A 237-meter ice core from South Pole Station

KARL C. KUIVINEN

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

The Polar Ice Coring Office (PICO) used its new intermediate-depth drill system to collect a 237-meter ice core at Amundsen-Scott South Pole Station during November–December 1982. The core was collected for analysis of microparticle concentrations by the Institute of Polar Studies, Ohio State University (Mosley-Thompson, Kruss, and Bain, *Antarctic Journal*, this issue) of oxygen isotopes by the Quaternary Research Institute, University of Washington, and for carbon dioxide, beryllium-10, chlorine-36, and acidity by the Physics Institute, University of Bern, Switzerland (Stauffer and Schwander, *Antarctic Journal*, this issue). The core was split longitudinally, sampled, and packaged for retrograde to the respective investigators' laboratories in a subsurface science trench excavated adjacent to the drill platform.

The PICO intermediate drill is an electromechanical drilling system designed for continuous coring in firn and ice to a maximum depth of 600 meters in an open hole (Litwak, Kersten, and Kuivinen in press). The drill collects a 10.2-centimeter diameter core in runs of 70–150-centimeter length. A new cutting head includes three bits and core-catching dogs. The surface components are mounted on a platform and include: a Lebus winch with grooved drum containing 700 meters of seven-conductor cable, a dual tower device, a 2.5-kilowatt motor for high-speed raising and lowering of the drill, a 1.25-kilowatt motor for control of penetration and core break, and a control panel. The winch platform, the operators, and a work station are housed inside a modified Hansen WeatherPort shelter (figure 1). A 30-kilowatt, 208-volt alternating-current turbocharged diesel generator powers the winch and drill. The total weight of the drill system including winch platform, drills, generator, and shelter is 6,600 kilograms.

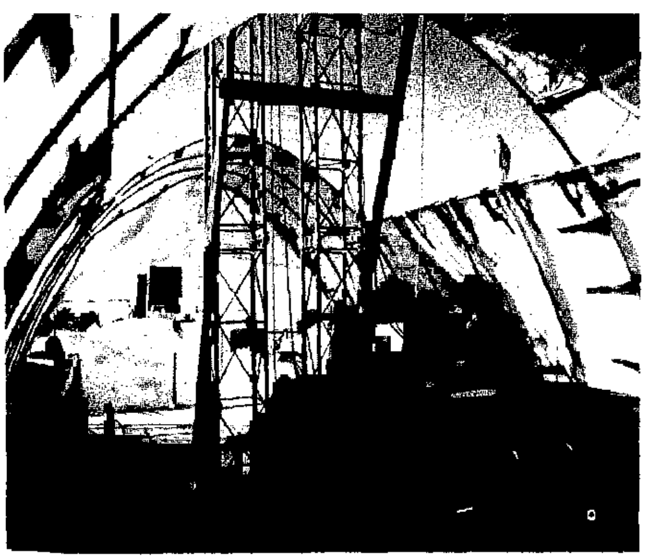

Figure 1. Winch platform including winch drum, tower assembly, and control panel inside the canvas-covered drill shelter at South Pole Station, December 1982.

The downhole portion of the drill was designed and built at PICO in 1979 and was used in conjunction with other winch systems during the 1979–1980 and 1980–1981 seasons at South Pole Station to a maximum depth of 108 meters. The winch platform was designed and assembled at PICO during 1981–1982 and was used with the downhole component of the PICO drill during 1982 at South Pole Station to a depth of 237 meters.

The 1982–1983 antarctic field season provided the first opportunity to use the complete PICO intermediate drill system in a field situation. PICO staff members B. Koci, K. Kuivinen, and J. Litwak were in Antarctica from 9 November to 20 December 1982.

