23. PALEOMAGNETIC STUDIES OF BASALT CORE FROM DSDP 163

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INTRODUCTION

Three specimens of basalt from DSDP 163 were obtained for paleomagnetic measurements. Site DSDP 163, Leg 16, is located at 11°14.7′N, 150°17.5′W, on the west flank of the East Pacific Rise in an area of low amplitude (20- to 40-gamma), surface magnetic anomalies. The age of the basal sediments is estimated to be approximately 70 to 76 my or lowermost Campanian (see Chapter 10). No geomagnetic time scale age is available, and the area may be characterized as a magnetic "quiet zone".

The three specimens were drilled from a single sample of basalt at a depth of 67 cm in Core 29, Section 4. This corresponds to a depth of 190 meters below the sea floor and 14 meters below the sediment-basalt interface. The sample, which is from the sixth of seven flows, penetrated, appears to be a fresh tholeiitic basalt with minor amounts of deuteric alteration and/or weathering (Yeats et al., this volume, Chapter 22). The initial intent of the study was to obtain a paleolatitude estimate for the site and magnetization parameters of the basalt. Although the magnetic fraction of the sample is unaltered, the remanent magnetization is unstable and not suited to paleomagnetic field determinations.

MAGNETIC MEASUREMENTS

Only the up versus down direction of the core is known and the azimuth unknown. Therefore, true magnetic inclinations, but only relative magnetic declinations, can be determined. The $+z$ direction for the specimens is defined to be down the core axis. The x and y directions lie in the horizontal plane and are internally consistent for the three specimens. Specimen J163-1 is a separate sub-core from the sample while J163-2 and J163-3 are halves of a second sub-core. J163-3 was subsequently used for a K-Ar date by J. Dymond (this volume, Chapter 25).

The original magnetizations (OM) of the specimens, together with demagnetized directions for J163-2 and J163-3, are shown in Figure 1. The numbered circles are repeat measurements of the natural remanent magnetization (NRM) of J163-1. The specimen was not demagnetized. The time interval between measurements was variable and ranged from fifteen minutes to approximately one month. Major changes in direction occur between the initial measurement, 1, and measurements 2 and 3, two weeks later; between measurements 3 and 4; and between measurements 4 and 5 to 19. The specimen was taken to the U.S. Geological Survey, Menlo Park, California for measurement 4. During the trip, the direction of magnetization rotated counterclockwise approximately 90°, with change in the sense of the z component. The changes in the individual components of magnetization are shown in Figure 2. Not only did the direction of magnetization change radically, but the intensity of magnetization increased from 1.2×10^{-3} emu/cc to 2.0×10^{-3} emu/cc. Subsequent measurements (5 to 11) show a general decrease in the magnetic moment. The speciment was "tumbled" in a four-axis demagnetization unit, with no applied alternating field, as a further check on the magnetic stability in the earth's field. The tumbling time was increased from fifteen minutes (12) to ninety minutes (17), in fifteen minute steps. The total moment of the specimen was reduced by 31.6 per cent, with only minor changes in direction. Measurements 18 and 19 were made at the University of Washington, Seattle, Washington. An intensity change occurred which was similar but less drastic and the opposite sense to that observed on the USGS trip.

A short-term storage test was conducted between measurements 9 and 10 (Figure 3). The initial magnitude and sense of the $+z$ component of magnetization was determined (point A); the sample was then stored for eight hours with the $+z$ direction opposed to the vertical component of the earth's field. Next, the sample was continuously run and monitored for forty-five minutes in the spinner magnetometer. In eight hours the intensity of the z component increased by a factor of 2 (point B) in the direction of the applied field. During ten minutes of spinning, the intensity decreased by about 10 per cent and remained constant. The specimen was then stored for twelve hours with the $+z$ direction parallel to the vertical component of the earth's field and remeasured. The z component changed polarity during storage (point C to point D), but showed a rapid return (five minutes) to a constant, low-intensity reversed polarity. Although the z component returned to the initial polarity, the magnitudes of the "stable" magnetization differ by a factor of 4.

