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19. MAGNETIC SUSCEPTIBILITY LOG MEASURED IN HOLE 395A, LEG 109[1]

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ABSTRACT

During Leg 109 a set of borehole logs was measured in DSDP Hole 395A. The susceptibility log, which was run to 600 mbsf (meters below seafloor), agreed in part with the susceptibility measurements of Leg 78B obtained with a Russian logging tool. Between 150 and 200 mbsf the log shows two zones of high susceptibility ($1–1.5 \times 10^{-3}$ G/Oe). The upper zone can be attributed to a 10-m-thick layer of magnetite-rich serpentinized peridotites. The lower high susceptibility zone is due to an increase in grain size of the titanomagnetites in a unit of massive basalts. The pillow basalts, which extend from 200 to 600 mbsf, show nearly uniform susceptibility with an average of 0.2×10^{-3} G/Oe. Some spikes in the deeper section of the log can be correlated with the abundance of fractures in the basalts indicating pyrrhotite or magnetite as a product of low temperature oxidation of sulfide grains as fracture-filling secondary minerals.

INTRODUCTION

The magnetic susceptibility log measured in drillholes is a relatively new method of obtaining information about the nature and content of magnetic minerals in deep rock formations. Prior to Leg 109, only two susceptibility logs had been conducted in ODP or DSDP drillholes: Hole 395A on Leg 78B was logged with a Russian tool (Ponomarev and Nechoroshkov, 1984) and Hole 418A on Leg 102 was logged with a USGS susceptibility probe (Salisbury, Scott, et al., 1986).

In ocean floor basalts the dominant magnetic mineral is titanomagnetite with various degrees of oxidation due to temperature and age. The magnetic susceptibility of the basalts is therefore mainly dependent on the volume concentration of the titanomagnetites. In special cases where the titanomagnetite grains have been altered by high temperature oxidation, an increase of the magnetic susceptibility due to titanium-free magnetite is observed. However, as shown by Day et al. (1977), there is also a strong dependency of the magnetic susceptibility on the size of the titanomagnetite grains. Therefore, the magnetic susceptibility gives indications to distinguish coarse grained basalts (massive flows with low cooling rate) from fine grained basalts (pillows with high cooling rate). A comparison of the rock-magnetic and microscopic properties obtained by laboratory measurements on core samples (Johnson, 1979a, b; Eisenach 1979) should elucidate the reasons of some interesting features in the susceptibility log.

Also, the overall variation of the magnetic susceptibility with depth provides information about the abundance of magnetic minerals like pure magnetite or pyrrhotite in different rock formations. The magnetic susceptibility measurement can therefore be used to identify lithologic boundaries due to different specific susceptibilities and concentrations of these magnetic minerals.

DESCRIPTION OF THE SUSCEPTIBILITY TOOL

As there exist various tools for measuring the magnetic susceptibility in drillholes, it is important to describe the principle of the measurement of the tool used during Leg 109. The magnetic susceptibility probe developed in the Institute of Applied Geophysics (University of Munich) is similar to an induction logging tool. The sensor consists of three vertically oriented coils at the bottom part of the device placed inside a nonconductive and nonmagnetic pressure barrel (Fig. 1). This housing is made of a pressure resistant ceramic tube surrounded by a elastomeric layer of silicon rubber for shock absorption and a fiberglass reinforced epoxy resin against water invasion under high pressure. The spacing between transmitter coil and receiver coil is 40 cm.

The lower coil is the transmitter coil producing an alternating magnetic field with a frequency of 1000 Hz. In a second coil wound on the transmitter coil, a voltage, which is not influenced by the electromagnetic properties of the surrounding medium, is induced. This voltage is used to compensate that part of the receiver coil voltage induced in free air corresponding to the magnetic permeability μ_0 (susceptibility = 0). The reduced voltage is preamplified by a factor of 1000 and bandpass-filtered to decrease induced noise and to suppress higher harmonics of the main frequency of 1000 Hz.

Two phase sensitive detectors, with 90° phaseshift between them, convert the amplified receiver signal to two DC voltages. The in-phase part of the signal is proportional to the electrical conductivity and the quadrature part of the signal is proportional to the magnetic susceptibility of the surrounding material. There is, however, also a small dependency of the susceptibility signal on the conductivity because of the skin-effect in highly conducting media. Recording both voltages, the in-phase and the quadrature part, permits a correction for the susceptibility in the case of highly conductive surrounding material.

