THE POLAR ICE CORING OFFICE (PICO): SHALLOW AND DEEP ICE CORING AND DRILLING

By
John J. Kelley

PICO
Polar Ice Coring Office

Presented at
2nd Internal Symposium on
Exploratory Drilling in Complex Conditions
June 2-7, 1992
St. Petersburg, Russia

Polar Ice Coring Office
University of Alaska Fairbanks
Fairbanks, Alaska 99775-1710

CP-92-01

May 1992

The Polar Ice Coring Office (PICO):
Shallow and Deep Ice Coring and Drilling

By:
J. J. Kelley
Polar Ice Coring Office
University of Alaska Fairbanks
Fairbanks, Alaska 99775-1710

Presented at
2nd Internal Symposium on
Exploratory Drilling in Complex Conditions
June 2-7, 1992
St. Petersburg, Russia

CP-92-01

May 1992

THE POLAR ICE CORING OFFICE (PICO): SHALLOW AND DEEP ICE CORING AND DRILLING

John J. Kelley

INTRODUCTION

The Polar Ice Coring Office (PICO) is operated at the University of Alaska for the Division of Polar Programs of the U.S. National Science Foundation (NSF). The mission of PICO is to provide engineering and technical services for the ice-coring and ice-drilling needs of NSF glaciological programs. PICO also provides logistics services in the arctic for the NSF.

PICO works closely with the faculties of the professional schools of the University of Alaska Fairbanks (Geophysical Institute, Institute of Marine Science, and School of Engineering). Research and development activities are carried out in support of PICO's needs by these faculties and students. It is essential to identify the requirements for an ice-coring project, then specify the type of drill and supporting equipment to meet these requirements for a given ice-coring task. Ice-core drilling systems must handle a variety of ice types from 0° to -57°C, with varying pressure and physical characteristics of the ice.

Numerous ice-core drilling systems have been developed and used over the past 30 years. All of these systems produce core by cutting, shaving, or melting the ice. Physical designs of the many varieties of coring devices vary considerably. Each project has unique requirements and requires an initial decision as to the most effective drilling system to be used. PICO has developed a variety of drills to meet the general needs of the U.S. glaciological community (Proenza *et al.*, 1990). The choice of a drilling system can be represented as a decision tree (Fig. 1) (Rinaldi *et al.*, 1990). The two systems can be subdivided into various categories, ranging from a

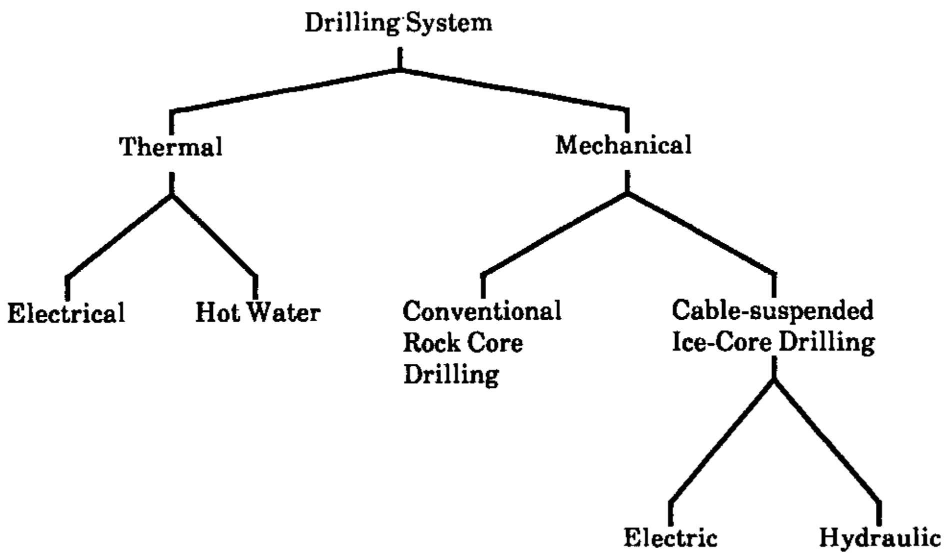

Figure 1. Drilling System Categories.

lightweight hand auger to the much more complicated electromechanical deep ice-coring system for use in fluid-filled holes (Fig. 2). Table 1 further describes the capabilities of each type of drilling system, its use, depth capability, and core size. Approximate weight, power requirements, and fuel consumption are given to illustrate the expected logistic requirements associated with each ice-coring system.

