Mem. Natl Inst. Polar Res., Spec. Issue, **49**, 93–98, 1994

ELECTROMECHANICAL DRILLING OF A 300-M CORE IN A DRY HOLE AT SUMMIT, GREENLAND

Jakob SCHWANDER and Heinrich RUFLI

University of Bern, Physics Institute, Sidlerstrasse 5, CH-3012 Bern, Switzerland

Abstract: During the EUROCORE project in 1989 at Summit, Central Greenland, a 304.8-m long ice core of 105 mm diameter was retrieved with an electromechanical drill. A dry drilling technique was used in order to minimise contamination of the ice. A special drill head with a small chipping depth was designed to assure minimal fracturing of the core. The quality was excellent to the depth of 180 m, but then deteriorated due to increasing brittleness of the ice. Down to 280 m we were able to maintain the mean length of unbroken core pieces above 0.1 m by reducing the pitch from 7 to 2 mm. The sticking of the consequently finer chips to the drill barrels was reduced by treating the barrels repeatedly with a silicone-based wax solution. Hole enlargement cutters near the upper end of the drill head prevented the drill from becoming stuck due to borehole closure.

1. Introduction

The depth to which ice cores can be retrieved with an auger in a dry hole is limited mainly by two factors: (1) closure of the hole due to the hydrostatic pressure of the ice, and (2) deterioration of core quality at greater depths. The latter is due to the stress during cutting. While the ice surrounding the drill is at hydrostatic pressure, the pressure inside the core barrel is close to atmospheric. The stress at the core base thus increases with depth due to the growing pressure gradient. Further, the high bubble pressure leads to stress concentration around the bubbles, and the anisotropy of the elastic modulus causes internal forces between the crystals. The additional stress from the cutters then leads to fracture of the core. Previous intermediate drillings (GILLET *et al.,* 1984; CLAUSEN *et al.,* 1989) have shown that problems with fractured cores start usually at depths between 100 and 140 m. At this depth, breaks are mostly longitudinal or at 45 degrees. The distance between fractures usually decreases gradually with increasing depth, and the breaks tend to be more horizontal. Eventually, the cracks are so frequent that they cross each other, and the core has a wafery appearance. At this stage, the fractures usually ascend slightly from the surface of the core toward the centre where they meet, leaving typically cone-shaped upper ends if the core breaks apart.

During the summer of 1989, in the framework of the EUROCORE project (Fig. 1), it was planned to drill an ice core that would provide samples of precipitation from the last 1000 years. This required a core down to a depth of approximately 300 m. The aim of the project was to investigate the atmospheric chemistry. The analysis of the core for trace gases and other trace species required clean and unfractured ice, which should especially not be contaminated by drilling fluids. Therefore, we decided to drill in a dry hole. This also simplified the drilling equipment, and made the logistics easier and less expensive. Being aware that drilling to that depth would probably be at or beyond the limit of good core quality, a drill was built that should minimise the stress during cutting. This

