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# Shallow ice-core drilling at Mount Wrangell, Alaska

**Takayuki SHIRAIWA[1], Syosaku KANAMORI[1], Carl S. BENSON[2], Daniel SOLIE[2] and Yaroslav D. MURAVYEV[3]**

1 Institute of Low Temperature Science, Hokkaido University, Sapporo 060-0819 Japan

2 Geophysical Institute, University of Alaska Fairbanks, Koyukuk Drive, P.O.Box 757320, Fairbanks, Alaska 99775-7320 USA

3 Institute of Volcanology, Russian Academy of Sciences, Petropavlovsk-Kamchatsky, Kamchatka Oblast 683006 Russia

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## Abstract

During the 2003 summer we initiated a three-year study of climate and volcanic history on Mt. Wrangell, Alaska (60°N, 144°W, 4317 m). It is being done in comparison with research on Ushkovsky Volcano (56°N, 160°E, 3903 m), Kamchatka Peninsula, Russia. Both are ice-covered, andesitic volcanoes on the north Pacific rim, at 4000 m altitude and within 6° in latitude. In June 2003 a research camp was established in the Summit Caldera of Mt. Wrangell for the purpose of ice core drilling, radio echo sounding of ice depth, and maintenance of previously established photo control points on crater rims for use in aerial photogrammetry. A 50m ice core of high quality was obtained in sections 50 cm long, with a new drill which performed very well. It will be analyzed for $\delta^{18}O$ and $\delta D$ as well as for chemical analyses of major ions and volcanic ash traces. The core extended back to 1981 and overlapped stratigraphically with core and pit studies done from 1961 to 1982 on Mt. Wrangell. The 10-m deep temperature was −18.9 °C and was found to be higher as much as 1 °C than those observed in 1970s.

## 1. Introduction

Time-series of decadal and interdecadal climatic events (DICEs) in annual accumulation rates and water isotopes in the North Pacific cryosphere were, for the first time, reconstructed from an ice core recovered from the summit plateau of Mt. Logan in the 1980s (Holdsworth *et al.*, 1992). The North Pacific DICEs were also found in an ice core recovered in a crater glacier at Ushkovsky volcano, Kamchatka peninsula (Shiraiwa *et al.*, 2003; Shiraiwa and Yamaguchi, 2002). Because the time-series of reconstructed accumulation rates both at Mts. Logan and Ushkovsky are nearly anticorrelated and the synchronous changes were considered to be generated by the Pacific Decadal and Interdecadal Oscillations (Mantua *et al.*, 1997; Shiraiwa and Yamaguchi, 2002), climatic conditions across the North Pacific are expected to have been interacted each other. In order to confirm the cross Pacific climate teleconnection and to reconstruct atmospheric and marine environmental changes, we need several additional ice cores from various regions of Alaska and Kamchatka.

For this aim, we need to 1) drill ice cores in dry snow facies of glaciers in Alaska (Mt. Wrangell, Mt. McKinley, Mt. Bona and other mountains) and Kamchatka (Mt. Ichinsky), 2) analyze the ice cores in terms of ion chemistry, heavy metals, water isotopes, dust concentration, bacteria, algae, pollen and various physical properties, and 3) correct the ice-core proxies in terms of strain history with 1$^{st}$ order 3D thermomechanically-coupled glacier model.

During the 2003 summer we initiated a three-year study of climate and volcanic history on Mt. Wrangell, Alaska. Summit glacier filling the caldera of Mount Wrangell has been studied for many years by C. S. Benson and his colleagues from glacio-volcanological viewpoints (*e.g.* Benson and Follett, 1986). The glaciological condition at the summit of Mount Wrangell is quite similar to that we found at Ushkovsky volcano in Kamchakta, therefore, the comparison of the two sites will be significant in reconstructing the past proxy climate time-series. Followings are the preliminary results from shallow ice-core drilling and the related glaciological studies at the summit glacier of Mount Wrangell in 2003.

