33. PALEOMAGNETISM OF MIDDLE JURASSIC BASALTS, DEEP SEA DRILLING PROJECT LEG 76[1]

Maureen B. Steiner, Department of Geology and Geophysics, University of Wyoming, Laramie, Wyoming

ABSTRACT

The magnetic properties of 29 m of Jurassic oceanic crust are quite ordinary. The samples from Leg 76 Hole 534A have average NRM intensities of $3.6 \pm 1.7 \times 10^{-3}$ Gauss, somewhat low median destructive fields, 89 ± 34 Oe, and a remarkable stability of remanent directions. Very simple tests indicate a low viscosity of remanence. The NRM (26.4° ±7.9°) and demagnetized (24.7° ±7.3°) mean directions are similar to those expected for Jurassic rocks of this age. The normal polarity of the samples agrees with the location of Site 534 just seaward of Magnetic Anomaly M-28. All of the characteristics of these basalts suggest that the origin of the Jurassic seafloor magnetic quiet zone is neither a result of low intensity of magnetization nor vicosity of remanence, and that we must look to other explanations for the origin of this peculiar feature.

INTRODUCTION

Leg 76 cored 29 m of late Middle Jurassic basalt. Hole 534A is presently situated at 28.3°N, 75.4°W in the western Central Atlantic Ocean, northeast of the Bahama Bank. Sediments just above the basalt have an age of middle to late Callovian, suggesting that these basalts are probably middle Callovian or older (Site 534 report, this volume).

These rocks are the products of mid-ocean ridge extrusion (Site 534 report, this volume) during the early phase of the opening of the Atlantic Ocean and the separation of Africa from North America. The occurrence of glassy margins was the criterion used to identify flow boundaries. Thus 29 flows were identified in the 29 m penetrated (Site 534 report, this volume); however, it is explicit in the discussion that these may simply represent 29 pillows.

The hole was sited about 100 km seaward of the Blake Spur Anomaly, judged to have an age of about 155 m.y. (Sheridan and Gradstein, this volume), using Van Hinte's (1976) time scale. The oceanic crust penetrated here has magnetic anomalies of drastically reduced amplitudes and is part of the "Jurassic quiet zone." A number of hypotheses have been advanced in the past to explain the reduced amplitudes of this crust. One of the ideas is that the magnetic carriers in this crust are more viscous than in other crust (Lowrie, 1973). Such viscosity could reduce the overall anomaly signal. Measurement of the intensity and stability of these basalts should allow a test of this idea.

Twenty-six of these units were sampled for paleo- and rock-magnetism in the form of 51 minicores (2.5-cm diameter, 2.4 cm long) cored perpendicular to the main core exis. The natural remanent magnetization (NRM) of all 51 cores was measured, and 40 were demagnetized. The others were used for viscosity experiments (Testarmata and Gose, this volume). Samples of this study were each subjected to stepwise alternating field (AF) demagnetization at 25, 50, 100, 150, 200, 250, and 300 Oe; some were also taken to 400 and 500 Oe. NRMs were measured first on the Digico magnetometer on board the *Glomar Challenger,* and again on the Schonsted spinner magnetometer (SSM-1) in the laboratory. Demagnetization was done on a Schonsted single axis AF demagnetization unit (GSD-1). The mean directions calculated in this study are simply arithmethic means. The statistical techniques for averaging inclination data of Briden and Ward (1966) or Kono (1980) were not used because the arithmetic mean of inclinations is fairly accurate for low-latitude data.

NATURAL REMANENT MAGNETIZATION

All samples exhibit positive inclinations, consistent with normal Jurassic polarity. The normal polarity agrees with the location of this site, as the Site is situated very near the polarity transition (Magnetic Anomaly M-28 is actually reversed). The mean inclination of all 51 samples is 29.7° ±9.9° (one standard deviation). The mean of the NRM of only those 40 samples that were subsequently demagnetized is 26.4° ±7.9° (Fig. 1). The observed inclination at this site today is 59°; the theoretical centered axial dipole value is 47°. The Early Cretaceous inclination for this site is about 40°. Thus these samples would appear to reflect a pre-Cretaceous, that is, Jurassic direction, consistent with their Jurassic age. This point will be discussed further in the discussion section. The mean NRM intensity of the samples (N = 32 whole samples) is $3.6 \pm 1.7 \times 10^{-3}$ Gauss, quite comparable to other oceanic basalts of younger ages (Fig. 2).

