THE SUSCEPTIBILITY PROBE SUSLOG 403-1

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Zusammenfassung

Die Suszeptibilitäs-Bohrlochsonde SUSLOG 403-1 (400 mm Abstand zwischen Sende- und Empfangsspule, 3 Spulen, Typ 1) ist die 120 °C-Version der zukünftigen Hochtemperatur-Suszeptibilitätssonde, die in der Kontinentalen Tiefbohrung (KTB) eingesetzt werden soll. Sie wurde mit im Vergleich zu Hochtemperatur-Bauteilen billigen elektronischen Schaltungen und Werkstoffen gebaut, um frühzeitig Erfahrungen in der Messung der magnetischen Suszeptibilität zu gewinnen und auftretende Probleme im Hinblick auf die Hochtemperatur-Version zu lösen. Ihre maximale Einsatztemperatur wird durch die Elektronik auf 120 °C begrenzt. Das Sondengehäuse wurde in der Druckkammer bis 75 MPa (750 bar) getestet.

Durch Messungen in einem Eichbohrloch und in verschiedenen anderen Bohrungen konnten anfängliche Mängel erkannt und behoben werden. Aus Vergleichsmessungen mit der Slimhole-Suszeptibilitätssonde GM250 (Geofizica Brno, Tschechoslowakei) konnte die Empfindlichkeit und der Meßbereich ermittelt werden.

Abstract

The susceptibility tool SUSLOG 403-1 (400 mm spacing between transmitter and receiver coil, 3 coils, first version) is the 120 °C prototype of a high-temperature probe, which will be developed for the Continental Drilling Program (KTB) of the Federal Republic of Germany. It was constructed to gain experiences with the measurement of the magnetic susceptibility in boreholes and to solve the problems which could arise in the development of the high temperature version. The maximum temperature of the tool is limited to 120 °C by the use of electronic components with military specifications. The housing of the probe has been tested in a pressure chamber up to 75 MPa (750 bar).

With the aid of measurements in a calibration pit and in various drillholes deficiencies could be recognized and several improvements of the tool were possible. In comparing the measurements with those of the calibrated slim hole tool GM250 (Geofizica Brno, Czechoslovakia) the resolution and the response characteristics could be deduced.

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1 The principles of the measurement and the construction of the tool

The susceptibility probe is similar to an induction log probe used for measuring the electrical conductivity. The sensor consists of two vertically oriented coils in the bottom part of the probe placed inside a thick walled non-conductive and non-magnetic pressure barrel (Figure 1). This housing of the sensor is made of a pressure resistant ceramic tube surrounded by an elastomere layer of silicon rubber for shock absorption and a glassfibre reinforced epoxy resin against water invasion under high pressure. The housing has been tested in a pressure chamber up to 75 MPa (750 bar) without any failure. For drillholes to a depth of 2000 m a pressure barrel of pure glassfibre reinforced epoxy resin can be used which sustaines pressures up to 30 MPa (300 bar).

