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DRILLING THROUGH THE GREENLAND ICE SHEET

Herbert T. Ueda
and
Donald E. Garfield

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U.S. ARMY MATERIEL COMMAND
TERRESTRIAL SCIENCES CENTER
COLD REGIONS RESEARCH & ENGINEERING LABORATORY
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PREFACE

This report was prepared by Mr. Herbert T. Ueda, Research Mechanical Engineer, and Mr. Donald E. Garfield, Mechanical Engineer, of the Technical Services Division, Cold Regions Research and Engineering Laboratory (CRREL), U.S. Army Terrestrial Sciences Center (USA TSC). The project was supervised by Mr. B. Lyle Hansen, Chief, Technical Services Division.

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ABSTRACT

In July 1966 a USA CRREL drilling team succeeded in penetrating the Greenland ice sheet at Camp Century, drilling through 4550 feet of ice and 12 feet of sub-ice material. The objectives of the project were to gain an understanding of the basic flow mechanism of large ice masses and to collect continuous, undisturbed cores for scientific analyses. The two techniques of core drilling used to complete the hole were thermal drilling and electrodrilling. This preliminary report describes the drilling equipment and techniques used at Camp Century from 1963 to the completion of the deep drill hole in 1966.

DRILLING THROUGH THE GREENLAND ICE SHEET

by

Herbert T. Ueda and Donald E. Garfield

Introduction

In July 1966, a USA CRREL drilling team succeeded in penetrating the Greenland ice sheet at Camp Century after drilling through nearly a mile of ice. This effort, under the sponsorship of the National Science Foundation, was undertaken to gain an understanding of the basic flow mechanism of large ice masses such as the Greenland and Antarctic ice sheets and to provide continuous, undisturbed cores for scientific analyses (Bader, 1962).

The mechanism of ice sheet flow can best be determined from knowledge of the ice temperature, ice morainal content, and ice movement, each with respect to depth. This information can only be obtained by drilling a hole completely through the ice sheet, measuring the temperatures, retrieving and examining the cores, and measuring the deformation of the hole for a number of years afterward (Wagner, 1968).

The ice cores contain terrestrial and extraterrestrial materials that have fallen to the Earth's surface, in addition to samples of previous atmospheres in the form of tiny air bubbles. With methods now being developed for age dating the ice, the cores can become a new chronological source of geophysical and geochemical information extending back tens of thousands of years (Langway, 1967; Oeschger *et al.*, 1966).

This report describes the two techniques of core drilling used to complete the hole, thermal drilling and rotary drilling with the Electrodrill.

Equipment and operations (thermal drill)

The remoteness of the drilling sites and the normally short operating season in the polar regions precluded the use of conventional core drilling techniques (Lange, 1965). In an attempt to overcome these problems, an electrically heated, cable-suspended thermal drill was designed (Fig. 1).

The melting element was an annular copper heater, $6\frac{3}{8}$ in. OD by $4\frac{7}{8}$ in. ID, with 18 cartridge heaters rated at 9 kilowatts. Spring-loaded core dogs, located just above the heater, were used to break off and retain the core. A 10-ft-long steel core barrel, a laminated plastic melt water collection tank, a switch housing, and a transformer comprised the remainder of the unit. A gear pump, located inside the melt water collection tank, pumped the water formed at the heater through heated nichrome tubes and up into the collection tank. The unit was 30 ft long and weighed 900 lb.

The drill was suspended from a 1-in.-diam. double armored electromechanical cable containing 12 electrical conductors. A hydraulic winch, with an attached 30-ft tower, was used to raise and lower the drill. Overall winch weight was 19 tons including 12,000 ft of cable. This unit was installed in an undersnow trench at Camp Century, Greenland (77° 10' N, 61° 08' W), about 140 miles east of Thule Air Base (Fig. 3).

