ANTIFREEZE-THERMODRILLING OF CORES IN ARCTIC SHEET GLACIERS

by

V.S. Zagorodnov
Institute of Geography, U.S.S.R. Academy of Sciences
Staromonetny 29, Moscow 109017, U.S.S.R.

ABSTRACT

In 1985-87 two Arctic sheet glaciers : Austfonna (Nordaustland) and Akademia Nauk (Severnaya Zemlya) were cored with an antifreeze electrothermal drill down to their beds at 566.7 m and 761 m depth, respectively. The paper discusses the use of electrothermal drills for studies of the structure and hydrothermal regime of glaciers. It deals both with the equipment and results. The difficulties of drilling are also discussed, as well as ways to cope with them. Experiments on the reduction of bore hole inclination and on drilling of an additional bore hole to obtain an extra core from the bottom glacial stratum are described.

INTRODUCTION

Svalbard and Severnaya Zemlya have mountain-valley glaciers, mountain-sheet glaciers, and sheet glaciers. Depending on the local conditions of climate and topography their surface strata are either composed of firn with ice interlayers, or of consolidated ice. Temperatures of the inner layers range from 0° to -15°C. The melt rates are no less than 100 mm of water per summer. Melt water, with a small amount of sediment penetrates into the glacial body down to several tens of metres, and either freezes there, runs off the glacier over waterproof layers, or percolates down to the bottom via channels. Inside some glaciers and near the bottom there are lenses of liquid water. The hydrothermal situations discussed above can be found in most high-latitude glaciers.

Research on the structure, composition and hydrothermal regime of Arctic glaciers requires drilling equipment that is capable of operating under diverse conditions. Low accessibility of glaciers explains the need for light-weight, low power-consuming, mobile equipment that can be handled by a small team of specialists.

In 1975, the glaciological expedition of the Institute of Geography of the USSR Academy of Sciences began using in Svalbard the electrothermodrills designed at the Arctic and Antarctic Institute by V..A. Morev. These devices, in general, meet the above listed requirements. The thermodrills have been employed to study sheet glaciers with complicated hydrothermal characteristics in the inner layers, located in Svalbard and Severnaya Zemlya /1, 2, 6/.

CHARACTERISTICS OF DRILLING EQUIPMENT

The antifreeze coring electrothermodrill has been described by several glaciological and specialized publications /3, 4, 5, 7/. It has been employed for drilling in Antarctica and in the Arctic. One of the transect bore holes on the Ross Ice Shelf was also made with it. There have been no major changes in the construction of the drill over the last 10 years. The drilling apparatus characteristics are given in Table 1.

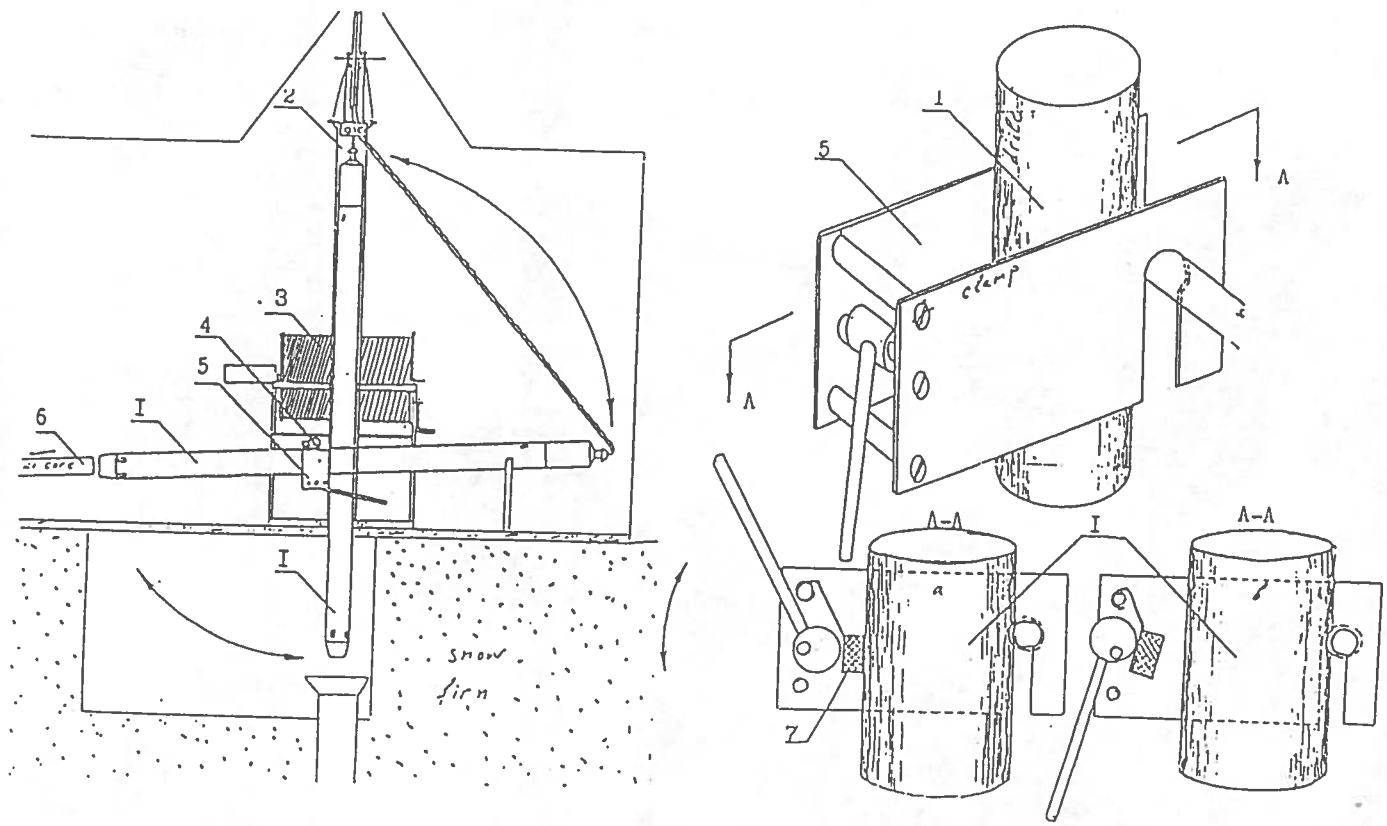
Innovations and improvements have been introduced in the design of a winch and ancillary equipment. The basic parameters of the ancillary equipement are given by Table 2.