## 2. Regional settings

Mount Wrangell (60°N, 144°W, 4317 m), in the southeastern interior of Alaska, is a huge, glacier-mantled, shield volcano (Benson and Motyka, 1978). Various kinds of glaciological and volcanological studies have been conducted by scientists from Geophysical Institute, University of Alaska Fairbanks. A glacier filling the summit caldera has been studied since 1960s by C.S. Benson and his colleagues (Benson and Motyka, 1978; Benson, 1984; Benson and Follett, 1986; Clarke *et al.*, 1989). One of the important findings from the above-mentioned studies was that a part of the summit glacier was categorized in "dry-snow facies" (Benson, 1962) where melting of snow was lacking. Drilling an ice-core in the dry snow facies is an essential condition for a high-quality paleoclimate reconstruction, therefore, Mount Wrangell offers an ideal site for this kind of research in Alaska.

Further advantage of Mount Wrangell as a drilling site is that it offers an exceptionally flat place for drilling at an altitude above 4000 m. This is particularly important for ice-core studies since complicated topographies often found in mountains make the interpretation of proxy records difficult. The summit caldera of Mount Wrangell is crowned by a 4 × 6 km oblong, 1 km deep glacier (Fig. 1). The snow surface in the caldera is relatively flat, varying from 4000 m to 4100 m in about 3.5 km. Ice flows out of the caldera through a breach of the southern rim at the head of the Long Glacier (28 km long) (Fig. 2). The caldera may have formed as recently as 2000 years ago. This youthful caldera remains geothermally active and has three prominent, post-calderan, craters with solfatara activity along the crest of its rim (Benson and Motyka, 1978).

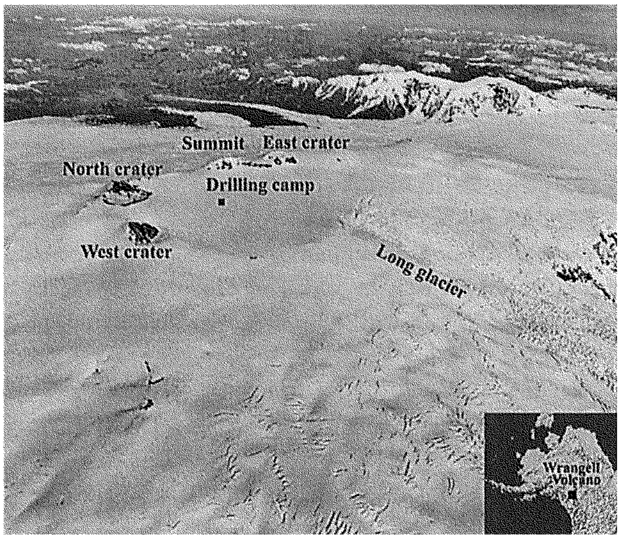


Fig. 1. Aerial view of Mount Wrangell from southwest. Original photograph is part of the University of Alaska's long-term research on Mt. Wrangell and was taken by AeroMap US, a photogrammetry company in Anchorage, Alaska.