Specimens J163-2 and J163-3 were demagnetized in a four-axis alternating field apparatus with peak field values of 25, 50, 100, 150, and 200 oe (Figures 1 and 4). Both samples exhibit unstable behavior. The specimens are halves of a single sub-core, yet the original magnetization directions differ by approximately 60 degrees with an opposed sense for the z component. The directions change continuously on demagnetization and, after the 200 oe treatment, are approximately 70 degrees apart. The intensity of magnetization of both specimens was reduced to about 50 per cent of the initial value after demagnetization at 25 oe. In addition, specimen J163-2 changed direction by about 20 degrees and decreased in intensity from 4.0×10^{-3} emu/cc to 1.9×10^{-3} emu/cc between two measurements of the original magnetization, one week apart.

In summary, the phenomena described above indicate that the basalt sample from DSDP 163 has a large, low coercive force component of magnetization and exhibits short-term, minutes to months, directional instabilities of sufficient magnitude to make the sample unsuitable for

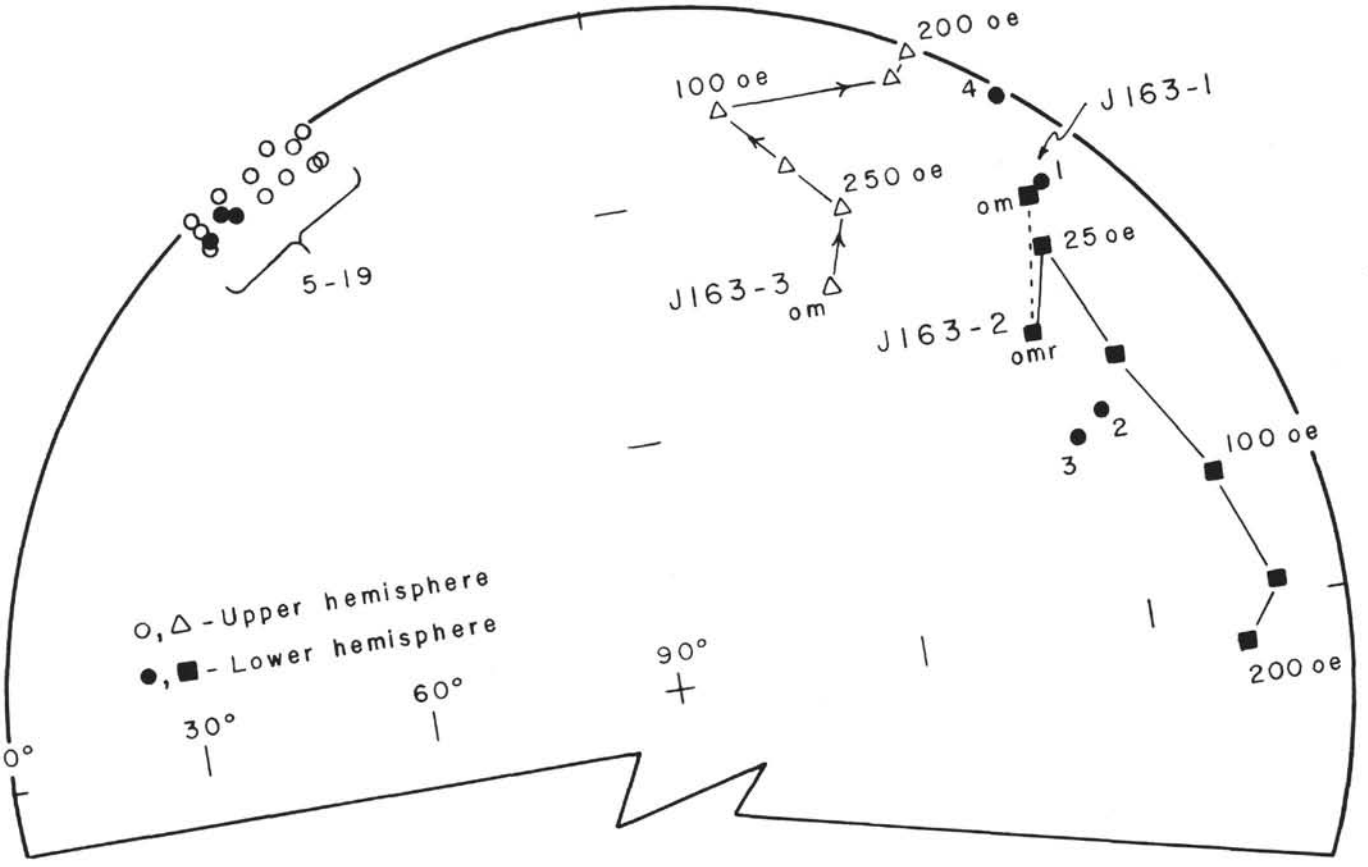

Figure 1. *Directions of remanent magnetization before and after partial demagnetization. Lambert equal-area projection.*

