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# Drilling into Antarctic Ice - The New BGR Ice Drill

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**Summary:** We describe a new ice drill consisting of an electrially heated probe that melts its way through the ice. The produced meltwater is recovered periodically with a bailer. The instrument is mounted in a closed container on a sledge and is operable irrespective of weather conditions. 48 boreholes in Antarctic ice were drilled so far in two Antarctic seasons by this system. The deepest hole reached 102 m.

**Zusammenfassung:** Ein neues Eisbohrgerät, bestehend aus einer elektrisch beheizten, sich durch das Eis schmelzenden Sonde, wird beschrieben. Das während des Bohrvorganges entstehende Schmelzwasser wird periodisch abgeschöpft. Das Gerät ist fest in einem überdachten Schlitten montiert und kann wetterunabhängig betrieben werden. Mit dem Gerät wurden in zwei antarktischen Einsätzen 48 Bohrungen niedergebracht. Die bislang tiefste Bohrung erreichte 102 m.

## INTRODUCTION

The employment of commercially available conventional drilling techniques in Antarctica is very expensive and difficult to handle from the logistic point of view. One available „cheap" method, the „hot water" drill, is not very well suited for the weather and, in particular, the wind conditions on the Antarctic Polar Plateau. To overcome these limitations, we have developed a new ice drill:

- that can be operated without putting unreasonably large strain on the logistic capabilities of Antarctic expeditions, and
- that can be operated irrespective of weather conditions, which minimizes the environmental impact on the ice.

The new instrument was built as part of a BGR-research project supported by the Deutsche Forschungsgemeinschaft (DFG). The aim of the project was to measure terrestrial heat flow in boreholes sunk into almost stagnant Antarctic ice fields and specifically along a profile across the Transantarctic Mountains. The results of this project will be discussed elsewhere. A survey of potential drill sites in the season 1990/91 (GANOVEX-VI expedition of BGR) had demonstrated periodic fierce weather conditions with high catabatic winds in the area. Given the experience of the 1990/91 survey, the ice drill had to meet the following specifications:

- housed in a closed container on a sledge,
- sufficiently compact for transport by helicopter or to be pulled overland by snowmobiles,
- operable independent of weather conditions.

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## THE DESIGN

The principle concept realized by our new drill is to let an electrially heated probe melt its way through the ice and recover the produced meltwater periodically with a bailer. This technique minimizes the risk of environmental hazards. It does not require the use of oil and/or antifreeze fluids. The only acting pollutant is the exhaust of the generator producing the electrical power for the probe.

Similar concepts have been realized in the past. IGNATOV (1965) describes in detail a melting device that penetrated Antarctic ice near the Vostok Station in Antarctica down to a depth of 52 m. PHILBERTH (1965) and AAMOT (1967, 1968a, b) discuss various melting devices with the emphasis on technical details to insure its vertical penetration through the ice. Of particular interest is the discussion by PHILBERTH (1984) of a non-retrievable probe. The lower end of its power supply cable was housed in the probe and paid out according to the drilling progress. One probe of this type reached a depth of 1005 m in the Greenland ice sheet.

Fig. 1 shows the principal components of the new BGR-instrument. A tripod, an electrically driven winch and an electronic unit for operation of the winch are mounted on a 2 m • 3 m large platform that is kept by two runners 30 cm above the snow surface. A 2 m high aluminum frame covered by canvass raises from the edges of the platform. The floor under the tripod has an opening through which the probe can be lowered into the ice.

The design of the probe is shown in Fig. 2. The thermal penetrator contains a heating element with a power output of 2.5 kW. The penetrator is connected to a 1.3 m long pipe, whose principal function is to collect the melted water. Four one-way valves are positioned at the upper end of the penetrator, through which the meltwater enters the pipe. The interior of the pipe is equipped with a heater (160 W) to prevent premature freezing of the meltwater within the pipe and of the outer surface of the pipe to the ice wall. A second penetrator (400 W) rests on the top section of the probe. Its function is to enable the probe to melt its way out of the borehole, if for some reason the probe becomes jammed by newly formed ice along the borehole walls. The total weight of the probe is 12 kg.

