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Rises, Trenches, Great Faults and Crustal Blocks

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Consider the earth's surface to be made of a number of rigid crustal blocks, and each block is bounded by rises (where new surface is formed), trenches or folding mountains (where surface is being destroyed), and great faults. Assume that there is no stretching, folding, or any distortion within a given block. Then, on a spherical surface, the motion of one block (over the mantle) relative to another block may be described by a rotation of one relative to the other. This requires three parameters, two to locate the pole of relative rotation and one for the magnitude of the angular velocity. If two adjacent blocks have as common boundaries a number of great faults, all of these faults must lie on "circles of latitude" about the pole of relative rotation. The velocity of one block relative to the other must vary along their common boundary, being a maximum at the "equator" and vanishing at the poles of relative rotation.

The motion of Africa relative to South America is a case for which enough data is available to critically test this hypothesis. The many offsets on the Mid-Atlantic Ridge appear to be compatible with a pole of relative rotation at 65°N, 35°W (± 5°). The velocity pattern predicted by this choice of pole roughly agrees with the spreading velocities determined from magnetic anomalies.

We assume that crustal blocks of continental dimensions are rigid. If the distances between Guadalupe I., Wake I., and Tahiti were measured to the nearest centimeter and then measured again several years later, we suppose these distances would not change. The distance from Wake I. to Tokyo would shorten because there is a trench between these two points, and the distance from Guadalupe I. to Mexico City would increase because a rise is between them. But within the Pacific Block, we assume there is no stretching, injection of large dikes, thickening, or any other distortion that would change distances between points.

If this hypothesis is true, the conclusions which follow will be in accord with observations. If this hypothesis is only partially valid, perhaps we will be able to assess the extent of such distortion by comparing observations with this model.

We begin by considering blocks sliding on a plane. We ignore the possibility of rotations and consider translations only. Figure 1. shows two rigid blocks separated by a rise and faults. From the rise alone, we cannot tell the direction of motion of one block relative to the other, the motion does not have to be perpendicular to the axis of the ridge. (There appears to be a tendency for the ridge to adjust itself to be almost perpendicular to the direction of spreading, but this is a dynamical consideration and not a requirement of geometry.) But from the direction of a transform fault, we can decide upon the direction of relative motion of the two blocks. Now we could use the spacing of the magnetic anomalies parallel to the ridge crest to determine the velocity and direction of relative motion. The fault shown at the bottom of the figure

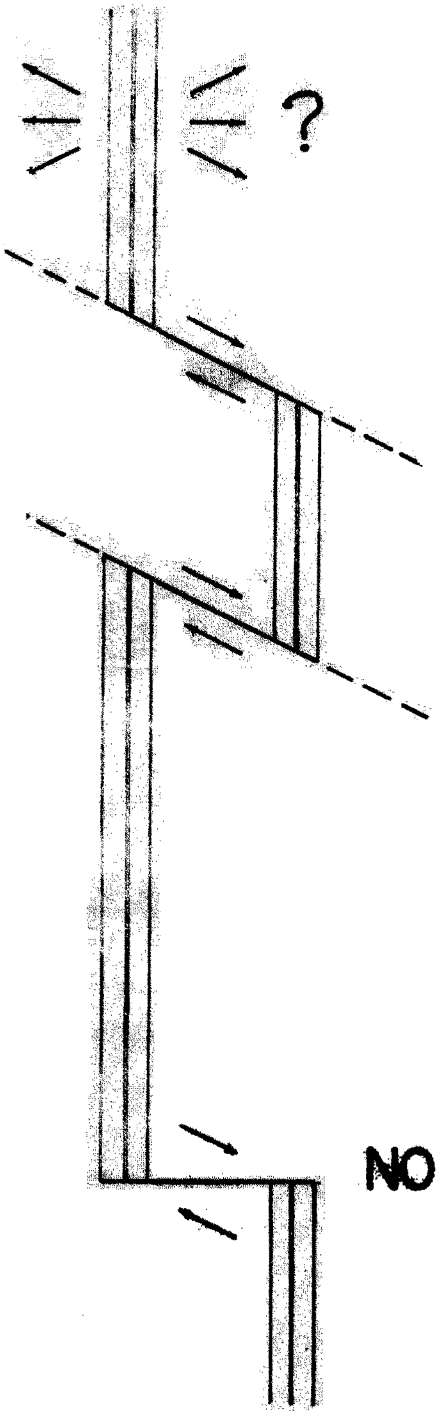

Figure 1.

The motion of the left hand block relative to the right hand block cannot be determined from the strike of the ridge, but can be from the strike of the transform faults. The fault at the bottom is inconsistent with the other two and would not exist.