paleomagnetic field determinations. To test the possibility that the basalt cooled in a very weak or zero magnetic field and never acquired a stable thermo-remanent magnetization, an anhysteretic remanent magnetization (ARM) was given to specimen J163-2. The ARM provides a means of modeling thermo-remanent magnetization without the use of heat, which may cause undesirable chemical changes (Park and Irving, 1970). A peak alternating magnetic field of 1000 oe together with a d.c. field of 0.5 oe was used to give the ARM. The specimen was measured immediately after giving it the ARM, then stored for twelve hours with the ARM direction opposed to the vertical component of the earth's magnetic field and remeasured (Figure 4). The intensity of magnetization decreased from 3.22×10^{-3} emu/cc to 2.19×10^{-3} emu/cc. Upon demagnetization, the ARM shows identical behavior to the NRM (Figure 4) and indicates that the basalt will not hold a stable magnetization.

MINERALOGY AND CURIE TEMPERATURE

Various investigators have shown that chemical changes of the ferromagnetic minerals after a lava flow cools may alter the remanent magnetization and affect the magnetic stability of the rock (Johnson and Merrill, 1972a; Marshall and Cox, 1971; Irving, 1970). A polished section was obtained for reflection light examination of the iron-titanium oxides. The dominant magnetic mineral is a skeletal titanomagnetite with a few grains of ilmenite. The titanomagnetite grains range in size from 10 to 100μ with few particles smaller than 10μ. The mean grain size is of the order of several tens of microns. This is in sharp contrast to a general size range of 1-5μ for dredged samples from the Mid-Atlantic Ridge (Irving, 1970; and others) but roughly equivalent to particle sizes for dredged samples from the Juan de Fuca Ridge (Johnson, personal communication). No high-temperature deuteric oxidation features are present. A further remarkable feature is the absence of any visible titanomaghemite in the section, indicating little or no low-temperature oxidation of the titanomagnetite. This contrasts with results from dredged samples which commonly show extensive alteration to titanomaghemite as the age of the sample increases (Marshall and Cox, 1971; Irving, 1970). In summary, the magnetic mineral appears to be a very fresh, unaltered, large-grained skeletal titanomagnetite in spite of its 70 to 75 my age.

A saturation magnetization versus temperature curve was run (Figure 5) giving a Curie temperature of 215°C$\pm$10°C. There is no evidence for unmixing of any titanomaghemite on heating. The graph shows slight unmixing (the 580° hump) on the cooling curve because the helium atmosphere is slightly oxidizing due to outgassing of the oven. The saturation magnetization for the whole rock at room temperature, which did not change before and after heating, is 8.92×10^{2} emu/gm. Using curves from Syono (1965), the Curie temperature indicates that