Several types of tests were performed on the NRM to examine the likelihood that the magnetization observed is a primary Jurassic magnetization. Nine samples were subjected to a one-day storage test in the shipboard earth's field (about 0.35 Oe). No directional change occurred, and the difference in the directions was generally well within the measurement repeatability of the Digico spinner magnetometer. Forty samples were then remeasured 6 months after storage in a nonshielded

[1] Sheridan, R. E., Gradstein, F. M., et al., *Init. Repts. DSDP,* 76: Washington (U.S. Govt. Printing Office).

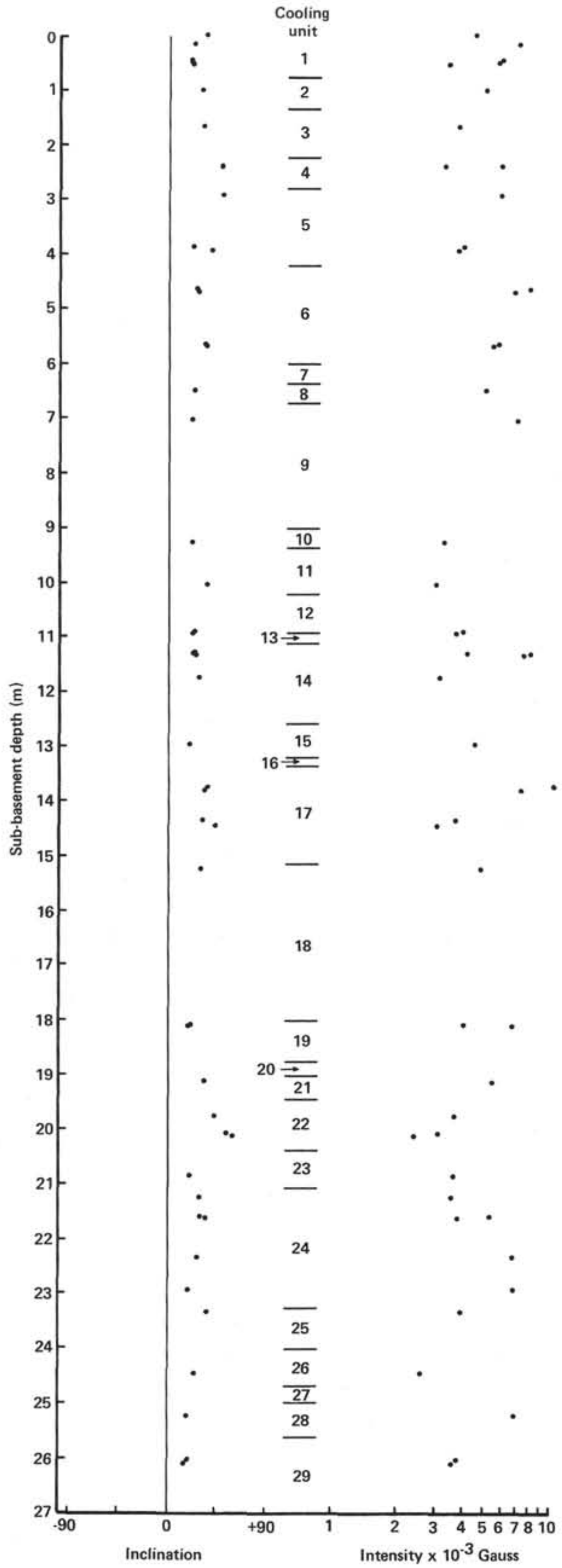

Figure 1. NRM inclinations and shipboard NRM intensities plotted against depth. (Petrologic cooling units are also shown. Depth is in meters below the basalt/sediment interface.)

