volcanoes. The bulk of the extrusives beneath stations 9, 47, and 48 which are responsible for the observed magnetic anomalies may therefore be an order of magnitude older than the dated surface specimens. Age determinations on the inaccessible buried rocks would reduce the calculated rates of spreading. Specimen 33, by way of distinction, was collected from an upthrusted and considerably eroded seamount (*4*), so that a more deep-seated layer may have been sampled, giving a closer approximation to the age of formation of the seamount. In addition, due to the greater ages and distances involved, time lapses between the first and last eruptions on Bald Mountain would not significantly alter the calculated rate of spreading. As noted above, the age of 0.31 million years for sample 48 was obtained after the deuteric zeolitic material had been removed. The K-Ar ages reported for the altered plagioclase component of submarine lavas are markedly lower than for associated biotite and whole rock samples (*7*). Since the beneficiation process probably did not remove all of the altered plagioclase from sample 48, the resulting age is considered to represent a minimum value. Specimen 47 has a high content of large, resorbed, but unaltered plagioclase. However, since the argon retentivity of plagioclase is open to question this result may also be lower than the true age. Conversely, specimen 33 is an extremely fine-grained, very fresh, phenocryst-free basalt, and hence the age obtained should closely approximate the time of extrusion. If the ages determined for samples 47 and 48 are in fact too low, the true rates of ocean-floor spreading will be less than stated in Table 1 and may approximate the rate based on the results for the Bald Mountain basalt.

A major change in the rate of spreading may possibly have taken place over the last 8 million years; the current rate appears to be two or three times greater than in early Pliocene times. Different rates of spreading may be responsible for the different morphological features found at 45°N. Plastic flow beneath the ridge (*8*) may be the result of the more rapid rate near the axis, whereas slower spreading rates may have resulted in brittle fracturing of the crust (*8*), and may have produced the block-faulted morphology of Bald Mountain (*3*). But Phillips (*9*) inferred a decrease in spreading rate in the last 9 million years based on magnetic anomalies at 27°N.

An alternative possibility is that, although the rate of spreading may have remained at a constant high value since the beginning of the Pliocene, there may have been one or more quiescent periods within the last 8 million years, thereby yielding a low overall rate. A discontinuity in the Miocene has been postulated (*10*) from evidence of abrupt changes in sedimentary thicknesses. The bathymetry at 45°N (*1, 4*) reveals a marked change in topography at 28°40′W. The rugged topography and orientation of features trending 19° east of north is replaced, west of 28°40′W, by a due-north orientation, with seamounts of low relief separated by large, smooth sedimentation ponds. Such a line of demarcation could represent the position at which sea-floor spreading, once active in an east–west direction, halted for some time. Renewed spreading at a later date may then have commenced parallel to the new orientation which we observed on the Median Rift Valley.

The rate of ocean-floor spreading at 45°N calculated from magnetic anomalies is 0.8 cm/yr (*6*), in agreement with the rate calculated for the basalt dated from Bald Mountain. This further suggests that the discrepancies in spreading rates are due mainly to sampling problems and only in part to the tendancy for K-Ar values to give lower limits, since fission-track dates are independent of the effects of argon loss. This rate is also in excellent agreement with the magnetic spreading rate of approximately 1 cm/yr across the Reykjanes ridge south of Iceland and the rate of 1.2 cm/yr based on new isotopic ages from Iceland, as reported by Moorbath *et al.* (*11*).

The progressive increase of the ages as determined by K-Ar and fission-track (*3*) methods with distance from the axis of the Mid-Atlantic Ridge, and the evidence that the extrusives are of similar or younger age than might be implied from the magnetic anomaly patterns, provide a positive although limited test for the hypotheses of ocean-floor spreading (*3*).