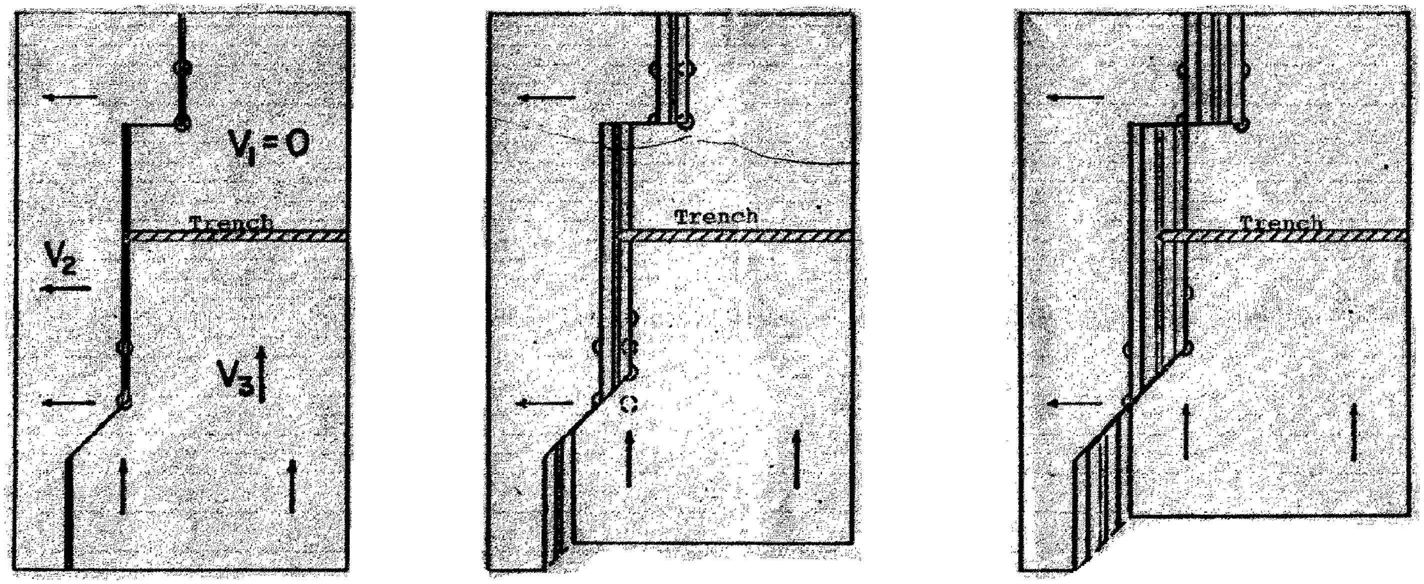

Figure 2. Three crustal blocks bounded by a rise, trench, and faults at three succesive time intervals. Note the motion of the circular "seamounts". The strike of the transform faults is parallel to the difference of the velocities of the two sides; the crest of the ridge drifts with a velocity that is the average of the velocities of the two sides.