Composite Materials

Since many field investigations require operations on glaciers in remote regions of the world, lightweight, state-of-the-art materials are used to enhance design flexibility and minimize weight (Koci, 1989a). When specific strength (strength/specific gravity) is compared to specific modulus (modulus of elasticity/specific gravity) for several composite materials, aluminum, and steel, the data show that the composite materials are stronger and stiffer than aluminum or steel on a per weight basis (Fig. 3).

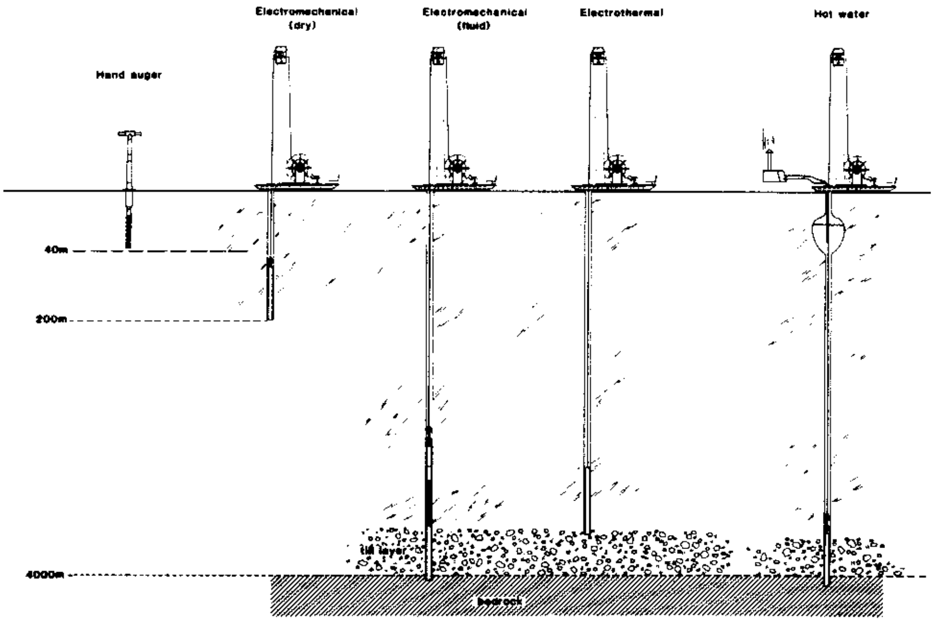

Figure 2. Illustration of various PICO drilling systems and their capabilities.

Table 1. Description of PICO drilling systems showing capabilities, core size, weight, and power requirements.

Drill Type	Depth Capability	Use	Core Size Length	System wt	Power Requirement	Expected Fuel Consumption
Hand Auger	40 + m	Shallow sampling from a remote area.	7.5, 10, 15 cm 1 m	100 Kg 50 m System	--	--
Electromechanical (dry)	150 m below firn ice transition or 300 m	Deeper drilling (ice); remote area.	7.5, 10, 13 cm 1 m	1,000 Kg with spares including generator	4 Kw	200 L/200 m
Electrothermal	Depth of ice with fluid	Warm ice, remote area.	8 cm 3 m	20 Kg (drill only)	4 Kw	300 L/200 m
Electromechanical (fluid)	Unlimited including limited bedrock sampling	Sampling into bedrock requires major support and 25L of fluid per m.	13 cm 6 m	5,000 Kg without generator or fluid	35 Kw	15 L/hr
Thermal (hot water)	Unlimited including bedrock sampling	Access to or sampling of bedrock. Size of system is a function of depth requirement.	30 cm 10 + m	From 1,000 to 10,000 Kg	20 Kw and a 30 Hp pump	80 L/hr