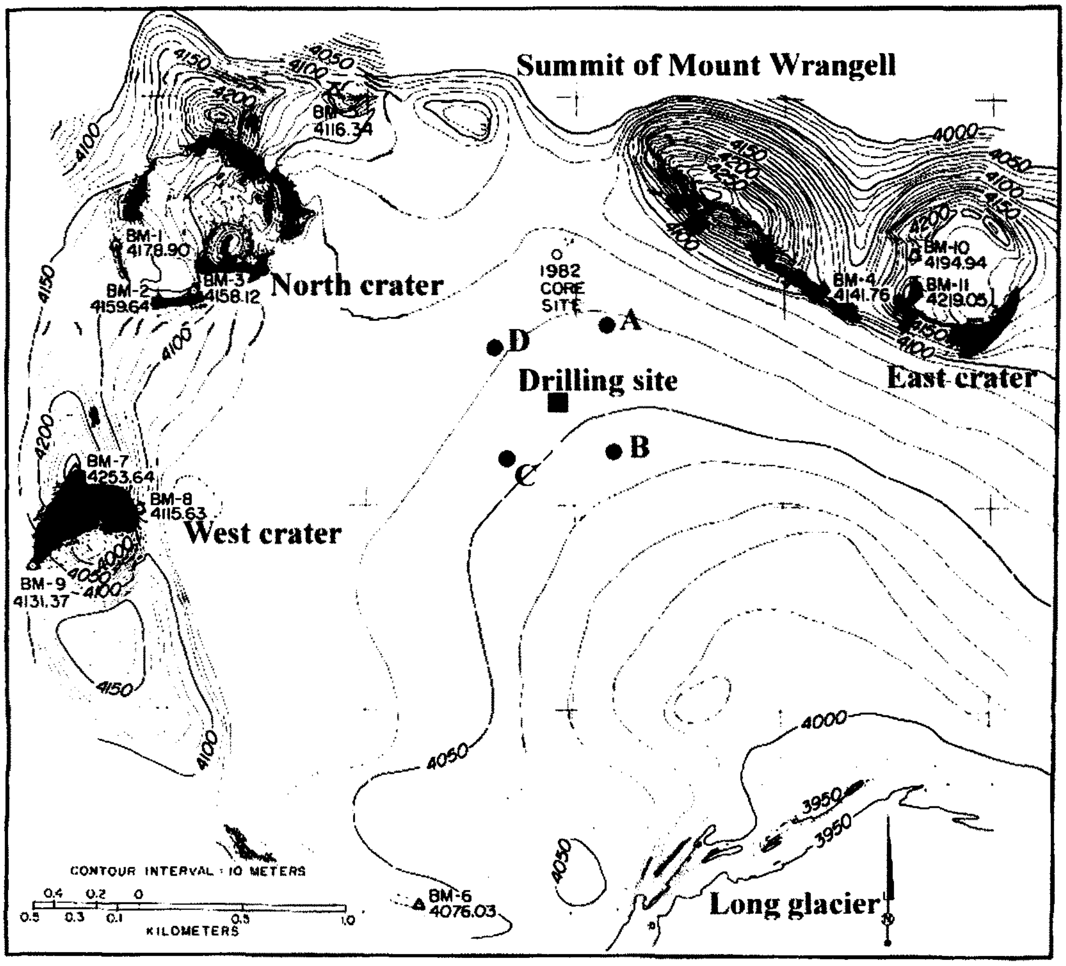


Fig. 2. Plane map of the summit glacier of Mount Wrangell. The drilling site and the strain-grid network are denoted by a solid square and solid circles A to D. The original map was presented at Benson and Follett (1986).

## 3. Members

This project was launched as an International collaborative program among U.S.A (Geophysical Institute, University of Alaska Fairbanks: GI-UAF), Russia (Institute of Volcanology, Russian Academy of Sciences: IV-RAS) and Japan (Institute of Low Temperature Science, Hokkaido University: ILTS-HU). The members of the 2003 field campaign are as follows;

Dr. Takayuki Shiraiwa (ILTS-HU) Leader, Glaciologist
Prof. Carl S. Benson (GI-UAF) Glaciologist
Dr. Daniel Solie (GI-UAF) Geophysicist
Dr. Yaroslav D. Muravyev (IV-RAS) Volcanologist/Glaciologist
Mr. Syosaku Kanamori (ILTS-HU) Graduate student at Hokkaido University

Drs. Martin Truffer and Martin Peter Luethi, both from GI-UAF, were also the members of the project but they could not join the field campaign due to their own field works at other glaciers in Alaska.

## 4. Itinerary

We chartered a turbo-charged Single Otter plane from the Alaskan aircraft operator, Ultima Thule Outfitters (Pilot: Mr. Paul Claus), and flew in the personnel from Chitna to the northern foot slope of Mount Wrangell at 2900 m a.s.l., after unloading the equipment at the summit caldera (June 13). This is for acclimatization. We climbed the slope to the summit from June 14 to 17 by making three camps; Camp 1 (62°03′41.0″ N; 144°02′57.0″ W; 2976 m), Camp 2 (62°02′53.2″ N; 144°03′45.3″ W; 3272 m) and Camp 3 (62°01′50.4″N; 144°05′27.9″ W; 3685 m). We arrived at the summit drilling camp at an altitude of 4100 m and coordinates of 61°59′53.6″ N and 144°02′30.0″ W in June 18.

