Shallow and Deep Ice Coring Devices Developed by the Polar Ice Coring Office

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1. INTRODUCTION

The acquisition of good quality continuous ice cores for paleoclimatological investigations world wide has created a need for a variety of ice coring drills. 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 project. Ice core drilling systems must handle a variety of ice types from 0° to -57°C, 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. Figure 1 schematically illustrates a decision tree for choice of a drilling system /9/. The two systems can be subdivided into various categories. Figure 2 illustrates several types of drilling systems from a lightweight hand auger to the much more complicated electromechanical deep ice coring system for use in fluid filled holes. 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 is given to illustrate the expected logistic requirements associated with each ice coring system.

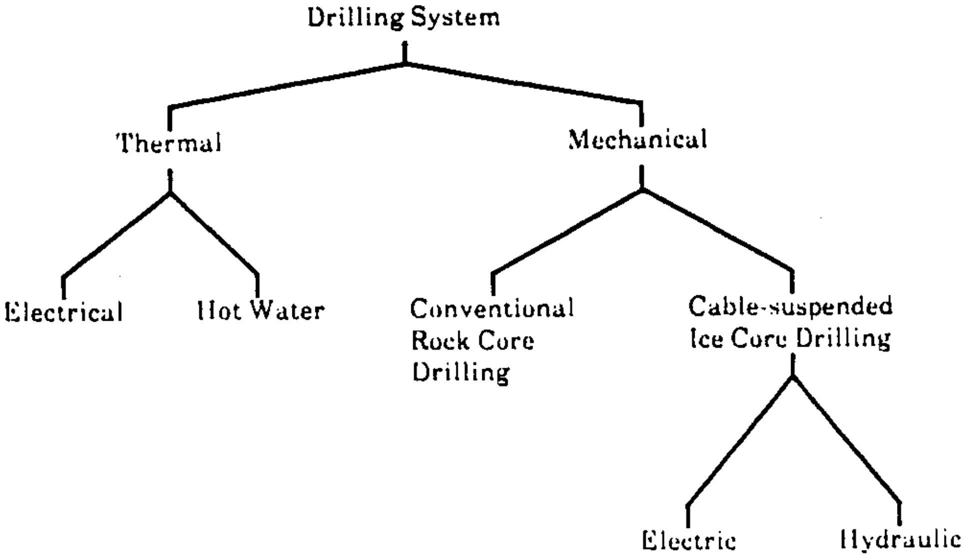

Figure 1. Drilling System Categories.

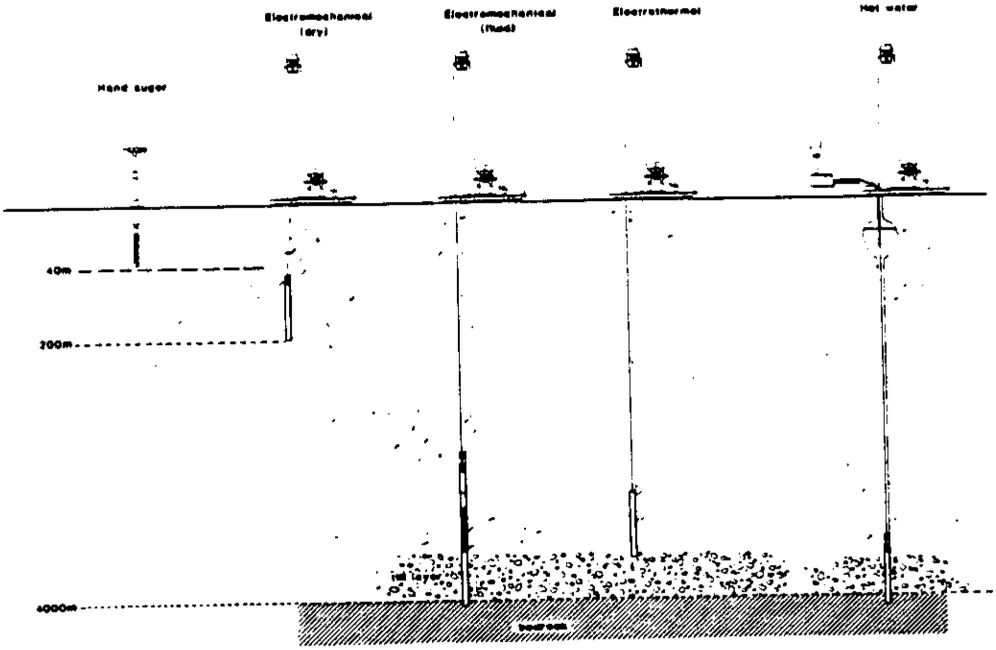

Figure 2. Illustration of various PICO drilling systems and their capabilities.