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Mid-Atlantic Ridge: Age and Spreading Rates

Abstract. *Fission-track dating of basaltic glass from the Mid-Atlantic Ridge gives results which are consistent with the proposal of ocean-floor spreading. Solidification ages from ~10,000 years to ~300,000 years were measured. Correlation is also possible between the magnetic anomaly patterns over the Crest Mountains at 45°N and the geochronology of the outcropping basalts. Renewed volcanic activity well removed from the axis of the Mid-Atlantic Ridge has been demonstrated to have taken place in recent times.*

Two of the most striking features of the surface of the solid earth are the apparently matching borders of the continents on opposite sides of the Atlantic Ocean and the vast, seismically and volcanically active mountain ridge system bisecting the Atlantic. The matching coastlines have been taken as evidence of the drift of continents that followed the splitting of an originally larger land mass (*1*), and the ridge is similarly cited as the possible line from which the continents are moving (*2*). Additional findings—particularly the existence of a system of parallel magnetic anomalies that are symmetrical about the axis of the ridge system—have supported the earlier suggestion (*3*) that the ridge is the site of upwelling and subsequent lateral spreading of material from giant convection cells within the earth's mantle. These strips of alternating magnetic intensity (relative to the regional average) may be due to material on the ocean floor which rose and cooled through the Curie point during epochs of different polarity of the earth's magnetic field, and may therefore express the time at which the rocks were formed; their age would be expected to increase with distance from the axis of the ridge system (*4*).

Table 1. Fission-track data.

Sample No.	Spontaneous fission tracks counted	Area surveyed (cm^2)	Induced track density* (track/cm^2)	Uranium (wt ppm)	Fission-track age (yr)	95% confidence limits on ages (yr)
1	3	9.69	12,420 (± 3.9%)	0.31 (± 14%)	17,000	1,500–68,000
9	63	14.42	10,450 (± 4.1%)	0.21 (± 14%)	286,000	222,000–366,000
56	2	8.90	11,150 (± 4.4%)	0.38 (± 14%)	13,000	1,000–47,000

* For a neutron dose of 1.08×10^{16} (± 2.9 percent) (neutron density × velocity × time).