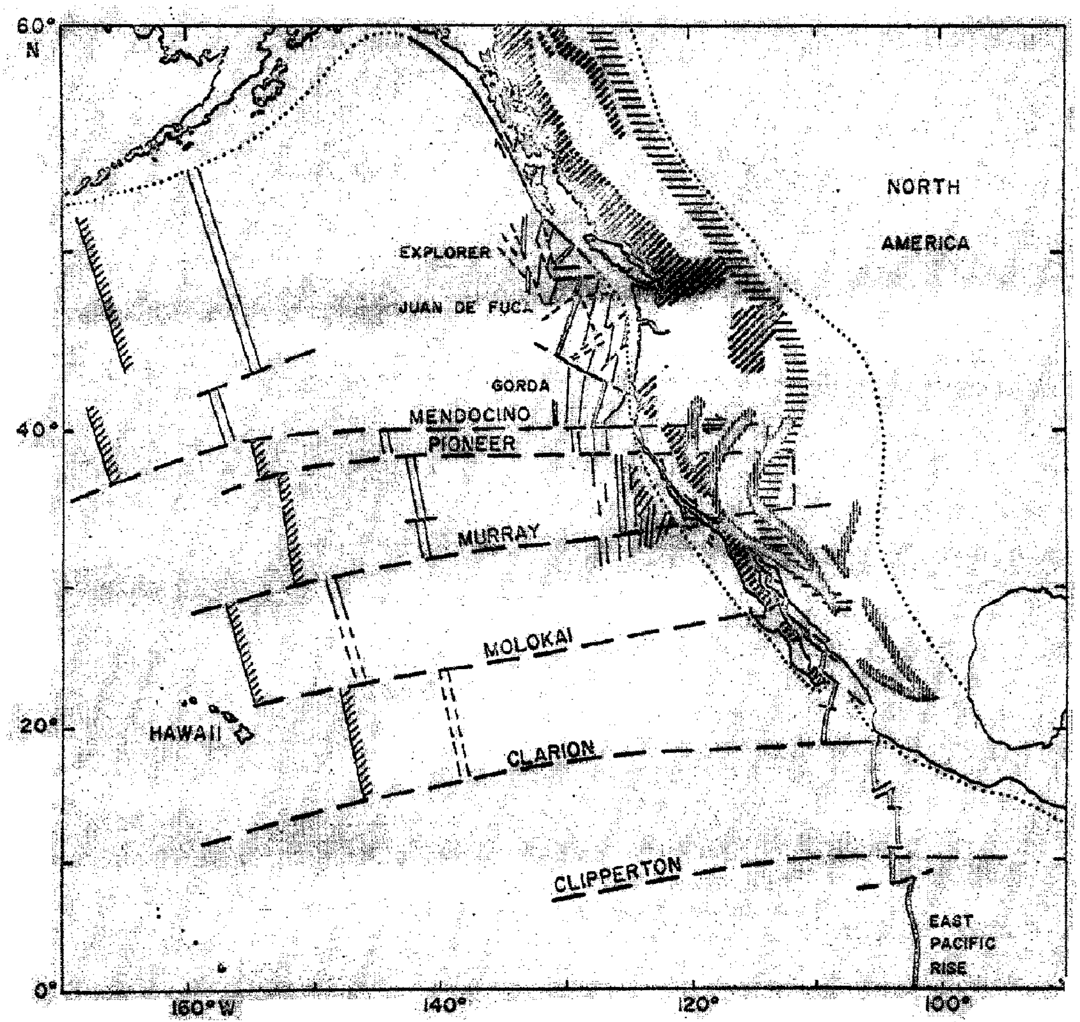

Figure 3.· An example analogous to the preceeding schematic diagram. Consider North America to be stationary, the Pacific to be moving northwest toward the Aleutian Trench, and the small block in the lower right hand corner to be moving northeast toward the Middle America Trench. [Vine, 1966.

is incompatible with those above and would not occur.

Figure 2. shows three blocks bounded by a rise and faults and a trench at three successive time intervals. We see that the strike of a fault depends on the difference between the velocities of the two sides, and that the axis of the rise has a "drift" velocity equal to the average of the velocities of the two sides. An example of this geometry in nature is shown in Figure 3. The three blocks are North America (considered stationary), the Pacific Block (moving northwest toward the Aleutian and Japan Trench), and a small block bounded by the Middle America Trench and the East Pacific Rise between the Gulf of California and the Tehuantepec Ridge (moving northeast into the trench).

We now go to a sphere. A theorem of geometry proves that a block on a sphere can be moved to any other conceivable orientation by a single rotation about an appropriate pole. We may use this to prove that the relative motion of two rigid blocks on a sphere may be described by an angular velocity vector. We need three parameters, two to specify the location of the pole and one for the magnitude of the angular velocity. Look at Figure 4. and consider the left block to be stationary and the right block to be moving as shown. Faults of great displacement can occur only where there is no component of velocity perpendicular to their strike; the difference in velocity of the two sides must be parallel to the fault's strike. (Consider the great depths of the Gulf of Aqaba and the Dead Sea as contrasted to the short mountain range in Lebanon. The axes of these features depart from a smooth small circle representing the motion of Arabia relative to the Africa-Mediteranean Block in a manner which qualitatively explains these

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features. Can the ridges or troughs of great faults generally be correlated with local strike this way?) We thus see that all the faults common to these two blocks must lie on small circles concentric with the pole of relative rotation.

Figure 5 shows the offsets of the ridge in the equatorial Atlantic. Sets of concentric circles about various poles were computed and plotted on this figure of Heezen and Tharp [1965]. The case for the pole at 65°N, 35°W is shown, but pole positions at 60°N, 30°W and 70°N, 65°W give almost equally good fits. There is fair control of the longitude of the best fitting pole but larger uncertainty in the latitude of the best pole. That is, we can draw lines perpendicular to the faults and they intersect up north at grazing angles giving good control in one direction but poor control in the other. Figure 6 shows the bathymetry of the Atlantis Fracture Zone at 32°N and a small circle drawn about the pole at 65°N, 35°W. There is no line of earthquakes or other indication of tectonic activity entirely separating North and South America, and we shall assume that North America and South America at present move together as one block. The Caribbean area almost entirely separates the Americas, and perhaps there is slow movement with gradual distortion in the Atlantic area. But if there is relative motion, we may assume it is very slow at this "hinge" or "pole" between the Lesser Antilles and the Mid-Atlantic Ridge. The fracture zone at 32°N is between Africa and North America, and we see that these two blocks seem to be moving apart about the same pole as Africa-South America.

