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The Intersection Between the Mid-Atlantic Ridge and the Vema Fracture Zone in the North Atlantic[1]

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ABSTRACT

Near 11°N, the Mid-Atlantic Ridge is offset by the Vema Fracture. The hypothesis of sea-floor spreading has suggested that the fracture is a transform fault, and this has been confirmed by the first motion studies of recent earthquakes along the fracture. The fault zone is developed as a deep and narrow east-west trending through, bordered on the south side by a high and steep rocky wall representing an uplifted slice of crust. More than 1 km of evenly and horizontally bedded sediments fill the trough, indicating stability and considerable age. Several similar valleys of smaller dimensions occur south of the Vema Fracture, but these appear to be seismically inactive. Thus the young and active Mid-Atlantic Ridge is offset by a system of much older and possibly long-inactive fractures, suggesting that sea-floor spreading in this area, if present, has recently begun. The tectonics of the southern wall are not understood; discontinuities in the mantle may account for its presence.

Recently, Hess' hypothesis of sea-floor spreading (1962) has been receiving an increasing amount of attention as a result of an explanation of the magnetic pattern over the midoceanic rises (Vine and Matthews 1963, Vine 1966). The fracture zones that offset the crests of rises in numerous places have been explained by Wilson (1965) as transform rather than as transcurrent faults. The differential movement along a transform fault, which results from sea-floor spreading from two offset center lines, occurs along the fault only between those centers. The movements are in the opposite sense of those of a transcurrent fault. The first motion studies of earthquakes on midocean rises

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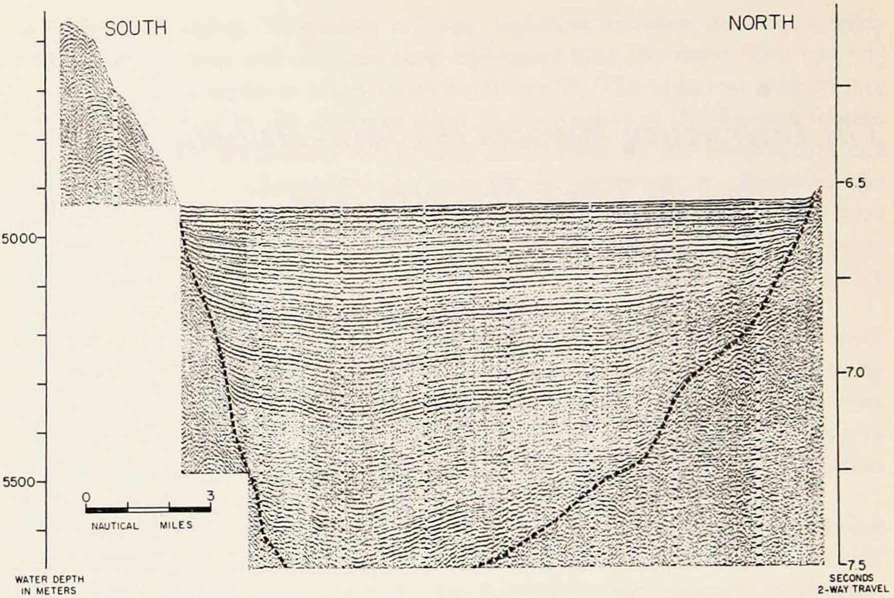

Figure 1. Cruise tracks in the Vema Fracture area.

(Sykes 1967) demonstrate the existence of transform-fault movements on many fracture zones.

Since 1964, the authors and several colleagues, particularly C. O. Bowin, Richard Cifelli, W. G. Melson, and Raymond Siever, have carried out detailed and integrated geological and geophysical studies of tectonically important parts of the Mid-Atlantic Ridge. On cruise 1965-1 of the R/V Thomas Washington of the Scripps Institution of Oceanography and on cruise 20 of the R/V Atlantis II of the Woods Hole Oceanographic Institution in December 1965 and in February and April 1966, respectively, the intersection of the Mid-Atlantic Ridge and the Vema Fracture Zone was surveyed in detail. The survey area (Fig. 1) includes the Vema Fracture itself and segments of the Ridge to the north and south between 40° and 45°W, 9° and 12°N. Navigation was by various means, including radar reflector buoys, celestial and VLF positioning (Silverman and van Andel 1966). Bathymetric, magnetometer, and reflection profiler observations were made, and numerous cores and dredge hauls were obtained. Additional data were acquired on cruise 31 of the R/V Atlantis II in April 1967. This report deals primarily with the topographic and reflection profiler information. The area was first described by Heezen et al. (1964); possible extensions of this group of fracture zones across the Equatorial Atlantic have been discussed by Krause (1964).

