THE THERMAL PROBE DEEP-DRILLING METHOD BY EGIG IN 1968 AT STATION JARL-JOSET, CENTRAL GREENLAND

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ABSTRACT

A special thermal probe deep-drilling method was used by Expédition Glaciologique Internationale au Groenland (EGIG) 1968. The wire for the transmission of the electric power and the measured values pays out of the probe and becomes fixed in the refreezing meltwater.

Two probes were constructed, each with a diameter of 10.8 cm and lengths of about 2.5 m (probe II) and 3 m (probe I). With the available maximum power of 3.7 kW the velocity was 2 m/hr.

The probes had sufficient wire for the penetration of the ice sheet (2500 m), but the breakdown of the main heater stopped probe I at a depth of 218 m and probe II at a depth of 1005 m. The ice temperatures recorded after cooling occurred were: -29.0°C at 218 m, -29.3°C at 615 m and -30.0°C at 1005 m depth. The method as such worked without significant problems.

Thermal probes of this type are relatively inexpensive (about $15,000), easy to handle (about 10 cm diameter, 200-300 cm length) and work fast (50-100 m/day or more). A small summer expedition could penetrate 4000 m of ice or more.

The summer 1968 campaign of EGIG (Expédition Glaciologique Internationale au Groenland) contained a German-Swiss thermal deep-drilling program at station Jarl-Joset (33°28′ W, 71°21′ N, 2865 m above sea level), where the ice thickness is 2500 m. Two penetrations were made with a thermal probe system which I originated (K. Philberth, 1962a, 1962b, 1962c, 1966a, 1966b, 1970), and then developed together with B.L. Hansen and H. Aamot (1967a, 1967b, 1968, 1970). Probe I corresponds closely to the drawings provided by H. Aamot, but probe II is different in some respects.

The probes were produced in Germany by the German-American Eastman International Company GmbH. The field work was done by the Benedictine Father H. Jännichen (physicist), E. Gmeineder (engineer) and me, in cooperation with five French technicians.

The characteristic feature of this type of probe is that the wire for the transmission of electric power and remote sensing pays out of the advancing probe and becomes fixed in the refreezing meltwater. The probes are thus not retrievable. It is no problem to supply sufficient wire and sufficient sidewall heating for the penetration of the thickest and coldest Antarctic ice layers. The sidewall heating can be supplied by the heat of the ohmic resistance of the stored wire.

Probe Specifications

Figure 1 shows the EGIG thermal probes I and II and the lower part of both. Probe I had an insulated and a bare wire, an oil reservoir which was attached in the field, and was 292 cm long (including reservoir) and 10.8 cm in diameter. Probe II had two insulated wires and no reservoir, and was 255 cm long and 10.8 cm in diameter.

The lower part of the probes contained the cartridge main heater, the mercury heat flux control for the stabilization of verticality (K. Philberth, 1964, 1966a), the pressure-protected box for the instrumentation and auxiliary heaters above and below it.

Figure 2 shows the upper parts of probes I and II. The sidewall around the bare-wire coil and of the oil reservoir of probe I contained a 100-ohm resistor wire for additional heating. The wire coils were "orthocyclic" (Lenders, 1962; Aamot, 1969). Each coil contained about 3150 m of copper wire, stored in 23 layers of 600 windings each (insulated wire) and 29 layers of 485 windings each (bare wire). The bare wire diameter of probe I was 0.090 cm, and the insulated wire was 0.095 cm (net) and 0.126 cm (gross). The insulation was Teflon-sealed Kapton tape.

Figures 3, 4, and 5 are the circuit diagrams of probes I and II and of the surface instrumentation for control and supervision, respectively. In the pressure-protected box are a 12-step relay, thermistors, a pair of strain gauges, a simple inclinometer, calibration resistors and diodes. Part of the surface instrumentation is the "Last-Brücke" (compare Fig. 9) for the continuous supervision of probe performance. It is a bridge designed by B. Philberth in which the complex impedance of the probe (L, R, C) is compensated, independent of the frequency, by a reciprocal network (c, r, l). The precision is in the order of 0.01 - 0.1 per cent; progress of less than 30 cm can be observed.

Performance

The cartridge heater of probe I experienced a short circuit at a depth of 218 m, that of probe II at a depth of 1005 m. The short circuit ended the run. The cause was probably moisture content of the insulation, resulting in electrolytic action and then failure.

Probe I measured a cooling curve for a 5-day period at a depth of 218 m, resulting in a virgin ice temperature T_j = -29.0°C. Probe II was stopped intentionally at a depth of 615 m, where a cooling curve for a 6.5-day period was measured, resulting in T_j = -29.3°C. At a depth of 1005 m the cooling curve of probe II was interrupted after 5.2 hours by wire breakage. T_j was determined to be -30.0°C. Figures 6 and 7 give the cooling curves. The changing power in probe I in the last 100 minutes (Fig. 6) caused an irregularity of its cooling curve in the first 300 minutes.

The depth of the probes was measured by four methods: inductance of the coil, time integration of the velocity, resistance of the length of the bare wire (probe I only), and hydrostatic pressure measured by strain gauges. The first two methods worked continuously. The inductance method made use of the harmonics (100, 300 cps) of the DC power supply: the values of c, r_w (AC resistance) and r_G (DC resistance) are read on the "Last-Brücke." They depend slightly on the value of l and are functions of the depth of the probe. Figure 8 shows these relations for the first section (50-615 m) of probe II, and Fig. 9 for the second section (615-1005 m).