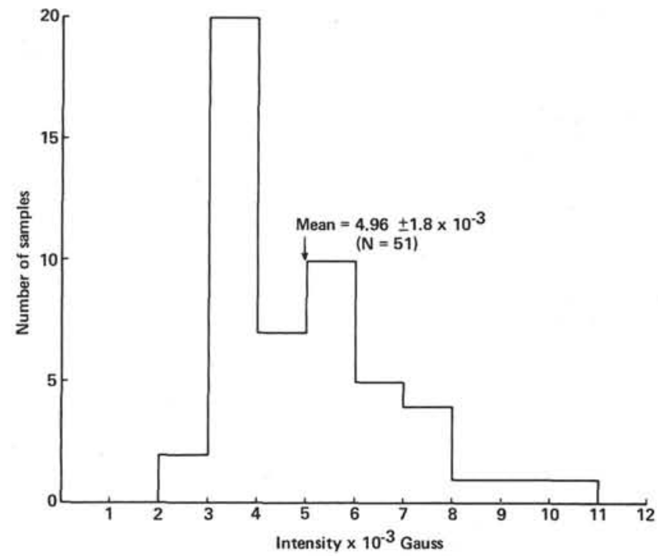

Figure 2. Histogram of shipboard NRM intensities.

laboratory environment (about 0.45 Oe). Again, very similar directions were obtained, generally within the repeatability of the two spinner magnetometers involved. This test was also repeated after samples had been demagnetized to 300 Oe, as will be discussed in the next section.

Another test was the comparison of multiple samples from the same unbroken piece of core. In twelve instances, more than one (up to 4) samples were taken from the same piece of basalt. The NRM directions within each block were extremely consistent, although intensities decrease away from the chilled margins.

DEMAGNETIZATION

Thirty-three of the 40 samples exhibited very little or no change of direction in response to AF demagnetization up to 300 Oe (Fig. 3). These results are remarkable in that the remanent intensity at 300 Oe has been reduced to 3% of the NRM. Treatment at 400 and 500 Oe often produced erratic directions and intensity reductions to 0.02 to 1% of the NRM.

The excellent directional stability of these samples is in striking contrast to the low coercivity of their remanence. Median destructive fields (MDFs), the point at which half of the remanence has been erased by demagnetization, were relatively low, averaging 89 ±34 Oe. Figure 4 displays this relatively rapid decline of remanence with increasing demagnetization.

The 200-Oe step was chosen as the demagnetization level for display in Figure 5, as this was the level up to which little change in directions occurred and beyond which small changes began to occur. At 200 Oe, the mean inclination has changed very little from the NRM: 24.7° ±7.3° (N = 40).

After samples had been demagnetized to 300 Oe (or 500 Oe), they were stored in the earth's field (0.45 Oe) in random orientations for seven months. A dozen were then remeasured, demagnetized in a slightly higher field

