AN OVERVIEW OF ICE DRILLING TECHNOLOGY

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Abstract

The significant advancements in ice drilling technology since the Ice-Core Drilling Symposium at Lincoln, Nebraska, in August 1974 are reviewed. Three examples are: the flame jet and hot water drilling through the Ross Ice Shelf in Antarctica and the deep core drilling at Dye 3 in South Greenland.

Introduction

The predominant application of ice drilling technology has always been the acquisition of cores for glaciological and hydrological research. Another major application has been the provision of access holes through glaciers, ice shelves, lake and sea ice covers.

Both of these applications have been reexamined for the period 1949 to date in order to determine the significant advancements in ice drilling technology since the 1974 Symposium on Ice-Core Drilling.

Review of Ice Core Drilling

MacKinnon's (1980) compilation and other data in the author's files have been used to construct Figure 1 which shows that 37,500 m of ice core have been drilled during the period 1949-1982, and that the level of activity in ice core drilling has remained high since 1974. The 17,300 m of core acquired during the period 1975-1982 is 46 percent of the admittedly incomplete total of core collected since 1949. How the core was acquired, i.e., what kinds of drills and cutting removal techniques were used, and how much of the 37,500 m of core was acquired with each of the techniques are addressed below.

There are several types of manually-operated corers. The SIPRE coring auger uses auger flights on the exterior of the core barrel and the space between the core and the interior of the core barrel to transport cuttings to the surface. Although 51 percent of the sites were cored with the SIPRE auger, less than 8 percent of the core was obtained with it. A few coring augers similar to the SIPRE auger have been made -- a recent example is Koci's (1984a) lightweight hand auger. There have also been a few augerless manual corers which have very narrow kerfs; the cuttings are collected on top of the next core and in the clearance between the core and the core barrel. About 4 percent of the sites have been cored with manual corers other than the SIPRE and less than 1 percent of the core was obtained with them.

The coring auger has been adapted to or modified for use with a variety of power assistance ranging from hand-held electric drills or gasoline motors to exploration drilling equipment. These adaptations were used at less than 3 percent of the sites and account for less than 2 percent of the core.

Rotary drilling equipment ranging in size from backpackable diamond core drills to conventional rotary rigs rated for 1500 ft of 2 3/8-inch drill pipe has been used for core drilling in ice. Cuttings were removed using compressed air, brine, kerosene, diesel fuel, water

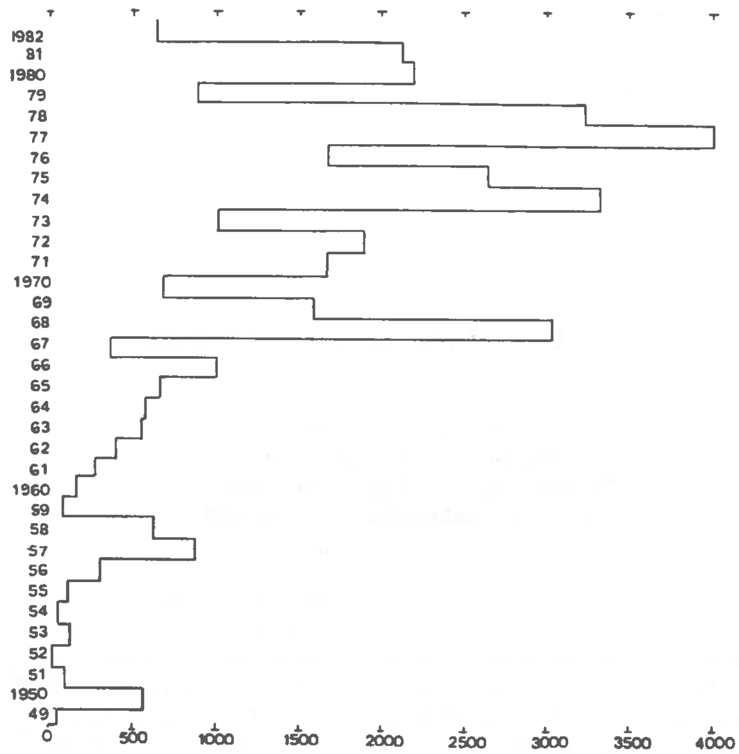

Figure 1. Meters of ice core drilling in the years 1949-1982. The cumulative total is 37,500 m.

and reverse air vacuum circulation. Core barrels which required tripping the drill rod or pipe string for each core recovered were used more often than the wireline core drilling technique. Rotary drilling equipment was used at 5 percent of the sites to obtain 9 percent of the core.