Drilling took place in the center of the taxiway oval at South Pole Station. The drill platform and shelter were set up on a wooden platform after drifted snow and the past two years' accumulation were removed from its surface. A core processing and science trench (3 meters deep by 3.5 meters wide by 14 meters long) was excavated parallel to the drill shelter, roofed with timbers and plywood, and a stairway and tunnel were constructed to connect the drill platform with the science trench. Two vans were positioned adjacent to the drilling platform; one served as a workshop and break room and the other as a laboratory for the preparation and examination of ice core thin sections.

Drilling started at a depth of 108 meters in a hole drilled by PICO in 1980–1981 (Kuivinen 1981). A direct-current drill motor was used throughout the drilling operation. Bits with a 78° cutting angle were used first at 108 meters. These produced very fine chips which packed around the core inside the inner barrel and caused the core to be twisted off at the base before completing a run. Attempts were made to remedy the problem by reducing the clearance between the core and inner barrel wall, increasing the cutting angle of the bits to 55°, and sharpening the cutters, but the problem persisted.

Cutters with a 78° angle from horizontal and no adjustments for penetration eventually produced good core in 70-centimeter runs with penetration rates of 0.5 centimeters per second to a depth of 215 meters. Thereafter, core quality deteriorated, with frequent cracks and wafering occurring and with the length of runs reduced to 30 centimeters or less. Unsuccessful attempts were made to drill using a new head and bit configuration designed and built at the University of Bern. Problems encountered with this head were (1) penetration was limited to 10 centimeters per run due to chips packing behind the cutters and (2) packing around the core dogs resulted in failure to catch the core. Drilling was finally stopped at a depth of 237 meters.

In summary, the new winch and drill system worked well; we experienced no mechanical failures and only one electrical problem with the load-cell readout which was later bypassed. The tower system took 6 workhours to assemble, yet was erected easily, and provided a stable tower throughout the 1-month drilling season. The drill shelter with its 6-section canvas cover and Velcro tie-down straps was easily erected in 8 workhours and provided a satisfactory windbreak throughout the field season. The drill head and bit designs will be revised to include self-stabilizing bits which should result in improved core quality, penetration rate, and run length in the system's next field application.

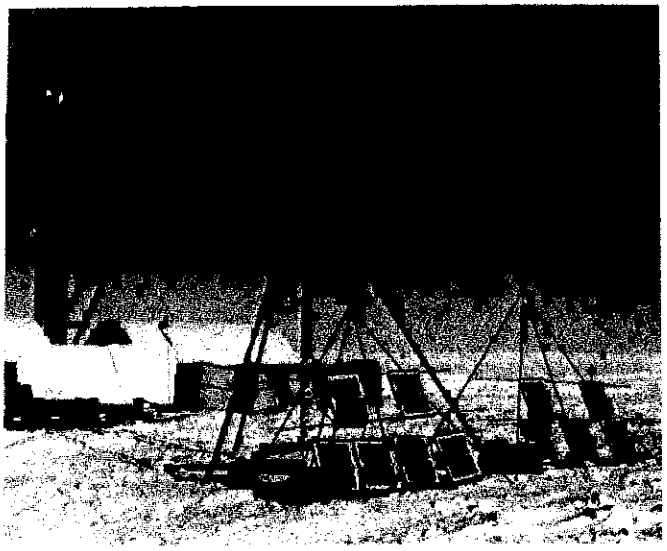

Figure 2. Solar-powered drill at South Pole Station 1982.

PICO lightweight coring augers (Koci in press) were used by other investigators at the South Pole, on Mount Erebus, and in the Allan Hills region to collect more than 100 meters of firn and ice core for later analysis.

Tests of a solar-powered version of the auger were conducted at South Pole Station (figure 2). Solar panel performance was 20 percent above the rated power output, exceeding results from Greenland during July 1982, due to the lower ambient temperatures and higher altitude at the Pole. We found that 300 watts of power from the solar panels was sufficient to produce penetration rates of the same order as with the electromechanical drills.

