22. MAGNETIZATION OF SEAMOUNT-DERIVED SEDIMENTS FROM SITE 869 INFERRED FROM DOWNHOLE MAGNETOMETER LOGS[1]

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ABSTRACT

Magnetic field variations from downhole magnetometer logs were measured at Site 869. Magnetic field component readings were made with both the Japanese downhole three-component magnetometer (JDTCM) and the general purpose inclinometer tool (GPIT) log. The latter only provided two horizontal components. Some discrepancies between magnetic field variations by the JDTCM and by the GPIT were noted. The origins of these discrepancies have not been identified, but some of the discrepancies are likely related to resolution differences between the JDTCM and GPIT. Magnetic field variation data from the GPIT were used after accounting for these discrepancies.

Downhole magnetometer logs suggest that almost all the magnetization is remanent and acquired in the Southern Hemisphere, but that in some parts there is an induced or viscous magnetization. Normal polarity magnetization was observed below 380 mbsf. A zone of reversed polarity magnetization is suggested between 319 and 378 mbsf and is interpreted as recording reversed-polarity Chron 33R. Magnetic field variations between 334 and 338 mbsf within the reversed magnetization zone imply a possible short normal polarity interval, although this zone is complex and may record various overprint components.

Magnetic units and subunits are determined using magnetic boundaries from downhole magnetometer logs as well as magnetostratigraphy by paleomagnetic study, and lithologic and logging units identified by shipboard study. Apparent inclinations in each magnetic unit indicate two inclination groups (6.9°–13.6° and about 22°). The apparent inclination is shallower than that obtained from paleomagnetic study. The difference is probably caused by induced magnetization.

INTRODUCTION

Downhole measurements are useful complements for coring studies because they provide nearly continuous readings of geological and physical properties of the borehole wall. One parameter that can be readily measured is the geomagnetic field, which contains information about magnetization of the surrounding materials in the borehole. The magnetization reflects not only the content of magnetic minerals, but also the record of geomagnetic field history (e.g., reversals and paleolatitude).

A fluxgate-type Japanese downhole three-component magnetometer (JDTCM) has been used to measure the magnetic field in oceanic crust and seamounts that have strong magnetizations (>1 A/m). This type of magnetometer is convenient for measuring strong magnetizations and for obtaining vector magnetic data. Several downhole three-component magnetometer logs have been recorded in the oceanic crust to reveal the magnetic structure of the oceanic crust and the origin of magnetic anomaly lineations (Kinoshita et al., 1989; Hamano and Kinoshita, 1990). Downhole magnetometer logs run in seamounts revealed their magnetic structure during Leg 143 (Nogi et al., this volume).

Volcaniclastic turbidites have an intensity between that of basalt (>1 A/m) and sedimentary rocks (~0.001 A/m). Therefore, magnetic variations caused by volcaniclastic sediments are detectable by fluxgate-type sensors. We had an opportunity to measure volcaniclastic turbidites at Site 869 using the JDTCM. Magnetic field data were also available from the general purpose inclinometer tool (GPIT), used as an orientation tool for the formation microscanner log, and were used to obtain more information about magnetization in the borehole. We present a comparison between magnetic field data by JDTCM and GPIT and the magnetization of volcaniclastic sediments in the borehole from downhole magnetometer logs.

JAPANESE DOWNHOLE THREE-COMPONENT MAGNETOMETER

Downhole magnetometer log measurements were made between 239 and 725 mbsf at Site 869 with the JDTCM. The JDTCM has a sensitivity of about 2 nT. Unfortunately, the horizontal component of the magnetic field variations was not recoverable as a result of rapid tool rotations in the hole. High-amplitude (~30,000 nT), sharp decreases in the horizontal magnetic field were in the record. Similar sharp decreases in the horizontal magnetic field were also recorded within weakly magnetized limestone sections at Sites 865 and 866, where the logging cable speed was faster than 2000 m/hr (Nogi et al., this volume). An abrupt change of the tool orientation, owing to the fast logging cable speed and the unstable hole conditions, are suggested as the cause of these variations; however, the origin of only sharp decreases have not been identified at the moment (Nogi et al., this volume). Although logging speed is slow (<1000 m/hr) at Site 869, the unstable hole condition probably cause the abrupt change of tool orientation. The vertical component of the magnetic field variations was also contaminated by the rapid tool rotation, but it was possible to remove this effect by filtering. Magnetic variations in the vertical component having a wavelength shorter than 4 m were filtered out by a window-type filter to remove the tool-rotation effect.

Magnetic boundaries were determined using only the vertical component, applying the method of Nogi et al. (this volume). The spatial differential of the vertical field component was calculated. The absolute value of these was used for determining magnetic boundary, rather than the intensity of the spatial differential of the downhole magnetic field (ISDDM) (see Nogi et al., this volume). Magnetic variations of the horizontal and vertical components at the magnetic boundaries exhibit similar behavior regardless of sign, assuming that the hole has a circular cross section with azimuthal homogeneity (e.g., Hamano and Kinoshita, 1990; Nogi et al., this volume). Therefore, magnetic boundaries can be determined from significant peaks of

variations in the absolute value of the vertical component spatial differential in the borehole.

