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Some thoughts on deep core drilling systems design

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Abstract: There should always be an on going effort, particularly in our field of deep drilling in ice, to simplify and be innovative in our continuing effort to provide data for the glaciological community. We must strive to simplify for the obvious reasons of cost and reliability and we should be innovative in our attempt to constantly improve our equipment and techniques, particularly under the harsh Polar conditions which we all know too well.

This paper discusses some ideas and innovations which I feel might be useful for future designs and which might improve on the methods by which we pursue the concept of deep core drilling in ice. These include a possible method for retrieving whole cores in the brittle zone; a method for orienting core samples; a different type of drilling drive possibly using a hydrostatic principal as a gear reducer or a more conventional reducer driven by a standard deep well submersible motor; a novel anti-torque restraint utilizing the counter torque of the gear drive which is deployed only during drilling; a vertical stabilizing pendulum mechanism at the upper end of the drill; and a chip removal system which facilitates the collection and removal of the cuttings.

In addition an expedient method for setting up and operating a drilling system in a remote location and the use of alcohol as a drilling fluid are discussed.

1. Introduction

The history of deep drilling in ice has been one of brilliant successes and at times periods of frustration and disappointments. It is during the periods of disappointments that we realize that we still have not tamed the awesome forces of Mother Nature in our attempts to unlock the deep secrets that she has stored within the depths of the great ice sheets. However, we are progressing thanks to the efforts of the various International groups such as PICO in the U.S., the Danish and Swiss, the French, the Japanese, the Russians, and the Australians. Hopefully at some time in the future, we can reach the point where deep drilling in ice becomes a routine, mundane task no matter where or how thick the ice may be. Until that time however, it would behoove us to continue in our efforts to improve our methods and techniques to accomplish the task at hand in the most economical and expeditious manner. It is with this in mind that this paper hopes to present some ideas and innovations which might possibly be considered in the future designs of deep core drills.