BOREHOLE CONDITIONS

As the induced voltage in the receiver coil also depends on the geometry of the surrounding material, it is very important to know the diameter of the borehole. Hole 395A was drilled on Leg 45 between 9 December 1975 and 9 January 1976 in 7.2 Ma crust. It was cored with a 9 7/8-in. bit (25 cm) from a depth of 4579 to 5149 m. The average borehole diameter, however, is approximately 30 cm (Melson, Rabinowitz, et al., 1979).

From caliper measurements in Hole 395A on Leg 78B it can be seen that the diameter varies between 28 and 48 cm (maximum tension of the caliper tool) with cave-ins and washouts over lengths of more than 10 m. These cavings

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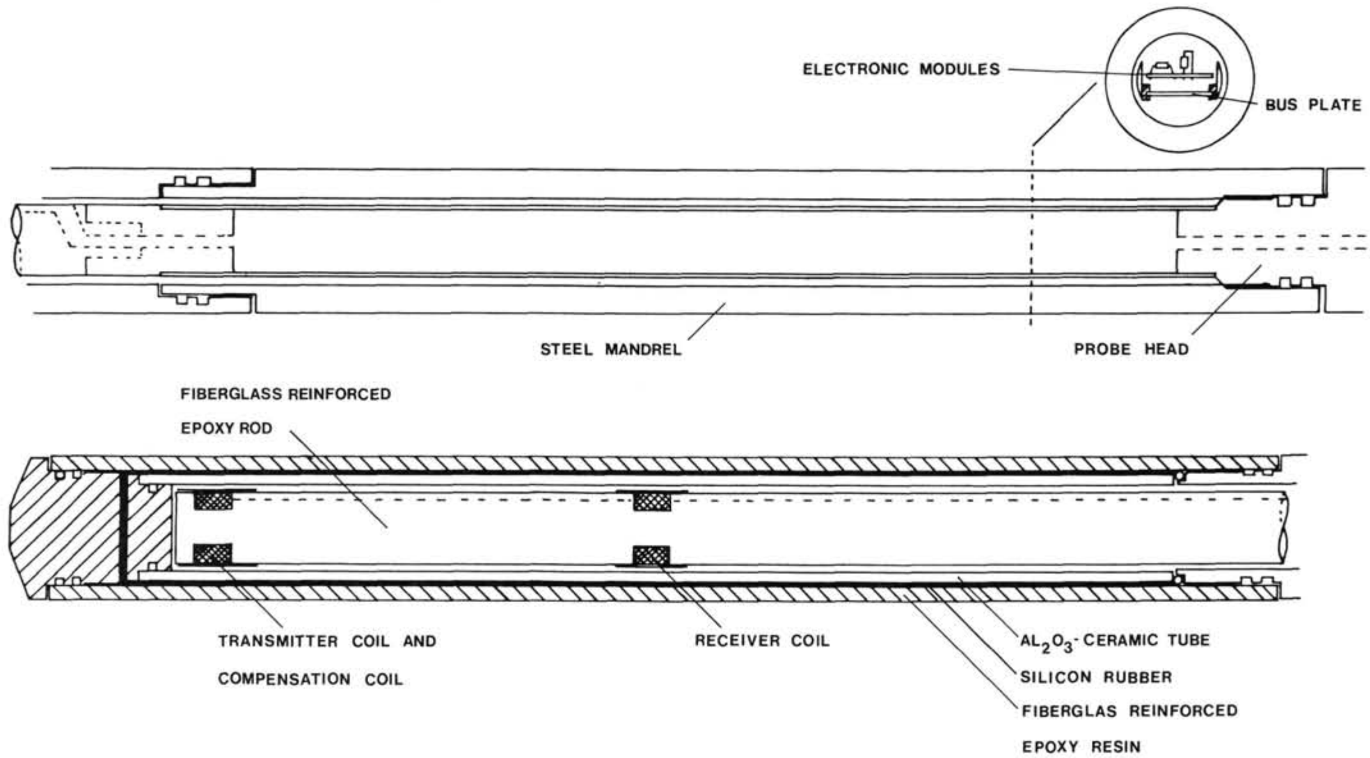

Figure 1. Electronic unit and sensor part of the magnetic susceptibility tool.

falsify the susceptibility log in two ways. In sections with larger diameters, the signal proportional to the susceptibility normally will be decreased. But when there is a highly conductive fluid in the hole, the signal will be increased in sections of larger diameters because of an increase of the higher conductive fluid around the probe. In boreholes like 395A with salt water of conductivity 4 S/m, the apparent susceptibility must be corrected by subtracting a part proportional to the conductivity from the recorded susceptibility values.