GENERAL PURPOSE INCLINOMETER TOOL

Magnetic field data from the GPIT were used to yield more information about the magnetization at Site 869. The GPIT contains a three-component fluxgate magnetometer for providing tool orientation with respect to the Earth's magnetic field. Its sensitivity is about 50 nT (A. Dumont, Schlumberger Co. Ltd., pers. comm., 1993). Magnetic field variations of the vertical and horizontal components obtained by the GPIT at Site 869 and those of the vertical component by the JDTCM are shown in Figure 1.

Although the curves are similar, some discrepancies between the vertical components recorded by the GPIT and JDTCM were observed. The overall agreement of these two curves implies that the readings are valid and reflect geology. Some short-wavelength (about 5 m) magnetic variations of the vertical component observed by the JDTCM were not seen in the GPIT curve (Fig. 1). Likewise, short-wavelength (about 5 m) magnetic variations were noted in the GPIT horizontal component, but are not reflected in the GPIT vertical component. However, these variations are in good agreement with the JDTCM vertical component variations. Power spectrum pattern of the GPIT horizontal component is similar to that of the JDTCM vertical component between the wavelength of 4 and 50 m (Fig. 2). In contrast, the power spectrum pattern of the GPIT vertical component is different from that of the GPIT horizontal component (i.e., wavelengths shorter than 10 m) (Fig. 2). This is supporting evidence that the JDTCM short-wavelength vertical component magnetic variations are caused by the surrounding rock, not by tool rotation or artificial effects, and that the vertical component of the GPIT magnetic field is less sensitive for variations whose wavelength is shorter than 10 m. However, magnetic field variations in the GPIT horizontal component seem smoother than those of the JDTCM vertical component. The short wavelength (<10 m) power spectrum of the GPIT horizontal component also decreases to a low level. This suggests that the GPIT magnetic readings are less sensitive to short-wavelength variations than measurements by the JDTCM, an effect caused mostly by the low resolution of the GPIT's magnetic sensor. These observations suggest that magnetic field variations of the vertical and horizontal components recorded by the GPIT, with wavelengths longer than 10 m, are reliable for estimating gross features of magnetization in the borehole.

The absolute value of the GPIT vertical component magnetic field is different from that of the JDTCM, with this difference being almost 1000 nT (Fig. 1 and Table 1). Therefore, relative changes of the GPIT magnetic field data with wavelength longer than 10 m were used for the analysis.

DATA PROCESSING

Magnetic boundaries are defined from the GPIT ISDDM as well as the absolute value of the spatial differential of the vertical component of the JDTCM magnetic field. Only peaks that exceed threshold levels of 100 nT/m for the GPIT ISDDM and were 80 nT/m in the absolute value of the JDTCM spatial differential were regarded as magnetic boundaries. The magnetic units and subunits are determined using magnetic boundaries as well as magnetostratigraphy by paleomagnetic study (Sager et al., this volume), and lithologic and logging units identified by shipboard study (Sager, Winterer, Firth, et al., 1993).

The inclination resulting from a single, homogeneous, cylindrical magnetized body, called the apparent inclination, is obtained from the ratio between the spatial differential of the vertical to the horizontal component of the magnetic field (Nogi et al., this volume). The ratio between the spatial differential values of the vertical to horizontal components of the magnetic field recorded by the GPIT in each magnetic unit were obtained from linear regression (Fig. 3). The apparent
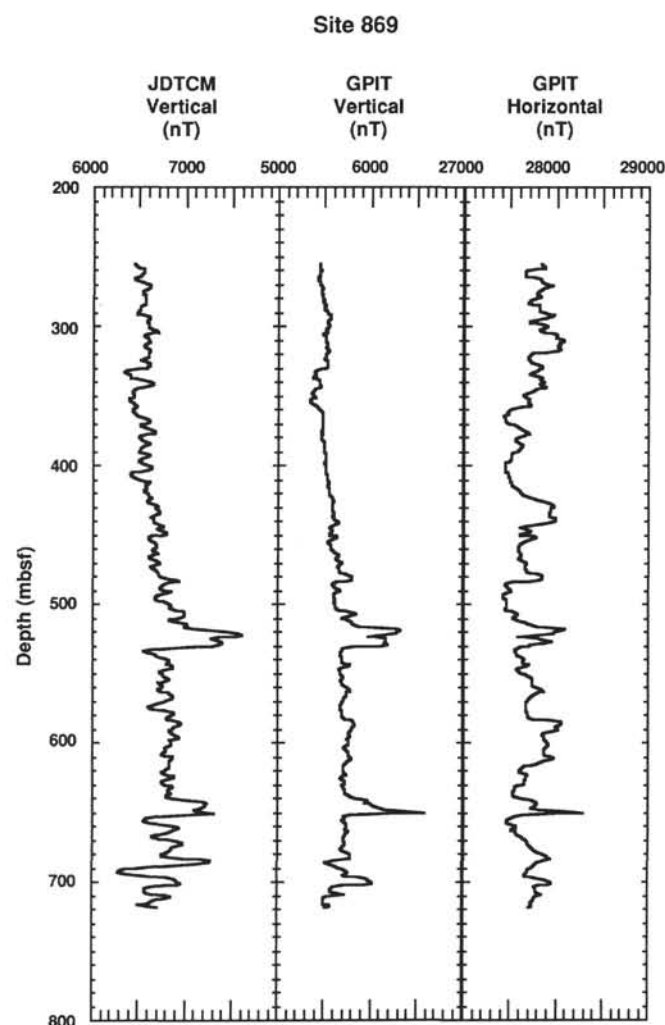

Figure 1. Horizontal and vertical magnetic field variations by the Japanese downhole three-component magnetometer (JDTCM) and the general purpose inclinometer tool (GPIT) at Site 869.