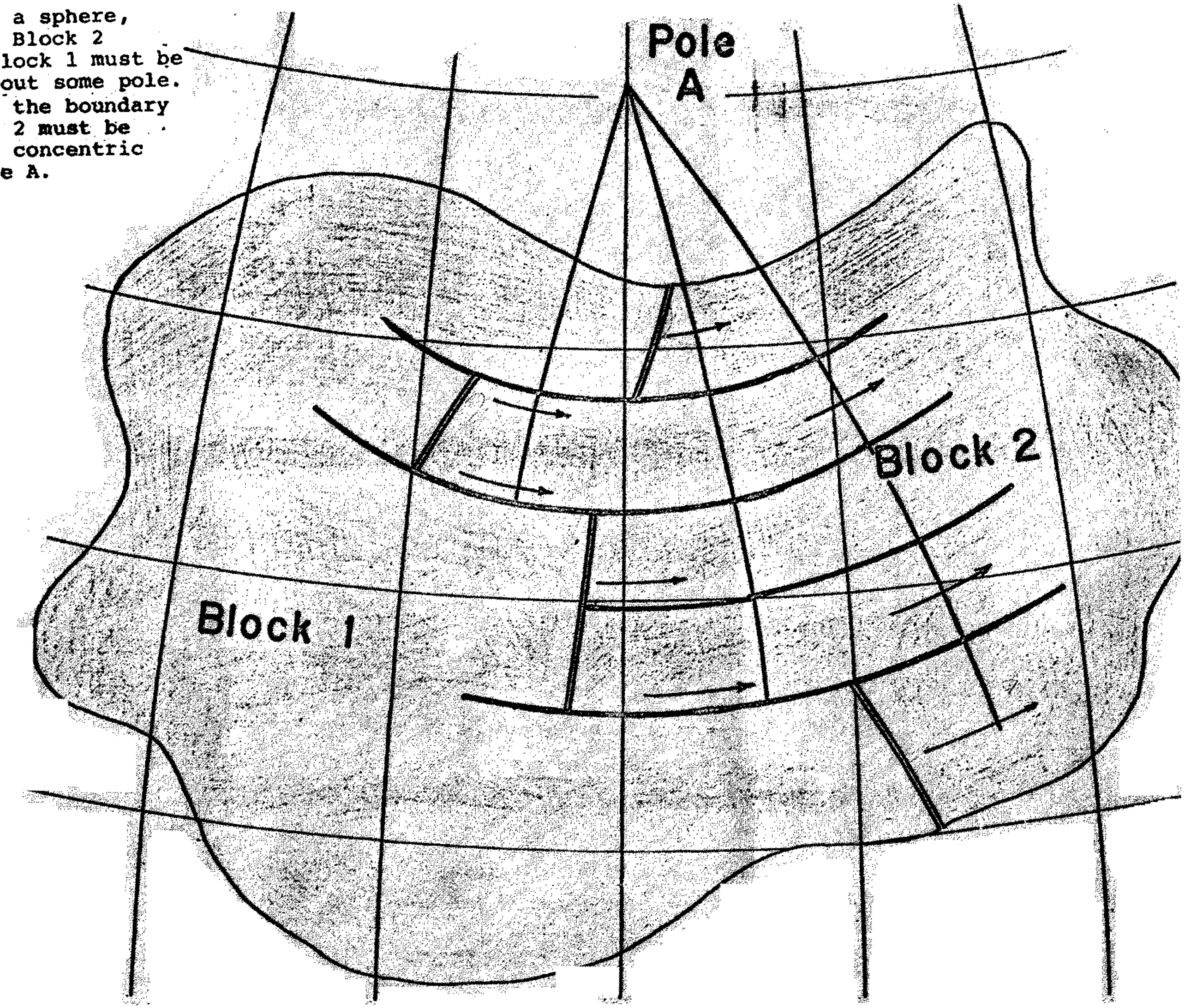


Figure 4. On a sphere, the motion of Block 2 relative to Block 1 must be a rotation about some pole. All faults on the boundary between 1 and 2 must be small circles concentric about the pole A.