We have not added any device to insure a vertical attitude of the drill in ice as they were used in previous drill designs (i.e. AAMODT 1967). The observation of our drill during the start of each

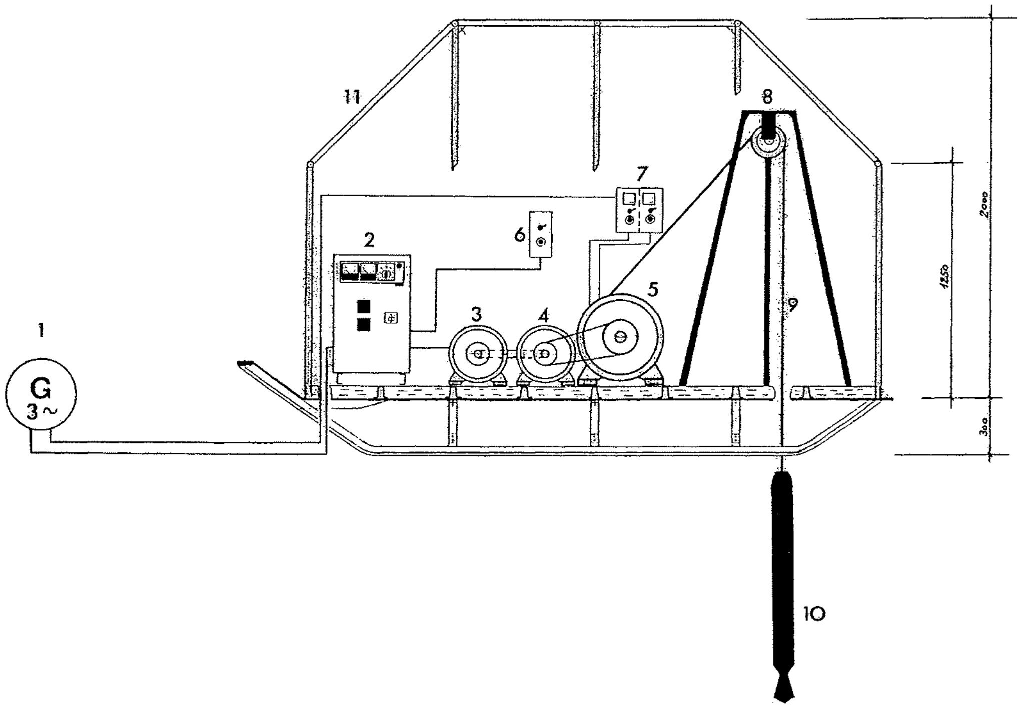


**Fig. 1:** The sledge with its principal components: 1 = generator; 2 = electronic control unit; 3 = engine; 4, 5 = transmission and winch; 6 = winch speed control unit; 7 = power supply regulator; 8 = tripod; 9 = „Keflar"-cable; 10 = thermal probe; 11 = canvass of sledge.

**Abb.1:** Die Einzelkomponenten des Bohrschlittens: 1 = Generator, 2 = Elektronische Steuereinheit, 3 = Motor, 4 und 5 = Übersetzung und Winde, 6 = Windensteuerung, 7 = Leistungsregler für Bohrsonde, 8 = Dreibock, 9 = Keflar-Kabel, 10 = Sonde, 11 = Dachbespannung.