Table 1. Vertical and horizontal magnetic field calculated from IGRF 1990 (IAGA Division V Working Group 8, 1991) and mean value of components from JDTCM and GPIT at Site 869.

	IGRF90	JDTCM	Difference (JDTCM–IGRF90)	GPIT	Difference (GPIT – IGRF90)
Horizontal (nT):	33729	—	—	27718	–6011
Vertical (nT):	6246	6709	463	5623	–623

inclination of each unit was calculated (Table 2) using the ratio between spatial differential values.

The magnetization acquired in the Northern or the Southern Hemisphere was determined from the magnetic variations in each magnetic subunit. Vertical and horizontal magnetic field vary in the opposite sense, if the magnetization of surrounding materials are acquired in the Northern Hemisphere. In the case of magnetization originating in the Southern Hemisphere, these vary in the same sense. Therefore, variations in the same sense in the JDTCM vertical and the GPIT horizontal components in a given unit were regarded as representing a magnetization that originated in the Southern Hemisphere; others are regarded as having been acquired in the Northern Hemisphere.
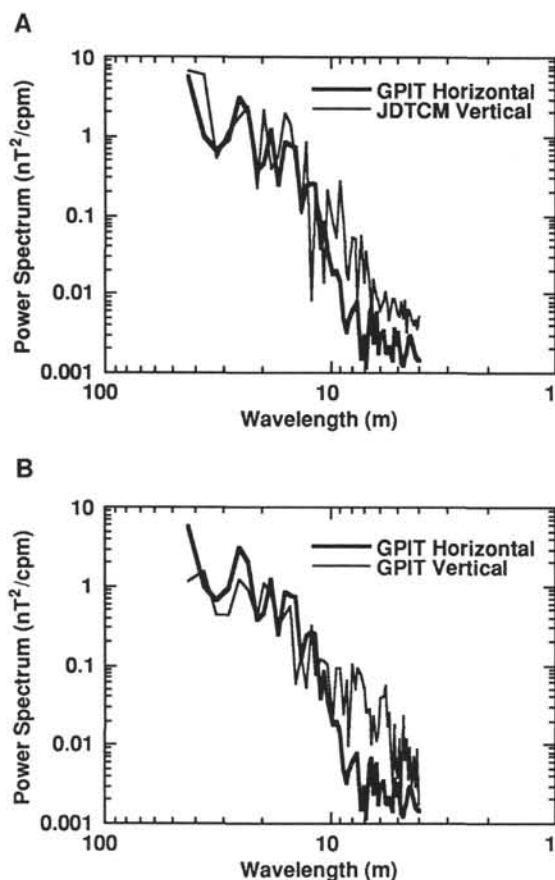
Figure 2. **A.** Power spectrum of horizontal magnetic field by the GPIT and vertical magnetic field by the JDTCM. **B.** Power spectrum of horizontal and vertical magnetic field by the GPIT.

Table 2. **Magnetic units and magnetization in each magnetic unit from downhole magnetometer logs.**

Magnetic unit		Depth (mbsf)	Hemisphere	Polarity	Apparent inclination (degrees)	Correlation coefficient
1	a	<<293	Southern	Normal	1.2 ± 0.83	0.19
	b	293–319	—	—		
2	a	319–330	Southern	Reverse?	1.7 ± 1.7	0.11
	b	330–338	Southern	Reverse		
	c	338–344	Southern	Normal?		
	d	344–378	Southern	Reverse		
	e	378–403	—	—		
3	a	403–441	Southern	Normal?	6.9 ± 1.3	0.63
	b	441–450	Northern	Normal?		
4		450–482	Southern	Normal	13.6 ± 1.9	0.78
5		482–531	Southern	Normal	23.2 ± 3.1	0.70
6	a	531–583	Southern	Normal	22.9 ± 1.9	0.72
	b	583–651	Southern	Normal		
7		>>651	Southern	Normal	21.2 ± 2.9	0.65
All		—	—	—	17.1 ± 1.0	0.61

The mean magnetic field of the horizontal and vertical components obtained by the GPIT and the vertical component recorded by the JDTCM were calculated (Table 1) and subtracted from each magnetic variation. The polarity of magnetization in each magnetic subunit was also determined from the sign of both the GPIT horizontal and JDTCM vertical fields with respect to each mean value as well as discrete sample paleomagnetic results (Sager et al., this volume). However, it is difficult to determine magnetic boundaries arising from normal to reversed polarity changes or intensity variations of magnetization of volcaniclastic sediments. Weak magnetization of volcaniclastic sediment, which is usually less than 1 A/m, causes only small amplitudes of magnetic field variations (<800 nT) at the magnetic boundaries (Fig. 4). Also, variations caused by turbidite boundaries can be several orders of magnitudes in magnetization. The amplitude of magnetic variation derived from the intensity change of magnetization is comparable to that from a normal-reversed magnetic boundary (Fig. 4). A highly variable intensity change is expected in Site 869 sediments (calcareous oozes with variable amounts of volcaniclastics), because those sediments consist of various kinds of materials having highly variable magnetic content. Therefore, Koenigsberger (Q) ratio, the ratio of primary to induced magnetization, the intensity of natural remanent magnetization (NRM), and inclination of characteristic remanent magnetization (ChRM) from discrete sample paleomagnetic results were used to constrain the determination of the polarity of magnetization.