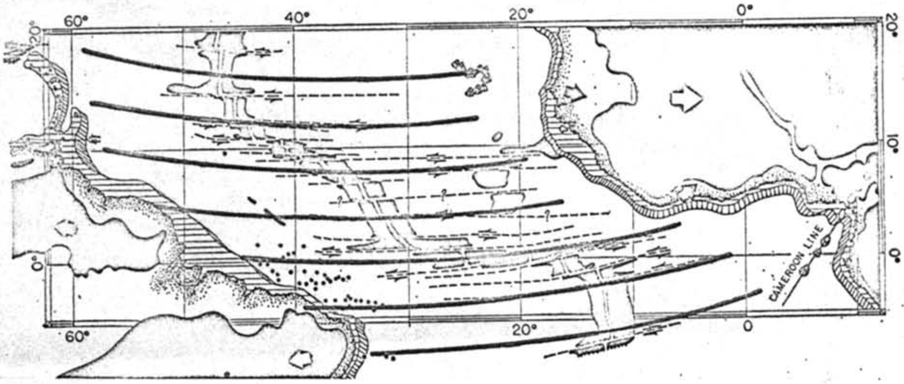
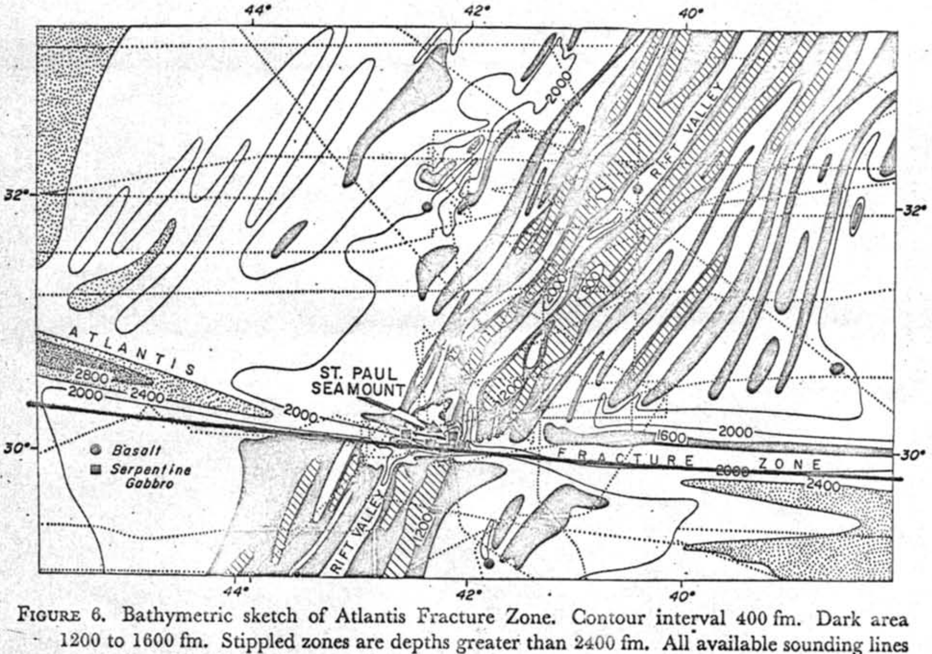


Figure 5. The strike of the transform faults in the equatorial Atlantic compared to circles concentric about a pole at 65°N, 35°W. (The present motion of Africa relative to South America) [Adapted from Heezen and Tharp, 1965]



Pole at
65°N, 35°W

FIGURE 6. Bathymetric sketch of Atlantis Fracture Zone. Contour interval 400 fm. Dark area 1200 to 1600 fm. Stippled zones are depths greater than 2400 fm. All available sounding lines are indicated by dashed lines. [Heezen and Tharp, 1965]

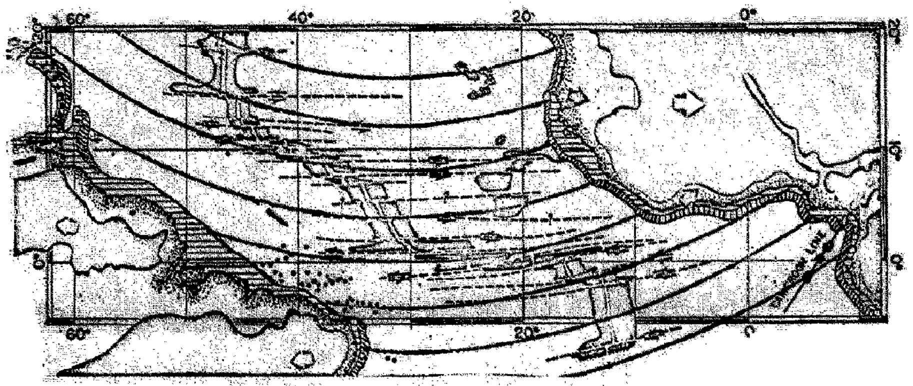
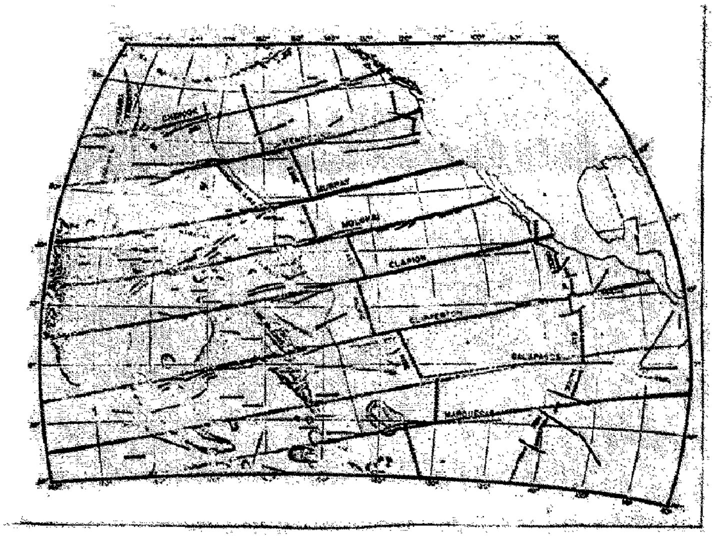


