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Hot-water drilling on the Siple Coast and ice core drilling at Siple and South Pole Stations

K. C. Kuivinen *and* B. R. Koci

Polar Ice Coring Office
University of Nebraska
Lincoln, Nebraska 68588-0200

The Polar Ice Coring Office (PICO) used a new hot-water drill and a new 200-meter winch and electromechanical coring drill at three antarctic locations during the 1983–1984 field season. Hot-water drilling of shot holes for the University of Wisconsin-Madison seismic program was conducted at Upstream B (83°31.2′S 138°05′W) on the Siple Coast. PICO collaborated with the Physics Institute, University of Bern, Switzerland, in two drilling and core processing projects: (1) a 201-meter ice core was collected at Siple Station for analysis by the University of Bern group and (2) at South Pole Station, a core was drilled from 230 to 353.5 meters in a hole left open after the 1982–1983 season.

In early November, a team of three drillers (Jay Arneson, Bill Boller, and Bruce Koci) invaded the Upstream B camp on the Siple Coast to drill an array of seismic holes for University of Wisconsin (at Madison) (Bently et al., *Antarctic Journal*, this issue) and to drill a deep hole to test the feasibility of using hot-water drills to place thermistor strings and other scientific instruments to various depths on the ice.

Two 80-kilowatt oil-fired burners were used to generate water from snow on the surface and to heat the water to 90°C for drilling 8-centimeter diameter holes. An array of 17 holes, each to a depth of 23 meters, was completed in 1 working day. Hole depth was limited to 23 meters since water pooled at this depth and there was no way to place the explosive charges before refreezing occurred.

The water required to drill each shot hole was in the 150-gallon range. All drilling apparatus and water tanks were moved between sites by two Alpine skidoos without problem. The simplicity and lack of drilling problems suggest that investigating organizations could drill their own shot holes in the future.

The deep-drilling challenge was handled by using four 80-kilowatt heaters, two of which were used to generate water on the surface and two to heat the water while drilling. Tanks similar to fuel bladders with a hole in the top proved very satisfactory for water storage. Tank capacities were 500 and 1,000 gallons.

The drill hose was a standard 2-centimeter interior-diameter, reinforced hose surrounded by 20 pairs of #24 wire and jacketed with a Kevlar-strength member. Performance of this hose proved satisfactory. The flow rate was 30 liters per minute at a temperature of 90°C. A thermal gradient of 12°C per 100 meters was observed between the heater outlet and the nozzle during drilling operations. The drill hose with thermistors attached was left down hole.

All the thermistors in the string survived the freezing-in process and a temperature profile will be forthcoming.

From mid-November through early December a four-person team from PICO and the University of Bern drilled, logged, and packaged a 201-meter ice core from Siple Station. The team consisted of Karl Kuivinen and John Litwak from PICO and Henry Rufli and Jakob Schwander from the Physics Institute, University of Bern, Switzerland.

Drilling and core processing took place in a trench excavated by tractor to 3 meters wide by 3 meters deep by 12 meters long. The trench was roofed with 4-by-4-inch timbers and ½-inch plywood sheets to provide protection against wind, blowing snow, and heating by solar radiation of the drill and core processing equipment—all problems that had hampered a drilling project at Siple during the 1978–1979 season.

The PICO electromechanical drill and 200-meter winch system (Koci in press) was used to collect 10-centimeter diameter core in a total of 12 days of operation. Core quality was excellent down to a depth of 144 meters but deteriorated beyond that depth. Drilling reached a depth of 201 meters.

The ice core was flown to South Pole Station for processing, sampling, and packaging for retrograde to Switzerland (Stauffer and Schwander *Antarctic Journal*, this issue).

At South Pole Station both drilling teams combined efforts to continue core drilling and processing of core from 230 meters to 353.5 meters below the surface in a hole drilled to 230 meters in the 1982–1983 season (Kuivinen 1983).

The ice at the South Pole was known to be hard and brittle after the 201-meter hole drilled in 1981 with G. Holdsworth's drill (Kuivinen et al 1982). During the 1982–1983 season, an attempt to drill core to 500 meters was unsuccessful because our drill bits could not be accurately adjusted and to an inability to generate the chips coarse enough for transport away from the drill head.

Using information gathered in 1982–1983 through use of Swiss and PICO drilling heads, we proceeded to design and build modified heads for drilling in 1983–1984.

The ice at South Pole is −52°C, much colder than ice normally cored by electromechanical means. As a result, most tool steels are either too brittle or not hard enough. The use of die steels noted for their toughness and resistance to wear appears to have solved the problem.