LOG EVALUATION AND CORRECTIONS

The susceptibility log was conducted on 7 June and lasted 10 hr including the runs through the drill pipe. The logging speed was 10 m/min running down the hole and 5 m/min while pulling up. The susceptibility and conductivity signals were digitized every 10 cm. The depth indicated by the winch counter has to be corrected by the actual depth of the casing shoe which caused the full scale change in the susceptibility at the top of the log (Fig. 2). The depth correction for the upward measurement was −31 m.

The influence of the highly conductive borehole fluid on the apparent susceptibility was reduced by subtracting a fraction of the recorded conductivity signal from the susceptibility log. Also an offset correction was necessary because the warm-up time before the first zero control on board was too short. After the log run a second zero control shows this offset. For the caliper correction an average borehole diameter of 30 cm has been assumed.

DISCUSSION

Figure 2 shows the susceptibility log smoothed by a running average of 50-cm length, the lithostratigraphy as determined from the recovered cores (Natland, 1979), and the magnetic susceptibility measured on discrete core samples (H. P. Johnson, pers. comm., 1986). The two susceptibility measurements correlate well in amplitude and depth. The massive basalt Unit 4 and the breccia zone between 340 and 350 mbsf can be easily recognized in both drawings. In contrast, below 500 mbsf there are some differences between the two measurements, which cannot be explained until now.

The average susceptibility for the pillow basalts between 200 and 600 mbsf deduced from the log is 0.2×10^{-3} G/Oe. The core samples of this interval have an average susceptibility of 0.17×10^{-3} G/Oe, which is the same value found by Lowrie et al. (1973) for basalts obtained from various DSDP holes in the Atlantic Ocean. With exception of stratigraphic Units 3 and 4 in the depth of 120–200 mbsf, the susceptibility log shows very uniform character. From 200 to 600 mbsf the borehole is drilled through fine grained pillow basalts. The uniformity of the log and the relative small average susceptibility value can be explained by the small grain sizes of the titanomagnetites in these pillow basalts, which range from smaller than 1 μm to 20 μm (Fig. 3).

With increasing depth more spikes can be seen in the log. From 470 to 600 mbsf there is a high abundance of spikes which may be attributed to an increase of the abundance of rocks containing fractures filled with secondary magnetic minerals (Natland, 1979). This suggestion is strengthened by the results of the temperature gradient log (Shipboard Scientific Party, 1988; Kopietz et al., this volume) which gives indications for water circulation systems at the depths of 430 and 470 mbsf where large changes of the temperature gradient can be correlated with spikes in the susceptibility log. Pyrrhotite, which has high magnetic susceptibility, may be present as a product of hydrothermal alteration in these fractures and could be the reason for the spikes. An increase of sulfide mineralization is also indicated by some maxima (475 and 545 mbsf) of the sulfur concentration log (CSUL) measured with the Schlumberger GST/ACT/NGT tool (Shipboard Scientific

