DEEP CORE DRILLING IN THE EAST ANTARCTIC ICE SHEET: A PROSPECTUS

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ABSTRACT

A major objective of the International Antarctic Glaciological Project (IAGP) is to core drill through the East Antarctic Ice Sheet and into the bedrock beneath it.

The drilling site will be remote from major bases at an elevation of over 3000 m. All equipment and supplies will be flown in using ski-equipped C-130 aircraft.

A unique drill pipe consisting of lengths of fiberglass-reinforced epoxy pipe cemented to lightweight steel tool joints has been developed which weighs only 2.87 kg/m and costs less than $25/m.

This development makes it possible to use a lightweight wireline core-drilling system which minimizes the logistics burden, the time required for drilling, and the cost of the operation.

The wireline core-drilling system consists of a coring bit attached to the core barrel outer-tube assembly which is rotated by the drill pipe, the non-rotating core barrel inner-tube and core-lifter assembly, a wireline hoist with an overshot attached to its cable which is used to retrieve the core-laden inner tube through the inside of the drill pipe, a means of supporting and rotating the drill string, and a means of circulating the drilling fluid which removes the cuttings from the hole and prevents its closure by plastic flow of the ice due to the overburden pressure.

Cold air will be the drilling fluid for the upper 1000 m of the hole. Use of a reverse air-vacuum circulation system eliminates the requirement for an air-cooling system and results in the production of very clean uncontaminated ice cores.

At a depth of about 1000 m arctic-grade diesel fuel (DFA) will be used as the drilling fluid to reduce hole closure and remove the cuttings.

The DFA will be pumped through the drill pipe and carry the cuttings up through the annulus to a separator on the surface. The clarified DFA will be recirculated through the drill string.

It is intended to field test all components of the wireline core drilling system on the Ross

Ice Shelf Project in Antarctica during the 1975-1976 austral summer.

A program is recommended which would make it possible to begin the U.S. deep core drilling in ice portion of the IAGP as early as the 1976-1977 season.

Introduction

One of the objectives of the International Antarctic Glaciological Project (IAGP) (Anonymous, 1971) is to core drill through the East Antarctic Ice Sheet and into the bedrock beneath it.

The technique that was used successfully to core drill through the Greenland Ice Sheet at Camp Century (Ueda and Garfield, 1968) and through the Antarctic Ice Sheet at Byrd Station (Ueda and Garfield, 1969a) will be reviewed briefly to point out why it cannot be used in East Antarctica.

A description of the wireline core-drilling system for the East Antarctic drilling with particular emphasis on the new composite drill pipe and its impact on equipment, financial and logistical requirements is followed by recommendations for the drilling program.

Review of Prior Deep Core Drilling in Ice

It is not possible to drill deep into the ice unless the hole is filled with a fluid to prevent or greatly reduce hole closure due to the flow of the ice caused by the overburden pressure. The hole cannot be filled with fluid unless the hole through the permeable firn which overlies the impermeable ice is lined with a casing frozen into the impermeable ice.

At both Camp Century and Byrd Station the hole for the casing was drilled with a CRREL thermal drill (Ueda and Garfield, 1969b; Ueda and Hansen, 1967).

The fluid used to prevent hole closure was a mixture of trichlorethylene (TCE) and diesel fuel, arctic (DFA) whose density is nearly the same as ice.

An electromechanical coring device (modified Electrodrill) using a hoist and an armored cable to transmit power and to raise and lower the drill was used to core drill from the bottom of the casing to the bottom of the ice sheet and on into the material beneath the ice sheet.

The drill cuttings were removed from the hole using a unique glycol-dilution technique to put them into solution. A volume of concentrated aqueous ethylene-glycol solution, the amount depending upon the downhole ice temperature and the volume of cuttings to be formed, was sent down on each run.

The downhole pump and motor in the Electrodrill caused this fluid to flow through an annular space between the motor and its cylindrical housing on its way to the cutting bit. Heat from the motor transferred to the glycol solution provided the heat needed to dissolve the ice chips.

The diluted solution was removed in the bailer section on each return trip. Any dilute solution remaining downhole stayed downhole because it was denser than, and immiscible with, the mixture of DFA and TCE above it.