Thermal core drilling was used at 23 percent of the sites to acquire 55 percent of the core.

Electromechanical corers are cable-supported core drills whose cuttings are removed by several methods depending upon whether the hole is dry or filled with liquid. In dry holes the auger flights on the rotating inner core barrel lift cuttings into a storage space above the core and retain additional cuttings between the inner core barrel and the non-rotating outer barrel or flight sheath; see Rand (1976), Rufli et al. (1976) and Litwak et al. (1984). A similar construction was used by Theodórsson (1976) to drill through firn and on into a water-filled hole in the solid ice. In the electrodrill, Ueda (1969), the cuttings were dissolved in an aqueous ethylene glycol solution below the immiscible and lighter hydrocarbon liquid used to prevent hole closure. In the Danish "ISTUK" drill, Gundestrup et al. (1984), the slurry of cuttings and the liquid used to prevent hole closure was pumped by pistons into storage spaces above the core. Electromechanical corers were used at 13 percent of the sites to recover 24 percent of the core.

Having examined the percentage of core obtained by different kinds of drills and techniques let us look at the distribution (Table 1) by number of holes and depth. For this purpose the depth

Table 1

Type of Drilling	Depth Range (meters)	Percent of Holes 1949-82	Percent of Holes 1975-82	Percent of Core 1949-82	Percent of Core 1975-82
Manual	0 - 20	52.1	56.5	8	5.7
Intermediate	20 - 500	46.0	41.1	64	60.8
Deep	> 500	1.9	2.4	30	33.5

interval 0-20 m is arbitrarily designated manual core drilling, the interval 20-500 m as intermediate and anything over 500 m as deep drilling. The distribution during the period 1975-1982 is essentially the same as the distribution during the period 1949-1982.

Advancements in Ice Core Drilling

Mellor and Sellman's (1976) General consideration for drill system design and Mellor's Mechanics of Cutting and Boring Part II (1976), Part IV (1977) and Part VII (1981) provides a rational basis for improvements in ice coring equipment and a measure of the efficacy and efficiency of the various drilling techniques.

Reeh's Antitorque Leaf Springs (1984) is a guide for the rational design of antitorque leaf springs.

The antitorque springs on the Danish shallow drill, Johnsen et al. (1980) and on their deep core drill, Gundestrup et al. (1984), were made in accordance with Reeh's design.

Suzuki's (1984) solution to the antitorque problem is unique and ingenious. He cuts four grooves along the hole wall. Fins above the cutters and the cutters provide the antitorque reaction to the coring bits. The vertical thrust of the side cutters can either increase or decrease the thrust on the core barrel.

Improved core bit cutter design lowers the driving and reaction torques required to cut ice cores. Improved core dog design greatly reduces the force required to break cores, permitting lighter-weight cables, towers and winches.

Both of these improvements have been demonstrated in recent electromechanical core drillings: see Gundestrup et al. (1984), Holdsworth (1984), Koci (1984c) and Suzuki (1984).

New developments in the removal of drill cuttings from liquid-filled holes have been included in three core drills. In the Danish "ISTUK" drill the slurry of cuttings and the liquid used to prevent hole closure is pumped by pistons into storage space above the core. In the French electro-mechanical drill, Donnou et al. (1984), the slurry of cuttings and hole fluid is centrifuged to separate the cuttings from the hole fluid. The cuttings are transported to the surface inside the centrifuge basket. The French, Gillet et al. (1984), also developed a small diameter electromechanical core drill in which the cuttings were filtered from the hole fluid and transported to the surface inside the filter.

Thermal core drilling in a liquid-filled hole in cold ice can only be done if the meltwater is removed from the hole or mixed with another liquid to form an aqueous antifreeze solution whose freezing point is equal to or less than the ambient ice temperature.