Another modification was to make the front of the bits with a cutting angle of 50°, rather than the 45° angle usually used for coring in warmer ice. The 45° cutters would not dig into the ice and at best generated very fine chips with little penetration. The 50° cutters with a 15° clearance angle succeeded in generating the coarse chips required for chip transport up the barrel, while not inflicting too much damage on the core during drilling.

Additionally, efforts were made to improve core quality by minimizing the clearance between the rotating inner core barrel and stationary outer barrel, by maintaining concentricity of the head and bits to within 0.1 millimeters in roundness and 0.1 millimeters in cutting surface flatness. The use of heads and bits with a 55° angle made by H. Rufli further improved the core quality, but it was still far from excellent.

Drilling progress was at a rate of 12–15 meters per 8-hour work day in the interval of 300–350 meters depth.

At the end of the field season, the PICO hot-water drill was loaned to French glaciologists at South Pole Station who made unsuccessful attempts to recover a sampling instrument stuck at a depth of 190 meters.

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Core processing and first analysis of ice cores from Siple and South Pole Stations

B. STAUFFER *and* J. SCHWANDER

University of Bern
Bern, Switzerland

Analysis of ice cores from the Antarctic allows us to study the history of climatic parameters such as temperature, annual accumulation, and atmospheric composition. The main goal of our laboratory analysis of these ice cores is to investigate the preindustrial atmospheric carbon dioxide concentration and its natural variations and to measure the carbon-13/carbon-12 ratio in the preindustrial carbon dioxide and in other atmospheric trace gases such as methane. The cores drilled during 1983–1984 field season at the south Pole will be analyzed during the coming year. Several analyses have been made, however, on such cores drilled in the previous field seasons:

- The analysis of the carbon dioxide concentration of air extracted from ice cores indicates that the preindustrial atmospheric carbon dioxide concentration was about 280 parts per million by volume as compared to present levels of about 340 parts per million. There is some evidence that this value is more accurate (Moor and Stauffer in press) than the lower value reported earlier by a laboratory in Grenoble and by our laboratory (Barnola et al. 1983).
- We also measured the carbon-13/carbon-12 ratios of carbon dioxide and of the methane concentration. These results are still preliminary and will be reported later.

During the 1983–1984 field season, we had the opportunity to collaborate with the Polar Ice Coring Office of the University of Nebraska in two core-drilling and core-processing projects, one at Siple Station where there is a high snow accumulation (50 centimeters, water equivalent) and one at South Pole Station where there is a low annual accumulation (7 centimeters, water equivalent). Ice cores from locations with high annual accumulation rates allow us to study climatic parameters in great detail, because layers of precipation are large. Core drillings at locations with low annual accumulations, on the other hand, allow us to recover ice from an earlier epoch at a shallower depth.

Drilling at Siple Station reached a depth of 201 meters, and core quality is excellent down to a depth of 144 meters. (See Kuivinen, *Antarctic Journal*, this issue, for details about the drilling.) After recovery, the ice cores were flown to South Pole Station for processing and packing (Stauffer and Schwander 1983). They were split in half, the electrical conductivity was measured (Hammer 1980), and the visual stratigraphy was recorded on video tape. On 250 samples porosity measurements were made.

In the laboratory analysis of the core from Siple Station our primary goal is to investigate the anthropogenically caused increase of the atmospheric carbon dioxide concentration. The ice core arrived in our laboratory at the end of May 1984 and will be analyzed within the next year. Therefore, only results from the field measurements can be reported:

- The signal of the electrical conductivity measurements shows clearly visible seasonal variations, which allow us to date the layers of ice with an accuracy of about 3 years.
- Ice at a depth of 144 meters fell as precipitation in about 1753.
- The signals from volcanic eruptions are not very pronounced.
- Fascinating results were obtained by measuring the density and porosity on 250 firn and ice samples. They show that air gets enclosed in the depth interval where the density increases from 0.80 megagrams per cubic meter to 0.84 megagrams per cubic meter. (See figure 1.)
- The detailed analysis shows that the air enclosure occurs at different depths for summer and for winter precipitation (Schwander and Stauffer 1984).