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Core processing and analyses of ice cores drilled at the South Pole

BERNHARD STAUFFER *and* JAKOB SCHWANDER

University of Bern
Bern, Switzerland

Analyses of ice cores provide unique information on the history of the Earth and the planetary system. This information helps in the understanding of climatic mechanisms. Our laboratory had the opportunity to take part in a joint core drilling and core analysis project at the South Pole. Our main scientific goals in this project were:

- To reconstruct the history of the atmospheric carbon dioxide (CO_2) concentration by analyzing air extracted from ice samples from different depths and, therefore, different ages.
- To reconstruct the history of solar activity by measuring the beryllium-10 and chlorine-36 concentration in ice samples. Both isotopes are produced by cosmic radiation in the atmosphere.
- To measure the acidity of ice cores as a function of depth, which gives, for example, information concerning the volcanic activity in the past.

Ice cores from the South Pole are especially well suited for the CO_2 analyses. Because of the low temperature there is no danger of any interaction of CO_2 with the liquid phase. Three members of our laboratory (W. Bernhard, J. Schwander, and B. Stauffer) were in Antarctica from 9 November to 27 December 1982 to collaborate in the processing of ice cores at the South Pole. During the season, ice cores of a total length of 103 meters drilled in 1980–1981 and 120 meters (from a depth of 106 to 227 meters below surface) drilled in 1982–1983 were processed. The drilling site was 250 meters from South Pole Station.

To set up a processing line, a trench 3 meters deep, 3.5 meters wide, and 14 meters long was excavated next to the drilling site. The core processing procedure is shown schematically in figure 1. The visual stratigraphy (breaks, meltlayers, varying optical transparency) were recorded on graph paper and also with a video camera on tape. The video recordings are very useful later to select samples for special analyses. Breaks and melt layers are visible in the video recordings and, with improved illumination and recording techniques, it should be possible in the future to see finer details as well.

The acidity measurements can be performed in the field, and they were therefore included in the core processing. To perform these measurements, two electrodes were moved with a constant velocity over the flat and clean surface of the ice core. For a voltage of 1,000 volts between the electrodes, the current through the ice was about 2 to 4 microamperes (μA), depending on the acidity in the ice (Hammer 1980). The acidity in the ice shows the following characteristic features:

operated in the field in Antarctica. Since this equipment requires much smaller samples, it will be possible to increase the resolution with which the yearly snow layers can be examined by a factor of at least five over that used in the study reported here. Such extremely high resolution sampling will permit the intrinsic errors to be quantified, and the capability for field operation should eliminate nearly all of the extrinsic errors.

This project is a joint research effort of Virginia Polytechnic Institute and State University and the University of Kansas. This research was supported in part by National Science Foundation grant DPP 78-21417.

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South Pole ice core drilling, 1981–1982

KARL C. KUIVINEN *and* BRUCE R. KOCI

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

GERALD W. HOLDSWORTH

National Hydrology Research Institute
Snow and Ice Division
Environment Canada
Calgary, Alberta T3A 0X9

ANTHONY J. GOW

U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire 03755

A cooperative ice core drilling, core processing, and stratigraphic logging program was conducted at Amundsen-Scott South Pole Station during the 1981–82 season by investigators from the Polar Ice Coring Office (PICO), the national Hydrology Research Institute/Environment Canada (NHRI), and the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). A 202.4-meter ice core was collected, logged and packaged in the field, and then shipped to the CRREL ice core storage facility, where it will be made available to National Science Foundation-sponsored glaciologists for further analysis.

The principal objective of the field program was to collect a 200-meter core from the South Pole Station in order to extend the site's ice core chronology beyond the existing 115-meter depth. This was accomplished by using the Canadian Rufli-Rand electromechanical drill, which had been used in 1980 on Mount Logan (5,300 meters elevation) to collect ice cores to a maximum depth of 103 meters (Holdsworth in press). The drill's design is based on principles established by Rufli, Stauffer, and Oeschger (1976) and by Rand (1976). The drill collects a core 96–99 millimeters (3.8–3.9 inches) in diameter in runs averaging 1 meter in length. Unique to the Canadian drill system is a geodesic dome that serves as a structural unit supporting the central fixed tower and providing shelter for the drill crew. The entire packaged drill system, including winch platform, tower, drill, and shelter, weighs 730 kilograms (1,606 pounds).

