THE CANADIAN RUFLI-RAND ELECTRO-MECHANICAL CORE DRILL AND REAMING DEVICES

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ABSTRACT

An electro-mechanical ice core drill of medium depth capability, was built in Ottawa in 1980. The design is based on principles established by Rufli *et. al.* (1976) and Rand (1976). New to the design however, is a geodesic dome structure which serves both as a structural unit to support the central fixed tower and to provide shelter for the drill crew. The whole unit can be packed in shipping crates weighing a total of 760 Kg, and by suitable dis-assembling, may be fitted into a Helio-Courier (STOL) aircraft in about five loads, including the generator.

The ice core is about 96-100 mm in diameter, depending on the cutter setting, and averages about 1 m in length.

The drum has 270 m of cable with a tensile strength of 4200 Kg. The deepest holes to date are 103 m, in ice at -29°C, (Mt. Logan, 5340 m altitude) and 202.4 m in ice at -51°C, (South Pole, 3100 m altitude).

Currently being constructed, is an electro-thermal drill unit which will connect directly into the electro-mechanical cable termination. This design, (Zotikov, 1979) is based on the Soviet ETB-3 drill. The diameter of this drill is compatible with the hole drilled by the mechanical drill and similar sized cores will be produced. An anti-freeze fluid would be used below the firn/ice transition.

INTRODUCTION

The principle of operating an electro-mechanical rotary coring drill in ice was firmly established by the USA CRREL drilling engineers operating a modified Arutunoff electro-drill, first in Greenland and then in the Antarctic (Ueda and Garfield, 1969), under the general direction of B. Lyle Hansen. A subsequent requirement for rapid retrieval of clean 100 m cores with light weight equipment, led J. Rand (USA CRREL) and H. Rufli (University of Bern) in the early 1970's to simultaneously develop similar core drills based on the same mechanical principles as the Arutunoff electro-drill. The design embodies a drill frame suspended by an electro-mechanical cable, wound on a drum situated below a tower with a pulley mounted on top. Power for the winch and cable conductors is provided by a suitable portable electric generator. The drill frame consists of a cable termination, the drill motor, a speed reducing gear, a torque limiter (or clutch), an anti-torque device, and lastly the outer barrel. The removable core barrel rotates inside this outer barrel.

The Canadian version of this drill was built in 1980 and briefly field tested in the Yukon before being used to obtain 103 m of core from a site on Mt. Logan (5340 m). The major problems encountered were poor cutter design, inefficient and inconveniently arranged core breakers, an inadequate anti-torque system, and a generator break-down. These all contributed to poor over-all drilling rates, particularly below the firn/ice transition (F/I/T). Attention was paid to these problem areas before the drilling operations were carried out at South Pole in 1981/82. Despite these remedial actions, trouble was still experienced with both the cutters and the anti-torque system. Solutions to some of these problems are suggested.

DRILL RIG AND CORE DRILL DESCRIPTION

The equipment consists of (1) a geodesic dome, which acts both as a structural unit to support the tower and as a shelter for the drill crew; (2) a main base plate, on which is mounted the winch system, the tower and the control panel; (3) the core drill unit (Fig. 1a - 1c). These are now discussed in turn:

(1) The geodesic dome is constructed of 100 pieces of 2.5 cm (1") Ø aluminum tubing with flattened and individually grooved ends which fit into key-ways on a hub situated at each node of the structure. The tubes are fastened to the hubs by washers and a single stove bolt and nut. Specifications and details of its construction may be found in Holdsworth (1979). Over-all dome diameter is 4.88 m (16') and its height about 2.29 m (7.5'). It may easily be erected by two persons in about 1.5 hrs. A heavy duty white canvas canopy covers the outside of the dome frame. In the crest of the canopy is a zippered/velcro fastener opening for tower access. The top rim of the pulley rises about 2.9 m (9.5') above the top of the dome, or 5.2 m (17') above the bottom of the base plate, which rests on the snow. The tower, pulley and winch follow the design of Rufli (1976).

(2) A 1.2 m (4') x 0.9 m (3') aluminum base plate frame supports the tower, the winch drum, the winch motor and gear reducer, and the control unit. The tower is made from two pieces of 16.83 cm (6.625") Ø aluminum tube (wall thickness 0.34 cm or 0.134"), 224 cm (88") and 254 cm (100") long. They are joined by an aluminum collar situated at the top of the geodesic dome. The collar has four external lugs which facilitate the connection of four turnbuckle ties, which hook onto the top ring of the dome, thus enabling the tower to be plumbed vertically. Initial coarse verticalizing of the tower is achieved by shifting the dome relative to the base frame.

The cable drum is made from rolled aluminum and is capable of accomodating up to 500 m of 0.8 cm (0.3") Ø cable. However, at the full drum width of 41 cm (16") between flanges, the present tower is not high enough to avoid spooling problems near the edges without a level winder. A movable set of flanges has been installed to alleviate this problem and 350 m of cable can be accommodated at a flange spacing of 31 cm (12"). The drum is keyed to the output shaft of a Morse 35RW-B reduction gear box (40:1 ratio) driven by a 2 HP, DC motor via a V-belt which acts as a torque limiter to protect the motor. This motor, and the 1 HP version in the drill unit, are both controlled by Doerr SCR motor controllers set on the control panel. These units must be warmed by heating pads at ambient temperatures below about -15°C. The panel frame also contains an ammeter/volt meter set for each motor and the input power supply at 220 V AC, which is converted to 180 V DC for consumption by the motors.

A digital counter counts the revolutions of the cable sheave, the shaft of which is connected to a direction sensing multi-pole switch. A depth resolution of 4 cm is achieved in steps of 4 cm with an accuracy of 1 cm at each step.

