Reports

Morphology and Sediments of a Portion of the Mid-Atlantic Ridge

Abstract. *In October 1964, a detailed geophysical and sampling survey was made of the central part of the Mid-Atlantic Ridge between 22° and 23° north latitude. The results indicate a large difference in age between the relief of the crest and that of the flanks of the Ridge and suggest that the crest portion is very young. Detailed surveys of two sediment-filled valleys on the upper western flank of the Ridge reveal different sedimentary sequences in the two valleys and indicate the probable existence of a locally controlled depositional regime and a significant local supply of sediment.*

Most studies of the ocean floor have been carried out on a regional basis, and most of the available information has come from expeditions crossing entire ocean basins. Patterns of relief and sediments have been assembled from sounding tracks and samples spaced tens to hundreds of kilometers apart. These efforts have yielded a broad regional knowledge of the morphology, structure, and sedimentation in the oceans and have produced various hypotheses regarding the origin of major features of the ocean floor (*1*). Samples from closely spaced areas and detailed geophysical surveys are needed to provide much of the information necessary for testing and refining these hypotheses, but detailed investigations of mid-ocean areas have, so far, been few (*2*). In this report we present the preliminary results of such a detailed study of a small portion of the Mid-Atlantic Ridge.

In recent years the mid-ocean rises have received much attention and have played an important part in theories regarding the origin of oceans and continents (*1*). From this work emerged an image of the "normal" Mid-Atlantic Ridge as a broad and continuous rise, approximately 4000 m above the deep-sea floor, incised by longitudinal valleys. Either a single major valley or several valleys may appear in any cross section (*3*). The valleys have steep walls, rising to 2000 m above the valley floor, and vary in width from 1 to 30 km. The valleys have been assumed to be the product of faulting. Heezen and his co-workers have postulated the existence of a single median graben ("rift") that is virtually continuous along the entire length of the Ridge (*3*). A portion of a median valley has been surveyed by Hill (*2*), but otherwise the details of morphology and structure are not known.

In 1963 we made a reconnaissance study of the relief and sedimentation of the equatorial Mid-Atlantic Ridge in the vicinity of St. Paul's Rock. In this area the structure of the Ridge is complicated by major transverse fracture zones and is thought to contain large-scale horizontal and possibly vertical displacements (*4*). Results of that study made desirable a comparison with a more "normal" segment of the Ridge. For this purpose we selected a small portion of the Ridge between 22° and 23° north latitude (Fig. 1), distant from transverse structural complications and containing a well-developen median valley (*3*). Preliminary bathymetric data were available from earlier cruises (cruise 17 of the Woods Hole Oceanographic Institution's R.V. *Chain* and the Scripps Institution of Oceanography's *Zephyrus* expedition). In October 1964, on cruise 44 of R.V. *Chain*, continuous bathymetric, seismic reflection, gravity, and magnetic observations were made on 12 east-west sections in this area, 8 to 10 km apart (Fig. 2); six anchored radar-reflector buoys were used for navigation (range up to 35 km). Two flat-floored valleys in the western part of the area were surveyed in greater detail; in all, 21 gravity cores, three piston cores, and seven dredge samples were collected.

The bathymetric sections showed a single major longitudinal valley in the crest at approximately 45° west longitude (Figs. 2 and 3). Its shape varies from a simple V, with slopes often exceeding 30°, to a complex system with internal steps and ridges. The valley floor lies at a depth of 3800 to 4100 m; it is bordered by ridges rising to depths of 1900 to 2650 m, with a single peak at 1170 m. Near the southern margin of the area studied, the median valley becomes less distinct among several others (Fig. 2, section c); toward the north, the valley shoals to 3500 m, and a profile (HC-624) of water temperature and salinity indicates that it is closed by a sill at about 3150 m. The valley has an uneven bottom, and records obtained, at low cruising speeds, by reflection seismic and high-resolution echo sounding techniques, indicate that no more than a few tens of meters of sediment can be present. Flow of sediments along the rift or down the flanks of the Ridge to accumulation basins elsewhere cannot account for the absence of thick sediments, since numerous sills and ridges prevent long-distance transport along the bottom.

Flat-floored valleys with thick sediment fill are common on the flanks of the Ridge. None are found, however, within a band extending 100 km westward or 50 km eastward from the axis of the median valley (Fig. 3). Beyond the area investigated, many such sediment pockets have been reported as far as the edge of the abyssal plain (*5*). The thickness of the valley fill in the area we studied varies from 80 to 330 m, about 200 m being the value most often found.

