

Deep Ice Core Drilling Technology

The deep ice coring drill used during this project is an electro-mechanical liquid-filled type. A schematic diagram and photos are shown in Fig. 3, and the main specifications of the drills used at Dome Fuji are summarized in Table 1. The ice drill consists of a core barrel, a chip chamber, a pressure tight section, and an anti-torque section (Takahashi et al., 2001). Three cutters are attached to cut an ice core of 94 mm diameter, leaving a borehole of 135 mm diameter. To prevent borehole closure during drilling, the borehole is filled with an anti-freezing fluid, n-butyl acetate. Its density is about equal to the ice, and the viscosity at temperatures below -50°C is low. Since the second deep ice coring project drilled only during the austral summer season, the design of the drill could be improved to increase the productivity under this premise. The equipment was able to penetrate up to 3.84 m for each core, as opposed to the 2.3 m cored during the first deep ice coring project. Effective transportation and storage of the cutting chips generated by the drill turned out to be one of the biggest problems. Technicians experimented with various pumps to solve this problem, and finally an archimedean screw pump was used, which is operated by rotating a core barrel (Fig. 3C) through a spiral spring located within a double tube. A propeller-like booster attached to the driving shaft of the core barrel provides momentum for the transportation of the borehole liquid and cutting chips to a chip chamber (Fig. 3B).

A special pipe perforated with many small holes was manufactured for storing the cutting chips, while the liquid could easily pass through the perforations (Fig. 3A). However, the cutting chips create a countercurrent in the chip chamber during drill ascent, leading to leakage of the chips from the chip chamber. A current prevention system, including a new check valve and direct current (DC) drill motor, was adopted to prevent this from happening.

Difficulties and Progress

In the first season, 2003/2004, the final drilling depth achieved was 362 m despite significant logistics problems with weather and transportation of equipment. However, with the considerable experience gained in the 2003/2004 season, it was possible to drill ice cores smoothly during the summer season of 2004/2005. The hole was deepened by approximately 1500 m, reaching a total drilling depth of 1850.35 m.

To reach the bedrock of Antarctica under the ice sheet, 1200 meters had to be drilled in the last projected summer season 2005/2006. Hence, it was necessary to arrive at the Dome Fuji station at the earliest possibility. The team arrived at the station on 17 November 2005. The drilling resulted in a record high 133 m of drill core per week without encountering problems, and a drilling depth of 3000 m was achieved on 12 January 2006. Through most drilling runs, a 3.7-m ice core of excellent quality was obtained. When the drilling

depth exceeded 3000 m near the bedrock, the ice temperature was close to the pressure melting point. The cutting chips immediately froze to become ice, which made chip transportation within the corer very difficult. At this depth, nearly four hours were required for each single ice coring operation, with performance rapidly decreasing. Finally, only ten centimeters of the ice core could be drilled on average with each core. Because it had been expected that the “warm” ice would cause problems, the normal drill was replaced with a special short teflon-coated drill in an attempt to determine the most suitable drilling method. The final drilling depth was 3028.52 m on 23 January 2006, when drilling had to stop to provide sufficient time for demobilization of the operation and crew.

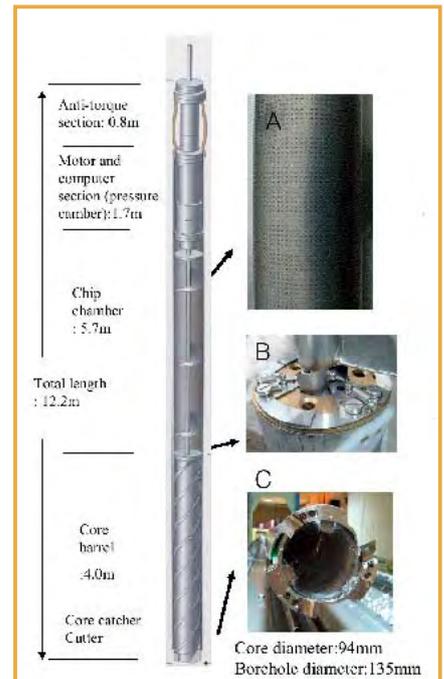


Figure 3. Schematic of a new JARE deep ice coring drill. [A] Chip chamber with many small holes for stable cutting; [B] Adverse current prevention system of chips when the drill is raised; [C] Development of special alloy for cutter which can be used to core cold hard ice as well as “warm” softer ice.

