Magnetic Polarity of Pillow Basalts from Reykjanes Ridge

Abstract. *A first attempt to measure directly the magnetic polarity of submarine basalts dredged from the Reykjanes Ridge indicates that the first two magnetic anomalies over the ridge resulted from a reversal of the earth's magnetic field. Volcanic criteria were used to determine the orientation the samples had before they were dredged from the sea floor.*

One of the major assumptions regarding sea-floor spreading is that submarine magnetic anomalies result from reversals of the earth's magnetic field (*1*). The anomalies are assumed to be due to oppositely polarized subparallel units of mafic rock increasing in age from the central rift outward. The central unit was magnetized by the earth's field at the time of cooling of the melt injected into the rift between the slowly separating oceanic blocks. The occurrence of reversals has been well established for subaerial rock units; however, lack of oriented samples from the sea floor has so far prevented a direct test of the model of sea-floor spreading.

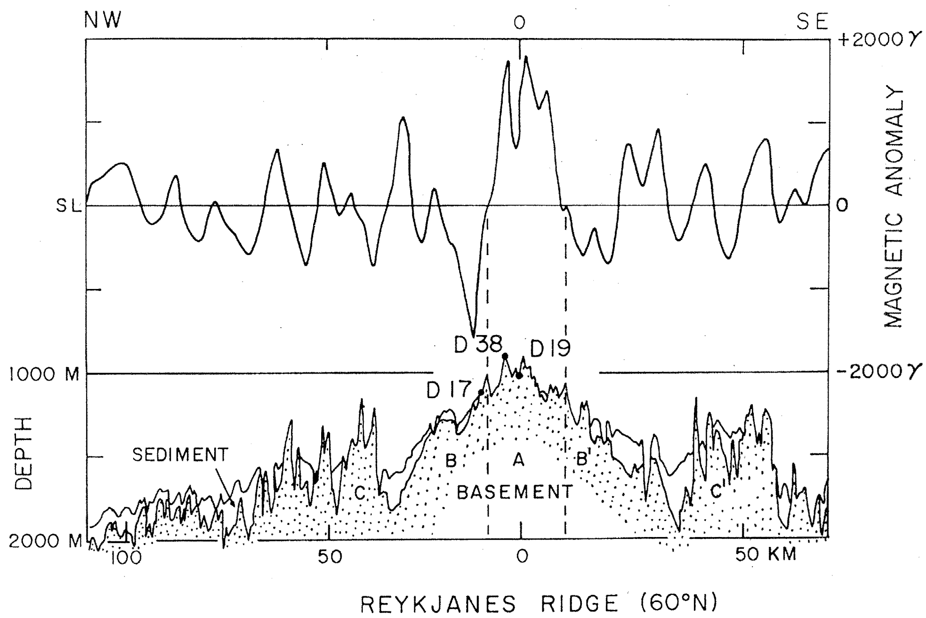

Fig. 1. Reykjanes Ridge: topography, magnetic anomalies, and location of samples; D17: 60°02.0′N, 29°35.4′W, depth 910 to 1080 m; D19: 60°00.9′N, 29°24.0′W, depth 950 m; D38: 59°59.1′N, 29°31.5′W, depth 890 to 960 m.

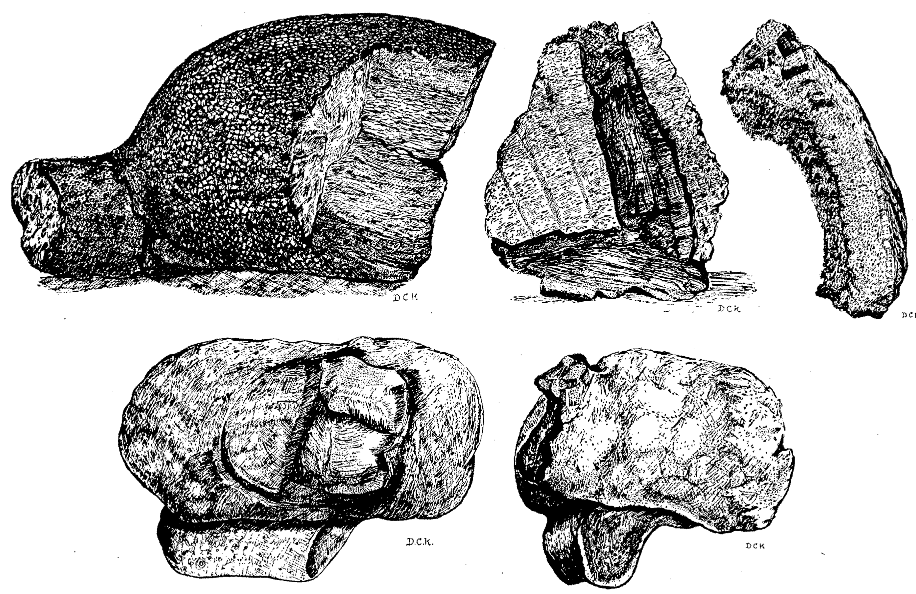

Fig. 2. Basalt fragments for which the original orientation could be determined by analyses of their volcanic features. Top: left, pillow D19 (61 by 48 by 30 cm); right, two views of the crust D38 (38 by 30 by 8 cm). Bottom: two views of pillow D17 (30 by 30 by 23 cm).