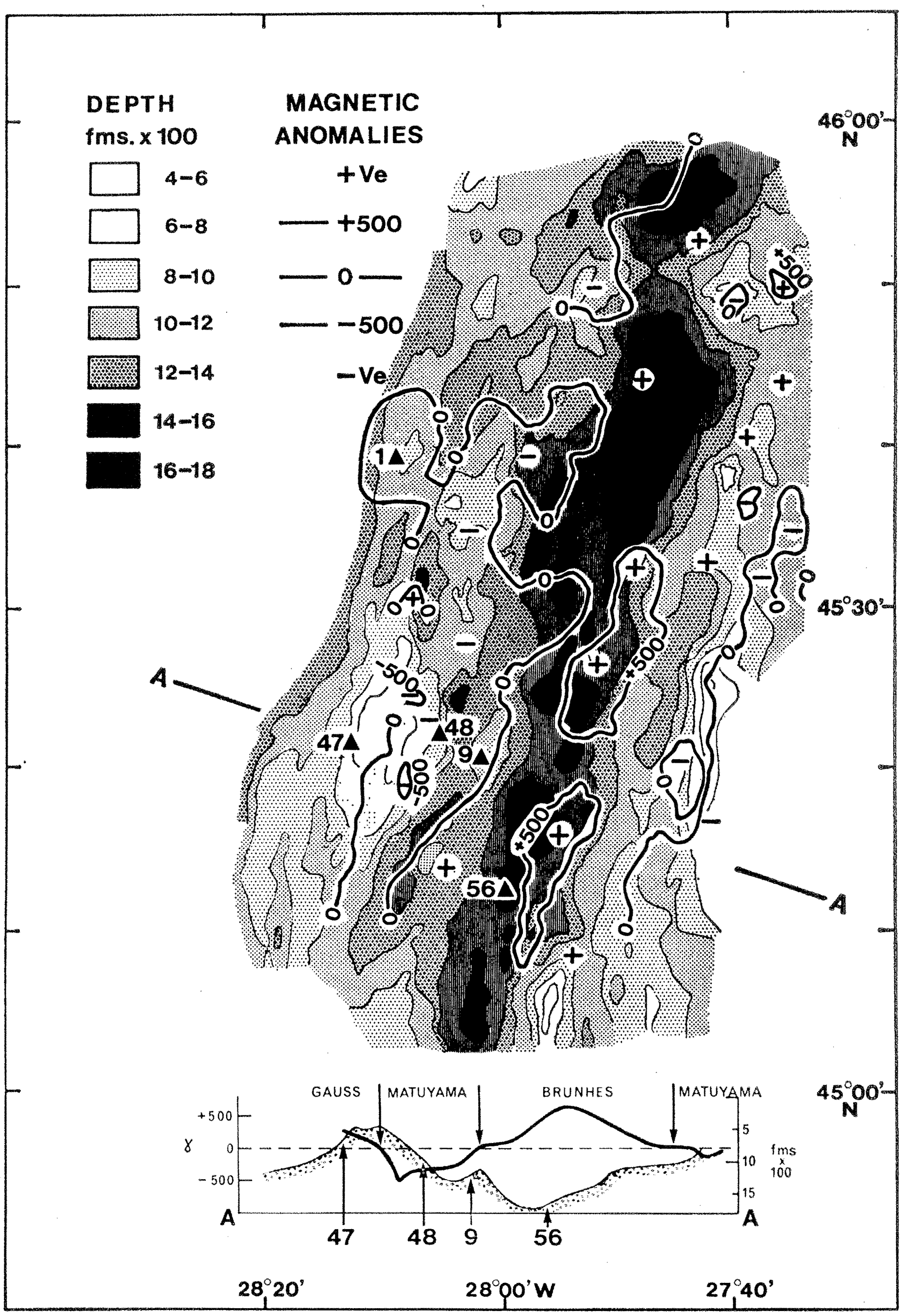

Fig. 1. Contour map of the Mid-Atlantic Ridge at 45°N showing the location of the three samples that have been dated by fission-track techniques (Nos. 1, 9, 56). A simplified magnetic anomaly map for the area is superimposed, showing only the magnetic highs and lows, and the +500, 0, and −500 gamma contours (1 gamma = 10^{-5} gauss).

Direct age measurements should provide a useful test of the idea of ocean-floor spreading and would test whether the magnetic results are related to the ocean-floor chronology. Because the Mid-Atlantic at 45°N is probably the most thoroughly mapped portion of the ridge (*5, 6*), we have selected samples of basaltic glass (*6*) taken from that site (*7*). The locations of the three samples reported here are given in Fig. 1. One sample (No. 56) is from the center of the Median Valley; another (No. 9) is in the valley part way up the ridge; and the third (No. 1), from just outside the crest of the ridge, lies in a region where the parallel-band character of the magnetic anomalies is disturbed.

Fission-track dating (*8, 9*) was chosen because it yields the appropriate age, namely the time of cooling of the sample and because the low potassium content (<0.5 percent) makes potassium-argon dating difficult and unreliable for young samples, such as would be expected near the axis of the ridge (*10*). The track-identification criteria (*9*), sample-scanning procedure (*11*), and neutron dosimetry (*12*) are standard, and have been described for other glass samples. The only unique aspect of the experimental procedure arose from the unusually low-track densities and the need, therefore, to scan large areas of sample at high magnification in order to locate a few tracks (*13*).

Track fading is a possible difficulty that must be assessed, since, if present, it would lead to a low density of spontaneous fission tracks and to the calculation of an erroneously low age. In order to establish that the age measured is not merely a lower limit, we have annealed neutron-irradiated fragments of the samples used, to establish track-fading characteristics. Figure 2 indicates that tracks will last 10 minutes at 325°C, 1 day at 260°C, and, by extrapolation, 10^{11} to 10^{12} years at ocean-water temperatures. Since it has been shown (*9, 14*) that such extrapolations lead to valid conclusions and since 10^{11} years is much greater than the ages of interest, track fading is not a problem as long as the samples remained at sufficiently low temperatures. Because each sample was taken from the thin, glassy veneer of an exposed pillow lava, we have assurance that the temperature has remained very close to that of water at the ocean bottom (~4°C). Consequently the ages we measure are true (solidification) ages rather than lower limits.

