

Technical Report 231

CORE DRILLING THROUGH THE ANTARCTIC ICE SHEET

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December 1969

CORPS OF ENGINEERS, U.S. ARMY COLD REGIONS RESEARCH AND ENGINEERING LABORATORY HANOVER, NEW HAMPSHIRE

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PREFACE

This report was prepared by Mr. Herbert T. Ueda, Research Mechanical Engineer, and Mr. Donald E. Garfield, Mechanical Engineer, Technical Services Division, U.S. Army Cold Regions Research and Engineering Laboratory. The work reported here was part of the USA CRREL deep ice core drilling program under the direction of Mr. B. Lyle Hansen, Chief, Technical Services Division. The program was partially funded by the National Science Foundation, Office of Antarctic Programs. This report was published under DA Project 1T061101A91A, In-House Laboratory Independent Research.

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Citation of trade names or manufacturers in this report is for information only and does not constitute official approval or endorsement.

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by

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INTRODUCTION

On 29 January 1968, a USA CRREL drilling team successfully penetrated the Antarctic ice sheet at Byrd Station (80°91'S, 119°31'W) after drilling through 7100 ft of ice. The primary objectives of the drilling were: 1) To cut a hole completely through the ice sheet to allow measurements of the temperature profile, the ice flow within the sheet, and the ice flow relative to the underlying bed. 2) To provide a continuous, undisturbed core for investigating the physical, structural and geochemical properties of the ice. 3) To permit the future in situ extraction of entrapped atmospheric gases such as the carbon dioxide used to age date the ice.

EQUIPMENT

Drill

With the exception of the first 289 ft, drilling was accomplished with a cable-suspended, electromechanical, rotary coring Electrodrill* purchased from the Reda Pump Co. in 1964. After being modified and tested for coring in ice, it was used to complete the penetration of the Greenland ice sheet at Camp Century (77°10'N, 61°08'W) in 1966 (Garfield and Ueda, 1968). After further modification, it was used during the 1966-67, 1967-68 austral summers at Byrd Station.

The Antarctic version of the drill weighed 2650 lb, was 87 ft long, and consisted of six sections (Fig. 1): an inclinometer housing, a reaction torque section, a bailer, an electric motor, a pump and gear reducer section, and a core barrel with attached cutting bit.

The inclinometer housing was fabricated from 304 stainless steel and was designed to permit rapid installation and removal of the inclinometer, thus permitting hole deviation measurements to be made on any coring run. A Parsons Survey single shot inclinometer, sealed in a pressure-tight container and electrically triggered from the surface, measured the direction and magnitude of the hole inclination from the vertical.

The reaction torque section consisted of four sets of hinged friction blades designed to swing freely out against the hole wall when the drill motor was started. This restrained the rotation of all drill sections except the core barrel and cutting bit. Additional restraint was provided by two leaf springs and by the inherent torsional rigidity in the suspension cable.

The bailer was used to collect the cuttings formed during drilling. Cuttings from dense material such as rock are normally removed from the circulating fluid by gravity as the fluid is

* The Electrodrill is an invention of Mr. Armais Arutunoff, Reda Pump Co., Bartlesville, Oklahoma.



Figure 1. Electrodrill

diverted 180° by a baffle at the top of the bailer. The cuttings then settle and collect in the bailer. In ice, where the density of the cuttings approximated the density of the hole fluid (0.92 g/cm³), the cuttings were dissolved in an aqueous ethylene glycol solution which was then removed from the hole. The relationships shown in Figure 2, the freezing points for aqueous ethylene glycol solutions (Cragoe, 1955), and Figure 3, the ice temperature versus depth profile for the location, are needed to utilize this technique.