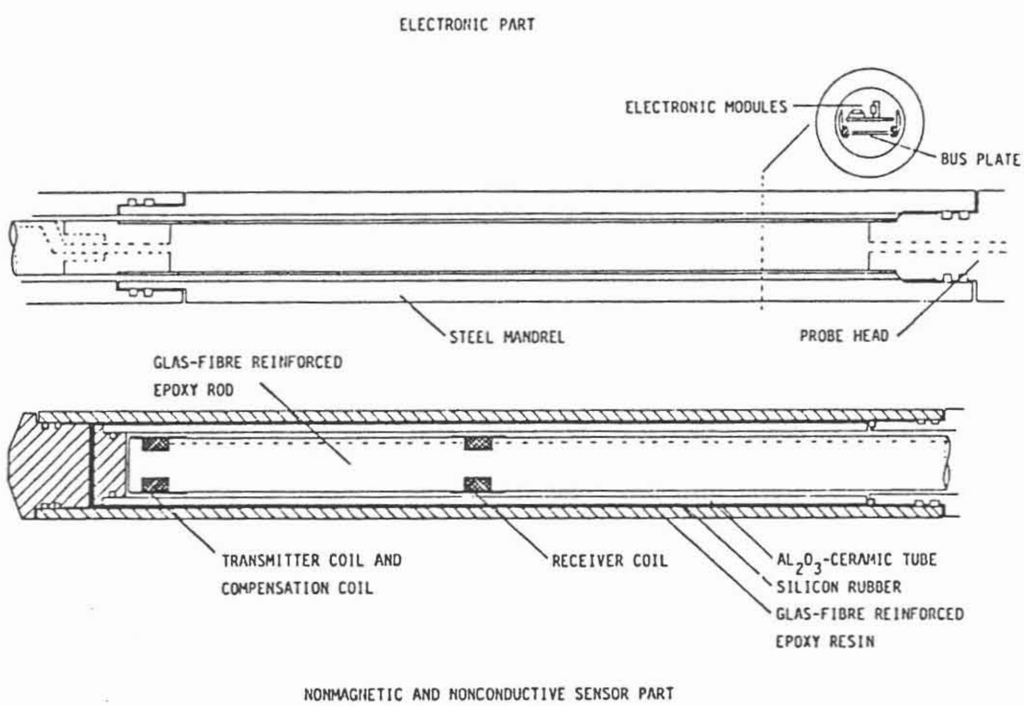

Figure 1: Electronic unit and sensor part of the magnetic susceptibility probe SUSLOG 403-1.

The lower coil (Fig. 1) is the transmitter coil producing an alternating magnetic dipole field with a frequency of 1000 Hz. In a second coil wound on the transmitter coil a voltage is induced, which is not influenced by the electromagnetic properties of the surrounding medium. This voltage is used to compensate that part of the voltage in the receiver coil which is induced in free air corresponding to the magnetic permeability μ_0 (susceptibility=0). The compensation circuit is that part of the electronic circuits determining mainly the the temperatur drifting of the sensor. To maintain stability over the whole range, it is necessary to keep the drifting below 0.02 µV/°C.

The distance between transmitter and receiver coil of 0.4 m is twice of that of the slim-hole tool GM250 which is used for calibration. The reason for this choice is the smaller calibre correction due to the larger response volume of the tool with the longer spacing. From measurements and also from theoretical calculations one can estimate that 80% of the susceptibility-proportional signal is generated within a diameter equal to the transmitter receiver distance.

The electronic is placed in the top part of the tool, consisting of modules connected to a 10-conductor bus plate for easyly exchange. The electronic units are developed considering the high temperature version in which only electronic parts, specified to a working temeperature up to 200 °C, will be used.

In Figure 2 the electronic blocks of the probe are shown. The quadrature oscillator produces two voltages with 90° phase shift. The inphase voltage drives the output amplifier which supplies the transmitter coil, and it is also used to trigger the inphase detector. The dipolemoment of the magnetic AC-field is approximately 0.01 Am^2. The quadrature detector is triggered by the 90° phase shifted voltage.

After eliminating the free air response in the receiver coil by the compensation circuit, the receiver voltage is preamplified

