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24. REMANENT MAGNETIZATION OF CEMENT CORES FROM HOLE 648B: A POSSIBLE LOGGING TOOL FOR THE DOWNHOLE MEASUREMENTS OF MAGNETIC FIELD[1]

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ABSTRACT

The remanence properties of 62 cement samples from Cores 7R, 11R, and 12R recovered from Hole 648B were examined. The remanent magnetization consists of two components, where the soft component is carried by the basalt fragments in the cement sample and the hard component is carried by fine magnetic grains originally contained in cement. The hard component was used to estimate the variation of the magnetic field inclination within the hole. The result indicates that some parts of the basalt section within the sub-bottom depth between 15 and 20 m are reversely magnetized, which can be attributed to the displacement of pillow basalt after its solidification.

INTRODUCTION

During Leg 106, 14 minicore samples from the recovered basalt sections of the drilled core were paleomagnetically studied. The stable inclinations of the samples were obtained by progressive alternating field demagnetizations. The results indicate negative stable inclinations at the sub-bottom depth between 10 and 20 m, where the depth range is uncertain by about several meters due to the very low recovery rate of the cored samples. Within this section, six minicore samples were measured; of these four samples show negative inclination and the other two have shallow normal inclinations. This tendency was also confirmed by the shore-based study (Bina et al., this volume), where 9 of 12 samples in this range indicated negative stable inclinations. Due to the extremely difficult drilling conditions, the orientation of these samples cannot be fully trusted as noted by Leg 106 scientists, and it is uncertain whether the negative inclinations were caused by the reversed earth's magnetic field or caused by the misorientation of the rock pieces or by a block rotation. However, if the field reversal is real, it would help to determine the actual age of the crustal rocks at Hole 646B. Leg 106 scientists raised the possibility that these basaltic rocks were erupted during the Blake event, which occurred at approximately 100,000 years B.P. and lasted about 5,000 years.

The basaltic rocks recovered during Leg 109 are mainly from the deeper part of the hole. Hence, the cause of the negative inclinations cannot be clarified from the paleomagnetic measurements of recovered basalt cores. Much more information could be obtained from downhole measurements of the magnetic field in Hole 648B through the section with the negative inclination. The average intensity of the magnetization of the basaltic rocks from this hole ($> 10^{-2}$ emu/cm^3) is large enough to affect the magnetic field appreciably within the hole (see Hamano and Kinoshita, this volume).

During the drilling of Leg 109, cement was poured into this hole on several occasions in order to prevent the falling of rock rubble from the walls of the hole, and some cement cores were recovered during the subsequent drilling. In the present study, the remanent magnetization of the recovered cement cores was investigated to test the possibility of using cement cores to infer the nature of the magnetization surrounding the hole, and to see if the negative inclination could be confirmed.

DESCRIPTION OF CEMENT CORES

During Leg 109, Hole 648B was cemented many times (Detrick, Honnorez, Brian, Juteau, et al., 1988). Cores 7R, 11R, 12R, and 14R mainly consist of the drilled cement. Core 7R consists of 1.64 m of cement which was obtained from drilling between 15.0 and 24.0 m sub-bottom depth. Cores 11R and 12R are the result of successive coring of the same batch of cement. These two cores consist of 4.80 and 5.09 m of cement, respectively, and the cores were obtained by drilling from 14.8 to 24.2 m (Core 11R) and from 15 to 26 m (Core 12R) sub-bottom depth. Core 14R is a short cement core (0.92 m), which was obtained after Core 18R, which consisted of basalt rubble. Hence, the depth of Core 14R is very uncertain.

In the present study, Cores 7R, 11R, and 12R were mainly used. Because of the apparent continuity of the cored cement, we can safely assume that each core was continuous in the hole. However, the position of the core is uncertain within the drilled section of about 10 m. The uncertainty of the absolute depth for Cores 11R and 12R is several meters, since the recovery rate of these cores are about 50%. The uncertainty of Core 7R is much larger.

From Core 7R, five oriented minicore samples were taken for the measurements. From Cores 11R and 12R, 57 minicores were obtained. Average sampling interval for these cores is about 20 cm.

EXPERIMENTAL PROCEDURE

Remanent magnetizations of the minicore cement samples were measured with MOLSPIN Portable Rock Magnetometer. Using this system, the measurements of the magnetization of samples during the alternating field demagnetization steps were effectively performed by referring to the Zijderveld plot (Zijderveld, 1967) and equal area projection of the data during the demagnetization steps.

For each sample, successive AF (Alternating Field) demagnetizations were made at the steps of 50, 100, 150, 200, 300, 400, and 600 Oe of peak alternating field. Demagnetization with the peak field of 800 Oe was necessary for some samples. The AF demagnetizations were performed with a Schonstedt AC Geophysical Specimen Demagnetizer (Model GSD-1). Low field magnetic initial susceptibility was also measured with a Bartington Magnetic Susceptibility Meter (Model MS1).

[1] Detrick, R., Honnorez, J., Bryan, W. B., Juteau, T., et al., 1990. *Proc. ODP, Init. Repts.*, 106/109: College Station, TX (Ocean Drilling Program).