Concentrated glycol was sent downhole in the bailer on each coring run, the amount depending upon the downhole temperature and the volume of cuttings expected. This glycol was mixed with the dilute solution downhole with the aid of an aspirator assembly and circulated along the drill by the pump. It dissolved the cuttings and was diluted to the equilibrium concentration for the downhole temperature. The net heat required for this process was obtained from the waste heat produced during drill operation by friction in the electrical, mechanical and hydraulic systems. A bailer full of dilute solution was removed on each return trip of the drill to the surface with the core. The excess solution remained downhole as it was denser than, and immiscible with, the hole fluid; it did not dissolve any additional ice since it was at the equilibrium concentration. A slightly rich solution was used, resulting in some excess melting of ice from the hole wall and subsequent downhole accumulation of solution. This excess was periodically removed as its presence was undesirable when measuring equilibrium ice temperatures. Theoretical glycol consumption is about 0.26 gal/ft at 10° F and 0.62 gal/ft at -20° F based on an annulus of $6\frac{3}{6}$ in. OD by $4\frac{1}{4}$ in. ID. Actual consumption during the Byrd Station drilling was 0.85 gal/ft.

The depth versus temperature relationship at this location created difficulties in the use of aqueous ethylene glycol solutions. The minimum temperature region in the hole required that all solutions sent downhole be diluted to about 90% glycol to insure arrival at the bottom in a liquid state. The same condition made drainage of the dilute solution from the bailer at the surface extremely difficult as the solution from the greater depths came up either partially or completely frozen.

The cutting bit and pump were powered by a 17½-hp, **3**phase, submersible induction motor operated at 2300 v and a nominal speed of 3600 rpm. The motor interior was filled with insulating oil and was sealed from the ambient hole environment. A compensating piston maintained pressure equilibrium with the downhole pressure. The glycol solution circulated through an annular space around the motor housing. Heat from the motor provided part of the heat of solution for dissolving the ice cuttings.

The motor output was directly coupled to the pump and gear reduction section. A 3600-rpm, 3-stage centrifugal pump rated at 80 gal/min at 120-ft head circulated the glycol solution. Ice cuttings were removed from the bit and placed in the circulating flow where they were eventually dissolved. A 2-stage planetary gear reducer









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Figure 4. Twenty-foot core from 6500-ft depth.

slowed the motor shaft speed from 3600 rpm to 225 rpm, the speed at which the core barrel and cutter were rotated. The reducer was sealed from the ambient fluid and pressure-compensated with the ambient pressures. The gear reducer was coupled to the core barrel through a splined, hollow driveshaft. An 18-in. axial movement of the shaft between the gear section and core barrel permitted 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. Outer barrel OD was 5.75 in. and inner barrel ID was 4.63 in. Core was removed by first breaking the connection at the top of the barrel. The barrel was removed from the hole with an auxiliary hoist and inclined at a 12° angle. The cutter and core lifter were then removed and the core permitted to slide onto a 20-ft inclined trough (Fig. 4). Tapered split-ring core lifters with external splines were used throughout the drilling.



Figure 5. Diamond bit.



Figure 6. Diamond and steel bit inserts.

Steel and diamond cutting bits were used in the ice. A diamond bit (Fig. 5) was used to cut through the 15 ft of rock debris-laden ice at the bottom of the sheet and in the unsuccessful attempts to obtain a core from the sub-ice material. The diamond bit consisted of eight tungsten carbide inserts serving as the matrices for the surface set diamonds (Fig. 6a). Diamond distribution was approximately 0.22-0.28 carats/stone and 8 carats/insert. The steel bit consisted of eight mild steel inserts (Fig. 6b). Bit dimensions were $6\frac{1}{8}$ in. OD and $4\frac{1}{2}$ in. ID producing an average core and hole diameter of $4\frac{1}{4}$ in. and $6\frac{3}{6}$ in.



Figure 7. Installing steel cutting bit on bottom of core barrel.

Cable

The drill was suspended from a 1-in.-diam, double armored, electromechanical cable (Fig.8). The two outer layers of armor, which mechanically supported the drill, consisted of preformed high strength steel wires, each layer being of opposite lay. Inside, a polyethylene jacket enclosed three #12 AWG and nine #22 AWG stranded, individually insulated copper conductors. Drill motor power was conveyed through the #12 wires while the smaller #22 wires were used for instrumentation purposes when required. The 12,000 ft of cable weighed 1.4 lb/ft and had a breaking strength of 70,000 lb. The cable was terminated at the top of the drill as illustrated in Figure 9. With this simple but effective termination, the full strength of the cable could be developed (Czul and and Gennari, 1965).