The inclination of probe I for its total path and of probe II for the second section was always less than 4^o. However in the first section probe II reached an inclination up to 10^o (Fig. 8), probably because a piece of polyethylene had fallen into the hole and adhered to the sidewall of the probe.

Probe I (Fig. 10) was started at a depth of 7 m. Down to a depth of 35 m the firn absorbed the meltwater. Therefore the mean coil temperature T_{Wickel} (T_{coil}) reached 90^oC for a current J of 1.8 A. Later, for J equal to 2.7 A (corresponding to a total power N_{total} of 3.7 kW) and a velocity of 2.0 m/hr, the temperatures were as follows: less than 80^oC (mean value) for the coil, less than 55^oC for the thermistors, and about 300^oC for the Chromax wire in the cartridge heater. Probe II (Fig. 11) was started at a depth of 45 m and reached a current J of 2.3 A (corresponding to N_{total} = 3.7 kW) and a velocity of 1.9 m/hr. Under these conditions the temperatures were as follows: less than 80^oC (mean value) for the coils, less than 50^oC for the thermistors, and less than 250^oC for the Chromax wire. The level of the heavy interspace oil decreased quicker than expected.

The reheating process of probe II at a depth of 615 m is shown in Fig. 12. For about 30 hours only the coils were heated (Position 12); the heating current was increased until the temperature T_{Wickel} of the coils made it evident that the upper part of the probe had reached the melting point.

Glaciological Results

Extrapolation (K. Philberth, 1972; Philberth and Federer, 1971, 1973, 1974) of the measured temperatures (see above) yields a bottom temperature at this location of -12^oC. The difference between measured and calculated temperature profiles down to a depth of 600 m is about the same as the corresponding difference at Camp Century and can be explained by short-period changes of the climate. The Ice Age temperature is likely to have been by about 6^oC lower than today. The glaciological conditions would be favorable for the disposal of radioactive waste (B. Philberth, 1956, 1961; K. Philberth, 1976a, 1976b).

Suggestions

Low-voltage heaters are more reliable than high-voltage heaters. The probe could be equipped with a semiconductor DC/AC-converter and a small transformer, changing the high voltage DC power supply into low voltage AC with e.g. 1000 cps. Instead of the heavy oil an antifreeze solution could be applied, which is trapped in the probe and gets mixed with the penetrating meltwater. The destructive effect of unmixed meltwater inside the coil could be reduced by a very small auxiliary heater at the top. There is no meltwater penetration problem at all if the coil (with coaxial or double wire) is stored outside the (slender) cylinder of the probe; the wire of the coil could be stabilized by a semi-adhesive surface and taken off from "over-head."

For the stabilization of the verticality various other methods could be applied: controlled on-off-switching of heaters, flat bottom (K. Philberth, 1964, 1966a), pendulum method (Aamot, 1970), eccentric gravity center of the probe with more bottom heating at the side where the center of gravity is located, sharp fins at the upper end of the probe (B. Philberth).

Instead of two wires, one coaxial or multiaxial cable could be applied, if this is sufficiently reliable. After accidental wire break or wire short-circuit (coaxial cable), at least temperature measurements should be guaranteed for some days, e.g. by wireless or by "semi-wireless" transmission. The latter means transmission by frequency-modulated pulses, which can jump over wire interruption by virtue of its capacity.

A detailed report on the EGIG drilling and suggestions for improvement of probes is in press (K. Philberth, in press).

Acknowledgments

Excellent advice and cooperation were provided by B.L. Hansen and H. Aamot of the U.S. Army Cold Regions Research and Engineering Laboratory. The work was supported by the Deutsche Forschungsgemeinschaft and by the Swiss Federal Institute for Snow and Avalanche Research.