At relatively low magnetic latitudes, the magnetic polarity is predominantly a function of the direction of the horizontal component of magnetization; at higher magnetic latitudes it becomes increasingly a function of the vertical component of magnetization. Hence the magnetic polarity of rocks dredged from the sea floor at relatively high magnetic latitudes can be determined if the top and bottom of the sample are known.

In September 1967 Krause and Schilling (*2*) made several traverses of the Reykjanes Ridge with the R.V. *Trident* (University of Rhode Island) to test the sea floor hypothesis. During these traverses a very good sequence of samples was dredged at approximately 60° north. We now report the magnetic polarity of three of these samples (*3*). The Reykjanes Ridge is a continuous northeast-trending segment of the mid-Atlantic Ridge, which runs from latitude 55°N to the Reykjanes Peninsula of southwestern Iceland. The magnetic pattern of the ridge consists of a series of linear anomalies which trend parallel to the ridge (*4*). At 60°N the axial anomaly (2000 gammas) is bordered by a sequence of shorter wavelength, lower amplitude (500 to 1000 gammas) anomalies.

Megascopic inspection of the dredged rocks revealed three types which are distributed grossly symmetrically about the axis of the ridge. The first group was obtained from the median area A (Fig. 1) over the axial (positive) magnetic anomaly. These specimens consist of fresh pillow basalts or fragments. The basalt is highly vesicular and is rimmed with a relatively thick layer of grayish-black glass. The palagonite layer is either absent or very thin, suggesting a very young age (*5*). Some of the fragments exhibit well-preserved pahoehoe structures. The presence of these features and pillows indicates that a rather fluid lava erupted in the median zone relatively recently, presumably in the Brunhes magnetic epoch (0 to 0.7 million years ago).

The second group of samples was dredged from areas B and B′ (Fig. 1) immediately adjacent to the median zone. These specimens also consist of highly vesicular basalt; however, the pillows and fragments are altered and covered with a relatively thick layer of yellow-brown palagonite. Manganese crusts are present but are thin. One

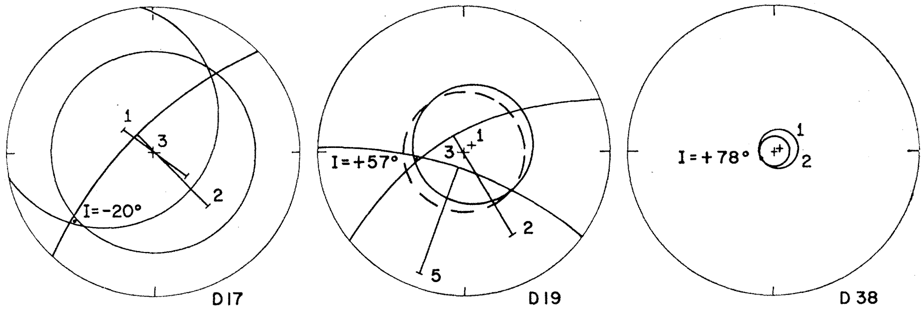

Fig. 3. Stereographic plots of the loci for the average remanent magnetization of cores drilled from reoriented samples.

sample (D17) cooled in contact with a yellow ooze, which caused induration and probably low-degree contact metamorphism. The specimens of this group were collected in areas characterized by a negative magnetic anomaly.

The third group was collected from the areas C and C′ (Fig. 1) about 45 km east and west of the axis of the ridge. The specimens consist mostly of large, massive slabs of fine-grained, well-jointed diabase which are unsuitable for direct determination of polarity. These specimens were derived from intrusives, probably from dikes. Areas C and C′ are associated with positive magnetic anomalies apparently representing a period of normal magnetic polarity several million years ago.

For three samples, D17, D19, and D38, recovered from the Reykjanes Ridge, the vertical and top can be determined from two or more of the following volcanic features.

1) Shape of pillows: Many volcanic pillows are flattened ovals in cross section (*6*). Because of their weight the lower surface was flattened during eruption. The difference in curvature is often significant (D19, Fig. 2).