In the central part of the area, valleys and ridges are distinctly elongate and parallel to the trend of the Ridge. The major elements of the relief can be traced over several adjacent crossings. On the flanks, even adjacent crossings show little similarity, individual topographic features have dimensions of 15 km or less, and there is weak orientation. Two flank valleys that were surveyed in detail are ovoid, with flat floors. The floors of the two are 4350 m deep, 6 km wide, and 10 km long (North Pond), and 4020 m deep, 6 km wide, and 14 km long (South Pond). Hydrocasts indicate closure at 3600 and 3550 m, respectively.

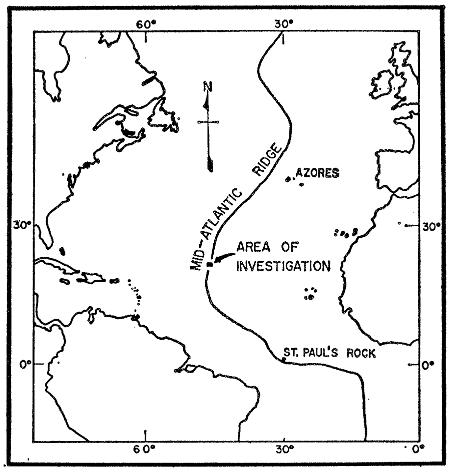

Fig. 1. Location of the Mid-Atlantic Ridge and the area investigated.

Dredging of the lower slope of the median valley from 4000 to 3200 m (Fig. 2, DR 3) yielded only fresh greenstone, a metamorphosed basalt (*6*), heavily fractured, sheared, and often slickensided. On the upper slope (Fig. 2, DR 2, 2670–2050 m), greenstone was found together with many fragments of diabasic, plagioclase-rich basalt, angular or slightly rounded, with rare olivine phenocrysts. This basalt is fresh, with manganiferous coating occurring only as thin, sparse flecks. Several pieces of basalt are coated with black, vesicular glass (n = 1.597) and with yellow-brown, earthy palagonite interlayered with thin veins of ruby-red glass. A few pieces of a conglomeratic rock, possibly a tuff of moderately well rounded basalt pebbles in a coarse matrix containing shell debris, also were recovered in this haul.

The dredge hauls from the flanks (Fig. 2, DR 6, about 4250 m; DR 10, about 3600 m) are markedly different. The only rock type they contain is a deeply altered basalt, with discolored margins up to 2 cm thick. The diabasic basalts are porphyritic, with large plagioclase phenocrysts and an abundance of olivine. All samples contain abundant palagonite in large, earthy lumps; friable manganiferous crusts several centimeters thick cover the basalt fragments and some of the palagonite. A dredge haul taken in this vicinity (22° 56′N, 46°35′W; about 3125 m; *Chain* cruise 17) yielded a very similar basalt, along with abundant manganiferous crust and palagonite (*7*).

Small pipe dredges attached to the rock dredge and one short (88 cm) core in the median valley (Fig. 2, FC 14) yield a yellowish-brown foraminiferal ooze with abundant sand-size fragments of rock, minerals, and glass. Sediments on the flanks contained only foraminiferans and rare manganese micronodules in the coarse fraction. Apparently, local supply of sand-size, nonbiogenous material is restricted at present to the central part of the Mid-Atlantic Ridge.

The deposits of North and South Pond are surprisingly varied. Two piston cores in North Pond (Fig. 3, PC 3 and PC 11) contain a sequence of yellowish-brown, firm clays alternating with layers of coarse foraminiferal sand. The sand layers are graded or laminated and vary in thickness from 0.1 to 50 cm. The two piston cores are only about 3 km apart, but cannot be correlated well. The cores are not at all distorted, and absence or major thinning of layers due to coring appears improbable. In South Pond, a single piston core (Fig. 4, PC 22) has a very different sequence, with 455 cm of very soft, almost soupy, yellowish-brown clay overlying a series of firm clays and foraminiferal sands. Several short cores and pipe-dredge samples from the hills surrounding the ponds contain yellowish-brown clays, but no foraminiferal sands. One core (PC 24) from the highest point of the rim of South Pond (3000 m) contains pieces of consolidated foraminiferal ooze of late Tertiary age (*8*).

The variability of the sedimentary sequence in North Pond and the large difference between the sediments of the two ponds indicate that the depositional regimes in the ponds are, to a large extent, locally controlled. The mechanism of this control is not clear to us, but the coarse foraminiferal sands are almost certainly the products of local transportation, although no source deposits on the surrounding hills have been located and the winnowing of such large quantities from the yellowish-brown clays that cover the hills seems unlikely. The widespread and abundant occurrence of palagonite suggests that a significant local source of fine-grained sediment is available, although Goldberg (*9*) has claimed that essentially all of the noncalcareous fraction derives from distant sources.