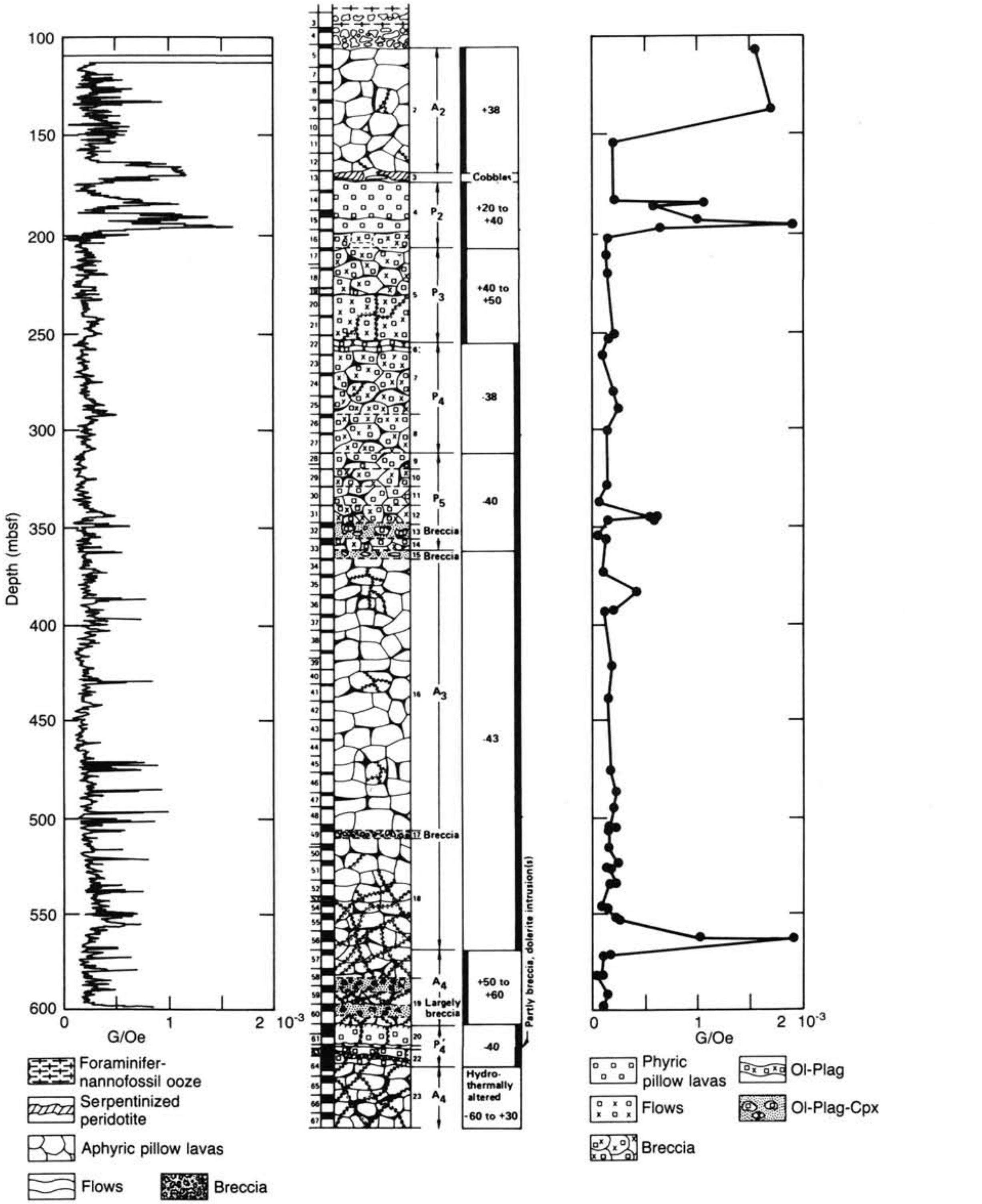

Figure 2. Magnetic susceptibility log, stratigraphy, and susceptibility measured on core samples of Hole 395A.

Party, 1988). Pure magnetite as a product of low temperature oxidation of the sulfide grains could be also a fracture-filling secondary mineral (Johnson, 1979b).

The maximum in the susceptibility log between 163 and 173 mbsf is caused by a layer with nearly homogeneous susceptibility of 1.1×10^{-3} G/Oe. This layer consists of serpentinized peridotites with titanium-free magnetite as dominant magnetic mineral indicated in the stratigraphy by Unit 3. From this interpretation, it follows that the thickness of the Unit 3 is much larger as indicated in the lithostratigraphy of Hole 395A. This would be supported by the lithostratigraphy of Hole 395 (Natland, 1979), because the plutonic complex there has a thickness of 10 m. Another argument for the serpentinized peridotites is the extremely low core recovery of 1% for this