To ensure uniform and vertical movement of a thermodrill in the process of drilling-melting, an additional motor-reducer was installed on the winch by changing the voltage of this motor, it is possible to adjust the rates of descent and lifting of the drilling instrument from 0.05 to 36 m per hr. In the process, using this motor, the rate of descent of the thermodrill is kept below the rate of drilling-melting. This ensures vertical movement. On Austfonna the devices were employed for drilling a bore hole down to 566.7 m.

BASIC CHARACTERISTICS OF ANTIFREEZE ELECTROTHERMAL CORE DRILL

Length : drill/core	3.6/2.7 m
Maximum diameter : bore hole/drill/core	118/108/82 mm
Weight : drill/core	75/13 kg
Capacity of heater	2-5 kW
Ice temperature	0° -35°C
Antifreeze	ethyl spirits

Table 1



Arrangement for Re-orientation of Drill in the process of operation. 1 - thermodrill, 2 - mast, 3 - winch, 4 - axis, 5 - fixator, 6 - ice core, 7 - rubber.

Fig. 1

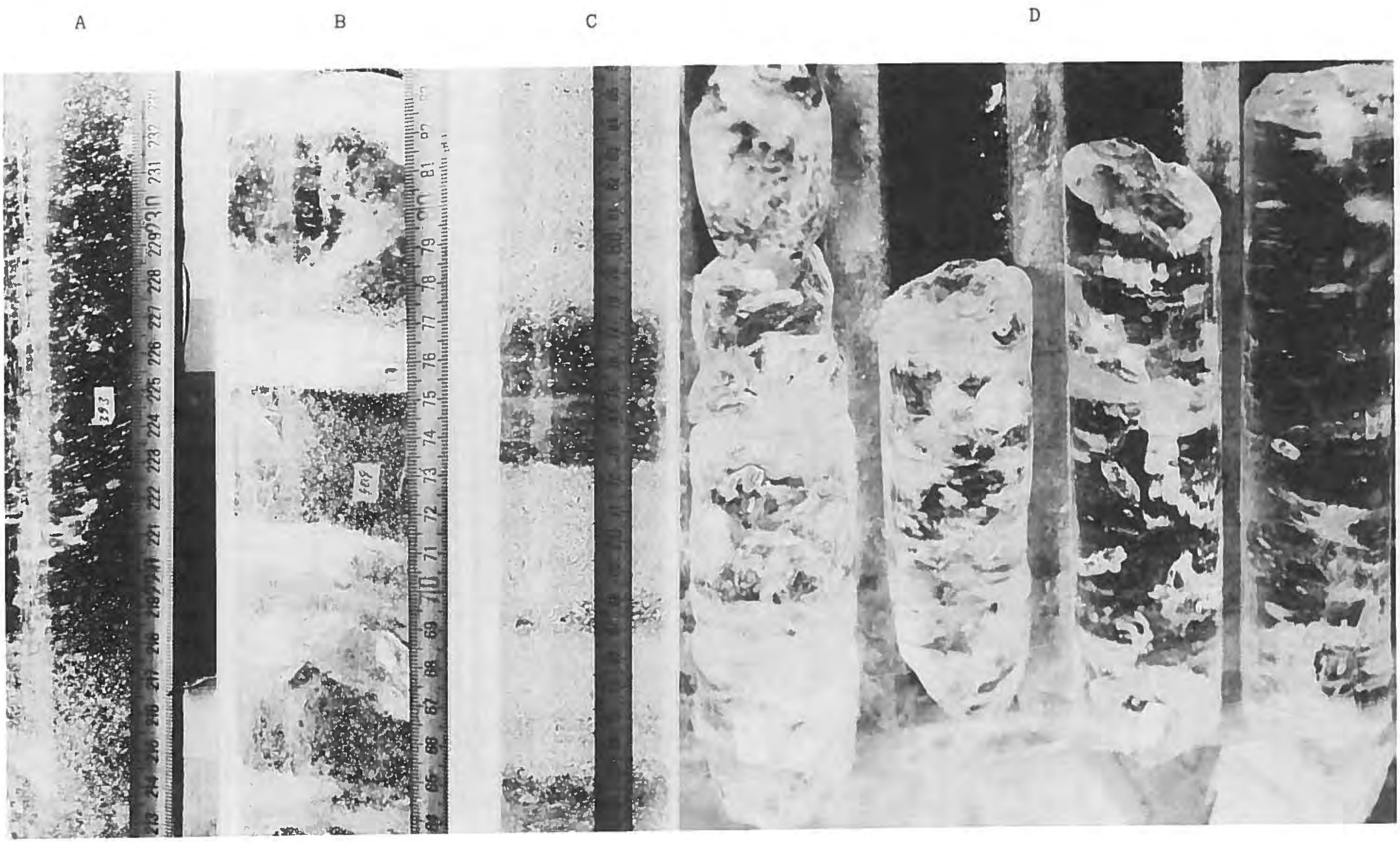


Fig.2 : Fragments of Core
A and B - Akademia Nauk Glacier, depth 477 m and 496 m respectively
C and D - Austfonna Glacier, depth 480 and 566.7 m, respectively.

ANCILLARY EQUIPMENT FOR ANTIFREEZE CORE THERMODRILLING

Dimensions :	drilling installation	80 x 80 x 300 cm
	control devices	25 x 40 x 150 cm
	operational zone	1.8 x 2 + 1 x 1 m
Weight :	winch (cable, mast)	500 kg
	control devices	150 kg
	arrangements	90 kg
Electric power capacity :		
	main motor	1.6 kW
	supplementary motor	0.15 kW
Rate of descent-lift :		
	main motor	1320-2100 m/hr
	supplementary motor	0.05-36 m/hr
Cable-line		800 , 8.9 mm, 1 x 2 mm^2 2 layers of steel armour