- a. No. 12 AWG, 19-wire stranded copper conductors covered with 0.070 in. polyethylene insulation. 3 each.
- b. No. 22 AWG, 7-wire stranded copper conductors covered with 0.011 in. polyethylene insulation.
 9 each.
- c. Galvanized steel wire (0.083 in. diam). 24 each.
- d. Galvanized steel wire (0.105 in. diam). 24 each.
- e. Cotton filler.
- f. Mylar tape (0.007 in. thick), 0.010 in. Nylon braid.
- g. Polyethylene insulation (0.055 in. thick).

Figure 8. Cross-section of 1-in.-diam armored cable.



Figure 9. Cable termination.

Hoist and tower

A 25,000-lb-capacity electrohydraulic hoist built by the Leithiser Co. of York, Pennsylvania, raised and lowered the drill in the hole. Previous difficulties in winding a cable under high tension directly on a reel prompted the selection of a capstan drive principle. The cable was first wound several times around the two large, hydraulically driven grooved wheels at the front end of the hoist (Fig. 10). These wheels absorbed most of the tension in the cable, which was then



Figure 10. Electrohydraulic hoist with 12000 ft of cable.

wound on the storage reel under a nominal tension of about 1000 lb. The 12,000-ft-capacity storage reel was hydraulically traversed to maintain an orderly wrap. An orthocyclic winding principle kept the cable wound neatly on the reel. The hoisting rate was variable from 37-150 ft/min. Total hoist weight with cable was approximately 40,000 lb.

The hoist was installed in the main tunnel on a foundation of 12×12 -in. and 12×6 -in. timbers embedded in the tunnel floor (Ueda and Hansen, 1967). To suspend the 87-ft-long drill, a 70ft aluminum tower was erected directly over the hoist (Fig. 11). The tower foundation consisted of 6×12 -in. timbers spanning the width of the tunnel and laid on the snow surface. A large hole was cut through the 21 ft of snow cover through which the drill could pass. This arrangement eliminated the need for an additional 40 ft of tower height (Fig. 12, 13). Tunnel temperatures averaged -17°C.

The slower rate of cable and drill descent required while the drill was being lowered the last few feet in the hole and during drilling was provided by a hydraulic cylinder at the top of the tower (Fig. 14). The cable was passed around a 42-in.-diam sheave attached to the end of the cylinder piston rod. With a 12-ft piston stroke, this arrangement permitted 24 ft of drill movement, variable from 0-2 ft/min. A link in the cylinder suspension instrumented with strain gauges provided a direct indication of the cable load.



Figure 11. Aluminum tower. (Official U.S. Navy photograph.)

Hole fluid

Because of the plastic nature of ice, an unfilled drill hole would have contracted at a rate increasing with depth and time (Gow, 1963). At some depth, estimated to be 1500 ft at Byrd Station, it would no longer have been possible, within the time required to complete a coring run, to return to the previously drilled depth. To overcome this limitation, the hole was continuously loaded with a mixture of arctic diesel fuel and trichlorethylene mixed to a density of 0.92 g/cm³ which provided the necessary hydrostatic compensation. The level of this mixture in the hole was maintained between 250 and 350 ft from the surface throughout most of the season. Approximately 12,900 gal of diesel fuel and 2100 gal of trichlorethylene were consumed during the operation.



Figure 12. Equipment layout, Byrd Station. (Artist's sketch - NSF.)



Figure 13. Subsurface equipment layout.



Figure 14. Hydraulic cylinder at top of tower for slow speed cable and drill descent.

Below this mixture, a small volume of dilute aqueous ethylene glycol solution of density 1.1 g/cm^3 was usually present. This solution was periodically removed; however, a shortage of trichlorethylene during the latter part of the season necessitated leaving the glycol solution downhole to help maintain the liquid column height. At the end of the drilling, the glycol solution had attained a height of 1500 ft from the hole bottom.

