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DEEP CORE DRILLING IN ICE

B. Lyle HANSEN

University of Nebraska-Lincoln, Lincoln, Nebraska 68583-0850, U. S. A.

Deep core drilling in ice began about 1950 with three projects. The French bored two holes in Greenland at Camp VI and at Station Centrale to depths of 126 m and 150 m respectively (HEUBERGER, 1954). The Juneau Icefield Research Project (MILLER, 1954) core drilled about 100 m into the temperate Taku Glacier in Alaska. The 1949–1952 British-Norwegian-Swedish Antarctic Expedition cored to a depth of about 100 m on the shelf ice along the Dronning Maud Land coast (SCHYTT, 1958). Mechanical drill rigs were used for all of these corings.

Dr. Henri BADER, an eminent Swiss glaciologist, was a participant on the Taku Glacier drilling which used a wireline rig provided by LONGYEAR who also provided one of their most experienced operators, Anders ANDERSON.

In wireline core drilling an outer barrel with the core bit on the lower end is attached to a string of drill pipe which rotates the outer barrel. A non rotating core retaining inner barrel is lowered into place by a wireline which releases when the inner barrel latches into place. At the end of a coring run the wireline is sent down with an overshot which unlatches the inner core barrel so it can be lifted to the surface to remove the core. The drill pipe is only removed from the hole to replace the core bit or at the completion of the drilling operation.

Drill cuttings are removed from the hole by circulating drill fluid down the pipe and up in the annulus between the hole wall and the pipe, or in the case of reverse circulation, the fluid goes down the annulus and caries the cuttings up inside the drill pipe.

On the Taku Glacier melt water from the surface or a crevasse was used as the drilling fluid.

I mention here that almost all of the deep sea core drilling is done with the wireline technique.

This technique has an advantage for deep core drilling in ice, you can drill through the interface at the bottom of the ice sheet and on into the bedrock, obtaining sample of that material. You can also use directional drilling to obtain more than one core from levels of interest.

When Henri returned to the University of Minnesota, where he and I were working together as research associates, he asked about the feasibility of thermal core drilling to depths of thousands of meters.

I told him it would be necessary to use high voltage to limit cable losses and that a special transformer would be needed in the drill. He promptly hired an EE graduate student to design the toridal core transformer, and I forgot about thermal core drilling in ice.

About three years later we were both working at the Snow, Ice and Permafrost Research Establishment (SIPRE). Core drilling into polar glaciers in both the northern and southern hemispheres was included in the plans for the 1957–1958 International

Geophysical Year (IGY) activities (BADER, 1958; CRARY *et al.*, 1962).

SIPRE was responsible for providing much of the equipment required for the US IGY glaciology program. It was at this time that the SIPRE coring auger was developed. SIPRE accepted the responsibility for the entire US IGY core drilling in ice program: designing and modifying drilling equipment, establishing techniques of ice core analysis and developing bore-hole instrumentation methods.

Chet LANGWAY was a pioneer and leader in the core analysis. I was responsible for the bore-hole measurements. I was only a spectator on the core drilling portion of the program.

The core drilling in Greenland was a pre-IGY activity that produced two cores at Site 2, 305 m in 1956 and 411 m in 1957 (LANGE, 1968; LANGWAY, 1967). During the IGY two cores were obtained in Antarctica, 308 m at Byrd Station in 1957–1958 and 256 m at Little America in the 1958–1959 austral summer (PATENAUDE *et al.*, 1959: RAGLE *et al.*, 1960).

A conventual rotary drill rig was used with compressed air to remove the cuttings. With this equipment it was necessary to remove the entire string of drill pipe and reassemble it every time a core was retrieved, a very time consuming procedure. Several air compressors and a large air to air heat exchanger to cool the compressed air were needed.

I made borehole measurements of temperature, and diameter in the 411 m hole at Site 2 and at Little America. Resurvey of the Site 2 hole showed significant hole closure (HANSEN and LANDAUER, 1958).

Chet LANGWAY developed a comprehensive and detailed program to investigate the Site 2 core. His collaboration with Hans OESCHGER at the University of Bern and with Willi DANSGAARD at the University of Copenhagen produced very exciting results which were the stimulus for an effort to drill all the way through the Greenland ice sheet.

