

Report

## A report on ice core drilling on the western plateau of Mt. Belukha in the Russian Altai Mountains in 2003

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**Abstract:** A 171 m deep ice core from the surface to the bottom has been successfully drilled on the West Belukha snow-firn Plateau in the Russian Altai Mountains in the summer of 2003. The drill system used in this project was an electro-mechanical drill with a barrel 135 cm long and 9.5 cm in inner diameter manufactured by Geo Tecs Co., Japan. The maximum core length for a drilling run is 55 cm. It took 87.5 hours in actual working time of 7 working days to drill the core down to the bottom of the glacier. The total number of drilling runs was 325. The mean length of the drilled core was 48.6 cm. Most of the cores were not brittle and had a good cylindrical shape. High air temperature above the melting point in the drilling shelter caused some trouble in drilling. One of the major troubles was slip of cutters due to adhesion of cutting tips to the cutters and shoes.

**key words:** ice drill, electro-mechanical drill, ice core, Belukha, Altai Mountains

### 1. Introduction

Several ice cores have been recently recovered from glaciers in mid- and low-latitudes. Ice cores in these areas could provide new information on the regional environment as well as the global one that has not been revealed from polar ice cores (e.g. Thompson *et al.*, 1993). There are still many regions in mid- and low-latitudes where ice cores have not been recovered in spite of the existence of glaciers. In order to understand the history of the global environment, it is important to study ice cores from these areas.

The success of ice core drilling depends on logistics, technology, and operation. Glaciers in mid- and low-latitudes are usually located at high altitude in mountains. For easier logistics in such remote places, the drilling system must be light weight to be

transported easily and small in size to be operated in a limited space in a small shelter. Melting and refreezing of snow due to high solar radiation intensity or air temperature can cause many mechanical troubles in a drilling system. The ice core drilling systems for mountain glaciers have been developed by *e.g.* Takahashi (1996), Ginot *et al.* (2002), and Zagorodnov *et al.* (2002). However, drilling on mountain glaciers is still not easy because unexpected troubles often occur during drilling.

In the summer of 2003, a 171 m deep ice core from the surface to the bottom was successfully drilled on a mountain glacier in the Russian Altai Mountains by a Russia-US-Japan joint research group. The drill used was a new electro-mechanical drill designed for mountain glacier drilling. In this paper, the drilling system and the operation in this project are reported.

## 2. Drilling site

The drilling was carried out on the West Belukha snow-firn Plateau (4100–4150 m a.s.l.) in the Russian Altai Mountains (49° 49'N, 86° 34'E, Fig. 1b and 1c). The Altai Mountains are located in the central part of the Eurasia continent and extend from western Siberia to the Gobi Desert for approximately 2000 km in length. The West Belukha snow-firn Plateau is located on the west side of the summit of Mt. Belukha (4499 m a.s.l.), which is the highest peak in the Altai Mountains. The lower part of the West Belukha Plateau formed the Brat'ev Tronovih Glacier flowing southward down to approximately 2300 m a.s.l. There is another plateau (the eastern plateau, 4062 m a.s.l.) on the east side of the summit of Mt. Belukha, where a 140 m deep ice core has been drilled by a Swiss-Russian group in 2001 (Olivier *et al.*, 2003). The northern side of the western plateau is a rock cliff down to 3000 m a.s.l. This plateau was selected for the ice core drilling site because of its flatness (the surface does not exceed 5 degree slope) and high elevation, enough to keep snow in dry condition.

Prior to this drilling in 2003, a two-year preliminary investigation was carried out in the summers of 2001 and 2002. According to the results of the investigation, the glacial depth of the plateau ranges from 150 to 190 m and the surface flow velocity is less than  $1.5 \text{ m a}^{-1}$  (Fujita *et al.*, 2004). Annual snow accumulation was 2.4 m in snow depth from the summer of 2001 to 2002, and 1.6 m from 2002 to 2003. Snow pit observations showed that snow at this site is almost dry and that snow temperature is below the melting point. More detailed information on the drilling site has been given by Fujita *et al.* (2004).

## 3. Drill system

The drill system used in this project was a new electro-mechanical drill, which is an improved type of the previous model manufactured by Geo Tec. Co., Japan (Takahashi, 1996; Fig. 2). Specifications of the drill system are shown in Table 1. The improvements were made for use on mountain glaciers up to 250 m deep.