Table 1 gives the fission-track data,

uranium content [by fission tracks (*15*), calibrated as described in ref. (*16*)], and ages. The low uranium contents and low ages combine to produce unusually low track densities, and only a few tracks could be detected even after scanning more than 10,000 fields of view for each sample. The statistics may be poor but nevertheless are more than adequate to establish that samples 1 and 56 are of nonzero age and are at least several times younger than sample 9.

One conclusion stands out clearly from our results, that there are extremely young rocks along the Mid-Atlantic Ridge. For the dating of such young glass as was encountered here, the fission-track technique is uniquely applicable.

To appreciate two further, less definite, but equally important conclusions, we assemble with the three ages determined here, three others, determined by K-Ar dating and reported elsewhere (*17*). The ages are 310,000 years for sample 48 (Fig. 1), 10 km from the Median Valley, 750,000 years for sample 47 (Fig. 1), 18 km from the valley, and 8,000,000 years from samples from site 33, 60 km directly west of site 56. Of the six locations, five (Nos. 56, 9, 48, 47, and 33) lie in areas whose magnetization follows the usual regular, symmetrical bonding parallel to the Median Valley; the sixth sample (No. 1) lies in a magnetically disturbed area. Of the six ages, five (Nos. 56, 9, 48, 47 and 33) increase monotonically outward from the very low value at the Median Valley (Fig. 3); the sixth sample (No. 1) is much younger than the other (No. 47) at a comparable distance from the Median Valley.

Two interpretations should be considered. With a total of six ages it is statistically possible, although improbable, that the five ages from regular magnetic regions just happen to fall in a sequence that increases monotonically outward from the centerline of the ridge, while the single sample from magnetic anomaly falls below the age that would be inferred from the sequence of the others.

We prefer, however, the alternative interpretation, that the ages are the natural consequence of ocean-floor spreading, which would give the monotonic increase of ages at a rate which is a direct measure of the spreading of the ocean-floor away from the Median Valley—the generally assumed location of the upwelling of new ocean bottom. In this model the low age of the sample and the existence of the magnetic disturbance at site number 1 are the joint natural consequences of a separate, local igneous event occurring away from the Median Valley.

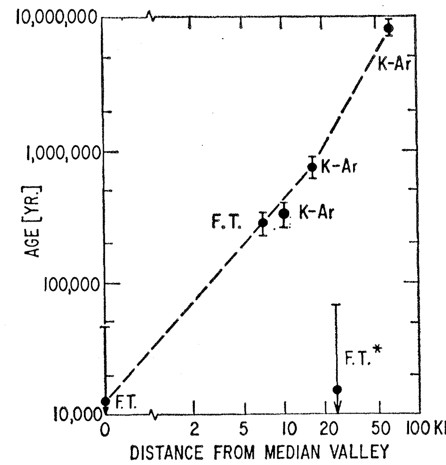

Fig. 3. Age of basalts as a function of the distance from the Median Valley of the Mid-Atlantic Ridge. The samples at a distance of 0, 7, and 24 km were dated by the fission-track technique; those at 10, 18, and 60 km were dated by K-Ar dating (*17*). The sample marked with an asterisk comes from a magnetically disturbed region while the other five come from regions having the usual regular magnetic structure parallel to the Median Valley.