OPERATING PROCEDURE

The drilling operation normally required two men per shift. A third man, whose primary duty was core handling and logging, assisted when the drill was at the surface. One man operated the hoist while the other prepared and analyzed ethylene glycol solutions, mixed and pumped the diesel-trichlorethylene hole fluid, assisted with the handling of the core, and maintained the equipment as required.

An operating cycle began with the lowering of the suspended drill into the hole. At each appropriate section, the drill was stopped and the following steps were performed: 1) lubrication of the gear section, 2) lubrication of the motor section, 3) pumping of the required volume of concentrated glycol into the bailer, and 4) installation of the inclinometer when it was used.

Since the drill weight alone was inadequate to pull out the cable, i.e. freewheel, initial lowering was accomplished by driving the hoist in reverse. As cable was paid out, the added weight eventually became great enough to freewheel the drive. Lowering rates were controlled by variable relief and flow control valves which regulated the hydraulic oil flow in the hoist.

The descending drill was stopped 3 to 4 ft from the hole bottom. The hydraulic cylinder at the top of the tower was then actuated and used to further lower the drill and cable until the drill cutting bit touched bottom. The reduction of load on the cable as the drill touched bottom was observed on the cable tension indicator as were all drill actions. After contact with the ice, the drill motor was started and the hydraulic cylinder lowering speed set at the desired drilling rate. An initial $1\frac{1}{2}$ ft of axial drill motion was required before the cutting bit started to advance into the ice, due to the axial freedom in the coupling between the core barrel and gear section.

After the desired length of core was drilled, usually 15-20 ft taking 40-50 minutes, the drill motor was stopped and the hydraulic cylinder drive reversed. Again a $1\frac{1}{2}$ ft vertical drill movement was necessary before the core lifter began to seize the core. A fairly reliable indication of a core break could be observed on the weight indicator. A typical indication was a steadily increasing load, usually reaching a maximum of about 2000 lb, followed by a sudden decrease in load. An oscillating or bouncing indicator needle movement after the load drop, created by the free drill on the end of the elastic cable, indicated a core break. A load decrease accompanied by a damped needle movement indicated a slip.

Breaking the core at times proved to be a tedious and extremely frustrating process. Raising the drill too fast did not allow the core lifter to seize the core; therefore, a rate of 1 to 2 in./min was usually used. This slow rate consumed considerable time. In the extreme case, the seizing and slipping action of the lifter continued for the entire 20 ft of core length, consuming more time than was necessary to drill the core. Another exasperating situation involved hauling the drill to the surface after a seemingly indicative core break, only to find no core in the barrel. Fortunately these occurrences were rare and towards the latter part of the season an effective and reliable technique for rupturing the core was implemented.

This technique consisted of continuing to operate the drill motor and pump but stopping the drill advance after the desired core length had been drilled. This permitted the pump to continue

circulating the glycol solution which, after a few minutes, wore a neck around the bottom of the core. This reduced the cross-sectional area of the core with a subsequent decrease in the rup-turing load and also gave the core lifter a better opportunity to grip the core.

After rupture of the core, the hoist drive was engaged to raise the drill out of the hole. During retraction, the cable was passed through an air wiper; this removed and returned to the hole most of the fluid still clinging to the cable. This was part of a continual effort to keep the hole fluid, with its trichlorethylene content, from dripping onto the equipment and attacking the various surfaces and materials, and contaminating the air around the working area with its toxicity.

As the top section of the drill reached the surface, the drill was stopped and the inclinometer removed. At the next stop, the bailer was drained using a large 4-in.-diam flexible hose. Finally the core barrel was detached from the rest of the drill and maneuvered to a position in front of the core removal ramp. After core removal, the barrel was raised back to a vertical position, lowered into the hole, and another cycle begun.

PERFORMANCE AND RESULTS

The initial penetration into the ice sheet began during the 1966-67 austral summer (Ueda and Hansen, 1967). Starting from the tunnel floor, 39 ft below the 1967 surface level, the USA CRREL thermal drill with an oversized 8-in.-diam core barrel drilled to a depth of 289 ft. After the hole was cased and the drilling equipment installed, the Electrodrill was used on a one-shift basis beginning on 2 February 1967. The hole depth was advanced to 745 ft.