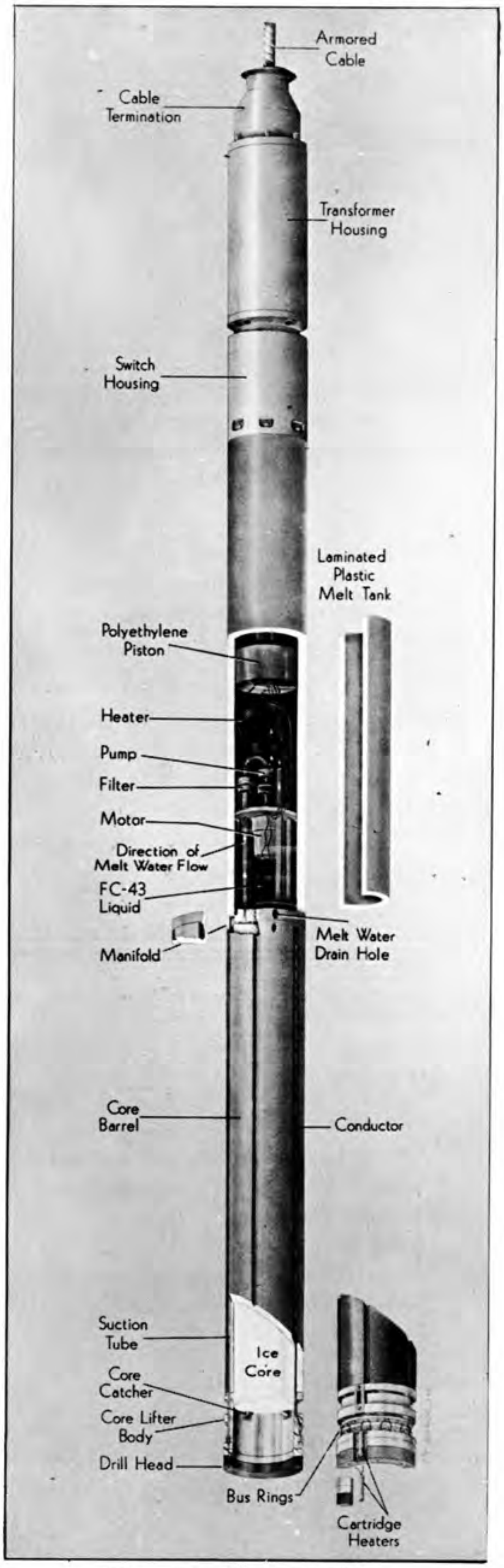


Figure 1. Thermal drill.

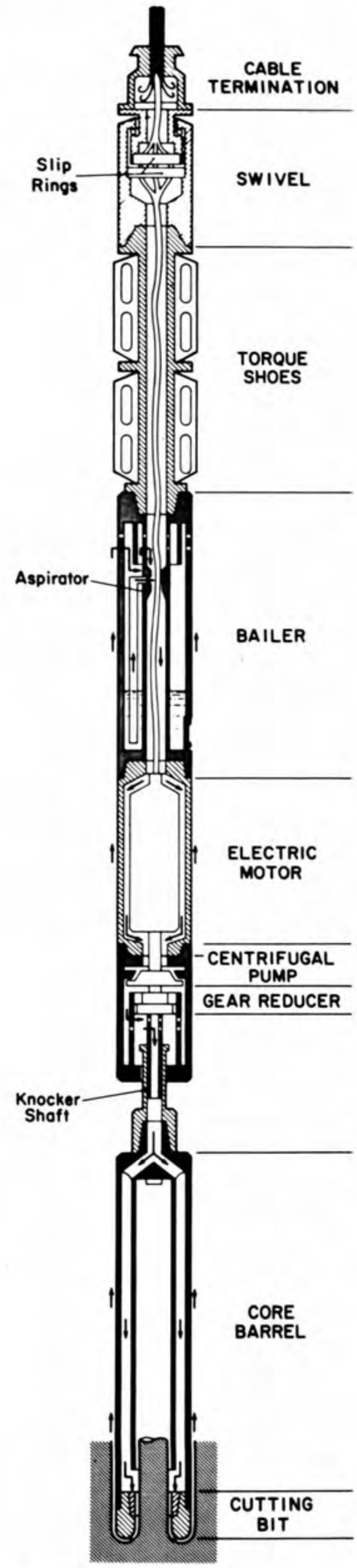


Figure 2. Electrodrill.

