ICE CORE QUALITY IN ELECTRO-MECHANICAL DRILLING

F. Gillet, D. Donnou,
C. Girard, A. Manouvrier,
C. Rado and G. Ricou

Laboratoire de Glaciologie
et Geophysique de l'Environnement,
C.N.R.S., Grenoble, France

ABSTRACT

Using an electro-mechanical drill working on the principle developed by J. Rand and H. Rufli, four holes have been drilled in different locations. In each of these drillings it has been observed that the core quality was excellent in the firn, but in the ice, fractures appeared. Certain pieces of core were highly broken and sometimes core was completely sliced into irregular discs 1 or 2 cm thick.

After a brief description of the drill, we describe the main phenomena observed and we attempt to determine the possible causes of the fracturing.

INTRODUCTION

In 1976-77, with the help of information given by J. Rand and H. Rufli, we built an electro-mechanical drill based on design features of the two drills previously developed.

Four holes have been drilled with this equipment as follows:

Site of core	year(s) 19--	Depth (m)	Temp °C	Firn to ice (m)
Dome C (I)	77/78	140	-53	100
Dome C (II)	78/79	180	-53	100
Adelie Land D57	80/81	203	-32	80
James Ross Is.	1981	150	-14	70

During these four operations, we never had problems with sticking of the drill in the hole. However, in connection with the core catchers, we occasionally had some difficulties recovering the cores. Sometimes it was difficult to penetrate the ice. The main problem encountered concerned the quality of the cores. For all drillings, this quality was excellent in the firn but deteriorated on arriving at the firn/ice transition. It is important to try to understand the reasons for this: the aim of this paper is to determine the main factors which may have an effect upon this phenomenon.

EQUIPMENT

The drill unit is 4.20 m long and weighs 120 Kg. The hole that is bored is 14.3 to 14.4 cm in diameter and the core retrieved has a diameter of 9.9 to 10 cm. The drill is comprised of three main sections:

The Anti-torque Section

This section of length 1.10 m is equipped with four 0.72 m long steel springs working in the same way as J. Rand's unit (Rand, 1976). A slipring assembly avoids any twisting of the cable if the anti-torque device rotates. An 11 Kg lead weight, having a 17 cm axial movement, helps to break the core by shock impact or to recover the drill if it is slightly stuck at the bottom of the hole.

The Motor Reducer Section

This section of length 0.80 m consists of a 3 phase, 380 V, 1.5 HP submersible AC motor connected to the gear reducer (ratio 1:27) which is mounted in a tube filled with oil. The oil is used for lubrication and also for heat dissipation. The shaft going to the core barrel rotates at a speed of 105 RPM. It is constrained by two bearings (Rufli, 1976) to limit the vibrations which can occur in the upper part of the barrel (Fig. 1).

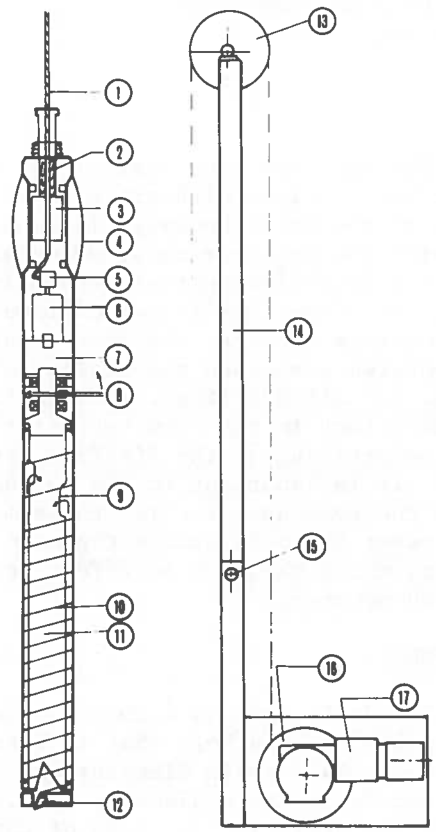

Figure 1. Schematic diagram of the drill, tower and winch assembly. (1) Electro-mechanical cable. (2) Cable termination. (3) Knocker weight. (4) Spring. (5) Slip-ring. (6) Submersible motor. (7) Gear reducer. (8) Clutch. (9) Chip inlets. (10) Auger flights. (11) Core barrel. (12) Cutters. (13) Sheave. (14) Mast. (15) Rotation axis of mast sections. (16) Cable drum. (17) Hydraulic motor reducer.