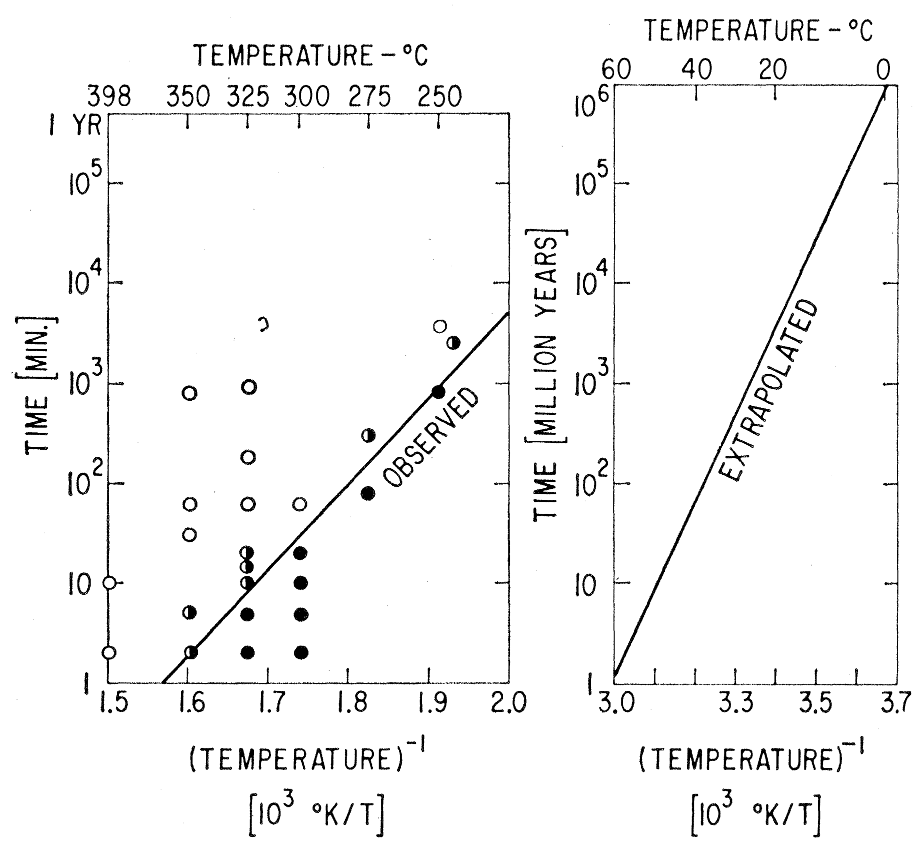

Fig. 2. Track fading conditions for sample No. 56. Solid dots indicate time and temperature conditions where tracks are unaffected. Open dots indicate conditions where tracks are reduced in number or are absent. The line in the right-hand portion of the graph represents the extrapolation to large times of that on the left. Essentially equivalent results obtain for sample 9.

Our second conclusion is that the sequence of ages progressing outward from the Median Valley 13,000, 290,-000, 310,100, 750,000, and 8,000,000 constitutes strong, direct support for the idea of ocean-bottom spreading. In addition to the evidence of the sequence of ages, the value of the spreading rate that we will infer here and in (*17*) from the various samples will demonstrate the consistency of the assumed explanation of the age sequence.

The third conclusion arises from the finding that the ages vary in a regular manner in the regions of regular magnetic anomalies and that the age is low in the one region that was disturbed magnetically. These results support, by direct dating, the inference made by Vine and Mathews (*4*), that the magnetic anomalies correspond to reversals of the earth's magnetic field in the past and hence can be used to infer the chronology of the ocean bottom.

We now tentatively infer the local rate of spreading of the ocean floor at 45°N. Sample 9 is located just under 7 km from the axis of the Median Rift Valley; the age difference (age of sample 9 less age of sample 56) is 273,000 years. The local rate of spreading is therefore ~2.5 cm/yr, with one standard deviation allowing values in the range 1.8 to 3.5 cm/yr. In view of the small distance between samples, the rate of spreading may not be typical for the area at 45°N when greater distances and time intervals are considered. Ocean-floor spreading is not necessarily continuous in the strict sense of the word, but may be the result of a number of small, relatively rapid movements. Such a movement may have occurred between stations 9 and 56. These spreading rates are to be compared with averaged values inferred from other considerations (*18*, *19*), and from K-Ar ages over greater distances (*17*), which give values in the order of 1 to 2 cm/yr for the Mid-Atlantic Ridge in this area, as is discussed further (*17*). Significant differences in spreading rate are likely to occur over small distances from place to place along the ridge, which, when integrated through time, will give the average rate of spreading inferred from magnetic anomaly patterns. A continuing program is planned to assess this question along with that of the chronological significance of the magnetic-anomaly patterns.