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Table 1. NRM intensity, MDF, stable inclination, and susceptibility of 62 cement samples.

Sample	Depth (m)	NRM Intensity (10^{-6} emu/cm^3)	MDF (Oe)	Stable inclination (°)	Susceptibility (G/Oe)
648B-7R-1, 3 cm	15.030	23.100	190.000	36.300	12.500
648B-7R-1, 33 cm	15.330	48.400	122.000	23.800	14.400
648B-7R-1, 85 cm	15.850	22.500	260.000	33.000	19.900
648B-7R-1, 113 cm	15.130	28.700	244.000	42.500	12.700
646B-7R-1, 142 cm	16.420	37.200	200.000	77.100	14.300
646B-11R-1, 12 cm	14.920	62.600	132.000	33.600	32.000
646B-11R-1, 21 cm	15.010	96.100	32.000	27.600	17.400
646B-11R-1, 77 cm	15.570	107.600	60.000	47.700	14.000
648B-11R-1, 94 cm	15.740	36.600	169.000	4.400	9.500
648B-11R-1, 106 cm	15.860	22.400	186.000	1.100	8.900
648B-11R-1, 124 cm	16.040	181.500	102.000	64.100	52.400
548B-11R-1, 135 cm	16.150	48.800	131.000	35.500	14.500
648B-11R-1, 145 cm	16.250	142.900	51.000	57.500	15.700
648B-11R-2, 5 cm	16.360	130.400	80.000	40.100	15.700
648B-11R-2, 22 cm	16.520	49.500	112.000	48.000	12.000
648B-11R-2, 29 cm	16.590	50.500	140.000	48.300	14.900
648B-11R-2, 44 cm	16.740	157.700	47.000	37.300	94.500
648B-11R-2, 50 cm	16.900	428.300	77.000	52.900	81.800
648B-11R-2, 79 cm	17.090	105.300	54.000	40.500	95.900
648B-11R-2, 91 cm	17.210	39.800	195.000	24.300	10.200
648B-11R-2, 120 cm	17.500	34.800	185.000	71.600	10.600
648B-11R-2, 135 cm	17.650	33.500	173.000	58.400	10.100
648B-11R-3, 10 cm	17.900	36.300	155.000	70.800	12.000
648B-11R-3, 20 cm	18.000	42.900	177.000	61.700	10.600
648B-11R-3, 40 cm	18.200	79.100	168.000	3.400	18.500
648B-11R-3, 56 cm	18.360	116.400	180.000	−15.600	10.300
648B-11R-3, 75 cm	18.550	261.600	80.000	27.100	311.700
648B-11R-3, 91 cm	18.710	51.200	61.000	53.500	23.600
648B-11R-3, 103 cm	18.830	67.000	122.000	68.500	15.600
648B-11R-3, 113 cm	18.930	30.000	141.000	33.900	14.800
648B-11R-3, 129 cm	19.090	40.900	192.000	20.900	21.800
648B-11R-3, 140 cm	19.200	52.800	86.000	28.700	25.100
648B-11R-CC, 2 cm	19.320	138.200	273.000	23.600	32.600
648B-11R-CC, 24 cm	19.540	133.400	55.000	46.300	65.700
648B-12R-1, 8 cm	15.080	50.400	118.000	80.400	11.100
648B-12R-1, 26 cm	15.260	27.100	105.000	38.700	12.900
648B-12R-1, 45 cm	15.450	32.000	113.000	64.500	10.600
648B-12R-1, 54 cm	15.540	27.300	135.000	72.800	12.800
648B-12R-1, 75 cm	15.750	61.500	41.000	47.200	17.100
648B-12R-1, 93 cm	15.930	16.000	212.000	38.900	14.900
648B-12R-1, 100 cm	16.000	6.500	500.000	37.700	14.200
648B-12R-1, 111 cm	16.110	11.200	220.000	52.300	12.800
648B-12R-1, 123 cm	16.230	16.300	224.000	45.300	14.200
648B-12R-1, 135 cm	16.350	16.300	212.000	43.400	19.700
648B-12R-2, 7 cm	16.470	163.600	153.000	53.100	47.000
648B-12R-2, 23 cm	16.630	62.500	183.000	43.700	23.500
648B-12R-2, 47 cm	16.870	703.900	112.000	60.200	90.100
648B-12R-2, 64 cm	17.040	158.100	242.000	52.100	62.700
648B-12R-2, 78 cm	17.180	453.400	107.000	57.300	64.000
648B-12R-2, 91 cm	17.310	1079.200	38.000	66.800	87.500
648B-12R-2, 108 cm	17.480	357.500	109.000	68.900	102.700
648B-12R-3, 6 cm	17.660	39.900	108.000	22.300	10.800
648B-12R-3, 16 cm	17.760	32.700	164.000	4.100	11.100
648B-12R-3, 29 cm	17.890	16.900	200.000	45.300	11.000
648B-12R-3, 46 cm	18.060	16.500	124.000	40.600	11.700
648B-12R-3, 58 cm	18.180	247.000	39.000	58.800	54.400
648B-12R-3, 89 cm	18.490	13.800	269.000	45.800	14.600
648B-12R-3, 101 cm	18.610	134.000	110.000	54.400	40.400
648B-12R-3, 114 cm	18.740	213.900	69.000	65.300	88.900
648B-12R-3, 133 cm	18.930	53.900	177.000	50.900	9.400
648B-12R-CC, 5 cm	19.350	27.100	136.000	59.000	20.600
648B-12R-CC, 17 cm	19.470	113.100	91.000	67.400	30.000