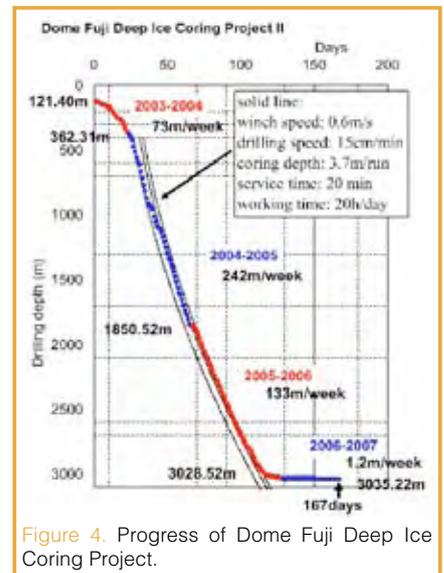


Figure 4. Progress of Dome Fuji Deep Ice Coring Project.

Ultimately, to reach the bedrock, the deep ice core drilling was extended for another year. In the fourth drilling season, 2006/2007, the total drilling period was 39 days. The total drilling length was 6.70 m, and the final drilling depth reached was 3035.22 m. The average core length was approximately 10 cm, which was half the length expected. The overall progress of deep ice core drilling throughout the seasons 2003 to 2007 is summarized in Fig. 4.

When a drilling depth of 3034.34 m was reached, a special type of small ice pieces appeared to be abundant in the chip chamber and in the frozen water chip accumulating on the

Table 1: Specs of the JARE phase 1 drill and the improved model used for normal and "warm" ice during Phase 2.

Item	Phase 1 Model	Phase 2 Model	Phase 2 Model (for warm ice)
Type	Electro-Mechanical Drill	Same as Phase 1	no change
Core ØxL	94 mm x 2,200 mm	94 mm x 3,840 mm	94 mm x 2,000 mm
Cutting Speed	15-20 cm/min	Same as Phase 1	no change
Static Pressure	30MPa	Same as Phase 1	no change
Drill Size ØxL	122 mm x 8,593 mm	122 mm x 12,200 mm	122 mm x 8,106 mm
Cutter	3 x Block Type	Same as Phase 1	Special
Core Barrel ØxL	101.6 mm x 2,321 mm	101.6 mm x 4,000 mm	101.6 mm x 2,256 mm
Chip Chamber ØxL & Density	112 mm x 3,260 mm $\rho = 500 \text{ kg m}^{-3}$	112 mm x 5,533 mm $\rho = 550 \text{ kg m}^{-3}$ Hole: 1.2 mm Ø x 45,000	112 mm x 3,160 mm $\rho = 550 \text{ kg m}^{-3}$ Hole: 1.2 mm Ø
Chip Pump	Archimedean Pump & 1 Turn Screw Booster	Archimedean Pump & 1 or 0.75 Turn Screw Booster x 2-3	Archimedean Pump & 1 or 0.75 Turn Screw Booster x 2
Motor Output Power	AC Brushless Motor 600 W for 15 min at 12,000 rpm	DC Permanent Magnet Motor with Brushes, 600W for 15 min. at 4,000 rpm.	no change
Reduction Gear Type & Ratio	4 Stage Planetart Gear 1/170	Harmonic Drive Type: CSF17, 1/100, 1/80 (, 1/50)	no change
Electronics	Monitoring Computer (10 Parameters)	Same as Phase 1 (version 2)	no change
Pressure Chamber ØxL & Pressure	122 mm x 1,700 mm 30 MPa	Same as Phase 1	no change
Anti-Torque	3 x Leaf Spring	Same as Phase 1	no change
Cable ØxL	7-H-314K, 7.72 mm x 3,500m	Same as Phase 1	no change
Hole Liquid	n- butyl acetate	Same as Phase 1	no change
Special Items		1. System to Prevent Adverse Current of Chips 2. Super Banger	1. Special Cutter Mount 2. Teflon Coated Drive Shaft, Screw Booster, Cutter, Core Catcher, Outer Tube, Core Barrel

