DIRECTIONAL DRILLING

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ABSTRACT

Directional Drilling (DD) technology can be used in deep glacier boreholes to obtain additional ice cores from any depth and to create supplemental boreholes for geophysical research on glacier ice properties. Experimental directional drilling was done using an antifreeze thermo-electric drill in a test well. The test demonstrated that a whipstock deployed in the main borehole permits slant drilling to obtain extra ice cores. The whipstock was placed 25 cm above the bottom of the 4.5 m deep borehole. The antifreeze thermal drill was inclined in the cavity to an angle of up to 3°. When the second borehole reached a depth of about 6 m from the whipstock it had no inclination. The distance between axes of the main and secondary boreholes was about 0.3 m. The whipstock was frozen into the main borehole during slant drilling and afterwards, it was heated electrically and removed from the hole.

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INTRODUCTION

Increased interest by a number of scientific disciplines in the study of glacial ice has recently led to a high demand for ice cores. The difficulty and expense of obtaining sufficient quantities of high quality ice samples from great depths in glaciers can make interdisciplinary studies of only deep layers impossible. The problem can be partially solved by increasing core diameter, but this increases the expense of extracting the core, and the resulting material may not be adequate to address the scientific concerns. One of the main goals of glacier physics is the study of glacial ice under natural conditions of temperature, pressure and shear stress. Such research can be done by simultaneous deployment of sensors and tranducers at specific locations in slant shafts off the main borehole (Fig. 1).

One way to obtain sufficient ice from any depth in a glacier is to extract it from slant shafts after the main borehole is complete. Special tools are used in industrial drilling to divert the drill bit in specific directions (Smith International; Eastman Chistensen; and others). However, the extremely high cost (>$100,000) and complexity of industrial technology make it unacceptable for the study of glaciers.

Positive results have been obtained by using simple whipstocks for deflection of thermal drills in deep boreholes in Antarctica (Vostok Station). An electric hot point drill at a depth 570 m was deflected up to 32° by a whipstock in a temperate glacier (Fig. 2). When the secondary shaft reached the bottom at a depth of 587 m the inclination had decreased to 29°. The secondary slant shaft was bored with a thermal drill after the whipstock was fixed at the bottom of the borehole. In the above example, the new borehole simply extended the previous one. An additional 2.5-m ice core has been taken from the bottom (567 m) of Austfonna (Svalbard) ice cap (Fig. 3) (Zagorodnov, 1988) by directional drilling. At present, deflection of mechanical drills in glacier boreholes is more complicated and has not yet been accomplished.

