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The glaciological expedition to Mount Ichinsky, Kamchatka, Russia

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Abstract

During summer 2006, we carried out ice-core drilling to bedrock on a glacier at the summit of Mount Ichinsky, Kamchatka, Russia, and recovered a 115-m-long ice core. We also prepared samples, performed ice-core analyses in-situ, and measured the borehole temperature. The temperature of the borehole was −13℃ at 10 m depth, and the pore close-off depth was 25 m. The melt-feature percentage, or the thickness of frozen ice layers in a 1-m-long section of ice core, varied from 10% to 100%. These ice layers were formed by both rainfall, surface melting, and frost on the glacier surface, which we observed during our expedition. We hypothesize that the fluctuations in the proportion of ice layers show climatic variation in Kamchatka.

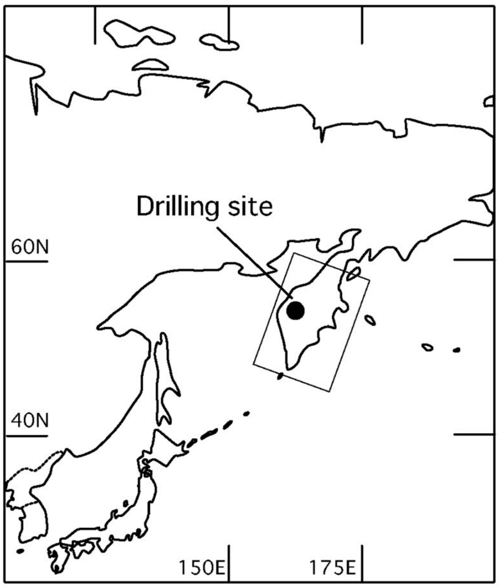
1. Introduction

It has been proposed that the climate in the North Pacific has fluctuated widely on a decadal or several-decades-long cycle known as the Pacific decadal oscillation (PDO) (*e.g.,* Minobe, 1997; Mantua *et al.,* 1997; Mantua and Hare, 2002). This PDO has been identified in an ice core obtained from Mt. Logan, Canada, in the 1980s (Holdsworth *et al.,* 1992), and in an ice core obtained from a crater glacier of the Ushkovsky volcano, Kamchatka Peninsula, in the 1990s (Shiraiwa *et al.,* 2003). Shiraiwa and Yamaguchi (2002) showed that the time series of the reconstructed accumulation rate at Ushkovsky was tended to be negatively correlated with that at Mount Logan, whereas it was positively correlated with the PDO index, defined as the leading principal component of the North Pacific monthly sea-surface temperature variability poleward of 20° N (Mantua *et al.,* 1997).

It has also been pointed out recently that the PDO may be associated with not only climatic conditions but also the marine ecological system (Mantua *et al.,* 1997). We hypothesize that the PDO is related to variation in the marine ecological system associated with chemical substances transported from the Asian continent via the atmosphere. To test this hypothesis, we are analyzing ice cores from the regions surrounding the northern North Pacific for chemical substances, as wells as for stable isotopes, of which seasonal variation reveals fluctuations in the annual accumulation. On the North America side, we have obtained ice cores from Mount Wrangell, Alaska, in 2003 and 2004 (Shiraiwa *et al.,* 2004), which we are analyzing currently. On the Asian side, we obtained an ice core from Ushkovsky in 1998, but we could not extract meaningful information on chemical substances from that ice core, because Ushkovsky volcano is near several active volcanoes and thus includes a huge amount of chemical substances emitted from those volcanoes. Therefore, we mounted an expedition to obtain an ice core from the caldera glacier on Mount Ichinsky, which is located far from any active volcanoes.