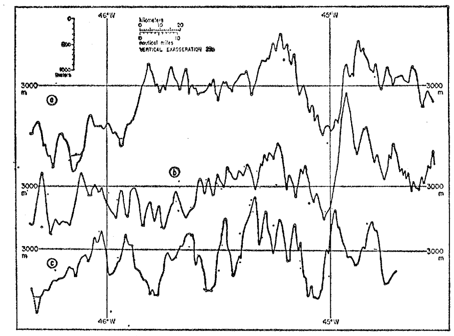

Fig. 3. Typical east-west cross sections; *a*, *b*, and *c* refer to locations on Fig. 2. The values given for depths and slopes are uncorrected. Dotted lines indicate subsurface reflections from sparker records.

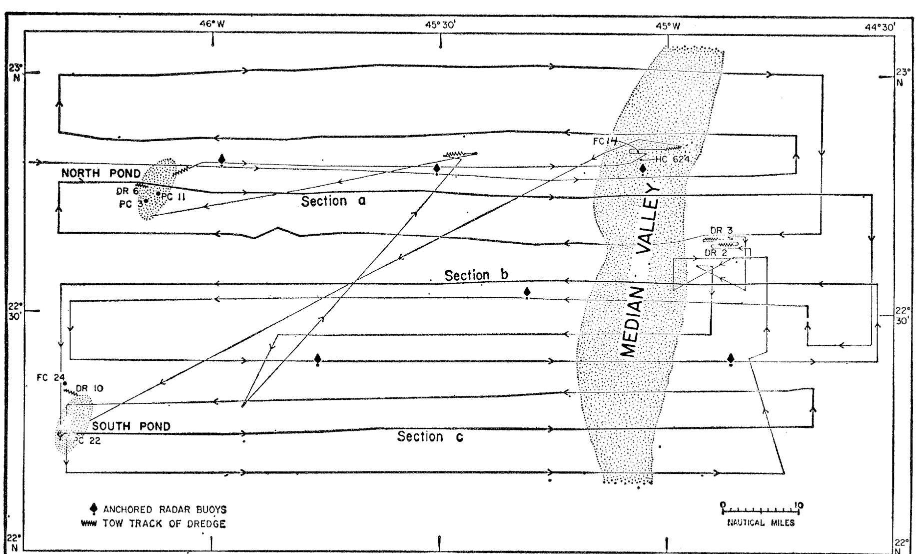

Fig. 2. Diagram of sounding tracks, position of buoys, samples discussed in text, and major topographic features of the area investigated. The buoy in South Pond was used for pond survey only.

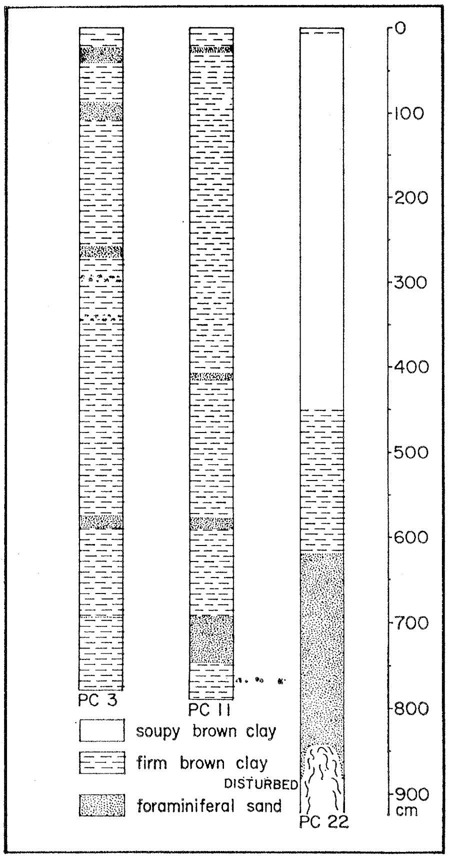

Fig. 4. Schematic lithology of piston cores from North and South Pond. The sample locations are shown in Fig. 2.