RESULTS OF THE MEASUREMENTS

In total, 62 minicore samples were successively demagnetized by the alternating magnetic fields. The magnetic susceptibility was also measured for these samples. Table 1 summarizes the observed paleomagnetic properties of the cement samples. Figure 1 shows the depth variation of the NRM (Natural Remanent Magnetization) intensity for the three cement cores. NRM intensity varies from 6.5 to 1079.4 × 10^{-6} emu/cm^3. More than two orders of magnitude variation of the NRM intensity is much larger than the basalt samples cored from the same hole. As evident from Figure 1, the intensity is less than 10^{-4} emu/cm^3 for most of the depth. At some depths deeper than 16 m sub-bottom depth, several peak intensities are obtained in Cores 11R and 12R. The surrounding parts of these peaks have larger intensities compared to the background value. In these high intensity samples, basalt fragments or powders with various sizes are clearly seen. Hence,

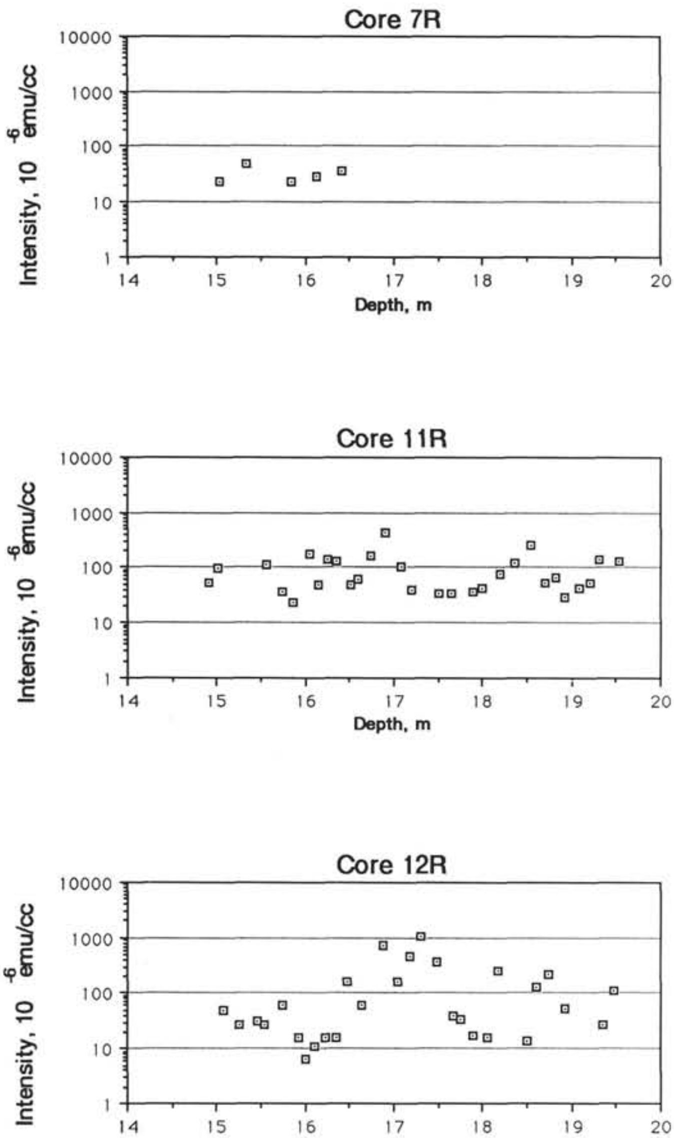

Figure 1. Depth variation of the NRM intensity of the cement cores of Cores 7R, 11R, and 12R.

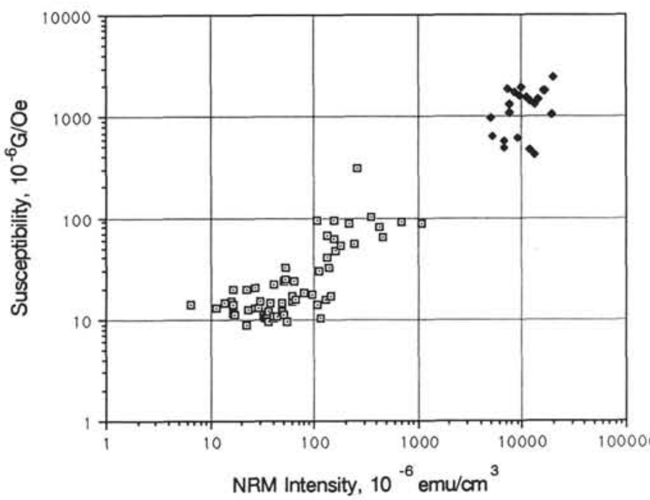

Figure 2. The relation between the NRM intensity and the magnetic susceptibility.

it is not unreasonable to assume that the high intensity is caused by these basalt fragments contaminating the cement cores. In Figure 2, the relation between the observed susceptibilities and the NRM intensities is shown, where the relation among the basalt samples is also plotted. The correlation suggests that the intensities are mainly controlled by the amount of the magnetic minerals in the cement samples.