After installing the camp facilities, we started a shallow ice-core drilling in the evening of June 20 and ended in the morning of 23. This was followed by the radio-echo sounding of ice thickness and the borehole thermometry together with installation of strain-grid network around the borehole. The photographic and seismological control points at the North Crater were detected and surveyed with GPS in relation to the borehole at the end of campaign.

All the personnel, a 50 m-long ice core, and the equipment were flown out to Chitna by the same aircraft in June 29. The ice core was stored in a refrigerator truck at Chitna and then transported to Anchorage. It was then shipped to Japan in a freezer container of a cargo plane, and arrived at freezer facility of ILTS-HU in July 7.

## 5. Ice core drilling

A 50-m long ice core was drilled by a newly designed light-weight mechanical drill (Fig. 3) to assess potential of the glacier developing in the caldera of Mount Wrangell. The drill was specially designed, by Mr. Kunio Shinbori of ILTS-HU, for ice-core drilling in high mountains where weight of the drill system is crucial for the operation. The drill system is composed of a drill-motor, a chip chamber, a core-barrel, a winch with 200 m cable, a mast and a control-unit. The system weighs a total of 100 kg and is back-packable by four people. It can be operated with a generator (700W) which adds 10 kg to the system weight.

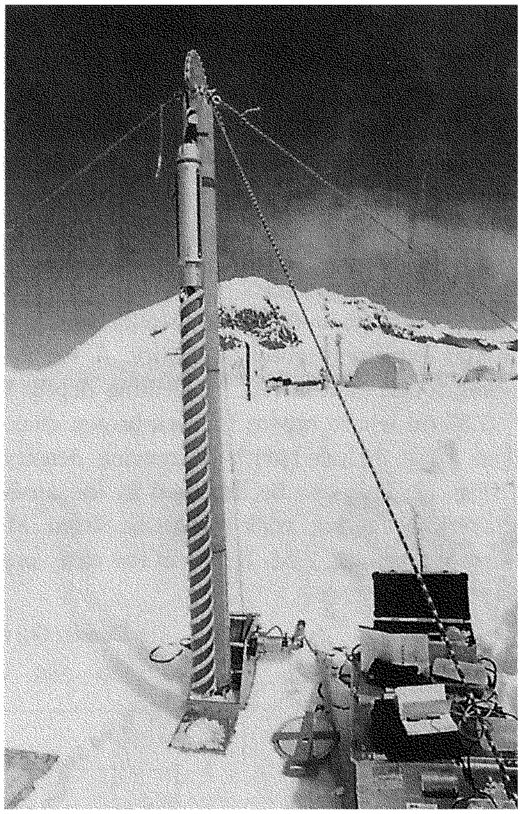

Fig. 3. The portable ice-core drilling system "Dokodemo Drill version 2" installed at the drilling site of the summit glacier of Mount Wrangell.

The drilling was started from a level of 85 cm below the surface of June 20. After the system was assembled, we started the drilling on June 20 at 16:40 and ended it on June 23 at 10:59. The drilling was stopped only once, because of a blizzard, from the morning to the afternoon of June 22. Figure 4 shows cumulative net drilling time (h) versus depth (m). It took 22 hours in total to drill ice cores down to 50.29 m. Average drilling speed, *i.e.* total drilling depth divided by net drilling time, was 2.27 m per hour, which is faster than that recorded at King Col, Mount Logan in 2002 (Shiraiwa *et al.*, 2003). The faster drilling speed resulted from the simplicity of the new

