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29. BGR MAGNETOMETER LOGGING IN HOLE 395A, LEG 109[1]

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ABSTRACT

During Leg 109, the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) three-axis borehole magnetometer was used for magnetic measurements in Hole 395A. First, measuring procedures and data evaluation are explained. Then, we discuss the application of a newly developed centralizer unit that yielded precise determinations for the azimuth of the gyro, by which the three-axis fluxgate system is controlled, improving data quality considerably. Although three-component measurements were not conducted during Leg 109 because of a breakdown of the probe, a detailed continuous log of the vertical magnetic intensity was made and interpreted to obtain a magnetization profile and a statistical classification of rocks penetrated by the borehole.

The main results are (1) proof of two reversals of the Earth's magnetic field, one of which (as should be stressed) occurred inside a petrographic unit, (2) correlation of rough petrographic classification with significant differences in magnetic anomaly patterns, (3) correspondence of detailed statistical analysis of the magnetic log in one section to the detailed lithologic profile. In other profiles, necessary additional information is not yet available. The authors recommend that research during future legs prove the correlation of detailed statistical log analysis with petrography.

INTRODUCTION

Downhole measurements of the magnetic field were expected to provide information about the nature of the young oceanic crust penetrated during drilling of Hole 395A. These measurements are performed two ways: (1) when performing "three-dimensional measurements," the probe is held stationary at discrete depth points, and (2) when performing "magnetic logging," the probe is moved continuously either downward or upward. During Leg 109, measurements recorded the vertical component of the magnetic field. These three-dimensional measurements locate magnetic source bodies near the borehole and determine the direction of magnetization of the rocks penetrated by the hole. A log obtained with the probe during magnetic logging mode provides important information about the magnetic properties of rock adjacent to the borehole and shows variations in magnetization and anomaly patterns that can distinguish rock type.

During Leg 102, measurements were performed and interpreted in this manner (Bosum and Scott, 1988). Although three-component measurements were not conducted during Leg 109 because of probe breakdown, a detailed continuous log of vertical magnetic intensity was made and interpreted to obtain a magnetization profile and statistical classification of rocks penetrated by the borehole.

Measurements performed with the BGR probe during Leg 109 should complement former measurements performed by Ponomarev and Nechoroshkov (1984) and those of a self-contained, high-temperature, three-axis magnetometer of Japanese design (Hamano and Kinoshita, this volume).

DESCRIPTION AND TECHNIQUE OF THE BGR MAGNETOMETER

The BGR magnetometer, which was developed by the Federal Institute for Geosciences and Natural Resources, Hannover, Federal Republic of Germany (Bosum and Rehli, 1985), comprises the following components:

1. A three-axis Foersterprobe Fluxgate System, which measures the Earth's magnetic field in three mutually perpendicular directions, one parallel and two perpendicular to the borehole (sensitivity 1 nT).
2. A gradiometer, which measures the gradient of the magnetic field parallel with the borehole (sensitivity 2 nT/40 cm).
3. A directional unit, consisting of a gyroscope used as a directional reference (mean drift 1°/hr), and two inclinometers (accelerometers) with a sensitivity of 5×10^{-3}. This unit is fixed to the magnetometer, thus defining its position and orientation.
4. An electronic unit for processing signals, transmitting data, and supplying power.

Measurements are performed continuously as the probe is moved downward and upward in the borehole (magnetic log), as well as with the probe held stationary at discrete points at increments of 5 to 10 m (three-dimensional measurements). While in a fixed position, the three-axis magnetometer measures the magnetic field inside the borehole in three components, from which the total magnetization of the penetrated magnetic rock can be calculated in direction and intensity. Susceptibility measurements can be used to calculate induced magnetization. Thus, the combination of three-dimensional and susceptibility measurements provides the information needed to determine remanent magnetization. The authors stress that determining declination of magnetization is the great advantage of borehole magnetics, in comparison to investigations of drill-hole samples, the azimuthal orientation of which normally is unknown. Using declination and inclination, paleopole positions were determined from data obtained during Leg 102 in Hole 418A for the first time from ocean drilling surveys (Bosum and Scott, 1988; Salisbury et al., 1986).

