A NEW ELECTROTHERMAL DRILL FOR CORING IN ICE

F. Gillet, D. Donnou, and G. Ricou
Laboratoire de Glaciologie CNRS
Grenoble, France

ABSTRACT

The use of a drill tip made of a bare resistance wire fed at low voltage has allowed us to attain drilling speeds of 6 m/hr in temperate ice. The diameters of the hole and the core sample are 140 mm and 102 mm, respectively. In a cold glacier, a vacuum pump eliminates the meltwater. Using an armored electric cable, 500 m long, and a variable speed winch the equipment weighs a total of 1880 kg. The core barrel with the transformer and the unit for removing the meltwater weighs 170 kg and is 8.20 m long. The cores obtained are 2.8 m long.

A new model thermal corer developed at our laboratory was tested for the first time in 1968 on the Saint-Sorlin Glacier, France. It differs from the CRREL model (Ueda and Garfield, 1969) in that it works with a bare resistance wire in direct contact with the ice. This makes it possible to apply a strong power density to the drill tip. A corer making a hole of approximately 14 cm gives a 10.2-cm core, and reaches a speed of 6 m/hr in temperate ice, with 6 kW of heating power. In cold ice, the speed is slightly reduced, and depends on the temperature of ice. The special shape of the heating element has also proved to be very effective for drilling in debris-filled ice, which is often found near bedrock.

Functioning Principles of the Corer

The speed of a thermal drill is determined by the energy density furnished per cm^2 of the cross section of the working face. With a commercial heating element, made of a magnesia-covered resistance, protected by a metal tube, it is impossible to reach a significant power density (Shreve and Kamb, 1964). Moreover, it is difficult to suitably ensure the contact between these heating elements and the metallic mass that surrounds them. This causes still another reduction of the thermal exchanges. On the other hand, by using a bare wire resistance in direct contact with the ice, the power density can be greatly increased (Remenieras and Terrier, 1951). However, the feed rate in the ice is not directly dependent on the dissipated energy per unit of lateral surface of the wire resistance, but rather on the energy density per cm^2 of the drilling cross section. Therefore, it is absolutely necessary that the energy be concentrated in the direction of advance. Technically, the problem was solved by winding a wire resistance into a helix and mounting it on an annular resistance support.

This resistance coil must be able to resist being crushed by the corer, and must not lose its shape, or the sample will be of an unsuitable diameter. (The drill tip is shaped to keep the convecting water currents from going into the core barrel and melting the core.) A wire of sufficient diameter is thus necessary (1.3 - 1.6 mm). Because the resistance of this wire (approximately 2.5 m long) is low (2 - 3 ohms), it is necessary to work at low voltage, with a transformer placed in the corer. Since considerable power is being transported, the on-line losses must be reduced as much as possible. A three-phase current is therefore used. When working in a cold glacier, the meltwater is extracted with a vacuum pump, and stored in a tank that is emptied each time a core is retrieved. The readings of a compass in the borehole are transmitted electrically to the surface, giving the orientation of the ice samples. Finally, a constant tension on the electromechanical cable ensures the verticality of the drilling.

Description of the Installation

The equipment includes the following components and specifications:

(1) *A corer* (Fig. 1), with an outside diameter of 130 mm, that can function as well in a cold glacier as in a temperate glacier when the hole is full of water. In the latter case, the suction assembly for the meltwater is removed. The unit is then 5.9 m long, and weighs 135 kg. In a cold glacier, on the other hand, the total length is 8.2 m and the total weight 170 kg.

(a) *Suspension:* The electromechanical cable is attached with Araldite resin to a piston acting on a spring linked to a linear potentiometer. This gives a reading of the tension that the cable exerts on the corer. At the top of the suspension is a heating resistance of 600 W which can be used in case of wedging on the ascent. A switch at the top enables one to change over to this resistance from the heating resistance of the drill tip.

(b) *Orientation:* An electric motor turns a photoelectric cell around a compass, the disc of which has a hole in it. When the cell arrives in front of the hole, it stops the rotation of the motor. Then, one must simply read the information furnished by the potentiometer connected to the photoelectric cell to find out the orientation of the corer in the horizontal plane. This procedure is, of course, unusable near the magnetic pole.