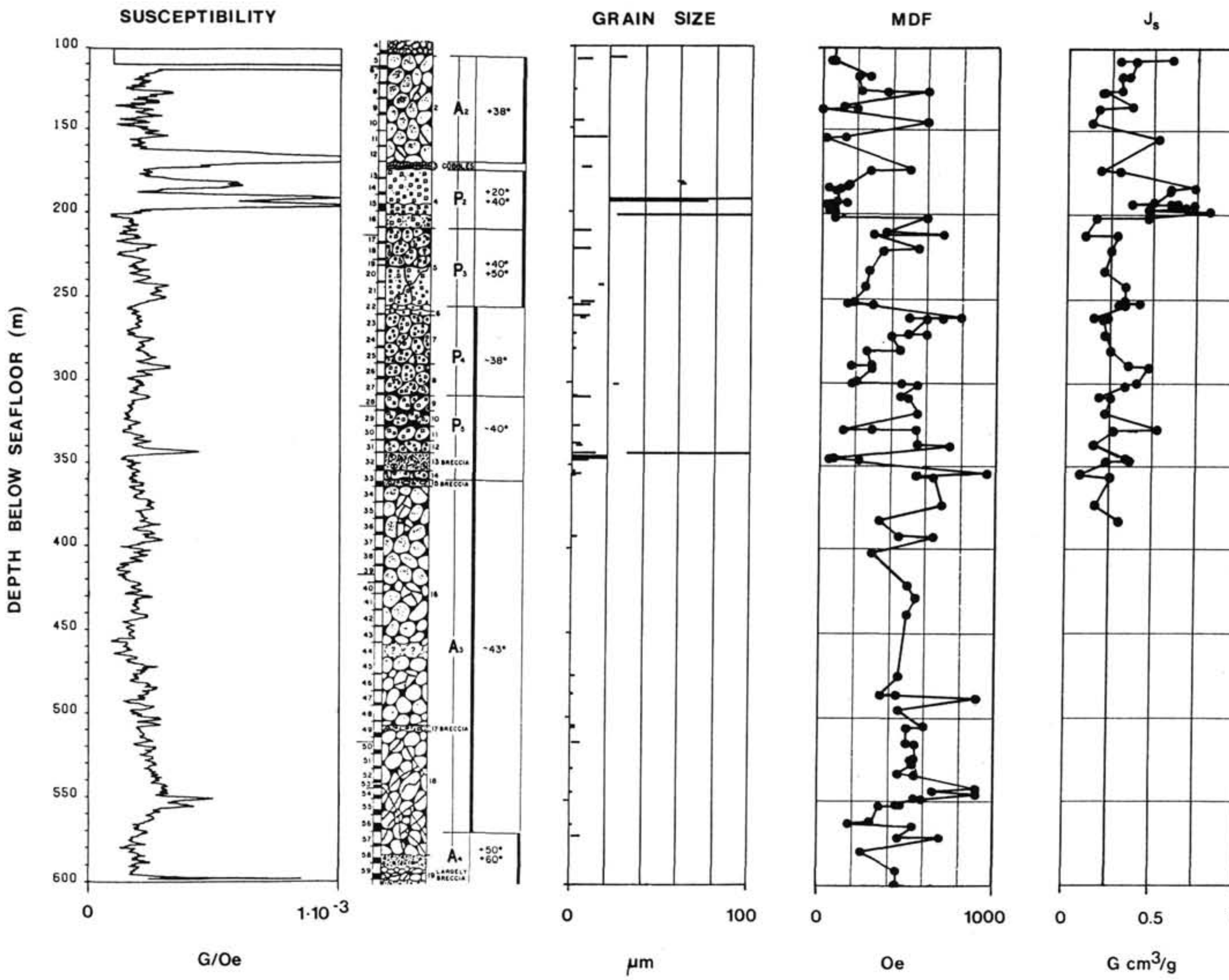

Figure 3. Magnetic susceptibility log in comparison with grain size of the titanomagnetites, median demagnetizing field (MDF), and saturation magnetization (J_s) measured on core samples.

zone. For comparison, the core recovery of the next high susceptibility zone (Unit 4), where massive basalts were drilled, was 32%.