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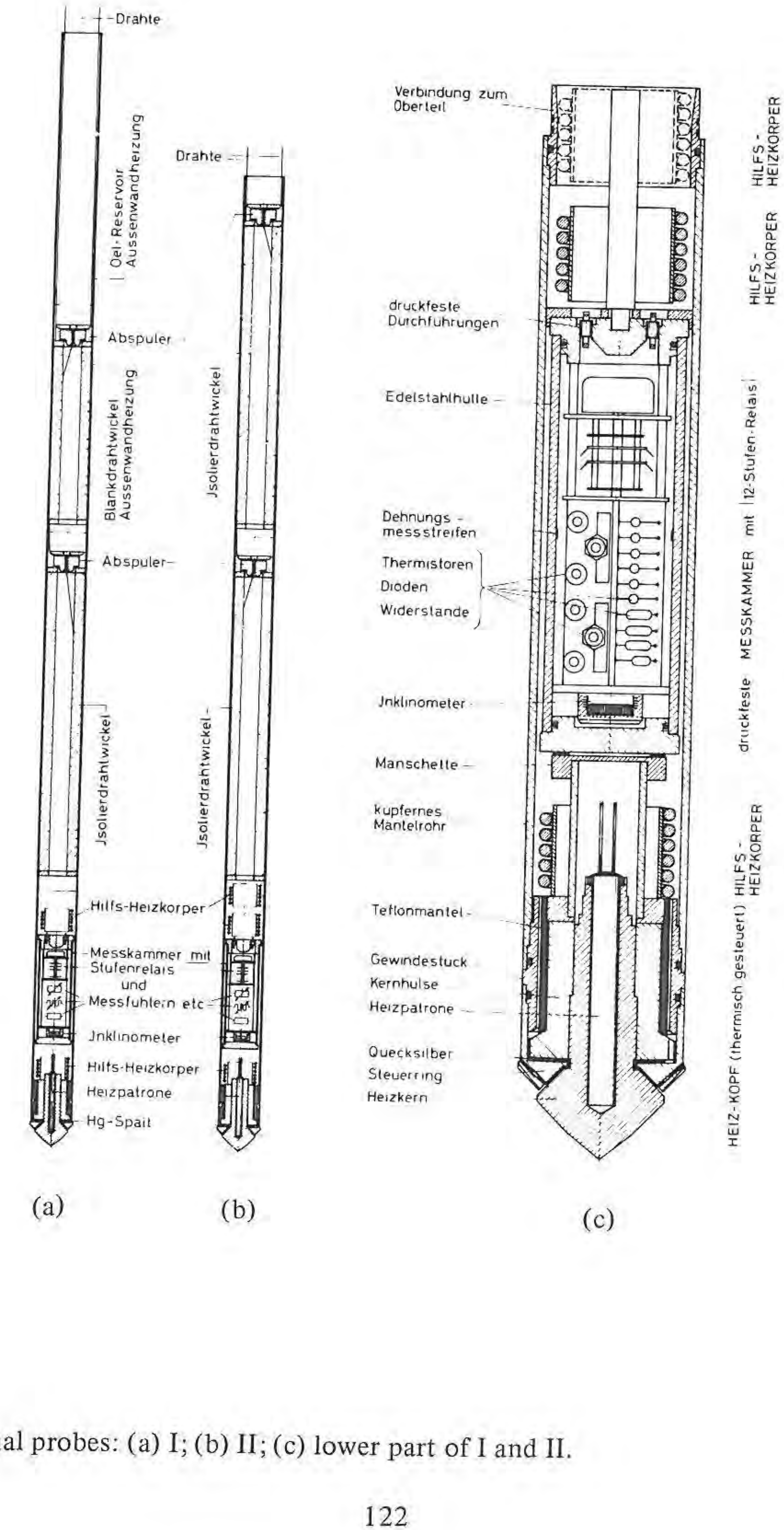

Figure 1. Thermal probes: (a) I; (b) II; (c) lower part of I and II.

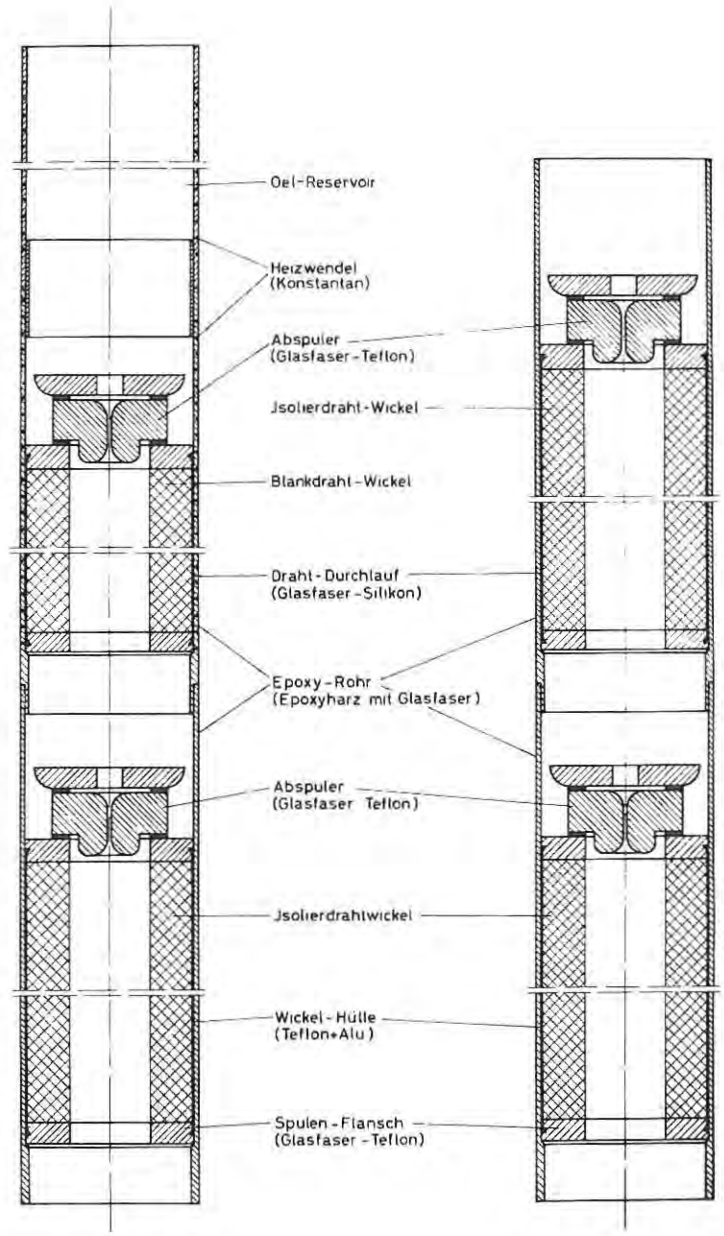

Figure 2. Upper parts of probes I (left) and II (right).