It will not be possible to use this technique in East Antarctica where the temperatures in the borehole will be in the minus 50^{o} C range because the fluid is too viscous and the permissible dilution is about zero (Fig. 1).

Wireline Core-Drilling System

A unique wireline core-drilling system is being developed which utilizes components and techniques from both the diamond core drilling and rotary drilling industries and is intermediate in size between the rigs typical of those industries.

It is an outgrowth of the system designed to drill the core and access holes for the Ross Ice Shelf Project. All components except a larger mast and all techniques will be field tested on the RISP.

A wireline core-drilling system consists of a coring bit attached to the core barrel outer-tube assembly which is rotated by the string of drill pipe, the non-rotating core barrel inner-tube and core-lifter assembly, a wireline hoist with an overshot attached to its cable which is used to retrieve the core-laden inner tube through the inside of the drill pipe, a means of supporting and rotating the drill string, and a means of circulating the drilling fluid which removes the cuttings from the borehole, cools the coring bit, and stabilizes the hole.

The objective in core drilling is to obtain a meter of good quality core for every meter of hole drilled and to do it as rapidly as possible.

The rate at which the hole is drilled is a function of four factors: the design of the bit, its rotating speed, the weight on the bit, and the removal of the cuttings by the circulation of the drilling fluid.

Mellor (1974) has examined the design of drag bits and the kinematic relations to rotating speed and the rate at which the hole is drilled. His results have been used to check the design of the bits used on prior deep core drilling and the similar bits designed for the wireline coring system.

These are drag-type coring bits with steel or diamond-set blades designed to cut 60-mm-diameter core in holes either 159 mm or 178 mm diameter. The latter is required to case the upper part of the borehole. The steel-bladed bits are used for coring in firn or ice and the diamond-set bits for coring in the sub-ice material.

Prior experience has shown that rotational speeds of 60 - 225 rpm produce good core. The Bowen S-1E Power Swivel which will be used to support and rotate the drill string on the wireline system has a speed range of 0-150 rpm. Its output torque is adjustable over the range 0-150 m·kg.

The weight on the bit in this wireline system is subject to several constraints. The weight on the bit required to cut ice or the sub-ice material is provided by gravity loading–a portion of the weight of the core barrel and/or drill collars is applied to the bit. The remaining portion keeps