The Core Barrel Section

The core barrel of length 2.3 m has an outer jacket made from a stainless steel tube, 14 cm OD with a 2 mm wall thickness. Three steel strips (1.5 mm thick) are fixed inside the jacket to provide a better movement of the chips on their way up the flights. The inner barrel is a steel tube 10.8 cm OD with a 2 mm wall thickness. Two different types of inner barrel have been used. The first, used at Dome C, was used with the same two cutters and core catching system as used in the SIPRE hand auger. The two lead auger flights, made of polyethylene, have a pitch of 15 cm. The second has three round cutters (Fig. 2) and three core breakers which are tripped against the core by giving a small reverse rotation to the motor.

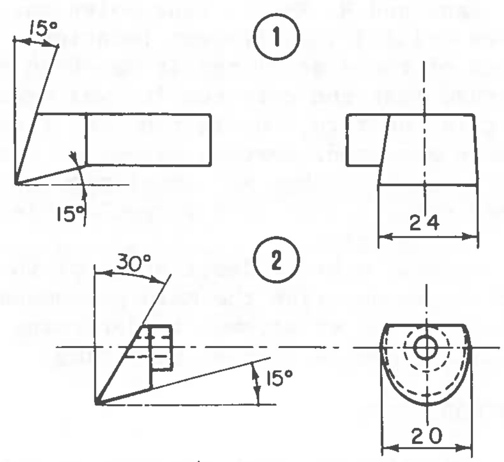

Figure 2. Cutter design. (1) Electro-mechanical drill No. I used at Dome C. (2) Electro-mechanical drill No. II used at site D57 and James Ross Island. (Dimensions are in mm).

The polyethylene spirals have now been replaced by stainless steel ones, which, being thinner, increases the space available to the chips. Corresponding to the three cutters, there are three auger flights with a pitch of 15 cm.

DESCRIPTION OF THE PHENOMENA OBSERVED AT THE FOUR DRILLING SITES

Dome C (I)

The density curve (Fig. 3) shows that the limit of the firn can be estimated to be at about 100 m depth. This depth was confirmed by other measurements made to determine the depth of the pore close-off. In the firn, the quality of cores was very good. The first broken cores appeared at 88 m, then at 90 m, 101 m, 105 m and 120 m. At 127 m the number of broken cores increased slightly until 138 m. Then, suddenly, all cores showed fractures in different places. As the electro-mechanical drill was just used for starting the hole for the thermal drill, we did not go deeper than 140 m with this equipment.

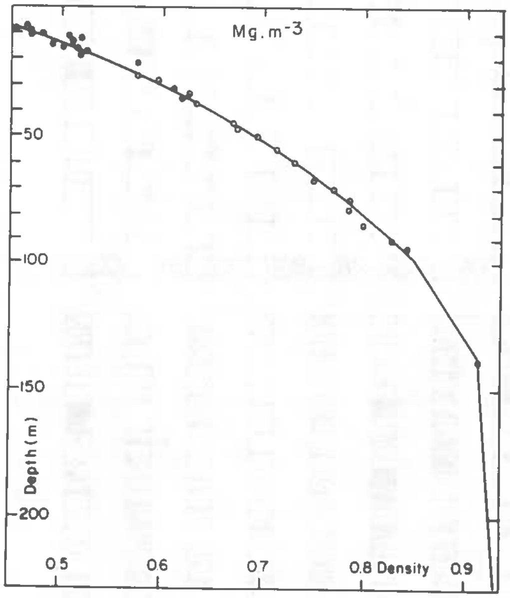

Figure 3. Density as a function of depth at Dome C.

Dome C (II)

The first broken cores appeared at 114 m, much later than at Dome C (I). At 115 m, the cutter shape was modified in order to increase the diameter of the cores in an attempt to make their retrieval easier. Then, until 126 m, 9 cores of 19 were partially broken. From this depth down, all the cores showed fractures, half of them being heavily broken. At 137 m, we increased the internal clearance of the cutters, in an attempt to restore them to their initial shape. We observed immediately, an increase in the quality of the cores, and, until 160 m, about 65 % of them were good. Beyond 160 m depth, almost all cores showed fractures, 30 % of them being heavily or totally broken. The most frequent fracture shape was a type of slicing into small irregular discs having a thickness of 1 or 2 cm.

Concerning the partially broken cores, we would notice that it was often the upper part of them that was most fractured.