The maximum values of the susceptibility log between 180 and 200 mbsf can be attributed to a coarser grained massive flow unit. Figure 3 shows the susceptibility log smoothed by a running average of 2 m, the grain size of the titanomagnetites (Johnson, 1979b; Eisenach, 1979), the median demagnetizing field MDF, and the saturation magnetization J_s (Johnson 1979a) for core samples recovered throughout Hole 395A. With exception of the breccia zone (Unit 13) between 340 and 350 mbsf, the grain sizes of the titanomagnetites of this massive basalts are larger than 25 μm with grains up to 100 μm and more. This is in good agreement with the small values of the MDF in the depth of 180–200 mbsf indicating also larger grains, as magnetic particles become softer magnetically with increasing grain size. From measurements on samples with synthetic titanomagnetites of various grain sizes (Day et al., 1976) and with the assumption, that there is no difference in the concentration of titanomagnetites, the increase of the susceptibility can be estimated from the increase of the grain size compared to that of the pillows. Based on the change of the grain size from 5 to 100 μm given by Johnson (1979b) and Eisenach (1979), the susceptibility should increase approximately by a factor of 4. This results in a maximum susceptibility of $0.8–1.0 \times 10^{-3}$ G/Oe which is in good agreement with most of the maxima in the log. The saturation magnetization (Fig. 2) shows a similar relation. As the saturation magnetization depends mainly on the concentration, the higher values between 180 and 200 mbsf probably relate to a volume concentration of titanomagnetites two to three times higher in the massive basalts than in the pillows. The possibility of pure magnetite as a reason for the high susceptibility can be excluded by the Curie temperature, which is below 200°C for this zone (Johnson, 1979a).

Comparing the susceptibility log and the measured median demagnetizing field (MDF), further small relative susceptibility maxima which correlate with minima of the MDF can be pointed out (250 m, 290–300 m, 340–350 m, and 550–560 m). In these zones also the larger grains of the titanomagnetites cause an increase in susceptibility as can be shown by the grain size of the basalt breccias at depths between 340 and 350 mbsf.

Comparing our log with the results of Leg 78B (Ponomarev and Nechoroshkov, 1984) there are some differences. The average susceptibility value for the pillow basalts measured by the Russian scientists is approximately 1.10^{-3} G/Oe. This is a much higher value than the average susceptibility measured with our tool. The maximum values (Unit 3 and 4) are in a comparable order of magnitude. However, there is a zone of high susceptibility between 415 and 460 mbsf where values of 1.8×10^{-3} G/Oe were measured by the Russian scientists and interpreted as a change of the mineralogy. In our uncorrected susceptibility log, a broad bulge with the apparent susceptibility of 1.5×10^{-3} G/Oe also has been recorded in this depth range. This bulge was interpreted as being caused by the influence of a zone of higher conductivity, because a large and deep washout is visible in the caliper log in this depth interval (Mathews et al., 1984). After the conductivity correction, the bulge in the susceptibility log disappears and a slight minimum (410–420 m) indicates the larger borehole diameter in this region.

CONCLUSION

Since the tool used on Leg 109 to measure the magnetic susceptibility is newly developed, it has to be tested in various boreholes. Logging in Hole 395A reveals the difficulties which arise when the tool has is run under extreme conditions. Large variations in the diameter and highly conductive borehole fluid cause an error in the susceptibility log which can be misinterpreted.

The susceptibility log measured in Hole 395A shows a clear dependency on the grain size of the titanomagnetites in the basalts. Coarser grained massive basalts can be easily distinguished from the fine grained pillows in the log. Compared to the massive basalts, the serpentinized peridotites (163–173 mbsf) also have high but more homogeneous susceptibility. The upper and lower boundaries of this stratigraphic unit are clearly defined in the susceptibility log and allow us to give an exact depth and thickness of the peridotite layer, which is in better agreement with the stratigraphy of Hole 395.

The spikes in the magnetic susceptibility log correlate with an increase of the fractures in the lower part of the borehole. The presence of pyrrhotite and pure magnetite as a fracture-filling secondary mineral might be an explanation for the observed increase in susceptibility. However, there was no remark in the description of the mineralogy which supports this assumption. But the temperature logs measured on Leg 109 confirm the existence of water circulating systems in this zones where susceptibility spikes occur, indicating hydrothermal alteration as a possible reason for the abundance of sulfides and magnetite.

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