The drill shelter, a core processing laboratory van, and PICO's 6.5-kilowatt generator were set up in the center of the station's taxiway oval (figure 1). A core storage trench (3 meters deep × 3 meters wide × 6.4 meters long) was excavated adjacent to the drill site. Drilling began on 17 December with a three-member drill crew and one core processor and continued for 22 days until drilling stopped at a depth of 202.4 meters. The average working day under normal conditions was 7.5 hours.

Initial problems with the antitorque spring-skate system and cutting bits were overcome as drilling progressed. During drilling runs in the upper 60 meters of the hole, the oversized antitorque system tended to jam in the hole, thereby reducing the penetration rate and causing a "stick-slip" motion as the drill

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Figure 1. The drill shelter and laboratory van in the center of the taxiway oval at South Pole Station, January 1982. (Photo by B. Koci)

progressed down the hole. The cutters used were mainly those with a 15-degree clearance angle; this, coupled with reduced penetration rates, produced very fine chips. After installation of cutters that took bigger bites and addition of ice skates to the antitorque springs, drilling resumed, with the drill current increased slightly from the normal 1.0 ± 0.2 ampere to 2.0 amperes. Upon completion of one run and winching of the drill, it was apparent from cable-blistering at the sheave and tangling above the drill/cable termination that the antitorque section had failed to keep the drill from rotating downhole. As a result, approximately 62 meters of cable had to be cut off and the remaining 273 meters of cable reterminated. The antitorque system was completely reworked to eliminate jamming in the hole.

Normal drilling resumed on December 23 at a depth of 60 meters (with runs averaging 80–90 centimeters and turnaround times of 17.5 minutes) and continued to the firn/ice transition at approximately 115 meters. Below this depth, turnaround times increased to 20 minutes per run (5 minutes of actual drilling time) and core lengths were reduced to 70–80 centimeters.

At 127 meters, the cable was reterminated to correct a short circuit and the antitorque system was reworked. The increased hardness of the ice at this depth and the −51°C temperature dulled the cutter edges; the resulting fine ice chips were difficult to transport along the drill's auger flights. This made it necessary to sharpen the bits before each run. These problems contributed to gradually declining core production (5–8 meters per day) and to termination of drilling at 202.4 meters.

CRREL's contributions to this project were providing glaciological expertise, including measurements of the basic physical and structural properties of the cores, logging, and stratigraphic analysis, and packaging of the cores at the drill site, and furnishing refrigerated facilities for processing cores for analysis by NSF-approved investigators. All cores were successfully age-dated on the basis of well-preserved annual layering, using techniques previously applied with success by Giovinetto (1960) and by Gow (1965). This depth—202.4 meters—is the deepest at which visible stratigraphy has been successfully delineated in ice cores. The core is estimated to represent a record of snow accumulation extending back approximately 2,000 years. This attention to stratigraphy is needed to ensure that sampling of the cores for geochemical, microparticle, entrapped gas, and stable isotope records will be performed on the basis of natural stratigraphic breaks. In the past, much valuable information has been lost because of the failure of most investigators to recognize the importance of stratigraphy in the selection and preparation of their samples.

While at the drill site, A. J. Gow also initiated studies of the density, bubble patterns, and crystal dimensions of the cores. Preliminary measurements of density and load are presented in figure 2. The firn/ice transition occurs at a depth of approximatey 115 meters, the deepest ever recorded in Antarctica.