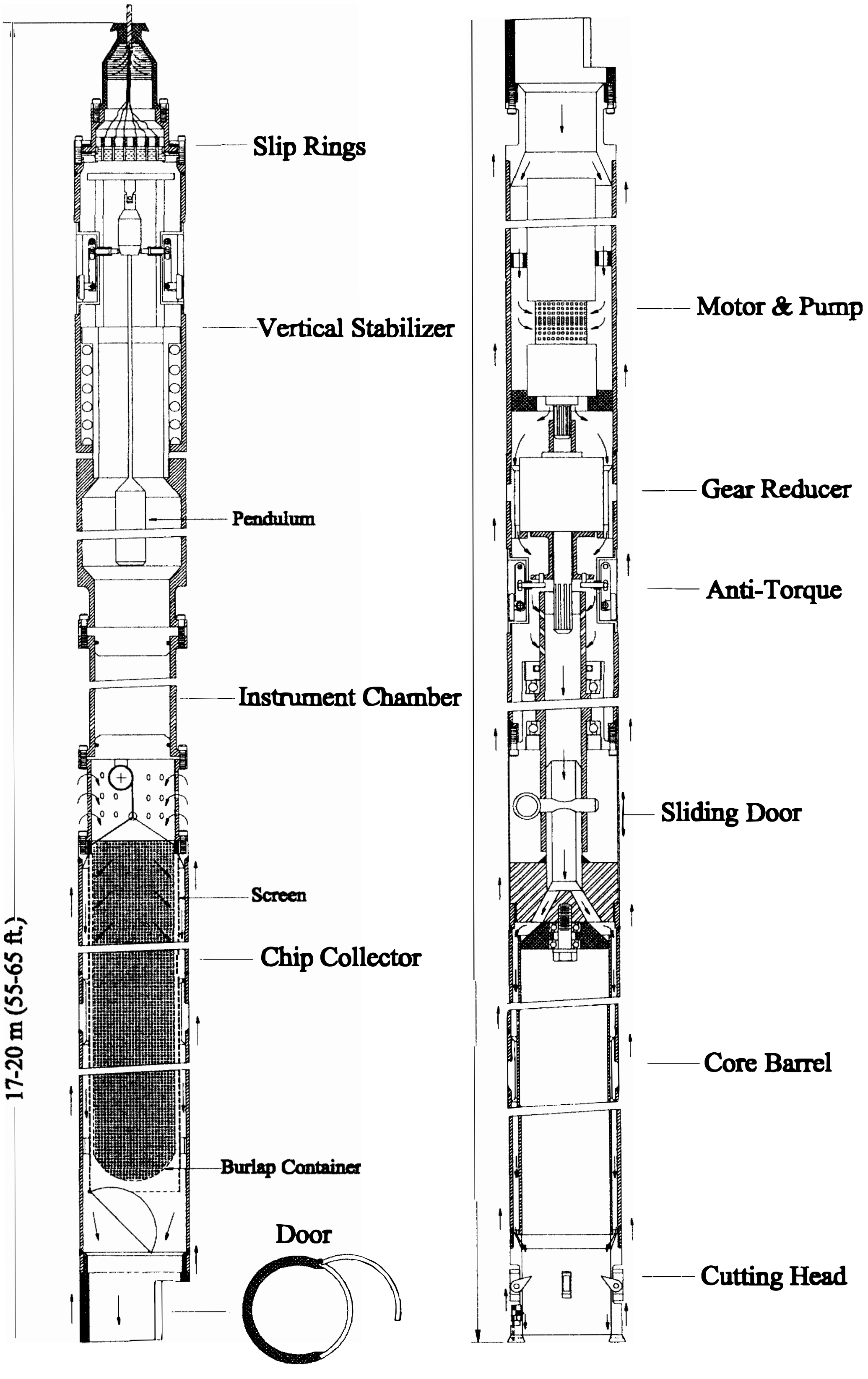

Fig. 1. Overall view of proposed drill.

2. Proposed drill design

Figure 1 shows an overall view of a proposed drill. It's primary feature is the use of a pump to circulate the hole fluid, in the vicinity of the drill only, to remove the cuttings from the cutting area and to collect it in a collection chamber. The technique of pumping fluid has been used successfully for years in conventional drilling and was the system used on the old Electro-drill back in the mid 60's. Estimates of the drill length and weight are 17-20 m (55-65 ft.) and around 500 kg (1100 lbs.) respectively.

Beginning at the top of the drill, just under the cable termination, is a set of slip rings so that the entire unit below this point can swivel freely. The next section contains a novel idea referred to as a vertical stabilizer. The mechanism is shown in Fig. 2. If the drill is inclined slightly, the upper portion of the pendulum assembly will act upon the grooved skates, forcing them into the ice wall in a direction to counter the inclination of the drill. Being under spring tension, they will retract as soon as the cable pulls the drill upward. The grooves will have sharp cutting edges to enable them to dig into the ice wall and provide an additional counter torque if needed.

Beneath the vertical stabilizer section is an open chamber which allows the pendulum bob to swing. Beneath this is the instrument chamber which will house among other items, a remote reading compass. This will be discussed later with regard to core orientation. The instrument chamber will have to be fabricated from stainless steel and be sealed. This is the only section which needs to be sealed, the remainder of the drill can be open to the down-hole environment.