2. The drilling site

Mount Ichinsky (55° 46′N, 157° 55′E; summit eleva-



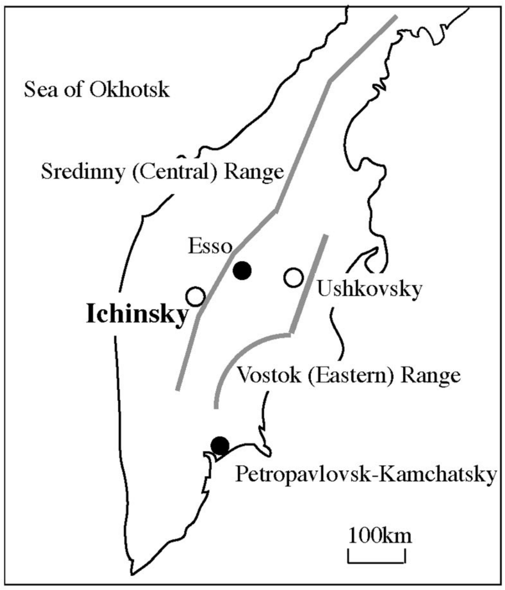


Fig. 1. Location of Mount Ichinsky.

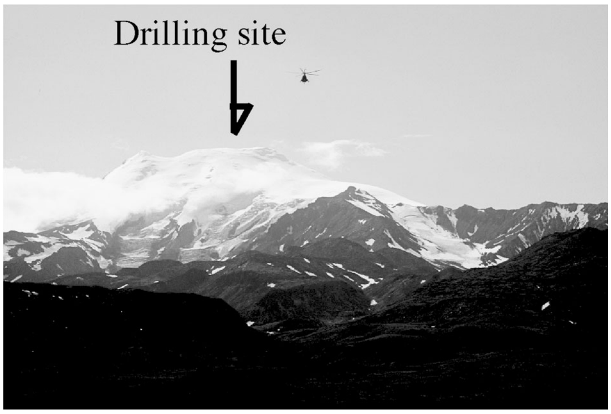


Fig. 2. View of Mount Ichinsky from the relay point.

tion, 3607 m) is in the central part of the Kamchatka Peninsula, Russia (Figs. 1 and 2). It is a stratovolcano and the highest mountain in the Sredinny (central) Range of Kamchatka. On its summit is a caldera measuring 3 km×5 km. The caldera is covered with an ice cap that is approximately 500 m in diameter. Mount Ichinsky erupted several times in the Holocene. The age of the earliest volcanic deposit overlying a Late Pleistocene moraine is estimated as about 10000–15000 years, and the most recent eruption occurred within the last 1800 years and at least several hundred years ago (Volynets *et al.,* 1991). Glaciers flow from the caldera down both the steep northeast slope and the gentle southwest slope.

3. Participants

This project was launched as an international collaborative program between the Institute of Volcanology and Seismology, Russian Academy of Science, Russia (IVS-RAS), and the Research Institute for Humanity and Nature (RIHN) and the Institute of Low Temperature Science, Hokkaido University (ILTS-HU), Japan. The participants in the project are as follows;

Dr. Sumito Matoba (ILTS-HU), leader and glaciologist
Dr. Sergey Ushakov (IVS-RAS), chief of logistics and volcanologist
Mr. Kunio Shimbori (ILTS-HU), chief driller
Mr. Tetsuhide Yamasaki (Geotech Inc. Ltd.), driller
Mr. Alexander A. Ovsiannikov (IVS-RAS), logistics and volcanologist
Mr. Alexander G. Manevich (IVS-RAS), logistics and geophysicist
Mrs. Tatyana M. Zideleeva (IVS-RAS), cook and glaciologist
Mr. Stanislav Kutuzov (Inst. Geography-RAS), drilling assistant and glaciologist
Mr. Hirotaka Sasaki (Grad. Sch. Environ. Sci. -HU), ice-core processor and glaciologist
Dr. Yaroslav D. Muravyev (IVS-RAS), ground support and volcanologist/glaciologist.

Initially, we planned to carry out the project in June, 2006, and Dr. Takayuki Shiraiwa of the Research Institute for Humanity and Nature, Mr. Kazuo Higuchi of Mountain Activity Support, Hokkaido, and Mr. Tatsuru Sato and Mr. Takeshi Toida of the Graduate School of Environmental Science, Hokkaido, were also expected to be members of the expedition. However, we were forced to change our plans because of customs troubles and bad weather at Mount Ichinsky.

4. Itinerary

We traveled from Petropavlovsk-Kamchatsky, where the IVS-RAS is located, to Esso, the helicopter site closest to Mount Ichinsky, carrying 1500 kg of equipment by truck, and the members of the expedition by bus.