2) Location of pillow necks: Different pillows in a pahoehoe flow unit are often interconnected by narrow channels or necks. These necks tend to be confined to the base of the pillows (D17, D19, Fig. 2).

3) Location of pillow stems: Some pillows have stemlike extensions at their base, which fit into the depression of underlying pillows or an irregular surface. In the case of D17 (Fig. 2), consolidated ooze surrounds the stem. Such stems have been commonly used for top and bottom criteria by field geologists working on pillow lavas (*6*).

4) Basalt stalactites: Some pieces of basaltic crust, which solidified over large gasbells, exhibit small ridges and droplets of basalt on their inner surfaces. Basalt stalactites hanging on the roof of small tumuli or lava tunnels are common volcanic features. Sample D38 (Fig. 2) is a crust fragment which originated near the top of a tumulus. The convex side is covered with a thin layer of palagonite; the concave side is characterized by ridges and stalactites of fresh black lava.

In addition to these features, criteria from crystal settling, vesicle distribution, and vesicle flattening were considered. However, the results of these observations were inconclusive, probably because of the very rapid cooling of the crust and pillows. Several cores were drilled from the three samples for which the vertical and top could be determined. In Fig. 3 the loci of the average directions of magnetization (each drilled core provided up to nine specimens) are plotted with regard to the hypothetical vertical. The intersections of the loci provide the direction of remanent magnetization of the oriented specimen.

Of the three samples, D38 is the most reliable because the vertical could be established very accurately (within 2°). The magnetization in this sample has an inclination of +78° ±3°, which is remarkably close to the inclination (+74°) of the present field at the recovery site. The positive inclination suggests that the axial anomaly of the ridge may indeed result from rocks magnetized with a normal polarity (assuming the sample to be representative for the area).

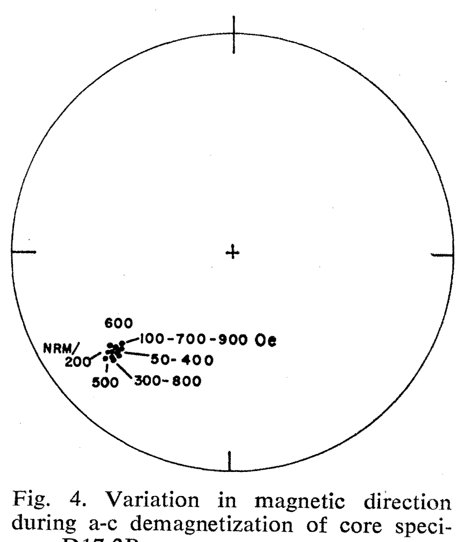

Fig. 4. Variation in magnetic direction during a-c demagnetization of core specimen D17-3B.

Originally, three possible positions for the vertical were thought to exist in sample D19. However, after reemplacement of the relatively long pillow neck, which broke on the ship, this number could be reduced to one. The inclination of the magnetization in this sample is +57° ± 4°. Because this sample was also dredged from the axial zone, the results duplicate those of D38 and confirm the normal polarity of the rocks in this central area, although the inclination is too low by about 17°. The deviation of inclination probably results from the pahoehoe lava having flowed onto an inclined slope that may have been rotated by as much as 17° because of block faulting. The inclination of magnetization in sample D17 is −20° ± 5°, indicating that the basalt probably solidified during a period when the magnetic field was reversed. Because consolidated ooze was found only around the stem, the vertical for this sample could be established with good confidence (± 3°). The specimen was dredged from an area with a negative magnetic anomaly, northwest of the axial-positive anomaly. This suggests that the rocks in area B were indeed magnetized in a reversed field (Matuyama epoch) and that the negative anomaly is the direct result of this polarization.

Stepwise a-c demagnetization (maximum 1000 oersted) indicates no change in the direction of magnetization (Fig. 4). This is what can be expected for a specimen with a thermo-remanent magnetization parallel to the induced magnetization. The stability indicates that the low inclination of D17 cannot be due to deviations of the resultant vector caused by differences in the directions of the two magnetic components. It can be explained neither by assuming secular variations of the magnetic field (deviations of 50° and more have not been recorded for the Matuyama magnetic epoch) nor by assuming that the lava flowed over an inclined surface (rotations of 50° or more are uncommon for block-faulted areas).