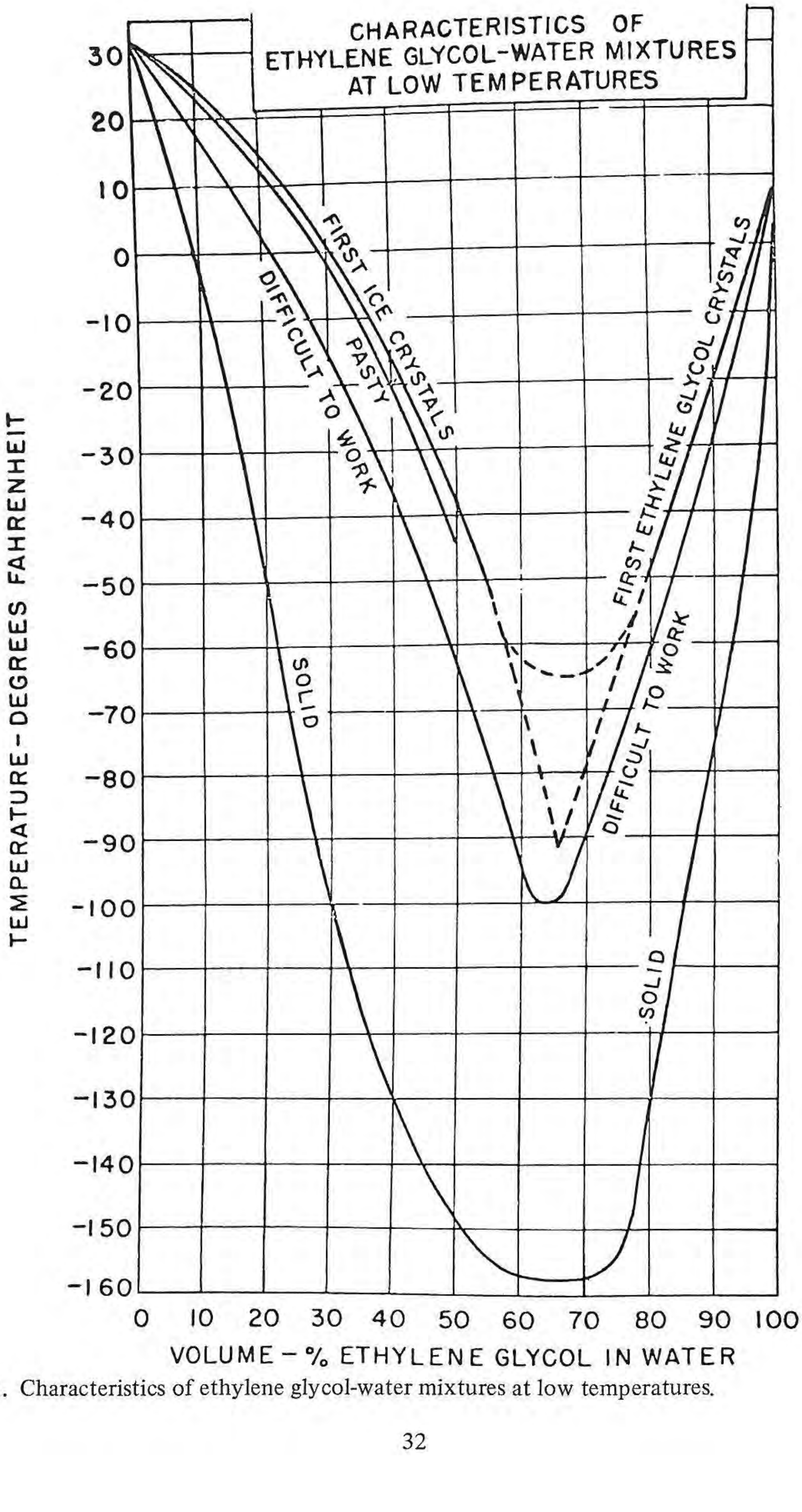

Figure 1. Characteristics of ethylene glycol-water mixtures at low temperatures.

the string of drill pipe in tension at all times. The portion of the weight of the core barrel and/or drill collars supported by the drill pipe provides pendulum steering to keep the hole plumb.

The weight on the bit is controlled by adjusting the rate of penetration by means of a flow control valve on a hydraulic cylinder. The entire weight of the drill string is supported by this cylinder which serves a dual purpose: it provides the drilling feed (range 0-0.6 m/min) and it serves as the main hoist with a speed range of 0-30 m/min. Core will be obtained in 6-m lengths.

The cuttings are removed from the hole by circulating cold air or DFA.

Reverse air-vacuum circulation has been used to drill large-diameter holes for several purposes including mine rescue. There are no known instances of its use for core drilling. A vacuum pump connected to the drill pipe through the power swivel causes air to flow down the annulus between the drill pipe and the hole wall, pick up cuttings as it flows past the bit, and carry the cuttings up the drill pipe.

Reverse air-vacuum circulation will be used to drill a 178-mm-diameter hole through the firn and into the impermeable ice so that this portion of the deep hole can be cased. Six-inch (162-mm I.D.) fiberglass-reinforced epoxy pipe will be used as casing. The lower 10 m of the casing and the annulus between it and the hole wall will be filled with water which, when frozen, forms the seal between the casing and the ice.

At the low temperatures in the East Antarctic Ice Sheet it should be possible to use the reverse air-vacuum circulation to core drill to a depth of 1000 m.

At that depth hole closure becomes a problem and it is necessary to fill the hole with DFA.

The DFA will be pumped down through the drill pipe and carry the cuttings up through the annulus to a separator on the surface. The clarified DFA will be recirculated through the drill string.

Circulation of the cold DFA may make it feasible to freeze the interface between the ice and the sub-ice material and prevent the intrusion of water if the bottom of the ice sheet is at the pressure melting point.

Composite Drill Pipe

The weight of the drill pipe required for core drilling to depths of 3000 or more meters in ice is a major factor in the design of the drilling system, the logistics requirements for deployment to and from the drill site, and the cost of the equipment and its utilization.

Core drilling in ice places less stringent requirements on the drill string in the following ways. The ambient temperature is low and many materials are stronger and have higher fatigue resistance at lower temperatures. The cuttings and hole wall are not abrasive. The power required to cut the ice is very low.