After two unsuccessful attempts to penetrate the ice sheet, a third hole was started in 1963 and advanced to 1755 ft by 1964, but not without difficulty. Drilling rates averaged about 1 in./min at power inputs of 5–6 kw and core recovery was 96%. Numerous problems were encountered. The most serious involved the removal and collection of melt water and the presence of residue in the hole which severely reduced the heat transfer, and subsequently the melting rate, of the heating element. Increasing the power did not increase the rate and only resulted in premature heater burnouts. Other problems included the breakage of electrical conductors within the cable, breakage of cable outer armor strands, and leaks in the winch hydraulic system.

To counteract hole closure caused by the plastic flow of the ice, the hole was loaded with a fluid of the same density as ice (0.92 g/cm^3). This fluid, a mixture of diesel oil and trichlorethylene, possessed strong solvent properties. It eventually removed a rust inhibiting compound used on the cable, creating a residue which continually settled to the bottom of the hole, impeded the melting rate, clogged the pumping circuit, and ultimately forced the discontinuation of drilling with the thermal method.

Further trials with the thermal drill in fluid-filled holes have not been pursued. However, for relatively shallow holes (less than 1500 ft) in clean ice, and where a fluid is not used in the hole, the thermal concept is feasible. In locations where a layer of permeable snow or firn must be penetrated before impermeable ice is reached, which is usually the condition encountered on the large ice sheets, thermal drilling is a very effective method. A unit for this purpose, the USA CRREL drill, has been developed (Ueda and Garfield, in press). This cable-suspended unit melts a hole $6\frac{7}{16}$ in. in diameter or larger and retrieves a core $4\frac{13}{16}$ in. in diameter or smaller, at a rate of $1\frac{1}{2}$ in./min with 3.5-4 kw of power. Gross weight of all necessary equipment is approximately 2400 lb including 1500 ft of cable.

Equipment and operations (electrodrill)

In 1964, a reconditioned electrodrill (Sutton and Arutunoff, 1954) was purchased and modified for use in ice. This cable-suspended, electromechanical rotary drill was invented by Mr. Armais Arutunoff, President of Reda Pump Co. of Bartlesville, Oklahoma.

The final version of the unit was 83 ft long and weighed 2650 lb. It consisted of six main sections (Fig. 2). At the top of the drill was a swivel section where the suspension cable terminated and where the electrical power was transmitted through a slip-ring assembly. This section allowed the rest of the drill to rotate relative to the cable. Below the swivel were the torque shoes which provided cutter reaction torque. Hinged shoes were designed to be thrown out against the hole wall and restrain the rotation of all but the core barrel and cutting bit. Problems with the slip rings eventually resulted in the elimination of the swivel section and it was discovered that cutter counter torque could be provided by the suspension cable alone without torque shoes. This technique of torque reaction was used throughout the remainder of the drilling.

The bailer was located just below the torque section and was modified for drilling in ice. In the original design the cuttings were deposited in the bottom of the bailer after being removed from the path of fluid flow. Since the density of the fluid in the hole was essentially equal to the ice chip density, this technique could not be used. Instead, the chips were dissolved in an aqueous ethylene glycol solution. This technique depends on a knowledge of the relationships shown in Figures 4 and 5, the freezing point diagram for aqueous ethylene glycol solutions (Cragoe, 1955) and the ice temperature versus depth profile for the location. A volume of concentrated glycol, the amount depending upon the downhole ice temperature and the volume of chips formed, is sent down in the bailer on each run. An aspirator assembly ensures mixing of the concentrated solution into the pump flow. This glycol dissolves the chips and dilutes itself to the equilibrium concentration for the downhole temperature. A bailer full of dilute solution is removed on each return trip with the core. Any solution remaining downhole will stay downhole since it is denser than, and immiscible with, the hole fluid. It will not melt any ice since it is

Figure 3. Undersnow trench installation, Camp Century, Greenland.