(3) Lastly, the drill unit is fixed to the cable by a termination installed by the manufacturer (Rochester Corp. USA). The cable is steel armoured and carries seven 22 g conductors in the core. Power is conducted two sets of three wires and the seventh is used as an earth. The cable has a breaking strength of 40.9 KN (9200 lbs) and a minimum radius of curvature of 22 cm, which determined the sheave diameter. For normal operations, this cable is heavier than is necessary. It is useful, however, in the case of a badly stuck drill.

A U-bolt, mounted on top of the drill frame, accepts the clevice from the cable termination. A pivot bolt completes the connection. The electrical conductors are led to the motor through an Envirocon seven pin plug and bulkhead connector mounted and sealed on top of the frame. Mounted around the motor are three 0.52 cm (0.2") thick x 3.8 cm (1.5") x 93 cm (36.75") plate springs, which provide anti-torquing action.

The motor output shaft is connected to a gear reducer, which is connected to a torque limiter, the output shaft of which connects to the core barrel cap by a quick release pin. The core barrel (218 cm long) is a seamless stainless steel tube with stainless steel auger spirals welded to it. Three spirals with a pitch of 22 cm emanate from the three cutters set in the drill shoe. These spirals direct the cuttings to an inlet port at the top of the barrel.

The cuttings and the core must be separated within the core barrel to prevent the core from being impeded in its smooth upward motion relative to the core tube, during cutting and to prevent damage to the core during its extraction from the tube if it becomes jammed with chips. The separation is achieved by inserting a sliding disc inside the core barrel, a technique devised by H. Rufli. The remainder of the core barrel functioning is given in Rand (1976) and is evident from Fig. 1c. Further coverage is given in the next section.

SPECIFIC AREAS CONSIDERED CRUCIAL TO SUCCESSFUL DRILLING/CORING OPERATIONS

Cutters

For fast and consistent drilling rates, the three cutters must be efficiently designed according to the basic principles discussed by Mellor (1976,1977) and correctly matched. If they exist, deficiencies in design appear near the F/I/T. The cutters used are the oval type designed by J. Rand. For the Mount Logan operation, cutters with different back rake (30°, 35°) and clearance angle (15°, 20°, 25°) were tried. Some cutters were hardened, others unhardened,to allow filing for experimentation purposes. This practice should be avoided, since without a jig, sharpening was poorly executed in the field. It is clear that cutters should be of hardened steel or that they should have tungsten carbide inserts. The most efficient and stable clearance angle below the F/I/T was about 15° and the back rake about 30° to 35°. The clearance between the tips of the cutters and the rim of the shoe should be able to be controlled, as Johnsen *et. al.*(1980) point out. Cutters with large clearance angles (20°- 25°), although satisfactory in firn,caused frequent anti-torque failures in ice. This, combined with progressive dulling of cutter edges (causing powder sized chips and subsequent packing in the lower spirals) contributed to the over all low drilling rates (Fig. 2). The cutters used at the South Pole were hardened drill rod steel, and again the optimum clearance angle was 15° with a 4 mm clearance. Some cutters were given a hollow ground back rake face, in order to reduce the back rake angle near the tip without compromising the overall strength of the cutters. This evidently caused excessive wear on the blades because of the small included angle and because the edge temper of the steel was lowered by the grinding process. Beyond the F/I/T, the cutters had to be removed and resharpened, otherwise the cuttings would be fine powder instead of coarse chips. Repeat-sharpening also caused a reduction in the bottom clearance of the order of 0.5 mm. Coring runs were temporarily improved by sharpening after each run below 150 m depth. Subsequent checking of the hardness of the cutters revealed hardness irregularities over the surface. Hubs exceeded Rockwell 50 whereas blade areas were significantly less hard. Tests should be made before the cutters are installed. Tungsten carbide tips seem to be the answer to this problem.

Core Breakers

For good quality and efficient core breaks, proper attention must be paid to the design of the core breaker/catcher. For the South Pole operation, breakers were used that were designed by B. Koci of the Polar Ice Coring Office, Lincoln, Nebraska. In general, proper shape and blade length are needed to ensure a satisfactory fracture regime under moderate core break tension in the cable.

Initially, core breakers were only 1.3 cm (0.5") wide. This is insufficient for firn cores which tend to drop through the breakers upon lifting. For the South Pole operation, the width of the core breakers was increased to 1.9 cm (0.75"), thus increasing the circumferential coverage of blade edge to 18%. This ensured the retention of firn cores and seemed to give cleaner core breaks. Core break tensions in the Mt. Logan operation were estimated from winch motor current drain to be about 250 Kg whereas for the South Pole operation, many tensions were under 180 Kg, at a cable length of 100 m. These values include the weight of the drill and the suspended cable (about 90 Kg).

It is considered important to have hardened breakers in case a core site is exploited where fine particles, capable of causing wear on the edges, occur in the ice.

Anti-torque System

The use of plate springs to provide anti-torque against outer barrel rotation seems to be the simplest and most effective system. In the manufacture of the springs, insufficient attention was paid to the correct dimensions and tolerances. Hasps were slightly overthickened, causing a tight fit in the hole. This was serious near the F/I/T when a "stick-slip" type of movement developed. Above this, the firn was sufficiently deformable to allow downward motion of the springs. Also, two of the blades had a significant twist which reduced their edging effect particularly below the F/I/T. The addition of passive ice blades (or skates) on the springs (Fig. 3a) is of dubious value unless the leaf springs meet tolerances, and the ice blades have the correct rise. A solution not yet tried is to make the skates of spring steel so that the sharpened edges press against the bore hole wall (Fig. 3b). For optimum performance, the main plate springs should be shaped so that an even pressure distribution is exerted along their length (Johnsen *et. al.*, 1980). There should also be some simple method of simultaneously adjusting tension in all leaf springs. This is necessary when going from firn to ice.

The torque limiter was set at about 35 ft. lb. (0.14 m. Kg), but was apparently never activated. Detection of anti-torque failure was by monitoring cable twist. This practice should probably be avoidedin favour of a lower setting on the torque limiter and an alarm system, or else by the use of slip rings on the cable (Rufli *et. al.*, 1976).