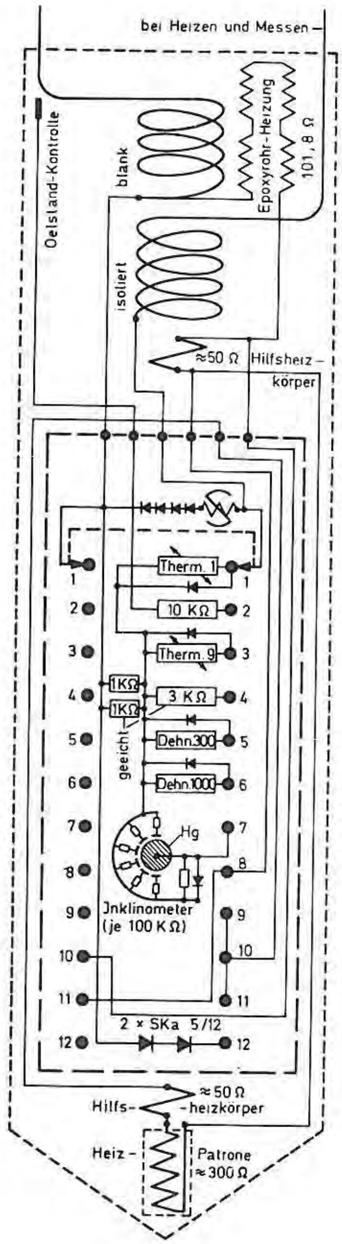

Figure 3. Circuit diagram for probe I.

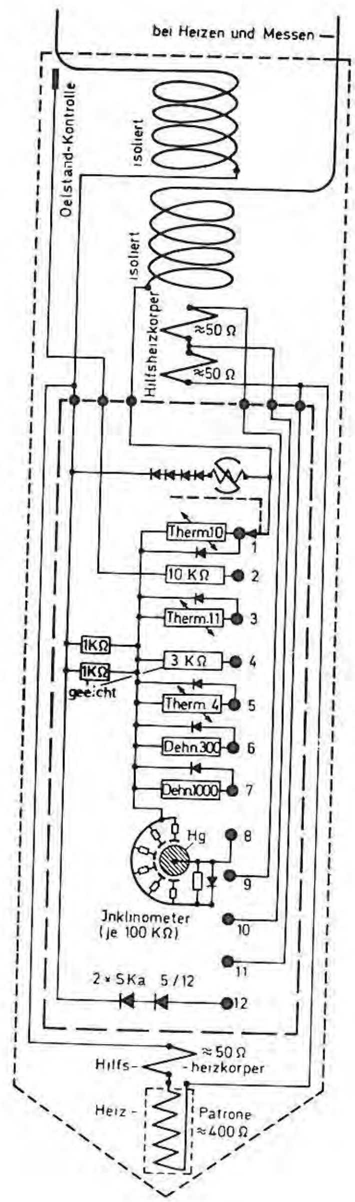

Figure 4. Circuit diagram for probe II.

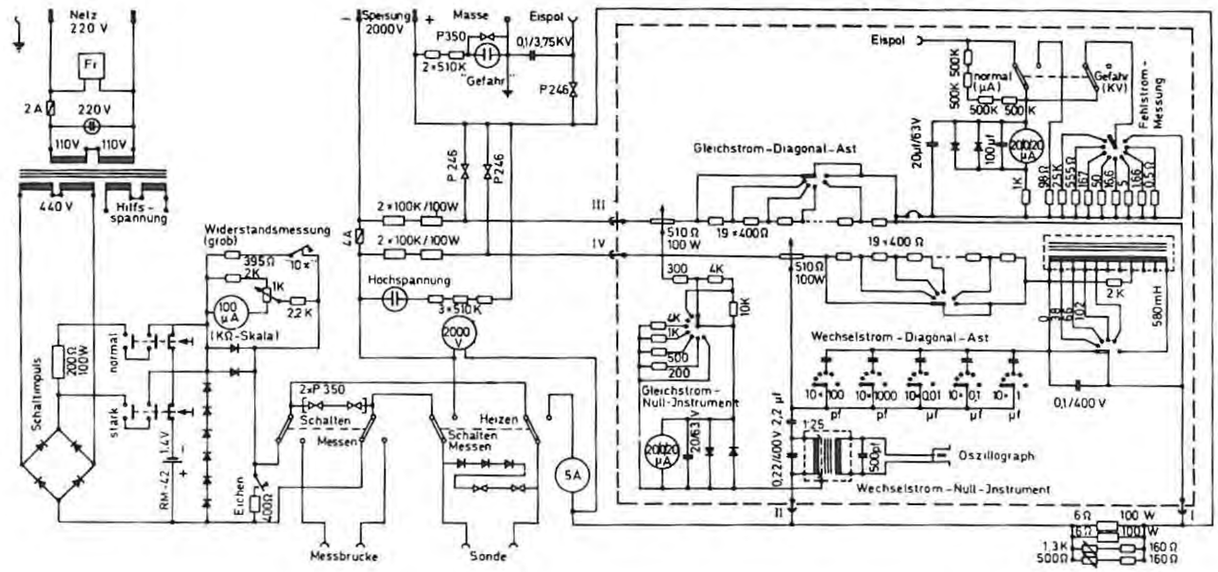

Figure 5. Surface instrumentation for control and supervision of the system.