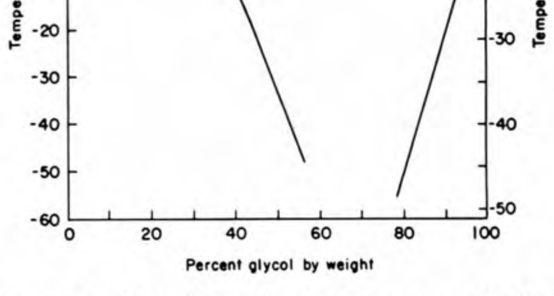


Figure 4. Freezing points of aqueous ethylene glycol solutions (Cragoe, 1955).

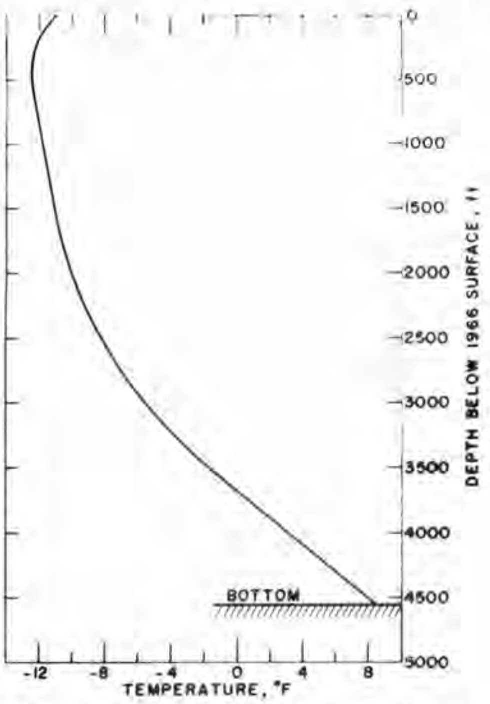


Figure 5. Drill hole temperatures, Camp Century, 1966.

at the equilibrium concentration. Glycol consumption is about 0.26 gal/ft of hole at 10F and 0.62 gal/ft at -20F. In ice colder than about -50F, the volume of glycol required makes the method logistically impractical.

In practice, more glycol was consumed, as the concentration of the solution was kept slightly rich. This resulted in some melting of the ice and subsequent downhole accumulation of solution. The excess was periodically removed, as its presence could prolong the period of time required for the hole to return to its original, undisturbed temperature. Approximate downhole temperatures were measured throughout the drilling.

Below the bailer was a 17½-hp, three-phase submersible induction motor, operated at 2300 v at a nominal speed of 3600 rpm. The glycol flowed through an annular space between the motor and its cylindrical housing. Heat from the motor, transferred to the glycol, provided the heat of solution to dissolve the ice chips.

Beneath the motor was a gear section which included a pump and gear reducer. The centrifugal pump was operated at 3600 rpm and rated at 80 gal/min with a 120-ft head. Below the pump, a planetary gear reducer dropped the shaft speed from 3600 rpm to 225 rpm, the speed of rotation of the core barrel and cutter.