MDF (Median Destructive Field) values also have a wide range of variation, from 82 to 500 Oe (see Fig. 3). Sample 648B-12R-1, 91 cm, which has the highest NRM intensity, has the MDF of 88 Oe which is close to the lower end of the observed MDF. Sample 648B-12R-1, 100 cm has the lowest NRM intensity and the highest MDF of 500 Oe. For other samples, the inverse correlation between the NRM intensity and the MDF value is evident as shown in Figure 4. The MDFs of the basalt samples obtained from this hole, also shown in Figure 4, are mostly lower than 100 Oe. Hence, the inverse correlation can be explained if we assume that the cement core samples are a mixture of the high intensity and low MDF basalt fragments and the low intensity and high MDF pure cement powder.

Some examples of the variation of the magnetization during the demagnetization steps are plotted on Zijderveld diagrams in Figure 5. On this diagram, all the demagnetization steps expressed by squares align in a straight line if the remanence consists of one component. If a remanence consists of two components, two straight lines are required to approximate the locus of the demagnetization steps. As evident from Figure 5, most of the cement samples have two components, which is consistent with the above mixture model of the magnetization.

SOLIDIFICATION EXPERIMENT OF CEMENT

In order to examine the remanence properties of cement samples from Hole 648B in more detail, shore-based laboratory experiments were made on the cement powders used in the hole. In the ambient geomagnetic field, cement powder was mixed with distilled water and solidified at room temperature. It took several hours to solidify the cement. After the solidification, three minicore samples were taken, and the remanence properties were measured by the alternating field demagnetization. The NRM intensities of these cement samples are 4.8, 4.5, 4.7 $\times$ 10^{-6} emu/cm^3, and the MDF values are 410, 420, and 440 Oe, respectively. The NRM intensities are much lower and the MDFs are much higher than most of the cement samples from Hole 648B (see Fig. 4). The alternating field demagnetization indicates that the pure cement samples consist of one stable component, and the directions (Declination = 1.8°, 3.1°, and 4.2°; Inclination = 39.9°, 41.0°, and 42.7°) are identical to the ambient field (Declination = 0° and Inclination = 40° at the laboratory in Earthquake Research Institute, University of Tokyo). The error might be caused by the orientation of the samples.

This laboratory experiment confirmed that the cement can acquire a remanent magnetization during the solidification parallel to the ambient magnetic field, and the stability of the remanence is much higher than the basalt samples obtained from Hole 648B.

ORIGIN OF THE REMANENCE CARRIED BY THE CEMENT CORES FROM HOLE 648B

As shown in the previous section, the cement cores recovered from Hole 648B have two components of remanence. A

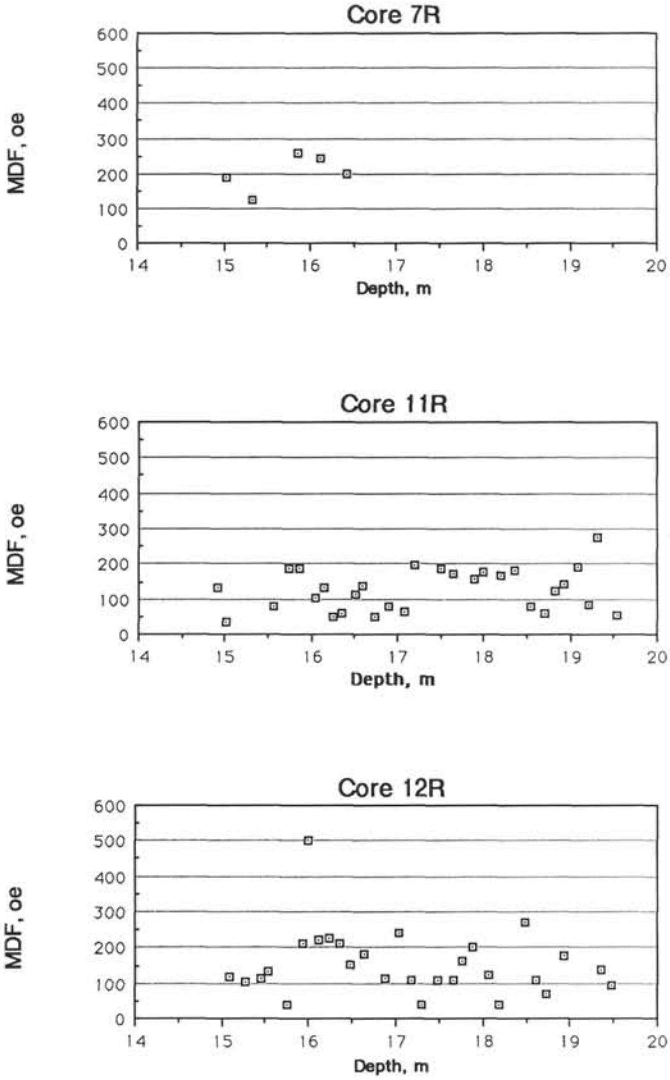

Figure 3. Depth variation of MDF for the cement samples.