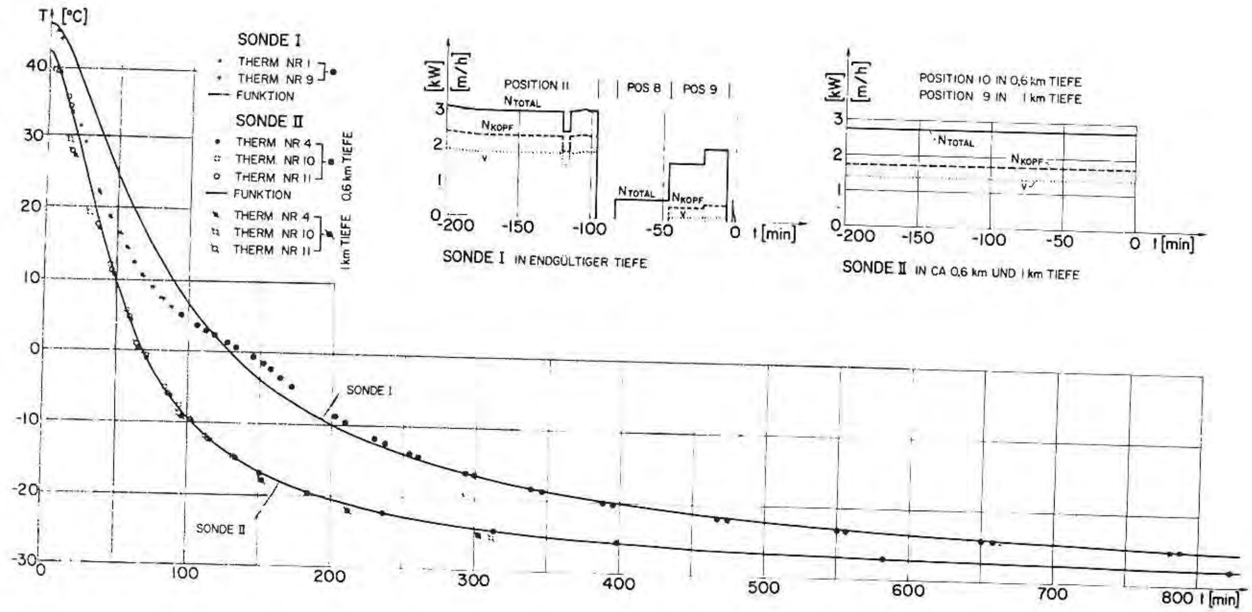

Figure 6. Cooling curves for probes I and II.

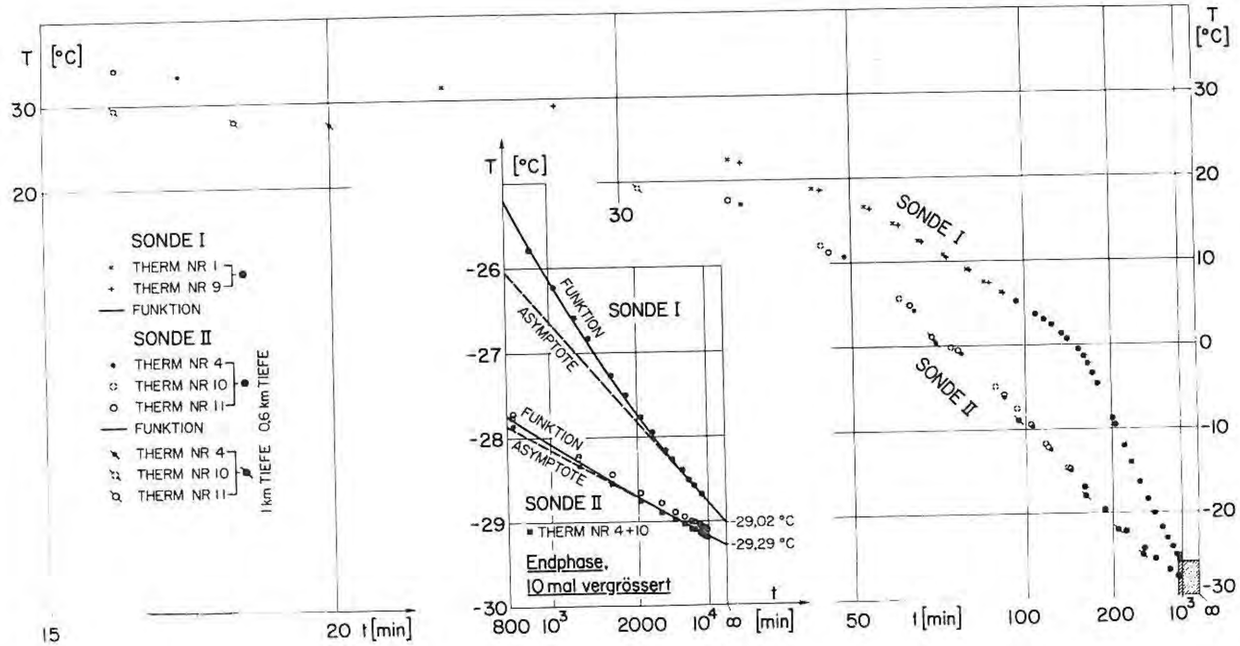

Figure 7. Cooling curves for probes I and II.