RESULTS

Magnetic field variations of the horizontal and vertical components obtained by the GPIT and the vertical component recorded by the

JDTCM are shown in Figure 5, with the mean of each magnetic variation subtracted (Table 1). Variations of the GPIT ISDDM and those of the absolute-value of the spatial differential of the JDTCM vertical magnetic field are also shown in Figure 5. Q ratio, intensity of NRM, and inclination of ChRM from discrete sample paleomagnetic study are shown in Figure 6. The boundaries, apparent inclination, and polarity of magnetization in each magnetic units and subunits are summarized in Table 2.

The trend of the vertical component field variations suggests that the magnetization of the deeper sediments (magnetic Units 4–7) was acquired in the Southern Hemisphere during a normal chron (i.e., the level of the vertical component gradually increases with depth). Below magnetic Unit 4, the boundaries of the magnetic units are marked by a set of sharp magnetic field decreases and increases in both the horizontal and vertical components. The vertical component of the magnetic field is virtually always positive relative to the mean value; negative values are not seen except in the vicinity of a few boundaries. This indicates that the magnetization of the lower sediments has a negative inclination. Shorter wavelength field variations in both the horizontal and vertical components in the lower parts of the section typically exhibit almost the same change in the same sense. This also shows that such magnetization originated in the Southern Hemisphere. The average Q ratio within this zone is higher than that of the upper part of the sediments. Assuming that magnetization consists of remanent and induced magnetization, higher Q ratios reflect dominance of a remanent magnetization. This result agrees with paleomagnetic results that show these sediments represent the Cretaceous Normal Superchron and were magnetized in the Southern Hemisphere (Sager et al., this volume).

Although complicated magnetic field variations were obtained in the upper part of sediments from magnetic Units 1 to 3, magnetic field variation in the horizontal component exhibits almost the same change as in the vertical component, indicating that most of the magnetization was acquired in the southern hemisphere. However, in magnetic Subunit 3b, the horizontal and vertical components vary in opposite senses, indicating that the magnetization originated in the Northern Hemisphere. The Northern Hemisphere magnetization is most likely an induced or viscous magnetization. The hemisphere and polarity of the magnetization in magnetic Subunits 1b and 2e were not identified.

A good correlation between the spatial differentials was obtained below magnetic Unit 3. The apparent inclination obtained by using all spatial differential values is 17.1°. Apparent inclinations for individual magnetic units range from 1.2° to 23.2°.

DISCUSSION

A close correspondence between magnetic variations from downhole magnetometer logs and Q ratio from discrete core samples is
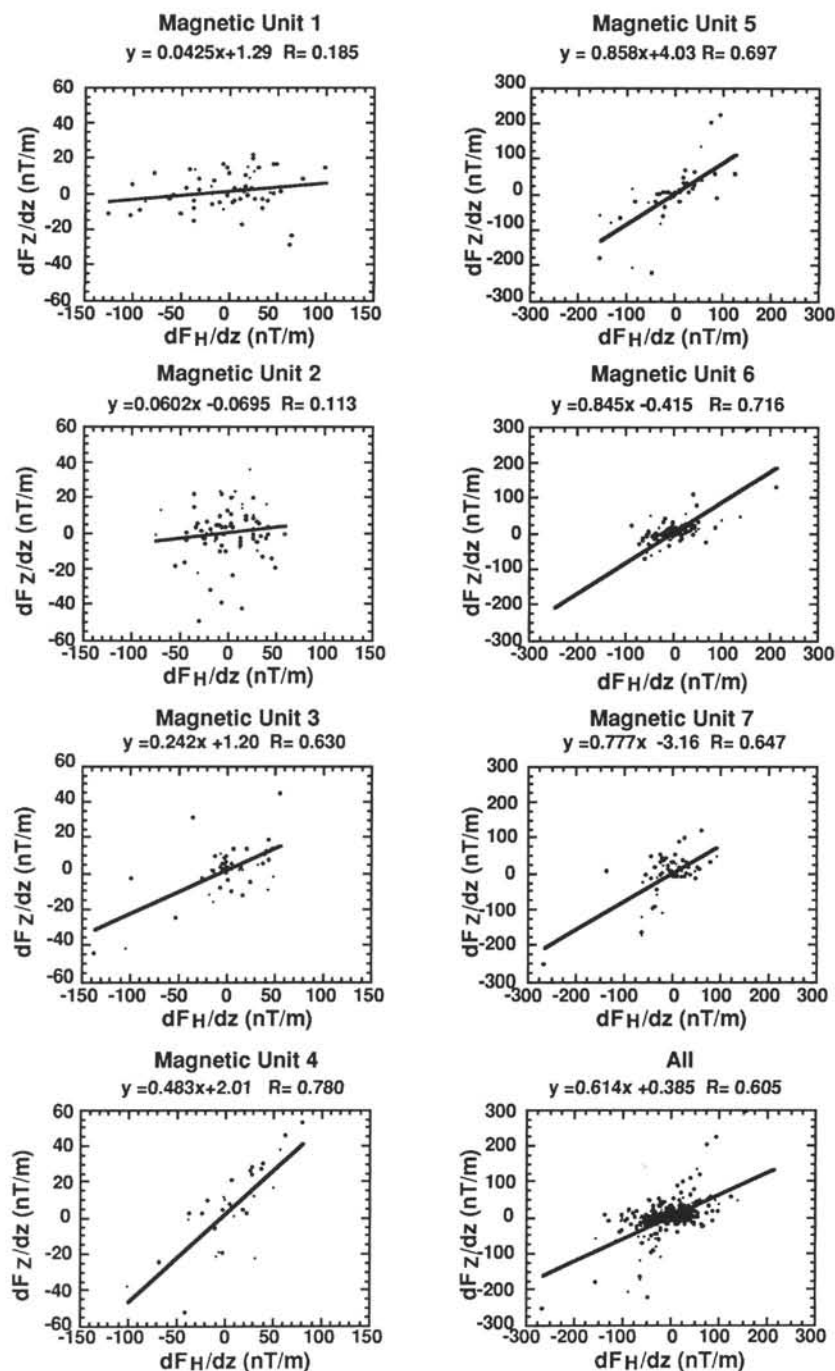
Figure 3. Correlation between horizontal and vertical component spatial differentials in each magnetic unit and all magnetic units. Regression lines and equations are also shown.