We flew personnel and equipment from Esso to the summit of the caldera via a relay point at the northern foot of Mount Ichinsky in an MI8 helicopter on 10 August, 2006. One flight was required from Esso to the relay point, and four flights from the relay point to the caldera summit, to transport nine people and the equipment.

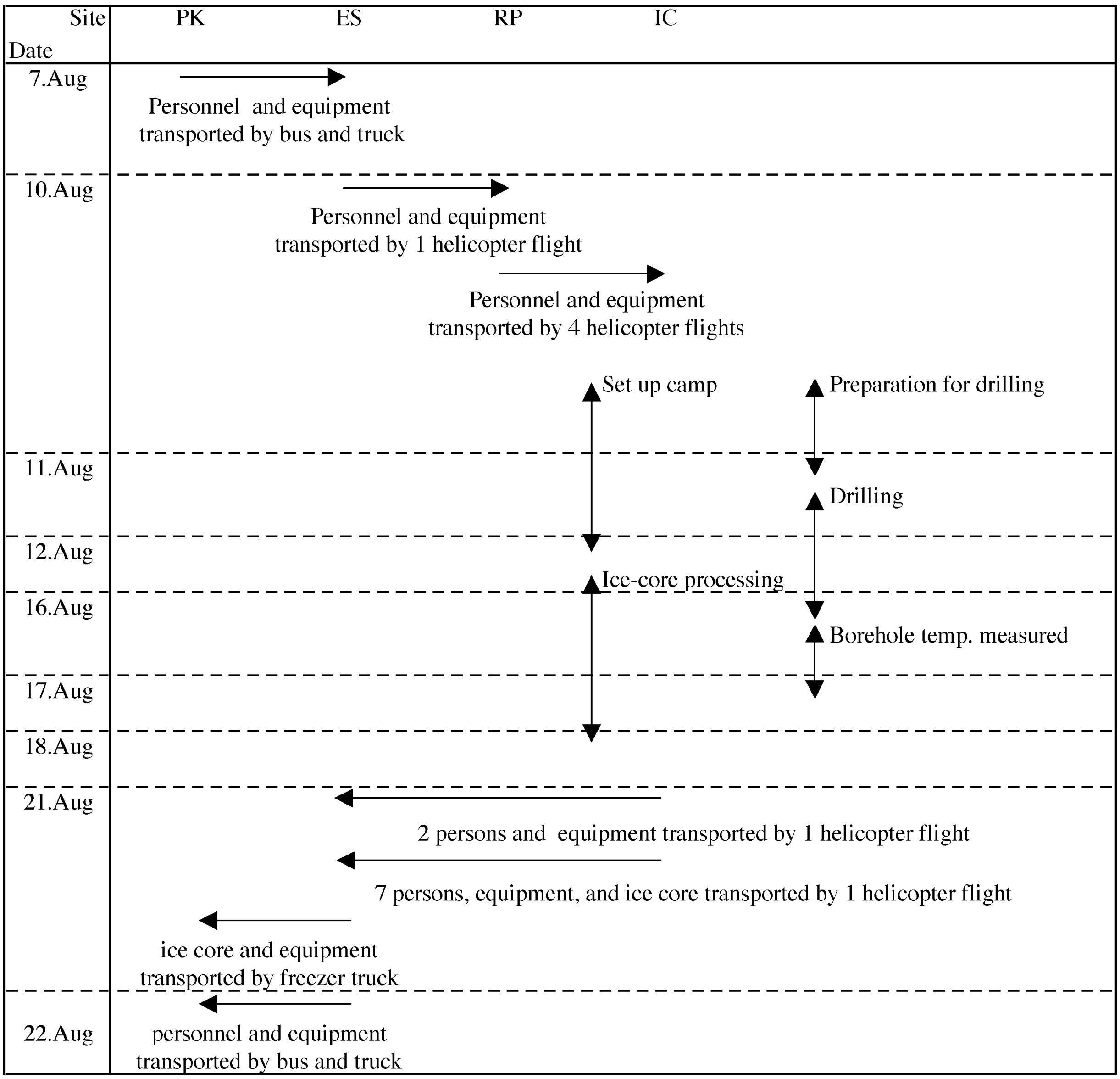
After establishing our camp, we started ice-core drilling in the afternoon of 11 August and finished in the afternoon of 16 August. We measured the temperature in the borehole from the night of 16 August until the morning of 17 August. In tandem with the ice-core drilling, from 12 to 17 August, we also measured the density of the ice core, observed its stratigraphy, and collected samples for chemical analysis from half samples of the ice-core samples from surface to 47.22 m depth.