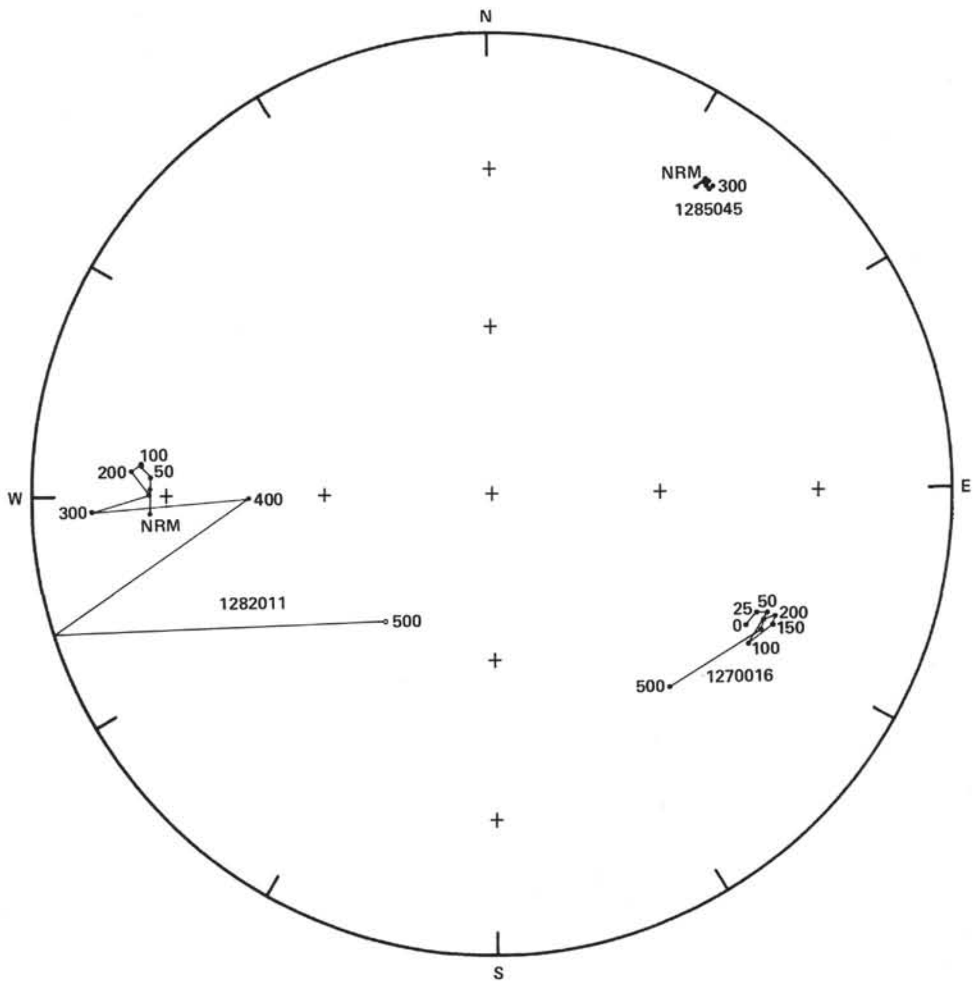

Figure 3. Typical directional responses to alternating field demagnetization (equal area stereonet plot).

(5–10 Oe greater than the peak AF to which they had been originally demagnetized), and measured again. All samples had acquired directions appreciably different from their directions at the end of demagnetization. Those samples demagnetized to 500 Oe retained only 0.2 to 0.8% of their NRM and upon treatment after storage at 510 Oe, did not display stable directions (i.e., they were viscous). However, all of the samples that had been treated to 300 Oe regained the original demagnetization direction after demagnetization at a slightly higher field strength.

DISCUSSION

The inclination of these samples is consistent with a Late Jurassic magnetization. Reliable Jurassic poles for North America are few, the most reliable being the Callovian Summerville Formation (Steiner, 1978) and the Oxfordian–Kimmeridgian Morrison Formation (Steiner and Helsley, 1975). This was a time of rapid change of apparent pole position for North America (Steiner, 1975; in press), and the choice of direction for comparison of Leg 76 samples is therefore highly dependent on the age of the magnetization. Inclinations at this site were computed for the Summerville and the two Morrison poles (see Steiner and Helsley, 1975) and are compared to the basalt inclinations for this site in Figure 6. The average inclination of Leg 76 samples best fits the upper Morrison direction, a Late Jurassic direction. This is slightly different from what we had expected, because the Callovian age of these samples would have predicted a shallower inclination than they have, more like the presumably same-age Summerville and the Canelo Hills results. (The drill string deviation is less than 1.5°.)