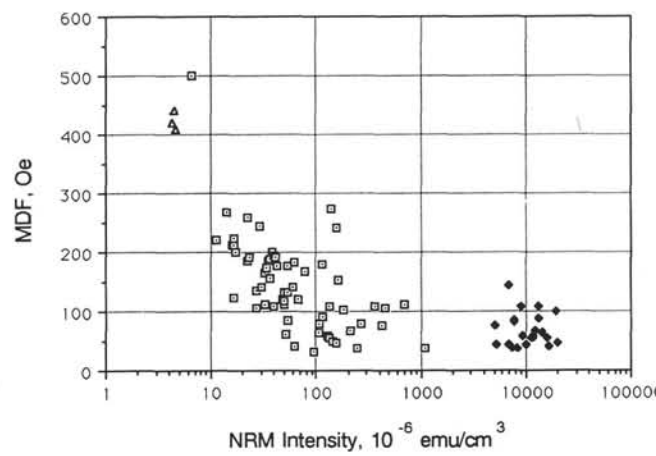

Figure 4. The relation between the NRM intensity and MDF. Data for the cement samples (open squares) and basalt samples (solid diamonds) recovered from Hole 648B and for the laboratory solidified cement (open triangles) are shown.

magnetically soft component is carried by the basalt fragments included in the cement and a hard component is carried by the fine magnetic minerals in the cement. The high MDFs of this component suggest that the magnetic grains are in micrometer size. Now we have to examine when these remanences were acquired, as there are two possibilities for its acquisition. One is the case that the remanence was acquired in the hole during the solidification of cement. The other is after the core was recovered on board.

The directions of the soft component, obtained by the least squares fit, have a very broad distribution, where the mean of the inclination is about 40°. The magnetic stability of the soft component, inferred from the observed MDFs, is comparable with the basalt samples recovered from the same hole. Hence, it can be concluded that the remanence was acquired due to the reorientation of the basalt fragment under the influence of the ambient magnetic field. The stability is too high to be secondary remanence such as IRM (Isothermal Remanent Magnetization) acquired during the drilling or on board. Although we think that the soft component was acquired in the hole, it is not appropriate to use the remanence to estimate the magnetic field in the hole because of the very broad distribution of the direction. The broad distribution is reasonable since the basalt fragments are too large to be fully affected by the ambient magnetic field, and the orientation of these basalt chips was influenced both by the mechanical force exerted during the solidification of the cement and by the ambient field.

In contrast to the soft components, the magnetically hard component has a systematic distribution in orientation. The mean and the standard deviation of the inclination are 44.6° and 20.0°, respectively (see Fig. 6). The mean value is consistent with the present field direction. This component of remanence is considered to be carried by the magnetic minerals originally contained in the cement. The high stability of this component is very important to isolate the stable component.

As noted before, the stable inclinations and declinations were obtained from the least squares fit to the hard component of each sample. The variation of the stable inclination with depth is the central part of the present study, and will be discussed in a separate section. The absolute value of the stable declination has no meaning since the cement cores are not azimuthally oriented. However, several minicore samples were obtained from a single long cement piece. The relative variation of the declination within these sets of samples can be used to check the validity of the assumption for the origin of the magnetization. Samples from 648B-12-2, 7 cm to 648B-12-2, 91 cm show a very small change of declination. This result is reasonable if the remanence was acquired in the hole under the effect of the magnetization of the surrounding material, because the declination of the magnetization in young rocks can be similar to the declination of the present geomagnetic field.

Based on the above discussion, it can be concluded that the stable component of the cement cores was acquired in the hole, and the direction reflects the field direction in the hole. The distribution of the inclination, the systematic variation of the declination within each piece of cement, and the large variation of the declination between the separate pieces preclude other possibilities for the acquisition mechanism of the stable component. The stable component cannot be acquired before the solidification of cement or after the coring.

MAGNETIC FIELD WITHIN A HOLE: A SIMPLE MODEL

Magnetic field within a hole generally consists of two components. One component is the ambient geomagnetic field and the other is the magnetic field caused by the magnetization