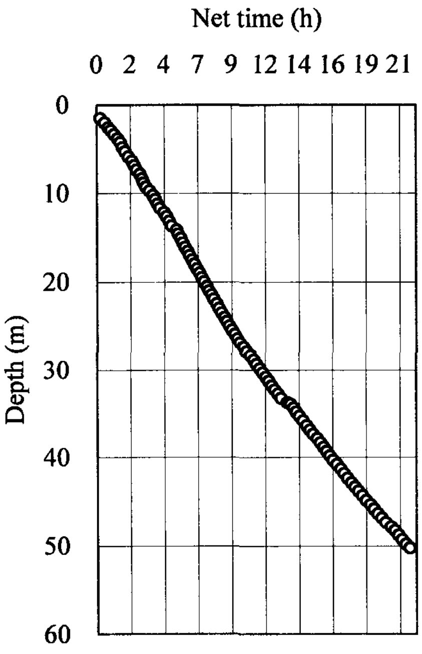


Fig. 4. Cumulative net drilling time (h) versus depth (m) at Mount Wrangell 2003.

drill: in particular, lack of outer jacket shortened the service time at the surface.

The ice cores drilled were approximately 50 cm in length and extremely good in quality. A visible dirt layer was found at Run No. 95 (drilling depths from 46.87-47.36 m) where brown to dark-brown dispersed particles were included with decreasing density upward (Fig. 5). This can be assigned to the air-borne dust layers by a big rock-avalanche from Mount Stanford in April 11, 1981. If this is the case, present

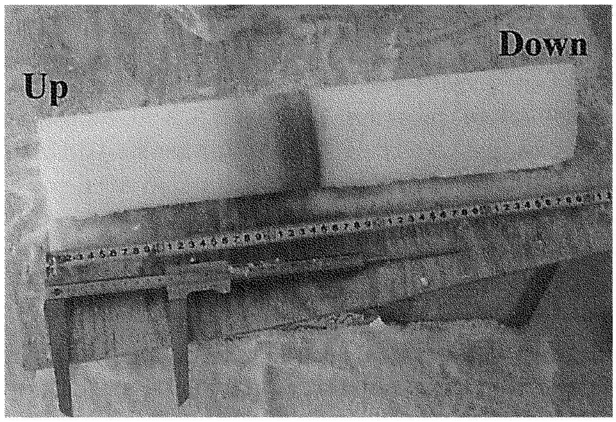


Fig. 5. A 8-cm thick dust layers found in the core covering 46.87-47.36 m from the surface. This dust layer is considered to have had been supplied to the drilling site when a rock-avalanche occurred at the southwest face of Mount Stanford in April 11, 1981.

50-m ice core can cover the time series from 1981 to 2003 and overlaps with that drilled in 1982 by C.S. Benson and others to a depth of 43 m (Benson, 1984). This indicates that we can date back to several tens of years with the two ice cores so far obtained at Mount Wrangell.

Bulk density profile shows a typical profile found in the dry snow facies: rapid increase up to 550 kg at 12 m and less rapid increase below this level (Fig.6). The density at 50-m was 700 kg $m^{-3}$ so the pore-close off depth could be located at 65 to 70 m which is extraordinary deep at mountain glaciers.

A total of 65 ice layers were found in the 50-m ice core. Most of them are thinner than 0.5 mm but some are as thick as 5-10 mm (Fig.6). These are the melt-