The Vema Fracture is a narrow east-west trending trough that is more than 5000 m deep. It offsets the Ridge in a left-lateral sense over more than

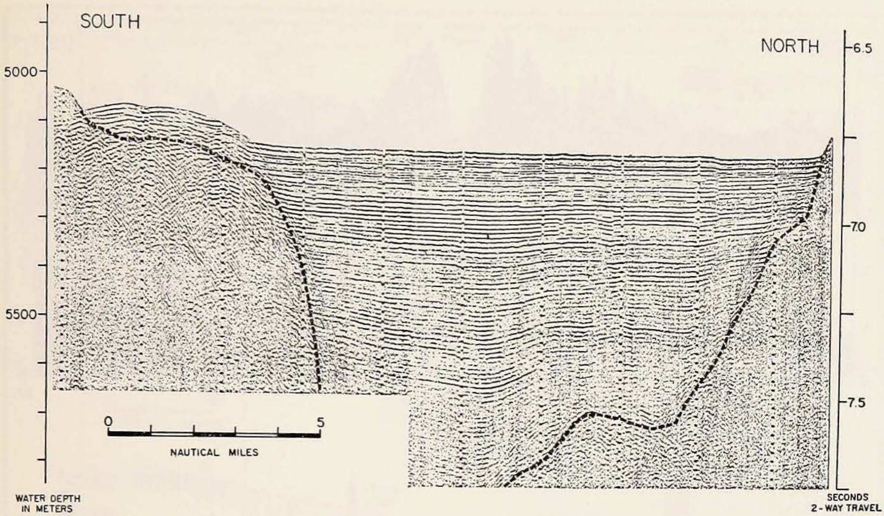

Figure 2. Sketch map of major physiographic units. Depths of flat floors of fracture valleys in meters corrected for the velocity of sound in seawater. Large black dots: earthquake epicenters (locations by courtesy of L. R. Sykes); sense of first motions shown where available. Thick solid lines: sections of Figs. 4, 5.

300 km. To the north and south, short undisturbed segments of the Ridge have been mapped; the southern segment may be offset slightly by subsidiary fractures (J. C. Burke, personal communication). Several east-west trending valleys, with less marked relief but similar configuration, occur to the south of the main fracture (Fig. 2). Another subsidiary fracture may exist near the northern edge of the survey area.

Profiles of the Ridge to the north and south of the main fracture (Fig. 3) are typical for the Mid-Atlantic Ridge, even though the Ridge is somewhat narrower here than farther north. The crest consists of a well-developed median valley having an average depth of 4400 to 4600 m; on each side, rugged crestal ranges with high relief and strong north-south linearity rise to 2200 to 2500 m. The entire crestal zone is essentially devoid of sediment; the V-shaped valleys, judging from reflection profiler data and from the results of several dredge hauls, contain no measurable sediment fill. Dredge hauls have revealed widespread occurrence of fresh and often glass-coated pillow basalts that appear to be most common near the bottom of the median valley. The flanks have fairly low relief with wide and quite equidimensional valleys and hills, without pronounced trends. The sediment cover here is almost continuous, and reflection profiling on the eastern flank has shown that many valleys are filled with as much as 500 m of sediment. There is evidence of structural disturbance, uplift, and faulting of these sediments following deposition.