Next is the chip collection chamber. The top of the chamber has a several holes

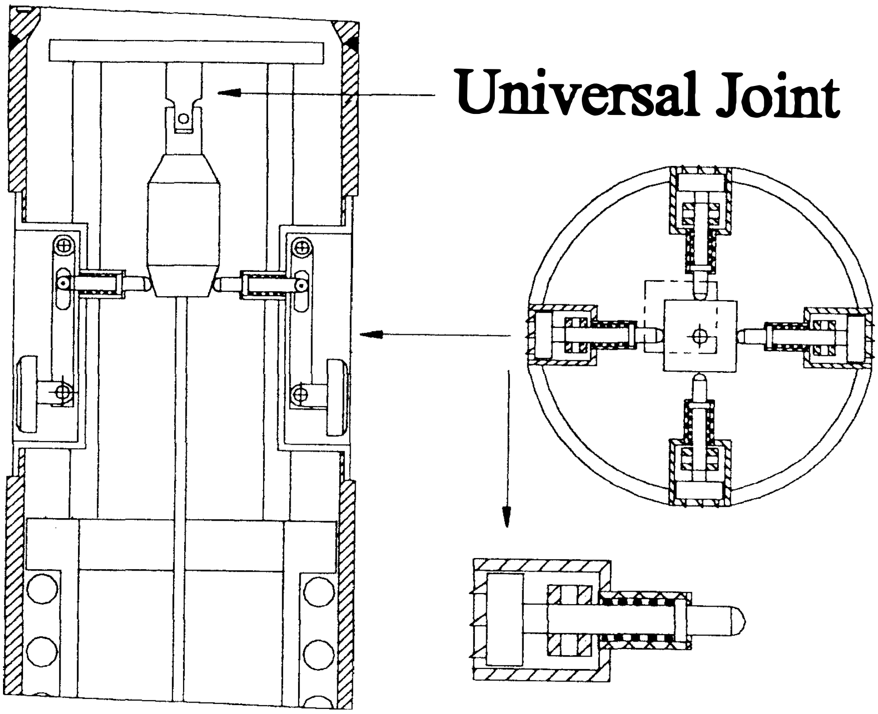

Fig. 2. Vertical stabilizer.

which will allow the chip laden hole fluid to pass through. Inside there is a rigid, perforated metal cylinder or screen running the length of the chamber. Inside of this cylinder is a filter bag made of suitable material. In tests conducted several years ago, it was found that ordinary burlap worked surprisingly well. At the bottom of the chamber is a gate which retains the bag. On the outer wall, just below the gate, there is a door which will allow the filter bag to be removed when the drill is brought to the surface. The filter bag is suspended by a wire which is connected to a spring wound reel at the top of the chamber so that a replacement bag can be installed through the bottom immediately after removing the full bag.

Below the chip collection chamber is the driving unit which consists of a modified conventional deep well motor and centrifugal pump assembly and a gear reducer The motor and pump combination is commonly used in water wells and is pressure compensated. Additional compensation may be necessary for deep holes but should not present a problem. The motor is three phase operating at 460 volts and 1750 or 3400 rpm. The design would require a shaft extension of the pump in order to connect to the gear reducer.

The gear reducer is a harmonic drive type which would reduce the motor speed to about 100–150 rpm. Another possibility is the use of a hydrostatic drive to provide the necessary reduction. A hydrostatic drive consists essentially of a hydraulic pump driving a hydraulic motor. If properly compensated it should be usable at any depth and conceivably operate using the hole fluid in an emergency. The efficiencies are somewhat