All personnel and equipment, and the 115-m-long ice core, were flown to Esso by the same helicopter on 21 August, which required two flights from the summit to Esso. The first flight did not stop at the relay point because the helicopter had mechanical trouble and had to return Esso as soon as possible for repairs. The ice core was stored in a freezer truck at Esso and transported to Petropavlovsk-Kamchatsky on 21 August. The itinerary is summarized in Table 1.

5. Camp site

Our camp (Fig. 3) included a drilling tent, kitchen

Table 1. Dates of field studies and logistics.



PK: Petropavlovsk-Kamchatsky
ES: Esso
RP: Relay point
IC: Ichinsky

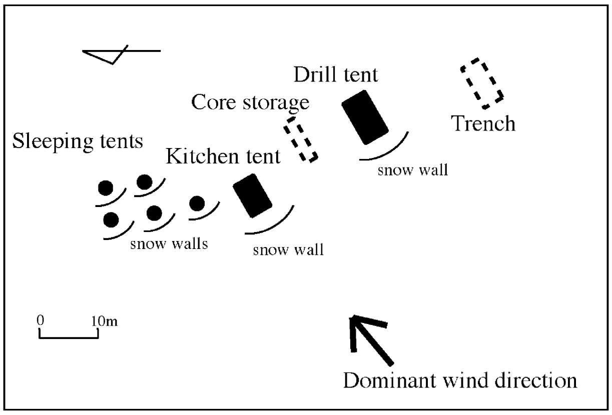


Fig. 3. Campsite map.

tent, sleeping tents, and an ice-core processing trench. We chose a flat area for the drilling site, where we believed that the strain of ice was simple, and where the thickness of glacier was the largest. The GPS position of the drilling site was 55°40′38.3″N, 157°43′28.2″E, 3595 m a.s.l. To prevent the collapse of the tents by strong winds, we dug down 50 cm below the snow surface before erecting the tents, and we constructed 1-m-high snow walls on the windward side of all tents. We also dug a trench (4 m×2 m, 2 m deep), which we covered with plywood and vinyl sheets. In this trench, we made a 3-m-long worktable and a 1-m-long light table with snow, installed a band saw (Ryowa model BSW-200), and carried out ice-core processing.

There was heavy rain with strong winds from the night of 11 August to the morning of 13 August; as a result, the guy ropes of the drilling tent were pulled out of the snow surface, and the drilling tent was almost blown away on the morning of 13 August. We repaired the drilling tent in the afternoon of 13 August and were able to restart drilling in the afternoon of 14 August. From 18 to 19 August, another very heavy storm tore the kitchen tent and two sleeping tents, so four expedition members lived in the ice-core trench from 19 to 21 August.

After the rainfall on 11 August, some crevasses appeared up near the drilling and kitchen tents. We connected the kitchen tent, drilling tent, and the ice-core processing trench with a life rope so that we could walk safely between them, even during white-out conditions.

6. Ice-core drilling

We used an electromechanical ice-core drilling system developed by Geotech Co. Ltd., Nagoya, Japan. The system was also used for an expedition to Mount Belukha, Altai Mountains, Central Asia, in 2003. The details of the drilling system are described by Takeuchi *et al.* (2004). We used a generator (YAMAHA model EF 2300) with a four-cycle, single-cylinder gasoline engine for the drilling operation. The fuel was 96-octane gasoline, which we bought in Petropavlovsk-Kamchatsky. For high-elevation use, we replaced the fuel spray nozzle in the carburetor with one with a smaller hole. To prevent the air intake from closing up because of a frozen air filter in the cold conditions, we removed the air filter made of sponge from the air filter unit. To prevent the carburetor from freezing, we attached a metal plate from the exhaust muffler to the carburetor, to conduct heat to the carburetor.

After installing the drilling system in the drilling tent on 11 August, we started the ice-core drilling in the afternoon of 11 August. On 13 August, heavy rain and strong wind tore the drilling tent and wet the control box of the drilling system. We needed 1 day to repair the drilling tent and control box, and then we restarted drilling on 14 August. On 16 August, we recognized that the drill was slipping on a hard layer, could not advance any more, and tips of rock were collected in the drill barrel, so we made the judgment that the drill had reached bedrock. The length of the wire was 114.99 m, and the number of drilling runs completed was 236.