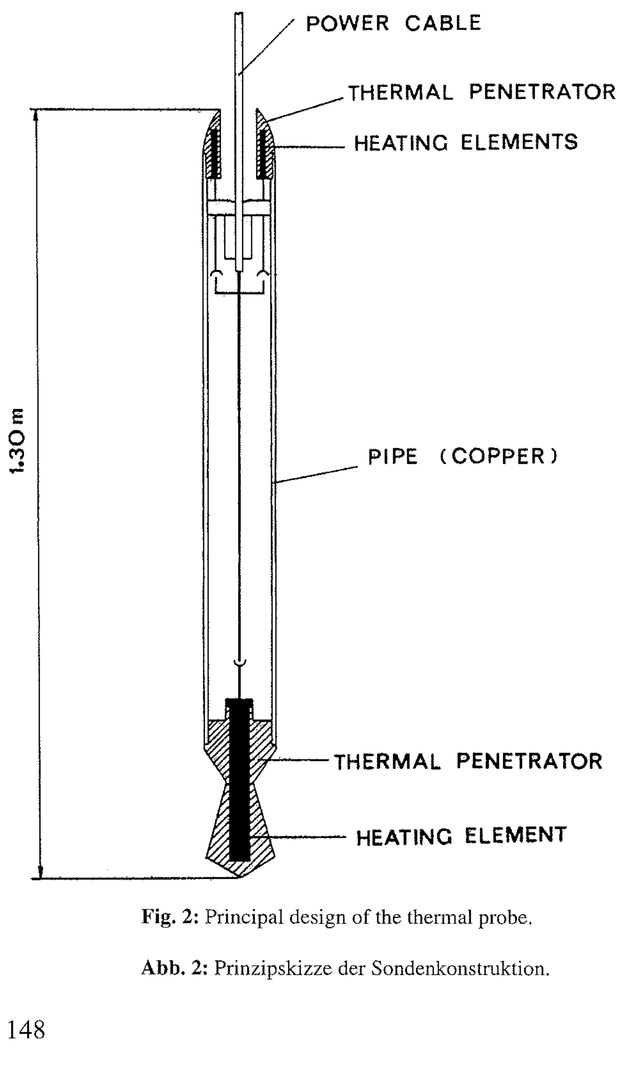


**Fig. 2:** Principal design of the thermal probe.

**Abb. 2:** Prinzipskizze der Sondenkonstruktion.

drilling operation showed us that any deviation from the vertical is corrected immediately by preferential melting on the side on which the device starts to lean. This process is greatly assisted by keeping a tight power cable between the winch and the melting device.

The electric power cable connecting the probe with the power supply is designed to resist prolonged wear and tear along the ice walls during operation. It is made up of four 2.5 $mm^2$ leads surrounded by a mantle made of „Kevlar". The diameter of the cable is 9.8 mm, the allowed maximum pull load is 200 kg.

The need to bail out the meltwater requires to lower and raise the probe frequently. The winch is designed to permit a maximum speed of 0.6 m/s of the probe through the borehole.

## FIELD OPERATIONS

The instrument was used during the field season 92/93 to drill successfully three boreholes through ice in Victoria Land, Antarctica. A first test of the probe on blue ice near Ambalada Peak failed however, due to an unforeseen reason. The length of the pipe of the probe during this attempt was 3 m. The drilling progress and the recoverable amount of meltwater were closely monitored. We recovered about 5.7 liters of meltwater per meter borehole to a depth of -4 m. A sharp reduction down to less than 1 liter per m ocurred below that depth. The probe froze to the borehole wall at -10 m and was lost.

We interprete these observations as follows: The blue ice being under tension had developed numerous open fissures, which are not obvious at the ice surface. Meltwater being produced during the summer season on the blue ice surface enters any developing fissure and reseals the ice apparently down to a depth of about -4 m. Fissures below this level are not reached by seasonal meltwater and remain open. The permeability of the ice below this level is apparently sufficient to drain about 30 liter of water within half a day from a borehole with a diameter of 8 cm.

To prevent a further probe loss we shortened the pipe to 1.3 m (which trippled the effectivity of the internal heating element). This measure proved effective.

The following boreholes were successfully completed:

| drill point | borehole depth | coordinates | |
|---|---|---|---|
| Ricker Hills | - 51 m | 75° 45.5' S | 158° 50.4' E |
| Mt Billing | -102 m | 75° 40.8' S | 160° 48.2' E |
| Mt Howard | - 83 m | 75° 39.5' S | 161° 12.8' E |

The equipment housed on sledges was transported from Gondwana Station (Terra Nova Bay, North Victoria Land) by helicopter into the field and pulled by skidoo overland between all drill points (Fig. 3) . The average speed over snow terrain was 11 km per hour.

