that the mode of cave development described here is universally applicable, we do believe that similar conditions may be recognized in other limestone caves which receive storm water recharge.

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Nonspreading Crustal Blocks at the Mid-Atlantic Ridge

Abstract. *Transverse ridges consisting of protrusions into crustal fractures of ultramafic bodies derived from the upper mantle exist at the intersection of the Mid-Atlantic Ridge with equatorial fracture zones. Shallow-water limestones containing detrital grains of quartz, microcline, and orthoclase 1 millimeter in diameter were found on the summit of one such transverse ultramafic body at the Vema Fracture Zone; these findings are explained on the assumption that the limestones were deposited within a narrow, shallow proto-Atlantic and were left behind during the further opening of the Atlantic. Transverse ultramafic bodies from the offset zones of the Mid-Atlantic Ridge behave as nonspreading blocks plastered between spreading crustal plates.*

The theory of sea-floor spreading implies that oceanic crust is continuously being produced at the axis of the Mid-Atlantic Ridge (MAR) and that it moves laterally at rates ranging from 1 to a few centimeters per year. Accordingly, only young material should be found at or close to the axial zone of the MAR. We present here results indicating that ancient, essentially nonspreading crustal blocks exist at the intersection of the MAR with fracture zones in the equatorial Atlantic. The axis of the MAR is offset laterally along these transverse fractures, as seen in the Atlantis, Vema, St. Paul, Romanche, Ascension, and other fracture zones (Fig. 1). The morphology of the Vema Fracture Zone is known in considerable detail (*1*); it is characterized by a deep valley running east-west and interrupting the axis of the MAR which is offset by about 300 km (Fig. 1). A steep and elongated transverse ridge can be observed bordering the valley on its southern side; this transverse ridge is considerably more elevated than the crestal zone of the MAR both north and south of the offset (Figs. 1 and 2); it abuts to the east against the displaced axial zone of the MAR; on the western side it continues and gradually flattens out beyond the zone of offset.

Extensive dredgings (*2, 3*) have established that the Vema transverse ridge is essentially an ultramafic body probably derived from the upper mantle by upward protrusion into a preexisting crustal fracture. Similar ultramafic transverse ridges exist at the intersection of the MAR with other fracture zones, as in the Romanche (*2*), Atlantis (*4*), and St. Paul fracture zones (*5*).

The crest of the Vema transverse ridge is capped by hard limestones and MnO_2 crusts. At one station on the very summit of the ridge (station P7003-5; 10°41′N, 44°18′W; 550 to 900 m below sea level) (see Figs. 1 and 2) we recovered a hard quartziferous limestone, which was studied by microscopic and x-ray diffraction methods. The limestone consists of abundant pelloids and ooids and of recrystallized fossils which include shallow-water (< 30 m) benthic foraminifera of the Miliolid group and gastropods and fragments of calcareous green algae of the Dasyclad group; the whole is in a fine calcitic matrix. The pelloids and ooids range in diameter from 0.2 to 0.8 mm. A common type of pelloid consists of clear calcite crystals surrounded by a dark micrite envelope; frequently, the core within the micrite envelope is empty; in other cases it consists of recrystallized calcite. Similar structures have been described in carbonate sediments deposited in shallow epicontinental basins, typically in the Bahama Banks (*6*). In addition, this limestone contains abundant angular grains of clear, monocrystalline quartz ranging in diameter from 0.2 to about 1 mm (Fig. 3); grains of microcline (Fig. 3) and orthoclase are also present. At the same site we recovered samples of a deeply pitted, selectively dissolved limestone with features suggesting subaerial weathering. Other suggestions of a past emersion of the Vema transverse ridge include our recovery at various sites on its crest of rounded pebbles of a strongly weathered basalt, and the aforementioned "micrite envelopes" with empty cores in the quartziferous limestone; identical types of "micrite envelopes" have been interpreted as due to selective dissolution under subaerial conditions (*6*).