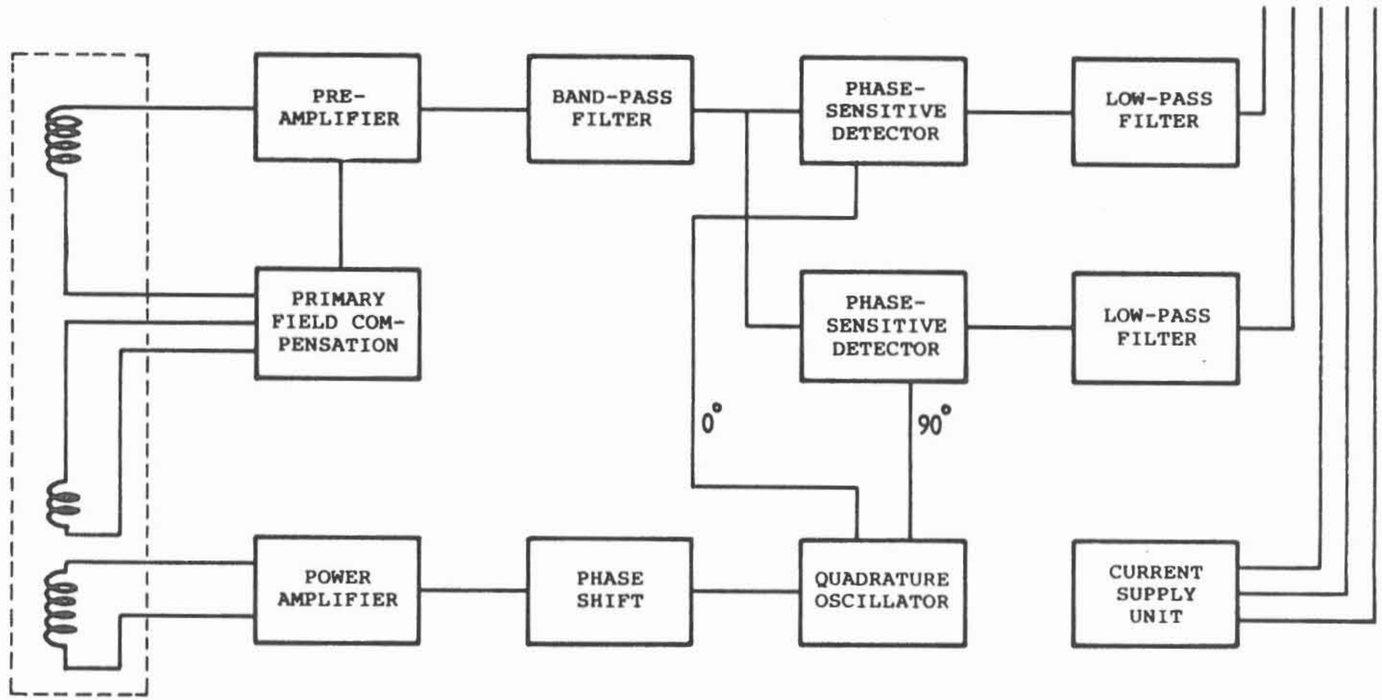

Figure 2: Electronic blocks of the susceptibility tool SUSLOG 403-1.

by a factor of 1000 and bandpass filtered to decrease induced noise and to suppress higher harmonics of the main frequency 1000 Hz.

The outputs of the two phase sensitive detectors are, in a first approximation, proportional to the magnetic susceptibility and the electric conductivity of the surrounding material. There is, however, also a small dependency of the susceptibility signal on the conductivity and vice versa. Recording both voltages, the inphase and the quadrature part, permits a correction for the susceptibility in the case of highly conductive surrounding material. But there is also additional information in the conductivity signal which can be used for better characterising of the drilled rocks.

Table 1: Specifications of the susceptibility probe Suslog 403-1.

Measuring range for susceptibility.........	$2 \cdot 10^{-5}$ to 0.2 SI
Measuring range for conductivity (appr.)...	0.01 to 10 S/m
Output voltage on both channels...........	0 to 10 V D.C.
Coil spacing	400 mm
Operating frequency.......................	ca. 1000 Hz
Measuring velocity........................	0.3 to 0.5 m/s
Power supply..............................	50 V D.C., 100 mA
Number of cores of the logging cable.......	Minimum 5
Length....................................	2 m
Outer diameter............................	75 mm
Maximum temperature.......................	125 °C
Maximum pressure..........................	75 MPa (750 bar)

2 Necessary corrections

Beside the conductivity correction described above the most important correction is that for the influence of the borehole calibre. The recorded apparent susceptibility has to be multiplied by a factor which depends on the borehole diameter and on the diameter of the casing (only in the case of an insulating casing) to obtain the true susceptibility value.

The correction chart (Fig. 3) shows the dependency of this factor on the borehole diameter, deduced from measurements in a calibration and test pit. There are also curves for certain stand-offs of the probe from the borehole wall (difference between the diameters of the casing and of the borehole). The probe measuring in the centralized position (casing diameter 60 mm)has the highest correction factors, while measuring along the borehole wall demands smaller diameter corrections which seem to reach a constant value with increasing borehole calibre. Therefore the susceptibility probe has no centralizing devices.