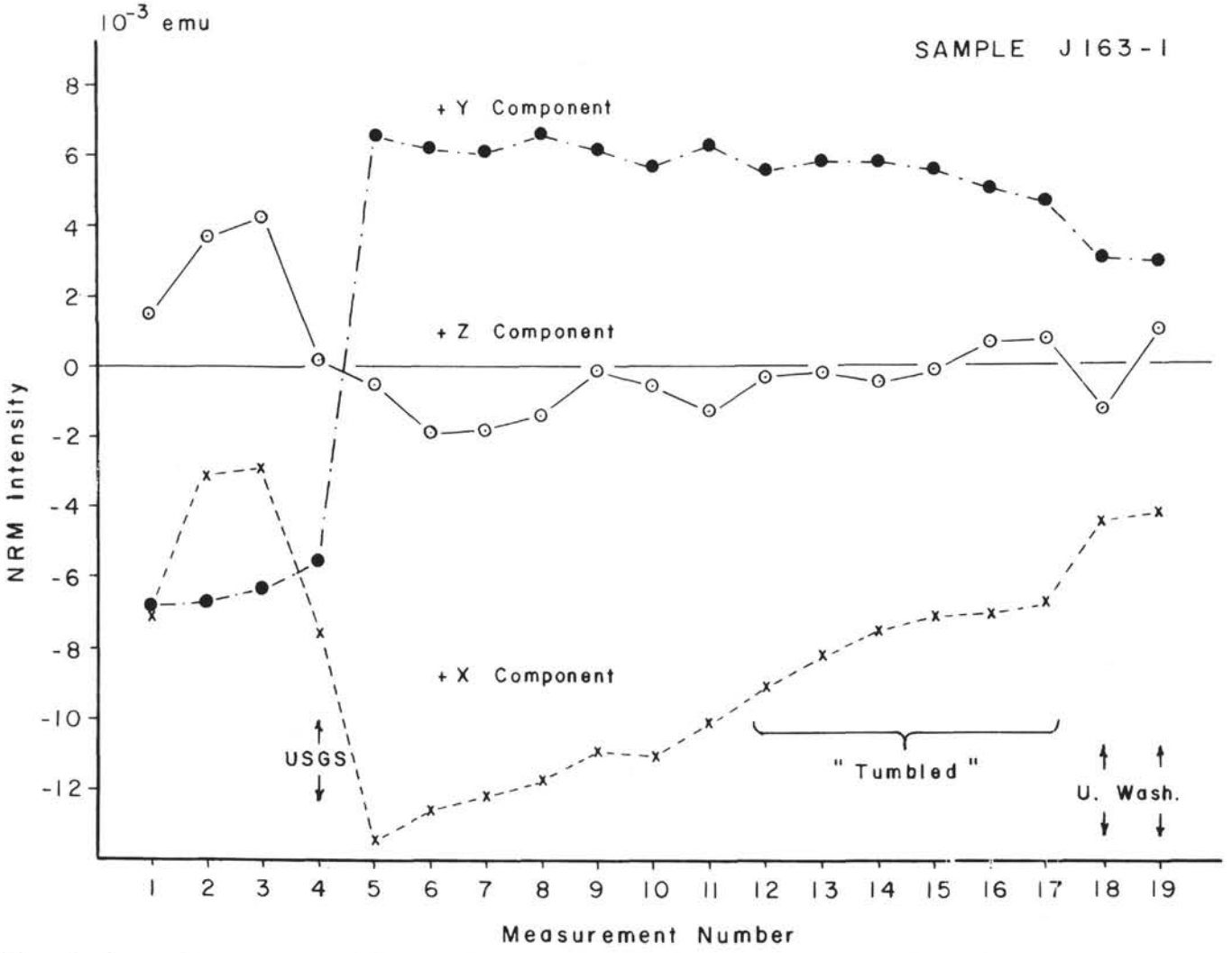

Figure 2. *Repeated measurements of the original magnetization for sample J163-1. See text for details.*

the titanomagnetite has about 47 per cent ulvospinel in solid solution. This contrasts with reported values of 60 to 70 percent ulvospinel for the Mid-Atlantic Ridge (Irving, 1970) and compares with a 50 per cent ulvospinel composition for some stable samples from Juan de Fuca Ridge (Johnson and Merrill, 1972b). An X-ray pattern of a magnetic fraction made by grinding the whole rock in acetone and using a hand magnet for separation gives a unit cell dimension of $8.46 \pm .01$ A which also corresponds to a 47 per cent ulvospinel solid solution. Syono (1965, p. 120) indicates that the magnetocrystalline anisotropy constant k_1 of an ulvospinel-magnetite composition similar to the sample titanomagnetite goes to zero close to room temperature. This, plus the very low Curie temperature, indicates that the blocking temperatures must be very close to room temperature. The combination of large homogeneous titanomagnetite grains and a room-temperature blocking temperature appear to be the source of the magnetic instabilities.

SUMMARY AND INTERPRETATION

The magnetic instability of the DSDP 163 basalt sample is in sharp contrast to the usual results reported for fresh and altered dredged basalts. The basic magnetic and oxidation state models for oceanic basalts presented by Irving (1970) and Marshall and Cox (1971) suggest one should anticipate a high coercive force spectrum (200 to 300 oe), extensive low-temperature oxidation, Curie and blocking temperatures in the range 300° C to 500° C, and a low-intensity, stable remanent magnetization for older basalt samples. The sample shows none of these characteristics but instead has a very low mean coercive force spectrum (25 oe), no evidence of low-temperature oxidation, a Curie temperature of 215° C, and room-temperature blocking temperatures, and a large, unstable remanent magnetization.