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 or sampling to/into 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

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

1.1 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 /6/. Figure 3 compares specific strength (strength/specific gravity) to specific modulus (modulus of elasticity/specific gravity) for several composite materials and aluminum and steel. The data show that the composite materials are stronger and stiffer than aluminum or steel on a per weight basis.

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

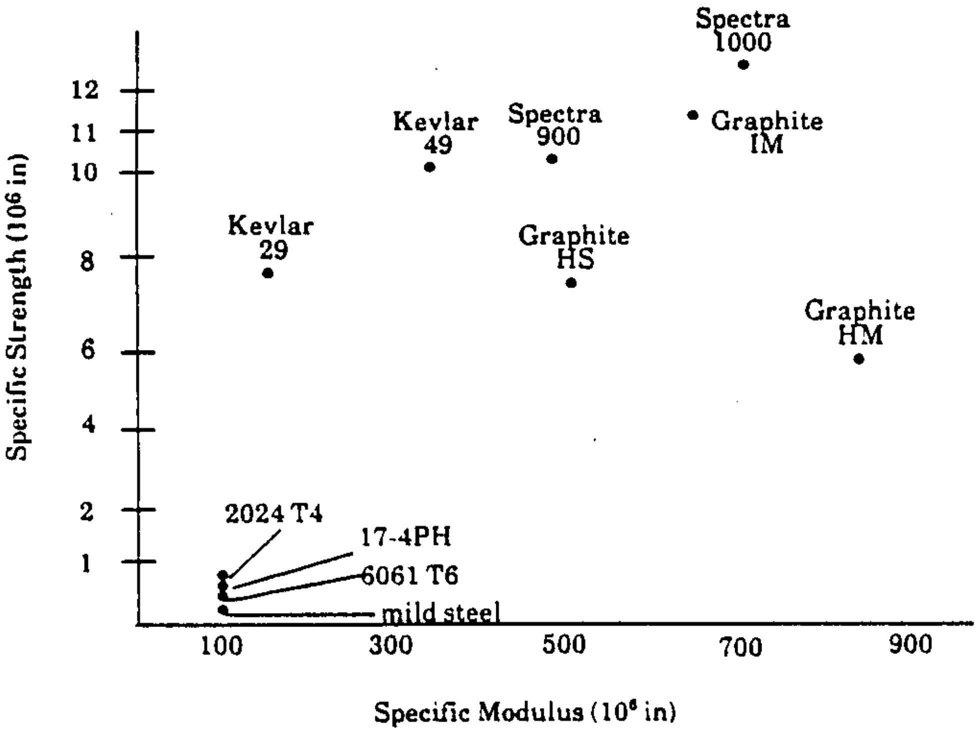

Figure 3. Description of specific strength to specific modulus for various materials (Source: Addax, Inc., Lincoln, Nebraska).

materials. Kevlar, rather than steel, is used in drill system cables which allows for weight reduction by a factor of eight-fold.

2. ICE CORING DRILLS

2.1 Lightweight Auger

Extensive use of glass epoxy composites has resulted in an auger capable of drilling in ice without the use of a tripod /7,8/ to depths of approximately 30 m, or to 50 m with a tripod to assist in raising the drill string. The core barrel is available in either 1- or 2-m lengths, is a piece of 7.5-cm diameter (10-cm or 15-cm core size also available) composite pipe wrapped with two ultrahigh molecular weight polyethylene spirals riveted to the barrel. An aluminum adapter held in place by quick-release pins is used to connect the core barrel to the extensions (Figure 4). The extensions are 5-cm-diameter composite pipes which are cut to either 1- or 2-m lengths with a weight of about 1 and 1.5 kg per meter extension, respectively (Fig. 4). 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 (O.D.) of the extensions, thereby eliminating the possibility of chips being scraped off the hole wall.