In order to obtain enough sample volume for various analyses, the core diameter of the drill was designed to be 9.5 cm. This is larger compared with, for example, the FELICS drill (7.6 cm, Ginot *et al.*, 2002) and smaller compared with the portable drill

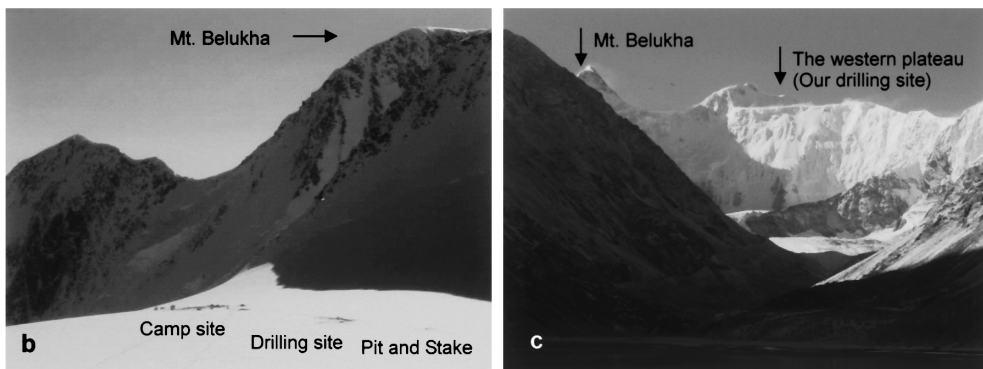
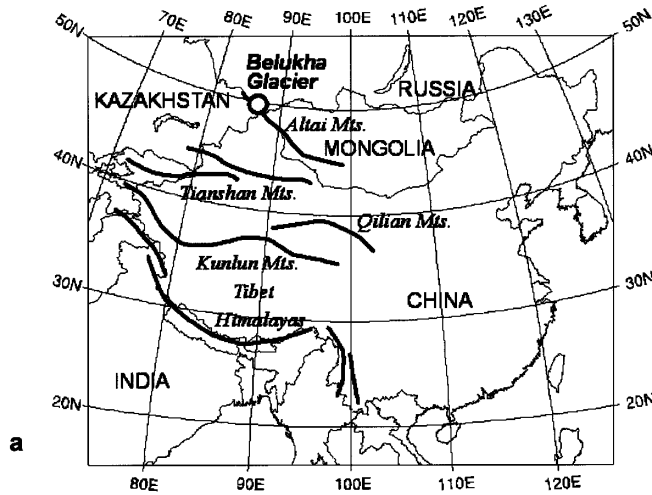


Fig. 1. (a) Location of the West Belukha snow-firn Plateau, in the Russian Altai Mountains. (b) View from the Akkem base camp located 7 km north of Mt. Belukha on 13 August 2003. (c) The western plateau taken from a hill on 9 August 2003.

of the Byrd Polar Research Center (BPRC, 10.2 cm, Zagorodnov *et al.*, 2002). The barrel length is 135 cm, which is shorter compared with the previous model or other drills. The length of the previous model is 200 cm and that of the FELICS drill is 190 cm, and that of the BPRC drill is 210 cm. Although a shorter barrel would require a larger number of drilling runs and thus would require more time for the operation, the lighter and shorter drill could save space for the operation and permit easy handling.

The maximum core length for one run with this drill is approximately 55 cm. For more effective operation, we used two barrels in this expedition. After a core came up to the surface in the shelter, it took time to remove the core and clean cutting tips out of the barrel. During this procedure we could immediately start the next drilling run with another barrel. Thus, two-barrel operation enabled us to save time.

To avoid having a core become stuck on cutting tips in the barrel, a cylindrical shaped separator made of polystyrene was used. Cutting tips are lifted by a spiral

Table 1. Specifications of the new electro-mechanical drill used in this project.