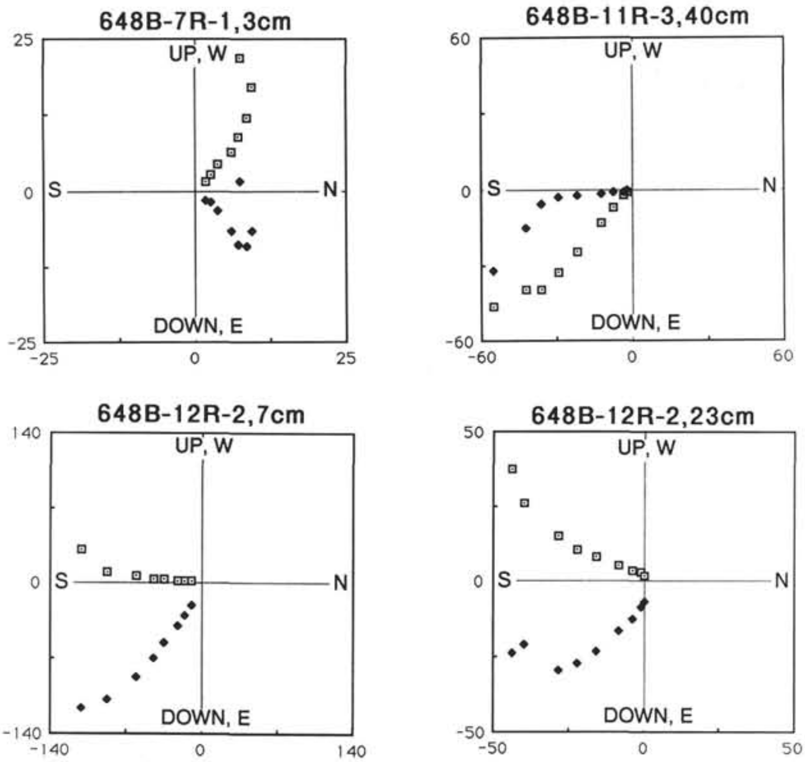

Figure 5. Zijderveld plot of the AF demagnetization curves for some cement samples from Hole 648B, where open squares are the demagnetization steps projected on a horizontal plane and solid diamonds are the projection on a north-south oriented vertical plane.

of the surrounding material. The induced and remanent magnetizations are responsible for this effect. The paleomagnetic measurements on the basalt samples recovered from Hole 648B indicate that Q-ratio (Koenigsberger ratio), which gives the relative importance of the remanent magnetization to the induced magnetization on the external field, is very high (more than 10). Hence, the induced magnetization can be neglected in the following calculation.

Assuming the total force of the present ambient geomagnetic field is F_0 and the inclination is I_0, the horizontal component, H, and the vertical component, Z, of the geomagnetic field can be expressed as

$$\begin{aligned} H &= F_0 \cos I_0 \\ Z &= F_0 \sin I_0 \end{aligned} \tag{1}$$

If we consider an ideal case where the material surrounding the hole is homogeneously magnetized, and the shape of the hole is a perfect circle, then the magnetic field due to the surrounding material at the center of the hole is given by

$$\begin{aligned} h &= 2\pi M \cos I \\ z &= -4\pi M \sin I \end{aligned} \tag{2}$$

where M is the intensity and I is the inclination of the magnetization (for more detail, see Hamano and Kinoshita, this volume). The observable actual magnetic field within the hole can be obtained by adding Eqs. (1) and (2) if we neglect the declination change. The inclination of the actual field is given by

$$\tan I_{obs} = (Z + z)/(H + h) \tag{3}$$

Based on IGRF80, the geomagnetic total force at the position of Hole 648B is 0.4 Oe and the inclination is 46°. The paleomagnetic measurements of the basalt samples from the present hole indicate that the mean intensity of the magnetization is about 10^{-2} emu/cm³. As the mean inclination of the surrounding material, we can use the inclination caused by the geocentric axial dipole. The value at this latitude is 40°. By using these values in Eq. (3), the observable inclination in the hole when the surrounding basalts are normally and reversely magnetized can be easily obtained as

$$\begin{aligned} I_{obs}\ (\text{Normal}) &= 32.4° \\ I_{obs}\ (\text{Reverse}) &= 58.1° \end{aligned}$$

respectively. The normal magnetization of the surrounding material reduces the inclination and the reverse magnetization increases the inclination in the northern hemisphere.

DEPTH VARIATION OF THE INCLINATION IN HOLE 648B

The depth variations of the inclination within the hole, obtained from cement Cores 7R, 11R, and 12R, are shown in Figure 7. The inclination is the stable component obtained from the least squares fit to the AF demagnetization curves of the cement cores. As explained in the previous section, the expected inclination is about 30° if the surrounding rocks are homogeneously magnetized in normal direction, whereas the mean inclination value for all the samples is 44.6°, which is very close to the inclination of the present geomagnetic field (46°). This suggests that the direction of the magnetization of the surrounding rocks varies in small scale probably less than several meters, and average out its effect in larger scale. The

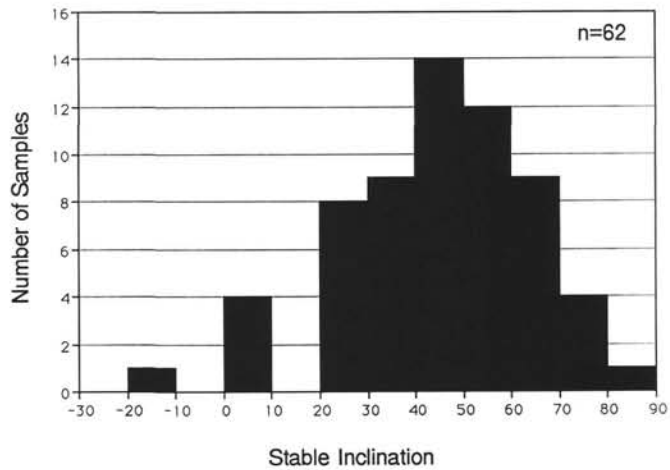

Figure 6. Histogram of the stable inclinations obtained from cement samples. The stable inclinations were determined from the least squares fit of straight lines to the locus of the demagnetization steps on the Zijderveld plot.

examination of the depth variation of the inclination in each cement core confirm this interpretation.