It is proposed that the cause of the magnetic instability is primarily due to the 47 per cent ulvospinel solid solution

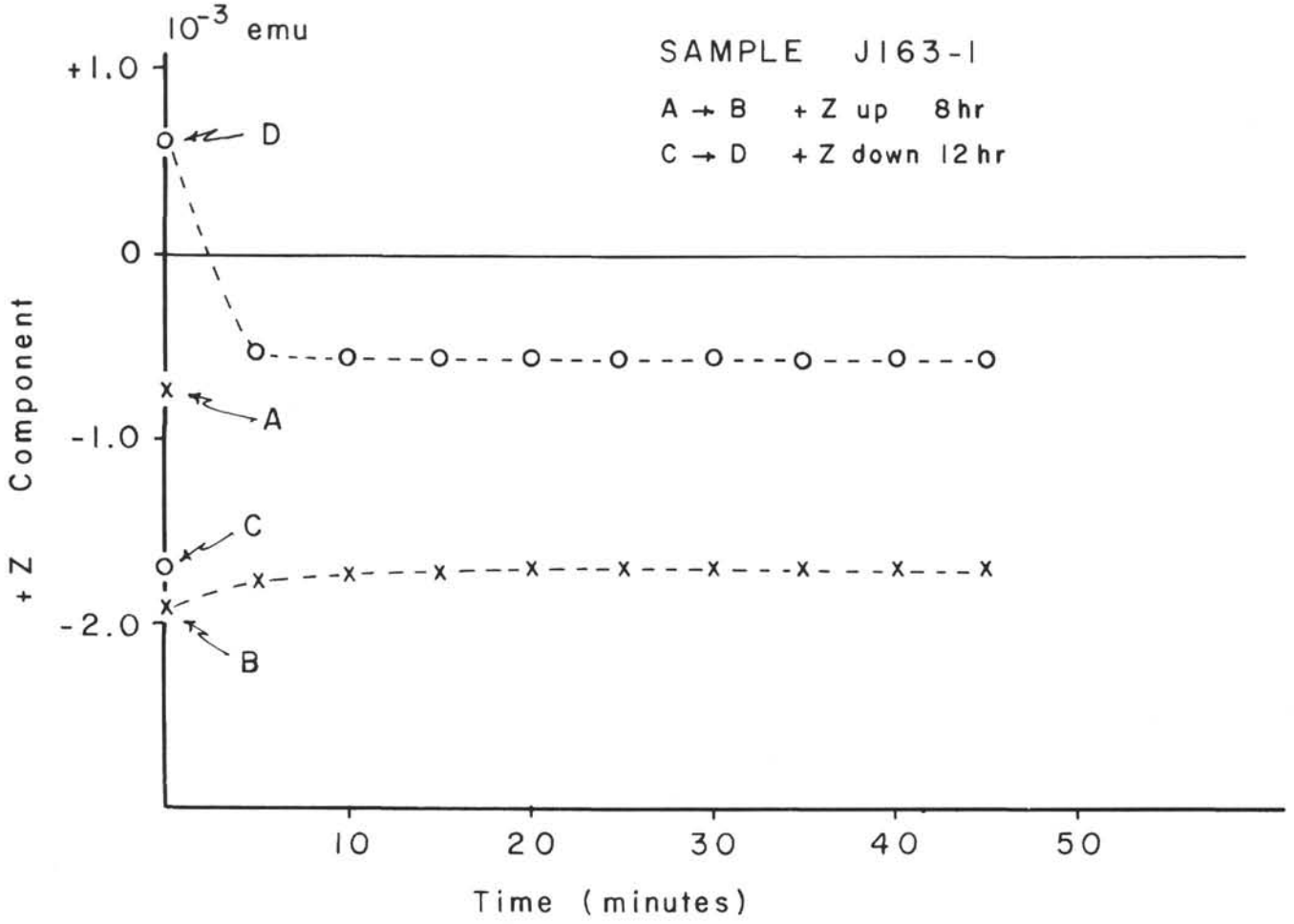

Figure 3. *Short-term storage test and time decay for sample J163-1.*

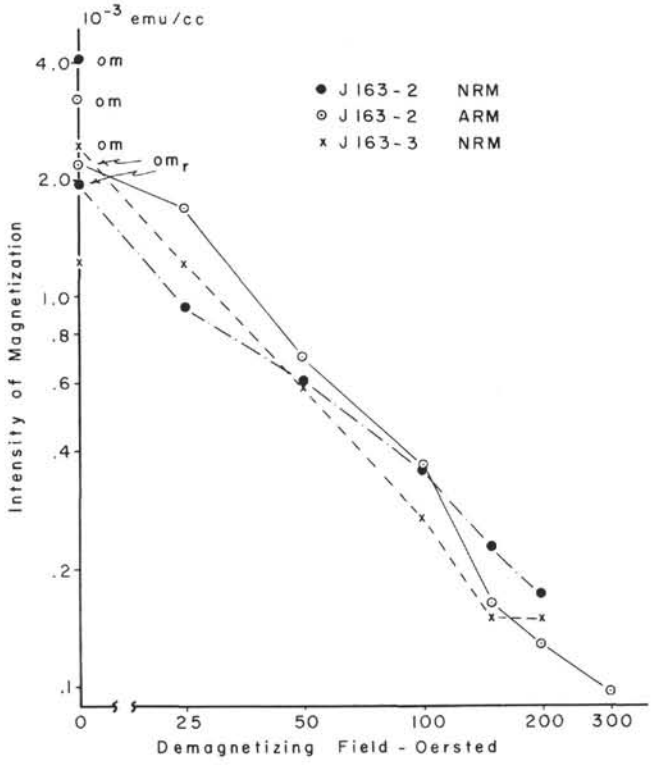

Figure 4. *NRM and ARM step demagnetization curves for samples J163-2 and J-163-3.*

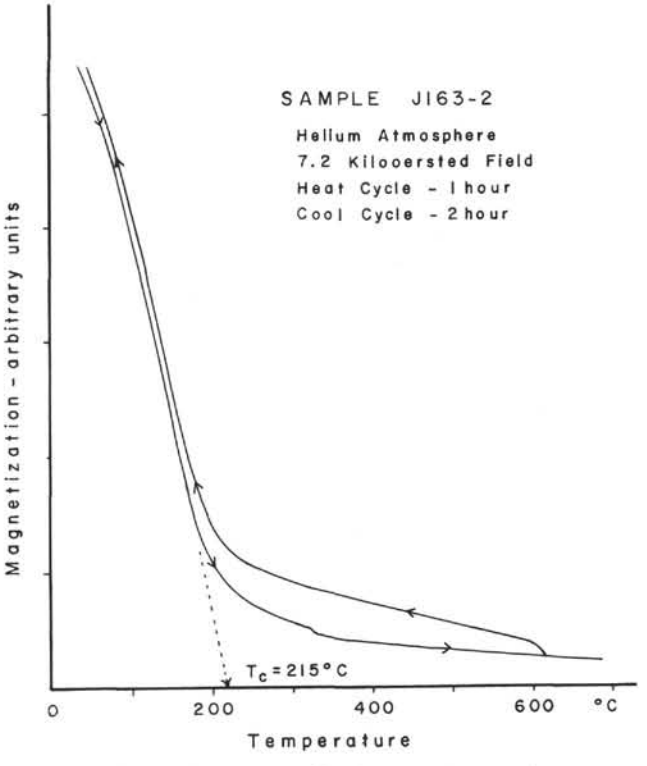

Figure 5. *Saturation magnetization vs. temperature curve for sample J163-2.*

composition with very low blocking temperatures. The large grains, greater than 10μ, also tend to be less stable magnetically then the smaller grains usually described for submarine basalts. It should be emphasized that dredged samples from Juan de Fuca Ridge have a stable magnetization with a slightly higher titanium content (50% versus 47% ulvospinel), slightly lower Curie temperature (200°C versus 215° C), and roughly the same particle size distribution (Johnson and Merrill, 1972b). Thus, the instability must be very sensitive to either titanium content and/or grain size, or perhaps an additional unknown variable. No obvious explanation is apparent for the lack of alteration of the titanomagnetite. The nonopaque minerals show minor amounts of deuteric alteration and/or weathering, and whole rock analyses show relatively large water concentrations (Yeats et al., this volume, Chapter 22).

DSDP 163 is located in an area that may be characterized as a magnetic "quiet zone". The unstable remanent magnetization related to a relatively low titanium content for the titanomagnetites suggests that some magnetic quiet zones may be due to minor compositional changes in the iron-titanium oxides. Further work with additional samples from all seven flows penetrated is being proposed to test and complete the preliminary results reported here.

ACKNOWLEDGMENTS

I wish to thank Monte Marshall for a helpful discussion. Paul Johnson and Ron Merrill provided both helpful insight and use of the thermal and X-ray equipment.

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