Drill	
Diameter (inner/outer)	95/125 mm
Core length	55 cm
Drill/barrel length	213/135 cm
Drill mortar	DC 100 V, 350 W, 4000 rpm, 8.5 kg cm (80 mm in diameter and 139 mm length)
Drilling speed	45 cm min <sup>-1</sup> (max)
Type of anti-torque	Leaf spring type
Winch	
Size	L 86 × W 39 × H 45 cm
Hoisting speed	84–59 m min <sup>-1</sup>
Winch mortar	DC 100 V 750 W
Torque	0.84 N·m (8.5 kg f·cm)
Controller	
Size	L 38 × W 31 × H 26 cm
Controlling system	4 way switch and a slide transformer
Mast	Fixed type, aluminum pipe (diameter: 80 mm, thickness: 4 mm, height: 230 cm)
Cable	Armored cable of 4.7 mm diameter

between the barrel tube and outer jacket and stored in the barrel. However, cutting tips stored in the barrel often cause the core to become stuck in the barrel. The separator separates the core from the cutting tips in the barrel and prevents the core from sticking.

A DC motor and a harmonic drive were used for the drill. In the previous model, an AC commutator motor of a commercial electrical grinder was used for drill for the reason of smaller diameter. In this model, the motor was specially manufactured according to the specifications in Table 1. This motor works on DC power and has slower rotation speed. The slower speed of the motor makes it possible to use a harmonic drive to reduce rotation. A harmonic drive has longer lifetime, less maintenance, and smaller size compared with a planetary reduction gear, which has usually been used with the AC motor in previous models.

The winch motor is a small 750 W DC motor. The winch drum and base are made of aluminum. The cable used was a 4.7 mm diameter armored cable. This is thinner than the previous model (5.7 mm diameter) and reduced the total weight of the system by 12 kg from the previous model. The lighter weight of the drill due to the shorter barrel enabled the use of this thinner cable. A 200 m length of the cable was reeled to the winch.

The controller consists of a 4 way switch and a slide transformer. The 4 way switch can change the direction of the winch motor rotation (up or down) and also switch power supply to winch or drill motor. The slide transformer can control the voltage to the winch or drill motor. Also, there is a cable length counter on the controller panel.

The mast is a fixed type one made of aluminum, and can be divided into two portions for packing in a box. The height is 230 cm. A rolling encoder is attached to a pulley at the top of the mast to monitor cable length.

Table 2. Size and weight of the drilling system in the shipping boxes.

	Content	Box size (W×L×H mm)	Weight (kg)
Box 1	Winch drum	450×500×450	67.3
Box 2	Mast	360×1125×195	20.6
Box 3	Winch base	480×920×335	53.5
Box 4	Drill	480×1535×195	68.9
Box 5	Controller	450×750×335	42.9
	Total		253.2