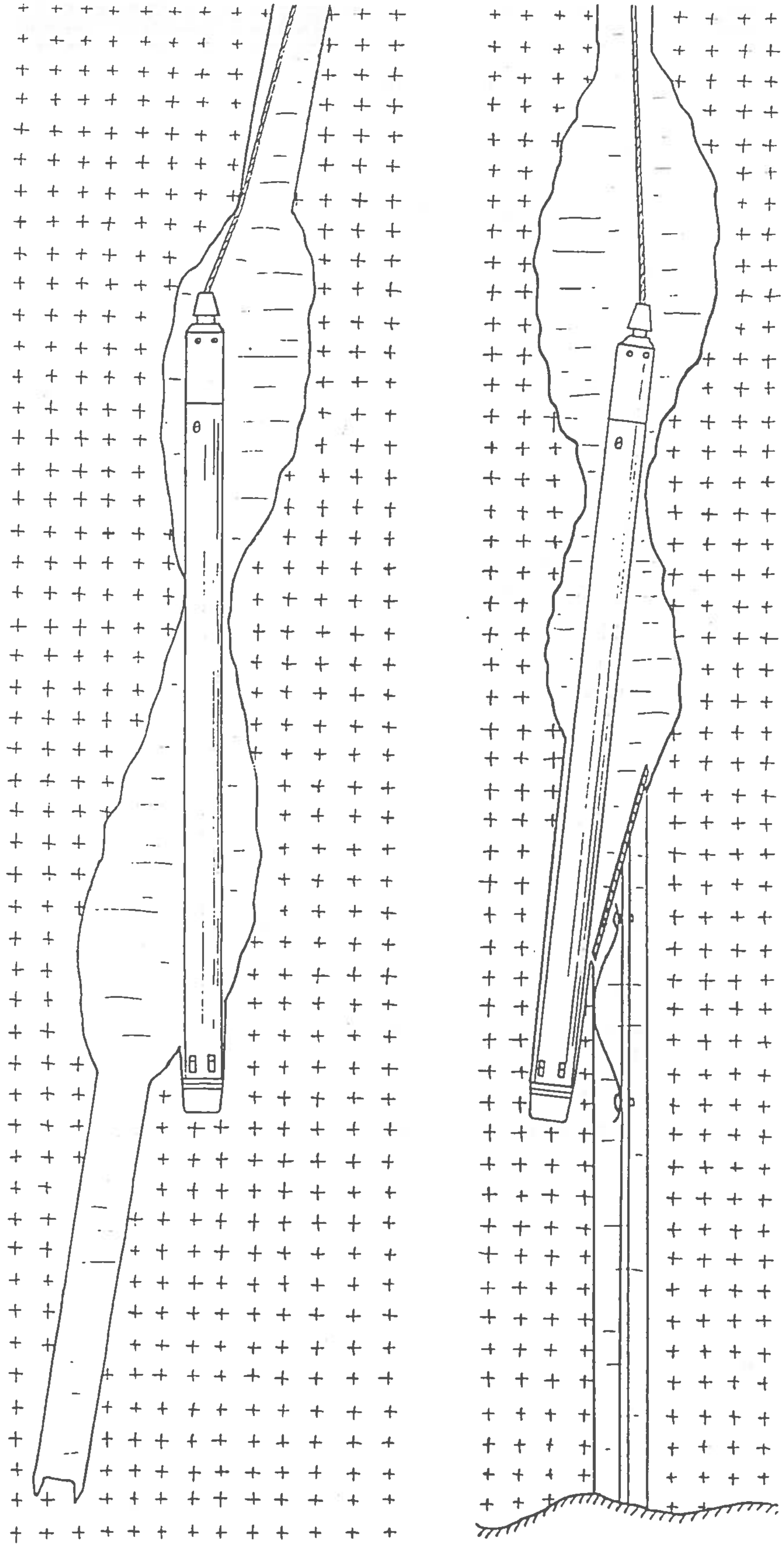
Table 2

To reduce the height of the mast and for more convenient servicing of the drilling instrument, a special apparatus was used to reorientate the drill from the vertical to the horizontal position. This apparatus is shown by Fig. 1. The drill attached to the cable-line is fixed by a special fitting on a turning axle. Upon debraking of the winch, the drill turns around the axle due to action of its own weight. The drill can be put into vertical position with the main motor of winch.

QUALITY OF CORE

The notion of "quality of core" includes the following criteria : homogeneity of the diameter along the core, vertical coring, number, size and form of fractures. As disclosed by the experience of drilling in Antarctica and the Arctic, the geometrical characteristics of cores depends completely on the technology of drilling. Selection of the optimal regimes avoids undesirable shape disturbances. Contact with insoluble admixtures in ice with concentrations over 0.5 gr/cm^2 produces unexpected reduction of the rate of drilling-melting and of the core diameter. The techniques used to eliminatic these problems are described below.

Absence of a scale of criteria of core fracturing persuaded us to employ qualitative parameters. Fig. 2a and b shows the typical fragments of cores from depths over 500 m taken from the above mentioned glaciers. They demonstrate the homogeneity of the shape and the consolidation of cores produced with the antifreeze-thermodrilling technology. The lowest quality core is demonstrated in Fig. 2 c and 2d and is represented by pieces 0.1-0.5 m long. Microfractures up to 3 mm wide are also observed in ice around air bubbles. The depth of technological pollution of the core is, obviously, no more than these microfractures. According to analysis of the core quality, the Arctic cores with high concentrations of air bubbles have more



Scheme of experements on decrease of inclination of the bore hole (A) and drilling a new hole (B).

Fig. 3

fractures and splits. In Antarctic ice, the concentration of air lenses is at least twice as high as in Arctic ice. Therefore, the Antarctic cores produced with the antifreeze-thermodrill have more fractures and splits. Probably, the more air bubbles there are, the more fracturing takes place in cores due to decompression.