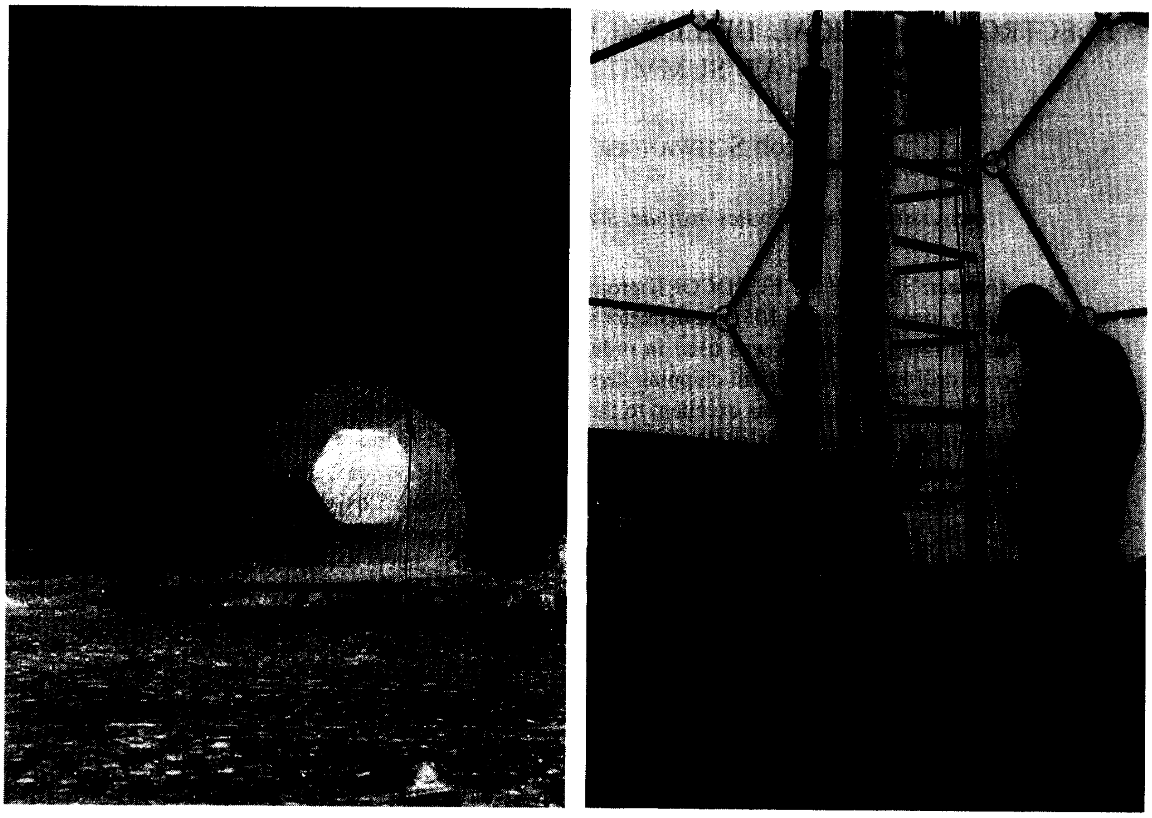

Fig. 1. left: Eurocore drill tower and shelter at Summit Station, (72.58° N, 37.64° W, 3225 m.a.s.l., mean temperature −32° C, accumulation rate 0.23 m ice equivalent).
right: Drill (anti-torque and motor section), control and tower.

electromechanical 105 mm core-drill has been described in SCHWANDER and RUFLI (1989). It was successfully tested at Dye 3 in summer 1988, where a 183 m long core of excellent quality was retrieved. Figure 2 shows the schematics of the drill and drill head. In the following, we summarise the main points of the design.

The stress reduction was achieved by the following measures:

1) small tolerance concerning the overall straightness of the drill,
2) precision of drill head (crown design),
3) low chipping depth.

The steel tubes used for the barrels were selected for good straightness. The drill head is made of three segments. The cutters are integrated in the lowest segment. In order to achieve optimum roundness and stability, cutters and ring are machined in one piece. Four core catchers are mounted in the centre piece. The uppermost segment is fixed to the core-barrel. The machining accuracy is about 0.02 mm. The head is centred by helical contact areas touching the wall of the borehole on the entire circumference of the head. Their width is about 1 mm, resulting in reasonable drilling power and still assuring good centring. Each of the four main cutters has a pre-cutter on the inner side. The idea of these pre-cutters is to reduce the cutting depth for each bit by a factor of two without considerably decreasing the mean size of the chips. At the normal pitch of 7 mm per revolution, the cutting depth is thus only about 0.8 mm. The rake and relief angles of the main cutters are