DISCUSSION OF CORE QUALITY

Generally, core quality for sampling purposes, was quite acceptable. Core breaks represent, over all, the single most disruptive feature of the core, although almost invariably, successive cores can be matched over part of their circumference. In the case of a very irregular break (possibly due to only one or two breakers operating) there will be slivers of core some of which fall back down the hole during winching up. From time to time, core is broken across, and this is seen to occur during drilling by a pulse in drill motor current. It is probably due to irregular drill feed rates. A recurring feature of core damage after the F/I/T is axial flaking of the sides of the core. It occurred below 80 m on Mt. Logan and below 150 m at South Pole. The exact reason for this is not known, but because the flakes appear to originate at the core breakers they may be caused by mechanical shock. Cutters were used which had a 2 mm (0.080") outside clearance and a 1.5 mm (0.060") inside clearance. This does not represent efficient cutting, but the slightly over-sized hole produced combined with low pressure on the cutters for the first 30 m, probably contributed to the relatively straight holes drilled. Core diameter was typically between 96 mm and 98 mm depending on the cutter widths and the hardness of the ice.

FUTURE DEVELOPMENTS

An electro-thermal (E-T) corer is being constructed after the principles of the ETB-3 drill of Morev (Bogorodsky and Morev, 1984). The heaters used will be the units described by Koci (1984), which are able to operate on the same line power as the electro-mechanical (E-M) drill motor. As a result, it will be possible to operate both drills with the same drill rig, simply by disconnecting the E-M drill (used principally in the firn) and replacing it by the E-T drill (used below the F/I/T).

A wider range of winch speeds is desirable. At the low speed end, the motor controllers tend to cause irregular feed rates and some undesirable manual control has to be exerted. This may have contributed to unwanted cross breaks in the core. On the other hand, winching up rates are too slow, contributing to longer turn around times. A solution is to use two motors, one for each function.

DRILL ACCESSORIES

In order to utilize the bore hole for measurements that will provide information on ice deformation, and thus compliment the ice core research, two reamers were constructed. These are, first, a general bore hole reamer which scrapes the wall of the hole to counter closure if this is a significant factor, and second, a bore hole notch reamer, which cuts a notch or horizontal groove in the bore hole wall at selected intervals down hole. Both reamers are able to be attached to the output drive shaft of the E-M drill by means of a long connecting rod (Fig. 4) fitted with bearing wheels and a universal joint to eliminate any detrimental bending moment that could be generated during the reaming action.

The first reamer (Fig. 5, Right) has eight cutters that may be adjusted to a given clearance. Cuttings fall into a reservoir rigidly attached below the reamer section, and separated from it by a neoprene annulus which prevents any chips falling into the bore hole.

The second reamer is shown in Fig. 5 Right). Three semi-elliptical cutters are attached to the mid-points of three leaf springs which exert an outward pressure towards the wall of the bore hole, thus loading the cutters. The leaf spring pressure is adjusted by means of an axial compression spring. The cutting action is terminated when the leaf springs make contact with the bore hole wall, and the radial thrust of the springs is almost exhausted. This action can easily be monitored on the ammeter connected to the drill motor circuit. As before, cuttings collect in the detachable chip reservoir which can serve both reamers.

A bore hole logger has been designed to sense the notches in the bore hole wall. From successive bore hole surveys, the change in spacing between notches can be easily determined. This, in turn enables the bore hole parallel, or approximately, the vertical strain rate, to be computed. This strain rate is a valuable parameter to know in ice dynamics problems.

ACKNOWLEDGEMENTS

John Rand and Henry Rufli provided me with the full benefit of their combined experience with E-M core drill development, and the relative success of this operation was due largely to them. Most of the pre-machining design phase was ably accomplished by Duncan Watt of Carleton University, Ottawa, and the machining and assembly was done at the Mechanical Engineering Department machine shop under the direction of S. Rocque and J. Herler. The reamers and some modifications to the drill were made at the National Research Council Mechanical Engineering Workshop in Ottawa. Extensive testing of the 10 KW generator for high altitude operation on Mount Logan was also carried out at the NRC.