As shown by experiments, when the extracted core is less than 1.5-1.7 m long, the number of fractures in it is considerably reduced. Longer cores are obviously fractured by the weight of the drill. This fracturing can probably be reduced by increasing the core diameter. According to experience accumulated in drilling over 3 thousand meters of bore holes in the Arctic glaciers, the technological core losses are one tenth of one percent of the depth of a bore hole, mainly due to core fracturing with decompression and drilling of ice with insoluble admixtures.

BORE HOLE PARAMETERS

Bottlenecks in a bore hole are usually formed because of insufficient concentration of antifreeze in the poured liquid. Two reasons for bottlenecks were found : inflow of meltwater to a bore hole from firn, and negative temperature gradient inside a glacier. In both cases concentration of spirit-water antifreeze in the upper part of a bore hole decreases and ice is formed on its walls. The former reason can be eliminated by shifting drilling to another place, or by installing a tube isolating a bore hole from waterpermeable firn layers ; the latter by withdrawal of antifreeze from the area of temperature fall or by adding more antifreeze. According to practical experience, bore holes filled with spirit-water antifreeze and drilled in glaciers with negative temperature gradients are usable for at least one month for descending-lifting of drilling instruments. The above described techniques do not allow long-time operation of a bore hole without maintenance : adding of antifreeze, redrilling of bottlenecks. If antifreeze is partially pumped out of a bore hole, it can be filled with ice by action of the non-compensated pressure of layers. If the liquid is not withdrawn, a surface slush block formes that is initially dissolved by antifreeze. A bore hole can probably be maintained for a long time with three-component antifreeze : water, glycerine, spirits, with higher specific weight than that of water and spirit-water antifreeze.