Figure 7. The strike of the faults in the faults in the equatorial Atlantic compared to circles concentric about a pole at 44.0°N, 30.6°W, the pole about which Africa must be rotated to make its coastline coincide with South America's. (Average motion since drifting began) [Adapted from Heezen and Tharp, 1965]



Chinook	46
Mendocino	38
Murray	28
Molokai	20
Clarion	12
Clipperton	2
Galapagos	-7
Marquesas	-15

Figure 8. Old fracture zones in the Pacific. Pole at 79°N, 111°E. [Adapted from Menard, 1967]

We may contrast this present motion of Africa - South America with the average motion of these two continents since they first split apart. Figure 7 shows concentric circles drawn about a pole at 44.0°N, 30.6°W; the pole about which Africa must be rotated to make its coastline coincide with the coastline of South America. [Bullard, Everett, and Smith, 1965]. This average motion is quite different from the present motion, the initial drifting must have been more north-south until the present more or less east-west motion commenced maybe 50 million years ago. Figure 8 shows the old fracture zones in the Pacific [Menard, 1967] and a set of circles concentric about 79°N, 111°E. The Mendocino and Pioneer fracture zones depart from the circles much sooner than do the other fracture zones, this is likely related to North America "overriding" and interfering with the flow of the rise.at an early date. These old fracture zones indicate that the Pacific once moved toward trenches off New Guinea and the Phillipines. About 13 million years ago this pattern changed and the Pacific now moves toward the Japan and Aleutian trenches.

If we assume that Africa and the Americas are opening up about a pole at 65°N, 35°W, then we may predict the velocity of spreading at each point along their common boundary (the Azores to Bouvet Island) If we know the latitude and longitude of a point on the crest of the ridge and the strike of the ridge at this point, we calculate the velocity of spreading perpendicular to the strike of the ridge according to:

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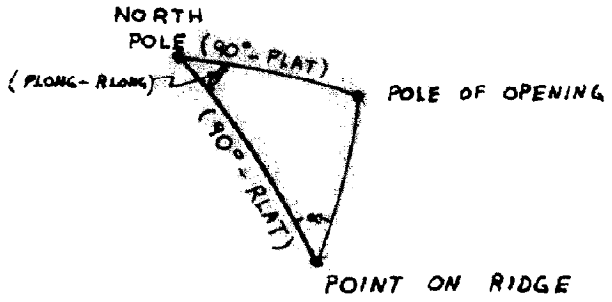

$$\theta = \{ \sin(RLAT) \sin(PLAT) + \cos(RLAT) \cdot \cos(PLAT) \cos(PLONG - RLONG) \}$$

$$\alpha = \arcsin \{ \sin(PLONG - RLONG) \cdot \cos(PLAT) \ / \ \sin\theta \}$$

$$V_{\perp} = V_{max} \ \sin\theta \cdot \cos(STRIKE - \alpha)$$

In order to be able to project a pattern of magnetic anomalies from a ship's track to a line parallel to the direction of spreading, we need to know the strike of the magnetic anomaly pattern. This relation is shown in Figure 9. It is convenient to let the "half-velocity perpendicular to the strike of the ridge" be the form in which the observations are placed. "Half-velocity" since this is the form in which spreading rates are commonly quoted. There appears to be some self-adjusting mechanism in the rifting process which gives rise to a symmetric magnetic anomaly pattern, but there is no geometrical requirement that spreading rates be equal on both sides. We define half-velocity to be the distance from a recognizable feature of a magnetic pattern to the corresponding feature on the other side of the ridge divided by two (and divided by the appropriate time). We choose "perpendicular to the strike of the ridge" since this means an observed rate need be determined only once, and this value then compared to a choice of calculated models.