Comparing the correction curves of the two tools GM250 and SUSLOG it is obvious that the tool with the smaller spacing has higher diameter corrections. As the probe SUSLOG is developed for deep drillholes (5 km or more) with large calibres, the longer spacing of 0.4 m has advantages: Beside the smaller diameter corrections the tool is also less sensitive to changings in the borehole calibre as break-outs or wash-outs. As with increasing spacing, the induced voltage in the receiver coil decreases proportional to L^{-3} (L = spacing) difficulties may arise with signal to noise ratio and with temperature drifting when the spacing is enlarged too much.

The larger diameter of the response volume of the SUSLOG tool is also advantageous for the conductivity measurements. The response volume of the conductivity signal however is small compared to usual induction log tools and the conductivity measurements with SUSLOG contain probably more information about the resistivity of the invaded zone than of the undisturbed rocks.

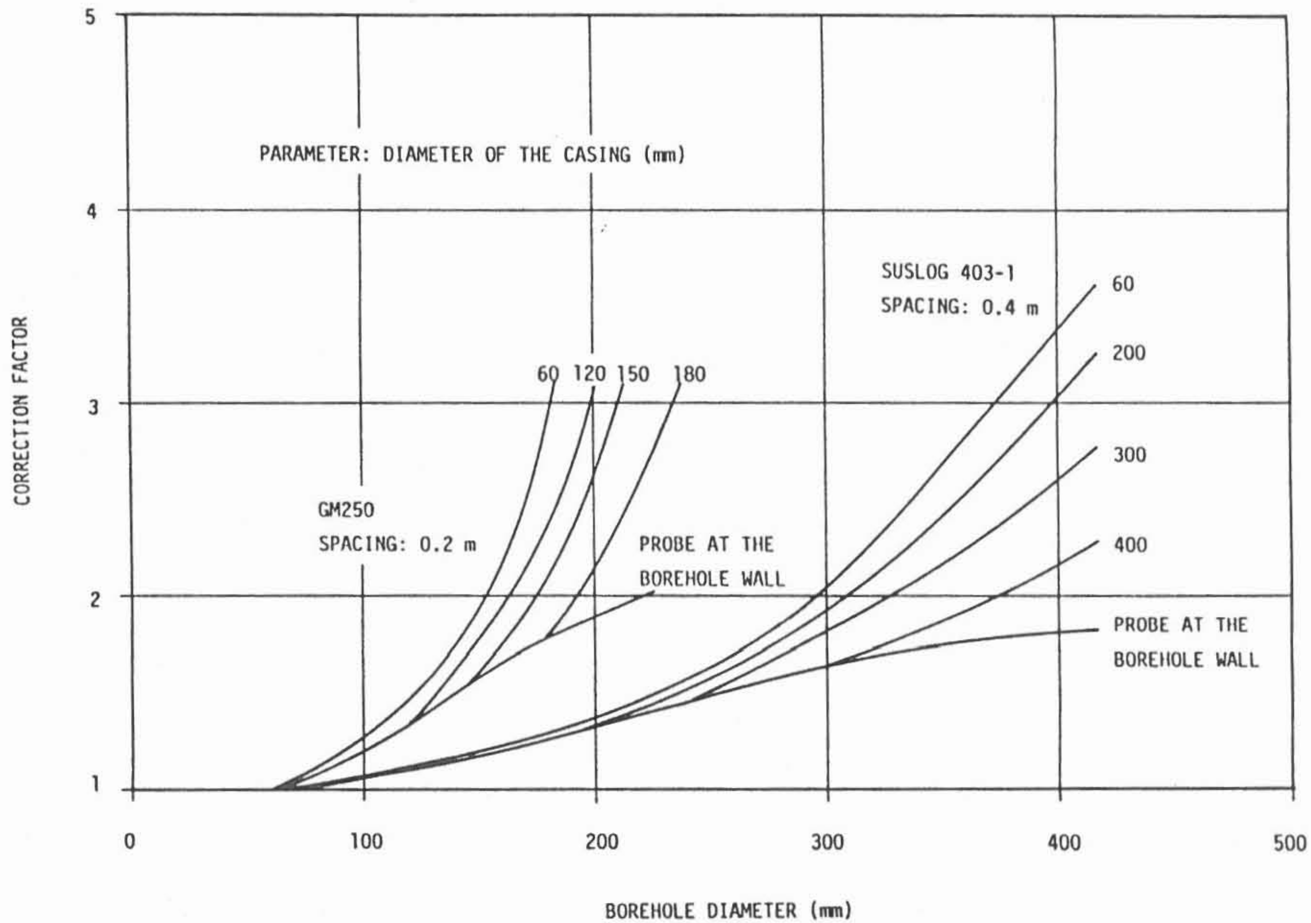

Figure 3: Borehole diameter correction curves for the susceptibility tools GM250 and SUSLOG 403-1.

3 Susceptibility logs of the borehole Griesbach

Within the geothermal preresearch of the KTB location many boreholes have been drilled which could be used for testing the tools. From the comparison of the logs measured with the two tools GM250 and SUSLOG the sensitivity, temperature drift and other tool characteristics could be deduced. For example