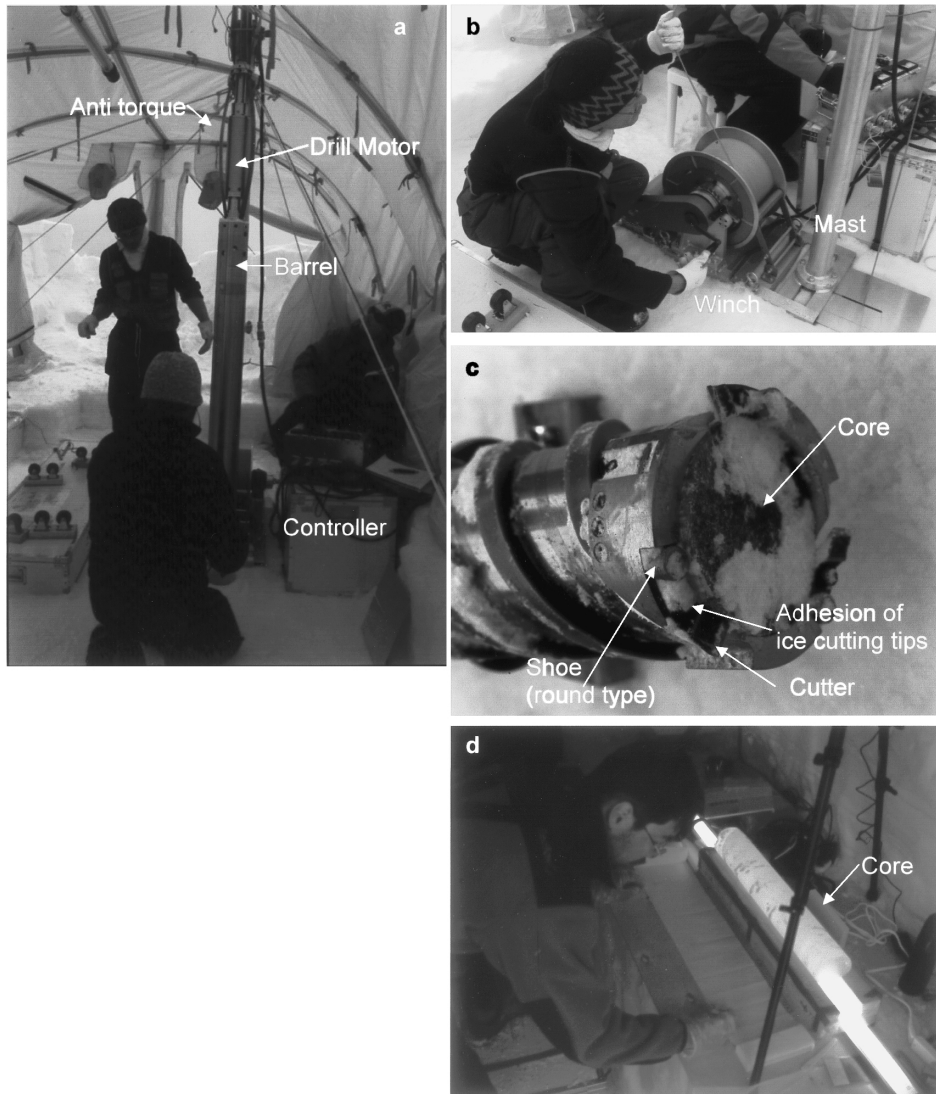
The drill system was packed in five aluminum boxes for transportation. The size and weight of each box are shown in Table 2. The total weight was 253.3 kg including the boxes.

An inverter generator with a four-cycle gasoline engine (EF2500i, Yamaha, Japan) was used. This new inverter type generator is lighter weight and has stable power output compared with the previous model. The weight is 29 kg without fuel. The maximum power is 2800 W; however, this becomes lower to approximately 1680 W (60%) at an elevation of 4000 m a.s.l. due to lower atmospheric air pressure. For high elevation use, the fuel jet nozzle in the carburetor was replaced with a nozzle with smaller hole type (Parts no. 1HX-1423E-31, Yamaha, Japan). Fuel consumption was 13.5–6.2 hours per 9.0L (full fuel). The generator worked well without any problem at the camp.

#### 4. Drilling operation

All of the drill equipment was transported as air cargo from the Research Institute for Humanity and Nature in Kyoto, Japan to Novosibirsk International Airport in Russia, 600 km north of the drilling site. It took 20 days from dispatch from Japan to customs clearance in Novosibirsk. Then, the equipment was carried by chartered truck from Novosibirsk to Gorno-Altai Airport in the Altai Republic, which is the closest airport to the glacier. Then, the drilling equipment together with fuel, food, and 12 expedition members were transported by MTB type helicopter from the airport to the western plateau (drilling site) via Akkem base camp, 7 km north of the plateau (2300 m a.s.l.). Two flights were required to carry all of the luggage to the Akkem base camp. From the Akkem base camp to the plateau four flights were required to reduce loading weight for high elevation flight. All of the luggage and members finally arrived on the plateau on July 26.

A quonset tent (Yoshida Tent Co., Japan) was used for drilling shelter. The tent was 4.5 m in length, 3.5 m in width, and 2.25 m in height. To secure space for the drill system, the snow surface level lowered by 70 cm by digging. This shelter was designed to withstand wind up to  $20 \text{ m s}^{-1}$ . The shelter was reinforced with lumber and ropes in case of strong wind. Although strong wind arose a few times during the drilling, the shelter stood up well without damage. A snow trench was dug in front of the drilling shelter in order to record stratigraphy, to measure weight, and to pack the core (Fig. 2). The trench was 2 m in width, 5 m in length, and 2 m in depth. Plywood boards were



*Fig. 2. Photographs of the drilling system used in this project and a snow trench for core analysis. (a) Overview of the drilling system, (b) mast and winch, (c) cutter mount of the barrel, and (d) recording stratigraphy of an ice core on a light table in a snow trench.*

used as a roof on the trench. For kitchen and dining, two dome type tents (The North Face, U.S.A.) were set up about 200 m north of the drilling shelter.