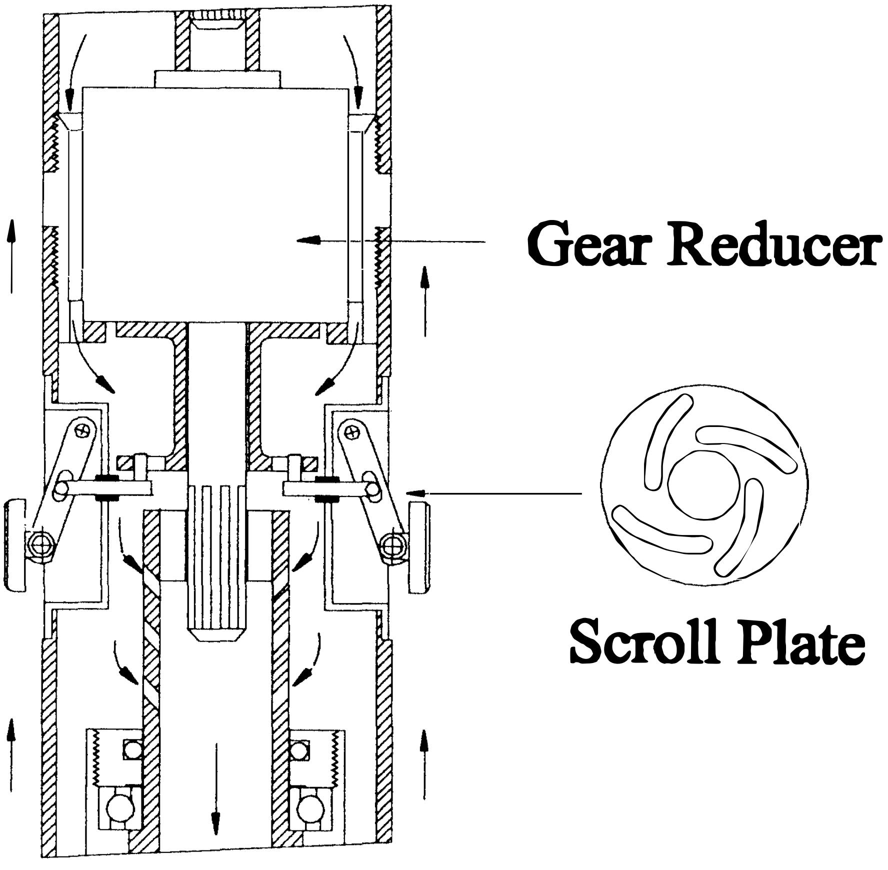

Fig. 3. Anti-torque mechanism.

low, however it probably wouldn't be significant considering the duty cycle of a drill run. It should also provide some speed control, at least on a given run.

Figure 3 shows a proposed anti-torque mechanism. The grooved skates are of the same construction as those used in the vertical stabilizer. They are actuated by a scroll plate which is attached to the freely rotating gear reducer. The scroll plate provides a cam action to the arms forcing the skates out against the bore hole wall. Stopping the motor at the end of a run should retract the skates for the trip up hole. Although four skate assemblies are shown, three may be adequate.

The core barrel is attached by a single shaft to the bottom of the drive section by a large pin for ease of removal at the end of each run. The outer barrel consists of two sections of tubing, each about 3 m (10 ft.) long joined together with a threaded joint for ease in shipping. The inner barrel is a thin metal or plastic cylinder containing the core which will be removed with the core and replaced with a fresh cylinder on each run. The top of the inner cylinder fits over a bearing assembly and the bottom end is retained by the