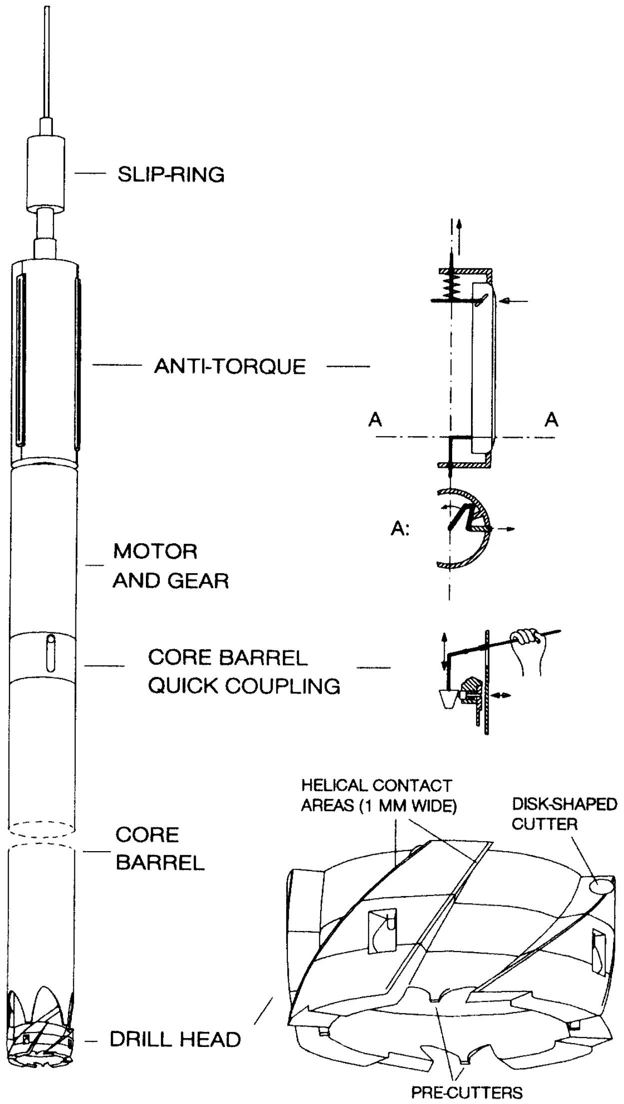

Fig. 2. Drill and drill head. The three skates of the anti-torque section are retracted while hoisting the drill. During drilling the upper part of the skates is activated by a decrease in cable tension and the lower part is forced out by torque.

45° and 10°, respectively. During the drill tests, we also tried V-bottom cutters, but we observed no difference in performance compared to flat ones.

2. The Eurocore Drilling

2.1. Drilling progress

Figure 3 shows the progress of the Eurocore drilling. The drilling started on June 20, 1989. No major problems were encountered to 130 m. Below that depth the drilling speed was substantially reduced due to difficulties with penetration. The drilling current was unusually high, and the anti-torque section often started to rotate. The reaming action of the anti-torque section produced additional chips that fell between the drill barrel and the wall of the borehole, leading to additional torque at the drill head. Also, the pulling force required to raise the drill was higher than normal close to the bottom of the hole, which was another sign of chips remaining above the drill head at the end of the run. Various actions were taken to improve the anti-torque section. We increased the spring load of the anti-torque skates and limited the outward movement of their lower end because we suspected that the skates were occasionally resting on a rim that they had cut in the hole (refer to Fig. 2 for the mode of action of the anti-torque). Also, we adjusted the sharpness of the knives on the anti-torque skates such that they could not dig too easily into the borehole wall. All these measures improved the performance of the drill, but could not solve the basic problem. At 180 m the drilling current increased again considerably due to packed chips around the drill head. We attributed this to riming of the cold drill barrels caused by the very warm and humid weather during these days, and therefore decided to drill at "night" when the temperatures were substantially lower. For a couple of days, this solved the problems with packed chips. In the meantime, we had received a wax solution (a silicone grease-based mixture, *Protect NA*, from Toko, Switzerland) to treat the drill barrel in order to prevent sticking of the chips. From then on, we heated and dried the inner and outer barrel every evening and then sprayed them with the solution. In addition, the outside of the inner barrel with the auger flights was treated before each run. We were then able to drill at a constant rate of approximately 12 m per night, and reached the final depth of 304.8 m on July 18. After all, it seemed that the foregoing difficulties with penetration were all linked with the problem of fine chips blocking the grooves in the drill head and the auger flights.

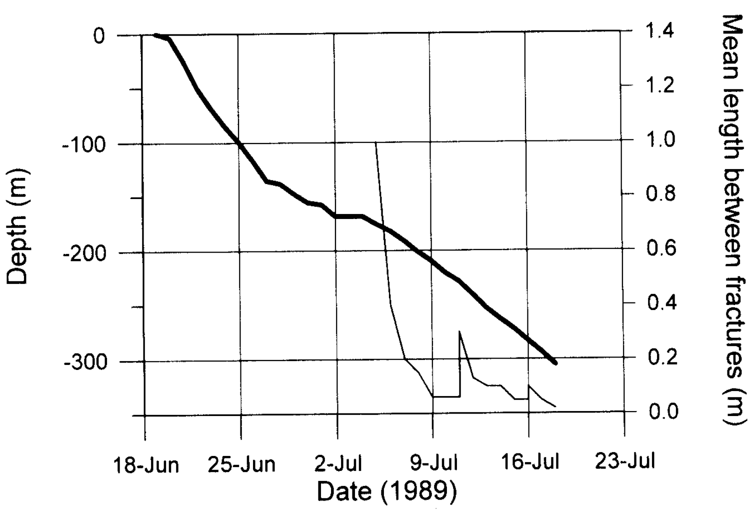

Fig. 3. Drilling progress (thick line); distance between breaks in the core (thin line), used as a quality index.