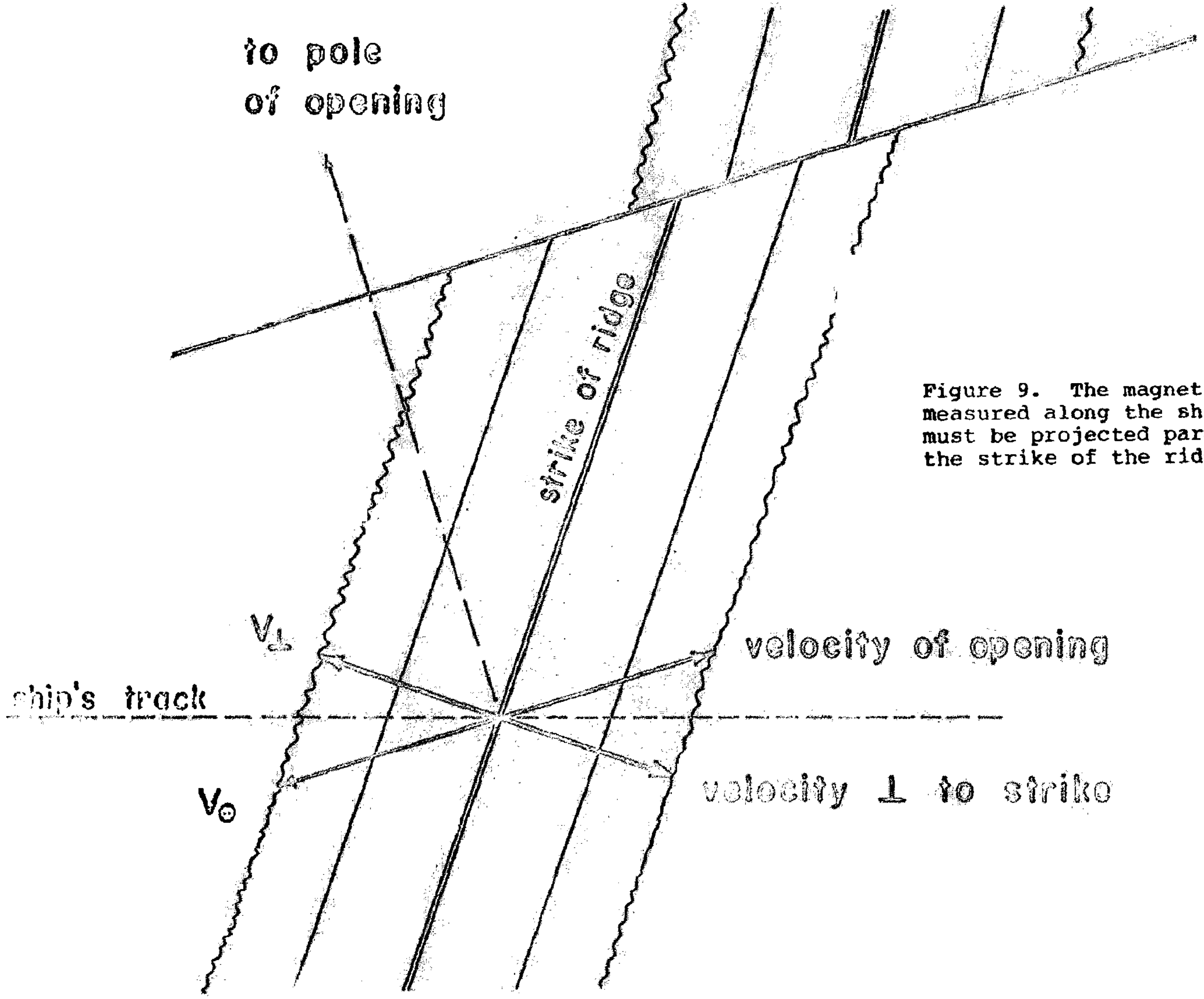

Figure 9. The magnetic profile measured along the ship's track must be projected parallel to the strike of the ridge.