When three-dimensional measurements were performed with the BGR probe during Leg 102, problems came up (1) because of the large diameter of the borehole (about 27 cm) in comparison with the diameter of the probe (9.2 cm) and (2) because the borehole was nearly vertical. Thus, the probe was free to swing around in the borehole and to rotate around its

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axis, causing the azimuth to change continuously. Figure 1A presents as example the original plot for depths ranging from 6269 to 6275 m below sea level during Leg 102 logging. On the left of Figure 1, the profile of the vertical component of the Earth's magnetic field (Mag Z) can be seen, and on the right, one can see the azimuth-angle between the horizontal y-axis of the magnetometer and the gyro-axis (Azimuth). The plot of the azimuth clearly demonstrates the rotation of the probe. The same rotation occurred during stationary measurements. Thus, the error when determining the direction of magnetization and the paleopole position was generally large. To overcome this problem, a centralizer unit was built and used in Hole 395A during Leg 109. As can be seen in Figure 1B, the plot of the azimuth (Azimuth) indicates that the rotation of the probe was virtually eliminated. Unfortunately, because of a breakdown of the three-axis fluxgate system, three-dimensional measurements could not be performed during Leg 109. This breakdown was the result of a weakening of the probe housing caused by a local accumulation of stress under high pressure, in turn caused by a problem in the mechanical manufacturing process, verified later by laboratory tests. Following Leg 109, the magnetometer probe was adapted for high pressure by using an improved mechanical design, which was used successfully in the Continental-Deep-Drilling Borehole Program (KTB) of the Federal Republic of Germany (Bosum et al., 1988).

Despite the failure of the three-dimensional measuring system during Leg 109, the vertical component of Earth's magnetic field was measured with a vertical fluxgate, which continued to operate. Based on the log of the vertical component, we present the following interpretation.

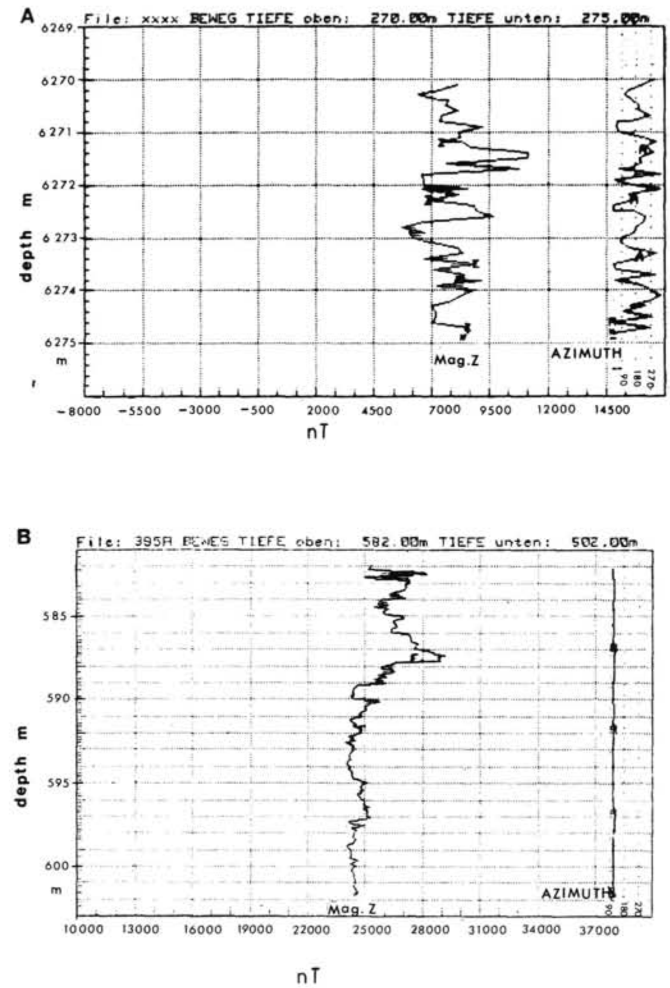

Figure 1. Detailed magnetic log containing the vertical component of the Earth's magnetic field (Mag. Z) and the gyro azimuth (Azimuth). **A.** Azimuth record during Leg 102 without centralizer. **B.** Azimuth record during Leg 109 after installation of a centralizer.