If individual directions are compared to these Jurassic poles, 33% of the samples have inclinations more consistent with the Summerville and the lower Morrison inclinations (and therefore a Callovian–Oxfordian magnetization), whereas 41% are more consistent with the upper Morrison inclination (a Kimmeridgian magnetization). The rest lie between the two inclinations (except for 5, which are steep enough to be either Cretaceous or Tertiary). It is likely in this small sampling of ocean crust (29 m) that secular variation has not been averaged out. This is a logical explanation of the discrepancy between the Leg 76 mean inclination and that of other similar-aged data. It is interesting to observe the similarity between the Leg 76 basalts and the overlying sediments (Ogg, this volume). The mean of the Callovian

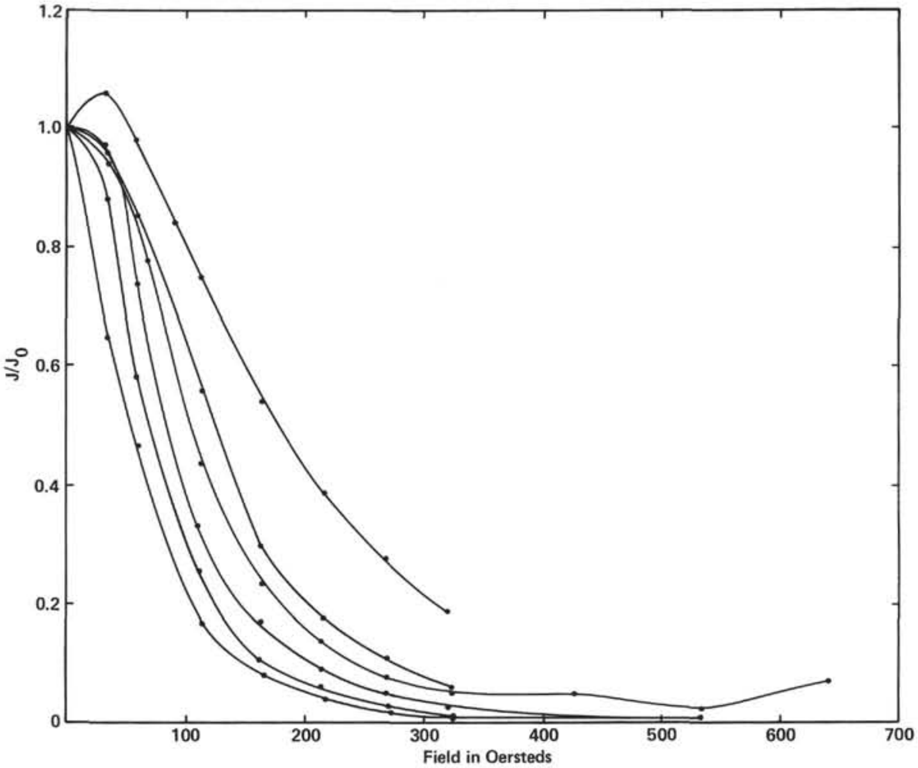

Figure 4. Typical decay of remanences with alternating field demagnetization.

samples is 23° ±7°, very similar to the basalt mean of 24.7° ±7.3°, although the sediment samples constitute a very small population (N = 8).

The NRM intensities of these basalts are not different from those of other oceanic basalts. One might have expected the intensities to be higher, had the samples had a large viscous component. One might have also anticipated weakly magnetized rock in order to explain the low amplitudes of the anomaly signature. Neither seems to be the case. The average value is compared to other basalts in Table 1.

Although these comparisons cannot be made exactly, because some are geometric means, some arithmetic, and others are vector averages, the result is still clear. From this limited, 29-m sampling of "quiet zone" crust, the average intensities of these rocks are similar to the rest of the oceanic crust. The average value, which is slightly low, is not low enough to explain the low amplitudes. The extreme consistency of inclinations (and assuming constant declination) would make these vectors nearly fully additive, and thus the vector average intensity value would appear to be very similar to the arithmetic mean value.

