) theorized that upper-mantle convection will occur from the base of the lithosphere extending down to the 700-km seismic discontinuity. This gives a convective layer depth of about 500 km under thick continental lithosphere and about 600 km under the thinner oceanic lithosphere. On the basis of these depths, the experimental models can then be scaled to the dimensions of Africa's convection system, and the two can be compared. The parameter used for this is the hotspot nearest neighbor separation distance, expressed in degrees of arc on a body with the Earth's radius. A computer program was written to automatically calculate this distance, taking into account the Earth's curvature.

When histograms are prepared of all the separation distances (Fig. 4), the

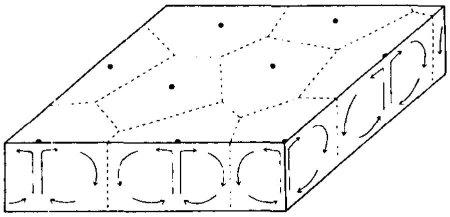

Figure 1. Inferred upper-mantle convection pattern associated with hotspot "plumes." Note resulting polygonal cells (dashed lines). Overlying lithosphere is assumed to be motionless relative to mantle.

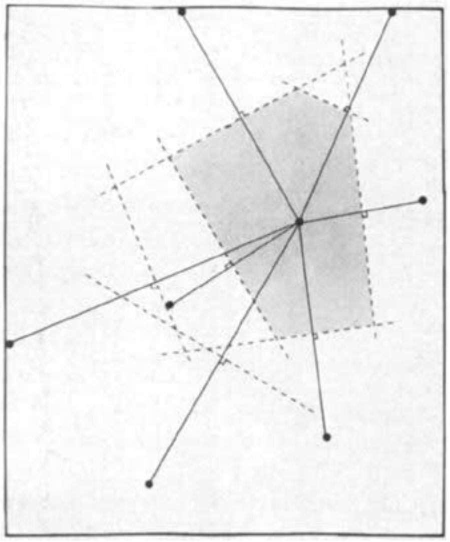

Figure 2. Construction of convection polygon. See text for details.