Site D 57

Referring to the depth-density curve (Fig. 4), the limit of the firn can be estimated to be at about 80 m depth.

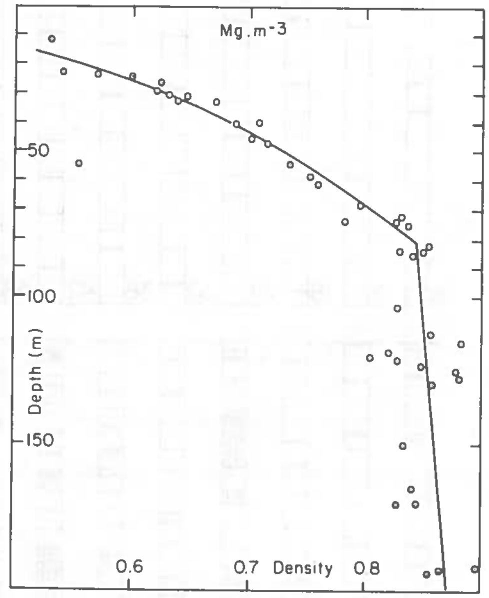

Figure 4. Density as a function of depth at Site D 57.

The first fractures appeared at 98 m and 100 m, where, respectively, 3 cm and 11 cm of the lower part of the cores were broken. Also, a few fractures in the ice were visible at the bottom of some cores. This could probably be explained by the action of the core breakers. More significant fractures appeared at 112 m depth. Their number increased with depth.

From 98 m until 203 m the total length of broken core is 13.4 m which represents 13 % of the total.

The logging of the core, carried out by M. Creseveur, enabled Figure 5 to be prepared. The main results are summarized in Table 1.