The temperature in the drilling tent was more than 0℃, and this warmth caused various problems during the drilling operation. Ice chips melted on the drill easily during the preparation in the drilling tent, and the melted ice refroze onto the inside and outside of the barrel or the head mount of the drill in the borehole, where surrounding borehole temperature was below 0℃. The frozen chips in the barrel scratched and broke the ice core during the drilling operation. When we pulled the ice core out of the barrel, the frozen chips acted as prongs and obstructed smooth displacement of the ice core from the barrel. When the melted chips froze on the shoes, that is, the parts of the drill head that control the cutting pitches of the drill, we felt with our fingers through the wire that the drill's cutters slipped on the bottom of the borehole, and the drill did not advance.

To prevent such problems, we shortened the amount of working time between when the drill was brought up above the snow surface and when it was returned to the borehole. Four or five people participated in the drilling operation, which involved taking down the drill, pulling the barrel out of the jacket, removing the ice core from the barrel, blowing the ice chips out of the barrel and jacket with an air compressor, replacing the barrel in the jacket, putting the drill back up, and inserting the drill into the borehole. To remove the ice core from the barrel after pulling the barrel out of the jacket, we inclined the barrel and tapped it with a plastic hammer to dislodge ice chips from the inside of the barrel. After a rather large amount of ice chips had dropped, the ice core was free to slide in the barrel and could be easily removed.

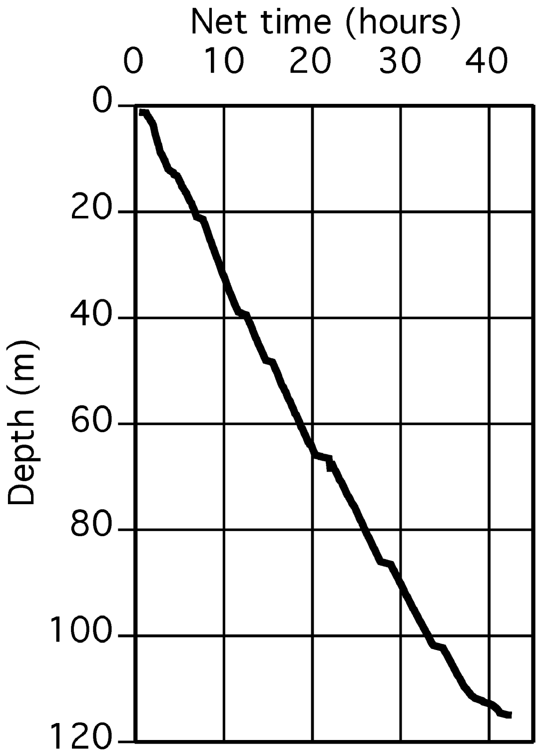


Fig. 4. Cumulative drilling time (h) versus depth (m).

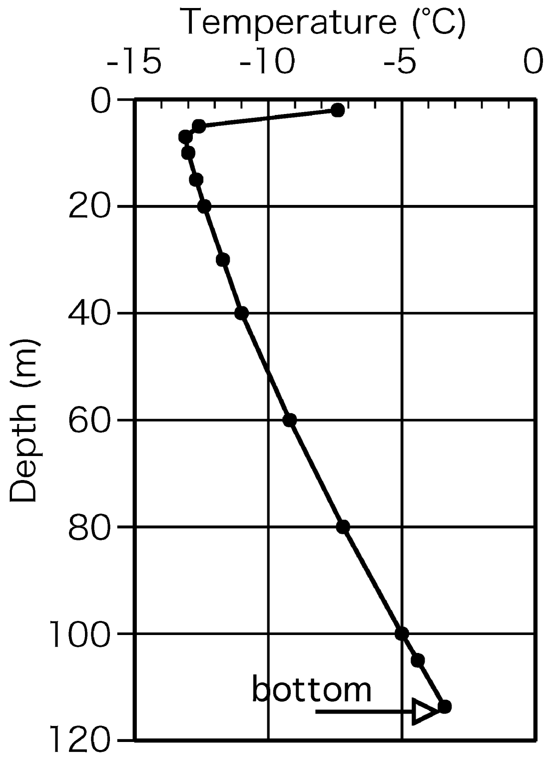


Fig. 5. Temperature profile of the borehole wall.