During this period, difficulties were encountered in starting the drill motor downhole. The viscosity of the insulating oil (General Electric 10-C) used in the motor and the lubricating oil used in the gear section resulted in much higher electrical starting surges than the motor starting system was designed for. Problems were also experienced with the glycol circulation system in the drill and on one occasion resulted in the drill being stuck at a depth of 390 ft for four days. Minor troubles with the hydraulic hoist consumed additional time. Drilling ceased on 18 February 1967.

Operations resumed on 23 October 1967, and drilling resumed on 1 November on a two-shift 24-hour-per-day schedule that was maintained throughout the 1967-68 season. The drill motor starting difficulty experienced the previous year was corrected by changing to a lower viscosity insulating oil (Sun Oil Circo 4X). No problems were experienced with the glycol circulation system.

By the end of November, a depth of 2520 ft had been attained. The hole began to deviate from the vertical at a depth of 750 ft. The inclinometer reading at 940 ft indicated the hole had returned to the vertical but beyond this depth the deviation resumed and continued to the bottom of the ice sheet. Efforts to correct the deviation were time consuming and ineffective. These efforts included slowing the drilling rate in order to suspend more of the drill weight, taking shorter cores, and welding spacers along the drill, thereby centering the upper part of the drill in the hole and allowing the relatively loose hanging core barrel to seek a more vertical path. The penetration rate for the month averaged 60 ft/day.

By the end of December, the hole depth had been advanced to 4600 ft with the inclination reaching 11° from the vertical. One gear section was lost from wear and one drill motor was burned out. Fortunately one spare unit was available for each. Problems with several key hydraulic components in the hoist resulted in much lost time.

Of the 16 hydraulic pumps and motors in the hoist, 7 became excessively worn or completely inoperative. Since only a limited amount of spare parts were available, the hoist was kept operable but at a 40% reduction in the hauling rate. This condition prevailed throughout most of the remainder of the season. The primary cause of the component failures was the inability to maintain the hydraulic oil at the design temperature. At the higher temperatures, the low viscosity of the Mobil HFA (Mil-H-5606) oil resulted in an excessive amount of metallic wear in the components. On one occasion, the operation had to be stopped with the drill at 4100 ft when the reel circuit pump failed. A replacement unit failed immediately after installation and 48 hours elapsed before a workable circuit could be improvised and the drill hauled out of the hole. Despite the delays, a penetration rate of 66.5 ft/day was achieved for the month.

Penetration rates increased considerably during January, mainly for two reasons: 1) the length of each core drilled was increased to a maximum of 20 ft in order to reduce the number of hauling cycles on the hydraulic hoist, and 2) the change in ice structure and the increased effectiveness of the steel bit at the greater depths produced drilling rates as high as 7.8 in./min.

On 28 January 1968, at a vertical depth of 7082 ft, the first indication of sub-ice debris was recorded. The drill was immediately retracted from the hole and the steel bit replaced with a diamond bit. The hole was advanced to 7094 ft and a core containing considerable rock and soil was obtained. On the following run, at a depth of 7101 ft, a sudden decrease in power and a corresponding increase in cable tension was noted, indicating an abrupt change in material had been encountered by the cutting bit. This was later concluded to be, after analysis of subsequent events, a layer of water estimated by the authors to be less than a foot thick. After a few minutes the power increased and drilling was continued to a depth of 7105 ft. A total of $7\frac{1}{2}$ ft of core containing more rock and soil debris was frozen into the upper part of the core barrel. No sub-ice sample was recovered.

By the next run, which was several hours later due to equipment repairs, it was noted that the fluid level in the hole had risen from 630 ft to 313 ft from the surface. The glycol column downhole had risen from 5743 ft to 5557 ft.

The procedure during this period was to drill with a diamond bit and without a core lifter. On the following run, a core lifter was installed and the diamond bit replaced with a steel bit. The purpose of the second run was solely to recover a core. If the core could not be ruptured and the core lifter could not be released from the core, the drill motor would be reversed and the less expensive steel bit would be sacrificed downhole with the core lifter.