James Ross Island Site

The density curve (Fig. 6) gives a

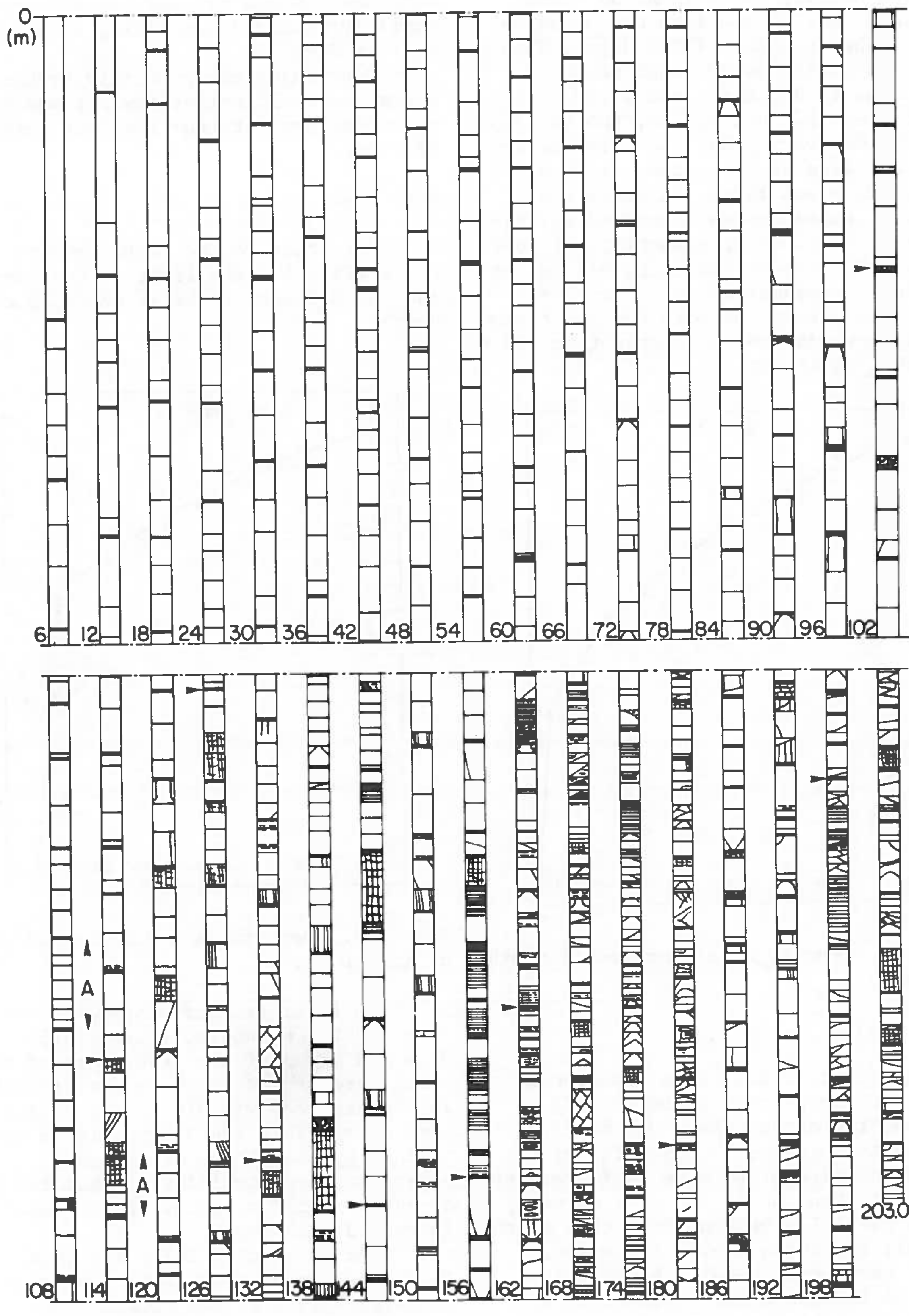

Figure 5. Core logging information at Site D 57, showing the different core fractures observed in the ice. The thick horizontal lines correspond to the limit of the cores obtained in each run. The symbol "A" indicates runs made with the core barrel used at Dome C (No. I).

TABLE 1

Depth (m)	Length of broken core (%)	Average length of core segments (cm)	Comments
0 - 98	0	29	Very good quality core
98-112	1.5	26	
112-120	11.0	22	
120 131	18.0	17	
131 143	24.0	17	Of the 24%, 14% were totally broken
143 152	7.0	21	At 143 m the clearance angle was reduced
152 155	53.0	1 - 2	Heavily broken into small discs
155 160	13.0	9	
160 179	13.0	6 - 8	Moderately broken into short sections
179 193	3.0	15 - 16	Cutters modified at 178.54 m
193 203	17.0	6 - 8	Core quality deteriorating in spite of frequent cutter sharpening. Chip transport is difficult.
Total depth reached 203.09 m			

firn limit at about 70 m depth.

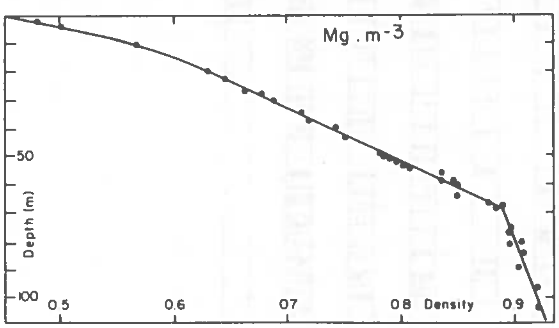

Figure 6. Density as a function of depth at the James Ross Island Site.

The first broken core appeared at 64.2 m depth and was heavily fractured on the top 30 cm. Down to 79.8 m only 4 % by length of the cores were broken. From 64.2 m until 150.5 m, the total length of broken cores reaches 13.7 m (16 % of the total core length).

Figure 7 shows the detailed logging of the different fractures observed in the core and Table 2 summarizes the main results.

Table 2

Depth (m)	Length of core broken (%)	Average core segment length (cm)
0 - 64	0	65
64 - 80	4	25
80 - 87	23	14
87 - 94	0.4	22
94 -107	11	19
107-116	16	15
116-130	4	14
130-144	12	9
144-145.7	56	-

Note: At 116.04 m the rate of penetration deteriorated and the cutters were modified to increase the hole diameter.

The depth given here (145.65 m) corresponds to the total length of core, but the depth actually drilled was 150.5 m. Thus, 4.85 m of missing core must be added to the logged core.

