The glaciological expedition to Mount Ichinsky, Kamchatka, Russia

Sumito MATOBA, Sergey V. USHAKOV, Kunio SHIMBORI, Hirotaka SASAKI, Tetsuhide YAMASAKI, Alexander A. OVSHANNIKOV, Alexander G. MANEVICH, Tatyana M. ZHIDELEEVA, Stanislav KUTUZOV, Yaroslav D. MURAVYEV, and Takayuki SHIRAIWA

1 Institute of Low Temperature Science, Hokkaido University, Sapporo 060-0819, Japan
2 Institute of Volcanology and Seismology, Russian Academy of Sciences, Petropavlovsk-Kamchatsky, Kamchatka Oblast 6830006, Russia
3 Graduate School of Environmental Science, Russian Academy of Sciences, Petropavlovsk-Kamchatsky, Kamchatka Oblast, Russia
4 Geotech Co. Ltd., Nagoya 460-0022 Japan
5 Institute of Geography, Russian Academy of Sciences, Moscow 119017, Russia
6 Research Institute for Humanity and Nature, Kyoto 603-8047, Japan

(Received September 30, 2006; Revised manuscript accepted November 3, 2006)

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 $\pm 13^\circ$C 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 20ºN (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 well 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 (55º 46’N, 157º55’E; summit eleva-
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 x 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 MIl8 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>
<thead>
<tr>
<th>Site</th>
<th>Date</th>
<th>PK</th>
<th>ES</th>
<th>RP</th>
<th>IC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7. Aug</td>
<td></td>
<td></td>
<td></td>
<td>Personnel and equipment transported by bus and truck</td>
</tr>
<tr>
<td></td>
<td>10. Aug</td>
<td></td>
<td></td>
<td></td>
<td>Personnel and equipment transported by 1 helicopter flight</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Personnel and equipment transported by 4 helicopter flights</td>
</tr>
<tr>
<td></td>
<td>11. Aug</td>
<td></td>
<td></td>
<td></td>
<td>Set up camp</td>
</tr>
<tr>
<td></td>
<td>12. Aug</td>
<td></td>
<td></td>
<td></td>
<td>Preparation for drilling</td>
</tr>
<tr>
<td></td>
<td>16. Aug</td>
<td></td>
<td>Ice-core processing</td>
<td>Drilling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>17. Aug</td>
<td></td>
<td></td>
<td>Borehole temp. measured</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18. Aug</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>21. Aug</td>
<td>2 persons and equipment transported by 1 helicopter flight</td>
<td>7 persons, equipment, and ice core transported by 1 helicopter flight</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>22. Aug</td>
<td>personality and equipment transported by freezer truck</td>
<td>Personnel and equipment transported by bus and truck</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PK: Petropavlovsk-Kamchatsky
ES: Esso
RP: Relay point
IC: Ichinsky
tents by strong winds, we dug down all tents. We also dug a trench (82 cm deep). The position of the drilling site was the largest. The GPS system was 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 238.

The temperature in the drilling tent was more than 0°C, and this warmth caused various problems during the drilling operation. Ice chips melted on the drill head 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°C. 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. 3. Campsite map.
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 5 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. Table 2 summarizes the drilling operation.

### Table 2. Drilling operation.

<table>
<thead>
<tr>
<th>Run No</th>
<th>Depth (m)</th>
<th>rake angle of cutter (degree)</th>
<th>shoe</th>
<th>number of catchers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.00</td>
<td>40</td>
<td>sP</td>
<td>3</td>
</tr>
<tr>
<td>101</td>
<td>48.38</td>
<td>45</td>
<td>no</td>
<td>2</td>
</tr>
<tr>
<td>157</td>
<td>75.93</td>
<td>40</td>
<td>sP</td>
<td></td>
</tr>
<tr>
<td>222</td>
<td>110.86</td>
<td>40</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>229</td>
<td>112.95</td>
<td>40</td>
<td>sP</td>
<td></td>
</tr>
<tr>
<td>232</td>
<td>114.02</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>235</td>
<td>114.99</td>
<td>bedrock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>236</td>
<td>114.99</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

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°C) 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 tem-
perature was reached. We estimated the equilibrium temperature from the equilibrium curve that we obtained from our measurements.

The temperature at 10 m depth was $-13.0^\circ$C, and the temperature at the bottom of the borehole was $-3.4^\circ$C (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 884.

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 0.966 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°C and a large amount of mist 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 mec-
Acknowledgments

We thank Kazuo Higuchi of Mountain Activity Support in Hokkaido, and Tatsuru Sato and Takeshi Toida of the Graduate School of Environmental Science, Hokkaido University, who also participated in this project during the first campaign in June. Without their contributions we could not have succeeded in completing the expedition in such a short period. We also thank Kazuki Nakamura of the Japan Weather Association in Hokkaido for provision of weather information. We are grateful to Akiyoshi Takahashi of Geotech Co. Ltd. for technical support and comments. This study was financially supported by a Grant-in Aid for Young Scientists (B) (No. 85104122). We also thank Dmitry Isaev of the Institute of Volcanology and Seismology for his substantial contribution regarding gen saturation in the blood for monitoring altitude adaptation. We would like to acknowledge an anonymous reviewer for valuable reviewing this paper and comments. This study was financially supported by the Amur-Okhotsk Project (Human Activity in Northeastern Asia and Human Impact on Biological Productivity in the North Pacific Ocean) sponsored by the Research Institute for Humanity and Nature. The field research was also supported by a Grant-in Aid for Young Scientists (B) (No. 18740289 to the P.I. Dr. Matoba) from the Ministry of Education, Culture, Sports, Science and Technology, Japan.

References