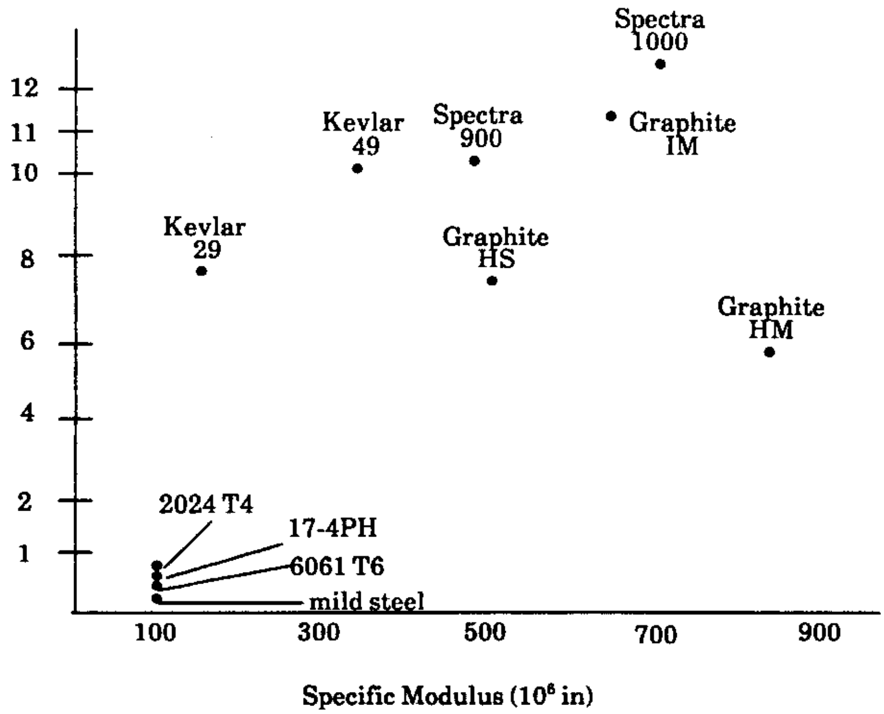

Figure 3. Description of specific strength to specific modulus for various materials (Source: Addax, Inc., Lincoln, Nebraska).

Composites and composite fibers are incorporated in most PICO drills from the lightweight hand auger to the deep ice-coring drill. High strength-to-weight ratios and high tolerance to damage are among the reasons for the selection of composite materials. Kevlar is used instead of steel in drill system cables, resulting in an eightfold weight reduction.

ICE-CORING DRILLS

Lightweight Auger

Extensive use of glass epoxy composites has resulted in an auger capable of drilling in ice without the use of a tripod (Koci, 1989c; Koci and Kuvinen, 1984) to depths of approximately 30 m, or to 50 m with a tripod to assist in raising the drill string. The core barrel is a piece of 7.5-cm diameter (10- or 15-cm core size also available) composite pipe wrapped with two ultrahigh molecular weight polyethylene spirals riveted to the barrel, and is available in either 1- or 2-m lengths. An aluminum adapter held in place by quick-release pins is used to connect the core barrel to the extensions (Fig. 4). The extensions are 5-cm-diameter composite pipes

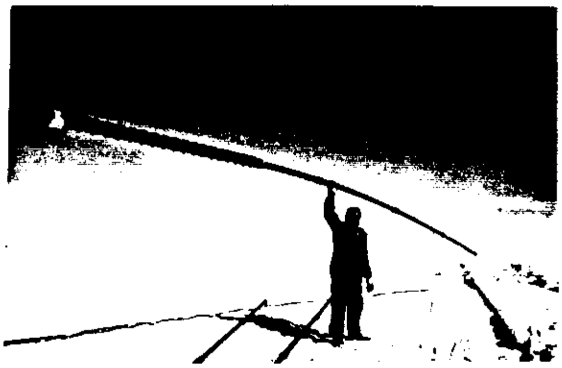

Figure 4. PICO hand auger with 2-m core barrel and 7 m of extension tubes.

cut to either 1- or 2-m lengths with a weight of about 1 and 1.5 kg per meter extension, respectively. New extensions weighing 400 g/m are being fabricated from graphite and SPECTRA (Allied Fibers, Inc.). Extensions are screwed together. The strength of the joints and pipe used in the lightweight auger are more than adequate for all shallow drilling operations. Another advantage of using screw threads is that nothing protrudes beyond the outside diameter of the extensions, thereby eliminating the possibility of chips being scraped off the hole wall.