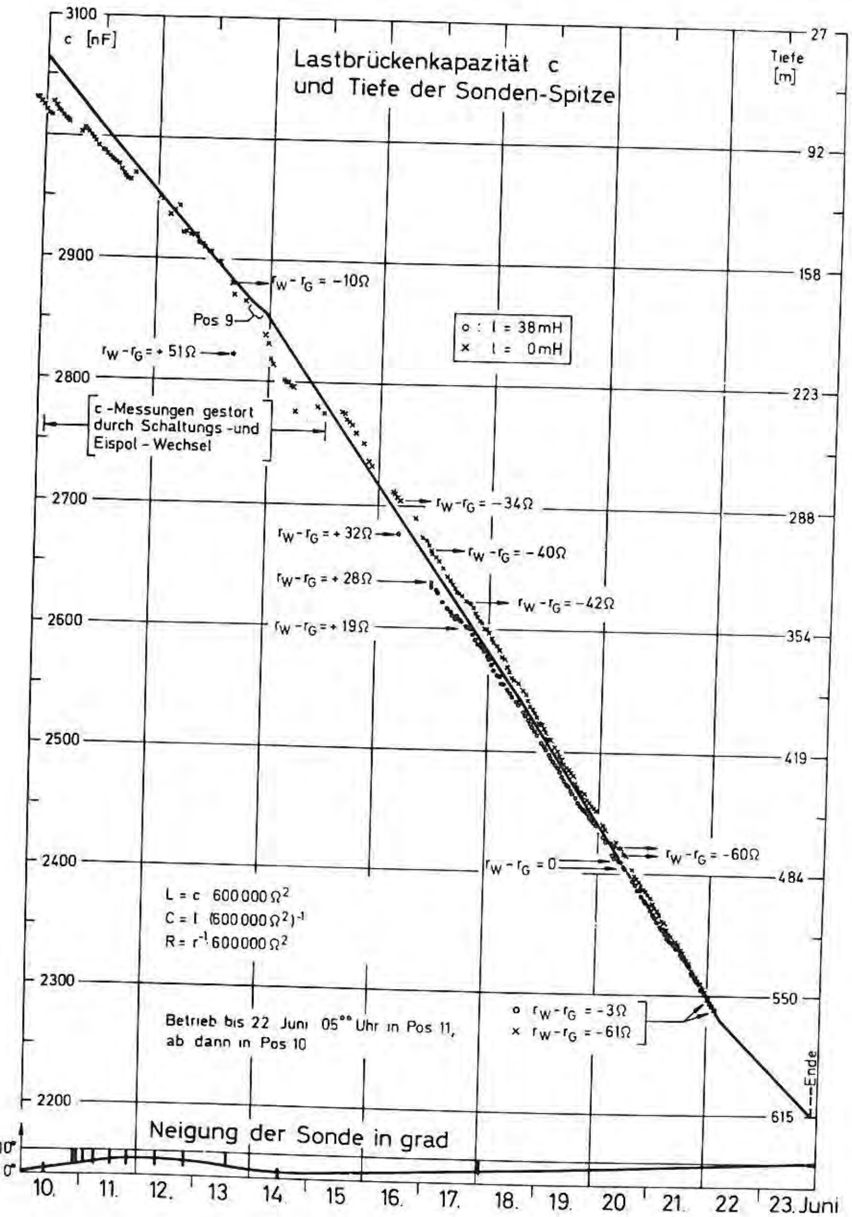

Figure 8. Relationship of wire inductance L and resistance R to depth for probe II (50-615 m).