(c) *Transformer:* Three-phase 338-V primary to 45-V secondary, 6.8-kVA rating, losses 56 W at no load to 460 W at rated load. The transformer is oil-cooled. A balancing piston located at the top allows for free expansion of the oil.

(d) *Recovery of the meltwater:* A vacuum pump lowers the pressure in a tank connected to the drill tip by 3 stainless steel tubes (4 mm I.D., 4.8 mm O.D.). The meltwater is sucked in by these tubes and stored in the tank. To prevent the water from freezing on the way up, the tubes are heated from the inside by a wire with a teflon insulation 1.25 mm in diameter. The normal heating power is 30 W/m. It can be regulated from the surface with a small variable transformer. The heating resistances in the tube and in the reservoir are mounted in series, so the transformer regulates the heating of the whole system. The tank is simply a stainless steel tube, 125 mm I.D. - 129 O.D., and 1.75 m tall. This height corresponds to the amount of water obtained when coring 2.8 m with core 102 - 104 mm diameter and hole 140 mm diameter.

The vacuum pump is a "Marion"-type membrane pump, modified to sit inside the corer. This model has proven to be more reliable and much easier to repair than the Gast model used by CRREL. A monophase 220-V electric motor with a usable power of 120 W

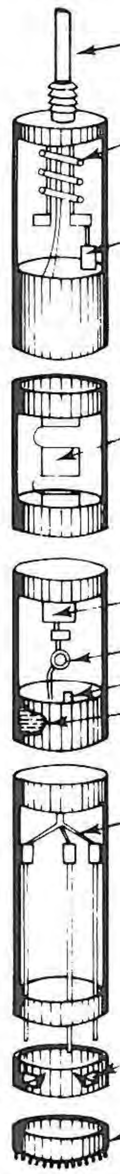

Figure 1. Diagrammatic sketch of corer.

operates the pump. The vacuum obtained can reach 700 mm Hg, which is enough to carry the water up the height of the core barrel. The proper functioning of the suction system can be checked with a vacuum gauge. A level indicator tells when the tank is full.

(e) *Core barrel:* Length 2.8 m, interior diameter 110 mm. It is made of an interior tube of polyethylene (110 mm I.D., 114 mm O.D.) and exterior tube of stainless steel (125 mm I.D., 129 mm O.D.). Between them are the suction tubes for the meltwater, and the electric wires for the resistance at the tip. The stainless steel crown (110 mm I.D., 130 mm O.D.) is hooked on the lower part of the corer. It is tooled at the bottom to allow a porcelain ring housing the bare resistance to be attached. This is attached with six brass screws, three of which are used at the same time for electrical input. Three core catchers are also used for removing the core.

(2) *An electromechanical cable:* 500 m long, 24 mm diameter, weighing 400 kg. The cable contains three conductors with 6 mm^2 cross section used for feeding the head, and nine conductors with 0.75 mm^2 cross section used for feeding the auxiliaries, and for measurements. The insulation is of polyethylene. The stress is supported by a steel braid with a 2200 kg capacity. This braid sits on a strip steel vault which prevents the pull on the braid from transferring the stress to the electrical conductors.

(3) *Winch and mast:* The winch has a chassis of a light alloy on which a movable drum with slip-ring contacts is fixed. The "Lebus" method is used for the winding of the cable, ensuring great functioning security. Until recently a 3 hp motor, connected with a "Jaeger" coupling to a reducing gear, was used for bringing the equipment back up. The purpose of the coupling was to limit the torque in case of jamming, and above all, to allow for an almost automatic descent during the drilling (Bird and Ballantyne, 1971). The free-fall descent was controlled by a foot-operated disc brake. A compressed-air disc brake ensured safety.

This device, after various incidents, has been shown to be unsatisfactory and has just been replaced by a variable-speed motor. Tremendous flexibility is thus obtained at slow speeds (recovery of the core, assembly and disassembly of the corer), as well as at high speeds for the raising and lowering of the unit. The coupling, mounted as a brake, is used only for drilling. The safety brake was also kept. The mast is a duralumin tube 5 mm thick and 200 mm in diameter. It is 8.80 m tall, and comes apart in three pieces. At the top, the pulley is equipped with a pulse generator connected to a depth counter.