Drilling was started on July 28. At least three people were required for drilling operation: one to control the winch and drill and two to lay the drill body down on the floor after each run. In order to avoid working in high air temperature in the shelter, the drilling operation was usually done from 6 to 11 o'clock in the morning and 16 to 23 o'clock in the evening.

The ice core was removed from the barrel and laid on a box. When an ice core was taken out of the barrel, cutting tips in and around the barrel were removed first to avoid sticking of the core in the barrel. Then, the ice core was pushed out slowly from the bottom of the barrel with a wood stake. Cores below approximately 100 m deep were very fragile and had to be carefully handled. The barrel was cleaned with an air compressor (AC660, Makita, Japan) and with a hand brush after each run.

The ice cutter was designed with a 45 degree rake angle, 30 degree knife angle, and 15 degree relief angle. Cutters with 40 and 35 degree rake angles were also prepared for cutting harder ice. A cutter of larger rake angle can reduce cutting torque. On the other hand, a cutter of smaller rake angle cuts into ice more easily at the beginning.

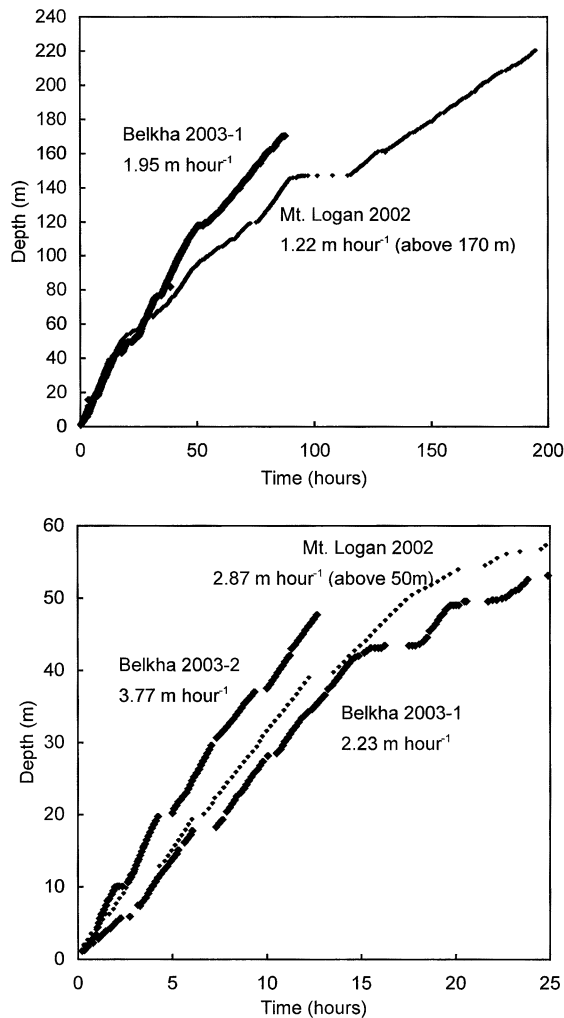


Fig. 3. Progress of drilling. (a) The first drilling on the Belukha Plateau and the drilling on Mt. Logan in 2002 by Shiraiwa *et al.* (2002), and (b) the first and second drillings on the Belukha Plateau, and the drilling on Mt. Logan during the first 25 hours.

In this drilling, the cutter of 45 degree rake angle was mainly used and worked well. A variety of shoes were used for the drilling. The height of the shoe determines the cutting pitch (progression of depth per rotation of the drill cutter, *e.g.* Takahashi, 1996), and has to be adjusted to take account for the ice condition. The shoe of 5 mm pitch (5 mm per one rotation) was most stable and worked well in this drilling. Round shaped shoes were also used to avoid adhesion of cutting tips at the shoes (Fig. 2), which occurred often when air temperature in the shelter was above the melting point.

The first drilling was stopped at 171.3 m depth on August 4. The cutter was chipped at that depth, probably due to hitting a stone. After the first drilling, the bore-hole wall temperature was measured every 10 m depth. The second drilling was started approximately 1 m south (downstream) of the first borehole on August 6. We stopped drilling on the same day at 48 m depth due to lack of core boxes.