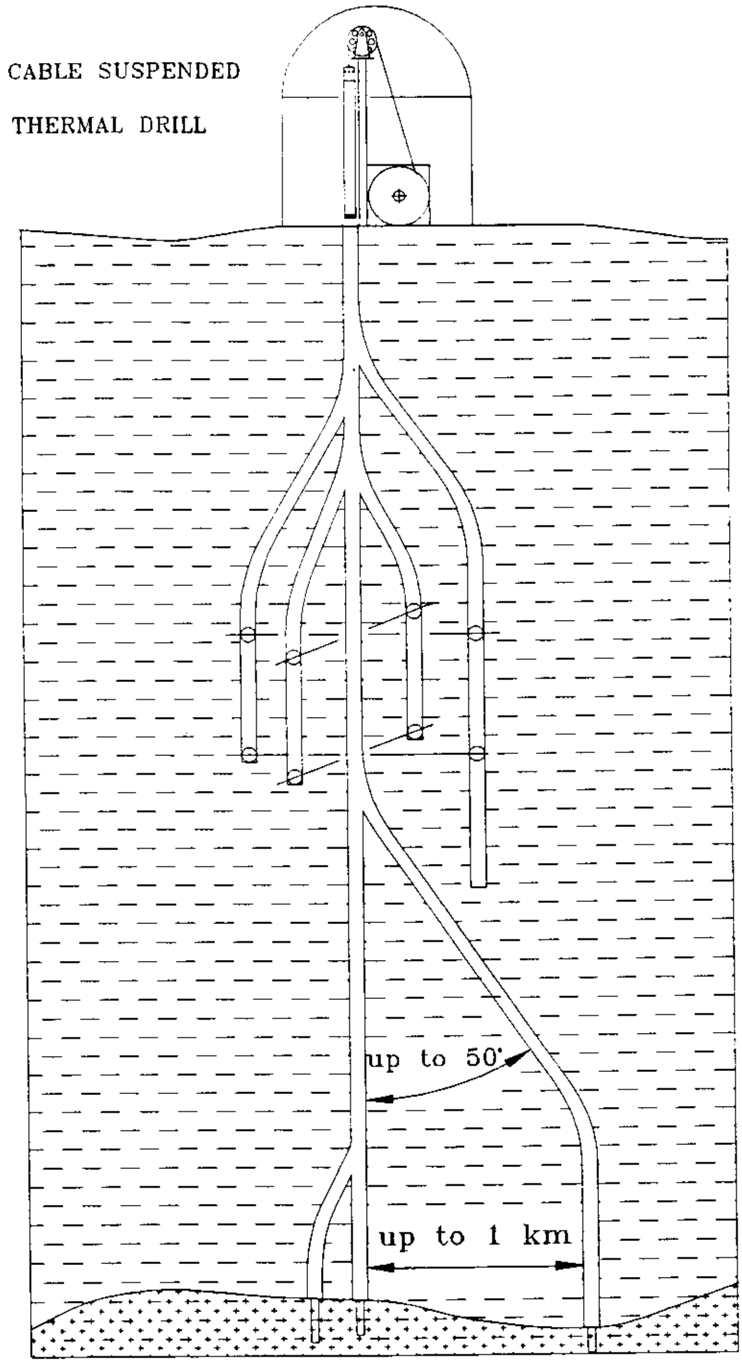

Figure 1. Schematic of branch holes created by directional drilling technology.

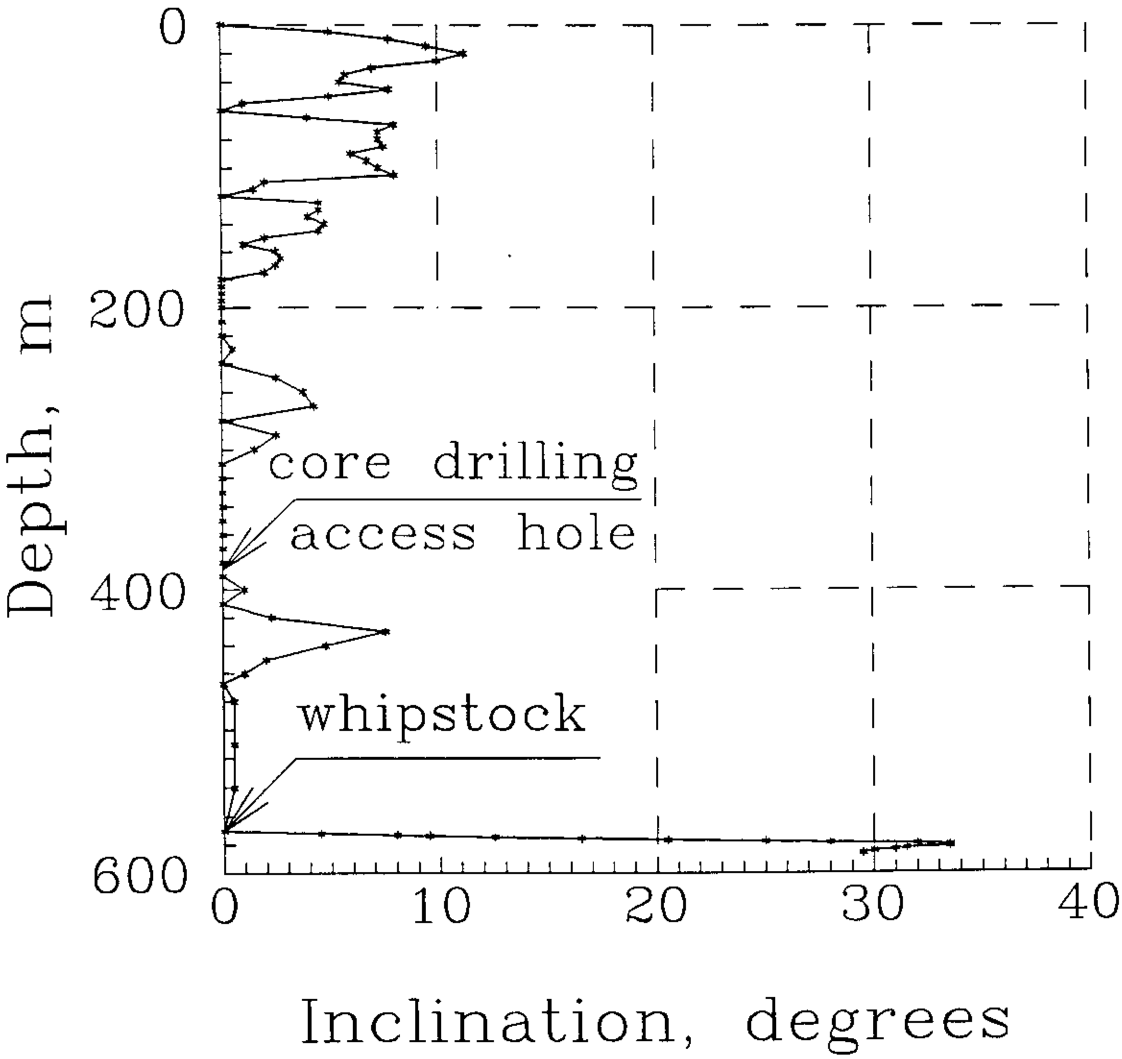

Figure 2. Inclination of the borehole drilled with the thermal core drill and hot point drill on Amundsenissen glacier (Svalbard, 1980).