(4) *Generator:* The generator provides a three-phase 380-V current. The power of the alternator is 10 kVA, that of the motor 23 hp (the extra power to compensate for losses due to the elevation). Total weight: 220 kg (with starter and batteries).

(5) *Accessories:*

(a) a switch housing with all the controls and dials, including control of the winch. In particular, it contains a variable transformer for controlling the power applied to the drill tip.

(b) for coring done in the Antarctic, the installation is placed in a 5.5 x 3.3 m portable cabin. The walls are made of two sheets of marine plywood (8 mm and 5 mm) enclosing a 15-mm-thick insulation. The whole is held together with aluminum corners.

(6) *Weight of the whole drilling unit* (without crating):

generator	220 kg
corer	170
cable	400
winch, chassis and mast	330
drive platform of the winch drum	180
housing for speed control of winch and brake resistance	290
housing for controls and measurements	190
accessories (compressor, tools)	100
Total	1880 kg

For a drilling operation in the Antarctic, of course, the drilling shelter (600 kg), replacement parts, space for the storage and study of samples, must all be added.

Results Obtained

(1) The first test drilling was carried out in temperate ice in 1968 on the Saint-Sorlin Glacier. Bedrock was reached at a depth of 67 m. The principle of coring with a bare-wire resistance was tested.

(2) In 1969 another coring was performed on the same glacier (Gillet, 1969), down to bedrock at 72 m. The material was then adapted for use in the Antarctic, and for descending to depths of 500 m.

(3) In July 1971, the Vallée Blanche, which, at 3500 m is one of the accumulation basins of the Mer de Glace, was drilled to bedrock at 187 m. The progress of the drilling is shown in Table 1. The drilling speed was fairly high down to 152 m. Various problems, in particular the breaking of the suspension system's potentiometer, which gives the force of the heating resistance against the ice at the bottom of the hole, greatly reduced the speed beyond 152 m. It is worth noting that the power on the heating head was limited to 3300 W (it is possible to go as high as 6000 W). This was done voluntarily to reduce the drilling speed. In fact, an analysis of the free-water content of the ice was performed on each sample as soon as it was extracted. The drilling speed, therefore, had to be adapted to the speed of the analysis. For these three drilling cases, sandy debris, easily observable in the samples, was found in the ice several meters from bedrock. The shape of the resistance proved to be extremely good for drilling through this debris. Sometimes, a small stone crushed several spirals of the helix. In general, these are fairly easy to straighten out. In more serious cases, the resistance must be changed, but this takes only a few minutes. The quality of the samples was excellent.

(4) In January 1972, this same equipment was tested at Terre Adélie [Adélie Coast], Antarctica, several kilometers from the coast. The purpose of this test was to see that the corer functioned properly in a glacier with a negative temperature (here, -15°C). The drilling reached 44 m. Various problems then arose with the vacuum pump motor and with the generator. This campaign permitted us, however, to test the meltwater recovery system, and to determine exactly how big the heating resistance must be to obtain holes of a suitable diameter. It also gave us the opportunity to work under the conditions that prevail on the Antarctic continent. When the granular ice became more compact, and the water remained in the hole, a drilling speed of 4.5 m/hr was obtained. At this time, only 65 per cent of the available power was being used.

Table 1

Progress Chart of the Drilling Operation, Vallée Blanche

Date (1971)	Depth reached, m	Average speed,* m/hr	Average power applied to the head, W	Observations
July 7	32	2.25	1300	Coring in snow at low power
July 8	52.5	2.35	2800	Coring in ice starting at 35 m Breakdown of the generator's regulator
July 9	70	2.3	2800	Repair of regulator Test 4200 W of power; a speed of 5 m/hr is reached
July 10	110	3.6	3300	
July 12	135	3.3	3300	Malfunctioning of the orientation system due to a leak
July 13	152	2.8 1.4	2800	Malfunctioning of suspension's potentiometer. It is then difficult to drill properly causing difficulties in the recovery of the core
July 14	168.5	0.8	2000	Difficulties in the recovery of the core Crushing of the resistance
July 15	180.5	1.6	2000	Fixing short-circuit on the plug of the corer's feeder cable
July 16	187	1.6	2000	Stone trapped in the ice brought up

*The figures are calculated including the time spent in maintenance and minor repairs.