Sellmann and Mellor (1972) have examined the power required for drilling in ice. Using their results it is estimated that the power required for drilling a 159-mm-diameter hole at 0.3 m/min is nearly 750 W. The torque at 100 rpm would be 7.2 m·kg.

In 1972, the Longyear Company entered into a feasibility study to determine if it was possible to develop an aluminum-and-steel composite rod within the dimensional confines of their existing PQ Wireline System.

This study indicated that such a rod could be produced and the program progressed through the prototype-manufacture and laboratory-test stages. Laboratory tests have confirmed that a rod manufactured within the size limitations of the PQ System and using aluminum tubes with alloy steel ends would be suitable for deep core drilling in ice.

In November 1972 CRREL undertook the design and development of an even lighter composite drill pipe consisting of CIBA Geigy 512 3 in. (76.2 mm) fiberglass-reinforced epoxy pipe (FRP) cemented to Hydril flush joint wash-pipe (FJ-WP) connections made from N-80 steel. This construction is feasible because the epoxy pipe has almost the same thermal coefficient of expansion as the steel connections.

Over 500 m of this composite pipe has been procured for use on the RISP.

Table 1 is a compilation of data that is useful in evaluating several different configurations of drill pipe. Since each of the drill strings are of different size and vary considerably in construction, material specifications, investment costs, etc., it should be understood that a true comparison of the strings cannot be made. The tables are intended to provide the technical data required to more intelligently plan a program of deep-ice drilling.

The pipes are: (1) Hydril "A-95" tubing connection on modified API upset tubing in Grade "N-80" steel with a nominal outer diameter of 4 in. (101.6 mm) weighing 11 lb/ft (16.4 kg/m), (2) Reynolds 4 in. Aluminum Drill Pipe, (3) E.J. Longyear's composite aluminum drill rod PQ-S, and (4) the CRREL FRP composite.

Comparisons of the weights in kg/m in air–15.83, 14.40, 6.32 and 2.87, respectively–show the drastic reductions achieved by Longyear and CRREL.

Comparisons of the 1973 cost figures in dollars per meter–20.33, 43.62, 82.00 and 24.86, respectively–show the significant saving in the cost of the pipe alone that resulted from the CRREL development. The overall saving that comes from reduction in the size of the drilling equipment required and the transportation costs is much greater.

The total weight of drill pipe and drill collars required for the 30-cm-diameter access hole through the Ross Ice Shelf is 3220 kg. The present drilling mast is designed for a load of 6800 kg.

Core drilling through 3500 m of ice will require a mast that will support 8400 kg.

Only two significant changes need to be made on the RISP wireline core drilling equipment to increase its capability to that required for deep core drilling in East Antarctica: (1) provide a taller mast with a greater weight capacity, and (2) a new wireline hoist designed to work to 3000-4000 m instead of the present 1000 m.