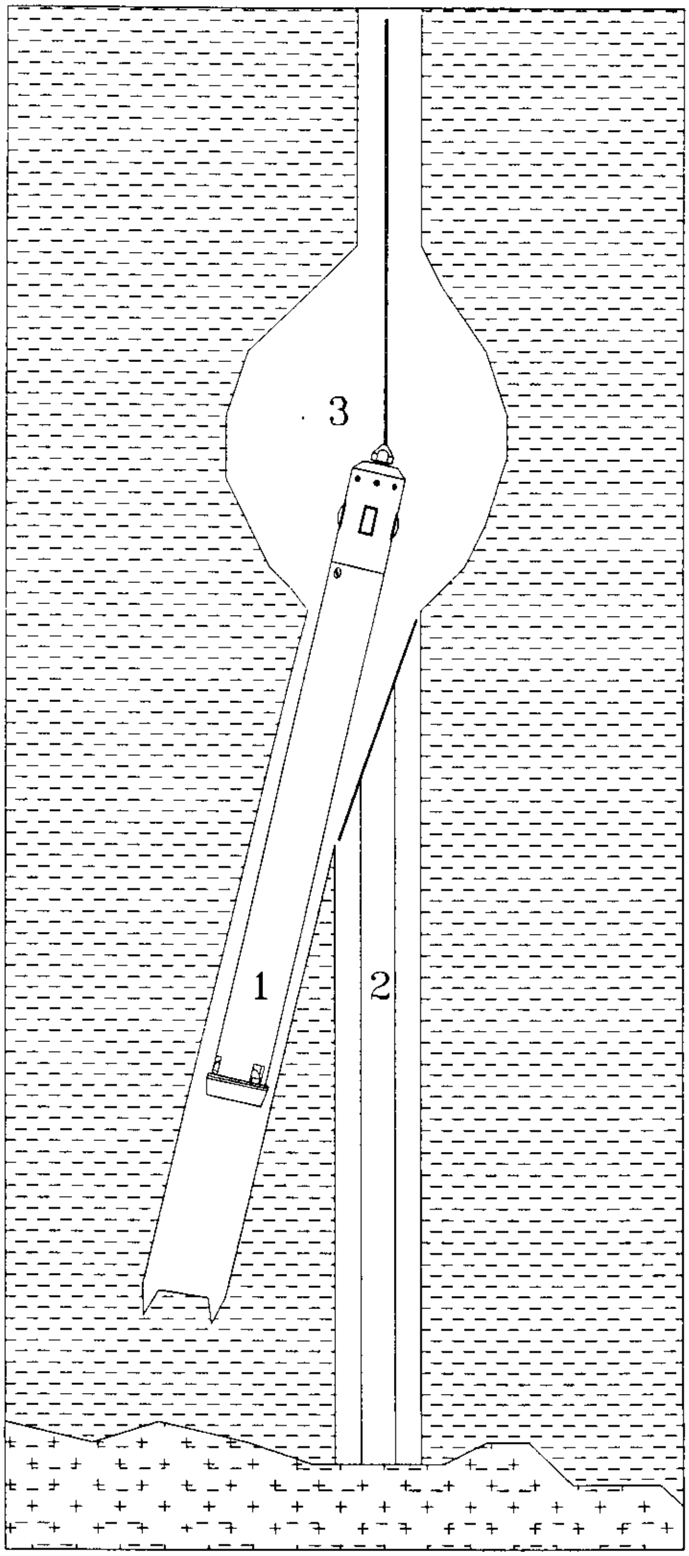

Figure 3. Schematic of taking additional ice core from the bottom portion of Austfonna (Svalbard, 1987) ice cape. 1 – thermal drill; 2 – whipstock; 3 – cavity

A new step in the development of DD technology is the design of a whipstock which can be placed at any given depth in previously drilled deep boreholes.

1.0 BOREHOLE INCLINATION

Experience has shown that during deep drilling, any type of drilling equipment tends to deflect from the vertical, usually with some negative consequences. Our main interest in this phenomenon is the development of directional drilling technology.