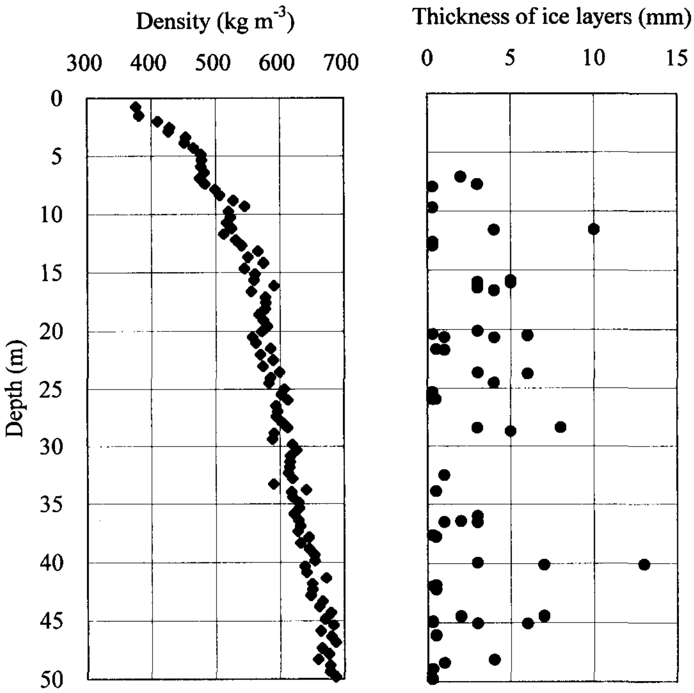


Fig. 6. Bulk density, distribution and thickness of ice layers of the 50-m long ice core.

frozen ice layers and indicate that the drill site suffers melting although the intensity is extremely low.

The ice core will be subjected to $\delta^{18}O$, $\delta D$, major ions, trace metals, a detailed density measurement with x ray, and crystallographic observation with thin sections at ILTS, Hokkaido University.

## 6. Borehole temperatures

Borehole temperatures were measured after the ice-core drilling was completed. We measured the temperatures by two ways; one (*method 1*) is the temporal measurements of the profile by using thermistors with a compact data logger. Both the thermistors and the logger were attached to the head of the ice-core drill and lowered in the borehole. After it reached the bottom of the borehole, we lifted it every 5 m and stopped at each level for about 1 hour. The first measurement was done in June 23 just after the drilling. Because we were afraid of temperature disturbance by drilling, we repeated this measurement in June 25 when we used a climbing rope, instead of the drill and drill-cable, in order not to disturb the air in the borehole. The other way of temperature measurements (*method 2*) was the continuous measurements at fixed depths with data logger. A total of eight platinum resistance sensors were connected to the data logger at the snow surface and individual sensors were located at 20, 15, 10, 8, 6, 4, 2 and 1 m below the original snow surface of June 20. We recorded the temperatures during 10 minute intervals from June 23 at 17:00 to June 26 at 11:40. The interval was then changed to 3 hours and restarted for measurement until May 2004. The accuracies of the measurements are ±0.5 °C for *method 1* and ±0.1 °C for *method 2*.

Figure 7 shows the temporal profiles of the two different measurements. The 10-m depth temperature was −18.9 °C by the *method 1* for June 25 at 20:00, and −18.2 °C by the *method 2* through the measurement period. Since it was −20 °C in 1961, 1965 and 1976 (Benson and Motyka, 1978) it may indicate that the temperature increased by at least 1 °C during the past three decades.

The temperature gradients from 20 to 45 m are constant at 0.2 °C per 10 m. If we extrapolate the profile downward with the same temperature gradient, the thickness of the glacier is calculated to be about 1000 m, by assuming that the bottom is at pressure melting point and the vertical temperature gradient throughout the glacier is constant.

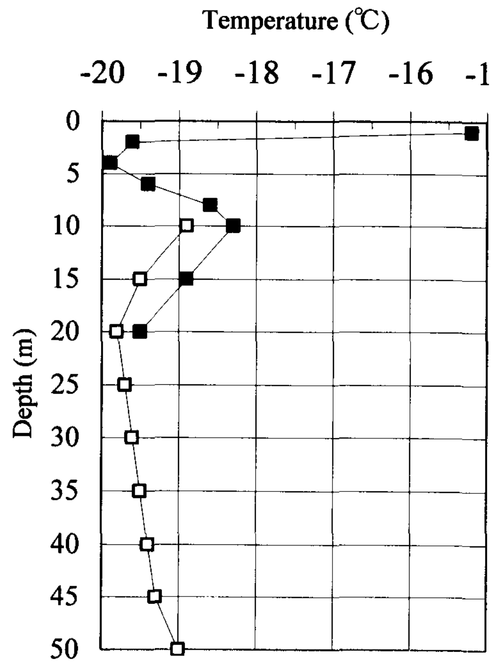


Fig. 7. Air temperature profiles in the 50-m borehole. Solid squares indicate the temperature measured by *method 2*, while the open squares by *method 1*.