MAGNETIC LOGGING

Data Evaluation and Interpretation Methods

As a magnetic log is strongly affected by the magnetic properties of rocks penetrated by the borehole, magnetic classification of the borehole profile can be done using this magnetic log. Furthermore, a rock magnetization log can be computed.

A magnetic log can be subdivided by statistical testing (Bosum et al., 1984). The likelihood of distribution of a suitable parameter, such as the mean value or the variance, is determined in a "window" of predetermined length. This window is moved along the profile, and using a statistical test (here, the U-test) the identity of a possible distribution is checked between neighboring intervals, assuming a certain significance level. With this procedure, homogeneous sections and discontinuities are revealed, representing a stratigraphic classification of magnetic profile free of subjective assessment.

Transforming magnetic measurements to a magnetization profile is accomplished mathematically by using a disk model in which the rocks penetrated by the borehole are cut into thin horizontal slabs, represented as disks having constant thickness and outer diameter and having a hole of constant diameter cut through the center (Bosum, 1985).

Besides statistical treatment and calculation of the magnetization profile, isolated anomalies can be interpreted with appropriate models by trial and error (Eberle, 1985; e.g., Fig. 4 and Fig. 3, Row 4).

RESULTS AND INTERPRETATION

The observed vertical component (Z) magnetic log is shown in Figure 2. The normal value of the vertical component of the Earth's magnetic field, estimated at 26,100 nT, is indicated by a vertical line. The most conspicuous feature of this magnetometer log is the change of sign (with respect to the normal field value) at depths of 261 mbsf and 564 mbsf. The value of ΔZ changes from about -5000 to $+5000$ nT and from $+3000$ to -2000 nT at these depths. Since downhole inside the source body the sign of the direction of the vertical magnetic field is opposite the direction of the magnetization, the direction of magnetization (i.e., the direction of the Earth's magnetic paleofield) is positive (normal) above 261 mbsf, negative (reversed) between 261 and 564 mbsf, again positive (normal) below 564 mbsf. Thus, two reversals of the Earth's magnetic field are indicated.

Besides this main subdivision, the magnetic log can be divided qualitatively into several different units, based on the anomaly pattern and field strength. These units are marked in column 1, where black indicates the zones of higher absolute value of magnetization. For comparison, the lithologic profile (Melson, Rabinowitz, et al., 1979) is presented in column 2. The meaning of the symbols is as follows:

A_2, A_3 = aphyric basalt,
A_4 = aphyric basalt, veined, fractured and altered,
P_2, P_5 = plagioclase-olivine-clinopyroxene phyric basalt (P5 only ± clinopyroxene),
P_3, P_4 = plagioclase-olivine-clinopyroxene phyric basalt.

As can be seen, the two classifications agree with each other in a general way, and in places coincide exactly. The boundaries, A_2/P_2, P_4/P_5, and P_5/A_3 are obviously defined by a change of the field pattern, whereas P_2/P_3 is not indicated so clearly. The striking anomaly between 420 and 431 mbsf is caused by an excavation of the borehole. The boundary P_3/P_4 is defined only by the magnetic log (field reversal). The authors stress that this reversal is recorded within a petrographic unit—the plagioclase-olivine-clinopyroxene phyric basalt. The boundary A_3/A_4 is defined by a field reversal and a change of rock type.