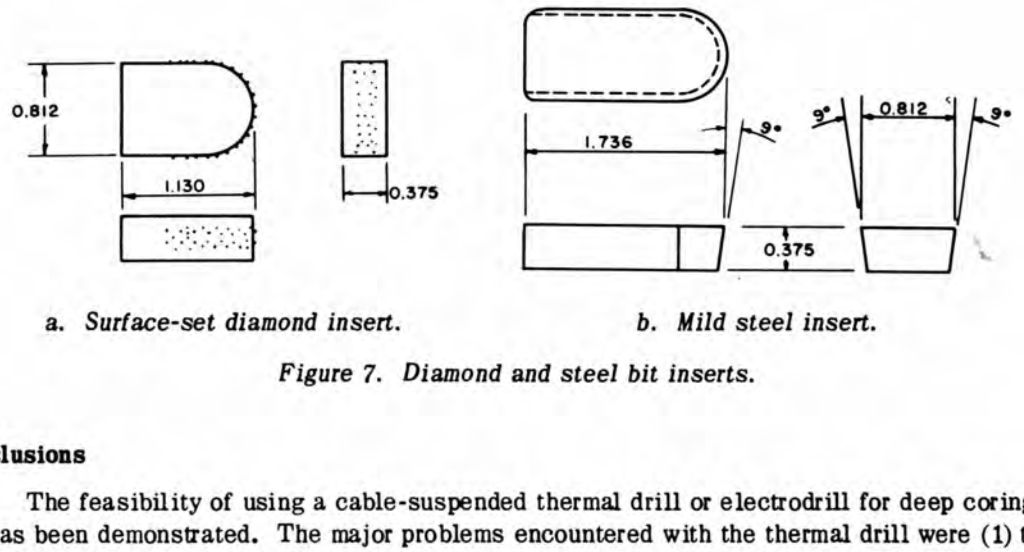
Power was transmitted from the gear reducer to the core barrel through a splined hollow driveshaft. An 18-in. axial movement of the shaft allowed the core to be broken by impact if necessary. The core barrel was a double tube, swivel head type capable of holding a 20-ft core.

Two types of cutting bits with similar configurations were used, a steel bit with eight vertical mild steel inserts and a diamond bit with eight sintered tungsten carbide inserts (Fig. 6, 7). Diamonds were distributed around the outer face of each tungsten carbide insert with approximately 0.22 – 0.28 karats/stone and eight karats/insert. Bit dimensions were 6⅛ in. OD by 4½ in. ID. Core diameters averaged 4¼ in. or slightly less.

Aside from minor difficulties, drill performance was highly satisfactory. With a rotary speed of 225 rpm and approximately 700 lb of drill weight on the steel bit, drilling rates averaged 5-6 in./min with 11-12 kw of power. Less than 1 kw of power went into the cutting of the ice. By keeping the remaining drill weight in suspension, the hole was kept plumb. Equal drilling rates at lower bit loads were realized using the diamond bit. Eight- to fifteen-ft cores were retrieved in good condition using a tapered split-ring core lifter. Core recovery was 98%.

By July 1966 the hole was advanced from 1755 ft, where thermal drilling had been terminated, to the bottom of the ice sheet, 4450 ft from the surface. Coring continued to 4562 ft, where a worn bearing in the gear section prevented further penetration. Sub-ice material consisted of a conglomerate of frozen till and various sized rocks (Hansen and Langway, 1966). In this material, drill rates decreased to 1½ in./min and drill weight on the bit increased to 1800 lb with the power input rising to 16 kw.

Figure 6. Diamond bit.



a. *Surface-set diamond insert.* b. *Mild steel insert.*

Figure 7. Diamond and steel bit inserts.

Conclusions

The feasibility of using a cable-suspended thermal drill or electrodrill for deep coring in ice has been demonstrated. The major problems encountered with the thermal drill were (1) the difficulty in designing a reliable melt water removal system when drilling in a fluid-filled hole, and (2) the requirement for a clean environment at the hole bottom. Neither of these problems affected the electrodrill and, in addition, the electrodrill penetrated faster. For core drilling deep holes in ice at temperatures higher than about -50F, the electrodrill with a steel or diamond bit, using the glycol chip removal concept, is the more desirable method.

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