Only five samples were measured from Core 7R. The upper four samples give low inclinations of about 30°, and the bottom sample shows a high inclination (see Fig. 7A). This may suggest that the upper 1-m section of the surrounding rocks is normally magnetized and the bottom of Core 7R indicates a transition to the reversely magnetized section. However, further examination is not possible because of the small number of the samples and the ambiguity of the depth of the sampled section. Figure 7B shows the 5-m section of the variation of the inclination along Core 11R. The two minima at about 15.8 and 18.3 m sub-bottom depth are the most prominent feature. In the section between the two minima, upper 1 m gives a mean inclination of about 45°, and the lower part of several tens of centimeters shows a high inclination of about 60°. The top part of Core 11R shows a low inclination of 30° indicating a normal magnetization of the surrounding rocks. The bottom section below the lower minimum consist of a high inclination and a low inclination parts with the length of about 50 cm. Core 12R is characterized by high inclinations throughout the core. Two minima are also observed at about 15.2 and 17.8 m sub-bottom depth. The variation of the inclination between the two minima is very similar to that of Core 11R, where the upper part is characterized by the inclination of about 45° and the inclination of the lower part is high. Although the relative position of Cores 11R and 12R is not apparent from the drilling data, the positions of the two minima suggest that Core 12R should be shifted down by about 50 cm. Then, the variation of the inclination between the two minima is very similar in both cores. The difference of the absolute inclination in these cores may be due to the difference of the horizontal position in the hole.

For the interpretation of the inclination data, we have to consider the effect of the surface roughness of the hole, which may cause extreme values of the inclination compared to the theoretical model and short wavelength variations. We can assume that the variation with the length shorter than the hole diameter (30 cm) is mainly caused by the surface roughness and the horizontal position of the cement samples in the hole. In some parts of the section, the averaged inclination exceeds the theoretical values in both directions. These can be caused by the surface roughness of the wall or the eccentricity of the cement sample. Also, a large variation of the magnetic field is

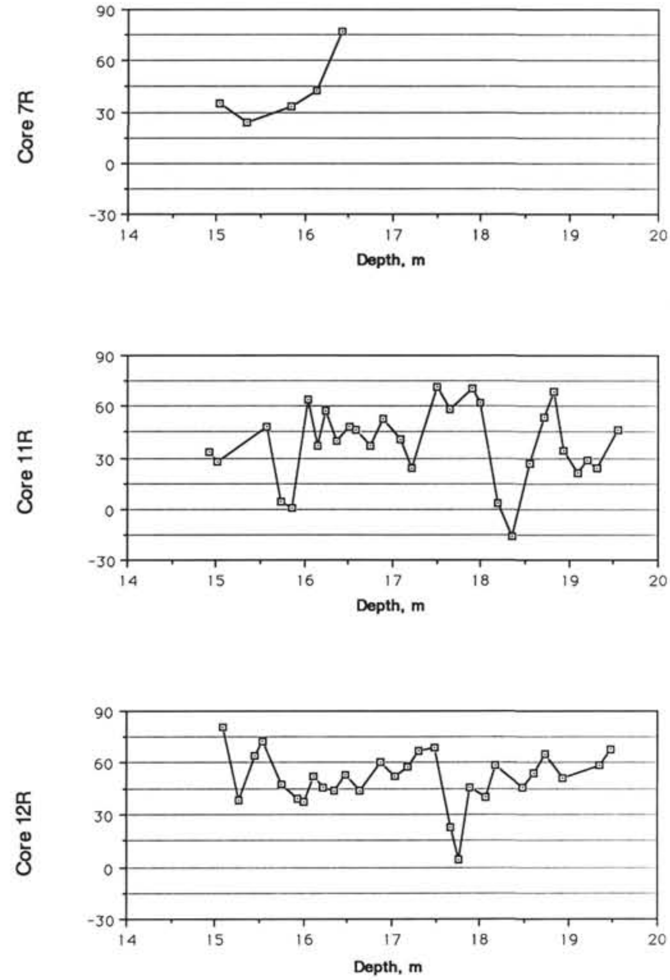

Figure 7. Depth variation of the stable inclination obtained from three cement cores.

expected at the boundary between the differently magnetized bodies.The inclination close to the ambient geomagnetic field (46°) indicates the variation of the magnetization within a short distance.

If we consider the averaged variation of the inclination, the data indicates that the surrounding rocks are magnetized in blocks with sizes of 50 cm to 1 m. The two minima observed in Cores 11R and 12R may represent some boundaries between the blocks. Some continuous high inclination sections such as the part above the lower minima indicate that the direction of the magnetization of the surrounding rock is rather close to the direction opposite to the present geomagnetic field. Based on these observations, we can conclude that the section between 15 and 20 m sub-bottom depth includes some reversely magnetized parts, but the magnetization varies along the hole within a short distance. The coherent distance is less than 1 m.