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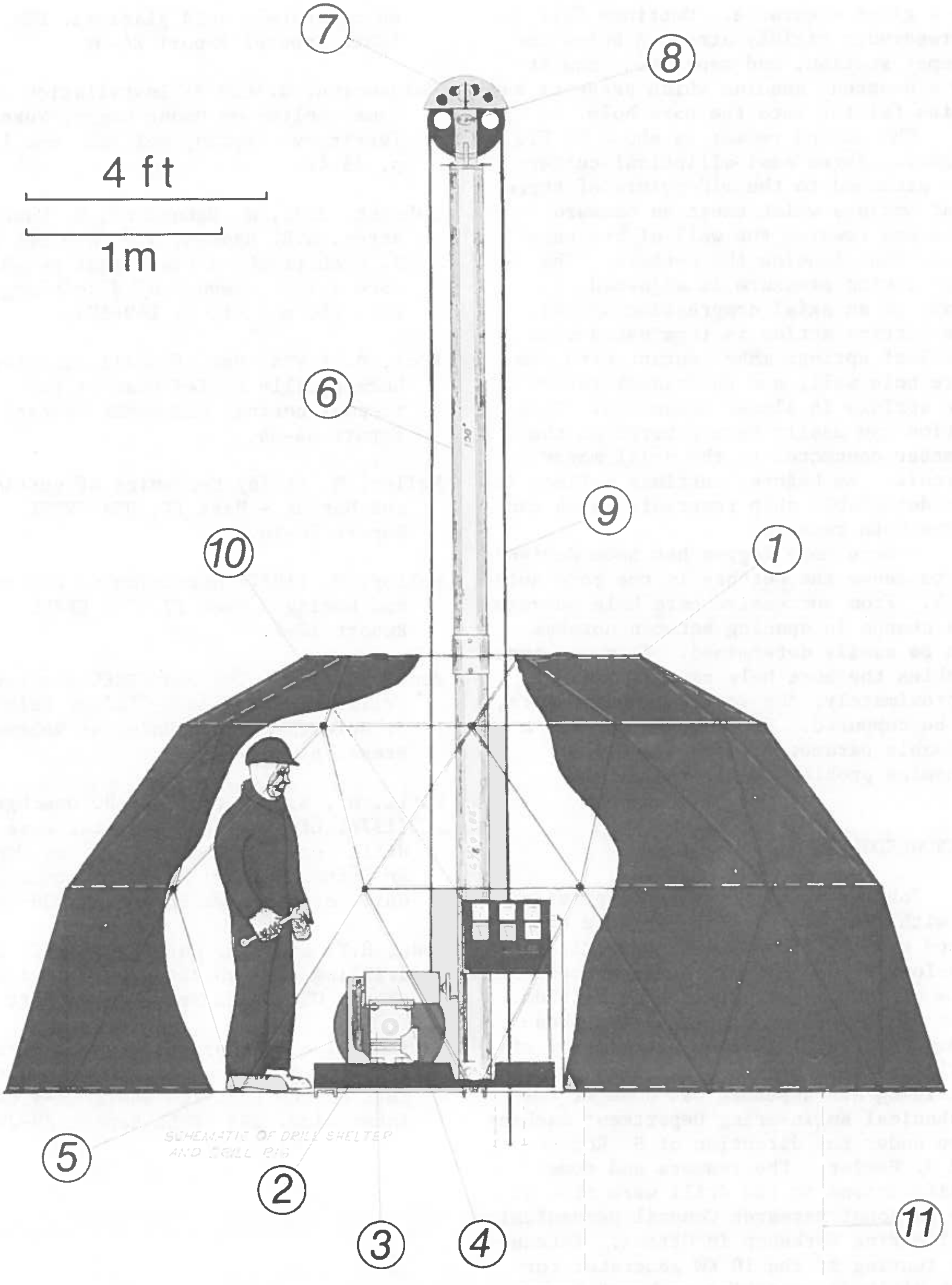

Figure 1a. Complete drill rig assembly (Drill unit not shown). (1) Tubular aluminum geodesic frame and canvas cover. (2) Base plate, of aluminum channel and ply-wood construction. (3) Gear reducer. (4) Winch motor. (5) Cable drum. (6) Aluminum tube tower in two sections. The drill unit is broken down into two parts which fit inside the tower sections for shipment. (7) Pulley cover, aluminum. (8) Revolution counter switch housing (not shown, but mounted on pulley support plate). (9) Electro-mechanical cable. (10) Power conversion unit and control panel. (11) Snow pit, approximately 4' x 3' x 4'(deep) (1.3m x 1m x 1.3m) necessary for extracting core barrel from the drill unit.