In order to avoid becoming stuck due to closure of the hole, a set of disk-shaped cutters, which enlarged the hole by 0.25 mm in radius, were mounted on the outside of the upper end of the drill head. These four disks were the only points where the drill touched the borehole wall when hoisted and lowered. In contrast to the test drilling at Dye 3 where these cutters were not yet mounted, we encountered no problems with sticking due to hole closure at Summit. During the Dye 3 project, we had to ream the hole very carefully after every interruption in drilling. Since the temperature, and accordingly the plastic deformation of the ice, are lower at Summit, borehole closure might possibly not have caused any problems, also without these extra cutters. One drawback of this hole enlargement is that additional small cuttings are produced that may accumulate around the drill head.

2.2. Core quality

The quality of the recovered ice core was excellent to 180 m, though the first internal fissures appeared at a depth of 135 m. Down to 180 m, the length of unbroken pieces (normally about 1 m) was only limited by the core-break at the end of a drilling run. When we had problems with penetration, many cores were only 0.5 m long or even shorter. Below 180 m, more and more additional fractures occurred and the length of unbroken pieces decreased. We observed that when the pitch was accidentally smaller than normal due to some ice that had built up at the base of the drill head, unbroken pieces up to one meter in length could still be recovered, even at depths of nearly 300 m. Therefore, we reduced the pitch from the regular 7 mm first to 3.5 mm, and, finally, to only 2 mm. The effect on core quality, as depicted in Fig. 3, was a net improvement on July 11 and 16. However, this pitch reduction resulted in finer cuttings that stuck more easily to the drill barrels. Thus, treatment with wax solution became absolutely essential, and had to be carried out very carefully.

3. Conclusions

At Summit, internal cracks in the core formed at shallower depths than during the drill test at Dye 3. However, we think that the core quality obtained in the Eurocore project was about the best we can expect from a drill of this type of construction, and that the slightly inferior core quality was due to the more brittle ice resulting from the 12 K lower temperature at Summit. It seems that if the basic boundary conditions like accurate machining and correct rake and relief angles are fulfilled, the quality of the core is mainly a function of the chipping depth, whereas the actual shape of the bits (for example, flat versus V-shaped bottom) plays only a minor role. The importance of a low chipping depth is also confirmed by the experience from cutting freshly drilled ice cores on a band saw, where small feed is essential to avoid fractures. However, with the design used for this drill, the decrease in pitch has its limits because eventually the fine cuttings will block the auger flights. Further reduction of the pitch would probably allow us to drill longer cores of good quality in a dry hole. We can think of basically two ways to remove the fine chips:

1) By mixing the fine chips with coarse ones. The kerf around the core would be cut in two steps. A small kerf adjacent to the core would be made with a round saw blade where each tooth cuts only a small fraction of a millimetre. This saw blade should make only a very narrow groove in order to produce a minimum amount of fine chips. The main kerf would be cut with ordinary chisel-type cutters. The rest of the drill could be constructed in the classical design. The fine chips from the round saw blade would be mixed with coarse chips from the main cutters.
2) By removing the chips with an air stream. The entire kerf around the core could be cut with a high speed milling tool.

The main reason for fractured cores would then probably stem from the core-break at the end of a drilling run, since the design of a "gentle" core-catching system is still missing.

Acknowledgments

The drilling was performed within the framework of the Eurocore project, which was supported by the European Economic Community (EEC) and Switzerland through COST 611. The construction of the drill was supported by the Swiss National Science Foundation and the University of Bern. We thank K.C. KUIVINEN for checking the manuscript.

References

CLAUSEN, H.B., GUNDESTRUP, N.S., HANSEN, S.B. and JOHNSEN, S.J.(1989): Performance of the UCPH shallow- and hand augers. Ice Core Drilling; Proceedings of the Third International Workshop on Ice Drilling Technology, Grenoble, France, Oct. 10-14, 1988, ed. by C. RADO and D. BEAUDOING. Grenoble, Centre National de la Recherche Scientifique, Laboratoire de Glaciologie et Geophysique de l'Environnement, 14-20.

GILLET, F., DONNOU, D., GIRARD, C., MANOUVRIER, A., RADO, C. and RICOU, G. (1984): Ice core quality in electro-mechanical drilling. CRREL Spec. Rep., **84-34**, 73-80.

SCHWANDER, J. and RUFLI, H. (1989): Electromechanical drilling in dry holes to medium depths. Ice Core Drilling; Proceedings of the Third International Workshop on Ice Drilling Technology, Grenoble, France, Oct. 10-14, 1988, ed. by C. RADO and D. BEAUDOING. Grenoble, Centre National de la Recherche Scientifique, Laboratoire de Glaciologie et Geophysique de l'Environnement, 32-37.

(Received April 20, 1993; Revised manuscript received October 28, 1993)