observed, suggesting that the magnetic variations and the apparent inclination from downhole logs are affected by induced magnetization. Paleomagnetic measurements show that the deeper part of sediments at Site 869 were magnetized in the Southern Hemisphere during a normal chron, so the induced or viscous magnetization will cause the inclination to appear shallowed. Apparent inclinations in magnetic Units 3 and 4 are the least reliable, but give values shallower than those calculated from magnetic Units 5 through 7. The latter give inclinations of 21.2° to 23.2°. Paleomagnetic study also shows two distinct inclination groups, −23.2° and −33.3° with the former being typical above Subunit IIID (Sager et al., this volume). The apparent inclination results are similar, but shallower than the inclination values from the paleomagnetic study. Assuming that only induced

magnetization is added to the primary magnetization, the Q ratio (Koenigsberger ratio) from downhole magnetometer logs in magnetic Units 3 and 4 ranges from 1 to 2.5, while that in magnetic Units 5 through 7 is almost 3. These are in good agreement with Q ratios from discrete sample paleomagnetic study.

The magnetization in magnetic Subunit 3a possibly indicates an origin in the Southern Hemisphere during a normal polarity chron. Horizontal and vertical magnetic fields increase with depth from the upper boundary of magnetic Subunit 3a, implying that magnetization in the Southern Hemisphere during a normal chron (Fig. 7). Q ratio and NRM intensity from discrete sample paleomagnetic study also increase around the upper boundary of Magnetic Subunit 3a. Paleomagnetic study further suggests a negative inclination below about 380

A

Magnetic Field (nT)

-1000 -500 0 500 1000

B

Magnetic Field (nT)

-500 0 500

——— Horizontal
- - - - - Vertical
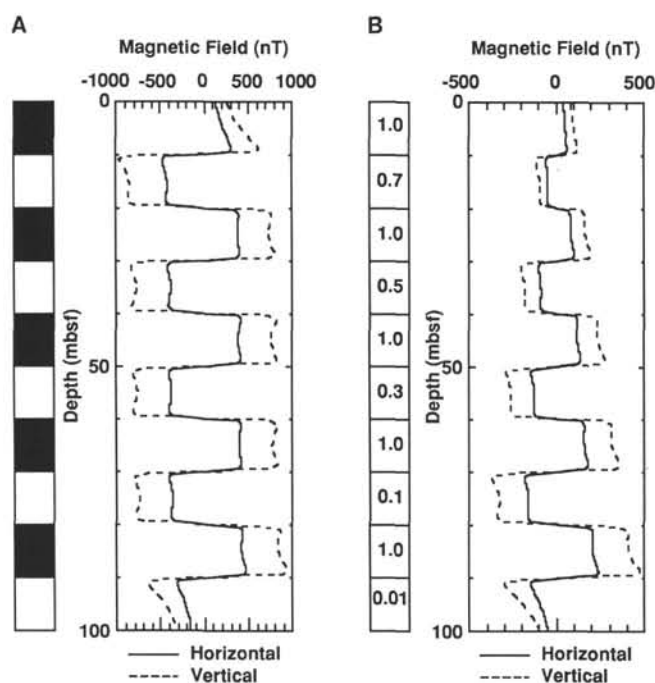
——— Horizontal
- - - - - Vertical

Figure 4. Magnetic-field variations of the vertical and horizontal components calculated from a circular hole model with cylindrical magnetized model. Magnetization is assumed that acquired in the Southern Hemisphere. Parameters used in the model are (1) radius of cylindrical magnetized body = 10 m, (2) radius of the hole = 0.3 m, (3) inclination = 45°. **A.** Variations of magnetic field from a horizontal normal-reversed model with an intensity of 1 A/m. Solid and open blocks at right are normal and reversed magnetized bodies acquired in the Northern or Southern Hemispheres. **B.** Variations of magnetic field with horizontal normal magnetization model with change in the intensity. The intensities (A/m) of the magnetized bodies are noted in open blocks.

mbsf. Although the magnetization in magnetic Subunit 3b is possibly affected by viscous or induced magnetizations, these data indicate that the primary magnetization of magnetic Unit 3 is normal and confirms the conclusion that the deeper sediments were magnetized in the Southern Hemisphere during a normal chron.