The AF stability of these samples also has been compared with other basalts in Table 2. Leg 76 samples appear to be low in AF stability in comparison with other basalts in Table 2. Compared to the Leg 11 samples of nearly the same age, they are quite low; they are also low in comparison to the nearby Cretaceous (Legs 51–53) samples. In comparison to many Tertiary samples, the stability of these Jurassic samples is much lower, but similar to very young basalts. A pattern seems to be apparent in this table: one of low MDFs in the first few million years, followed by a large rise in MDF, and then a return to lower values as time progresses. This is somewhat compatible with recent work on synthetic titanomaghemites of single-domain size by Özdemir and Banerjee (1981), in which they found a decrease in coercive force and coercivity of remanence with increased oxidation (z; $0 \leq z \leq 1$) above $z = 0.4$. They also found that when measurements are made at room temperature (as opposed to low temperature) there is an artificial, apparent rise in these parameters between $z = 0$ and $z = 0.4$. If the Leg 76 samples and those of other legs shown in Table 2 carry single-domain titanomaghemite, some of the increase and decrease of MDF with age in this Table might be a manifestation of these effects.

Microscopic examination of ten samples of the Leg 76 basalts in polished sections shows that, in general, the magnetic carriers are extremely fine-grained, less than 1 μm. The largest grains observed in nine (randomly selected) sections was 7 μm; a tenth was selected hopefully to exhibit large grains of the magnetic carrier. However, in this section the grains were generally 10 μm, and very few of the total population of samples had a grain size as coarse as this sample.

Özdemir and Banerjee also found an increase in viscosity of their samples at increasingly greater degrees of oxidation, especially at high z values of 0.8 to 0.9. Because Leg 76 samples do not appear to be very viscous, this finding may suggest that they are oxidized only to amounts less than $z = 0.6$ (see their fig. 4). This hypothesis may be supported by another fact: their room-temperature coercivities of remanence and coercive