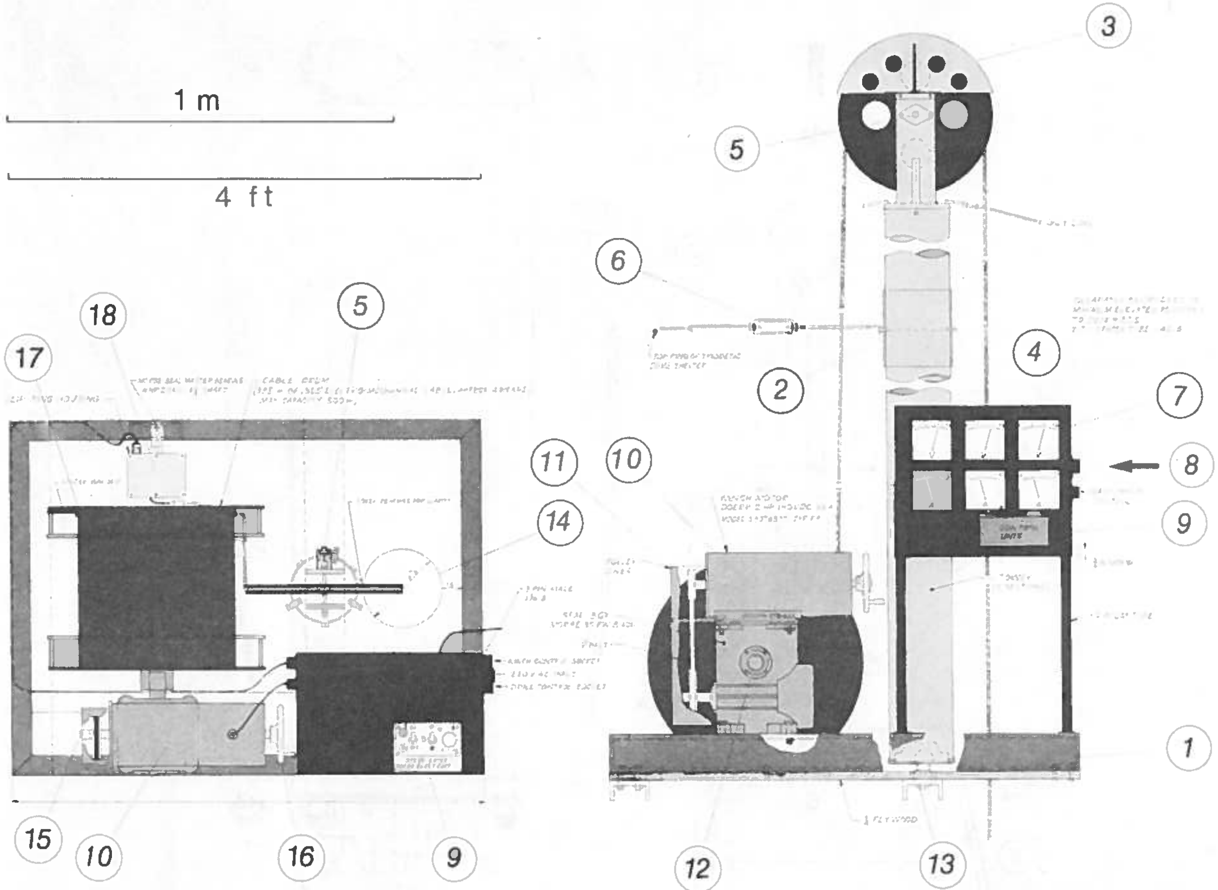

Figure 1b. Winch, tower and drive assembly. (1) Base plate, 4' x 3' (1.22m x 0.91m) constructed from aluminum channel with a ply-wood base containing a drill access hole. (2) Aluminum tube tower, 6.625" diam (16.83cm) in two sections joined by an aluminum collar fitted with four lugs at 60° and 120° which enable connection to the top ring of the geodesic dome for stability. Guy lines from the top of the tower are not necessary under normal conditions. (3) Pulley belt cover. (4) Electro mechanical cable (Rochester Corporation,number 7-H-325A, 0.313" (0.80cm) diam. 7 conductor. Length approximately 270 m. (5) Position for multi-pole switch for counting pulley wheel revolutions. Electrical conductor is fed through center of tower to digital counter on control panel. (6) Hook, rod and turn-buckle linkage to top ring of geodesic dome (four connections). (7) Power conversion unit and control panel with ammeter/voltmeter pair for input power, winch and drill motors. (8) Input power from generator (220 V AC at 3.5 KW). (9) Motor controller (Doerr Electric Corporation, Wisconsin). SCR solid state unit with forward, reverse and neutral or brake positions. Seperate units are used for winch and drill motors. (10) Winch motor (Doerr Electric Corp.). Permanent magnet, 2 HP, 180 V DC, 11.6 A, 1750 RPM. (11) V-belt pulley drive with safety cover. (12) Gear case. Unit is a Morse 35RW-B, 40:1 reduction. (13) Ball assembly for support of tower base socket. (14) Drill access hole in plywood base plate. (15) Crank for manual turning of motor output shaft fits here. (16) Manually operated control wheel for low feed rates on the winch. (17) Cable drum with adjustable flanges (currently contains 270 m of cable) . (18) Slip ring housing for transmission of power to the cable and drill motor. Complete drill, winch and tower/dome assembly fits into 8 transit cases (not including generator) for a total shipping weight of 760 Kg.

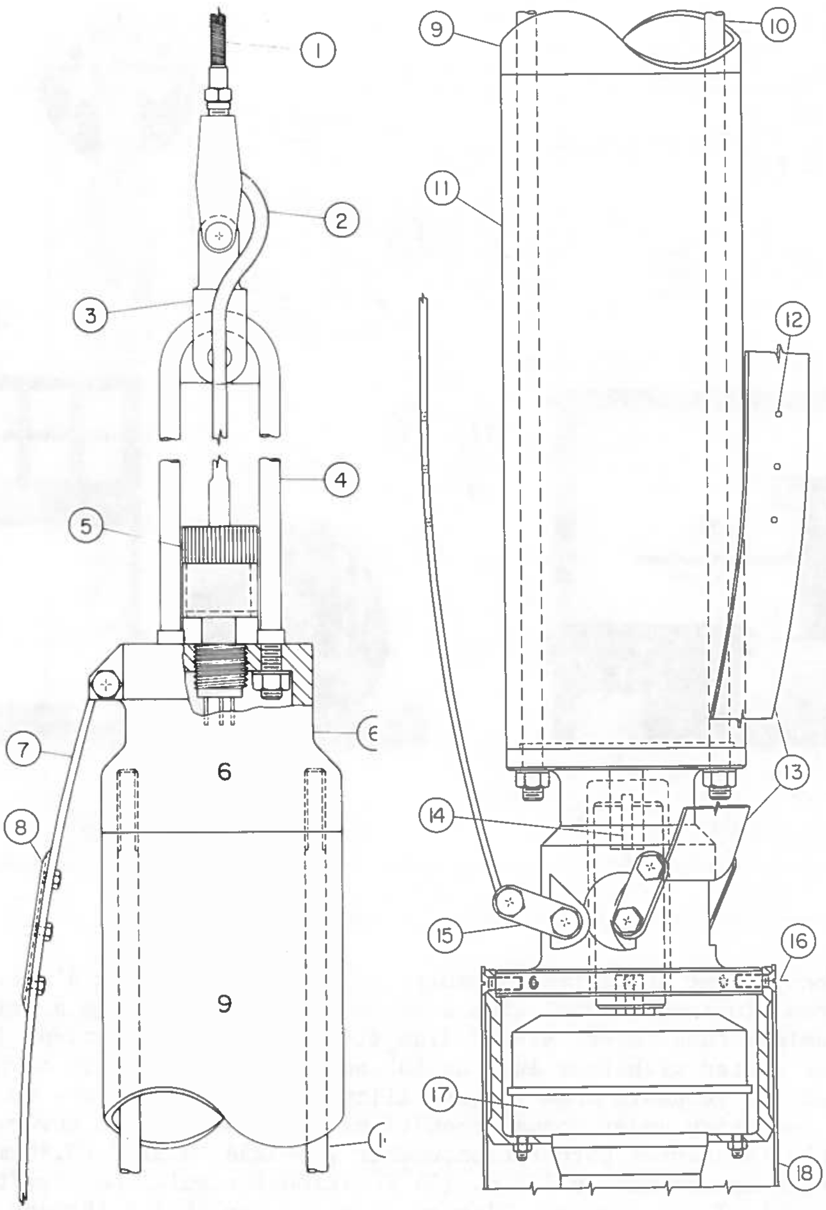

Figure 1c. Core drill unit. (1) Electro-mechanical cable (Rochester Corp. cable number 7-H-325A). (2) Electrical lead from cable termination. (3) Clevice connection to top of U-bolt on drill frame. (4) U-bolt. (5) Envirocon plug (VMK-FS) and bulkhead connector (VSK-7-BCL) assembly. (6) Aluminum end cap. (7) Plate spring (0.52 cm x 3.81 cm x 93.3 cm); three with fixed or adjustable hasps. (8) Ice blade attachment (see Fig. 3). (9) Extension tube (11.43 cm Ø x 47.3 cm). (10) Motor tie bolts. (11) Electric motor (Doerr Electric Corp., 1 HP, 1750 RPM, 180 V DC). (12) Holes for mounting ice blades. (13) Plate spring. (14) Keyed output shaft from motor, and gear box coupler. (15) Connecting link for spring attachment. (16) Screwed break point for drill dis-assembly. (17) Gear reducer (Sumitomo, cycloid drive, 17:1).