In 1957 Henri asked me again about thermal core drilling deep holes. I asked for a couple of weeks to think about the problem then told him it could be done. In 1958 he obtained funds to begin the project. Fortune smiled on us because that was when Herb UEDA agreed to join SIPRE and work full time on core drilling in ice.

We knew the hole had to be filled with a fluid to prevent hole closure. A mixture of arctic diesel fuel and trichloroethylene was chosen because the diesel fuel would be available at the drilling site in large quantities at a low price and trichloroethylene was the least expensive densifier that would provide a low viscosity hole fluid with an acceptable toxicity.

The transformer design that had lain in the files for several years was used and it worked to a tee. Almost everything else had to go through one or more revisions.

The biggest hurdle was getting rid of the melt water while drilling trough the transition from the permeable firn to the impermeable ice. We finally hit on the scheme of using a vacuum pump to draw the melt water up through heated tubes into a tank above the core barrel.

In the process of developing this technique three holes were drilled at Camp Century. A 186 m core was recovered in 1960–1961 season. A second core hole was started in 1962 from which 238 m of core were obtained. Don Garfield jointed the drilling team in 1963. A third hole was started in 1963 and 264 m of core were obtained. In 1964, the third hole was extended to 535 m using the thermal drill in a fluid filled hole.

In 1964 Mr. Armais ARUTUNOFF, the inventor of the Electrodrill and President of the Reda Pump Co. in Bartlesville, Oklahoma, agreed to sell a reconditioned unit to be used for glaciological research. In 1965 the Electrodrill was used to extend the third hole to a depth of 1002 m. Continuous core was recovered.

In June 1966, drilling was resumed with the Electrodrill. On July 2, at a depth of 1370.5 m, ice containing silt bands and small pebbles was encountered. On July 4, after drilling through 16.9 m of this material, the interface at the bottom of the ice cap was reached at a depth of 1387.4 m. The bottom material was frozen till, 3.55 m of this material was recovered. The total depth of the hole was 1391 m (UEDA and GARFIELD, 1968).

At the end of the 1963 season we were convinced that thermal core drilling was not the way to do deep core drilling but was useful for dry holes to intermediate depth. The first USA CRREL Thermal Drill was built in 1963 for Dr. W.S.B. PATERSON, Canadian Department of Mines and Technical Surveys. Two more drills were built in 1966 for the Australian National Antarctic Research Expedition and for the U.S. Antarctic Research Program (UEDA and GARFIELD,1969a).

In November 1966 drilling was started at Byrd Station, Antarctica with the installation of equipment and facilities. The Electrodrill was successfully tested to a depth of 227 m. by the end of the season in February 1967 (UEDA and HANSEN, 1967). Drilling was resumed in November of that year and the bottom of the Antarctic ice sheet was reached at a vertical depth of 2164 m on 29 January 1968 (UEDA and GARFIELD, 1969b).

In addition to completing the hole through the Antarctic ice sheet, in this same year, Herb UEDA used the CRREL thermal drill to drill four holes, 57–61 m in depth within an 8.5 km radius of Byrd Station for a Stanford Research Institute experiment. A fifth hole, 335 m deep was drilled in the main tunnel for future use of a C^{14} dating instrument (UEDA and GARFIELD, 1968). He really had a very productive drilling season.

The collaboration of the LANGWAY, OESCHGER, and DANSGAARD triumvirate was not only producing great results, it was using up a lot of ice core and creating a demand for more core at other locations.

In 1970 it was determined that new drilling equipment was needed for shallow and intermediate depth holes and that CRREL, the University of Copenhagen, and the University of Bern should proceed independently and immediately on this task. The results were the Rand, Rufli and Univ. of Copenhagen electromechanical drills for dry holes.

In 1971 the CRREL thermal drill was used to obtain a 372 m core at Dye-3 Greenland. Pall THEODÓRSSON from the University of Iceland was a participant in this drilling. He developed his own electromechanical drill for use in the water filled holes in Iceland.

Many others in other countries were actively engaged in ice core drilling during the late 60 s and early 70 s. In 1974 the first Ice Core Drilling Symposium was held at Lincoln Nebraska (SPLETTSTOESSER, 1976). Twenty-nine registrants from Australia, Britain, Canada, France, Iceland, Japan, Switzerland, U.S.S.R., U.S.A., and West Germany attended.

The development of deep core drilling in ice equipment since then is adequately covered in the Calgary and Grenoble Proceedings.

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