Curvature of a bore hole takes place because of regulation of driling pressure in the hole. The tested technique of drilling a vertical bore hole was described earlier. In actual conditions bore holes are usually inclinated. In some cases an inclined bore hole has advantages as compared to a vertical one. For instance, an inclined bore hole allows the orientation of pieces of core facilitating studies of the crystal patterns in ice.

Inclination of the bore hole in the Akademia Nauk glacier reached 25°, which made drilling rather difficult.

To reduce inclination the experiments shown in Fig. 3 were carried out.

First, with a thermodrill, two cone-shaped cavities were produced ; this being done with different regimes of heating, the duration increasing from 1/4 of an hour at the narrow side of the cone to 1.5 hrs at its wider side. The step of movement of a heater is about 1.5 times more than the width of the heater ; the vertical dimension of each cavity is 1/4 more than half a length of a drill. First the upper cavity was prepared, then the lower one. In a second phase, by action of its weight, the drill turns in cavities ; if the rate of its descent is made lower than the rate of drilling-melting then a new bore hole with a lower inclination will be produced. This was done made twice ; in the first case inclination of the new hole was 5° from the initial hole, and in the second case about 15°. Probably, if more time is spent on preparation of cavities, this angle may be increased.

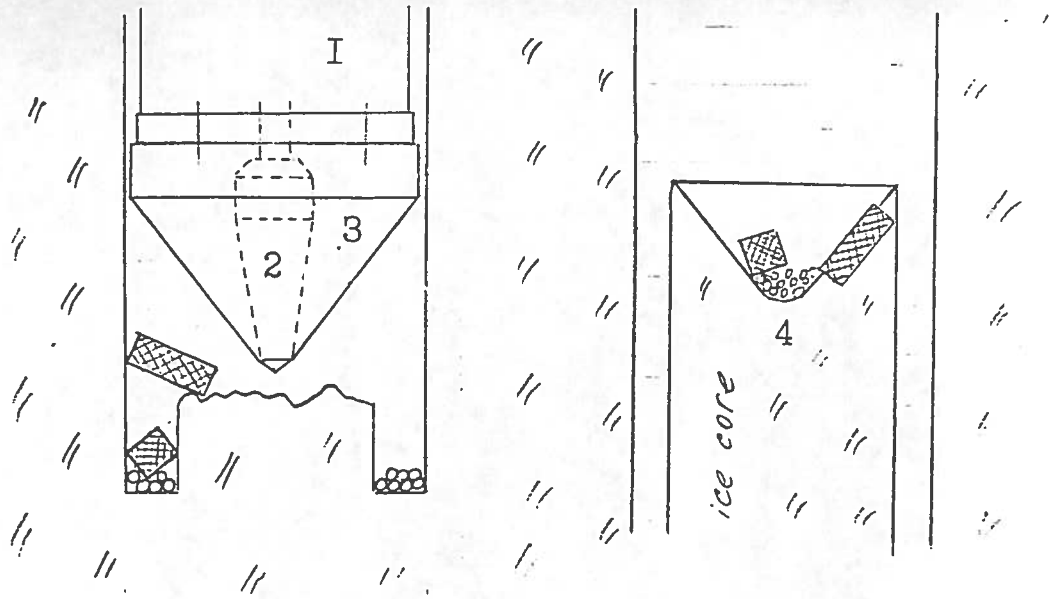
The need to change direction of a vertical bore hole can emerge because of freezing of a drill inside a bore hole, or because it is necessary to take one or several additional cores from the bottom strata of a glacier. Such an experiment, shown in Fig. 3, was implemented after drilling was finished in Austfonna. On the bottom of the bore hole a tube about 5 m long was installed, in its upper part a wedge and a flat spring fixed the apparatus in the bore hole. With the above described technique, 2 cavities were made and one more hole was bored. After the first attempt 1.65 m of core was extracted, and during the second operation the drill was stopped, probably by a wedge, after extraction of 0.95 m of core. The bottom of the second borehole was approximately 1.3 m from the glacier's bed. Other attempts to reach the glacier's bed were not made.

As was already mentioned, when coming across ice strata with 0.5 gr/cm^2 of insoluble admixtures, the rate of drilling-melting decreases 2-4 times and the diameter of the core becomes 50-70 mm. As a rule, dust strata are found near the glacier bottom, but in the process of drilling dirt is gradually accumulated in a bore hole. It is washed from the cable-line and comes with the antifreeze mixture and with meltwater. The above mentioned concentration of technological dirt is accumulated after 100-300 m of drilling, after which the bore hole is cleaned. The technology of evacuating dust, rock debris, nails, and similar items is illustrated by Fig. 4. By a conic heater equal in diameter to the drill, a pit is melted in the bore hole bottom that accumulates undesirable items. With the subsequent drilling, this dirt is extracted out of the bore hole to the surface. In several cases, rock debris up to 2 cm wide was removed from a bore hole. For this operation the core is not lowered by more than 0.3 m.