When using an autonomous, cable-suspended drill (Fig. 4), the drill bit is always in the center on a kerf, with only the upper part of the drill touching the borehole wall. Since the minimal radius (R_{min}) of an inflexible drill trajectory has the following proportions:

$$R_{min} = 1.5\,(L^2+1)(D_2\text{-}D_1)$$

where L is the drill length; D_1 is the drill diameter; D_2 is the borehole diameter. A shorter drill can produce a smaller radius of trajectory. The length of an antifreeze thermal drill is 3-4 times less than any mechanical type drill. Hence, R_{min} for such a drill is 9 to 16 times shorter. From a practical point of view, this means that an antifreeze thermal drill can be deflected from the main borehole within a much shorter depth interval than a mechanical drill. A thermal drill with specifications as in Table 1 has an R_{min} = 200 m; the maximum inclination during one run (1.7 m) is about 0.5°. Hence, an inclined borehole can be straightened within a much shorter depth interval with a thermal drill than with a mechanical drill.

The advantages of thermal drilling include the ability to make a cavity in a liquid-filled borehole. The drill can be turned at a larger angle if the cavity has a length approximately equal to the drill length. Figure 5 is a schematic illustrating the process of borehole straightening. Such operations were successfully performed

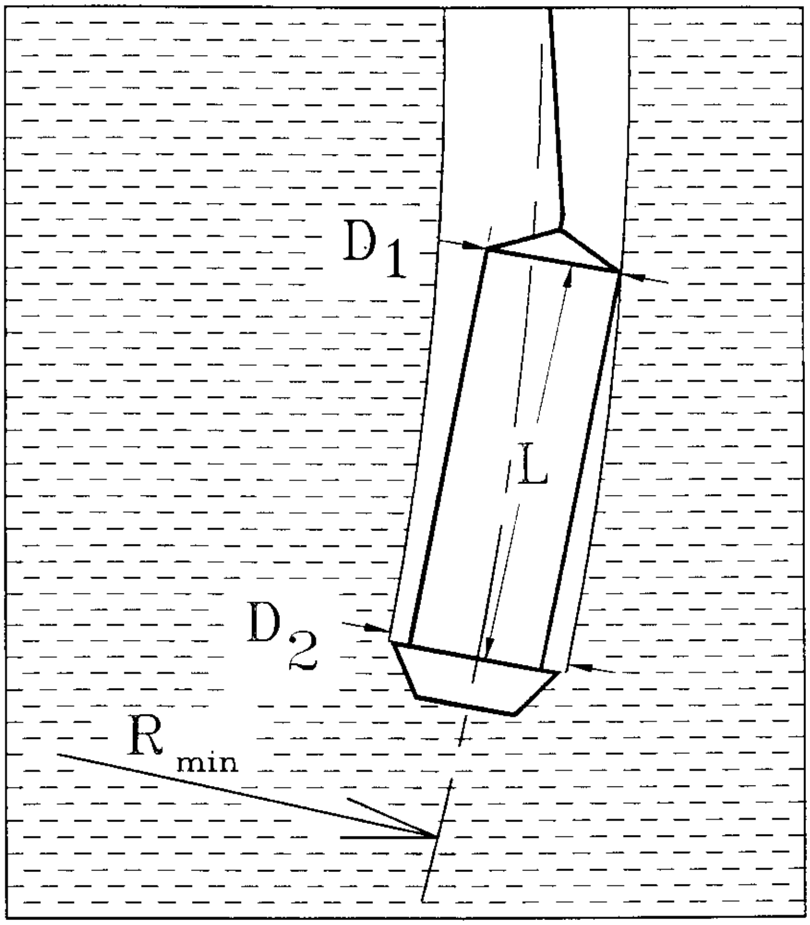

Figure 4. Position of the thermal drill in the borehole.

Table 1. Antifreeze thermal electrical drill specifications.

Heater outer diameter	108 mm
Heater inner diameter	84 mm
Borehole diameter	114 - 120 mm
Ice core diameter	78 - 80 mm
Drill length	2.0 m
Ice core length	1.6 m
Drill weight	40 kg
Power consumption	1.5 - 4 kw
Drilling rate	2.0 - 5.5 m/hr
Penetration rate (12 hr/day, depth 600 m)	210 m/week

at two deep horizons in a borehole filled with ethanol (Zagorodnov, 1988). This is the only described method permitting straightening of a borehole by 15° or more. Obviously, this method can also be used for obtaining additional ice cores from slanted boreholes.

Using a thermal drill and whipstock allows DD in vertical boreholes. Recently, experimental DD was performed in a PICO test well.