It took 80 hours of actual working time (7 working days) to drill the first core down to the bottom of the glacier (Fig. 3). Because of the shorter barrel, a lower ice core production rate (obtained ice core length per drilling time) had been expected; however, the production rate was higher than expected. For comparison, the drilling production rate at King Col on Mt. Logan is also shown in Fig. 3 (Shiraiwa *et al.*, 2003). In spite of the longer barrel length in the drilling on Mt. Logan, the production rate is smaller than that on the Belukha Plateau. In the second drilling on the Belukha Plateau, it took only one day to reach 48 m depth. The working time for the second core was 12.7 hours. The production rate was  $3.77 \text{ m hour}^{-1}$ , faster than the first drilling at  $1.95 \text{ m hour}^{-1}$  (Fig. 3).

All cores were stored in 23 insulated boxes of 129 cm length, 50 cm width, and 50 cm height (Insulation Shipping Containers Co., U.S.A.). The boxes were transported by helicopter from the drilling site to Gorno-Altai Airport, and then to Novosibirsk International Airport by chartered freezer truck. The cores were stored in a freezer at  $-20^{\circ}\text{C}$  until they were transported to Japan by air cargo.

## 5. Ice core properties

Most of the cores were not brittle and maintained a good cylindrical shape (Fig. 4). Cores from the surface to approximately 50 m were mixed ice and firn. Cores deeper than 50 m were bubbly ice with some clear ice layers.

The total number of drilling runs including failed runs (without core) was 325 for the first core drilling. The number of core pieces for the first core (171 m) was 324. Their mean length was 48.6 cm (Fig. 5). The shorter pieces of cores from about 40 m to 55 m and from 120 m to 135 m (Fig. 5) were due to drilling troubles, which are described in the next chapter.

The bulk density of the cores increased with depth and reached  $900 \text{ kg m}^{-3}$ , the density of pure ice, at approximately 50 m depth (Fig. 6). The density almost linearly increased with depth from 7 m to 42 m. For comparison, the bulk density profile of the ice core drilled on King Col on Mt. Logan, 2002 by Shiraiwa *et al.* (2004) is shown in the figure. The rate of density increase was faster on the Belukha Plateau compared with that of the Mt. Logan ice core.

Four visible dust layers (Fig. 4b) were observed in the ice core, excluding dust



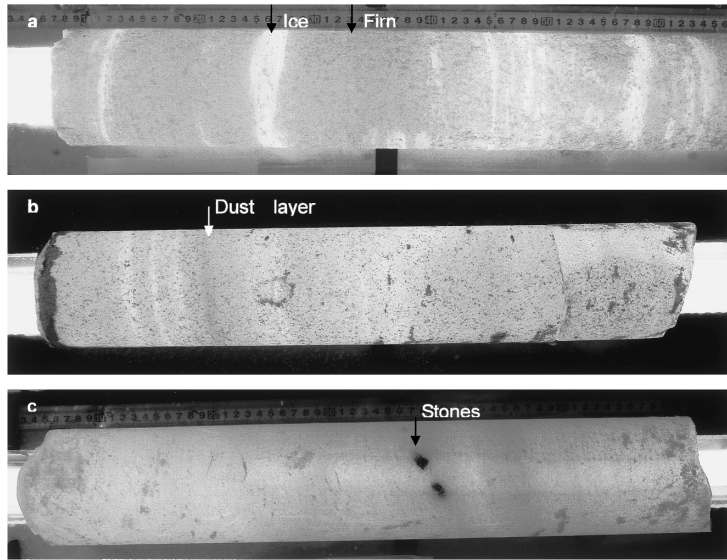


Fig. 4. Photographs of cores drilled on Belukha Glacier. (a) 18.0 m, (b) 54.6 m, and (c) 169.6 m in depth.