Table 1

Drill Pipe Data

		Hydril A-95	Reynolds Aluminum	Longyear PQ-S	CRREL Composite
Pipe Elements					
Area, A	m^2	1.985×10^{-3}	3.487×10^{-3}	1.898×10^{-3}	1.095×10^{-3}
Moment of Inertia, I	m^4	2.248×10^{-6}	3.992×10^{-6}	2.813×10^{-6}	1.074×10^{-6}
Section Modulus, S	m^3	4.425×10^{-5}	7.486×10^{-5}	4.923×10^{-5}	2.324×10^{-5}
Radius of Gyrations, r	m	3.366×10^{-2}	3.383×10^{-2}	3.851×10^{-2}	3.132×10^{-2}
Polar Moment of Inertia, J	m^4	4.495×10^{-6}	7.985×10^{-6}	5.626×10^{-6}	2.149×10^{-6}
Polar Section Modulus, Z	m^3	8.849×10^{-5}	1.497×10^{-5}	9.845×10^{-5}	4.649×10^{-5}
E I Value	$m^2 kg$	4.741×10^{4}	2.985×10^{4}	2.098×10^{4}	0.221×10^{4}
Dimensions and Weights					
Pipe Body Outside Diameter	m	1.016×10^{-1}	1.067×10^{-1}	1.143×10^{-1}	0.924×10^{-1}
Pipe Body Inside Diameter	m	0.883×10^{-1}	0.833×10^{-1}	1.032×10^{-1}	0.846×10^{-1}
Pipe Body Wall Thickness	m	0.665×10^{-2}	1.168×10^{-2}	0.556×10^{-2}	0.394×10^{-2}
Joint Outer Diameter	m	1.096×10^{-1}	1.460×10^{-1}	1.206×10^{-1}	1.016×10^{-1}
Joint Inner Diameter	m	0.862×10^{-1}	0.826×10^{-1}	1.032×10^{-1}	0.883×10^{-1}
Overall Length Shoulder to Shoulder	m	9.144	9.144	6.096	6.096
Total Volume	m^3	1.847×10^{-2}	3.710×10^{-2}	1.290×10^{-2}	0.713×10^{-2}
Weight with Joints					
In Air	kg/m	1.583×10^{1}	1.440×10^{1}	6.428	2.872
In 1200 kg/m^3 mud	kg/m	1.342×10^{1}	9.032	3.898	1.458
In 800 kg/m^3 DFA	kg/m	1.422×10^{1}	1.071×10^{1}	4.762	1.934
Joint Properties					
Torsional Yield	m·kg		5.184×10^{3}	1.244×10^{3}	0.484×10^{3}
Make up torque	m·kg	0.484×10^{3}	1.548×10^{3}	0.346×10^{3}	0.152×10^{3}
Tension, min. yield	kg	1.061×10^{5}			6.033×10^{4}
Pipe Properties					
Tension, min. yield load	kg	1.116×10^{5}	1.422×10^{5}	0.774×10^{5}	1.820×10^{4}
Tension, min. yield strength	N/m^2	5.518×10^{8}	4.000×10^{8}	4.000×10^{8}	2.069×10^{8}
Torsional yield strength	m·kg	2.696×10^{3}	3.260×10^{3}	2.143×10^{3}	1.940×10^{2}
Torsional stiffness	kg/rad	3.910×10^{5}	2.418×10^{5}	1.701×10^{5}	0.107×10^{5}
Resistance to collapse	N/m^2	6.070×10^{7}	7.242×10^{7}	3.449×10^{7}	1.690×10^{7}
Internal yield pressure	N/m^2	6.325×10^{7}	7.656×10^{7}	3.221×10^{7}	
Internal burst pressure	N/m^2	8.698×10^{7}	8.449×10^{7}	3.559×10^{7}	3.932×10^{7}
Thermal coefficient of expansion	$°C^{-1}$	1.242×10^{-5}	2.160×10^{-5}	2.160×10^{-5}	1.242×10^{-5}
Stretch per meter per kg load	m	2.388×10^{-8}	3.848×10^{-8}	7.070×10^{-8}	4.811×10^{-7}
Cost, dollars per meter (1973)		20.33	43.62	82.00	24.86

Recommendations

The following program should result in successful deep core drilling in East Antarctica with the least expenditure of funds for equipment, drilling and logistical support.

1. Test the RISP wireline core drilling equipment in Greenland on the GISP-75 program using only the reverse air-vacuum circulation to remove the cuttings. This eliminates the need to case the hole through the firn and would permit core drilling to 400 or 500 m at Jarl-Joset or some other site. It would provide field experience with the equipment and an opportunity to correct any minor deficiencies prior to shipment to Antarctica later in 1975.

2. Proceed with the procurement and construction of wireline core drilling equipment and drill pipe to core drill a hole through the Greenland Ice Sheet in the summer of 1976. This equipment can also be used for intermediate depth holes at other locations in Greenland.

3. Execute the first season's RISP drilling program using the existing equipment during the 1975-1976 season. This program should include the procurement of another 300 m of drill pipe to permit core drilling the sub-sea sediments to a depth of about 30 m which can be accomplished with the present equipment.

4. Procure the larger mast, a 3500-m wireline hoist and 3000 m of drill pipe for use in East Antarctica. These can be used in conjunction with the RISP equipment to carry out the U.S. portion of IAGP deep core drilling in ice program beginning as early as the 1976-1977 season.

Prior experience has demonstrated the desirability of testing drilling equipment and techniques in Greenland prior to their use in Antarctica, a practice which has been followed without exception on all U.S.A. core drilling in ice projects in Antarctica.

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