2.0 DIRECTIONAL DRILLING EXPERIMENT

2.1 Antifreeze Thermal Drill

The DD experiment was done with an antifreeze thermo-electric drill (Fig. 6) (Bogorodsky and Morev, 1984) (specification in Table 1). The drill was raised and lowered into the boreholes with Kevlar cable and a 400-m winch. The same winch

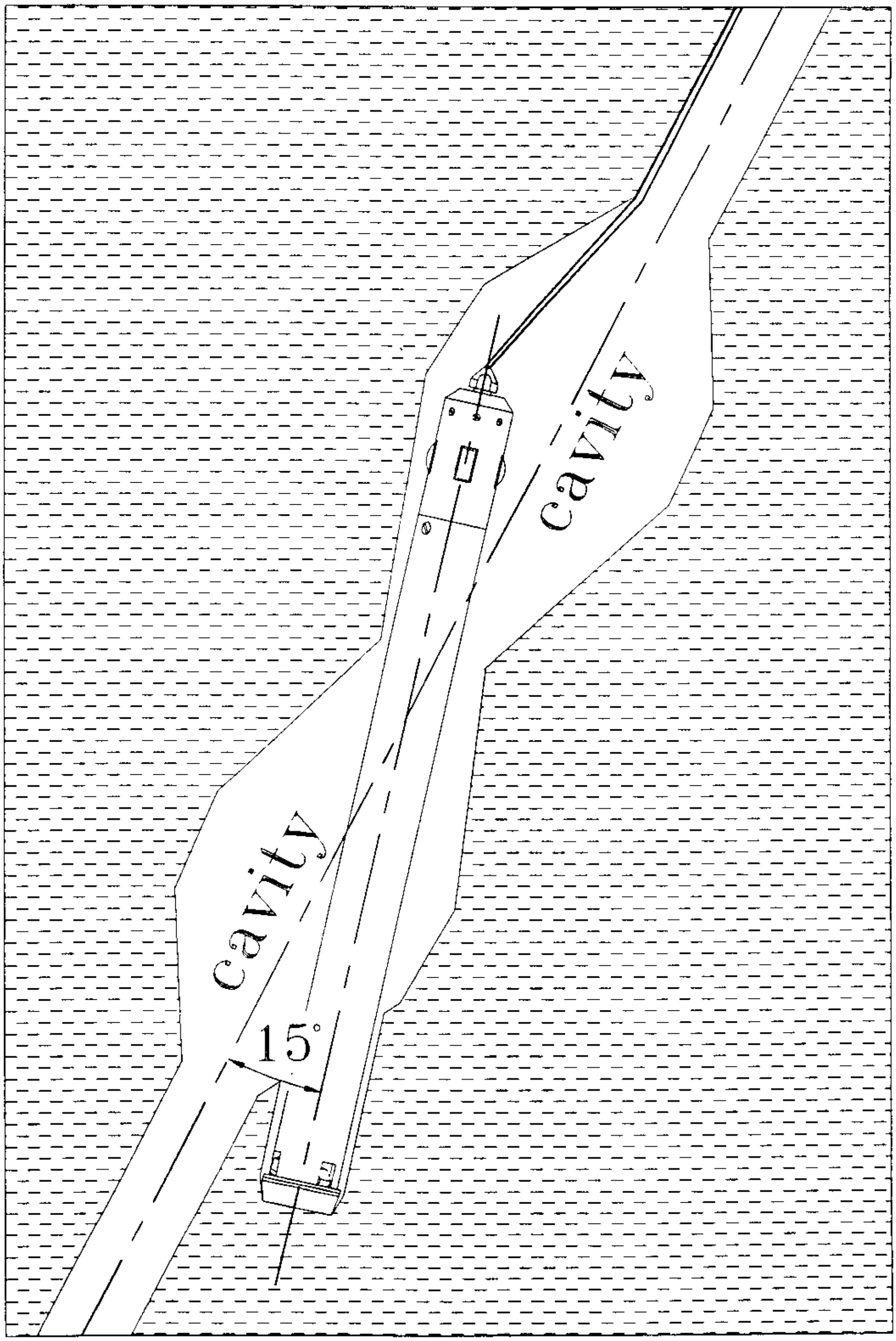

Figure 5. Borehole straightening by the thermal drill.

Figure 6. Schematic of antifreeze thermal electrical drill.

and cable was used for whipstock mounting and extracting. Because we expected relatively high ice temperatures, near the melting point of ice, ethanol was not used to fill the borehole.

2.2 Whipstock

The main parts of the whipstock (Fig. 7) are: a pipe with a sloping upper end, two clamping mechanisms for attaching the whipstock to the walls of the borehole, and devices for activating the clamping mechanisms and releasing the whipstock for recovery. The drill bit is deflected by the sloping surface at the upper end of the whipstock pipe.

During directional drilling, it is critical that the whipstock be securely attached to the walls of the borehole. This is accomplished by 24 flat springs directed outward into the borewhole walls and downward. Downward pressure on the whipstock forces the springs into the borehole wall, thus preventing the whipstock from sliding down the borehole shaft (12 springs hold at least 800 N). Since the springs are directed downward, they prevent the whipstock from sliding down the shaft but offer little or no resistance when pulling the whipstock upward out of the shaft. The springs not only prevent the whipstock from sliding down the shaft, but also prevent it from rotating in the shaft. This whipstock can be used in 108-145 mm diameter boreholes.