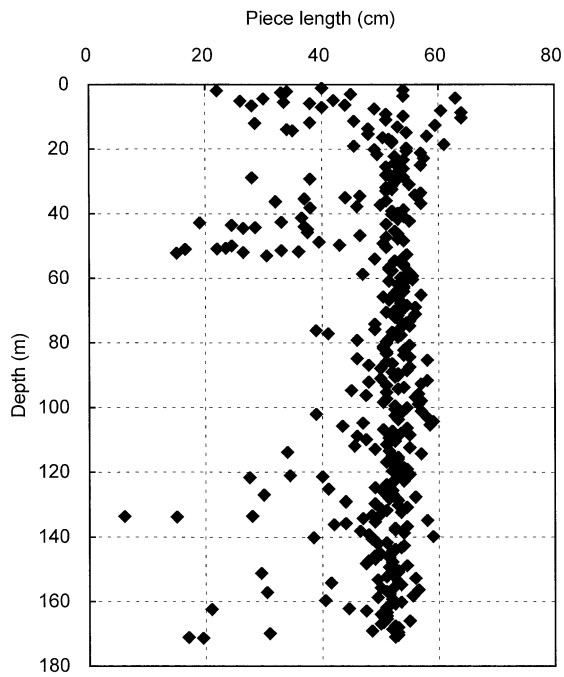


Fig. 5. The length of each core of the first core drilling versus depth.

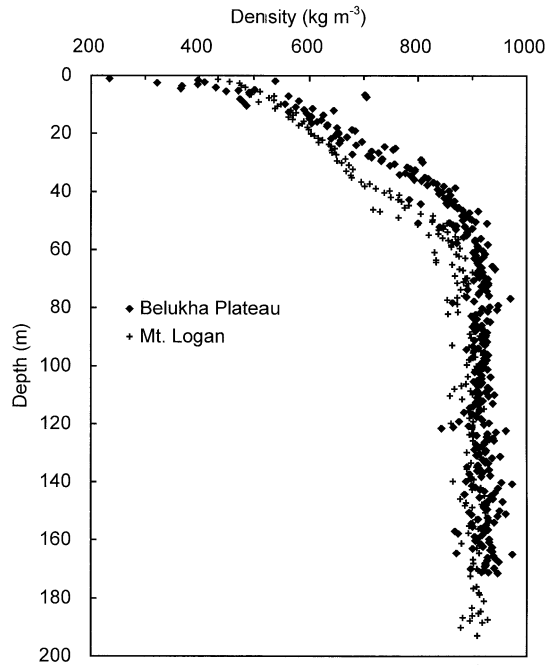


Fig. 6. Bulk density profile from the surface to the bottom obtained from the first drilling on the Belukha Plateau and the core drilled at Mt. Logan by Shiraiwa *et al.* (2002).

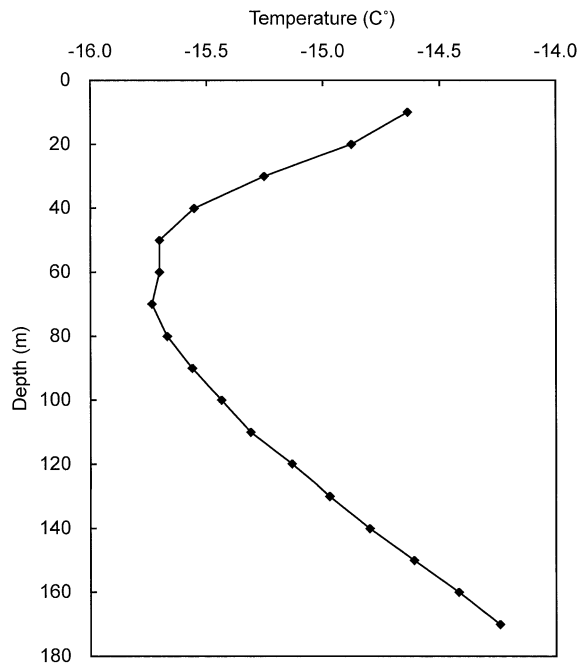


Fig. 7. Temperature profile of the borehole wall during the first drilling.

layers at the bottom part of the core. The depths of the dust layers were 51.4, 54.6, 57.8, and 122.4 m. The ice core drilled on the eastern plateau of Mt. Belukha by Olivier *et al.* (2003) also contained dust layers, which probably corresponded to those. Further discussion about the dust layers will be published elsewhere.

Cores deeper than 163 m from the surface were visibly dusty, suggesting the inclusion of silt and sand particles eroded from the bedrock. The core at 169.6 m depth contained small stones about 1 cm in diameter (Fig. 4c).