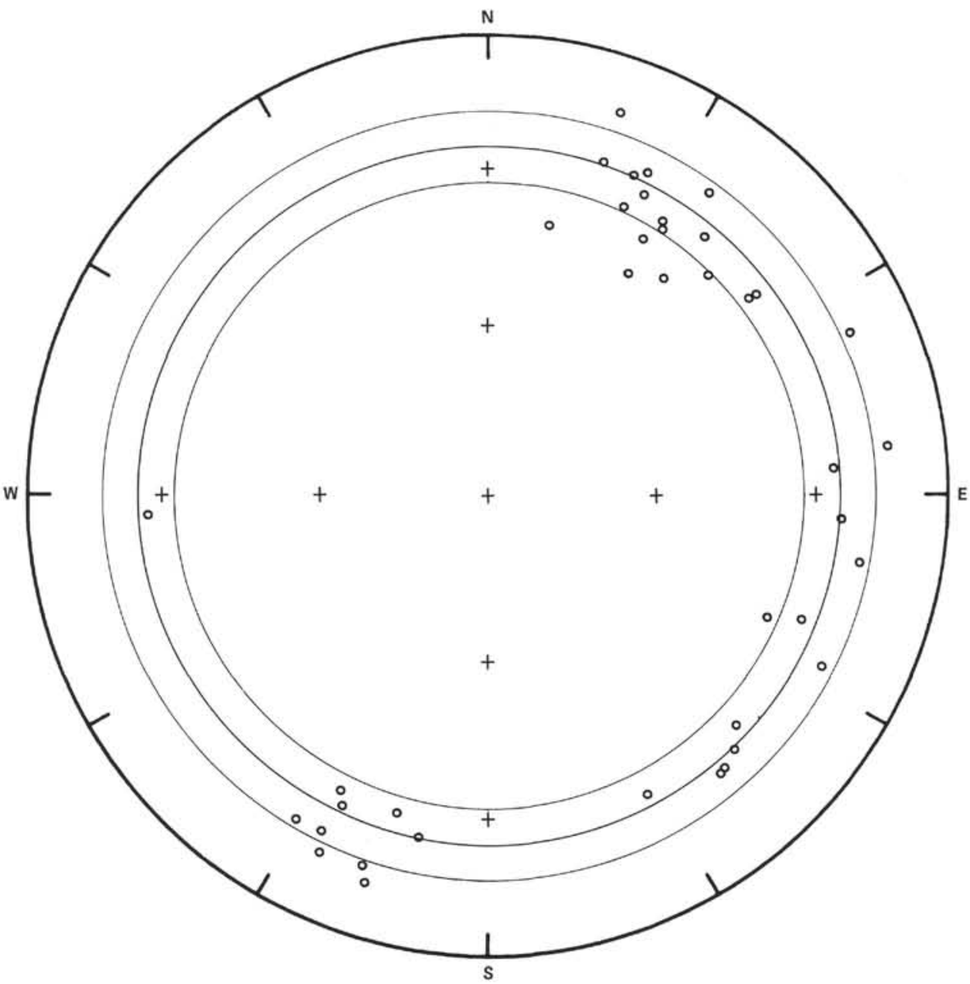

Figure 5. Directions of all samples (N = 40) after alternating field demagnetization to 200 Oe. (The mean and one standard deviation to either side are shown as circles. Declination is arbitrary in DSDP cores due to lack of azimuthal orientation of the core.)

forces are very similar for relatively unoxidized ($z = 0.13$) and medium oxidized ($z = 0.56$) samples (their fig. 4). The similarity of Leg 76 MDFs to the MDFs of very young crust (see Table 2) may suggest an oxidation level approximately near $z = 0.5$, and hence, may suggest that these samples are relataively unoxidized for their age. All of these ideas are quite speculative at present, because the exact composition and grain sizes are not known.

CONCLUSION

The Leg 76 Callovian basalts have extremely stable magnetic directions and apparently low viscosity of remanence. Their inclinations (24.7° ±7.3°) are what would be expected for Jurassic basalts, although slightly steeper than predicted, probably as a result of incomplete averaging of secular variation in this 29 m of crust sampled. These observations suggest that these basalts carry an original Jurassic magnetization, and thus suggest that the seafloor quiet zones are not the result of extreme viscosity of remanence. The directional stability of these samples, as well as the relatively average values of intensity (as compared to other oceanic basalts) suggest that we must look to other explanations for the origin of the quiet zones.

ACKNOWLEDGMENTS

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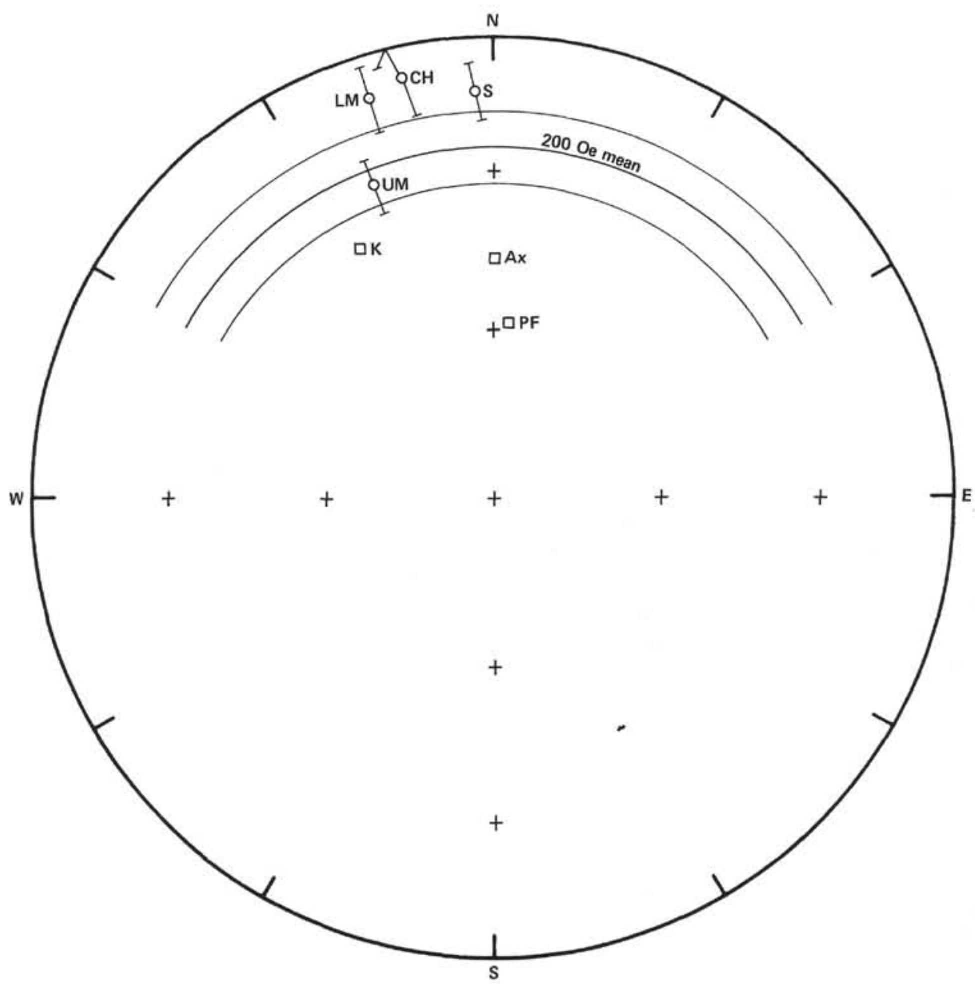