Thus, major differences exist between the flank and the crest portions in this part of the Mid-Atlantic Ridge. The crest has pronounced topographic linearity, little or no sediment cover, fresh rocks, and no manganiferous coating on rocks and sediments. The flanks have less topographic orientation, thick valley fills, strongly altered rocks, and thick manganiferous coatings. These observations suggest a large difference in age between (i) the relief and structure of the crest and (ii) the relief and structure of the flanks, with a very young age for the crest. Using a sedimentation rate of 2.7 cm per 1000 years, given by Ericson (*10*), for the Mid-Atlantic Ridge, we estimate that deposition in the flank valleys may have started at least 10 million years ago, whereas a few tens of meters of sediment in the median valley would require an age of no more than 100,000 years.

Using Goldberg's values (*9*), we obtain 70 million and 700,000 years for the respective ages. These calculations are obviously highly speculative, for the extrapolations are long, the estimates of total thickness are not accurate, and no allowances have been made for changes in sound velocity, for compaction, or for instantaneous deposition of sediments (turbidites). Nevertheless, the estimates give an approximation of the large time difference and emphasize most clearly the very young age we attribute to the central structural development of the Mid-Atlantic Ridge.

The finding of metamorphosed basalt on the slopes of the median valley critically confirms earlier hypotheses of vertical movements along this zone; the pressure-temperature for the metamorphism observed can be obtained only under some thickness of overburden. The topographic evidence described above precludes erosion as a major factor in the exposure of the metamorphosed rock; faulting and lateral displacement of the upfaulted rock seems to us the only reasonable alternative.

It is tempting to relate our observations to recent hypotheses on continental drift and sea-floor spreading (*11*) by assuming that the inferred age difference between crest and upper flank and the youth of the former are the result of continuous formation of new crust along the median line of the Atlantic (*12*). We do not, however, believe that our data either require or materially support such an interpretation. The ages postulated here refer only to the relief and the surficial tectonic events that have produced it. Although we found no evidence for older crust of sedimentary origin in the region of the crest, our data do not preclude its existence. Remnants of sediments and slopes predating the present relief may well exist, concealed by structural deformation or flows of basalt.

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References and Notes

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2. M. N. Hill, *Deep-Sea Res.* **6**, 193 (1960); D. H. Matthews and F. J. Vine, *Bull. Geol. Soc. Am.*, in press.
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5. Similar sediment pockets farther north and south on the Ridge have been described by M. Ewing, J. I. Ewing, and M. Talwani, *Bull. Geol. Soc. Am.* **75**, 17 (1964).
6. Thin-section identifications of the rocks of dredges 2 and 3 were made by W. G. Melson of the U.S. National Museum in Washington, D.C. To our knowledge, metamorphosed basalts of this type have not been reported from the Mid-Atlantic Ridge. The chlorite-albite-actinolite-epidote facies of these rocks can be formed without change in chemical composition, except for the addition of water, at somewhat elevated temperature and water pressure [F. J. Turner and J. Verhoogen, *Igneous and Metamorphic Petrology* (McGraw-Hill, New York. 1960), p. 534].
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12. Given a half width of the Atlantic Ocean of approximately 4000 kilometers at 20°N and an age of 10^7 years for the upper flank of the Ridge at 100 kilometers from the center, separation of Africa and the Americas would have taken place approximately 4×10^8 years ago, in the middle Paleozoic. An age of 7×10^7 years for the flank would place the separation in the Precambrian, at 2.8×10^9 years ago. While the last figure is obviously unreasonable, the first figure is fairly consistent with some postulated continental drift patterns.
13. Cruise 44 of R.V. *Chain* and associated programs were supported, through contracts or grants with the Woods Hole Oceanographic Institution, by the following: the U.S. Atomic Energy Commission [contract AT(30-1)-2174; this is report No. AT(30-1)-2174-30]; the U.S. Office of Naval Research [contract Nonr-2196(00)]; and the National Science Foundation (grants GP921 and GP1599). Participation of the senior author was made possible by contract Nonr 2216(23) of the Office of Naval Research with Scripps Institution of Oceanography. The bathymetric data were obtained with a Gifft transceiver and an Alden 419B Precision Graphic Recorder; the seismic reflection data were obtained with the Woods Hole continuous seismic profiler, a 100,000-joule sparker. The depths given are based on a sound velocity of 1500 m/sec. We are grateful to J. B. Hersey and Carl O. Bowin, who made the instrumentation and operational assistance available. Samples were taken with conventional dredges, a modified Kullenberg piston corer with piston release, and free corers (P. L. Sachs and S. Raymond. *J. Marine Res.*, in press). We thank the officers, crew, and scientific staff of R.V. *Chain* for their cooperation. H. W. Menard reviewed the manuscript. This is a contribution of Scripps Institution of Oceanography, New Series, and contribution No. 1633 from the Woods Hole Oceanographic Institution.

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