After these favorable results, a detailed statistical analysis and interpretation of individual anomalies was performed. Results are compiled in Figure 3.

As one can conclude by comparing the "qualitative" with the "statistical" subdivision of the magnetic log, in Row 1 or 2, respectively, of Figure 3B, the statistical analysis presents a detailed profile, even with a high significance level of 98%, which means that only boundaries of high significance are indicated. One can assume that the important boundaries are those that coincide with boundaries of the qualitative analysis, which identifies the main units. Within these main units, the correlation with the geological/petrographical detailed profile was investigated (Row 3; Melson, Rabinowitz et al., 1979). As can be seen in Figure 3B, the units P2, P3, P4, and A3 are subdivided in more detail by the magnetics, rather than petrology. P_5 is strongly subdivided by both methods. However, these boundaries do not correlate in every detail, perhaps because of errors in determining depths and incomplete core recovery. Unfortunately, the petrographic relevance of the magnetic boundaries within units P_2, P_3, P_4, and A_3 could not be studied more intensively because petrographic work on the borehole samples has been finished for a long time.

Based on detailed statistical subdivision, isolated anomalies were interpreted using a disk model. Figure 4 shows one example that contains the magnetic log (in high resolution scale), the section of the source body, the magnetization contrast, and the theoretical anomaly. Sections of the individual source bodies have been transferred to Figure 3B, Row 4. These sections represent intervals of unique magnetization, whereas Row 2 represents intervals of generally different anomaly patterns (e.g., different statistical variance). Therefore, the number of sections is considerably smaller in Row 4 than in Row 2.

Figure 3C presents the magnetization profile calculated from the magnetic log. The lower dots represent results of laboratory measurements of the natural remanent magnetization, J_R, and the upper ones represent the sum of J_R and the induced magnetization, J_i , calculated from the susceptibility log (Krammer, this volume). Because of the large Königsberger Q-factor ($Q = J_R/J_i$), J_i is of minor importance. In general, the magnetization values of the laboratory measurements agree with the magnetization profile, except for sections of stronger magnetic anomalies or magnetic inhomogeneities.

Based on the magnetization profile (Fig. 3C), a statistical analysis was also performed (Row 5, Fig. 3B), which is more general than the statistical analysis of the magnetic log in Row 2 because of smoothing effects during transformation. This analysis corresponds in a general way with the "qualitative" interpretation of Row 1.

CONCLUSIONS

As measurements of the gyro-azimuth indicate, introduction of a centralizer-unit can solve the problem of rotation of the probe. Therefore, in the future one should be able to determine the direction of the anomalous magnetic field from the three-axis borehole magnetometer at a level of high accuracy, even in large-diameter boreholes, as those drilled by ODP. This was recently demonstrated by measurements in the Continental-Deep Drilling Borehole (KTB of the Federal Republic of Germany). Unfortunately, the direction of the magnetic field could not be measured during Leg 109 because of a breakdown of this three-axis fluxgate system. This breakdown was caused by an unexpected weakening of the probe material that resulted from a mechanical manufacturing problem.

However, a detailed continuous log of vertical magnetic intensity was made and interpreted to obtain a magnetization profile and a magnetic classification of rocks penetrated by the borehole. Important magnetic boundaries, indicated by obvious changes of magnetic anomaly patterns, correlate with main petrographic boundaries. A newly introduced method of statistical analysis gave a much more detailed classification of the borehole profile than the normal "qualitative" procedure. In one section, the magnetic log correlates reasonably well with the lithological log. In the other sections, the log gives a higher resolution. Because petrographic work on the borehole samples had been completed, the petrographic relevance of the detailed magnetic boundaries in the latter case cannot be investigated.