COMPARISON WITH THE BASALT DATA

The lithology of Hole 648B, to the depth of 40 m sub-bottom, can be divided into three parts. The topmost layer to the depth of about 30 m sub-bottom mainly consists of sparsely olivine-plagioclase phyric pillow basalts. Below this layer, a thin layer of vesicular pillow basalts exist. The thickness of the layer is at most 3 m. The bottom layer within this section consists of massive flows. From the layers of vesicular pillows and massive flows, both Leg 106 and Leg 109 collected samples and paleomagnetic measurements were made. These results give consistent stable inclination for each layer. From the top layer, Leg 106 collected 12 samples. Among them, four samples show negative inclinations. The depth range assigned to the negative inclination samples is from 13.50 to 19.84 m sub-bottom. Within this range of depth, two samples with shallow normal inclinations were also found in Leg 106. Although the assigned depth is not certain due to the low recovery of the cores, we can say that the negative inclination part is within the lower section of the top pillow layer. Leg 109 collected two samples from the top layer; one of these has a negative inclination and the other has a positive one. The depth of the negative inclination sample is 23.11 m sub-bottom. The depth range of the possible reversed section from the paleomagnetic observations of the recovered basalts is from 14 to 23 m sub-bottom.

The depth range of the cement samples mostly overlaps the above section. The result of the cement measurements indicates that the section below 16 m sub-bottom contains the reversely magnetized part, although normally magnetized parts exist within this section. The observation is roughly consistent with the result of the paleomagnetic measurements of basalt samples. As for the top depth of the reversed section, the cement data will be more accurate since the recovery of the basalt cores is rather poor. In the present cement samples, recovery rate of Cores 11R and 12R is good (about 50%), and the observed variation of the inclination at the top part of Core 11R is consistent with that of Core 7R. Hence, the depth estimated by the cement core is more reliable.

Leg 106 raised the possibility that the reversely magnetized section was erupted during the Blake event which occurred about 100,000 years B.P. However, the cement data indicate that the magnetization of the reversed section varies within a distance of less than 1 m. This scale is rather close to the known diameter of pillows. Therefore, it is unlikely that the reversed section was caused by the reversed earth's field. Rather the high variation of the magnetization indicates the displacement or the rotation of pillows after their solidification. The scale length of the variation is reasonable if each pillow has a different direction of magnetization. Basalt samples collected from the lower vesicular section have consistently high stable inclinations of about 80°. It is improbable that this high inclination represents the real geomagnetic field; instead, it must be related to the rotation of this section after the acquisition of the remanence. Five samples collected from the massive flows have the inclination value of about 45° in average, which value is reasonable without any rotation after the eruption. This may suggest that the massive flows can be a reliable paleomagnetic recorder compared to pillow basalts.

During Leg 109, NRM-ARM relations were obtained for the samples from the three layers. The relation indicates that the variation of the strength of the geomagnetic field during the eruption of these three layers was within 10%. Considering the variation of the intensity during the recent several thousand years, the eruption period for these three layers may be less than a few hundred years. This short time-span suggests that the cause of the reverse magnetization is a rotation of pillows rather than a magnetic field reversal.

EVALUATION OF THE CEMENT METHOD AS A LOGGING TOOL

The present study indicates that cement solidified in holes, which penetrate the oceanic crust, can be used as an indicator of the actual magnetic field within the hole. Therefore, these cement cores can be used as a logging tool for the downhole measurement of the magnetic field. The observable parameter with this method is limited to inclination. Declination and the field intensity cannot be measured. However, closely spaced sampling on the scale of several centimeters is possible with this method, giving an resolution which cannot be obtained by the standard logging technique. This method does not require any instrument in the hole. Hence, high temperature parts of the hole can be logged with this method. By preparing special cement which contains a fine powder of magnetite, the place where the temperature is as high as 500°C could be logged. By using iron powder, the temperature can be extended to more than 700°C, but, at this temperature, no magnetization of surrounding rocks is expected. Another limitation of this method is its accuracy. The paleomagnetic sampling and measurement techniques applied in the present study give an accuracy of the inclination of about 5°. Hence, this method can be used only in highly magnetized regions. The required intensity of the magnetization is about 3×10^{-3} emu/cm^3. This limitation indicates that this method can be used in most of the basaltic layer. Sedimentary layers are beyond the limits of the method.

CONCLUSION

Observation of the remanent magnetization of cement cores indicated that the cement cores acquired their remanences when they solidified in the hole. Therefore, the remanence of the cement cores contains information on the magnetic field in the hole. Based on the cement method, the distribution of the magnetization in Hole 648B between the depths of 15 to 20 m sub-bottom was obtained. The section between 15 and 20 m sub-bottom depth includes some reversely magnetized parts, which is consistent with the results of the paleomagnetic study on the basalt samples recovered from this hole. However, the field origin of this reversed layer can be rejected from the present observations. Displacement or rotation of pillows after their solidification is a more probable cause of the reversely magnetized layer.

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