Cutting heads incorporate a tapered annulus and core dogs to insure positive catching of the core after each run down the hole. Adjustment screws are used to control the rate of penetration and to avoid jamming the drill head in the hole. Solar power and a small electric drive can be used to increase drilling rates. Solar power has been used to drive an electric motor (Koci and Kuvinen, 1984). Because only 250 watts are required to drive the drill, the motor/power system is neither large nor heavy.

Electromechanical Drill

The 10-cm-core diameter electromechanical drill system (Fig. 5) is capable of drilling to 300 m and serves as an intermediate drilling system between shallow depths and deep ice coring well below the firn to ice transition. This system was used on the Dunde Ice Cap, China (5400 m elevation) to drill three cores to bedrock, each yielding approximately 135 m of core.

Figure 5. 200-m electromechanical ice-coring system, Dunde Ice Cap, China. 10-cm ice cores are in the foreground.

Thermal Systems

Thermal-electric drilling systems use drilling heads in which heating elements are circularly embedded (Fig. 6). When the heated head is lowered into the ice, it melts a circular ring and penetrates deeper into the ice. The ice core then moves deeper into the chamber of the drilling system (Rinaldi *et al.*, 1990).

Thermal drilling is slow and power-consuming. The presence of water in the hole can result in freezing in the drill system. There is also concern about fracturing the core. Thermal drills cannot penetrate dirty ice.

The PICO electrothermal drill consists of a heating element attached to the end of a core barrel. The heating element is unique because it is hermetically sealed and

Figure 6. PICO electrothermal drill showing a 2-m-long, 8-cm-diameter ice core at the summit of Quelccaya Ice Cap, Peru.

pressure tight to approximately 5000 psi. Heating elements are 0.14-cm diameter and can provide power in excess of 40 w/cm^2.

Heat-transfer efficiency is high because the heating elements are in direct contact with the ice. Maximum power dissipation is 8000 watts in a 10-cm-diameter, 0.63-cm-thick ring. If the ice is colder, it tends to fracture. Thermal drills are useful for shallow and intermediate depths, but are too slow for deep drilling (Kelley and Koci, 1990).

In 1983, a lightweight winch with Kevlar cable was developed for use in high altitude, remote areas. The thermal drill described above was used to collect cores to bedrock on the Quelccaya Ice Cap, Peru. An electromechanical drill was used to make two starting holes through the firn to a depth of 35 m. Thereafter, a thermal drill was used to collect core to bedrock, which was reached at 163 m and 154 m (Koci, 1985). A similar system with an electromechanical drill was used to drill three holes to bedrock (135 m) on the Dunde Ice Cap, China. Comparable systems have been used in Greenland and Antarctica to obtain core to 300 m.

All PICO drills can use a variety of power sources. A 2-Kw array of Solanex, Inc. HE-60 panels (Fig. 7) was used on the Quelccaya Ice Cap, Peru, in 1983 to power the electromechanical and thermal drills (14°S, 70°W).

Hot-water drilling techniques are capable of reaching depths greater than 2000 m. Hot-water drills are used extensively to provide access holes for instrumentation and seismic investigations. The drill system consists of a down-hole hose and nozzles, winch, mixing manifold, and sled-mounted standard car wash heaters to provide hot water (Fig. 8). During the 1987-88 field season, two holes were drilled (370 m and 480 m) through the Crary Ice Rise, Antarctica (83°S, 170°W), to install thermistor cables (Kelley and Koci, 1990). The hot-water drill melted a hole 25 cm in diameter at an average drilling rate of 0.5 m per minute. Instrumentation on the drill stem included inclinometers to measure the tilt of the hole, thermistors to measure the water temperature and heat loss, and calipers to measure the size of the hole.

Figure 7. Two-Kw solar-powered drill system. Quelccaya Ice Cap, Peru, 1983.

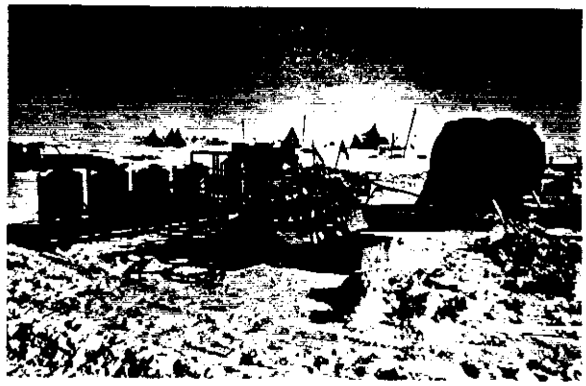

Figure 8. PICO hot-water drill. A modular approach is used in construction.

