THERMAL CORE DRILLING IN ICE CAPS IN ARCTIC CANADA

W.S.B. Paterson
Polar Continental Shelf Project
Department of Energy, Mines and Resources
Ottawa, K1A OE4, Canada

ABSTRACT

The CRREL shallow-hole thermal coring drill has been used to drill a 121-m borehole through the Meighen Ice Cap and three holes (230, 299 and 299 m) in the ice cap on Devon Island. Three of the four holes reached bedrock; in the 230-m hole, the drill became frozen in and was lost. Operating conditions, the performance of the drill, and problems encountered are described.

Drilling Program

The boreholes that have resulted from the Polar Continental Shelf Project drilling program in the Canadian Arctic Islands are listed in Table 1. The Meighen Ice Cap is a small (80 km^2) low-lying ice cap which is thought to have originated after the end of the post-glacial Climatic Optimum. The borehole is near the highest point of the ice cap which is also the region of maximum ice thickness. Accumulation is normally in the form of superimposed ice so that drilling was in ice throughout. The ice cap on Devon Island has an area of about 15,500 km^2 and consists of an east-west ridge drained by valley glaciers, most of which extend to sea level. The three boreholes are within 300 m of each other, near the summit ridge, and about 7 km west of its highest point. The summit ridge overlies a region of high bedrock so that the ice at the boreholes is relatively thin. Nevertheless, it spans a time period of about 100,000 years. The top 60 m of each borehole is in firn. The ice is well below the pressure-melting temperature in all cases.

The borehole measurements and the analyses in progress on the Devon cores are listed in Table 2. Two boreholes to bedrock were required because the down-borehole extraction of CO_2 for radiocarbon dating leaves the hole blocked by refrozen meltwater. Thus another borehole was needed for flow and temperature measurements. The third hole is blocked by the drill which became frozen in at 230 m. These boreholes have provided an opportunity to test the consistency of the results of oxygen isotope and other analyses between adjacent boreholes. The majority of the analyses listed in Table 2 were also performed on the Meighen core. In addition, closure rate and temperature were measured in the borehole.

Drilling Techniques

The CRREL thermal coring drill, described by Ueda and Garfield (1969), was used. Of the

Table 1

Details of Boreholes

Ice Cap	Latitude, °N	Longitude, °W	Date	Depth, m	Time Taken, days	Bedrock Reached	Ice Temperature, °C
Meighen	79.9	99.1	June 1965	121	22	yes	-15 to -19
Devon	75.3	82.3	May 1971	230	16	no	-20 to -23
Devon	75.3	82.3	May 1972	299	19	yes	-18 to -23
Devon	75.3	82.3	May 1973	299	16	yes	-18 to -23

Table 2

Devon Island Boreholes: Studies in Progress

Core analyses

1. Count of particulates —Polar Shelf Project
2. Electrolytic conductivity —Polar Shelf Project
3. Ice-fabric analysis —Polar Shelf Project
4. Oxygen isotopes —University of Copenhagen
5. Pollen —Geological Survey of Canada
6. Gas content —C.N.R.S., Grenoble
7. C^{14} dating —University of Bern
8. Si^{32} dating —University of Copenhagen

Borehole measurements

9. Change of inclination —Polar Shelf Project
10. Closure rate —Polar Shelf Project
11. Vertical strain rate —Polar Shelf Project
12. Temperature —Polar Shelf Project
13. Measurement of velocity of radio waves —Scott Polar Research Institute

ancillary equipment, the tower was built by CRREL while the hoist was designed and constructed by the Canadian Longyear Company. An Onan 5-kW gasoline-driven generator provides power for the drill and hoist. The equipment weighs about 1400 kg; the heaviest piece (the drum and 450 m of cable) weighs 450 kg. The equipment is transported to the site by a Twin Otter aircraft fitted with skis. For the first drilling, there was little shelter around the rig; as a result, bad weather caused frequent interruptions. Subsequently, all the equipment has been mounted inside a Parcoll building, with part of one roof section removed to make room for the tower. Drilling can then proceed irrespective of the weather, except in very high winds. The hoist and tower are placed on a substantial wooden platform set on the snow surface; it has never been necessary to relevel the platform during any drilling. The uppermost 3 or 4 m of each borehole is cased with plastic pipe to keep out surface meltwater. A cap is kept on the casing except when the drill is being raised or lowered through the top of it.