The whipstock attachment springs are activated when nylon strips are melted by electrical heating elements. The melting device was successfully tested in an ethanol-water solution at -25°C. An electrical diagram of the whipstock heating device is shown in Figure 8. The nichrome heating elements have 4 ohm resistance and operate at 20-60 volts DC. Commutation of the heating elements is accomplished by diodes when the polarity of the input voltage on the winch slip rings changes.

During deployment, the upper part of the whipstock is attached to the cable by a special cable connector and lowered into the borehole. The cable connector has a one-

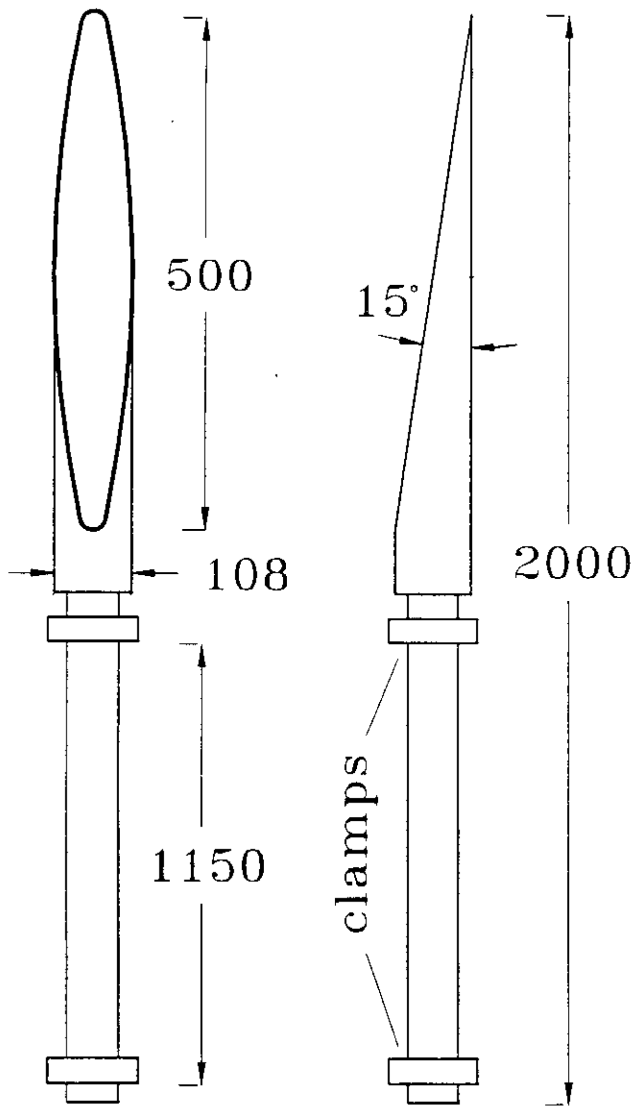

Figure 7. Whipstock structure (dimensions in mm).

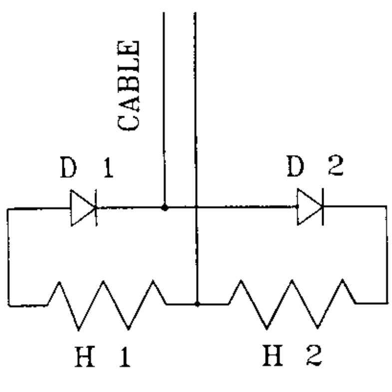

Figure 8. Electrical diagram of whipstock.
D1 and D2 – diodes;
H1 and H2 – heating elements.

pin electrical connection for operating the heat-activated releasing mechanisms on the attachment springs and for activating a release pin for detaching the cable from the whipstock after it is secured to the borehole wall.

2.3 Extraction Device (Fig. 9).

The whipstock has a 73 mm diameter access hole at the top and 69 mm orifice under the upper sloping surface. This permits the conical bottom end of the extractor to slide into the whipstock. Spring loaded catch pins on the sides of the extractor spread inside the whipstock, thus securing it to the extractor. If the whipstock is frozen into the ice or bound in by shear deformation, an electric heating element in the cone of the extractor will melt the surrounding ice during the pass through the access hole. In our experiments, a 3 kW capacity electric heating element was used. When the whipstock is freed, it can then be lifted from the borehole.

2.4 Test Well

The test well in permafrost has the following parameters: 0.8 m in diameter and 12 m deep. The well was filled with fresh water and allowed to freeze. The temperature of the surrounding permafrost is about -2°C.