The South Pole Station core, drilled from a depth of 230.0–353.5 meters, was held for 24 hours after recovery before processing to allow the ice to reach the same temperature as the processing trench (−25°C). Trench analysis of the South Pole Station core employed the same techniques as those used on the Siple Station core:

- A 5-millimeter thick layer was cut away from the core with a bandsaw, and the electrical conductivity was measured on the fresh, polished surface. A clearly visible dust layer was observed at a depth of 303.43–303.45 meters below the surface, but the electrical conductivity at this interval was no greater than that of other depths. The electrical conductivity results of the whole core are incomplete because there were many breaks and missing pieces.
- The visual stratigraphy was recorded on graph paper and on video tape.
- Several thin sections from a depth of 306 meters were prepared for crystal-size analysis. (See figure 2). Even at this depth, variations (which are probably seasonal in nature) of crystal sizes are found; these variations are similar to those found at the 106-meter depth (Stauffer 1982). There is no evidence that the amplitudes of the variations decrease or increase with depth.

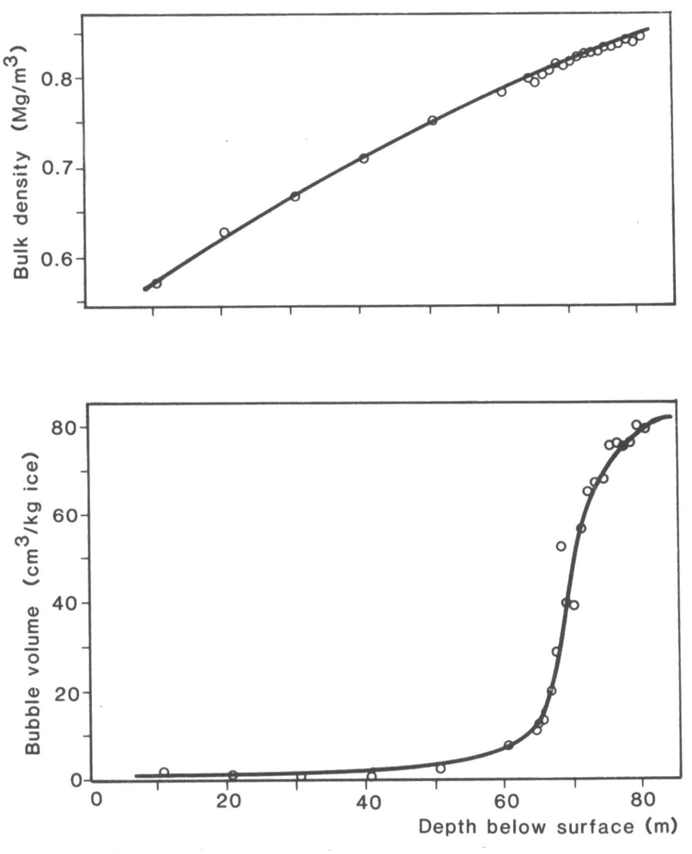

Figure 1: Bulk density and bubble volume versus depth at Siple Station. Each point represents a 1-meter average. ("cm^3/kg" denotes cubic centimeter per kilogram; "Mg/m^3" denotes megagram per cubic meter.)

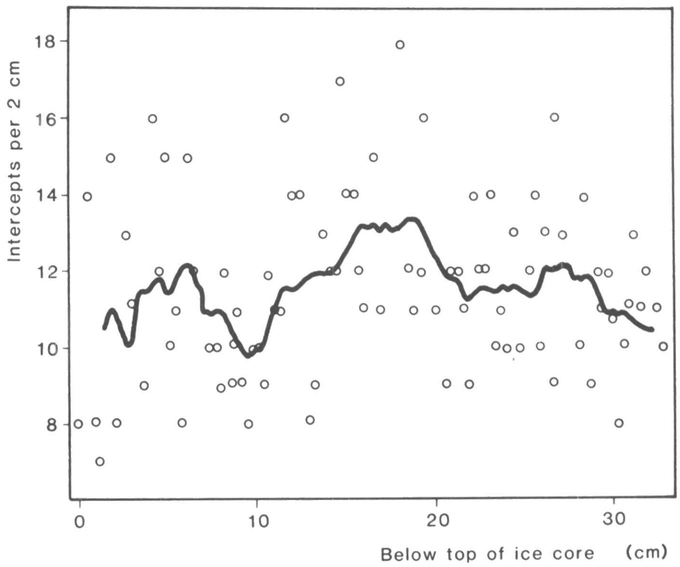

Figure 2: Number of crystal boundary intercepts per 2-centimeter length along a core section of 30 centimeter length from 306 meters depth below surface from the South Pole. The line connects mean values (10-values running means). ("cm" denotes centimeter.)

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