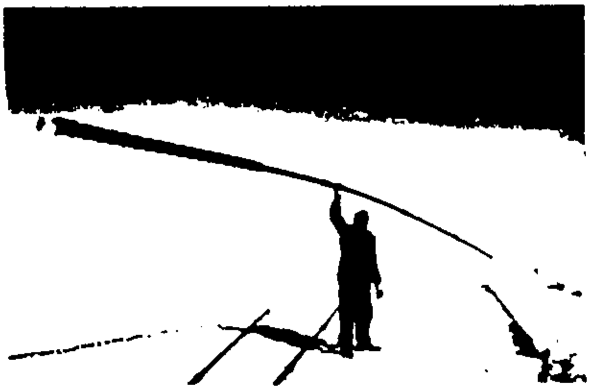

Figure 4. PICO hand auger with 2-m core barrel and 7 m of extension tubes.

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. The use of solar power and a small electric drive can be used to increase drilling rates. The use of solar power to drive an electric motor has been used /8/. Since only 250 watts are required to drive the drill, the motor/power system is neither large nor heavy.

2.2 Electromechanical Drill

Figure 5 shows the 10-cm-core diameter electromechanical drill system. This system 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. The system shown in Figure 5 was transported to the Dunde Ice Cap, China (5400 m elevation). Three cores to bedrock were drilled, each yielding approximately 135 m of core.

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

2.3 Thermal Systems

Thermal electric drilling systems use drilling heads that have heating elements circularly embedded in them (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 moves deeper into the chamber of the drilling system /9/.

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

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

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 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 since 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, the ice tends to fracture. Thermal drills are useful for shallow and intermediate depths, but are too slow for deep drilling /3/.

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. A 2-Kw array of solar voltaic panels was used to provide power. 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 /4/. 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. Figure 7 shows a 2-Kw array of Solanex, Inc. HE-60 panels 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 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 /3/. 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.

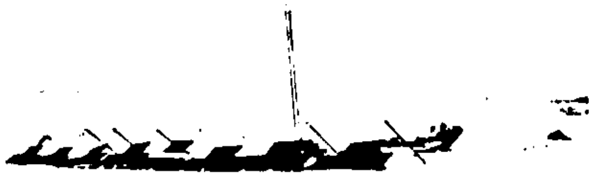

Figure 7. Two Kw solar-powered drill system. Quelccaya Ice Cap, Peru, 1983.

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

2.4 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 /5/. 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). Development of 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) /1/ hole.

Figure 9 is a schematic diagram of the deep ice coring drill that will be used to acquire ice cores through Greenland Ice Cap in support of the GISP-2, the second year of the Greenland Ice Sheet Program.

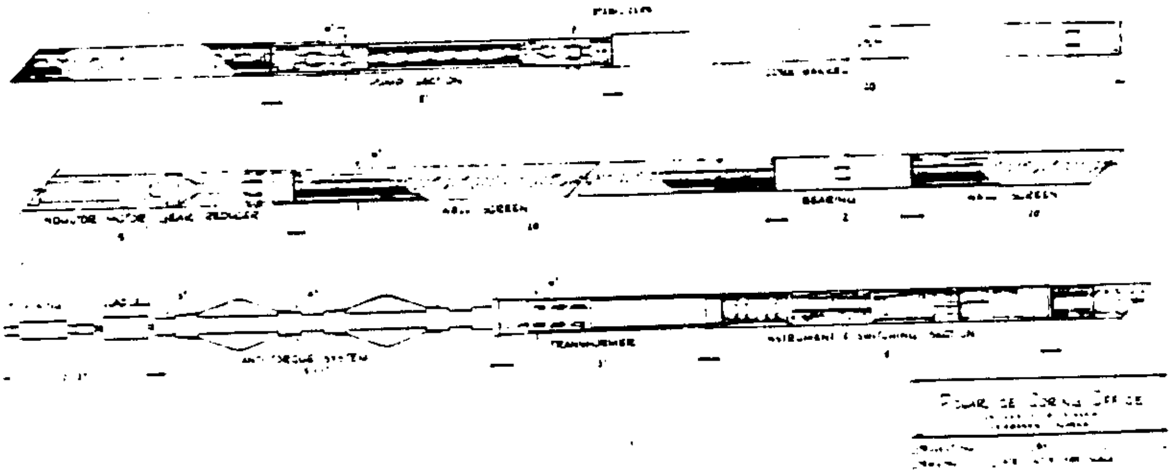

Figure 9. Schematic of the PICO deep ice coring drill.