Deep Ice-Coring System

Core quality rather than hole closure limits maximum drilling depth in a dry hole. Addition of a fluid not only compensates for the overburden pressure, but aids the drilling process by enhancing chip removal and damping vibration in the drill.

The practical limit to open-hole drilling is in the 200-300 m range (Koci, 1989b). Beyond that depth the ice becomes brittle due primarily to high bubble pressure in the ice.

A major drill development initiative is underway to design and build a drill capable of extracting high quality core through the Greenland Ice Cap (3200 m). This 13-cm drill is an expansion of the standard 4-inch PICO drill. The deep drill design is based on the incorporation of pumping and filtering mechanisms for operation in a fluid-filled (butyl acetate) hole (Gosink *et al.*, 1991).

A deep ice-coring drill (Fig. 9) is being used to acquire ice cores through the Greenland Ice Sheet in support of the GISP-2 project. Approximately 1500 m of high quality core had been taken from the Greenland Ice Sheet by the end of summer 1991.

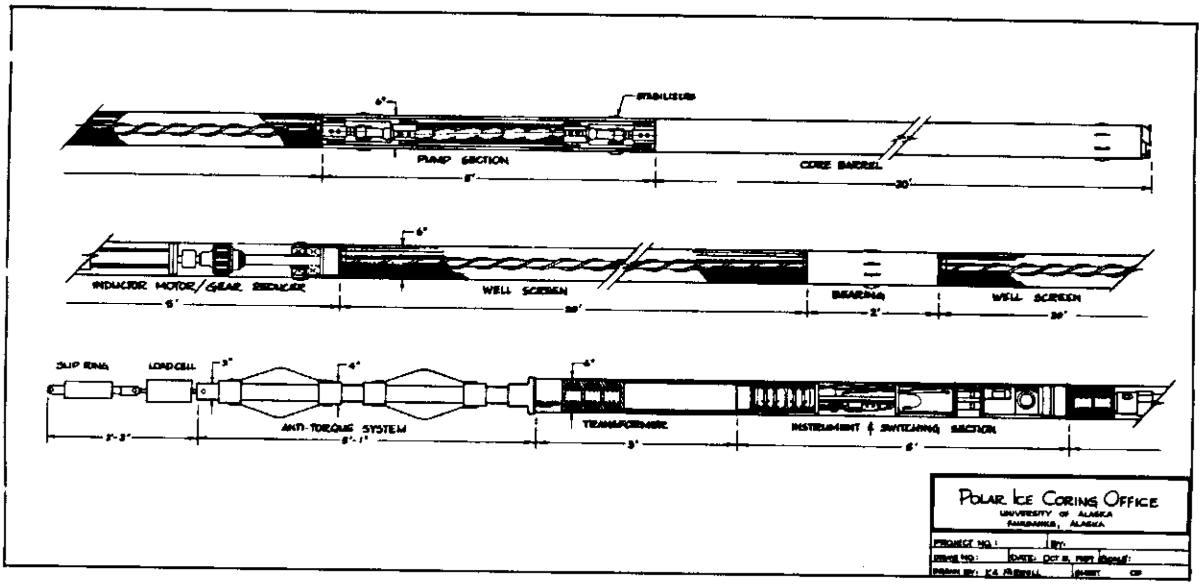

Figure 9. Schematic of the PICO deep ice-coring drill.

The drill consists of a cutting head with core dogs, core barrel, pump section, well screens, D.C. motor with gear reducer, instrumentation and switching section, transformer, anti-torque, and slip rings. Overall, the drill string is approximately 22 to 29 m long.

As the drill bit cuts the ice, chips and fluid are pumped into the filter, where chips are removed and the fluid allowed to recirculate. An instrument section (Hancock and Koci, 1989) monitors depth, inclination in two axes, azimuth, motor current, fluid pressure and temperature in the hole, cable tension, and other variables as needed. The drill is suspended by Kevlar cable with wires embedded and powered from the surface.