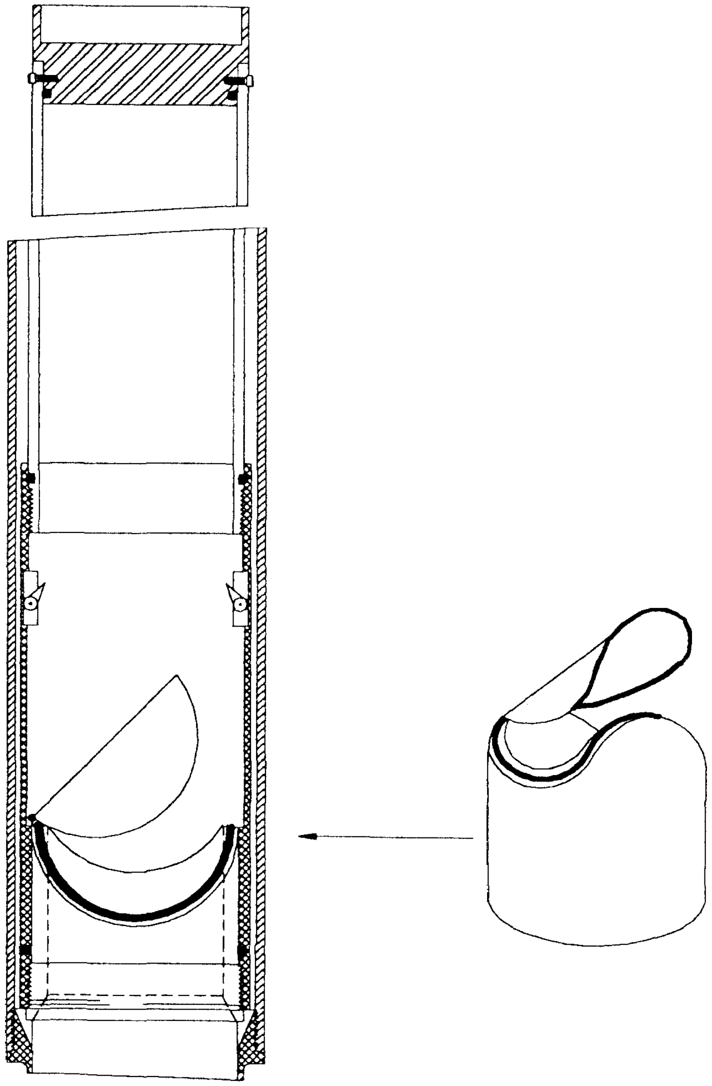

Fig. 4. Core barrel for retaining a core under in situ pressure.

cutter assembly and rests on a low friction seat, which will allow it to rotate independently of the outer barrel or preferably to remain stationary.

Figure 4 is a proposed system for retrieving a core under down-hole conditions which may be usable in the brittle zones. It is assumed that the pressures encountered for this design would be less than 3045×10^3 kPa (500 psi). The upper section is a transparent plastic tube sealed at the top. The lower section consists of a metal body containing a flapper valve assembly as shown. The cover has a cylindrical contour allowing the core to pass through. After the core is broken off and the drill is raised, the door closes and seals the chamber. Any air trapped in the chamber will be compressed and would actually be desirable for prolonging the undesirable effects of a small leak or for working with the sealed chamber at the surface. One requirement of the proposed design is that the core dogs would have to be internally attached, which may prove difficult.

The cutting head assembly is shown in Fig. 5. Effective core dog mechanisms for breaking and retrieving the core have been developed and perfected by the various drilling designs now in operation. The same can be said for cutter designs. Therefore no further elucidation of these items should be necessary at this time.

Attached to the lower end of the cutting head assembly is a proposed mechanism for marking and thus orienting a core. A similar idea was discussed by (Koci, 1988). A small protruding pin places a scratch mark on a stub of core, assuming there is one, remaining from the previous run. As the drill is lowered to the bottom in preparation for drilling, the pin is retracted by the mechanism shown. In order to orient the core, the remote reading compass in the instrument chamber is utilized. At the surface, the relationship between the compass and the position of the marker must be ascertained. An indexing arrangement at the top of the core barrel where it is attached to the remaining

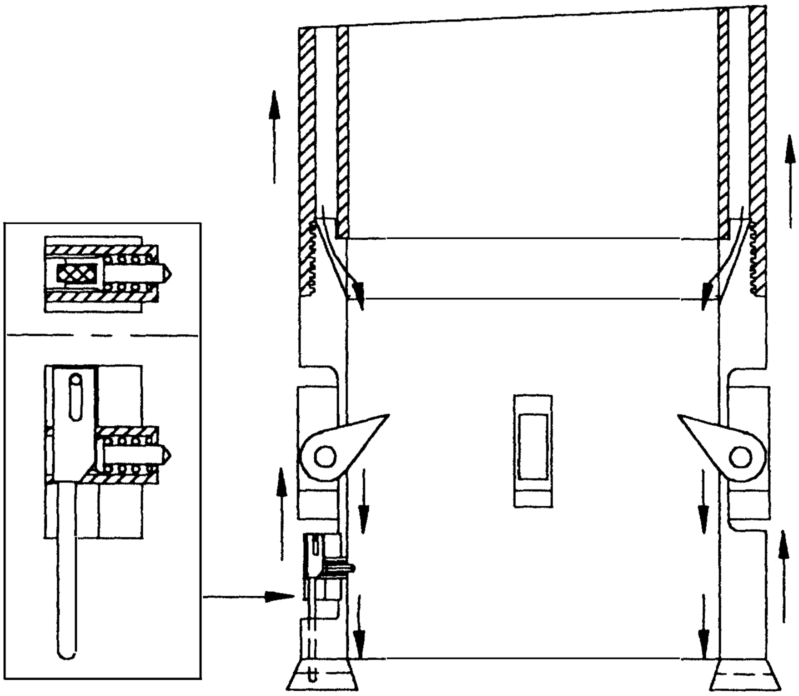

Fig. 5. Cutting head with core marking apparatus.

portion of the drill should permit this determination. Assuming that this relationship is maintained on the trip down-hole, the orientation of the core should be determinable. To assure that a core stub remains after a drilling run, the core dogs will have to be positioned accordingly.