The upper boundaries of magnetic Unit 2 and Subunit 2e probably show transitions between normal and reversed polarity zones. Complicated magnetic variations are obtained in magnetic Unit 2 (Fig. 7). Paleomagnetic study shows a reversed polarity zone between magnetic Subunits 2a and 2d (Sager, Winterer, Firth, et al., 1993; Sager et al., this volume). A normal to reversed polarity change at the top of magnetic Subunit 2a is also suggested by magnetic field variations of the horizontal component. The horizontal component field indicates the beginning of a decrease around the upper boundary of magnetic Unit 2 and an increase around the upper boundary of magnetic Subunit 2e. This possibly marks the boundaries between normal and reversed polarity. A decrease in the horizontal component in magnetic Subunit 2d is observed and the magnetization of this zone was not identified. However, this possibly reflects a decrease in Q ratio and intensity of magnetization, as observed in the paleomagnetic study.

Magnetic variations in magnetic Subunit 2c (shaded zone in Fig. 7) are possibly caused by magnetization that originated in the Southern Hemisphere during a normal chron. Magnetic variations in magnetic Subunit 2c show the magnetization originating in the Southern Hemisphere and both the horizontal and vertical components of magnetic-field increase in magnetic Unit 2c. On both sides of magnetic Subunit 2c, both the horizontal and vertical components of magnetic-

field decrease and suggest that the magnetization originated in the Southern Hemisphere during a reversed polarity chron. Increases in both the horizontal and vertical components of magnetic-field are interpreted as a decrease in intensity of magnetization and/or the change in the polarity of magnetization. Paleomagnetic study suggests that a reversed polarity zone is recognized from 324 to 382 mbsf, corresponding to the zone from magnetic Subunits 2a to 2d (Sager, Winterer, Firth, et al., 1993; Sager et al., this volume). However, negative inclination also was observed amid the positive inclination zone around magnetic Unit 2c by paleomagnetic study (Sager et al., this volume). Although Q ratio and NRM intensity were not obtained from this zone, significant changes in these parameters are not observed in the lower part of magnetic Subunit 2b and the upper part of magnetic Subunit 2d.

A short normal polarity interval probably is implied from magnetic variations in magnetic Subunit 2c as well as paleomagnetic studies. The reversed zone has been interpreted as Chron 33R (Sager et al., this volume). This reversed polarity chron is constrained by a nannofossil age (Mütterlose, this volume). However, there is no evidence for such a short normal polarity interval in a marine magnetic anomaly during this chron (Cande and Kent, 1992). We also note that other explanations can be invoked to cause this apparent short normal polarity interval within Chron 33R. It is possible that there is a zone of chemical alteration, undetected as a result of poor core recovery, that the magnetization represents a remagnetization acquired during Chron 32N. Further comparison with onshore magnetostratigraphic section are needed.

Because magnetic variations can be caused both by remanent and induced magnetization, downhole susceptibility logs would greatly complement future downhole magnetometer logs. Downhole magnetometer logs give continuous information concerning the magnetization of surrounding materials, which is not available at times of poor core recovery. A shallower inclination value from downhole magnetometer readings was obtained at this site than was obtained from paleomagnetic study, which was most likely caused by induced or viscous magnetization. If susceptibility log data are available and the viscous overprinting effect is negligible, corrections for induced magnetization can be made to magnetic variations from downhole magnetometer logs, and magnetic variations caused by natural remanent magnetization (NRM) could be obtained directly. Sedimentary rocks in the ocean usually have a low Q ratio and a large induced component of magnetization. Downhole magnetometer logs, combined with downhole susceptibility logs, are necessary to obtain good results in the sedimentary section. Moreover, if fully oriented data can be obtained (e.g., magnetometer with gyro), the declination of the magnetization of surrounding material could also be found.

SUMMARY AND CONCLUSIONS

Magnetic field variations from downhole magnetometer logs were collected at Site 869, where the major lithologic constituent is volcaniclastics. Magnetic field data obtained by the general purpose inclinometer tool (GPIT) supplied additional information concerning magnetization in the borehole. Absolute values of the magnetic field recorded by the GPIT were significantly different from those recorded by the JDTCM. The origin of this discrepancy has not been identified, but does not affect the conclusions of this study.

