Progress Reports

The Second Deep Ice Coring Project at Dome Fuji, Antarctica

by Hideaki Motoyama

doi:10.2204/iodp.sd.5.05.2007

Introduction

Throughout the history of the polar icecaps, dust and aerosols have been transported through the atmosphere to the poles, to be preserved within the annually freezing ice of the growing ice shields. Therefore, the Antarctic ice sheet is a "time capsule" for environmental data, containing information of ancient periods of Earth's history. To unravel this history and decode cycles in glaciations and global change is among the major goals of the Dome Fuji Ice Coring Project.

With an elevation of 3810 m, Dome Fuji (39°42'E, 77°19'S) is the second highest dome summit on the Antarctic ice sheet and might be one of the locations holding the oldest ice in Antarctica. The base of the ice underneath Dome Fuji is estimated to have formed at the beginning of the glacial cycle in the Quaternary era. Analysis of this ice can shed light on the mechanism of Quaternary glacial cycles. The second deep ice coring project at Dome Fuji, Antarctica reached a depth of 3028.52 m (3810 m above sea level) during the austral summer season in 2005/2006 (Figs. 1 and 2). The recovered ice cores contain records of global environmental changes going back about 720,000 years. During the recent 2006/2007 season the Japanese Antarctic Research Expedition (JARE) team finally reached a depth of 3035.22 m at the Dome Fuji station on 26 January 2007.

Figure 1. Dome Fuji station and other deep ice coring sites on Antarctica ice sheet. The routes to and from Dome Fuji station are shown by the green, red, and blue arrows.

Figure 2. Dome Fuji station in January 2006.

First Deep Ice Core Drilling at Dome Fuji

In December 1996, during the first deep ice core drilling campaign at Dome Fuji, the 37th JARE team had succeeded coring the ice to a depth of 2503 m. Due to a shortage of antifreeze supply, the drilling team temporarily stopped drilling and waited to receive supplies to arrive with the next drilling team (JARE 38). However, while reaming and chip recovery were repeated using the ice core drill in order to keep the hole open, the drill became stuck at the end of December at a depth of approximately 2300 m. The subsequent 39th and 40th JARE teams attempted to recover the drill by injecting high density liquid (hydrochlorofluorocarbon) 200 m below the surface of the ice sheet (100 m below the liquid level), but this attempt failed, and the borehole had to be abandoned.

A second deep ice coring project was commenced at Dome Fuji during 2001. It was decided to draw on new drilling technology developments and to establish a new borehole about 43 m north of the abandoned one with the aim of full penetration to bedrock. A pilot hole was drilled to a depth of 122 m, and a casing was installed by the 42nd JARE wintering team in 2001. In 2002 the 43rd JARE team constructed a new deep ice core drilling house, updated the station equipment, and began repairing the logistic equipment. The 44th Dome Fuji wintering team completed and prepared the new deep ice core drilling system in 2003—a completely new deep ice core drill of 4.0 m core barrel length. It subsequently proved to be of true world class quality, when it was able to recover 3.84 m of the ice core in each operation with almost no unexpected difficulties caused by ice chip clogging. Due to logistical considerations, only summer operations were performed.

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.

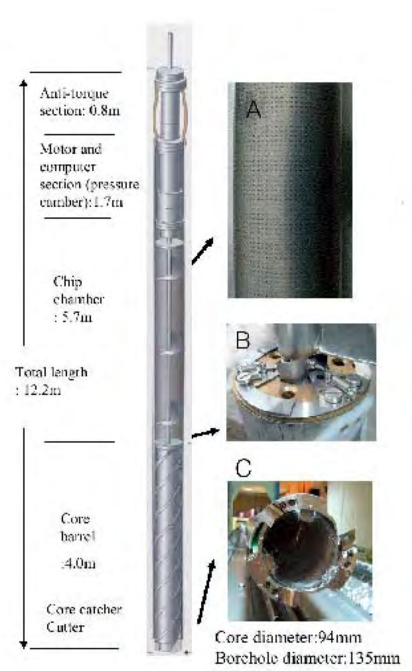

Figure 3. Schematic of a new JARE deep ice coring drill. [A] Chip chamber with many small holes for stable cutting; [B] Adverse current prevention system of chips when the drill is raised; [C] Development of special alloy for cutter which can be used to core cold hard ice as well as “warm” softer ice.

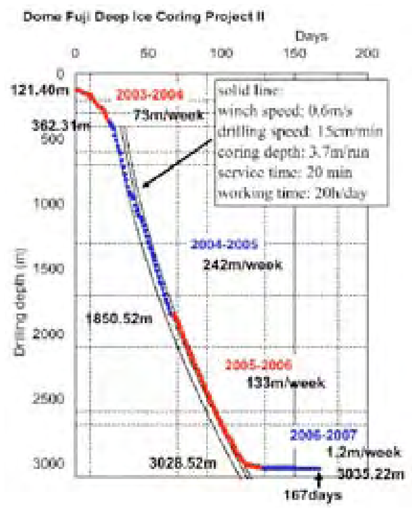

Figure 4. Progress of Dome Fuji Deep Ice Coring Project.

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 ρ = 500 kg m^{-3}	112 mm x 5,533 mm ρ = 550 kg m^{-3} Hole: 1.2 mm Ø x 45,000	112 mm x 3,160 mm ρ = 550 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

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 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, microorganisms 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

Fujii, Y., Azuma, N., Tanaka, Y., Nakayama, M., Kameda, T., Shinbori, K., Katagiri, K., Fujita, S., Takahashi, A., Kawada, K., Motoyama, H., Narita, H., Kamiyama, K., Furukawa, T., Takahashi, S., Shoji, H., Enomoto, H., Saitoh, T., Miyahara, M., Naruse, R., Hondoh, T., Shiraiwa, T., Yokoyama, K., Ageta, Y., Saito, T., and Watanabe, O., 2001. Deep ice core drilling to 2503 m depth at Dome Fuji, Antarctica. *Natl. Inst. Polar Res., Spec. Issue*, 56:103–116.

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.

Author

Hideaki Motoyama, National Institute of Polar Research, Kaga 1-9-10, Itabashi-ku, Tokyo 173-8515, Japan, email: motoyama@pmg.nipr.ac.jp.

Related Web Link

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

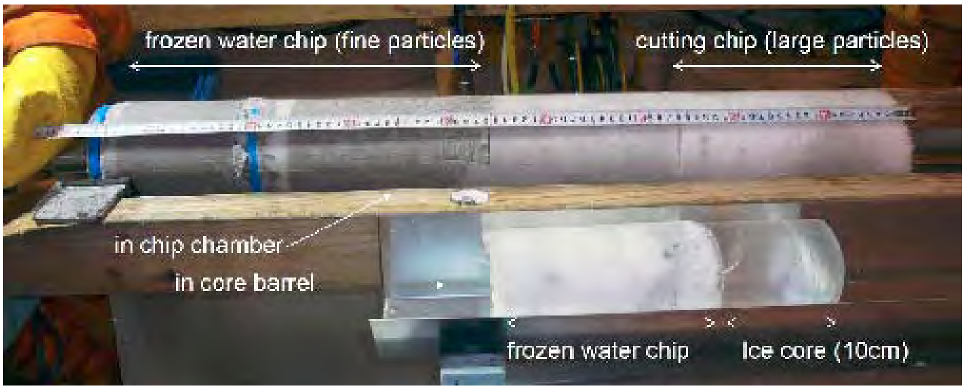

Figure 5. Cutting chips of ice core and a lot of frozen water chips.