## 7. Rapid static GPS survey for strain-grids

We installed four strain-grid points in order to measure the strain near the borehole (A to D: Fig. 2). The four strain grid points were located to the drilling site (DS) by a set of survey GPS (TOPCON) with a rapid static method (June 24). The DS was then located relative to BM 3 at the North Crater (June 25). Table 1 shows the exact coordinates of the survey point for the future survey. We could measure the absolute flow vector as well as strain by this strain grid network. Each survey point was located by a 3-m survey pole and marked by a 3.5 m-long wood marker for re-survey in 2004.

Table 1. Coordinates of the measured points.

| | Latitude (°) | Longitude (°) | Altitude (m) |
|---|---|---|---|
| Drilling camp | 61°59′53.617814″ N | 144°02′30.035349″ W | 4099.906 m |
| A | 62°00′03.088954″ N | 144°02′02.354940″ W | 4097.546 m |
| B | 61°59′40.087682″ N | 144°02′10.420254″ W | 4090.913 m |
| C | 61°59′44.123173″ N | 144°02′58.381445″ W | 4103.235 m |
| D | 62°00′06.774097″ N | 144°02′49.137880″ W | 4111.097 m |

## 8. Snow pit study

Because the ice core began 85 cm below the surface of June 20, we excavated 1.6 m-deep snow pit and studied it near the borehole on June 25 from 14:45 to 17:00 (Fig. 8). Studied items are stratigraphy, snow temperature measurements at 10 cm interval, density measurement at 3 cm interval, and snow sampling. Although we could not decide the snow surface of June 20 very clearly, a boundary between the surface fresh snow (0-21.5 cm) and a thin ice layer (21.5-22.5 cm) was tentatively assigned to the surface of June 20. The pit therefore covers the uppermost part of the ice core which was not obtained by the drilling.

Figure 8 indicates the snow density and temperature in June 25. The depth of 28.5 cm is assigned to the actual top of the ice core.

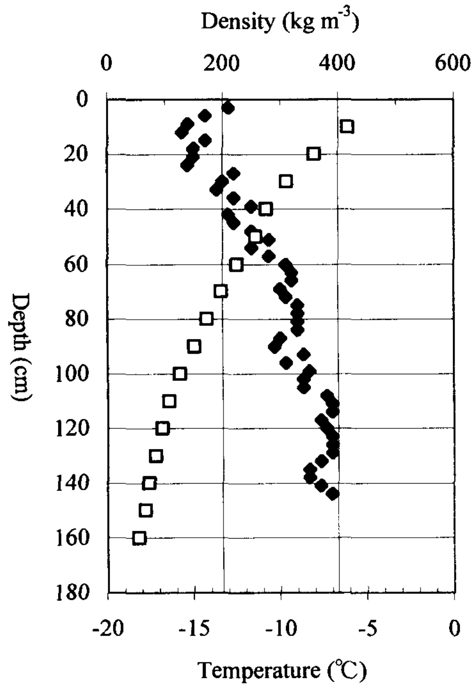


Fig. 8. Density (solid symbol) and snow temperature (open symbol) of the surface 1.6 m near the drilling site.

## 9. Comparison with other ice-core drilling sites

It was found that the summit glacier at Mount Wrangell was characterized by dry snow with few melt-frozen ice layers. This is particularly important for ice core study since intensive melting could disturb any kinds of signals in the glacier. The advantage of the present site becomes clear by comparing its glaciological parameters with those obtained at other drilling sites which are located along the North Pacific coast (Table 2).