From 78.25 m (beyond which there is

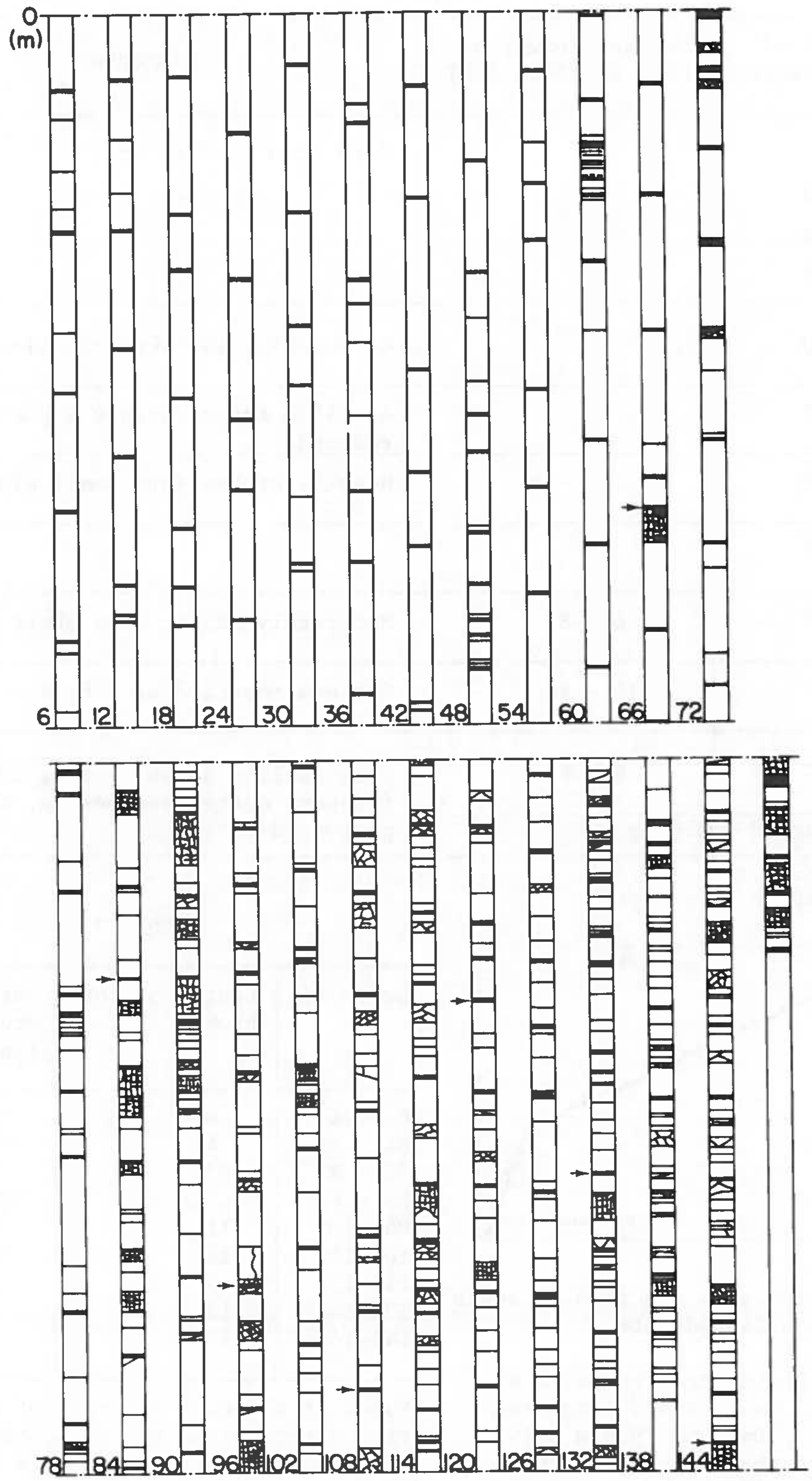

Figure 7. Core logging information for the James Ross Island site, showing the different core fractures observed in the ice. The thick horizontal lines correspond to the limit of the cores obtained in each run.

a difference between the depth reached by the drill and the depth corresponding to the length of cores retrieved) until 150.5 m, this deficiency represents about 6.7 %. This figure should therefore be added to the values given in Table 2. From 64 m until 150.5 m the total length of broken core is 13.4 m which represents 16% of the total.

DISCUSSION OF THE POSSIBLE CAUSES FOR THE DECREASE IN CORE QUALITY BEYOND THE FIRN-ICE TRANSITION

In view of the observations made, we believe that four parameters may have an effect upon the core quality. These are: (1) Cutter geometry and sharpness; (2) The physical properties of the ice; (3) Chip transport; (4) Stability of the drill (with respect to vibrations).

(1) Cutter Geometry and Sharpness

In all drillings, we would notice that an increase in core quality occurred after some slight modification was made to the cutters. At Dome C (II) this was at 137.00 m to 160.00 m, at site D 57 at 143.11 m to 151.76 m and between 178.54 m and 193.05 m, and at James Ross Island between 116.04 m and 129.05 m. Nevertheless we cannot state exactly what modification is the most effective. A round cutter is probably better than a cutter having the shape of the original SIPRE corer cutter blade. The barrel used at D 57 gave better cores than the first barrel used at Dome C, but this could also be the result of a better stability provided by three cutters.