Upon completion of drilling, all cores were airlifted to McMurdo Station for subsequent transshipment to CRREL, where they will be processed for analysis by approved investigators.

In addition to work with the ice core, PICO team members collected three gas samples for the Physics Insitute, University of Bern, Switzerland. The samples were collected through a Teflon tube inserted in 1980–81 in a borehole to a depth of 40 meters below the surface. The University of Bern reports that all gas samples show atmospheric composition. Collection of air samples from the firn will be repeated during the 1982–83 field season. These gas content analyses are important with respect to the interpretation of data from gas analyses performed on old ice samples (Stauffer 1981).

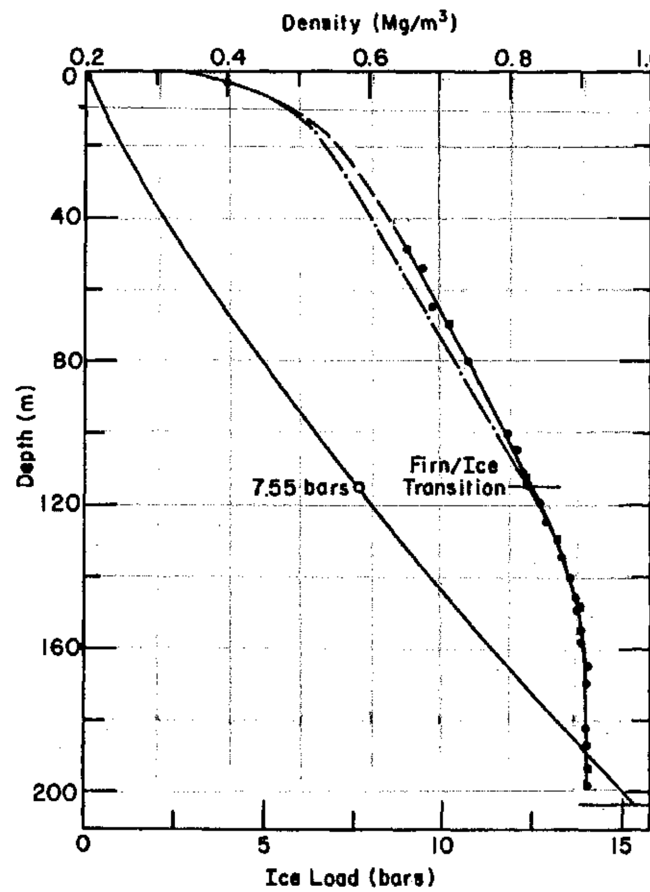

Figure 2. Density and ice-load profiles to 203 meters depth at the South Pole. Density curves obtained by Giovinetto (1960; dashed lines) and by Chiang and Langway (dashed-dotted lines) also are indicated. Density is measured in megagrams per cubic meter. (Figure by A. J. Gow)

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PICO also prepared the Gearhardt-Owen logging winch (used previously in logging and sampling the Ross Ice Shelf Project access holes at J–9) for use by University of Wisconsin-Madison geophysicists in their sonic logging of the 900-meter borehole at Dome C.

The drill team consisted of G. Holdsworth, B. Koci, and K. Kuivinen; A. Gow performed the core logging and stratigraphy.

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transition zone will be less complex, too. At a firn temperature of −50°C, the portion of gases adsorbed at the firn grain surface is expected to be minimal. Therefore, it is believed that gases enclosed in ice samples from South Pole Station represent the composition of the atmosphere at the time of enclosure better than ice samples previously available.

I thank the National Science Foundation, Division of Polar Programs, and PICO (NSF contract DPP 74-08414) for making the fieldwork possible and for providing excellent working conditions. I also thank the station leader and crew at South Pole Station for their efficient support.

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Ice core drilling, 1980–1981

KARL C. KUIVINEN

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

The Polar Ice Coring Office (PICO) conducted field tests of an intermediate-depth ice core drill at Amundsen-Scott South Pole Station during December 1980. Ice cores collected from two test holes of 49 meters and 108 meters were logged, packaged, and stored at the station for future sampling by other investigators.