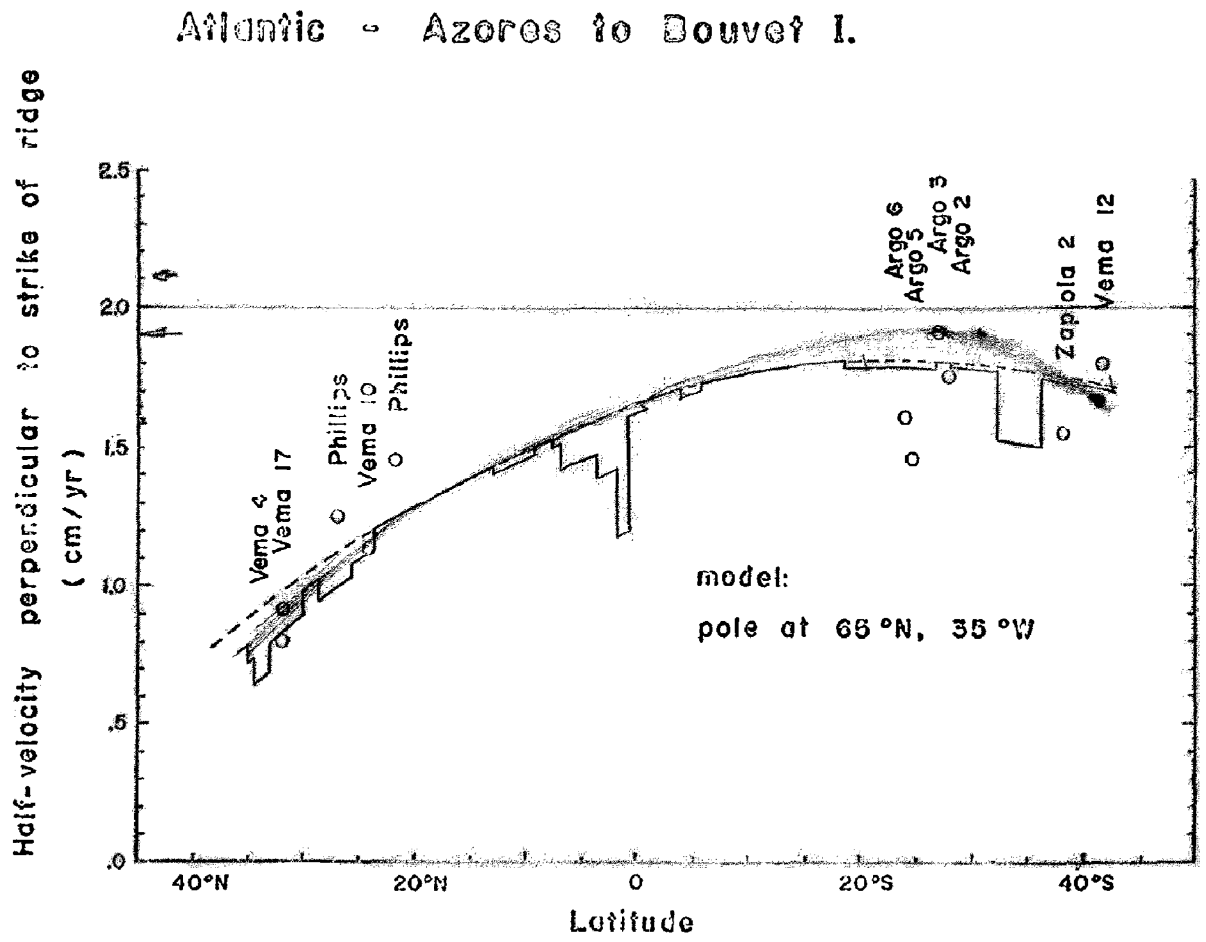

Figure 10. Spreading rates determined by magnetic anomalies are compared to the value calculated with the model.

Figure 10 shows several observed spreading rates in the Atlantic compared to the model. Since the ridge runs almost monotonically north-south with only a minimum of doubling back at the equator, latitude is a convenient coordinate against which to plot the rates. Knowledge of the latitude, longitude, and strike of the ridge were needed at each point; these values were taken from Figure 2 of Talwani, Heezen, and Worzel [1961] for the northern part, from Figure 7 shown here [Heezen and Tharp, 1965] for the equatorial region, and Figure 3 of Heirtzler and Le Pichon [1965] for the southern region. The solid line in Figure 10 was calculated using these values and with the choice of PLONG = 65.°N, PLAT = 35.°W, VMAX = 1.8 cm/yr. The dashed line ignores the strike correction; it gives not the half-velocity perpendicular to the strike of the ridge but rather the half-velocity parallel to the direction of spreading.

The observed values were obtained in the following manner. The two points marked "Phillips" were obtained by J. D. Phillips (private communication, to be presented at the Washington meeting, A.G.U., 1967). The magnetic profiles used here may be found in Heirtzler and Le Pichon [1965], Talwani, Heezen, and Worzel [1961], and Vacquier and Von Herzen [1964]. The strike of the ridge at the crossings of Vema 4, 17, and 10 was assumed to be 38°, 38°, and 30° respectively. Zero strike was assumed at the crossings of Argo, Zapiola, and Vema 12. No error is introduced by this assumption if the ship was heading due east or west; the error is larger the more the ship's course departs from this ideal. In the case of Vema 12, if the strike of the ridge were -30° instead of the assumed 0°, the spreading rate would be 20% less than the 1.8 cm/yr shown here.

Expected magnetic anomalies were calculated at locations near each crossing of the ridge using the normal-reversed time scale (and program) of F. J. Vine [Vine, 1966, fig. 12]. Features on these computed patterns were compared to the observed profiles and the relation between time and distance from the crest of the ridge established.

More magnetic profiles should be analyzed to critically test this hypothesis. Of particular interest in the Atlantic is the region between the Azores and about 20°N where the predicted value of spreading rate changes markedly.

References

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