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Excited Singlet Absorption in 1,2-Benzanthracene by the Use of Nanosecond Laser Photolysis and Spectroscopy

Abstract. *Using the technique of laser photolysis and spectroscopy, we have observed excited singlet state absorption bands in 1,2-benzanthracene at 560 and 520 nanometers. The bands decay in less than 50 nanoseconds and are replaced by the known absorption spectrum of the lowest triplet state.*

We recently observed the lowest excited singlet state of coronene in absorption, using the new technique of laser photolysis and spectroscopy (*1*). We now report observations for 1,2-benzanthracene, for which the excited singlet lifetime of 44 nsec (*2*) is almost an order of magnitude shorter than that of coronene, 300 nsec (*3*).

The technique is shown in Fig. 1. The mode of operation has been described (*1*). To obtain time-resolved spectra, a direct-vision combination of five prisms is used to form a spectrum on the photocathode of an image-converter camera (*4*). Xenon at 1 atm pressure replaces O_2 in the spark cell and gives a laser-induced spark lasting several microseconds. This provides a background source for the image-converter camera of almost constant intensity for times up to 1 μsec.

Figure 2 shows a time-resolved absorption spectrum for a poly(methylmethacrylate) plastic specimen containing a $10^{-3}M$ concentration of the aromatic hydrocarbon 1,2-benzanthracene, taken with a sweep-time of 200 nsec. The right-hand frame shows two absorption bands at 520 and 560 nm which decay in approximately 50 nsec. Concomitantly, they are replaced by three absorption bands at 430, 460, and 490 nm, which agree well in wavelength with the triplet-triplet absorption spectrum of 1,2-benzanthracene observed in separate experiments on a longer time-scale (*5*). The apparent drift of the triplet absorption to longer wavelength with time arises from nonlinearities in the electron-deflecting optics of the image tube. The left-hand frame in Fig. 2 shows the fluorescence emission, which decays at about the same rate as the new absorption bands. We attribute the new bands to absorption from the lowest excited singlet state of 1,2-benzanthracene at 25,910 cm⁻¹ (*6*) to a higher

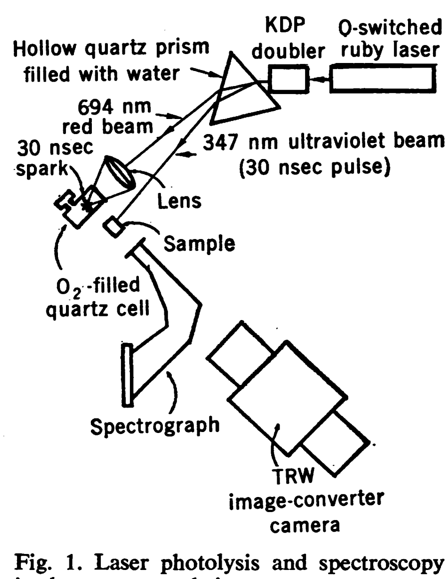

Fig. 1. Laser photolysis and spectroscopy in the nanosecond time range.

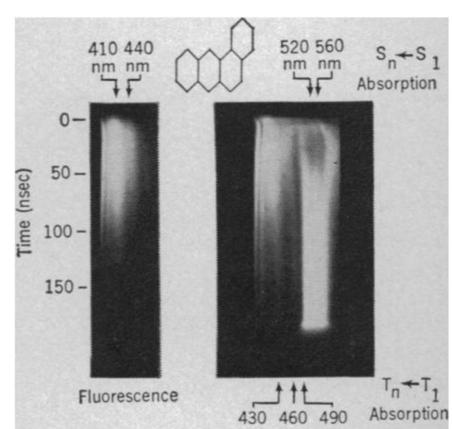

Fig. 2. Decay of fluorescence (left frame) plus decay of excited singlet absorption and build-up of triplet-triplet absorption (right frame) in 1,2-benzanthracene (structure shown at top) [25°C, poly(methylmethacrylate) plastic sample].