the logs measured with the tools GM250 and SUSLOG in the borehole Griesbach (Oberpfalz) in October 1986 are shown in Fig. 4. The susceptibility values measured on the drill cores with a hand held device are also drawn in form of a log, to test the absolute resolution of the tools. Both logs are calibre corrected and for the SUSLOG log the elimination of a small temperature drift was necessary. This temperature drifting of the probe has been minimized in the meantime and also the resolution has been improved by a factor of 7. The specifications in Table 1 represent the status of January 1987.

The differences between the two logs can be explained by the different probe characteristics. But it is also possible, that the tools did not measure along the same track at the borehole wall, resulting in different amplitudes of the peak values. Comparing the logs with the core measurements in the zones of smooth and relatively constant susceptibility (110 - 170 m), the values correlate well (0.8 - $1.0 \cdot 10^{-3}$ SI). Similar susceptibilities for the gneisses were obtained from other preresearch boreholes in the Oberpfalz (Püllersreuth $0.5 \cdot 10^{-3}$ SI, Poppenreuth 0.5 - $1.0 \cdot 10^{-3}$ SI).

In the zones of high susceptibility the distribution of the ferrimagnetic minerals is not as homogeneous as it seems from lithostratigraphy. The dominant ferrimagnetic mineral is pyrrhotit which is found together with nonferromagnetic pyrit bounded on fracture systems (70 - 75 m, 145 - 147 m, 172 - 180 m), but