On each of the drilling or unsuccessful core recovery runs, the hole bottom indication was between 7101 and 7102 ft, despite the fact drilling had reached 7105 ft. The diamond bit showed considerable wear, particularly to the matrix material, and abrasive wear was clearly visible on the lower 4 ft of the core barrel. An attempt to use a steel bit with the cutting surfaces built up with a tungsten carbide welding rod was also unsuccessful. After a few feet of drilling, the carbide surfacing was completely worn off. Various drill surfaces were showing signs of rusting, a phenomenon never noted previously. The only visible evidence of the nature of the sub-ice material was thin films of clay on the drill surfaces and clay particles filtered from the melted ice found in the drill sections. The tentative opinion of the authors was that the sub-ice material appeared to be unconsolidated or else the relative movement of the ice sheet over the bed was too rapid to obtain a sample by the dual run technique. During the time spent attempting to obtain a sub-ice sample, the water which had welled up into the hole mixed with the glycol solution in the lower part of the hole. An unstable condition existed with the denser more concentrated solution at the top of the solution column. Freezing out of the water from the rising, less dense solution eventually created a heavy slush in the bottom 1500 ft of the hole. Within a few days, the slush became difficult to penetrate with the drill. Circumstances did not permit the removal of the slush.

The effects of the downhole water caught in the drill sections and subsequently frozen during the trip out of the hole began to have serious consequences. At times, eight hours or more was required to thaw out the drill and prepare it for another run. Damage to parts of the drill from the high freezing forces created additional problems and delays. For fear of serious damage and the possible loss of the drill, attempts to obtain a sub-ice sample were terminated on 2 February 1968.

The overall penetration rate for the season averaged 70 ft/day. This included the several days of equipment breakdown during which no drilling could be accomplished. Penetrations of 100 to 120 ft/day were not uncommon even at the 6000 to 7000-ft depths. Actual drill rates depended upon the drill weight being allowed to rest on the cutting bit, i.e. the bit pressure, the cutting bit used, and the ice structure. Normally 25% to 50% of the total drill weight was allowed to rest on the bit. This dropped to 15% to 25% when the rate was decreased in the attempts to correct the hole deviation. Power input to the drill in ice was 7.5 to 9.0 kw with a bit rotation of 225 rpm.

The upper 4100 ft of hole was drilled with a diamond bit as it produced a higher drilling rate with less bit pressure than the steel bit. Below this depth, the steel bit outperformed the diamond bit until the sub-ice debris was encountered near the bottom of the ice sheet. The 4100-ft depth corresponds approximately to the depth at which the crystal orientation of the ice changed from random to highly oriented with a significant decrease in the number of visible air bubbles (Gow, 1968).

Core recovery exceeded 99% of the depth drilled. With the exception of brittle and fractured cores from 1300 to 3000 ft, the overall condition of the core was good to excellent. Cores averaged $4\frac{1}{2}$ in. in diameter and from 10 to 20 ft in length. At the greater depths, unbroken lengths of 15 to 20 ft were not uncommon.

Hole inclination measurements were taken at 50-ft intervals over the upper 2200 ft of the hole and every 100 ft beyond this depth (Garfield, 1968). The depth figures are from the 1968 snow surface to the bottom of the bit, 83 ft below the inclinometer. The maximum inclination measured was 15° at the bottom of the hole. Assuming a constant inclination over the interval between measurements, the vertical depth of the hole was 7101 ft. The loss in vertical depth was 94 ft. Horizontal drift at the bottom was 879 ft N 52° E.

After drilling had been terminated, a thermistor probe was suspended in a housing mounted below the partially disassembled drill. Temperatures in the hole were measured at 100-ft intervals to a depth of 5457 ft. A final measurement was obtained at 5942 ft. The drill could not penetrate the slush accumulation beyond the 6000-ft depth. A minimum temperature of -28.8° C was recorded at a depth of 2400 ft, and temperature increased to -13.1° C at 5942 ft. A straight line extrapolation of the temperature curve from -13.1° C at 5942 ft to the pressure melting point (-1.6° C) at the bottom gives a temperature gradient of 3.25° C/100 m. Using an average ice temperature of -9.0° C in this region and Ratcliffe's data for the thermal conductivity of ice, the basal heat flow is calculated to be $1.8 \ \mu$ cal/cm² sec at this location (Ratcliffe, 1962). An unknown proportion of the heat may be due to the flow of the ice.