DRILLING RESULTS

Bore hole drilling in the area of the ice divide of the Akademia Nauk glacier in July-August, 1986, met with some technical and technological difficulties (6). The negative temperature gradient inside the glacier produced slush from antifreeze solution in the bore hole. To cope with this problem the solution was pumped off till depth 160 m. Imperfections of the system of regulation of the drill pressure resulted in inclination of the bore hole ; below depth 360 m the inclination reached 25°. The average rate of drilling for 42 days was 13.3 m per shift. Because of antifreeze shortage drilling was stopped after 561 m of core had been produced. By summer of 1987 the bore hole was partially filled with ice, drilling was continued from depth 220 m at the same rate and 541 m of core was produced. The bore hole reached the bottom of the glacier. At the drilling site the glacier was 720 m thick.

Drilling of a bore hole 1.7 km from the ice divide of Austfonna was started in June 1985 before surface melting. 7 m down, at the boundary of firn and impermeable ice, water lenses were discovered. Firn layers at depths 15 and 30 m drained the drilling solution from the bore hole. Within the depth interval 7-20 m, the temperature of the ice strata is close to the ice melting temperature and downward it decreases. Water running into the bore hole from firn strata was freezing on its walls at rate of about 1 mm/hr. A negative temperature gradient in



WITHDRAWAL OF UNDESIRABLE ITEMS FROM A BORE HOLE.
1 - Core thermodrill ; 2 - Electric heater ; 3 - Metallic cone ; 4 - Ice core.

Fig. 4

the inner layers and the inflow of water from firn produced intensive formation of slush from the solution. These phenomena made it difficult to descend and lift the drilling instrument. Drilling was stopped at depth 204 m (1).

In spring 1987, operations were continued at the same site. In several bore holes it was found that the amount of intraglacial water in the 7 m deep firn strata had increased. The site of deep drilling was therefore moved to the ice divide. A new boring site was set up in 5 days. Operations lasted from 1st to 23 rd of June. At a depth of 566.7 m the drill touched the glacier's bed. Core losses were 0.3 per cent of the depth of the glacier. Except for minor breakages that were repaired without interruption of drilling, there were no major difficulties. The negative temperature gradient inside the glacier down to 165 m caused slush in the bore hole. To dissolve slush blocks, from 5 to 10 litres of spirit antifreeze was added to the bore hole even 4-5 days. Additional use of spirits accounted for no more than 3 % of its total use. In all 1000 litres of ethyl spirit was utilised for drilling in Austfonna. To fill such a bore hole with diesel fuel, five times as much would be required.

The core taken from the bottom strata of the glacier (Fig. 3d) is composed of friction-regelation ice. This ice (Fig. 5) has individual air bubbles up to 1.5 mm in diameter ; around them flat split is formed up to 20 mm wide. Split surfaces have a 30° inclination to the horizon. The major feature of this part of core is the presence of subvertical channels up to 100 mm^2 in diameter. Above the 2,5 m thick layer of this ice, no such channels were found. In the other core such channels were also present.

Four days after reaching the glacier's bottom the level of drilling solution in the bore hole raised from the depth of 80-85 m to about 60 m. The temperature at the glacier's bed measured 6 days after completion of drilling was -1.5°C ; the temperature of the ice melting at the glacier bottom was about -0.42°C. This temperature discrepancy is probably explained by the inflow to the bore hole of mineralized water from beneath the glacier. Three days directly after raising of