The quality of the samples was very good.

(5) In January 1974, we drilled to a depth of 304 m at Terre Adélie [Adélie Coast], and reached bedrock. The operation, on the whole, went very well. The progress of the drilling is summarized in Fig. 2. A very regular advancement can be seen. It was interrupted only once, at 86 m, by a series of measurements, and a test of thermal reaming of the hole. This reaming was not indispensable, but we wanted to test the possibility of doing it, if necessary. The experiment showed that it is a very delicate operation. In fact, the meltwater cannot be sucked in by the vacuum pump. It runs, therefore, in the hole, and refreezes a little further down. The water that accumulates in this way as ice causes the corer to deviate from its initial path. Therefore, beyond 60 m, because of this deviation, a totally new hole was drilled.

Considering these tests, it seems that if the deformation of the hole makes reaming necessary, it should be done with a mechanical, and not a thermal, procedure.

Despite the relatively high temperatures observed below 200 m (Fig. 3) there were no problems with jamming. As a matter of fact, the corer makes a hole with a diameter of at least 135 mm.

On the other hand, as the drilling below 200 m lasted only three days, the speed of the closing of the hole was insufficient to provoke jamming.

During this drilling, we also tested several different drill tips, with resistances of different diameters and fed with varying powers. Figure 4 represents the drilling speeds obtained, relative to the various powers applied to the tip. A rather large range of results can be seen, which it seems, can only be explained by variations in the quality of the ice. Because of certain deficiencies in the regulation of the generator, it was impossible to feed the drill tip with a power greater than 4100 W.

On the whole, the quality of the samples was excellent. We noticed, however, a significant number of diagonal breaks between 60 and 74 m and 112 to 120 m.

Between 150 and 170 m and from 261 to 264 m the cores had many horizontal fractures. This was also true but in a less noticeable way between 192 and 205 m. Deeper, despite a very strong stratification, the quality of the cores was excellent, and very few fractures were found.

Perspectives

After the excellent results obtained during the coring carried out at Terre Adélie [Adélie Coast] in 1974, it seems very possible that we will be able to drill to depths significantly greater than 500 m, as long as the ice is cold enough to prevent the hole from closing too quickly. We hope, therefore, to drill to a depth of 1000 m during the summer expedition of 1975-1976, in the Dome C region (approx. 74°S, 125°E), located on the Dumont d'Urville-Vostok route.

[Editor's note: This paper was supplemented by a 10-minute color film showing ice-drilling operations in Vallée Blanche.]