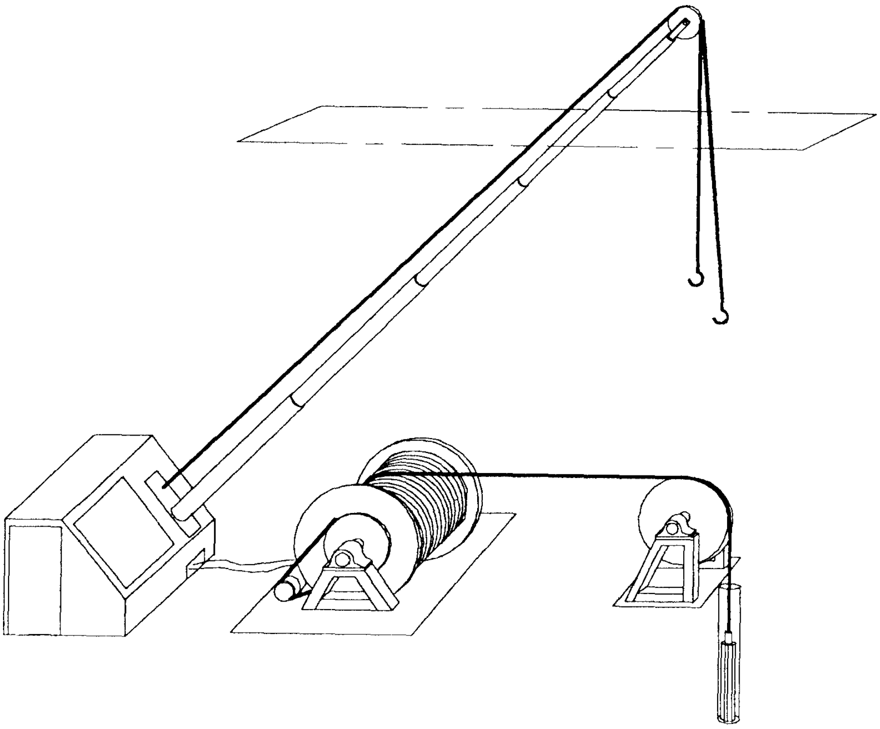

Fig. 6. Proposed tower-less drilling set-up.

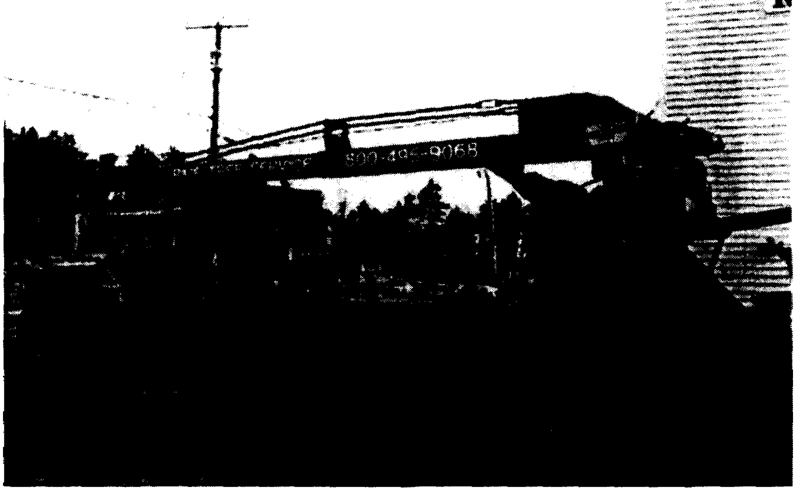

Fig. 7. Telescoping boom.