At another site on the crest of the

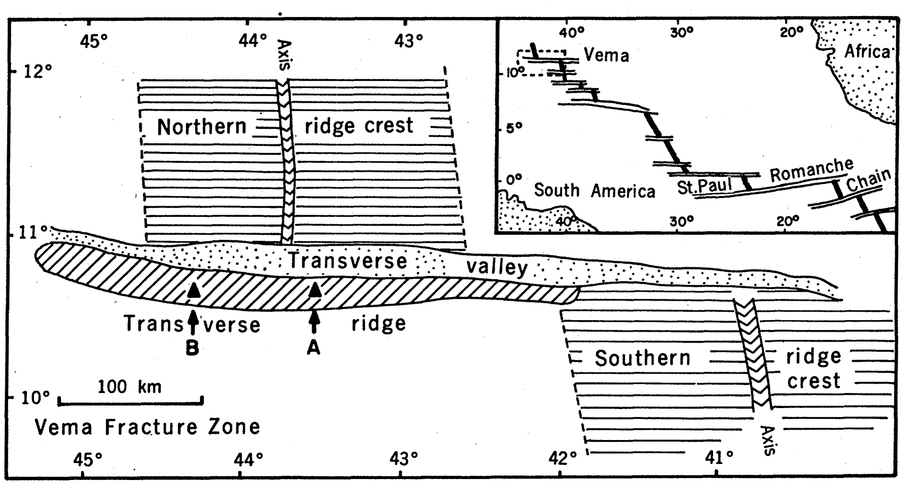

Fig. 1. Morphology of the Vema Fracture Zone, based on data of Van Andel *et al.* (*1*). Triangles indicate locations on the transverse ridge where the quartziferous limestone and the fossil shell were recovered. Arrows point to north-south profiles shown in Fig. 2.

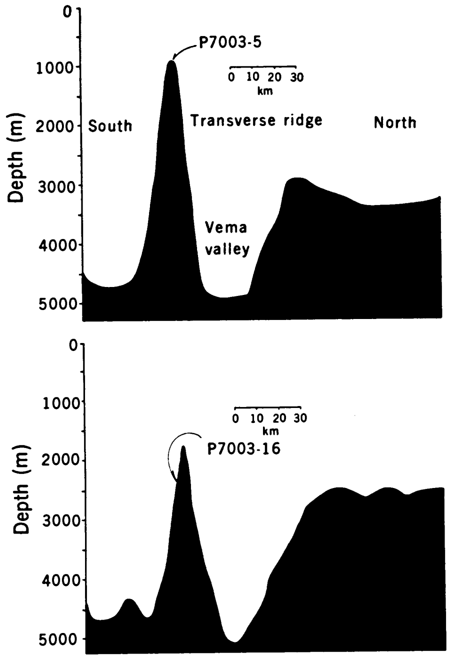

Fig. 2. North-south bathymetric profiles across the Vema Fracture Zone showing the sites on the transverse ridge where the quartziferous limestone and the fossil shell were recovered. The profiles were drawn from a bathymetric chart compiled by Van Andel.

transverse ridge (station P7003-16; 10°35'N, 43°39'W; depth, 2200 to 2900 m below sea level) we dredged a large fragment ($\sim$ 7 cm in diameter) of a bivalve shell resembling an oyster. The thick wall of the shell suggests a shallow-water habitat (*7*); the shell is encrusted by a MnO_2 crust 10 mm thick.

Our attempts to explain these findings, on the basis of the present geographical configuration of the Atlantic Ocean, have been unsuccessful. The coarse detrital grains of quartz, microcline, and orthoclase require a close-by and substantial granitic source, which is absent on the equatorial MAR. If a faraway source (either the African or the North American or South American continents) is assumed, possible transport mechanisms for the detritus include normal oceanic currents, atmospheric currents, or turbidity currents. Transport by normal oceanic currents is excluded since quartz particles 1 mm in diameter would readily settle on the sea floor close to the continent. Eolian transport across the Atlantic is also excluded, because even during exceptionally intense events, it is limited to particles < 30 μm (*8*).