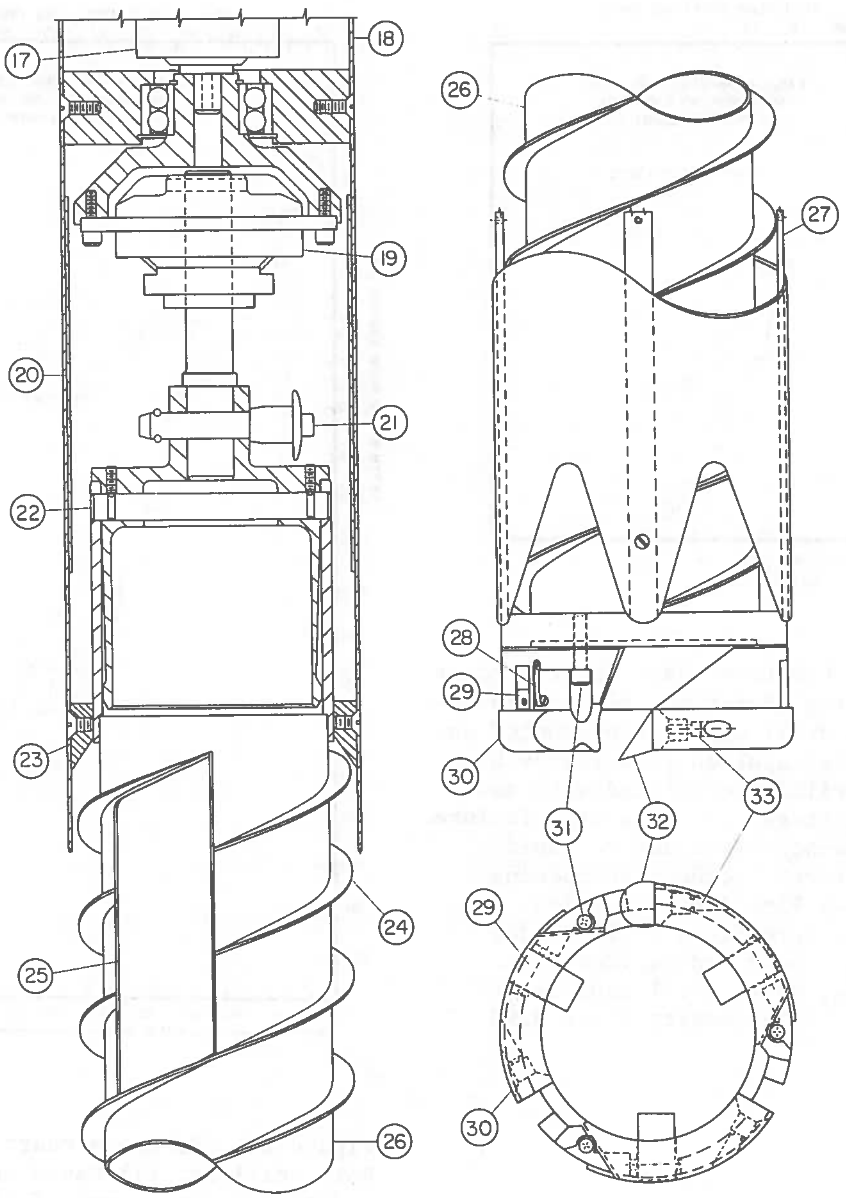

Figure 1c (continued). (18) Outer barrel (0.165 cm x 13.97 cm x 262.9 cm stainless steel). (19) Torque limiter (Morse 350A-1). (20) Rotary cover on release pin access hole. (21) Quick release pin. (22) Core barrel release pin. (23) Nylon bearing ring and chip seal. (24) Stainless steel spiral of 22 cm pitch. (25) Ice cuttings inlet port. (26) Core barrel (0.165 cm x 10.8 cm x 218.1 cm type 304 stainless steel). (27) Core cuttings elevator strips and spiral bearing surface (brass, screwed to outer barrel). (28) Core breaker spring. (29) Core breaker (1.9 cm x 3.2 cm). (30) Shoe for mounting cutters and core breakers. (31) Cap screw attachment of shoe onto core barrel flange. (32) Oval type cutters. (33) Cap screw attachment of cutter into shoe.

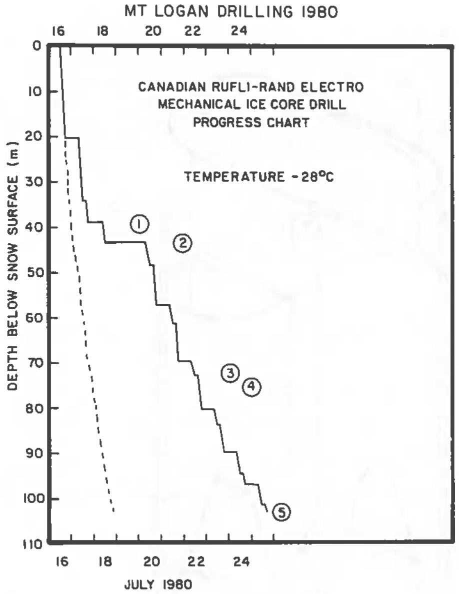

Figure 2a. Progress chart for the Mount Logan drilling operation. (1) Accumulation of fine drill cuttings prevented an advance. Water applied to solidify base of hole. Drilling continued with new sharpened cutters. (2) Generator failure. (3) Poor advance rates due to rapidly dulling cutters. Frequent sharpening required. (4) Firn/ice transition. (5) Drilling terminated at 103 m due to poor advance rates and expired time. In principle, drill still capable of taking core. Ice density above 0.90 Mg m^{-3}.