The CRREL drill produces a hole of diameter 16.4 cm and a core of diameter 12.2 cm in 1.5-m sections. About 50 minutes are required to drill each section and about 15 liters of meltwater are produced. The water is pumped continuously from the drill head into a storage tank in the upper part of the drill. We preserve the meltwater, filter it for pollen, and perform chemical analyses on it. We have used two versions of the drill. The main improvements in the later model were an improved mechanism for suspending the drill from the cable, a better pump motor, the inclusion of a water-level indicator in the storage tank, and the elimination of valves in the tubes which carry the meltwater from the drill head to the tank. These modifications eliminated several problems encountered with the first drill and the new version proved much more reliable, as shown by reduced drilling times for the 1972 and 1973 boreholes (Table 1).

Core recovery from the boreholes was complete but many of the cores were badly fractured. On Devon Island, starting at a depth of about 70 m, the cores had spoon-shaped fractures at the places where they were gripped by the core catchers. As depth increased, the pattern gradually changed to horizontal fractures; the transformation was complete by about 160 m, at which point there were horizontal fractures throughout each core. Horizontal fracturing continued to within a few meters of the base of the ice. In the lowest few meters, sections of core with spoon-shaped fractures alternated with horizontally-fractured sections. The fractures probably result from release of hydrostatic pressure, coupled with thermal shock. The change in pattern may be related to the development of a preferred orientation in the ice crystals, but this aspect of the cores has not yet been studied in detail.

Our normal practice is to drill for 14 or 15 hours per day because lack of manpower prevents round-the-clock drilling. Closure of the hole during shutdowns has never caused any problem; measured closure rates near the base of the ice are less than 0.3 mm/day. No dirt bands were encountered in the ice on Devon Island. On Meighen Ice Cap, pockets of dirt reduced drilling speeds by up to 25 per cent and also caused the valves in the suction tubes to stick open. This was a serious problem because it allowed water to escape into the hole while the drill was being raised to the surface. However, these valves have been eliminated in later models of the drill. The boreholes have shown little tendency to deviate from the vertical. The horizontal displacement between top and bottom was 0.7 and 1.0 m in the two boreholes where this was measured.

The major setback in the drilling program was the loss of the drill in the 230-m hole on Devon Island. This probably resulted from the leakage of water from the storage tank while the drill was down the hole. The tank was constructed with three small holes near the bottom and the plug in one of them had previously come out while the drill was being raised. The most likely explanation is that one of these plugs came out while the drill was down the hole. This would release about 10 liters of water, about half-way along the length of the drill, into ice at a temperature of -20°C. The alternative explanation, a pump failure, is considered less likely because the pump motor was drawing its normal current when the accident occurred. The first sign of trouble was a reduction of cable tension. Attempts to bring the drill to the surface failed because the motor on the hoist stalled repeatedly. When this was prevented by boosting the output from the generator, the main sprocket on the hoist broke. This put the hoist out of action and greatly reduced the chance of saving the drill. About 70 liters of ethylene-glycol solution were pumped down the hole, by means of a rubber hose to ensure that the solution reached the top of the drill, and an electric heater was kept running in the solution. These attempts to free the drill were unsuccessful, however, and were abandoned after three days. The cable was then cut a short distance above the drill to leave the hole free for measurements.

During the 1973 drilling, a plastic insulator became detached from the drill head and lodged between the head and the ice, reducing drilling speed to less than half normal. It was removed by the following method. The Swiss probe for melting ice down the borehole for gas extraction was run for approximately one hour. This melted a large pear-shaped cavity and it was hoped that the insulator would move to the lowest point of the cavity. This is apparently what happened because, after waiting for about 30 hours for the water to refreeze, the insulator was recovered in the next core.

An improvement we would suggest is a method of orienting the cores that does not rely on a magnetic compass. Although this is a problem peculiar to our area, which is only a few hundred kilometers from the magnetic pole, the lack of core orientation is a serious drawback. We would also suggest an improved system of indicating the water level in the storage tank. The system in our drill appears to be unreliable and in fact we have stopped using it. To avoid the possibility of overflow of the tank, the drill is run for a maximum of 55 minutes, even if the full 1.5 m has not been drilled by then. The pump was expected to be a possible weakness in the drill and so we flush it with alcohol after every run and fit a new one after about 200 or 250 m of drilling. In this way we have avoided any problems with it, except perhaps when the drill was lost.

Summary

The latest version of the CRREL drill is an efficient method of taking cores from depths of a few hundred meters. An idea we put forward for consideration is a drill that collects only meltwater, not ice. Such a drill would no doubt be smaller and lighter than the present one. It would be sufficient for most purposes because the cores have to be melted for most of the analyses performed on them.

Acknowledgment

As will be apparent, our drilling equipment and techniques are those developed by Lyle Hansen and other members of the Technical Services Division at CRREL. I should like to take this opportunity of thanking them for all their assistance.

REFERENCE

Ueda, H.T. and D.E. Garfield, 1969, The USA CRREL drill for thermal coring in ice: *Journal of Glaciology,* v. 8, no. 53, pp. 311-314.