2.5 Experiments

A vertical, 120-mm diameter main borehole was drilled to 4.5 m depth with the antifreeze thermo-electric drill. The penetration rate was about 3 m/hr. The whipstock was placed at 0.25 m above the borehole bottom. A cavity (Fig. 10) was prepared using the same thermal drill by holding the heat-activated drill bit stationary at 5 cm intervals for about 0.5 to 7 minutes at each depth. Both cavities were prepared in 4 hours. The secondary inclined borehole was drilled at a

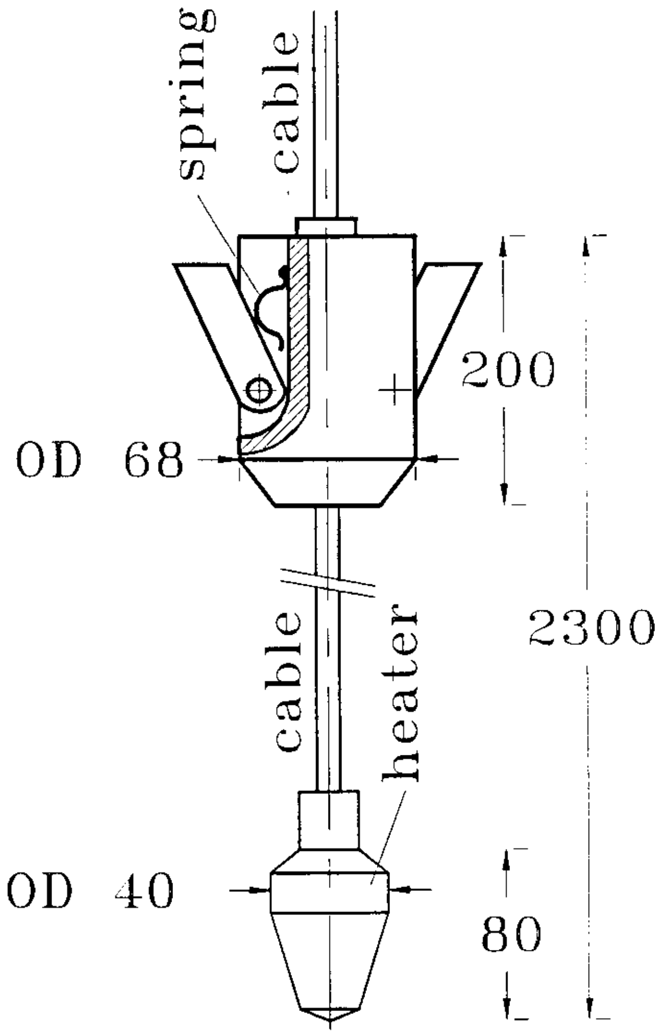

Figure 9. Structure of extractor device (dimensions in mm).