It has also been noted that a frequent sharpening of the cutters is necessary. It is, further, difficult to know whether the back-rake and clearance angles used are completely satisfactory. More significantly, the problem is to know whether these angles are suitable for all types of ice encountered at different depths.

(2) The Physical Properties of the Ice

Let us consider the increase in the quality of cores gained after modifications made to the cutters. This improvement lasted from a few meters to more than 20 m. The way in which it sometimes ended leads us to the idea that it was produced by a sudden change in the physical properties of the ice. Site D 57 provides a good example of this observation. At 151.76 m the increase in the quality of the cores was suddenly reversed after a few meters advance, and, until 154.84 m, we obtained 53 % broken cores, mainly at short discs, as if the ice was horizontally foliated. The same remark could also apply at 193.05 m.

In the James Ross Island Site drilling the phenomenon is not so clear, but it is of the same type. From 143.8 m down, 56 % of the cores were suddenly broken. Such variations in the physical properties of the ice are not suprising. In the thermal drilling made in Adelie Land at D 10 in 1974, the cores had many horizontal fractures between 150 m and 170 m and again from 261 m to 264 m. Deeper (to the final depth of 304 m) despite a strong stratification, core quality was excellent.

Intuitively, we think that the ice temperature has an influence. Cold ice is more brittle and can be more easily broken even if its mechanical strength is higher. If we compare the cores obtained at D 57 and James Ross Island, where the mean ice temperatures are -32°C and -14°C respectively, we do not see any significant difference in core quality. The percentage of broken cores is of the same order (13 % and 16 % respectively). At Dome C, we did not make a precise measurement of the length of broken cores. Nevertheless, the percentage of broken core was certainly higher than at either of the two other sites. However, the core barrel was not identical in all cases, and therefore it is hardly valid to make a direct comparison.

(3) Chip transport

The following observation was made mainly at Dome C. Below the firn-ice transition, the size of chips decreases and a large percentage of the chips is in the form of ice powder. This powder has a very high coefficient of friction, causing difficulty in moving the chips up the auger flights. This results in reduced run lengths. This seems more pronounced in colder ice.

Table 3 shows the average run length as a function of depth, at four sites.

When the drill surfaces, we observe that the lower part of the auger flight is full of compacted powder whereas the barrel is incompletely full. From this observation it may be inferred that the chips occurring between the core and the wall of the core barrel tube are compressed, causing torque to be transmit-

Table 3

Depth (m)	Dome C (I)	Dome C (II)	Site D 57	James Ross Is.
0-20			1.17	0.92
20-40			1.13	0.92
40-60	1.00	0.98	1.04	0.80
60-80	0.87	0.93	0.96	0.93
80-100	0.80	0.83	0.90	0.82
100-120	0.72	0.68	0.76	0.71
120-140	0.62	0.59	0.75	0.73
140-160		0.61	0.48	0.65
160-170		0.55	0.53	
170-180		0.48	0.60	
180-190			0.47	
190-203			0.50	

Note: Run lengths shown are in meters

ed to the core. This torque may cause the core to fracture into the small discs.

(4) Stability of the Drill

It is unusual to recover completely broken core. Generally, one or two pieces of the core are fractured. This irregularity suggests that a type of instability appears during the rotation of the drill. A similar phenomenon is observed in drilling in metals resulting in non-circular hole shapes. The vibrations set up in the drill unit as a result of this could induce stress fractures in the ice. We obtained much better results with the more stable three cutter barrel. Even then, vibrations do not seem to be completely suppressed, and it would be worthwhile examining the following improvements: (a) exact centering of the innner barrel axis with the outer barrel axis; (b) centering of the outer tube and the upper part of the drill unit in the hole.

CONCLUSION

The electro-mechanical drill shows many advantages, e.g. light weight and efficiency. We drilled to 140 m and 180 m in 70 h and 100 h respectively at Dome C and to 203 m in 130 h at Site D 57. The drill can be operated by two people in a safe and reliable manner. But, when working in ice, the quality of the cores must be improved, and if deeper cores are required, it will be necessary to increase the length of each run by solving the problem of powder generation and poor chip transport.

ACKNOWLEDGMENTS

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