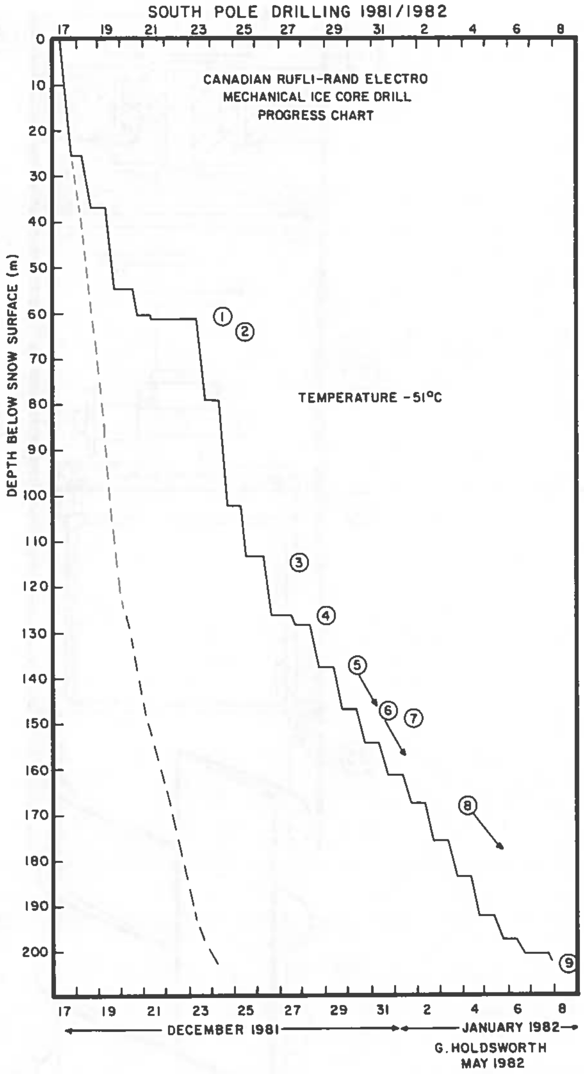

Figure 2b. Progress chart for the South Pole drilling. (1) Cable damage due to undetected anti-torque failure. (2) Anti-torque system retuned. (3) Firn /ice transition. (4) Fine tuning of the anti-torque system. (5) Cutters re-sharpened at regular intervals. (6) Beginning of sporadic longitudinal flaking of the core. (7) and (8) Cutters sharpened before each drill run and cutter sets rotated. (9) Hole terminated at 202.4 m, ice density 0.90 - 0.91 Mg m^{-3}. Drill still capable of penetrating further.

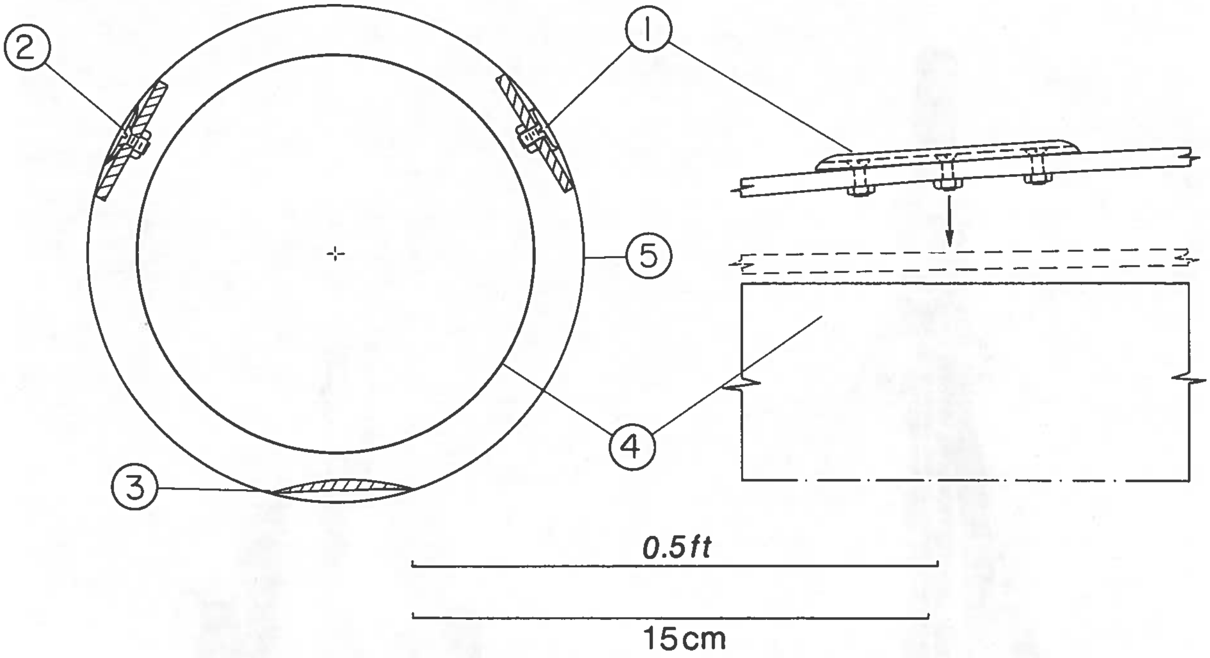

Figure 3. Ice blade attachments to anti-torque plate springs. (1) Passive blade. (2) Active blade (spring steel). (3) Alternate plate spring shape. (4) Motor casing or extension tube (5) Bore hole wall.