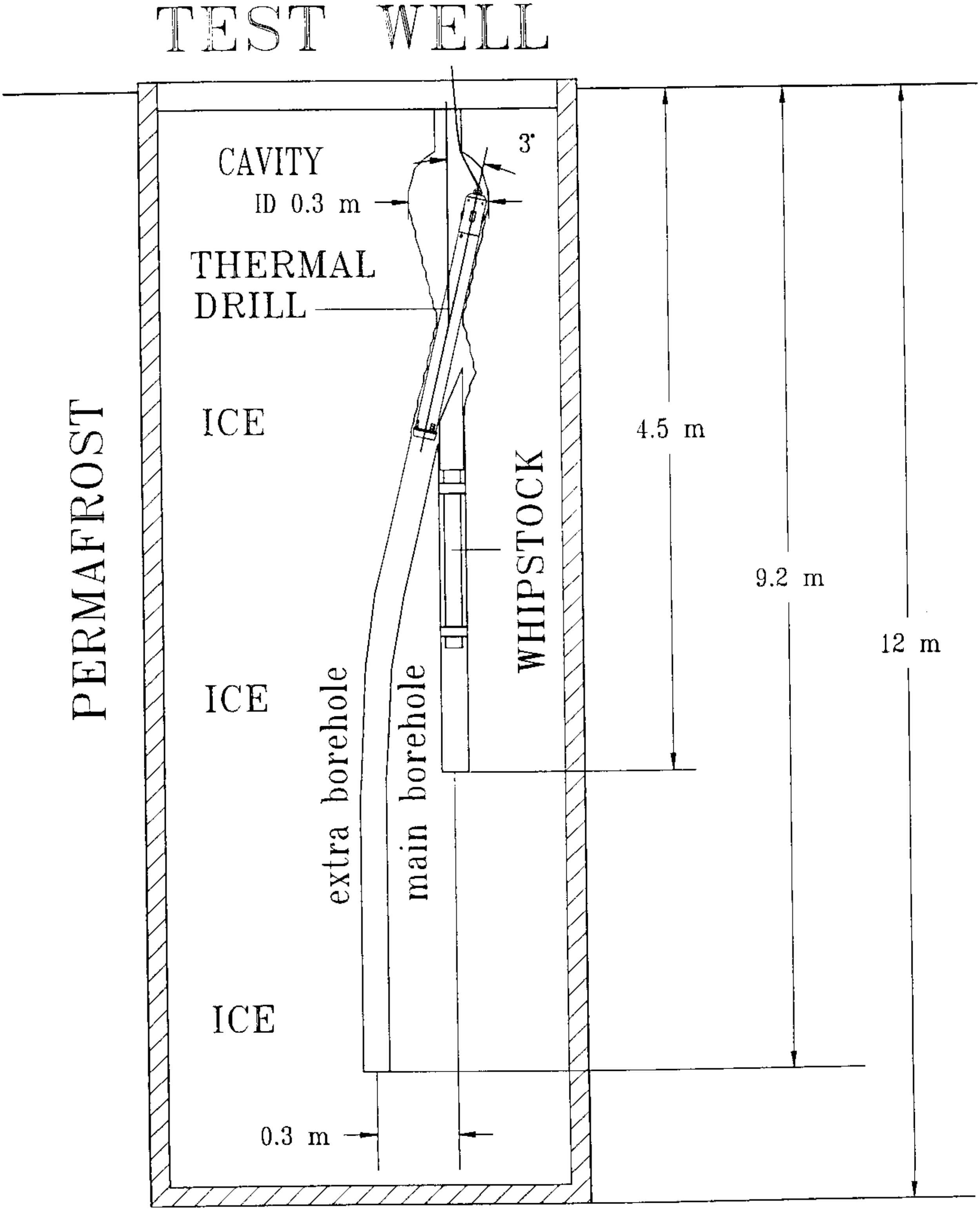

Figure 10. Schematic of Directional Drilling experiments performed in PICO test well.

penetration rate of 3 m/hr; ice core quality from the main and secondary holes was good. Borehole parameters are shown in Table 2.

Table 2. Borehole parameters.

Parameter	Units	Main Borehole	Inclined Borehole
Diameter	mm	120	120
Depth	m	4.5	9
Inclination	grad	0	0 to 3
Cavern: diameter/length	m/m	0.3/1.5	—

Five days after placement of the whipstock, it was heated by the electric element and extracted from the borehole. The heating element was lowered into the whipstock access hole and held for 4 minutes at 7 cm depth intervals. Along the upper sloping surface of the whipstock, the heater was held for 2 minutes at 7 cm depth intervals. Extraction required approximately 3.5 hours.

3.0 CONCLUSIONS

1. The whipstock prototype we tested is practical for antifreeze thermo-electric ice coring. No extra surface equipment is needed for directional drilling.
2. Only eight extra hours were needed for placement (about 4 hours) and recovery (about 4 hours) of the whipstock in the borehole. During that time, 25-35 m of ice core can be retrieved from the borehole. Hence, DD technology will be effective when additional ice cores are needed from boreholes deeper than 40-50 m.

3. The secondary borehole regains its vertical trajectory about 6 m down from the whipstock. The maximum angle of DD with the antifreeze thermal drill is estimated to be 40-50°.
4. The whipstock can be recovered, even when the borehole freezes or is deformed by shear.
5. The angle of deflection of the secondary shaft depends on cavity diameter, not the slope angle of the upper surface of the whipstock.
6. The access hole in the center of the whipstock allows scientific equipment to be lowered for simultaneous use in one or more secondary boreholes.
7. Modifications of DD technology:
   - Borehole logging equipment can be deployed with the whipstock placement device to permit DD in specific azimuth direction;
   - Special heaters can be deployed to melt the cavities in 0.5 to 1 hr;
   - The whipstock can be deployed with a rubber packer for antifreeze thermal drilling in boreholes filled with hydrophobic liquids (DF-A, kerosene, Butyl acetate).
8. Combined deployment of an electric thermal drill, a whipstock, and placing-logging equipment will make the following possible:
   - Additional ice cores from any depth and azimuth;
   - "Fresh" ice cores from "old" boreholes: Camp Century (1966); Byrd Station (1968); Dye-3 (1981); GISP; GRIP.
   - With the potential for retrieving additional ice cores, core diameter can be reduced by up to 80 mm, and borehole diameter can be 115-125 mm.
   - Reduction of the bulk and weight of drilling equipment (including shelters) and filling liquid will reduce transportation cost by one-fifth to one-third of that required for present projects using mechanical drills.

Directional drilling technology can provide additional boreholes and ice core from any chosen depth any time, and deep glacier boreholes become a natural depository of ice and a laboratory for geophysical experiments.

4.0 REFERENCES

Bogorodsky, V. V., and V. A. Morev. 1984. Equipment and technology for core drilling in moderately cold ice. CREEL, Special Report, SR 83-34, pp. 129-132.

Zagorodnov, V. S. 1988. Antifreeze-thermodrilling of cores in Arctic Sheet Glaciers. *In* C. Rado and D. Beaudoing (eds.), *Ice Core Drilling*. Proc. Third Intl. Workshop on Ice Drilling Technology. Grenoble, France, 10-14 October 1988, pp. 97-109.