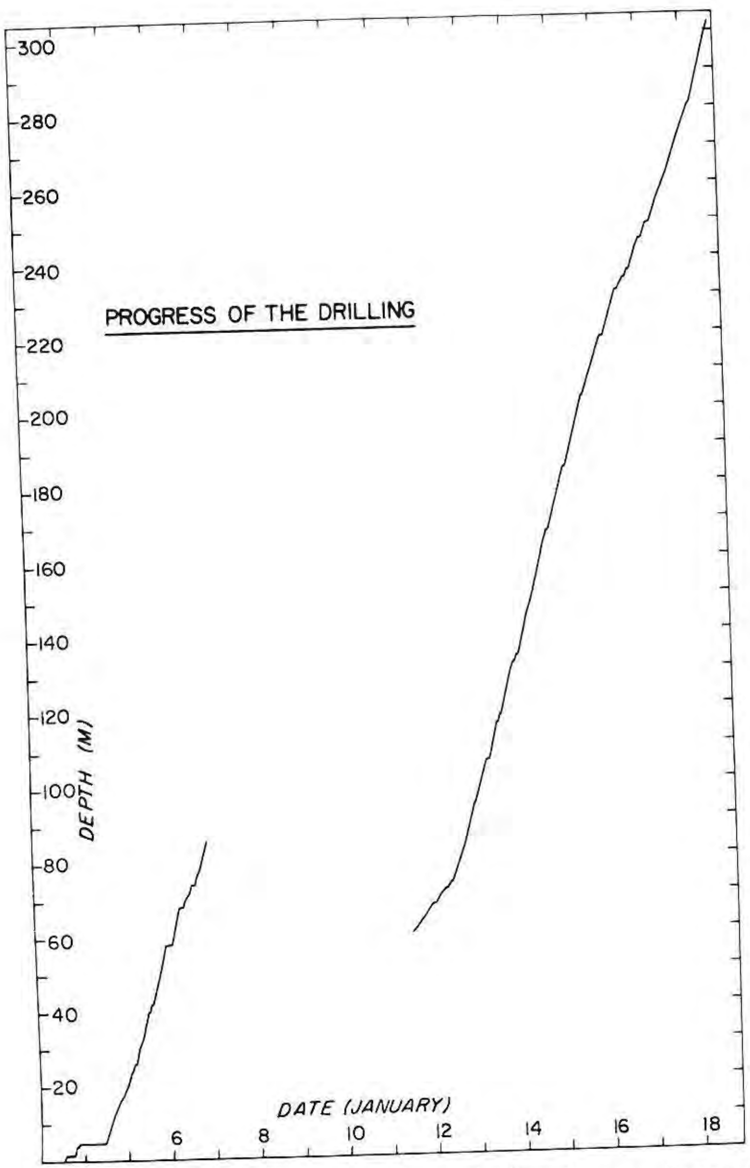

Figure 2. Progress of drilling, Adélie Coast, Antarctica, January 1974.