Turbidity currents are a possibility, because they can transport relatively coarse material for long distances. The Vema transverse valley apparently traps turbidites originating from the South American continental shelf (*9*). Since the quartziferous limestone has been found at the summit of a steep transverse ridge 4.7 km above the floor of the Vema valley, and since it is unlikely that a turbidite could climb uphill, the turbidite hypothesis requires that the summit of the Vema transverse ridge must have been at the level of the floor of the Vema valley when the limestone was deposited. This hypothesis implies a relative vertical motion of at least 4.7 km. However, we consider the turbidite hypothesis very unlikely for the following reasons. (i) The turbidites which piled up in the Vema valley during the Pleistocene are predominantly made of lutite; they include only extremely small amounts of carbonates and planktonic or benthic foram tests, as indicated by data from leg 4 of the JOIDES (Joint Oceanographic Institutions for Deep Earth Sampling) program (*9*). Thus, no similarity can be detected between the turbidites from the Vema valley and the quartziferous limestone from the Vema transverse ridge. (ii) The components of the limestone (shallow-water benthic forams, calcareous green algae, gastropods, ooids, and pelloid micritic structures) constitute a quite homogeneous and characteristic facies assemblage. The required long-range turbiditic transport would certainly have resulted in admixture with heterogeneous elements such as planktonic foram test, clay minerals, and so forth, which are instead totally absent.

We conclude that the limestones from the Vema transverse ridge could not have been deposited within the present or recent geographical configuration of the Atlantic. A narrower and shallower Atlantic basin (roughly at the stage of the present Red Sea) would provide a simple explanation for all our findings, namely, the presence of close-by continental granitic sources for the detrital quartz and feldspar grains of the limestone and, at the same time, a shallow epicontinental depositional environment required to explain the limestone and the molluscan fossils.

The conclusions reached above require that the quartziferous limestone was deposited sometime in the late Mesozoic after the initial stage of rifting which created the Atlantic. The limestone in question is remarkably similar in facies to shallow-water Jurassic and Cretaceous sedimentary rocks recovered, especially during the JOIDES program, at various sites in the Atlantic basin and representing proto-Atlantic deposits (*10*). Efforts to obtain a direct micropaleontological age for the limestone were unsuccessful. The Miliolids were identified as belonging to the genus *Triloculina* and some possibly to the genus *Quinqueloculina*, both occurring from Mesozoic to Recent times (*11*). An attempt at dating the limestone by palynological techniques also was unsuccessful (*12*). Indications that the Vema transverse ridge has long been exposed to seawater include the thick MnO_2 crusts, the partial phosphatization of its carbonates, and the strongly weathered state of the basalt pebbles.

Our conclusion that the Vema transverse ridge did not spread as the adjacent sea floor did can be extended to other fracture zones of the equatorial

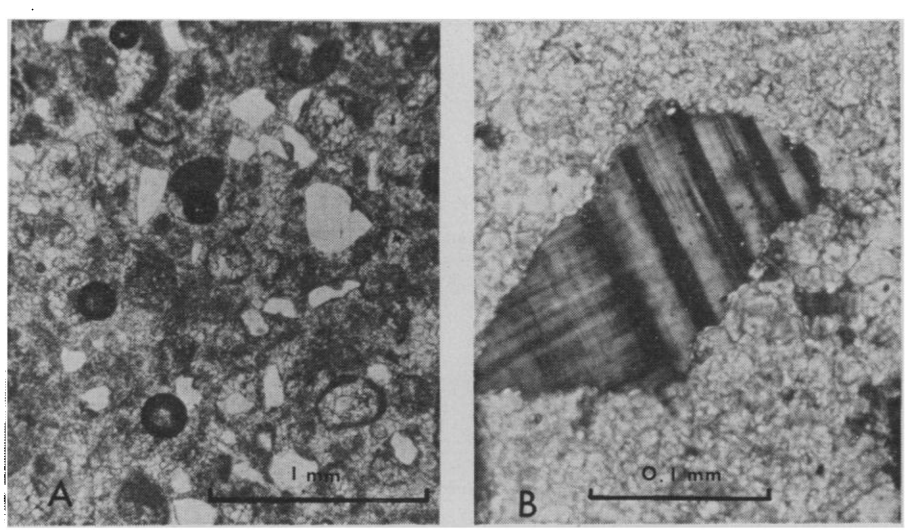

Fig. 3. Microphotographs of the quartziferous limestone: (A) quartz grains in a carbonate matrix showing some "micrite envelopes"; (B) grain of microcline in a carbonate matrix (crossed Nicol prisms).