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SUMMARY AND CONCLUSIONS

The penetration of the Antarctic ice sheet at Byrd Station has confirmed the feasibility of using the cable-suspended Electrodrill to core drill through thick ice sheets. An aqueous ethyleneglycol solution can be successfully used to dissolve and remove the chips formed, at least where the ice temperatures are above -30° C. The operation requires a minimum number of operating personnel and the method can produce high penetration rates with good quality core. In addition to the drill, the operation requires a hoist to haul the drill out of the hole, a tower to suspend the drill at the surface, the necessary length of cable, power, and sizable quantities of diesel oil and ethylene glycol. With adequate support facilities, such as those available at Byrd Station, such equipment can be installed and operated in a relatively short time. By utilizing the subsurface construction, the required tower height can be decreased and the working site can be sheltered from the ambient surface conditions.

An electrohydraulic hoist can be employed successfully for the operation, but selecting and maintaining the proper design temperature for the hydraulic oil is essential. A capstan drive on the hoist to allow reeling the cable on the drum under a nominal tension is recommended and undoubtedly prolongs the life of the cable.

The tendency of the Electrodrill, as presently designed, to deviate from a vertical attitude should be considered in any future drilling. The center of gravity of the drill must be lowered. The experience from this season has shown that attempts to correct a hole inclination, at least by the methods used, can be trying, time consuming and not too successful.

The difficulties that can be caused by a water layer at the bottom of an ice sheet were demonstrated. The fluid-filled hole must be in hydrostatic equilibrium with the ice sheet or the upwelling water can create serious problems. If an ethylene glycol solution is used, an excessive amount of the solution should not be permitted to collect at the bottom of the hole.

The problem of obtaining a sub-ice sample beneath the water layer still exists. If the material is unconsolidated or the relative ice movement is too rapid, the problem is further com - plicated. Either or both of these conditions may exist at the bottom of the ice sheet at the Byrd Station location.

A technique that will be tried in the future is to attach a smaller NX size core barrel with NX drill rod and cutting bit to the bottom of the Electrodrill with core lifters designed to retain unconsolidated material. This would permit higher bit pressures with the available drill weight and would reduce core rupturing forces. In addition, thin walled Shelby Tube samplers for unconsolidated material will be tried.

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13. ABSTRACT						
The Antarctic ice sheet was penetra 32 'W) during the 1967-68 austral sum mechanical rotary type 87 ft long, wand lowered the drill at a maximum of t of armored electrical cable and a austral summer, the equipment was in resumed in November 1967 and the holong averaging $4\frac{1}{4}$ in. diam were receaveraged 70 ft/day. The drilling ratio of 7.5 to 9 kw. Drill cuttings were circulated at the bottom of the hole each coring run. Hiquid water, indistrict, was encountered at 7101 ft. not successful. The hole began device corrective measures, was inclined 19 ily from a minimum of -28.8° C at 240 measurement ceased. The heat flow the sec.	ated by core drilli mmer. The drill was veighing 2650 lb. rate of 150 ft/min. a 70-ft-high alumin istalled and a dept be was completed in overed over 99% of ate varied from 1.4 e dissolved in an a e and returned to t icative of pressure Attempts to recove lating from the ver 5° at the bottom. 00 ft to -13.0°C at for this location i	ng at Byr s a cable An electr Other e um tower. h of 745 January the depth to 7.8 i queous et he surfac melting r a core tical at Ice tempe 5942 ft, s estimat	e-suspended electro- cohydraulic hoist raised equipment included 12,000 During the 1966-67 ft was drilled. Drillin 1968. Cores 10 to 20 ft a. The penetration rate n./min at a power input thylene glycol solution e in the drill bailer on at the bottom of the ice of sub-ice material were 750-ft depth and, despit eratures increased stead- where temperature ed to be 1.8 µcal/cm ²			
14. KEY WORDS Antarctic regions Ice co	oring					
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