Annual accumulation rate is the highest at Wrangell among the three drilling sites. It is 1.3 m $a^{-1}$ w.e. in the center of the caldera (Benson and Motyka, 1978) and 0.86 m $a^{-1}$ w.e. in the 1982 core site (Fig. 2) (Benson, pers. commu.). This will contribute to high-resolution of past climate reconstruction. The 10-m deep snow temperature is the lowest in spite of the fact that the site is lower than King Col of Mount Logan. Densification at Mount Wrangell is the slowest when we fit the vertical profiles of firn-density at three sites with mean-square approximation $\rho = \rho_i (1 - C_s e^{-\gamma h})$ where $\rho_i$ is the density of pure ice (918 kg $m^{-3}$) $C_s$ the ice porosity at the surface, $\gamma$ the index in the density-depth profile approximation and $h$ the depth.

The ice thickness at the drilling site is still unknown. This is because past attempts in radio-echo sounding weren't successful at Mount Wrangell: bed reflection has never been obtained at the center of the caldera glacier (*e.g.* Clarke *et al.*, 1989). Present study confirms the lackness of bed reflection at the drilling site. Clarke *et al.* (1989) estimated the thickness of the glacier as thick as 900 m. This is much thicker than those at King Col and Ushkovsky, and implies that the glacier at Mount Wrangell stores longer time history of climate and environmental conditions.

Table 2. Glaciological features at three drilling sites.

| | Wrangell | Logan King Col | Ushkovsky |
|---|---|---|---|
| Latitude | 61°59′54″ N | 60°35′20″ N | 56°04′29″ N |
| Longitude | 144°02′30″ W | 140°36′15″ W | 160°28′04″ E |
| Altitude (m) | 4100 | 4135 | 3900 |
| Annual accumulation rate (m $a^{-1}$ w.e.) | 1.3*～0.86****** | 1.2** | 0.54*** |
| 10-m depth snow temperature (°C) | −18.9 | −18.0**** | −15.8*** |
| Snow temperature amplitude (°C) | n.a. | n.a. | 16*** |
| Initial density (kg $m^{-3}$) | 370 | 420**** | 450*** |
| Initial porosity $c$ | 0.63 | 0.58**** | 0.55*** |
| Densification factor $\gamma$ | 0.028 | 0.031 | 0.038*** |
| Thickness of the glacier (m) | n.a. | ca 220**** | ca 240*** |
| Geothermal heat fiux (W $m^{-2}$) | 7.02***** | n.a. | 0.12*** |

*Benson and Motyka (1978); **Goto-Azuma *et al.* (2003); ***Shiraiwa *et al.* (2001); ****Shiraiwa *et al.* (2003); *****Clarke *et al.* (1989), ******Benson (person commu.)

## 10. Concluding remarks

We started US-Russia-Japan joint glacio-volcanological study in the North Pacific in which Mount Wrangell was the main target for the next three years. We drilled a 50-m ice core in the central part of Mt. Wrangell's Summit Caldera in June 2003. The ice cores were transported to ILTS-HU and will be subjected to the analyses on stable isotopes of water, major ions, trace elements, and biological signals. The borehole temperature was measured and it showed that the 10-m deep temperature was higher than those observed in 1970s'.

We are planning to drill a 300-m deep ice core in the year of 2004 at the same glacier. This will be associated with glacier dynamic observations which will be essential for the interpretation of the ice core.

## Acknowledgments

We would like to thank Prof. Takeo Hondoh, director of the Institute of Low Temperature Science, Hokkaido University, for his continuous support for the ice-core drilling program in mountains of the North Pacific rim. We are also indebted to Prof. Shunichi Akasofu, director of the International Arctic Research Center, University of Alaska Fairbanks, for his financial support for the American members in the project. We thank Mr. Kunio Shinbori, the workshop technician at ILTS-HU, for providing us with the portable ice-core drilling system without which this study wasn't possible. Mr. Paul Claus of Ultima Thule Outfitters supported our flight operation with his excellent and powerful aircraft. Japanese members were financially supported by Grant-in-Aid for Creative Scientific Research (Project no. 14GS0202; PI: Takeo Hondoh) from the Ministry of Education, Science, Sports, Culture and Technology of Japan, and the Inoue Scientific Field Study Foundation.

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