Table 2. Drilling operation.

Run No	Depth (m)	rake angle of cutter(degree)	shoe	number of catchers
1	0.00	40	5P[1]	3
101	48.38			2
157	75.93	45	no[2]	
222	110.86	40	5P	
229	112.95		no	
232	114.02	40[3]	5P	
235	114.99 bedrock			
236	114.99			

[1] Shoe of 5mm pitch (5mm per one rotation)
[2] Operation without shoe
[3] Dolphin mount sysytem (Takahashi, 2005)

According to Zagorodnov *et al.* (2002), an effective way to avoid jams caused by ice chips is to brush and lubricate with antifreeze the barrel and the inside surface of the jacket. However, we did not use liquid antifreeze because it could contaminate the ice core. We also did not brush the barrel, because it warmed up during brushing. Instead of brushing, we blew the ice chips out of the barrel and jacket with an air compressor. We completed these procedures within 2 min for each run, and inserted the drill back into the borehole before the ice chips in the barrel and jacket melted.

It took a total of 42.5 h to drill down to 114.99 m (Fig. 4). The production rate was 2.71 meters per hour. An ice core 90–93 mm in diameter and approximately 0.5 m long was consistently recovered from each drilling run. No brittle ice was found in the whole depth, although brittle ice usually appears below a depth of 100 to 150 m in mountain glaciers or small ice caps (Takahashi, 1996; Koci, 2002). No thick volcanic ash layer, which had been trouble for drilling at Mount Ushkovsky (Shiraiwa *et al.,* 1999), damaged the cutters of the drill. The drilling operation is summarized in Table 2.

7. Borehole temperature

The temperature of the borehole wall was measured after the ice-core drilling was completed, from the evening of 16 August to the morning of 17 August. The wall temperature was measured with a thermistor sensor (Techno-seven model BYE-64), which was kept in direct contact with the wall of the borehole by leaf springs (Kameda *et al.,* 1993). The resistance of the sensor (12 Kohm at 0℃) was measured by a digital multimeter with resolution of 10 ohm. Because of the large difference in the resistance between the sensor and the cable, the cable resistance was considered to be negligible.

The sensor was inserted into the borehole and stopped for measurement at the bottom (113.65 m), and at 105, 100, 80, 60, 40, 30, 20, 15, 10, 7, 5, and 2 m below the surface. The sensor was stationary during all wall-temperature measurements. Readings of the digital multimeter were made at 1, 10, 30, and 60 min after placement at each depth. The temperature decreased with time because the frictional heat generated by movement was dissipated until the equilibrium temperature was reached. We estimated the equilibrium temperature from the equilibrium curve that we obtained from our measurements.

The temperature at 10 m depth was −13.0℃, and the temperature at the bottom of the borehole was −3.4℃ (Fig. 5). From 10 m to the bottom, the temperature increased linearly with depth.

8. Ice-core processing and ice-core properties

We processed the ice-core samples from the surface to 47.22 m depth as follows. We recorded the stratigraphy of the ice core on chart sheets at real scale using a light table and measured the bulk density of the core. We then cut the ice-core samples in half vertically with a band saw. Half samples of the ice-core samples were packed into polyethylene bags and packed into insulated boxes and transported to Esso. The other halves of the ice-core samples were cut at 50- to 70-mm intervals, and each subsample was placed in a new polyethylene bag in the ice-processing trench after the surface of ice sample was removed with a band saw. The subsamples were then melted in a water bath, or at ambient temperature, and decanted into pre-cleaned polyethylene bottles either on site, or later in a laboratory at IVS-RAS. The total number of subsamples was 894.

Bulk densities from the surface to 50 m depth (Fig. 6) were calculated from the diameter, weight, and length of each ice-core segment obtained in a single drilling run. If part of a sample was lost, we excluded it from the measurement. Several calculated density values were too high because of the low precision of the scales and so on. Therefore, we multiplied all the densities by 0.965 as a correction value to adjust the highest density value to that of pure ice. The pore close-off depth was at approximately 25 m, which is shallow in comparison with that of the Ushkovsky glacier (55 m) (Shiraiwa *et al.,* 1999).