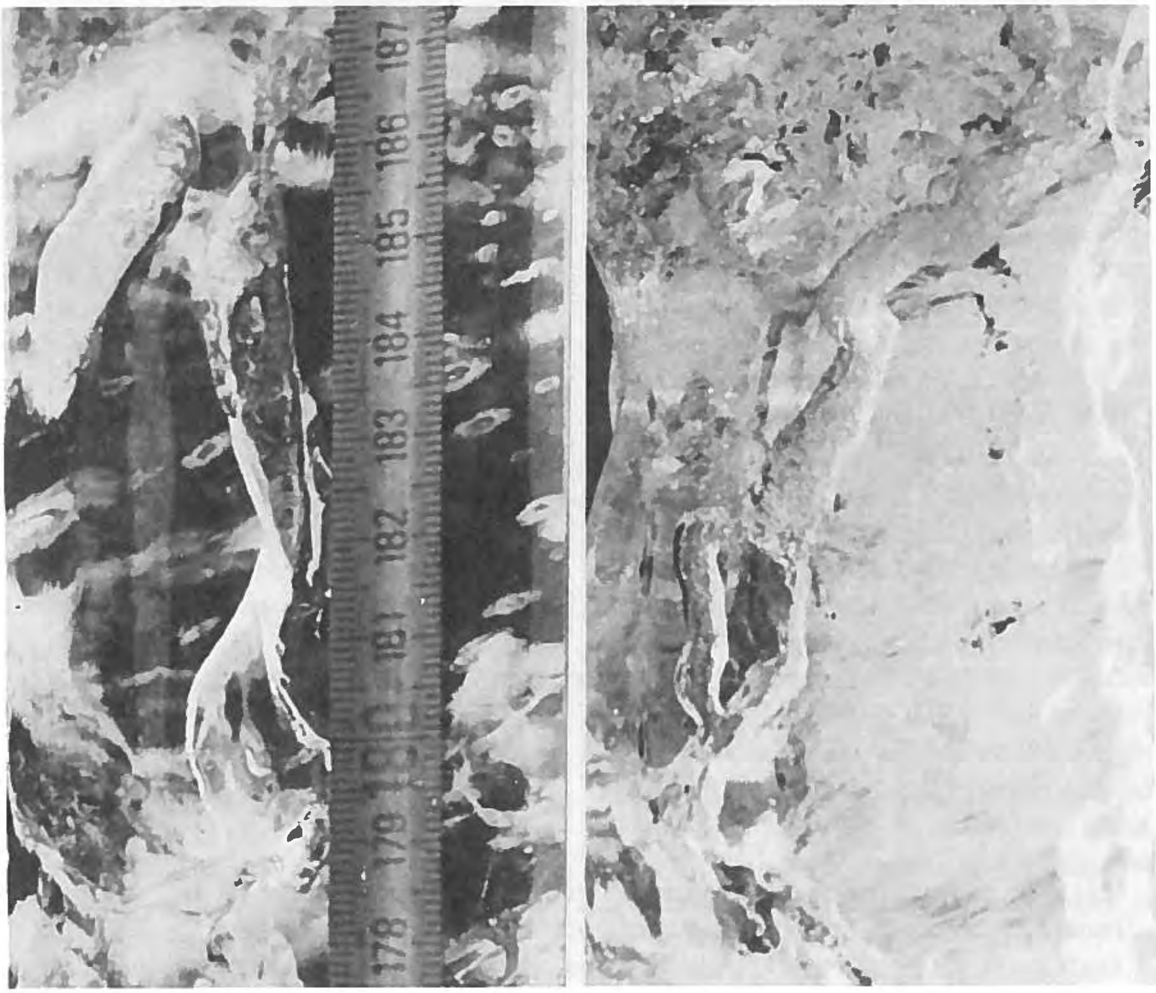
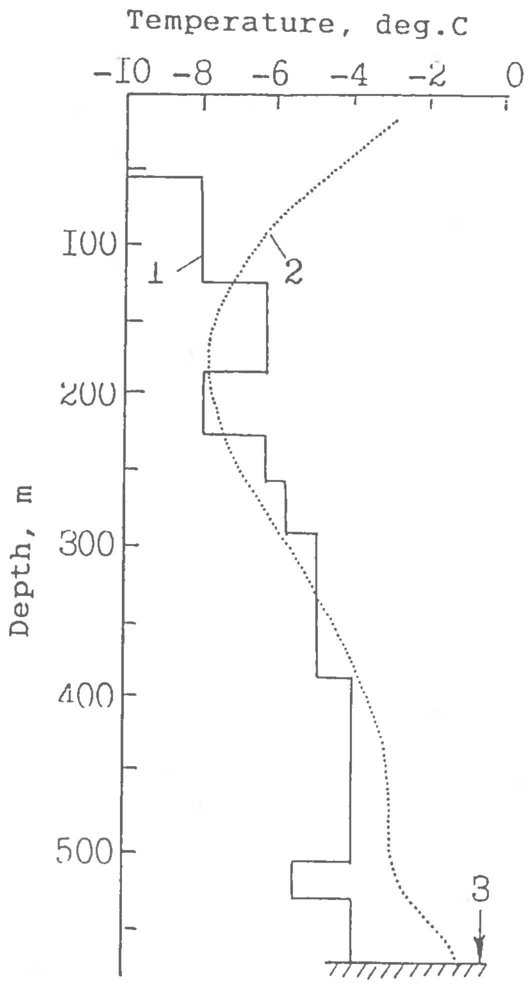


Fig. 5 - Fragments of core with channels from the bottom stratum of Austfonna.

the level of solution in the bore hole, the formation of slush and bottlenecks was not observed.

Fig. 6 shows the measured temperature profile in the glacier and the calculated profile of the freezing temperature of the spirit-water antifreeze in the bore hole. At the depths 150-350 m, spirit concentration in the solution was not sufficient, but in the process of drilling this did not produce significant amounts of slush. Above and below this sector, spirit concentration in the drilling solution was excessive ; this probably promoted levelling of antifreeze concentration in the bore hole. These observations explain why minor disturbances in the technology produce no rapid and irreversible processes causing damage.