The magnetic field variations suggest that almost all the magnetization was acquired in the Southern Hemisphere. Below 380 mbsf, magnetization was acquired in the Southern Hemisphere during a normal chron. A close correspondence between magnetic variations from downhole magnetometer logs and Q ratios from discrete core sample suggests that the magnetic variations from downhole logs are affected by induced magnetization. A reversed magnetization zone is suggested between 319 and 378 mbsf and is interpreted as reversed polarity Chron 33R consistent with previous paleomagnetic results. Magnetic
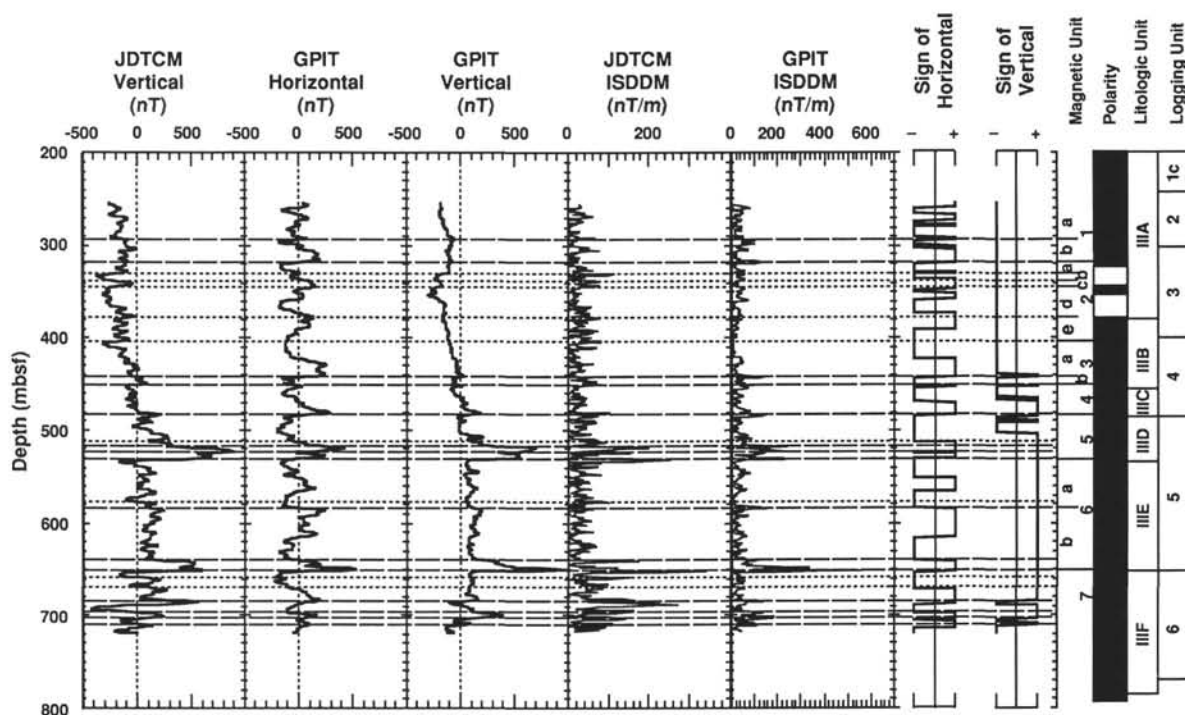
Figure 5. Horizontal and vertical component magnetic field variations after subtracting the mean value, and variations of the intensity of the spatial differentials of the downhole magnetic field (ISDDM). ISDDM measurements with the JDTCM were calculated using only the vertical component of the magnetic field. Signs of the GPIT horizontal and vertical components are relative to the mean value of each component. Magnetic units defined by ISDDM are also shown. Lithologic units and logging units are from Sager, Winterer, Firth, et al. (1993). Magnetic polarity is from Sager et al. (this volume), and solid and open areas indicate normal and reversed polarity, respectively. Dashed lines show the magnetic boundaries suggested by the ISDDM of both the JDTCM and GPIT, and dotted line denotes those suggested only by the ISDDM of JDTCM.
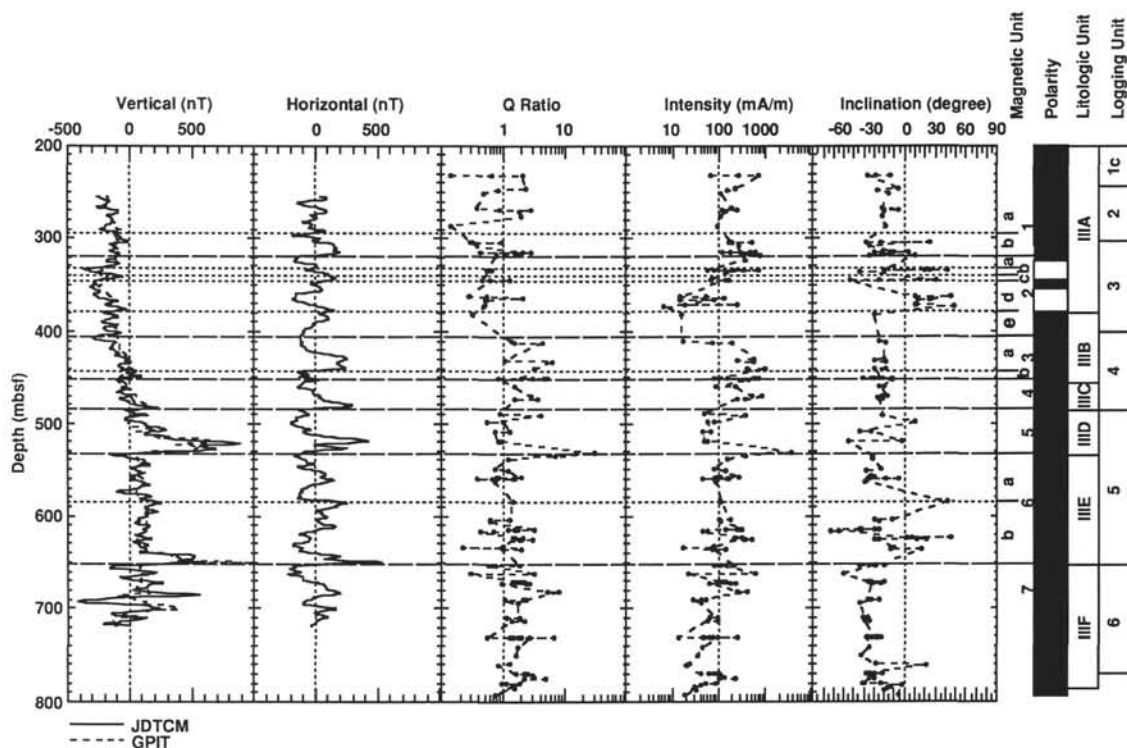