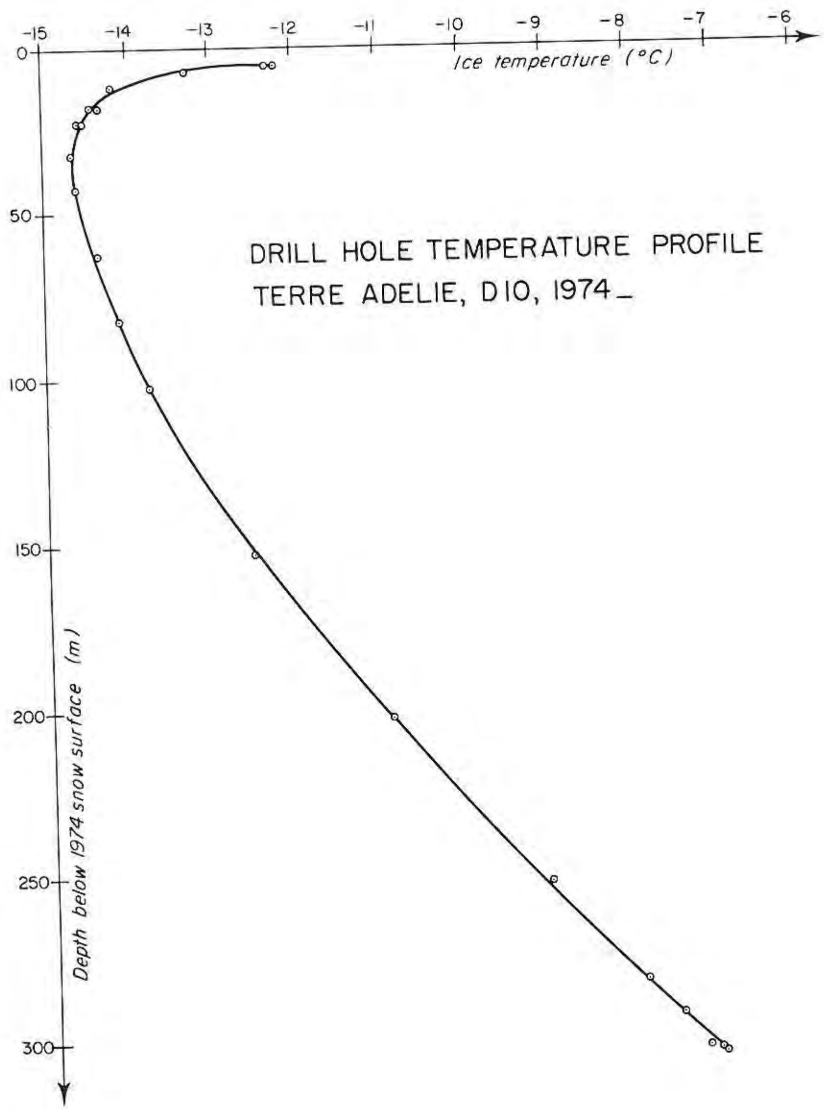

Figure 3. Drill hole temperature profile, Adélie Coast, Antarctica, January 1974. (Data obtained by Claude Rado.)

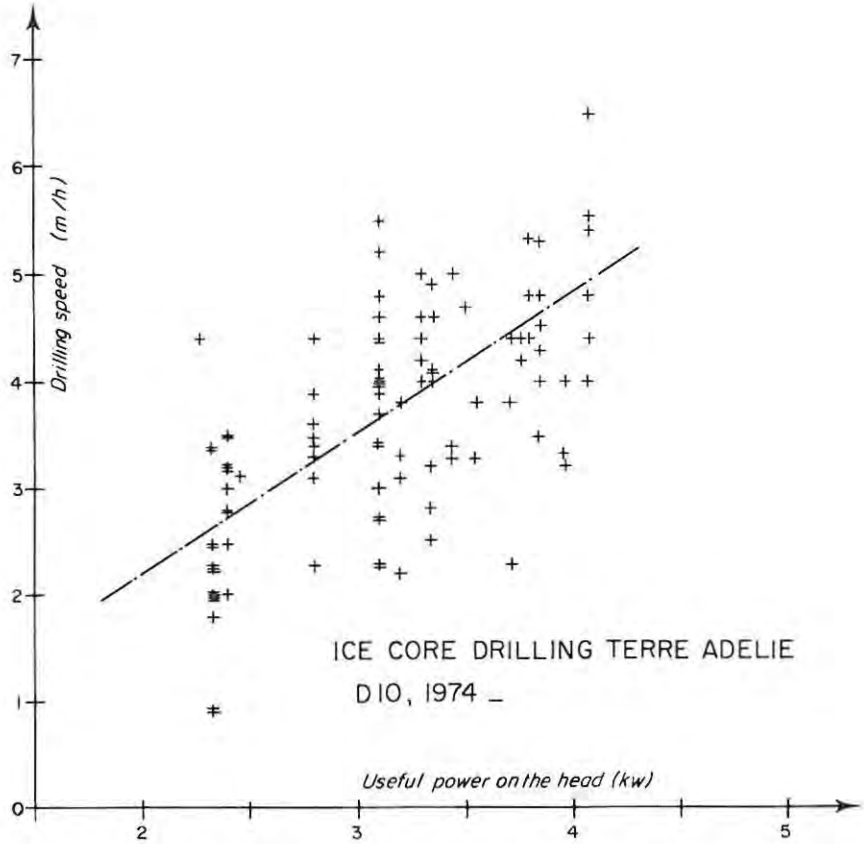

Figure 4. Speeds obtained in ice drilling, Adélie Coast, Antarctica, January 1974.

REFERENCES

Bird, I.G. and J. Ballantyne, 1971, The design and application of a thermal ice drill: Technical Note 3, Dept. of Supply, Antarctic Division, Melbourne, 25 p.

Gillet, F., 1969, Forages et carottages dans le glacier de St-Sorlin: Société Hydrotechnique de France, Section Glaciologie (unpublished).

Remenieras, G. and M. Terrier, 1951, La sonde électro-thermique EDF pour le forage des glaciers: Association Internationale d'Hydrologie Scientifique. Symposium de Bruxelles, août 1951, pp. 254-260.

Shreve, R.L. and W.B. Kamb, 1964, Portable thermal core drill for temperate glaciers: *Journal of Glaciology*, v. 5, no. 37, pp. 113-117.

Ueda, H.T. and D.E. Garfield, 1969, The USA CRREL drill for thermal coring in ice: *Journal of Glaciology*, v. 8, no. 53, pp. 311-314.