The borehole temperature changed with depth. Figure 7 shows the borehole-wall temperature profile measured every 10 m. The temperature decreased with depth above 70 m, reaching a minimum of  $-15.7^{\circ}\text{C}$  at 70 m, and then increased with depth up to  $-14.2^{\circ}\text{C}$ . The decrease of temperature above 70 m may suggest recent climate warming. The mean temperature was  $-15.2^{\circ}\text{C}$ .

## 6. Troubles and solutions

High air temperature above the melting point in the drilling shelter caused some troubles in the drilling operation. For two thirds of the total running time the temperature was above the melting point in the shelter (Fig. 8). The maximum air temperature was  $22^{\circ}\text{C}$ . On the other hand, the temperature in the borehole was lower than  $-10^{\circ}\text{C}$  (Fig. 8). This difference of temperature between the shelter and the borehole caused many troubles in drilling as suggested by *e.g.* Zagorodnov *et al.* (2002). One of the troubles was a slip of the cutters at the bottom of the bore hole due to adhesion of cutting chips to the cutters and shoes (Fig. 2c). This trouble particularly occurred at 40–50 m depth. In order to avoid this trouble, the following solutions were attempted:

- (1) Change shoe size to make the drilling pitch larger.
- (2) Burn teflon tape on the surface of the shoes.

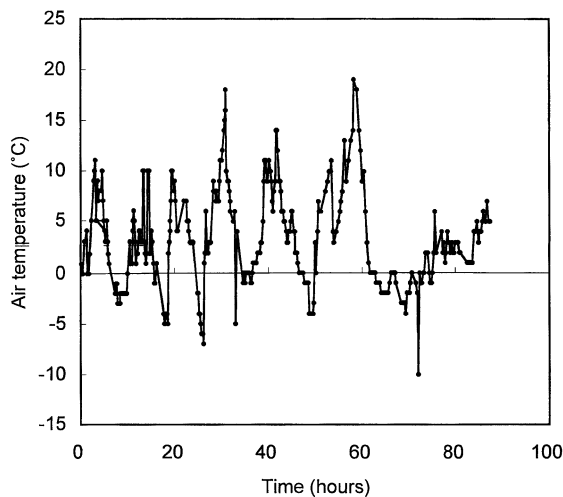


Fig. 8. Air temperature in the drilling shelter during each drilling run of the first drilling.

- (3) Pack the cutter and shoe screw holes with candle wax.
- (4) Cool the drill in the bore hole for several minutes before drilling.

Solution (1) worked sometimes, but did not solve the problem completely. Although teflon tape, solution (2), worked a bit, tips still adhered to cutter and shoe screw holes. Solution (3) particularly worked very well. The candle wax in the screw holes prevented adhesion of cutting tips to bottom of the drill mount. Solution (4) also worked although a longer time was required for running. To avoid this trouble, the cutter mount at the bottom of the drill should be improved. The flat bottom surface without any screw head or hole is likely one candidate for improvement.

The anti-torque generally worked well; however, it slipped several times at 40–50 m depth. Before the slipping of the anti-torque, several drillings were done at the same depth due to slipping of the cutters as described in the last paragraph. The drillings at the same depth probably cause scratching the bore hole wall by the anti-torque. That could result in decrease of friction between the anti-torque and the bore hole wall. When the anti-torque slipped, the leaf spring was tightened to generate more friction, and the edge of the leaf spring was sharpened with an electrical grinder. The anti-torque worked again after these treatments.

On August 3 (7th day at 162.73 m in depth) a joint between the barrel and drill motor had trouble due to a break of one of the small joint shafts. This trouble would be critical if it happened when the drill was in the borehole. The barrel would slip off the drill and could not be hoisted from the hole. In this case, the broken shaft was replaced with a screw of the same diameter as the shaft. A shaft made of stronger material should be used for the joint.

During the second drilling, the winch motor had trouble and the reeling speed significantly slowed down. This is probably due to overheating of the winch motor. The ratio of pulleys of the motor and drum was changed to reduce torque on the motor, and then the reeling speed was increased. To avoid overheating, the drill operator should carefully monitor the motor temperature.

In spite of these troubles, the drilling was successful this time. This was definitely owing to well-experienced and skilled drill operators and members of this expedition. However, the troubles which occurred this time suggested that the drill system can be improved in the future.

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