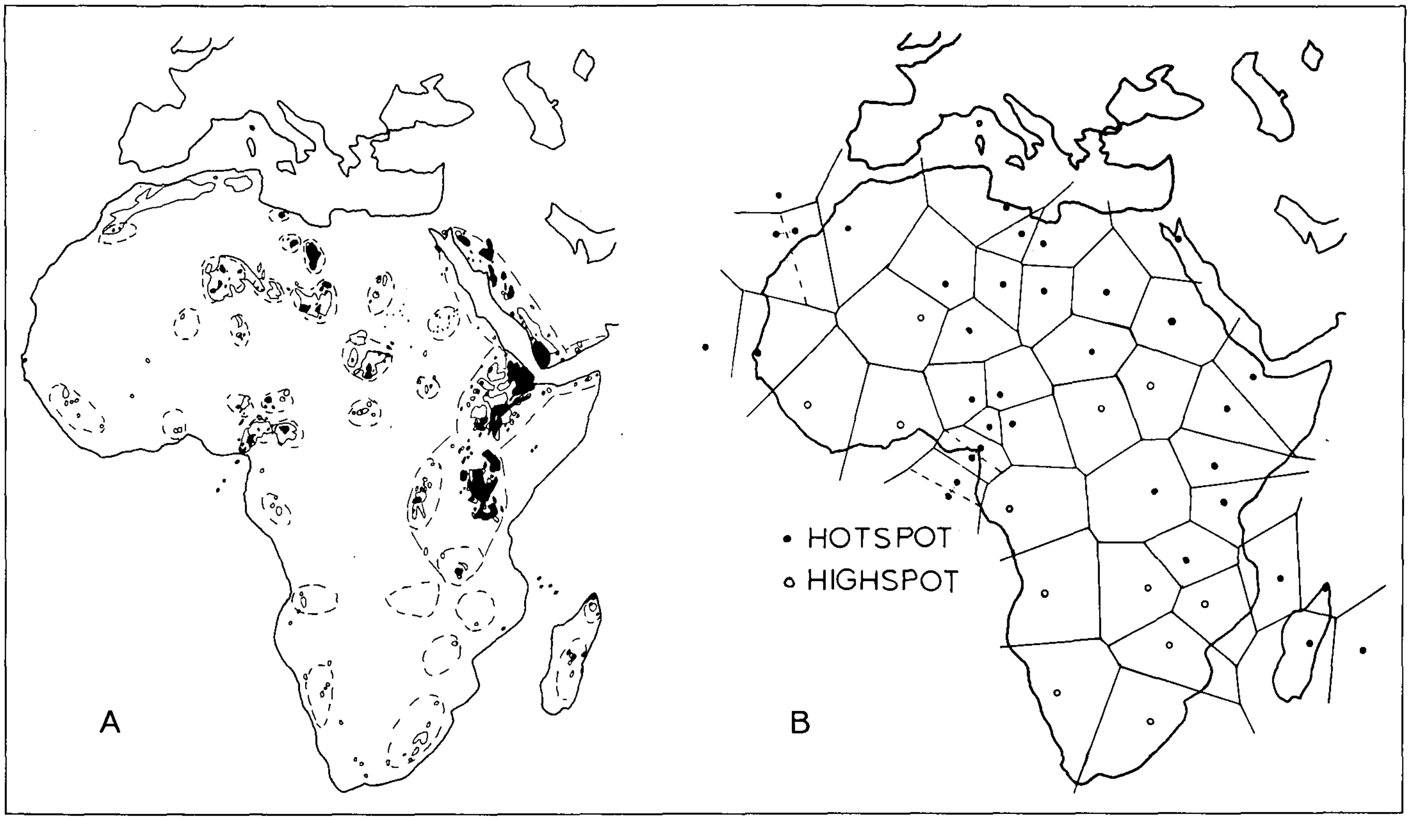

Figure 3. (A) Areas of volcanic rocks, high elevation, and high relief on African continent. Miocene to Holocene volcanic rocks are shown in black (Choubert and Faure-Muret, 1972-1975). Solid line is 1,000-m contour in northwest half of continent and 2,000-m contour in southeast Africa (Naumienko, 1968). Dashed lines indicate approximate areas of high relief (Aero Service Corporation, 1963). (B) Suggested population of hotspots and highspots (uplifts without volcanism), and resulting polygonal convection cell pattern.

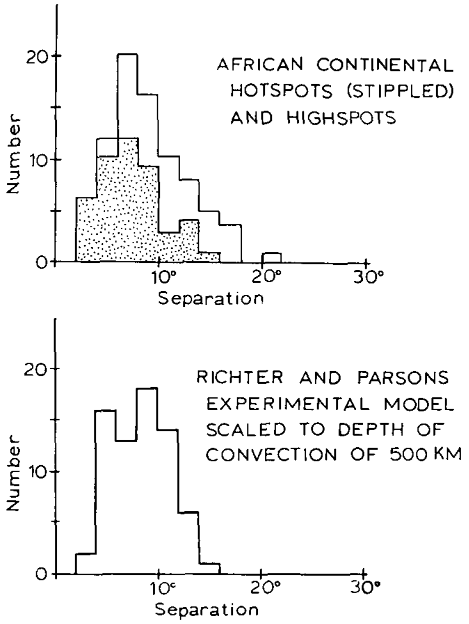

Figure 4. Computer-calculated nearest neighbor separation distances of hotspots and highspots compared to separations of scaled experimental model results. Note similarity of African data to experimental data. The 500-km depth of convection, plus overlying lithosphere, places base of convection system at 700-km seismic discontinuity.

African hotspots and the experiments display almost identical distribution patterns. Both plots show a peak at slightly less than 8°, with flanks that extend from 2° to more than 15°, indicating that although most hotspots in Africa are about 8° apart, the separation can take on a wide range of values. The upper diagram of Figure 4 also shows the distribution of the hotspots plus the highspots, which show the same pattern as the hotspots and so are presumably caused by the same phenomena. Figure 3 shows that the highspots are predominantly in the more stable cratonic areas of Africa, whereas the hotspots are in the comparatively weaker zones that have been tectonically active at some time since the middle Precambrian (Black and Girod, 1970; Thorpe and Smith, 1974). The cratonic areas are apparently more resistant to the penetration of hot magmas produced by plumes, and so no surface volcanism has resulted in most of these areas.

The returning downward flow pattern is not critical to the above discussion and in fact may occur in narrower conduits than the upward flow. The great African basins occur over polygon vertices, and this is where much of the downwelling occurred in the experiments, but it is not necessary for the mantle downwelling to be directly causing the basin subsidence.

Closer examination of pictures of the experimental models discussed above reveals that some of the polygon boundaries are displaced a slight amount away from the midpoint centers. This may be due to differences in strengths of the rising centers. One might expect the same phenomenon to occur with plumes of different strengths. However, this will not apppreciably alter the general polygonal pattern or separation histogram prepared in this study. The pictures also indicate that many rising centers are connected by lines of rising material that are weaker than the rising centers themselves. There is some danger in correlating small-scale model features such as this to the size of the Earth, but if these rising lines do exist under Africa, connecting the hotspots, then more well developed ones could lead to tensional features such as the African Rift Valley. Ultimately, continental break-up and aulacogens (Dewey and Burke, 1974) may result from these interhotspot rising lines.

## CONCLUSIONS

From the distribution of hotspots and highspots on the African plate, we suggest that the underlying convection pattern can be inferred. This pattern is, in plan form and size, what one would expect for Africa, on the basis of laboratory models, and is consistent with the idea that Africa is stationary relative to the underlying mantle. A hint of this pattern can also be seen in the hotspot population of Southeast Asia, which Wilson (1973) theorized is also moving slowly or is at rest relative to the mantle. However, in other areas of the world, plate motions have blurred or obscured the convective pattern, making Africa a unique window to the undisturbed mantle below.

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