3. Proposed drilling setup

Figure 6 is a proposed drilling setup inside a covered tunnel or other shelter. The primary feature of this setup is the hydraulically operated telescoping boom (Fig. 7) which is commonly used in tree cutting and trimming operations, and eliminates the need to construct a tower. Under severe, inclement conditions it can be retracted. When the drill reaches the top of the hole, it is attached to a cable lowered from the boom and raised. After removing the chip container bag, the drill is disconnected at the top of the core barrel and the upper sections moved aside. A second line is used to raise the core barrel out of the hole and to lower it onto an inclined platform for removal of the core. In this setup, no tower needs to be constructed and all of the heavy pulling loads are taken up by the sheave assembly located over the hole. The sheave would have to be designed so that it could be moved laterally out of the way of the drill during the surface operations.

4. Hole fluid consideration

Lastly, the use of alcohol as a hole fluid should be reconsidered at least for certain locations. Alcohol has been used successfully in thermal drilling (Zagorodnov *et al.*, 1998; Zotikov, 1979; Morev and Yakovlev, 1984). Prior to the Summit drilling, PICO examined the use of alcohol before selecting butyl acetate as the drilling fluid (Gosink *et al.*, 1994). Figure 8 shows the freezing point vs concentration of ethanol-water solutions. Figure 9 shows the temperature profile of the Byrd Station hole which probably isn't too

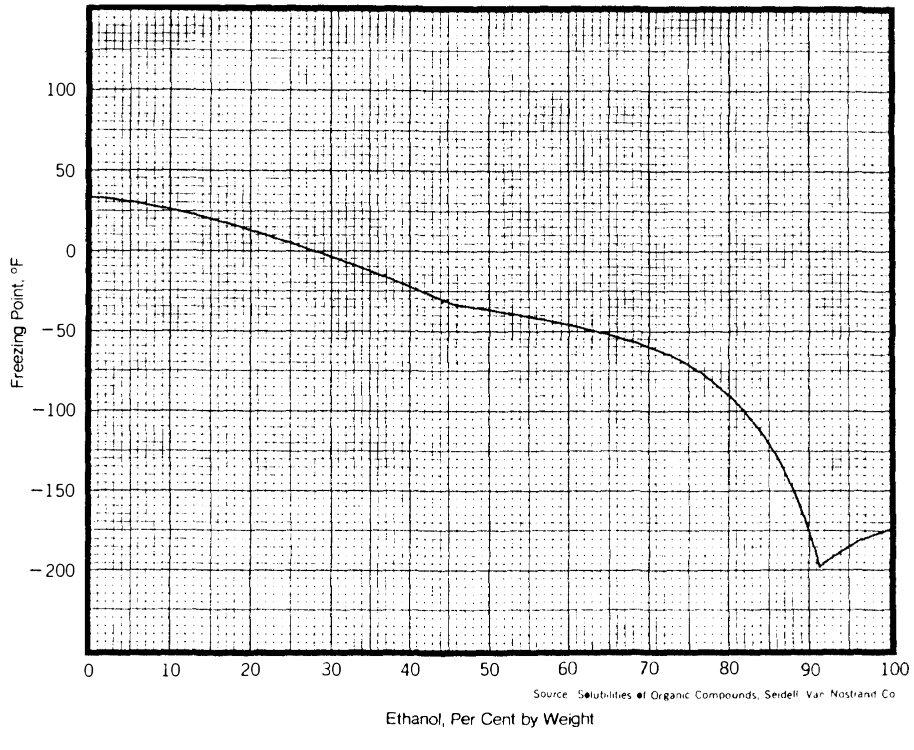

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Fig. 8. Freezing point vs concentration for aqueous ethanol solutions from Union Carbide (1977).