By analogy with a carefully studied and strikingly similar area of normal

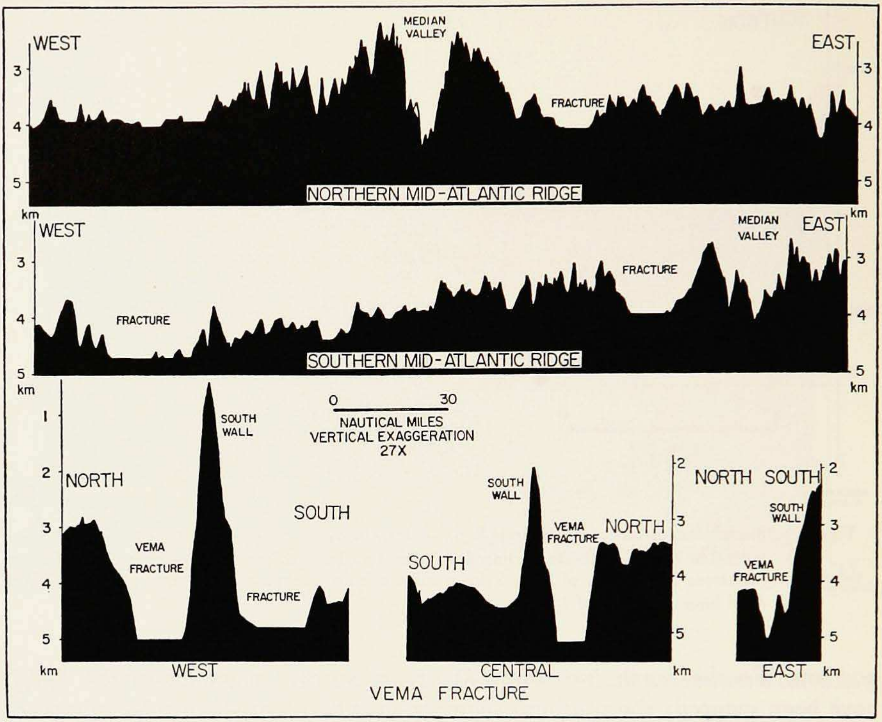

Figure 3. Topographic cross sections of the northern (upper row), and southern (middle row) Mid-Atlantic Ridge segments, and of the Vema Fracture valley (lower row). Depths in kilometers corrected for the velocity of sound in seawater. Locations: *top*, 45° 28′W, 11° 32′N to 41° 53′W, 11° 34′N; *center*, 43° 46′W, 8° 54′N to 40° 10′W, 9° 25′N; *bottom left*, 44° 20′W, 11° 19′N to 44° 28′W, 10° 04′N; *center*, 42° 35′W, 11° 21′N to 42° 09′W, 10° 08′N; *right*, 41° 17′W, 10° 55′N to 41° 12′W, 10° 33′N.

Ridge near 22°N (van Andel et al. 1965, van Andel and Bowin 1967), it has been concluded that the relief of the crest was recently formed, perhaps as late as Quaternary, but that a much greater age, Miocene or earlier, must be assumed for the relief on the flanks (Cifelli 1967). Recent earthquakes, heat-flow data, fresh basalts, and volcanic glass all point to considerable recent tectonic activity of the crestal zone.

In striking contrast stands the Vema Fracture valley, a narrow and almost straight-walled depression (Figs. 2, 3), bordered by steep 30°-to-45° slopes. On the southern side of the valley a straight and narrow wall, 10 to 25 km wide, rises to a crest that varies in height from an average of 2500 to 3000 m to the shallowest observed point of 540 m. This wall appears to have smooth sides; only locally have steps been observed. A similar wall on the northeastern side is not so high and is less well defined.

The valley, which is about 20 km wide at its widest point, has a flat floor.