Figure 6. Comparison of the 200-Oe mean inclination and one standard deviation of these samples to the most reliable Jurassic directions for North America. (These Jurassic directions are shown with one axis of their translated 95% circles of confidences. S = Summerville [Steiner, 1978]; LM, UM = lower and upper Morrison [Steiner and Helsley, 1975]; CH = Canelo Hills [Kluth et al., 1982]; K = Cretaceous [Van Alstine, 1979]; Ax = axial field; PF = present field.)

Table 1. Comparison of seafloor basalt intensities.

Age	Leg	Mean intensity (Gauss × 10^{-3})	Reference
Jurassic, M-28	76	3.6 (±1.7)	This study
Jurassic, M-25	11	0.6 (±0.17)	Taylor et al., 1973
Cretaceous, 67–118 m.y.	6, 7, 16, 17, 19	3.6–8.0	Marshall, 1978
Cretaceous, 100 m.y.	51–53	7–9	Bleil and Smith, 1980
Tertiary, 3 m.y.	37	4	Hall and Ryall, 1977
Tertiary, 7 m.y.	45	3.4	Johnson, 1979
9–10 m.y.	45	1.5	Johnson, 1979
Tertiary, 1 m.y.	49	4.3	Faller et al., 1979
1.6 m.y.	49	3.7	Faller et al., 1979
2.3 m.y.	49	5.1	Faller et al., 1979
10 m.y.	49	3.2–9.1	Faller et al., 1979
38 m.y.	49	5.2	Faller et al., 1979

Table 2. Comparison of AF stabilities of seafloor basalt.

Age	Leg	Mean MDF (Oe)	Reference
Jurassic, M-28	76	89 ±34	This study
Jurassic, M-25	11	200	Taylor et al., 1973
Cretaceous, 67–118 m.y.	6, 7, 16, 17, 19	65–175	Marshall, 1978
Cretaceous, 100 m.y.	51–53	112 ±41 (417D)	Levi, 1980
	51–53	140 ±72 (418A)	Levi, 1980
Tertiary, 3 m.y.	37	200–400	Bleil and Petersen, 1977
Tertiary, 7 m.y.	45	395 ±254	Johnson, 1979
9–10 m.y.	45	500 ±147	Johnson, 1979
Tertiary, 1 m.y.	49	112	Faller et al., 1979
1.6 m.y.	49	80	Faller et al., 1979
2.3 m.y.	49	188	Faller et al., 1979
10 m.y.	49	242–290	Faller et al., 1979
38 m.y.	49	138	Faller et al., 1979