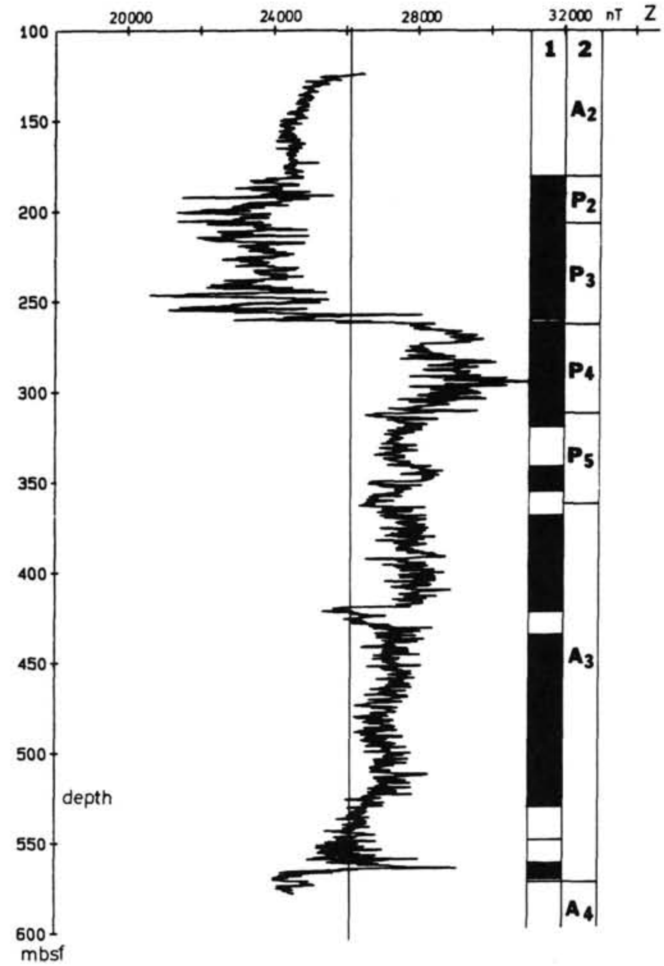

Figure 2. Shipboard magnetic log from Hole 395A showing the vertical component of the Earth's magnetic field (normal value at Site 395 = 26,100 nT); (1) qualitative, magnetic subdivisions based on the log and (2) lithology (for explanation see text).