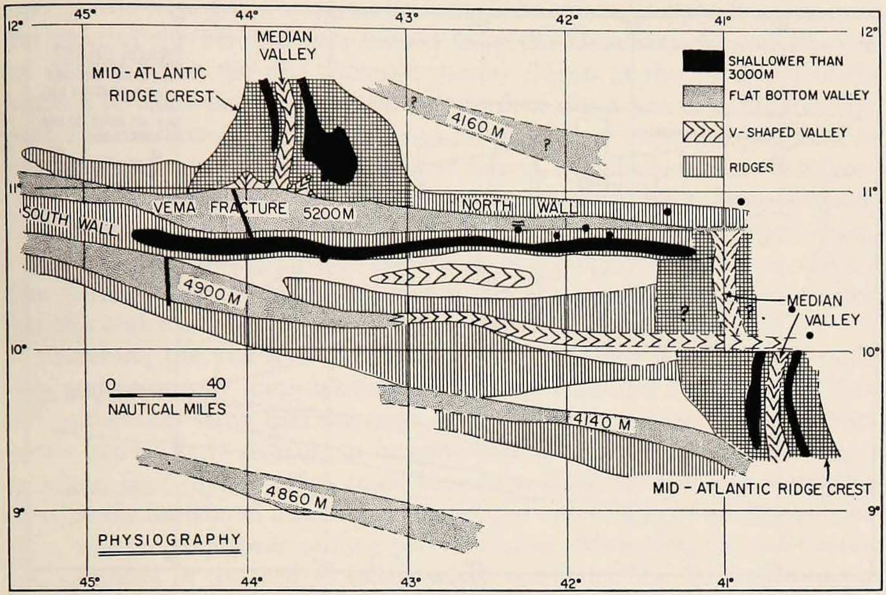

Figure 4. Reflection profile of the Vema Fracture valley (location on Fig. 2); scale for water depth in meters corrected for sound velocity in seawater; scale for penetration in sediments in seconds two-way travel. Vertical exaggeration, approximately 17 times. Obtained with a modified Rayflex Arcer at 1–2-knot ship speed, frequency 75 to 120 cycles, firing at 2-sec intervals.

Numerous crossings show that there is no regional gradient to this floor, but in some places local relief amounts to a few tens of meters. The valley is constricted near 45°W and narrows to a V shape at its eastern end. Hydrographic evidence shows the valley to be a closed basin; the actual sill depth is about 4300 m; the water below about 4600 m is isothermal. Temperatures of 1.80°C or less below the sill depth indicate that the valley was filled with western basin water at some time in the past. Recent computed earthquake epicenters, located with an accuracy of 10 to 20 km (courtesy of L. R. Sykes), occur on both bordering walls but not on the valley floor. Gerard et al. (1962) reported a high heat-flow value of 2.6×10^{-6} cal/cm^2 sec in the valley near 41°W.

Three subsidiary east-west trending valleys south of the main Vema Fracture are also long and narrow (Figs. 2, 3) and have flat floors in their western parts. The levels of these floors are somewhat higher than that of the Vema Fracture valley. At least one of these valleys appears to produce a small offset or an interruption in the Ridge crest; this is confirmed by data from the recent ATLANTIS II cruise. The valleys trend at a slight angle to the main fracture, which they should intersect several degrees west of the survey area. No recent earthquakes have occurred near them.

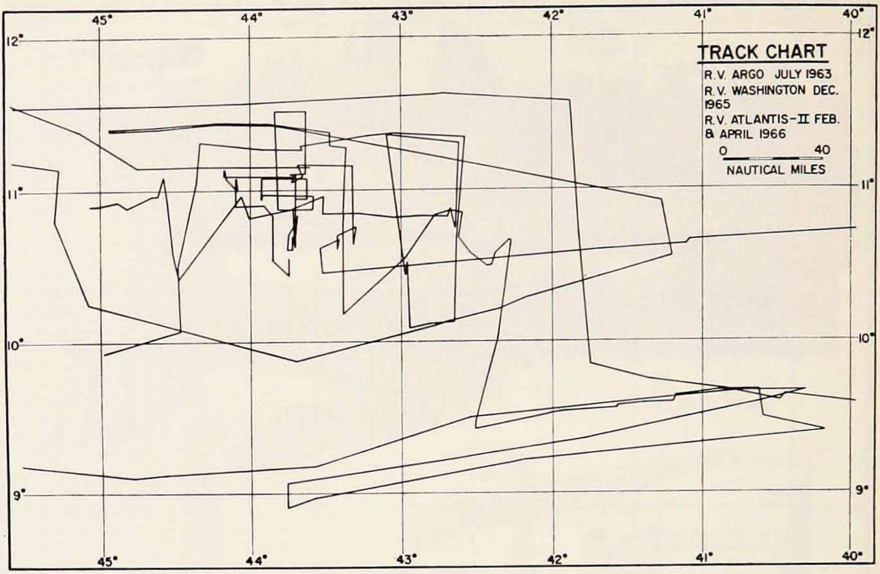

Figure 5. Reflection profile of the first subsidiary fracture valley south of the Vema Fracture (location on Fig. 2). Particulars as in Fig. 4.