Atlantic. Saito *et al.* (*13*) reported lower Miocene sediments at the intersection of the MAR with the Atlantis Fracture Zone. The offset of the MAR axis at the Atlantis Fracture Zone is only 30 km (*14*), and Saito's lower Miocene sediments were recovered from within the offset zone, about 10 km from one of the two offset axes; thus, their maximum possible distance from a spreading axis, either immediately north or immediately south of the fracture, is 20 km. If we assume a spreading rate of 2 cm/year, the maximum age of these sediments would be 1 million years if their occurrence is to be explained by sea-floor spreading. However, if they were deposited in the lower Miocene, they must be at least 15 million years old; that is, they are one order of magnitude too old to be accounted for by sea-floor spreading.

Within the offset of the MAR at the St. Paul Fracture Zone a ridge trending east-west is capped by a protrusive, predominantly ultramafic body which emerges at the St. Paul Islets. Recently obtained radiometric ages of rocks from this body, particularly a potassium-argon age of 835 million years for a brown hornblende mylonite (5), are inconsistent with sea-floor spreading. In the offset at the Romanche Fracture Zone we found the summit of the transverse ridges to be covered by thick MnO_2 crusts and by phosphatized limestones Miocene or older (*15*).

A summary of the data indicates that: (i) the Vema transverse ridge is essentially an ultramafic body (*2*); (ii) the petrology and chemistry of its ultramafic rocks suggest mantle derivation, and their textures suggest tectonic emplacement (*2, 3*); (iii) sedimentary rocks and fossils from the Vema transverse ridge are explained if it is assumed that they formed in a narrow and shallow primitive Atlantic and if extensive vertical tectonic motions occurred without much lateral spreading; and (iv) there are indications that the Vema transverse ridge is older than the adjacent sea floor.

We conclude that the Vema transverse ridge constitutes a nonspreading, mantle-derived protrusive block which became emplaced along a preexisting crustal fracture and is now plastered at the boundary between adjacent spreading plates or subplates. Present indications suggest that similar quasi-static ultramafic protrusions exist at other major fracture zones of the Atlantic, such as the Atlantis, St. Paul, and Romanche fracture zones. Thus, sea-floor spreading in the equatorial Atlantic can be viewed as operating in parallel spreading belts separated at the MAR offsets by thin nonspreading blocks (*16*). The presence of these relatively static, mantle-derived protrusive bodies at the offsets of the MAR can be considered within a broader scheme: it can be related to the possible presence of a stagnant mantle zone below the MAR (*17*), and it can be linked to the origin of the offsets themselves, as discussed in detail elsewhere (*16*).

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Fertilizer Nitrogen: Contribution to Nitrate in Surface Water in a Corn Belt Watershed

Abstract. *Measurements of nitrate concentration and relative enrichment in nitrogen-15 were made on samples of the surface waters of a typical Illinois corn belt watershed and the effluent of the subterranean tiles that drain the cropped land in the region. From these measurements, we estimate that at the time of peak nitrate concentration in the spring of 1970 a minimum of 55 to 60 percent of the nitrogen found as nitrate in the surface waters of this watershed originated from fertilizer nitrogen.*

As nitrate concentrations in surface waters in the United States continue to increase [see, for example, Harmeson and Larson (*1*)], even occasionally surpassing the U.S. Public Health Service (PHS) limit of acceptability, two questions among others become increasingly important: (i) What fractional responsibility must the rising rate of application of inorganic nitrogen fertilizers bear for the increase in the nitrate concentration? (ii) What will nitrate concentrations in surface waters be in the future, given a continuation in present trends or given a change in fertilization practices?

Until now, efforts to answer these and related questions have been based on the apparently straightforward technique of analyzing the relationship between nitrogen fertilizer applied to the soil and the concentration of nitrate and other nitrogenous constituents in water that drains from cropped land. The interpretation of such data is, however, far from straightforward because the large preexisting reservoir of nitrogen in the soil and the biological transformations it undergoes—particularly the cycling of NH_4^+ through bacterial protoplasm—serve as a buffer between the input of inorganic nitrogen and the discharge of nitrate to subsurface water.

We report here some results based on a different approach and aimed at providing an answer for the first question for a typical central Illinois corn belt watershed. In addition, we are hopeful that this new approach to the problem of estimating the impact of fertilizer nitrogen on surface water nitrate will help to generate the data needed to predict future nitrate levels.

The study has been carried out in the Sangamon River watershed. In 1922 a mainstream dam on that river