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, antitorque and slip rings. Overall, the drill string will be 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 /2/ 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 will be suspended by Kevlar cable with wires embedded and powered from the surface.

2.4.1 Drill Heads and Cutters

Drill heads and cutters are machined currently on a 4-axis CNC milling machine. This technology is transferred from the petroleum industry's use of matrix drill heads. An example of a drill head and cutter is shown in Figure 10. New heads and cutters 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.

2.5 Deep Drill Handling System

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

Construction of the drill handling system /10/ utilizes aluminum and composite materials. Drill components are stored in fiberglass-epoxy (AMERON) pipe. These pipes also contain the butyl acetate /1/ wash system used in the removal of the 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 and 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 well as 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.

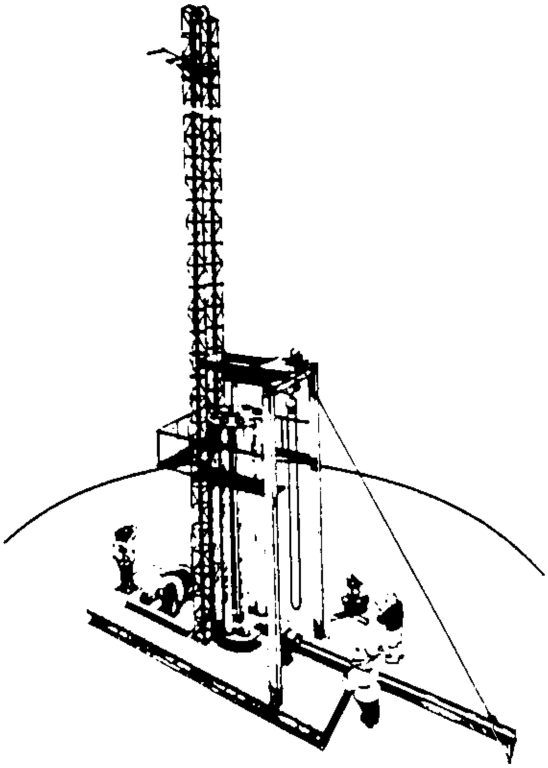

Figure 11. Deep ice core drill handling system

2.6 Development of a Hot Water/Mechanical Drill

Currently, PICO is developing a hybrid hot water/mechanical drill /3/ with a design capability of drilling to over 3000 m. A hose similar to the one used in the Crary Ice Rise Drilling Program, Antarctica, will be used to provide wire for instrumentation, additional strength, and insulation.

A conceptual drawing appears in Figure 12. The inner barrel will be a composite material to insulate the core from hot water which flows between both barrels to melt chips as they are generated at the cutting head. The core diameter will be at least

20 cm to allow trimming of material that is thermally fractured. Core length should be in excess of 10 m since no storage of chips is required.

Down-hole instrumentation will consist of the standard electronics package used in the electromechanical drill. Power to drive the cutting head will be provided by adown-hole mud motor driven by a triplex pump at the surface. It is expected that this drill will also be able to cut into subglacial material and bedrock.

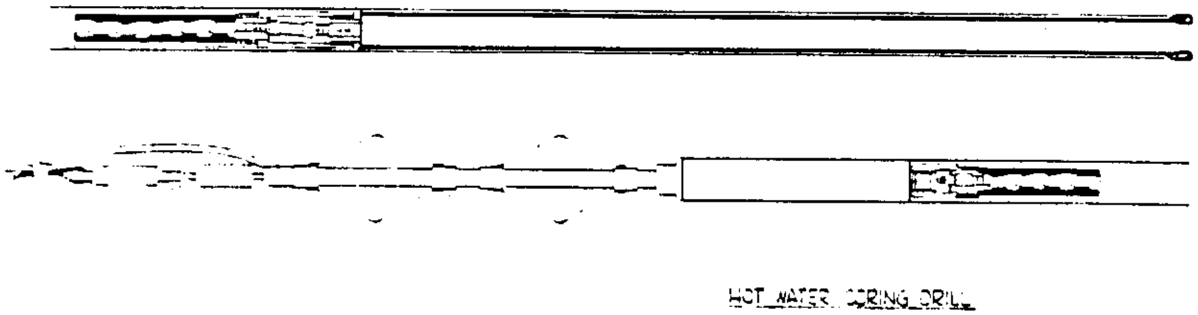

Figure 12. Schematic of hybrid hot water/mechanical ice coring drill.

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