Reflection profiler records have been obtained over a large portion of the main valley and in one of the subsidiary valleys. A crossing over the widest part of the main valley (Fig. 4) shows a thick sedimentary fill that exceeds 0.9 sec two-way travel time, or probably more than 900 m. The lowest part is possibly somewhat contorted, but in general the internal reflectors indicate horizontal layers butting against the valley walls. Internal unconformities are absent, and all deviations from the horizontal can be attributed to compaction over an uneven basement. Horizons A and B (see summary in J. I. Ewing et al. 1966), which have been found in large parts of the western North Atlantic and are present on a reflection profile of the Vema Fracture obtained by the Lamont Geological Observatory, cannot be recognized on our records. For the western part of the Vema Fracture, our records show the same even and horizontal bedding in the lower two thirds of the fill as in Fig. 4, but in the upper part can be seen minor unconformities that are related to foreset bedding, with supply along the southern side. This may have resulted from a late partial blockage of the valley.

The sedimentary fill in the first subsidiary valley south of the Vema Fracture is shown in Fig. 5. Here also the fill exceeds 900 m; bedding is horizontal, with little or no deformation. This section, except for a 300-m difference in level of the present floor, is identical to the one from the main Vema Fracture.

The source of this large volume of sediment is unknown. Heezen et al.

(1964), who have given evidence for some local mineral supply, have assumed that most of the material was derived from the Demerara Abyssal Plain to the west and that the fills represent narrow fingers at the distal end of the Amazon turbidite fan. A sand layer at a depth of about 9 m in a core from the southernmost fracture valley appears to be of Amazon origin judging from its content of mica and coarse iron, stained quartz, and shallow-water benthonic Foraminifera. Whatever its origin, a sediment thickness of approximately 1 km represents, at this distance from the continent and in this water depth, a very long time interval, probably in excess of several tens of millions of years. The horizontality of the reflectors and the absence of deformation suggest that this entire period was one of tectonic tranquillity.

Therefore, the young and active crest of the Ridge is offset by a much older and apparently long-stabilized complex of fractures; but high heat flow and earthquakes show that the main fracture, but apparently not the others, is now active. It is difficult to imagine that horizontal movements along a transform fault (Sykes 1967) could have been so gentle and so perfectly adjusted to the horizontal that no deformation, or even tilting of the despositional plain, was produced over so long period of time. Moreover, the deformation and volcanism in the median valley, which opens into the Vema Fracture at 600 to 800 m above the valley floor, have apparently had little or no influence on the shape and fill of the fracture zone at the intersection.

J. I. Ewing et al. (1966), M. Ewing et al. (1966, 1967), and Langseth et al. (1966) have concluded, on the basis of stratigraphic reflection profiling and heat-flow data, that sea-floor spreading in the Atlantic, if now extant, must have been preceded by a very long period of quiescence that probably began in the Quaternary. Van Andel and Bowin (1967), in a study of the Ridge at 22°N, have presented detailed information that can be so interpreted. The conflicting evidence discussed above for the Vema region can be resolved if it is assumed that the fill in the fracture valleys is almost entirely the product of a long quiet period followed just recently by renewed activity along the main fault.

Unexplained is the tectonic nature of the walls of the Vema Fracture, in particular the southern one. Serpentine and peridotite have been dredged from the base of the southern wall and basalt from its top. Therefore, this wall does not represent a volcanic edifice. Judging from reflection data generously provided by Lamont Geological Observatory, the basement below the Demerara Abyssal Plain is at approximately the same level as the basement on either side of the wall. The southern wall therefore represents a positive structural element of great elevation and length, whereas the fracture valleys appear to be normal portions of the deep sea floor. With a total height of more than 3 km above the basement on either side, the southern wall approximates the thickness of the entire crust in this region. Its structural origin and the forces that maintain its elevated position are an enigma; discontinuities in the mantle similar to those below the Mendocino Escarpment in the northeastern Pacific (Dehlinger et al. 1967) may be invoked, but the narrow linearity is peculiar.

At this time it is not possible to present solutions to these problems; further analysis of available data may cast more light on them. It is apparent, however, that even if the Mid-Atlantic Ridge and its associated tectonic elements are produced by sea-floor spreading, not all of its structural features and historic development can be directly and easily explained.

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