gases were trapped as air bubbles in the ice sheet and will be analyzed.

The ice cores recovered from the Dome Fuji station confirmed that the history of global environmental changes could be continuously recorded from 720,000 years in the past. More analysis will be conducted to clarify the Earth's climate, micro-organisms present in ice, and space climate. Currently, ice core studies are being conducted in cooperation with the National Institute of Polar Research in Tokyo, Japan, other universities, and other institutes.

For more information about the Dome Fuji Deep Ice Coring Project see the Web link below.

References

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- Takahashi, A., Fujii, Y., Azuma, N., Motoyama, H., Shinbori, K., Tanaka, Y., Watanabe, O., Narita, H., Nakayama, Y., Kameda, T., Fujita, S., Furukawa, T., Takata, M., and Miyahara, M., 2001. Improvements to the JARE deep ice core drill. *Natl. Inst. Polar Res., Spec. Issue*, 56:117–125.

ice core (Fig. 5). The crystal structure of these strange ice pieces differed from that of the cutting ice chips. The conclusion was that water beneath the ice sheet had probably leaked into the borehole and had frozen in the drill. In addition, the ice core was found to be contaminated with small rocks. Hence, since liquid water existed near the bedrock, the drilling machine was covered with ice when it was positioned in the ground to drill through the ice sheet, which had a temperature of -55°C or lower. The shape of the ice underneath the drill resembled frozen drops of water. Drilling was carefully continued for the next days, and finally, the last ice core was recovered topped with mysterious white frozen water from a depth of 3035.22 m below the surface.

Preliminary Analysis of the Ice Core

The oxygen isotope ratio of the ice core was measured to determine its age. This ratio fluctuates depending on the paleotemperatures, and it can be used to study the past glacial-interglacial cycles in great detail. The ages of the ice cores were estimated by comparing the determined age with the Dome C ice core data from the European Project for Ice Coring in Antarctica (EPICA). As a result, the deepest ice cores at Dome Fuji were estimated to be approximately 720,000 years old. Traces of atmospheric

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Related Web Link

<http://polaris.nipr.ac.jp/~domef/home/eng/index-e.html>

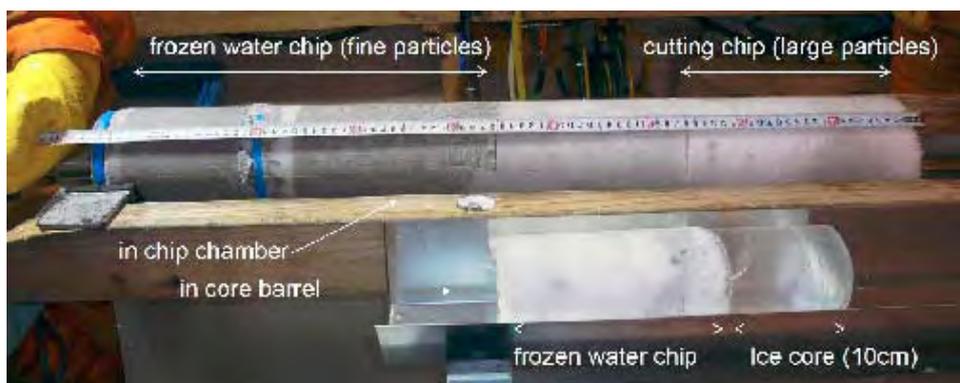


Figure 5. Cutting chips of ice core and a lot of frozen water chips.