The drill, designed and built by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), had been tested in Greenland during 1976 and had undergone several modifications at both CRREL and PICO prior to deployment to Antarctica in 1980. The objective during this season was to test the unit to a depth of 500 meters, collecting continuous ice core from the South Pole Station for later analysis. A drill shelter and core-processing laboratory van were set up in the center of the taxiway oval at the station. Drilling commenced using the original components of the CRREL drill: a 3,000-kilogram winch unit with armored cable, a horizontal tower, and various combinations of lightweight fiberglass drill barrels driven by a submersible pump motor. Drilling proceeded to a depth of 49 meters; beyond that depth the drill could not penetrate vertically. Runs made with an inclinometer indicated that the hole was being drilled in an ever-increasing spiral; this resulted in the drill's being wedged in the curved hole, thus preventing further penetration. It appeared that the drill was too light to deploy the cable properly and control penetration speed.

A new hole was then started using a heavier (120 kilograms) drill built by PICO. This unit collects core 4 inches (10.16 centimeters) in diameter, in contrast to the CRREL drill, which collects 3-inch (7.62-centimeter) core. Four days of drilling produced promising results: core of excellent quality averaging 1.40 meters per run during the first 90 meters, average core retrieval of 5.5 meters per hour, and winch line speeds of up to 400 feet per minute (122 meters/minute) during raising of the drill. At a depth of 92 meters, a line tension of 4,000 pounds (1,818 kilograms) was registered by the load cell during core break. When the drill was brought up, two breaks in the cable's armored jacket were apparent, and in other places the cable's neoprene sheath showed evidence of the cable's being slightly birdcaged. The damaged 100-meter portion of the cable was removed, and drilling continued to a depth of 105 meters, where the cable broke again during a core break that registered over 4,500 pounds (2,045 kilograms); the cable was again shortened and reterminated. On the next run it again broke, and the drillers decided to terminate the season's drilling because of the increasing danger to both personnel and equipment in the event of catastrophic cable failure. The change to the larger diameter PICO drill produced an expected increase in line tension needed to break the core, but the tension as recorded on the load cell should not have been sufficient to break the cable if it had been manufactured and spooled to the designer's specifications. The complete drill has been returned to the PICO workshop for further engineering research concerning core-break, cable, and winch design.

The PICO core-drilling program at South Pole Station was augmented by studies conducted by the Physics Institute, University of Bern, of the process of gas enclosures in ice and the composition of air enclosed in bubbles in cold ice. Data from their study should provide information about the composition of the atmosphere at the time the ice formed. Experiments were conducted in which air filling the pore space in the firn was collected and analyzed, and determinations were made of the variations in crystal size and shape of pores with increasing depth (see Stauffer, *Antarctic Journal*, this issue).

In addition to the drill test at the South Pole Station, PICO prepared and loaned a National Science Foundation Swiss shallow drill (100-meter capability) to the British Antarctic Survey for use in their drilling program on the Antarctic Peninsula. The British successfully collected cores from two holes of 30 meters and 83 meters. Unfortunately, this drill suffered severe damage and was not recovered after being dropped off the drilling tower and falling free from the surface to the bottom of the 83-meter hole.

Two members of the PICO team visited the Ross Ice Shelf Project drill camp J-9 and recovered a recorder and magnetic-data tape from the Norsk Polarinstitutt oceanographic freeze-in experiment.

The PICO drill team included Jay Arneson, Leendert Kersten, Karl Kuivinen, John Litwak, Philip Marshall, and Richard Tillson. Bernhard Stauffer of the Physics Institute, University of Bern, Switzerland, conducted the core analysis and gas sampling program upon completion of the drilling.

The Polar Ice Coring Office is supported under National Science Foundation contract DPP 74-08414.

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