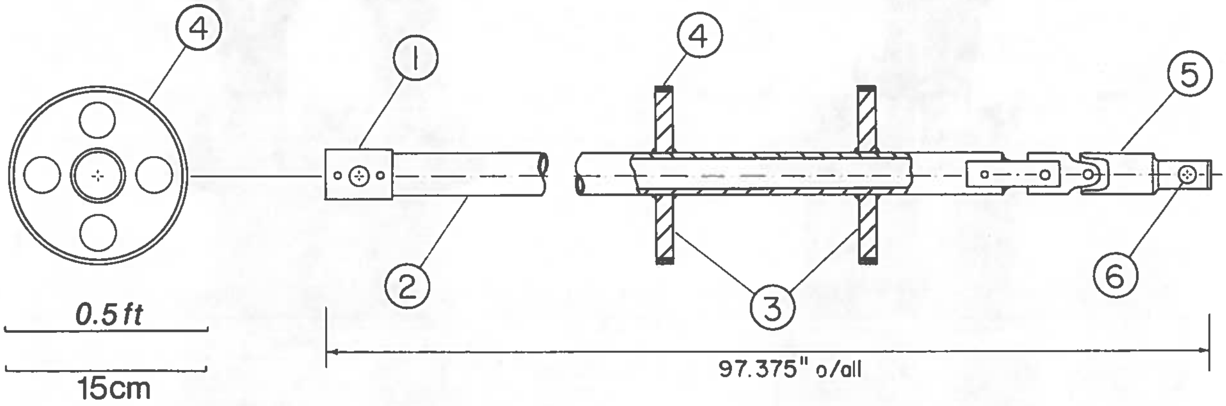

Figure 4. Connecting rod for reamer attachment. (1) Connection to clutch output shaft (see Fig. 1c item no. 21). (2) Main shaft. (3) Bearing wheels. (4) Teflon surface. (5) Universal coupling. (6) Connection to reamers.

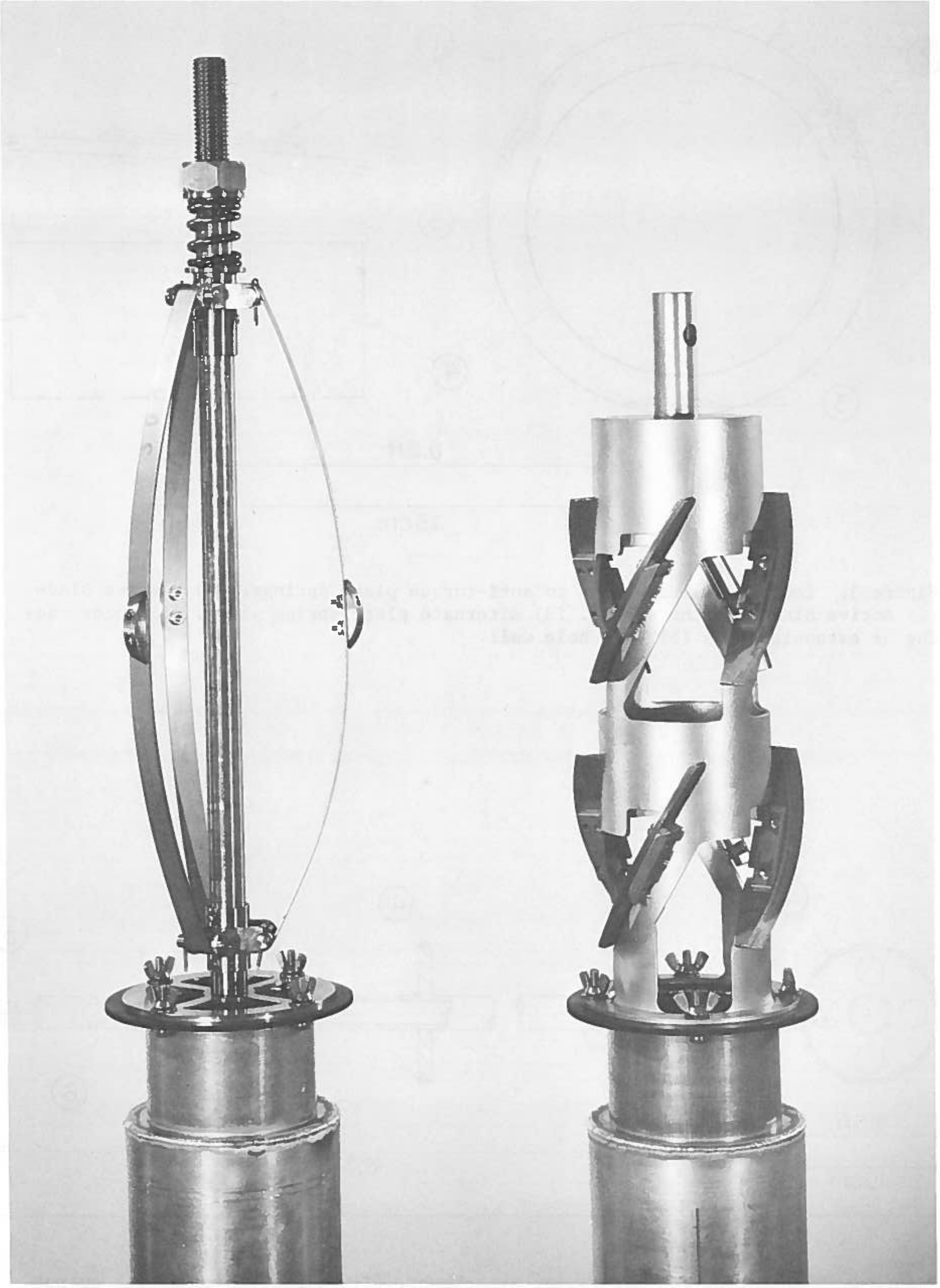

Figure 5. Bore hole reamers. (1) General bore hole reamer Mark I (right). (2) Bore hole notch reamer (left). Diameter of chip reservoir is 4 inches (10.2 cm), length 40 inches (100 cm). (Photo courtesy of National Research Council, Ottawa).