Figure 6. Horizontal and vertical component magnetic field variations by the JDTCM and GPIT, and Koenigsberger (Q) ratio, the ratio of primary to induced magnetization, the intensity of natural remanent Magnetization, and inclination of characteristic remanent magnetization (ChRM) from discrete sample paleomagnetic results. Dashed lines show the magnetic boundaries of magnetic units, and dotted line denotes those of magnetic subunits. Lithologic and logging units and magnetic polarity are the same as those in Figure 5.
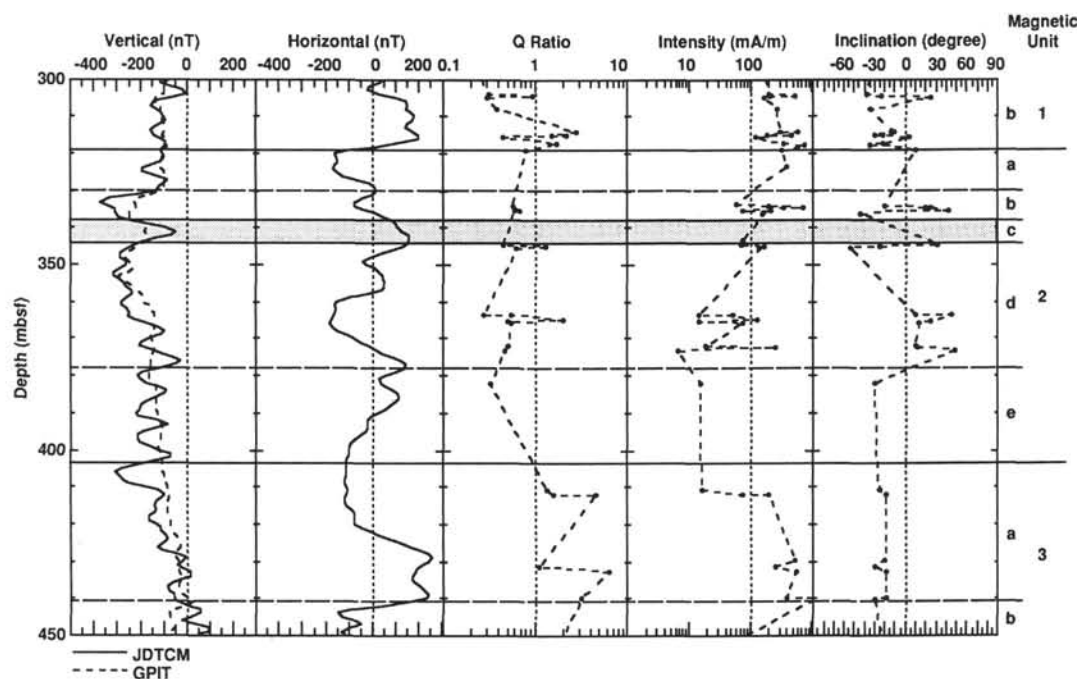
Figure 7. Horizontal and vertical component magnetic field variations by the JDTCM and GPIT, and Koenigsberger (Q) ratio, the ratio of primary to induced magnetization, the intensity of natural remanent magnetization, and inclination of characteristic remanent magnetization (ChRM) from discrete sample paleo-magnetic results between 300 and 450 mbsf. Dashed lines show the magnetic boundaries of magnetic units, and dotted line denotes those of magnetic subunits. Magnetic units and subunits are shown at the right. Shaded zone indicates a possible short normal polarity interval.

field variations between 338 and 344 mbsf in the reversed polarity zone imply a possible short normal polarity interval in Chron 33R.

Two apparent inclination groups (6.9°–13.6° and about 22°) were obtained from downhole magnetometer logs. The apparent inclinations are shallower than those determined from paleomagnetic study. Induced magnetization most likely caused this apparent inclination-shallowing.

ACKNOWLEDGMENTS

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