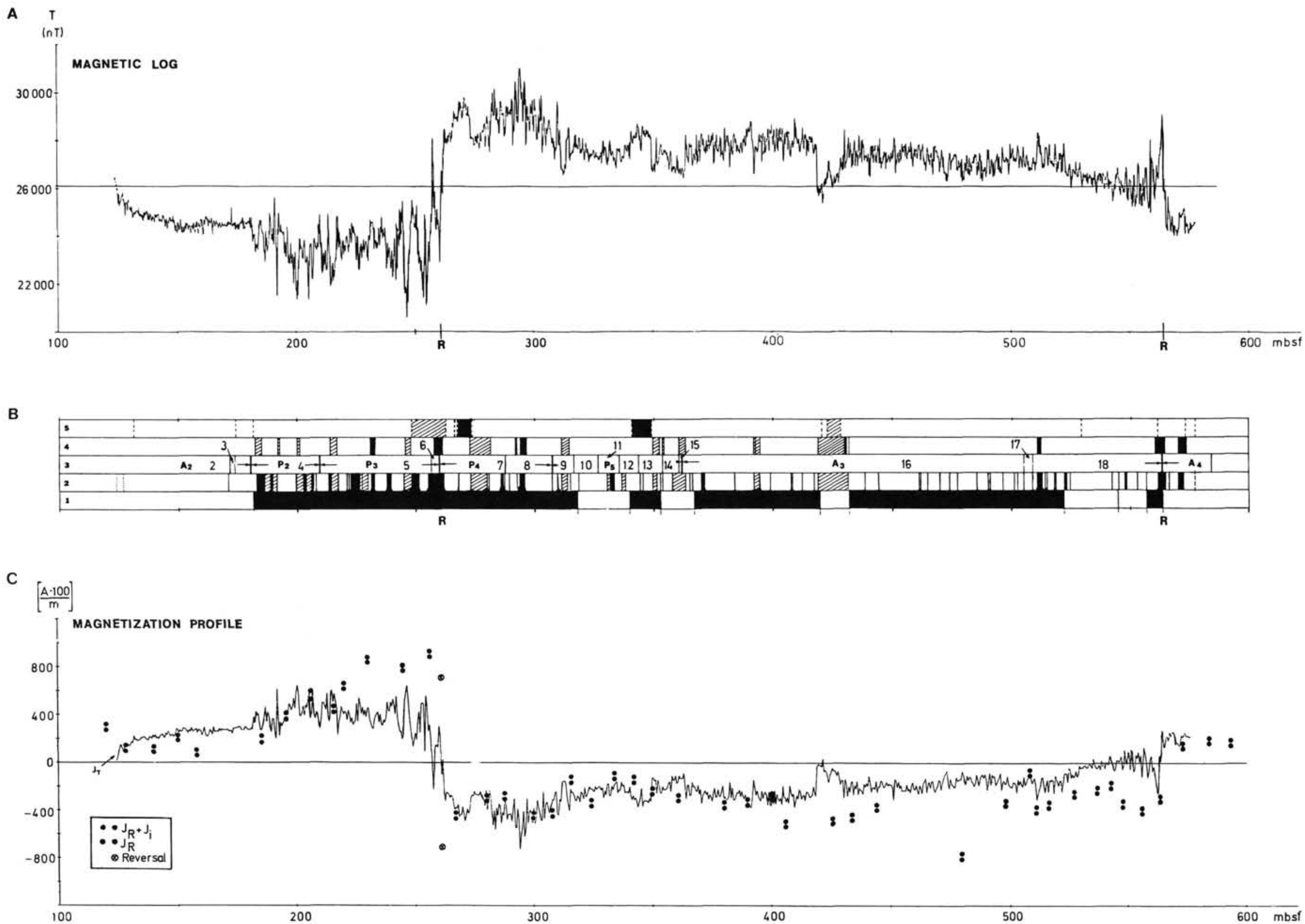

Figure 3. **A.** Magnetic log. **B.** Qualitative magnetic subdivision (Row 1) based on the magnetic log; detailed magnetic subdivision by statistical analysis (Row 2) based on the magnetic log; lithology (Row 3) (for explanation see text); a classification of the log by interpretation of the disk model (Row 4); a subdivision of the borehole by a statistical analysis of the magnetization profile (Row 5). **C.** Magnetization profile calculated from the magnetic log. Lower dots represent natural remanent magnetization, J_R, from laboratory results, and upper dots represent the sum of J_R and the induced magnetization, J_i, calculated from the susceptibility log. R = reversal of the Earth's magnetic field.

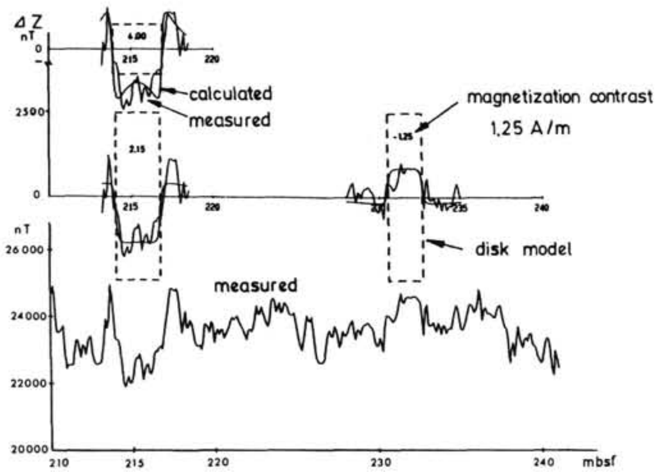

Figure 4. Interpretation of individual anomalies using the disk model.

Thus, we recommend careful study of the correlation between the results of detailed rock-magnetic logging interpretation and lithology in a future Leg.

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