PICO searched for an appropriate drilling fluid that would be environmentally safe and meet as closely as possible specific drilling fluid requirements (Table 2). Of nearly 250,000 compounds surveyed electronically, 11 potentially suitable fluids were found. Of these 11, only two, butyl acetate and anisole, fully met the constraints imposed by technical, scientific, health, and safety concerns. Also, the density of

Table 2. Specific drilling fluid requirements for PICO drills.

1. Non-toxic
2. Chemically clean
    a. no salt ions
    b. Not to interfere with analyses for:
        i. Al, Pb, Zn, Cu, Cd, Se, As, Sb
        ii. oxygen isotope ratios
        iii. CO_2 and C^{14}
3. Hydrophobic (will not attack ice grain boundaries)
4. Viscosity (less than 5 centistokes at 20°C)
5. Density 0.92 g/cc from -50 to 0°C
6. Will not attack drill materials
7. Dielectric desirable

butyl acetate was found to rapidly increase with decreasing temperature. Because the minimum internal temperature in the upper kilometer of the Greenland ice sheet has been observed to be -31°C, and minimum temperatures are expected to be colder in Antarctica, an added densifier will not be required.

PICO has also modified its deep-coring drill to accept a rock-drilling bit to penetrate the rock/till substrate under the ice.

Drill Heads and Cutters

Drill heads and cutters (Fig. 10) currently are machined on a 4-axis CNC milling machine. This technology has been transferred from the petroleum industry's use of matrix drill heads. New heads will be made of sintered tungsten with cutters made from tool steel, tungsten carbide, or laser-cut diamonds. The new heads are expected to maintain roundness and cost less than machined heads.

Figure 10. Ten-cm drill head and cutter used on PICO drill systems.

Deep-Drill Handling System

A carousel drill-handling system (Fig. 11) was designed and constructed to support the deep ice-coring drill on the Greenland Ice Cap during the GISP-2 program. The carousel is used to break the 24-m drill string into 6-m sections.

The drill-handling system (Rinaldi *et al.*, 1990) is constructed of aluminum and composite materials. Drill components are stored in fiberglass-epoxy (AMERON) pipe. These pipes also contain the butyl acetate wash system (Gosink *et al.*, 1991) used in the removal of chips from the well screen sections in the drill. The chip/slurry mixture is collected in a drain pan located under the carousel. An auger removes the chips to a holding tank where the butyl acetate drilling fluid is removed by a centrifuge and recovered.

Handling of drill-core barrels is accomplished by use of a tilt-table made of an aluminum beam. The only drill component that is laid down is the core barrel. Once the core barrel is in a horizontal position, the head can be serviced and the core removed. The core is immediately logged and cut into 2-m sections, then placed in a polyethylene tube in 2-m core trays.

The carousel handling system offers several advantages:

1. All drill components are handled in a vertical position. This simplifies the disconnect/connect procedure and minimizes dripping of the drill fluid.
2. Core removal is efficient, as is the servicing of drill components. Reconfiguring of the drill can be done while the drill is being lowered down the hole.
3. The drill is never dismantled over the bore hole. This procedure eliminates the possibility of a section free-falling to the bottom.
4. Chip removal is simplified.
5. Drilling fluid and soaked chips are contained closely.

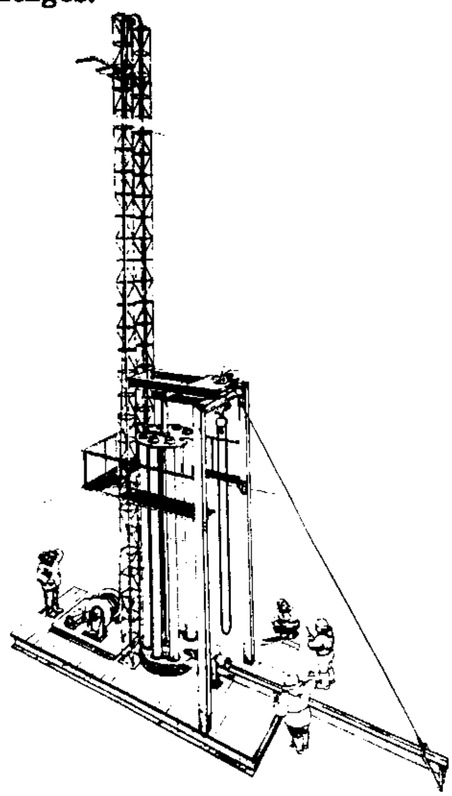

Figure 11. Deep ice-core drill-handling system.