## RESULTS

All completed boreholes show a rather smooth borehole wall. The holes are almost vertical as judged from the almost unimpeded travel of the probe down to the bottom. Each borehole developed one or several difficult spots through which the probe had to be sunk with special care. The greatest problem occurred inadvertently at the firn-ice interface. The bottom of the firn had a tendency to move inward and to reduce the borehole diameter. This section had to be redrilled occasionally. This problem was most severe at the last drilling point, where the firn/ice was warmest (-24° C ).

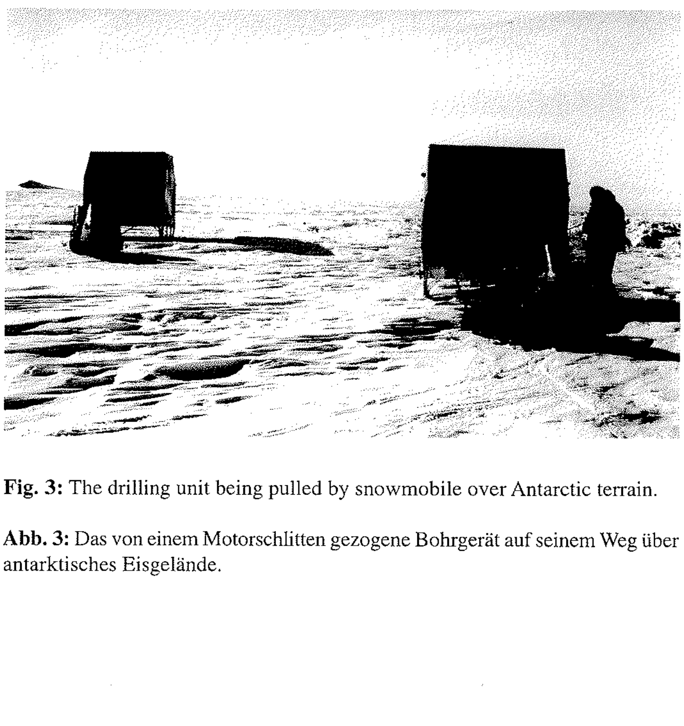

**Fig. 3:** The drilling unit being pulled by snowmobile over Antarctic terrain.

**Abb. 3:** Das von einem Motorschlitten gezogene Bohrgerät auf seinem Weg über antarktisches Eisgelände.

The recoverable amount of meltwater was about 5.7 liters per meter, which amounts to an average diameter of 8 cm of the borehole.

The drilling speed in firn gradually decreased from an initial 5 m/h to about 2.8 m per hour. The typical drilling speed in dense ice averaged around 2.2 m/h . The actual penetration speed was however closer to 0.9 m per h due to the time needed for the bailing trips.

## OUTLOOK

This technique offers advantages and disadvantages. Negative aspects are the relative low drilling speed (due to the frequent bailing trips) and the lack of recoverable drill cores at this stage. Advantageous are mainly two factors:
- The drilling process can be interrupted at any time.
- The borehole stays open for a long time.

The boreholes drilled so far have been measured in by GPS. We plan to revisit some or all of them in the future. All boreholes are marked by poles. In the future we will attempt to realize in addition an alternative concept that allows the recovery of cores. The penetrator will be replaced by a heated ring that melts its way through the ice, while the inner ice core enters a catcher located in the pipe. The lower end of the ice core will be separated from the borehole bottom by keeping the ring in a stationary location.

Apart from the availability of an ice core we hope to reduce by this way the number of required bailing trips. We also plan to build a separate bailer to be lowered instead of the pipe above the probe to remove remaining meltwater out of the borehole between drilling trips.

*Addendum*
The original system was employed for a second time on Antarctic ice in the season 1993/94 within the Italian Antarctic programme. 45 shot holes of depths varying between 18 m to 40 m were drilled at four shot points in support of the seismic refraction profile ACRUP-1 across the Transantarctic Mountains south of the Drygalski Ice Tongue in Victoria Land. 20 boreholes were drilled on the Polar Plateau at an elevation of 2000 m.

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