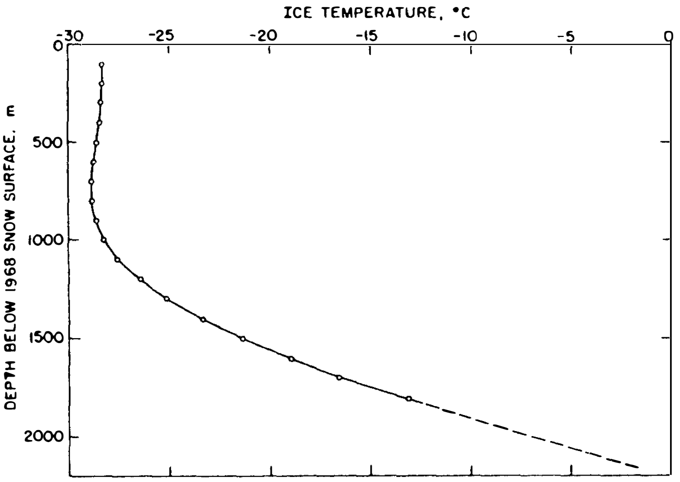

Fig. 9. Temperature profile from Byrd Station, Antarctica drill hole from Ueda and Garfield (1969).

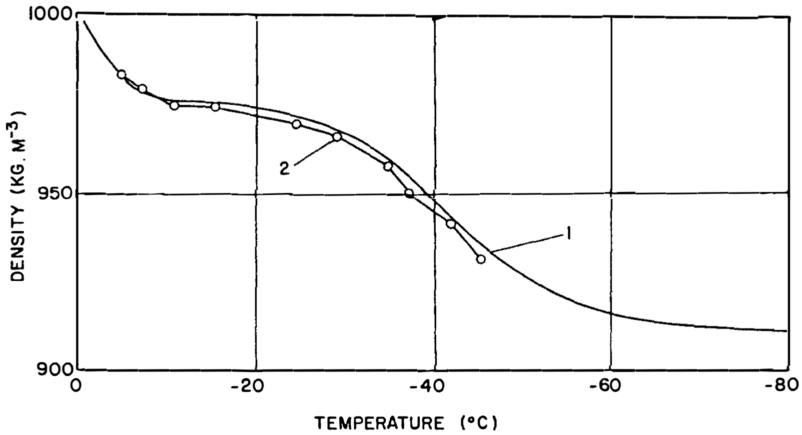

Fig. 10. Freezing point vs density for aqueous ethanol solutions from Morev and Yakovlev (1984). (1) Calculated. (2) Experimental.

different from many ice sheet sites from Ueda and Garfield (1969).

There are several disadvantages and advantages inherent with the use of alcohol as most of us know but it still may be useable at select sites. Figure 10 shows the freezing point-density relationship for ethanol-water solutions from Morev and Yakovlev (1984). With a decreasing temperature and the subsequent increase in density of the solution in the upper portion of most drill holes in the Arctic or Antarctic, there will be some instability in the fluid column, but beyond this point, the situation stabilizes as the density of the solution increases. Near the bottom of the hole, as the temperature increases the column will be over pressurized but it may be acceptable for a short period of time. The high viscosity at the lower temperatures may slow down the lowering and hauling rates in the upper part of the column. If necessary, a larger diameter hole can be drilled in this section of the hole. Hole temperature measurements will not be valid until the mixture reaches equilibrium which may take a prolonged period of time and the hole itself may become partially filled with slush. Some investigators may object to the contamination of the core, although some past experiences (Zagorodnov *et al.*, 1998) has shown that the effect may be tolerable. The flash point is lower than other fluids so some extra care would have to be exercised.

The advantages, on the other hand, can be significant. It is less expensive than any fluid now being used. It is by far the most environmentally acceptable fluid and the toxicity levels are reasonable. The smaller volume required makes it logistically favorable since the dilutant is water.

5. Conclusion

In conclusion, the community of ice core drillers must always strive to improve on the methods and techniques they employ for drilling holes and obtaining samples for the glaciologists. It is far from being an exact science as we all know. A different type of drill has been proposed in this paper using a pumped fluid system to remove the cuttings. This design hopefully will reduce the cost of fabrication, simplify the process of retrieving core samples and reduce the surface time and the overall time required to complete a drilling project. A core retrieval method for possible use in the brittle zone, a method for orienting cores, a drill vertical stabilization concept, and an idea for an anti-torque mechanism have been discussed as have a tower-less drilling setup and the possible reconsideration of alcohol as a drilling fluid. Hopefully some of these ideas can be considered in the future design of ice core drilling systems.

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