Development of alternative drilling systems

Currently, through the professional schools at the University of Alaska Fairbanks, PICO is investigating alternative systems to produce high quality ice cores and to minimize cost, weight, and size of the equipment. Two prototype drills are under consideration: a hot-water mechanical drill and a new version of an antifreeze thermo-electric drill.

A study of ethanol as a drilling fluid with respect to its effect on ice has recently been concluded (Gosink *et al.*, submitted). Aqueous ethanol may be a useful ice-core drilling fluid in warm ($\geqq$ -25°C) boreholes and where density overturn is not a problem; that is, in holes of moderate depth with temperature gradients of $\leqq$ 2°C per 100 m.

ACKNOWLEDGEMENTS

The Polar Ice Coring Office (PICO) is operated at the University of Alaska Fairbanks under National Science Foundation Contract DPP 88-020948. Photographs were taken and supplied by Bruce Koci. We gratefully acknowledge the editorial and manuscript preparation assistance of Helen Stockholm, Moira Ingle, and Stephanie Oakes of the Institute of Marine Science Publications Department, School of Fisheries and Ocean Sciences (SFOS). We also appreciate the excellent cooperation given to PICO by the School of Engineering, Geophysical Institute, and SFOS, Institute of Marine Science.

REFERENCES

GOSINK, T. A., J. J. KELLEY, B. R. KOCI, T. W. BURTON AND M. A. TUMEO. 1991. Butyl acetate, an alternative drilling fluid for deep ice coring projects. *J. Glaciol.* 37:170-176.

GOSINK, T. A., B. R. KOCI AND J. J. KELLEY. Aqueous ethanol as an ice drilling fluid. Submitted to *J. Glaciol.*

HANCOCK, W. H. and B. KOCI. 1989. Ice drilling instrumentation. Proceedings of the Third International Workshop on Ice Drilling Technology. Laboratoire de Glaciologie et Geophysique de l'Environment, Grenoble, France, 1988. pp. 38-50.

KELLEY, J. J. and B. KOCI. 1990. The Polar Ice Coring Office (PICO): Development of Shallow and Deep Ice Coring Devices. The 5th International Conference on Sea Ice and the Okhotskt Sea. Mombetsu, Japan 1990. pp. 129-132.

KOCI, B. R. 1985. Instruments and methods: Ice core drilling at 5700 m powered by a solar voltaic array. *J. Glaciol.* 31:360-361.

KOCI, B. 1989a. Design and logistic requirements for ice coring and sample return from remote high altitude locations. Proceedings of the Third International Workshop on Ice Drilling Technology. Laboratoire de Glaciologie et Geophysique de l'Environment, Grenoble, France, 1988. pp. 24-27.

KOCI, B. 1989b. Design of a drill to work in a fluid filled hole. Proceedings of the Third International Workshop on Ice Drilling Technology. Laboratoire de Glaciologie et Geophysique de l'Environment, Grenoble, France, 1988. pp. 28-31.

KOCI, B. 1989c. Evaluation of a prototype deep ice coring system. PICO (Polar Ice Coring Office) University of Alaska Fairbanks, Technical Report 89-1. 44 p.

KOCI, B. R. and K. C. KUVINEN. 1984. Instruments and methods: The PICO lightweight coring auger. *J. Glaciol.* 30:244-245.

PROENZA, L. M., J. J. KELLEY, B. KOCI, J. SONDERUP AND M. WUMKES. 1990. Shallow and deep drilling devices developed by the Polar Ice Coring Office. *In* Proceedings of POLARTECH '90, August 14-16, Copenhagen, Denmark.

RINALDI, R., B. KOCI and J. SONDERUP. 1990. Selection of a deep ice core drilling system: Technical Evaluation. Technical Report. PICO (Polar Ice Coring Office), University of Alaska Fairbanks.

WUMKES, M. Personal communication.