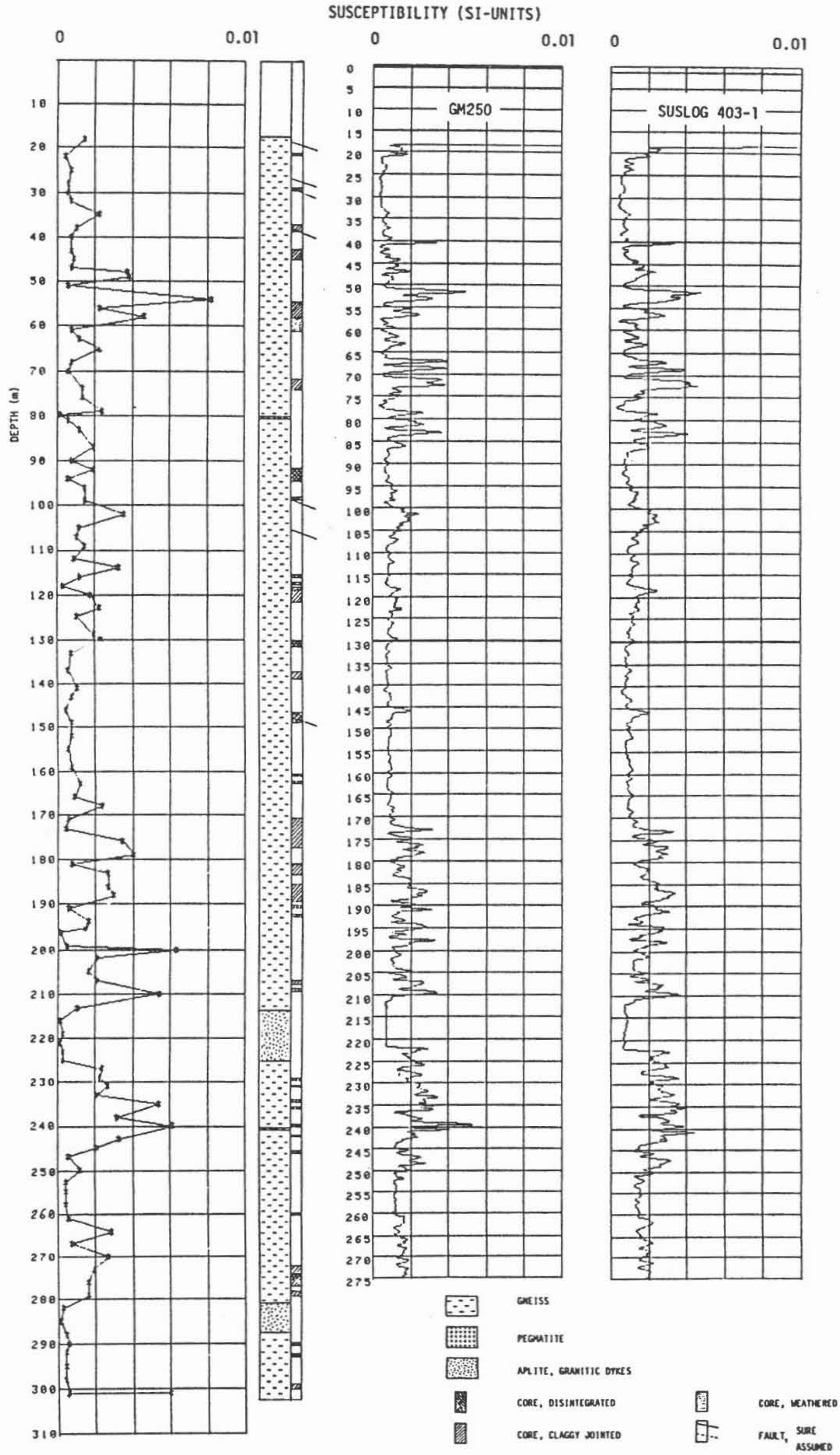

Figure 4: Susceptibility measured on cores (left) with lithostratigraphy (Burkhardt et al. 1987) and susceptibility logs measured with the tools GM250 (middle) and SUSLOG 403-1 (right) of the borehole Griesbach (Oberpfalz).

also appears fine disseminated within the gneisses. Laboratory investigations on core samples could not prove any vestige of magnetite (Wippern 1986).

Remarkably sharp is the appearance of the layer in the depth between 210 and 222 m (log depth) with fine grained granites which show up in the stratigraphy from the cores in the depth of 214 - 225 m (Burkhartd et al. 1987). Measurements in other boreholes show the same characteristic appearence of the granites in the susceptibility logs, easyly recognizable by their low and homogeneous susceptibility.

4 Further developments of the tool for the KTB

The test measurements in the preresearch boreholes of the KTB and also in Hole 395A of the Ocean Drilling Program (ODP) on Leg 109 have given a good proof of the functionality of the probe SUSLOG. Some problems and deficiencies which showed up in the tests have been eliminated or minimized. The influence of the temperature on the sensor for example has been decreased by heating experiments in the laboratory.

Similar to the probe SUSLOG a susceptibility tool will be developed for the extreme conditions in the KTB, using the same principle of measurement. The sensor is constructed in the same way with a difference in the material used for the coil carrier, which will be made of ceramic. The maximum temperature for the electronic part will be 200 °C. For measurements in boreholes with higher temperatures a heat shield, consisting of a dewar flask with integrated heat sink, limits the heating up of the electronic units for a certain time.

Also for the construction of the pressure barrel, especially for the sensor demanding non-magnetic and non-conductive material, the experiencies with the SUSLOG tool are of usefull help. Again a ceramic tube with high compressive strength together with high temperature plastic for shock absorption is scheduled for the sensor housing. This version of the SUSLOG tool for ultradeep boreholes is planned to be specified to a maximum temperature of 300 °C and to a pressure up to 300 MPa (3000 bar).

Acknowledgements

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