Removing the water by pumping it through heated tubes into a heated meltwater tank for transport to the surface was first accomplished at Camp Century in Greenland in 1963-64, Ueda and Garfield (1968). Variations of this technique are still being used in Antarctica at Dome C, Donnou et al. (1984), and at Vostok, Kudryashov, et al. (1984).

Mixing the meltwater with another liquid to form an aqueous antifreeze solution is a technique which has been used in thermal ice core drilling for about ten years. Bogorodsky and Morev's paper (1984) describes the equipment and techniques for use on ice not colder than -33°C that was used by Zotikov et al. (1979) to core drill through the Ross Ice Shelf. The different equipment and technique required for ice as cold as -55°C is the subject of Bogorodsky et al. (1984) contribution to this symposium.

Another significant development is the use of electronics both at the surface and downhole for the measurement and control of drill functions. The outstanding example of this technology is the Danish deep drill system. The French "Climatopic" Thermal Probe, Gillet et al. (1984), has a small telemetry section transmitting four measurements to the surface.

The Ross Ice Shelf Project (RISP) was the inspiration for three innovations in ice core drilling using rotary drilling equipment. It was the first time that a wireline core drilling system had been used in ice, the first time that reverse air vacuum circulation had been used in ice coring and the first time that lightweight composite drill pipe had been used.

The prospective use of these innovations was described in an earlier paper by Hansen (1976).

During the second RISP drilling season reverse air vacuum circulation was used to drill a 178-mm diameter hole through the firn and into the impermeable ice. That portion of the hole was cased using 162-mm (6-inch) I.D. fiberglass-reinforced epoxy pipe. Core drilling continued using a 159-mm diameter core bit and normal circulation using a mixture of DFA and trichlorethylene to remove the cuttings from the hole.

The cuttings were removed from the drilling fluid by a rotary vacuum filter.

Advancements in Access Hole Drilling

No attempt has been made here to review the large variety of techniques that have been used to drill access holes in temperate ice and through lake and sea ice covers.

Three techniques were successfully used to provide access holes through the Ross Ice Shelf.

One of them is the subject of Bogorodsky's and Morev's (1984) contribution to this workshop. Its application on RISP was described by Zotikov et al. (1979).

The second technique is flame jet drilling. Browning et al. (1978) used a water-cooled flame jet drill to provide two access holes through the Ross Ice Shelf in December 1977. One of the holes was reamed with the flame jet drill to maintain a minimum hole diameter of 30 cm.

Several thousand liters of cooling water were pumped from the J-9 in situ water well each time the flame jet drill was used.

Oily soot from incomplete combustion covered everything passing through the access hole and the people using the hole.

In an attempt to alleviate this problem the hole was successfully reamed with hot water flowing at a rate of 20 l/min through a No. 1H7 spray nozzle made by Spraying Systems Company, Wheaton, Illinois.

The success of this hot water reaming resulted in a decision to examine the feasibility of using hot water as the third technique to drill access holes for the next season.

Yen's and Zehnder's (1973) paper "Melting heat transfer with water jet" provided data on the heat transfer coefficient from a water jet to melting ice. F. Müeller's (personal communication, 1978) experience with hot water drilling in cold ice provided additional data confirming the feasibility, and Browning was awarded a contract to perform the hot water drilling for RISP.

The use of hot water to drill three access holes through the Ross Ice Shelf has been described by Browning et al. (1979) and Koci (1984b).

Napoleóni's and Clarke's (1978) paper "Hot water drilling in a cold glacier" and Taylor's (1984) paper "A hot water drill for temperate ice" are excellent references for anyone contemplating the use of this technique.

Verral's and Baade's (1984) paper "A simple hot-water drill for penetrating ice shelves" presents an ingenious solution to a problem which can develop when holing through the bottom of a floating ice sheet or shelf.

Availability of Drills and Drawings

With the possible exception of Koci's lightweight hand coring auger the equipment described and discussed at this symposium is a one of a kind item for which there is no commercial source of supply. Shop drawings, bills of material and procurement specifications are seldom available. However, it has been this authors experience that there is a free exchange of the available information and a ready willingness to assist one another.

Conclusion

Ice core and access hole drilling continues to be an active field with an influx of new participants who are improving the equipment and techniques in use.

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