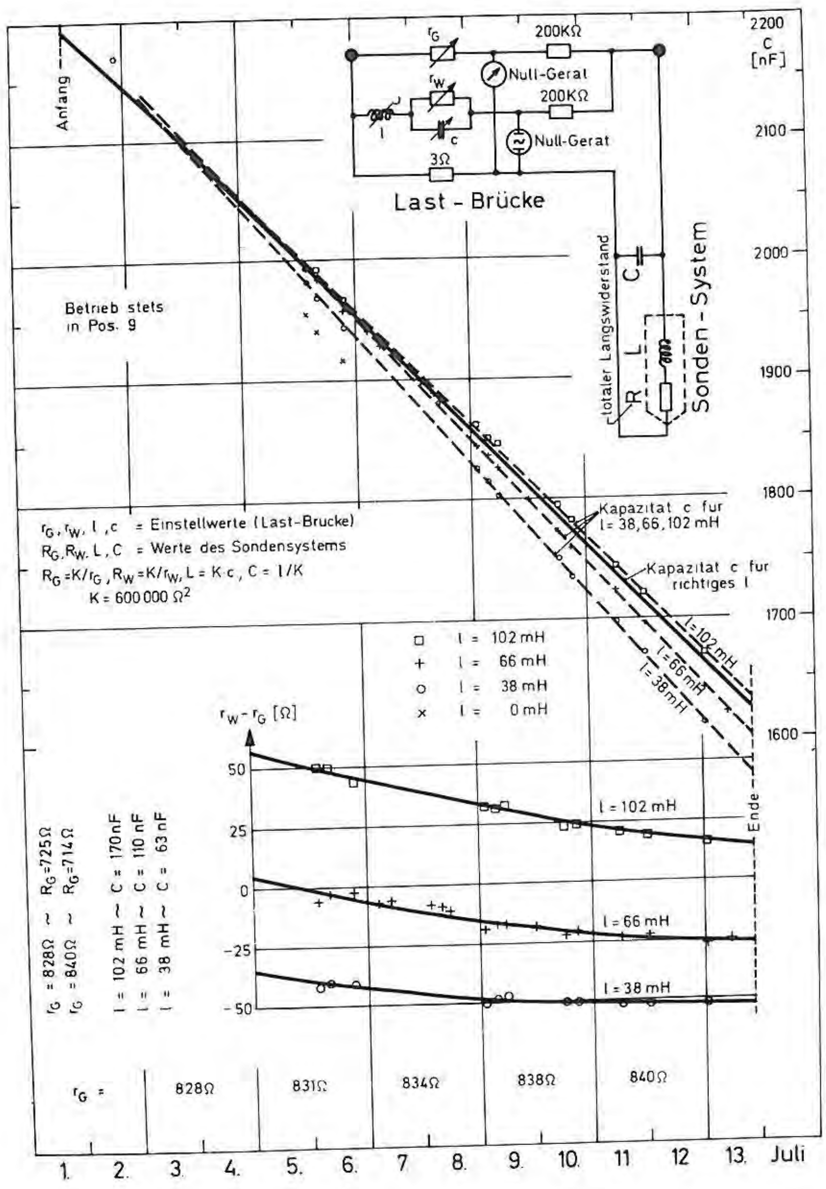

Figure 9. Relationship of wire inductance L and resistance R to depth for probe II (615-1005 m).

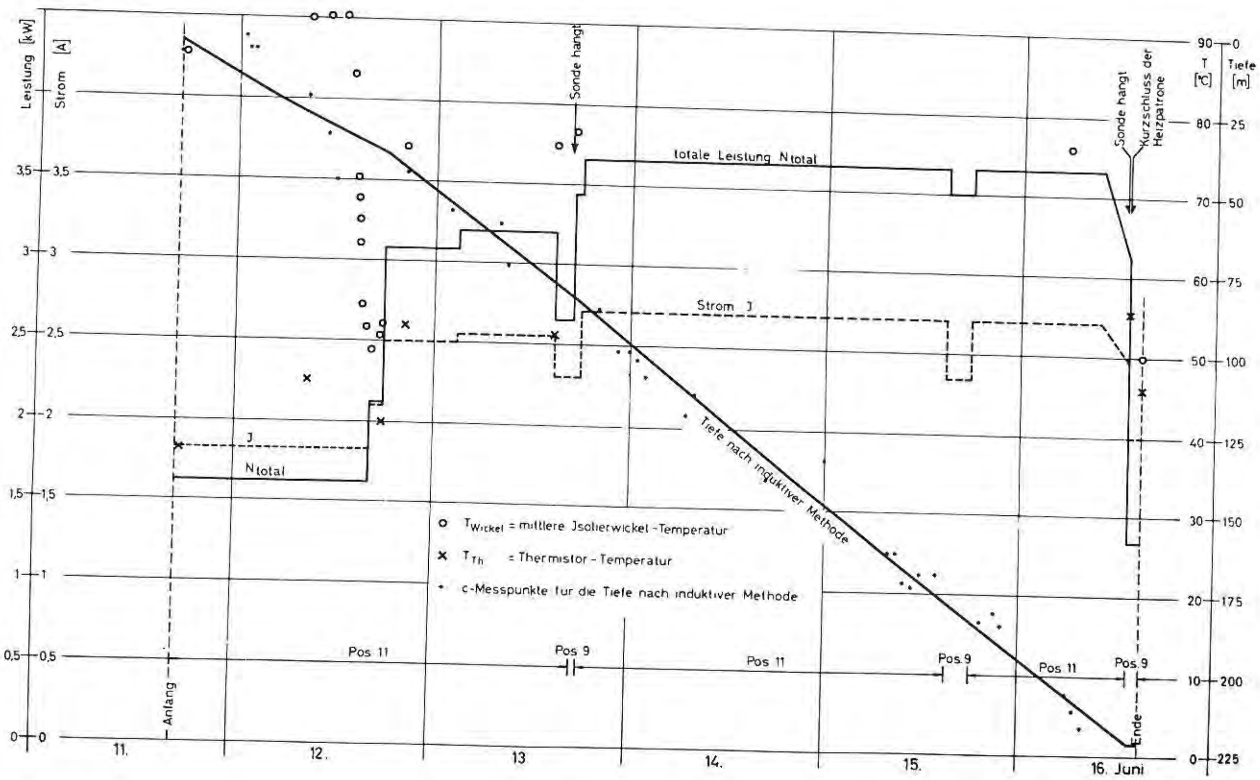

Figure 10. Total power, current and temperatures of coil (mean) and thermistors for probe I between surface and 218 m.