Drilling, preparation of the drilling solution, operation of the petrol-electric generator and transportation of the core to the base camp were carried out by 2 persons. Average rates of drilling of this bore hole per shift are shown in Fig. 7. The mean rate of drilling for 12 hours was 25.8 m. The rate of drilling-melting would be increased by 20-30 % with an electric power generator with a capacity 5-6 kW. Use of a more powerful electric motor for a winch would decrease by 20-40 % the time for lifting a drill from a bore hole. Some time could also be saved in the actual drill operation. The above improvements would achieve a mean rate of drilling of 70-80 m for 24 hours when drilling down to 1000 m. However, to reduce fracturing of the core, its length extracted at



Temperature profiles inside the glacier (2), temperatures of freezing of the antifreeze solution in the bore hole (1) and melt point of ice at the bottom (-0.42 deg.C) (3).

Fig. 6

a time should be reduced to 1.5-1.7 m. In this case the mean rate of drilling would be decreased down to 50 m for 24 hrs. The problem of improvement of the quality of core can probably be solved through work on perfecting the drill.

For example, the inside of the core-keeping tube could be re-designed to support the core along its fall length instead of only at the bottom.

CONCLUSIONS

The major advantages of the antifreeze-thermodrilling technology are : low dimensions and weight of equipment, simple and reliable operation, low power consumption, high quality of core. With rather simple techniques it is possible to reorientate a bore hole, thus producing an additional core from the near-bed strata of a glacier.

ACKNOWLEDGEMENTS

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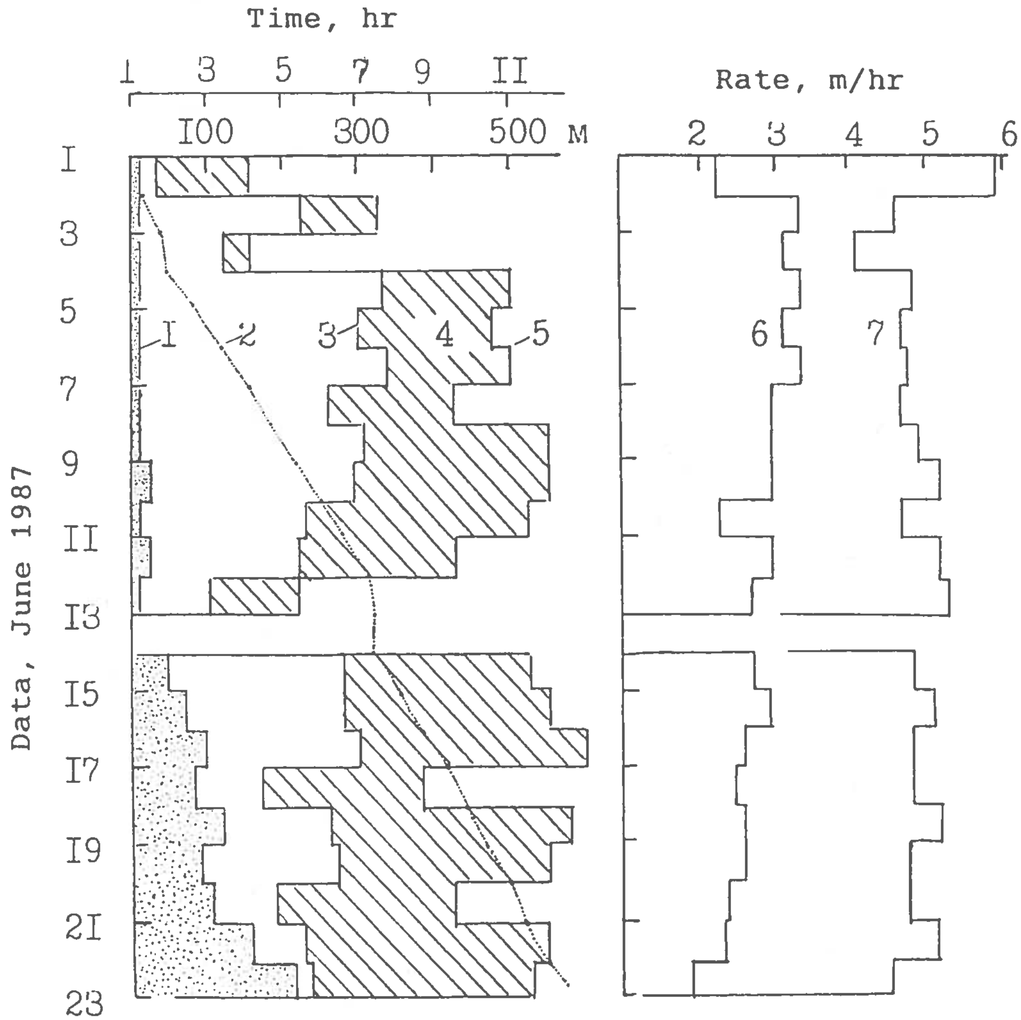

Mean daily parameters of drilling. 1 - total time of descent-lift of a drill, 2 - schedule of drilling of bore hole, 3 - time of drilling-melting, 4 - time of gescent-lift and operation of drill apparatus, 5 - time of drilling, 6 - rate of drilling, 7 - rate of drilling-melting.

Fig.7

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