We also recorded the profile of the melt-feature percentage (MFP, Fig. 7), which is the thickness of frozen ice layers in a 1-m-long section of ice core. MFP is generally used as an indicator of summer temperature at a site where ice layers are formed only by melting occurring at the snow surface (Koerner, 1977). However, the ice layers observed in the ice core at Mount Ichinsky were not only formed by surface melting. As described above, heavy rainfalls occurred during the expedition. We observed on the snow wall of the trench that rain infiltrated into the accumulated snow, pooled at the boundary of snow layers, and formed ice layers without disturbing the snow layers between the surface and pooled layer of rainwater. After a heavy storm on 18 August, we observed rapid growth of a thick frost layer on the glacier surface on 19–20 August, when the air temperature was below 0℃ and a large amount of mist

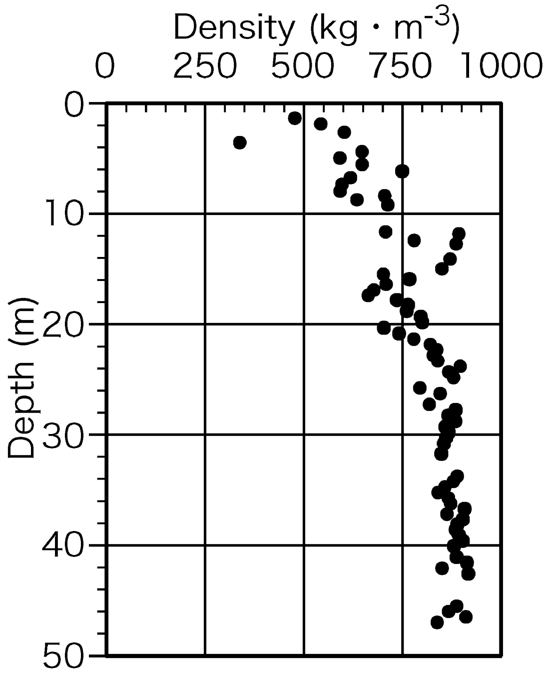


Fig. 6. Bulk density profile of the ice core from the surface to 50 m depth.

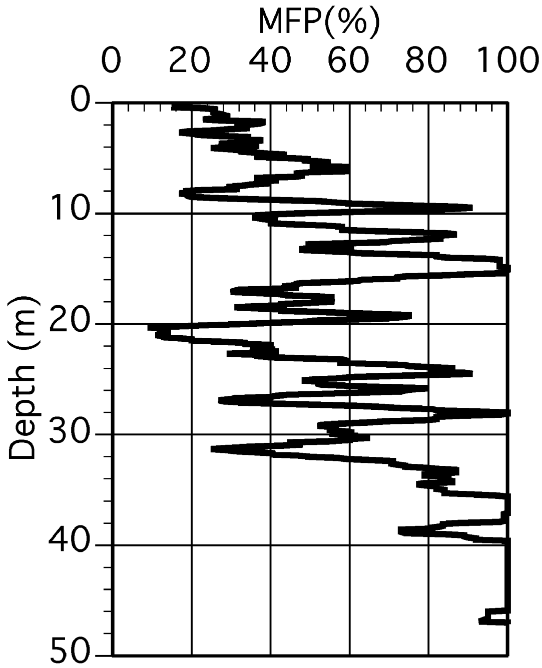


Fig. 7. Profile of the melt-feature percentage (MFP) in the ice core. MFP indicates the proportion of ice layers in 1-m-long sections of the ice core, measured at 0.1-m intervals.

from the Sea of Okhotsk was carried over the site by a strong wind. The interior of the frost was composed only of ice, which formed on 20 August, and its surface was covered with frost or snow flake, which were attached on the morning of 21 August. The thickness of the frost was 0.1–0.4 m, so the contribution of the frost to the surface mass balance and MFP analysis was not negligible. We expect that the mechanisms of formation of these various kinds of ice layers will be revealed by detailed stratigraphic observations and chemical analyses of the ice core, allowing information on climate variations on the glacier and related environmental variations in Kamchatka to be extracted.

Acknowledgments

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