The reason for the low inclination of D17 must therefore be sought in different processes. It is not the only sample for which a magnetic inclination was found to be too low. The average inclination of the magnetization in samples derived from the lava flow drilled at the Mohole test site is 36° ± 1°, which is lower than the present 54° inclination in this area (*7*). Almost all available data on the direction of magnetization in submarine rocks have been obtained by Vacquier's indirect method of analyses of the associated magnetic anomalies (*8*). With a few exceptions, the directions that have been obtained have inclinations which are lower than the dip of the present field for the respective sites. Because many of the seamounts are Tertiary or Cretaceous in age, polar or plate movement may account for the differences. The seamounts may have moved since their formation, as has been suggested (*9*) for the Pacific seamounts. These seamounts should have drifted northward after having acquired their remanent magnetization at lower magnetic latitudes. Because of the young age of our samples from the Reykjanes Ridge, this hypothesis cannot be used to explain the low inclination of D17. The only remaining possibility seems to be that this sample was magnetized during a reversal and thus obtained an intermediate direction of magnetization.

These magnetic measurements indicate that the basalts of the axial zone of the Reykjanes Ridge were magnetized in a field with normal polarity along a direction roughly parallel to that of the present field. The magnetization of the basalt dredged in the area with the negative magnetic anomaly adjacent to the axial positive zone has a reversed polarity. The results support the hypothesis that the magnetic anomalies of the Reykjanes Ridge are caused by basaltic complexes with opposite magnetic polarities probably produced by reversals of the earth's magnetic field.

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10. We thank D. Corrigan for doing some of the measurements and Mrs. D. Kennedy for the drawings. Supported by ONR contract Nonr 396(08).

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Atmospheric Absorption Anomalies in the Ultraviolet near an Altitude of 50 Kilometers

Abstract. *Rocket-borne radiometer determinations of ozone distributions by absorption of ultraviolet sunlight show anomalous effects near 3000 angstroms. The instrument uses four 40-angstrom filters in the spectral region between 2650 and 3300 angstroms. At altitudes below 40 kilometers, signals from filters centered near 3000 angstroms appear reduced at least 25 percent below calculated values. However, at higher altitudes an unpredicted sharp increase in signals is observed. These effects are inconsistent with ozone absorption and cannot be ascribed to instrument characteristics. A previously unobserved absorption band of an atmospheric constituent, possibly the metastable excited states of molecular oxygen* $O_2(^1\Delta_g)$ *or* $O_2(^1\Sigma_g{}^+)$*, can account for the anomalous effects.*

The distribution of atmospheric ozone has been measured frequently on balloons (*1*) and occasionally on rockets (*2*) by use of the intense Hartley and Huggins absorption bands in the middle ultraviolet. For routine measurements at a height between 20 and 60 km, we have adapted this technique for use on Arcas rockets (*3*). The ozone concentrations are derived from the height gradient of solar intensity in four wavelength bands between 2650 and 3300 Å, as measured with a filter radiometer. Seventeen flights have been made at nine locations in the last 4 years. Generally, we find that for wavelengths near 3000 Å the intensities below 40 km and the intensity gradients above 50 km depart significantly from those resulting from ozone absorption and Rayleigh scattering. These effects could be explained by an absorber other than ozone existing above 40 km. From the character of the data we can infer certain properties of that absorber. Of the known atmospheric constituents, molecular oxygen in a metastable excited state may account for this anomalous absorption.

The radiometer optical system consists of a transmission integrating sphere, an ultraviolet broad-band filter, narrow-band filters mounted in a wheel, and a photomultiplier (RCA type C70129C). The integrating sphere, with a field of view of 120°, is required because the measurements are taken during descent from apogee on a parachute. The broad-band filter consists of nickel sulfate hexahydrate and filter glass (Corning 9863), which absorb the light at wavelengths outside the region from 2400 to 3300 Å. The individual narrow passbands are formed by multilayer dielectric interference filters (typical half-width of 40 Å) and auxiliary blocking filters (*4*) in conjunction with the broad-band filter. The filter wheel is rotated at 1 rev/sec and contains an opaque position for dark current determination.

Filter center wavelengths were selected to be near 2750, 2950, 3050, and 3300 Å with a tolerance of ± 50 Å. With these wavelengths the change in ozone absorption coefficient is used to gain dynamic range for the expected thousandfold variation in ozone concentration between 25 and 60 km. The 3300-Å filter, with a low ozone absorption coefficient, is used as a reference. Signals from all filters are telemetered to the ground, where the ratios to the reference signal are calculated. Ideally, the half-widths and peak transmissions of the four filters are adjusted to give extraterrestrial signal ratios near unity. These filter parameters were initially calculated from the solar spectrum (*5*) and the detector response. From the earliest test flights on balloons, it was found that the signal ratios for filters near 3000 Å were lower than expected at the highest altitudes (near 30 km). This discrepancy in signal ratio does not directly affect the ozone calculation since only the height gradient of the logarithm of signal ratio is required.

As the data quality at the higher rocket altitudes has been improved with design changes, it has become apparent that the anomalous signal ratios may be due to an unexpected absorption. This is illustrated in Fig. 1 where