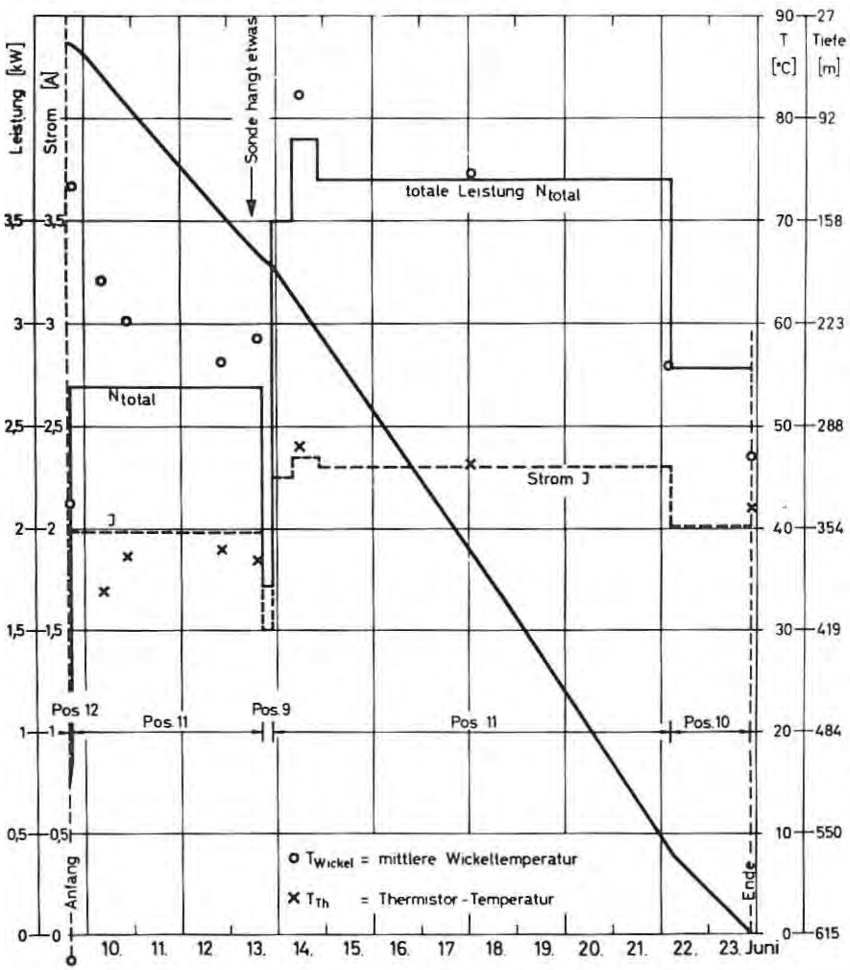

Figure 11. Total power, current and temperatures of coils (mean) and thermistors for probe II between 50 m and 615 m.

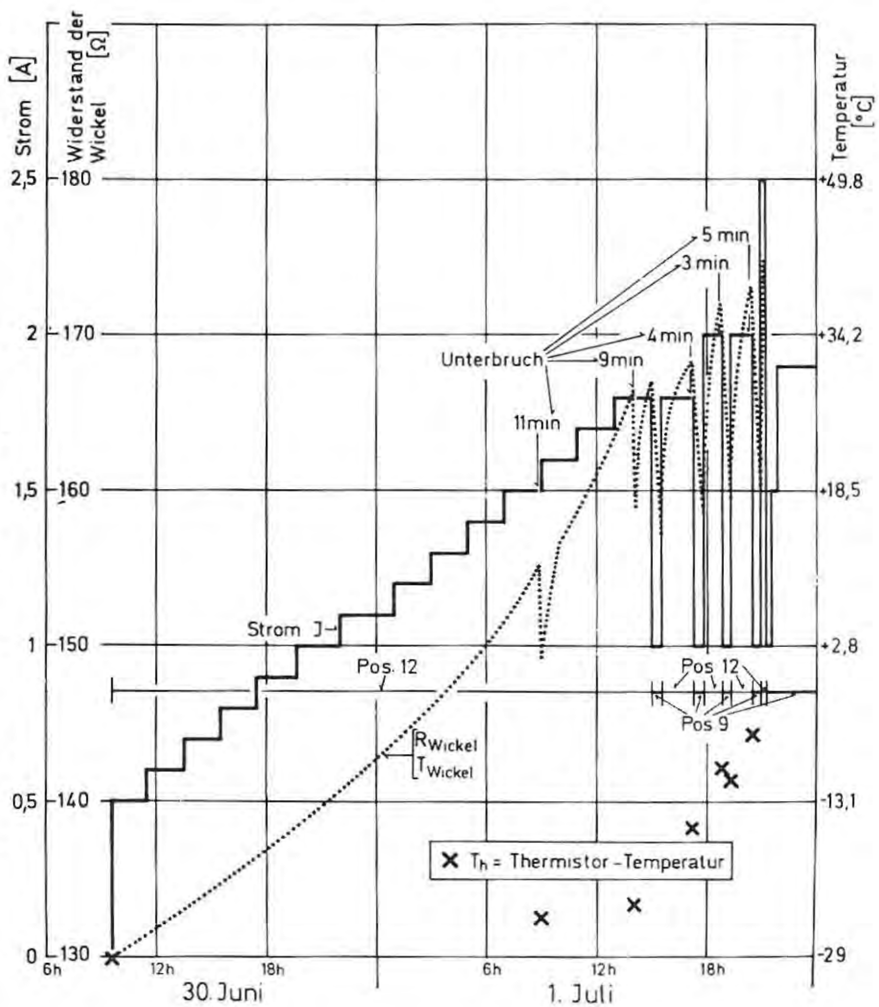

Figure 12. Reheating process of probe II at 615 m depth.