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Ice core drilling on the southern slope of the Nepal Himalayas

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Abstract: Two ice cores were extracted from Rikha Samba Glacier located in the central Nepal Himalayas in 1994 and 1998. Ice core quality in 1994 was poor due to cutter problems and samples were melted *in situ*. In 1998, a better ice core was successfully extracted and brought to Japan in frozen condition. The logistics of drilling, the transportation and preservation of ice, and problems of ice core drilling in Nepal are presented in this paper.

1. Introduction

The shrinkage of small glaciers and ice caps has significantly contributed to sea-level rise over the past 100 years in association with recent warming (Meier, 1984). Although the contribution of glaciers in the Himalayas is considered to be important, information about glacier shrinkage is quite limited. A few observations of the volume change of glaciers in the 1990s (Kadota *et al.*, 1997; Fujita *et al.*, 1997, 1998, 2001a, b) showed rapid shrinkage of glaciers in the Himalayas. In order to clarify what climatic variables brought about the rapid shrinkage of glaciers in this region, ice core drillings were carried out on Rikha Samba Glacier in Hidden Valley, western Nepal, 1994 and 1998 (Figs. 1 and 2). People who participated in the observations on this glacier were listed in Nakawo *et al.* (1997) and Ageta *et al.* (2001). Activities by Japanese scientists with respect to ice cores in the Nepal Himalayas are listed in Table 1.

Since glaciers in Nepal are located above 5000 m a.s.l., research work has to be carried out in thin air. Acclimatization against high mountain sickness is one of the most serious

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problems in activities in the Nepal Himalayas. In addition, transportation facilities are limited. Roads are located only at lower elevation in the south of the country. Supplies are generally carried by porters and domestic animals in the mountain regions. Although

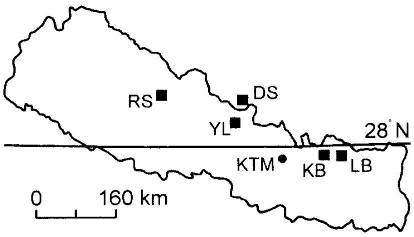

Fig. 1. Locations of glaciers (solid squares) where ice cores have been extracted around the Himalayas. Abbreviations denote Rikha Samba Glacier (RS), Yala Glacier (YL), Dasuopu Glacier (DS), Khumbu Glacier (KB), Lower-Barun Glacier (LB) and Kathmandu (KTM), respectively.

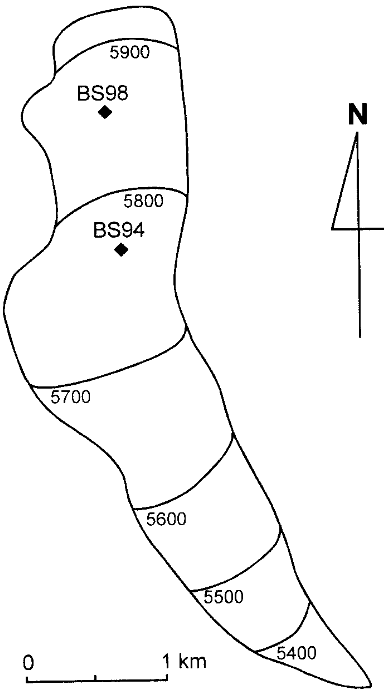

Fig. 2. Map of Rikha Samba Glacier. Rhombuses denote the boring site in 1994 (BS94) and in 1998 (BS98).

Table 1. Ice cores extracted in the Nepal Himalayas by Japanese scientists. Locations are shown in Fig. 1.

Year	Glacier	Elevation (m)	Length (m)	References
1980	Lower-Barun	6140	5	Ikegami and Azuma (1982)
1980	Khumbu	6400	5	Unpublished
1981	Yala	5180	30	Watanabe *et al.* (1984)
1982	Yala	5405	60	Watanabe *et al.* (1984)
1985	Yala	5350	6	Iida *et al.* (1987)
1987	Yala	5350	5	Ozawa (1991)
1992	Yala	5350	6	Shiraiwa (1993)
1994	Yala	5390	7	Yoshimura *et al.* (2000)
1994	Rikha Samba	5780	23	This paper
1996	Yala	5380	10	Unpublished
1996	Yala	5430	12	Unpublished
1998	Rikha Samba	5880	15	This paper

helicopters are available at less cost than in other countries, the capacity of a helicopter falls extremely at higher elevation and landing places are limited due to the steep topography. Therefore, drilling operation and transportation of ice samples is more difficult than in polar regions. In 1998, we successfully brought back ice samples in a frozen state. Details of the drilling operation and transportation of ice are presented in this paper.

2. Drilling in 1994

In October of 1994, a 23.25 m ice core was extracted by using a light-weight PICO hand auger (Koci and Kuivinen, 1984) at 5780 m a.s.l. (Figs. 2 and 3; Table 2). The glacier consisted of superimposed ice beneath 62 cm of snow. The length of each run was

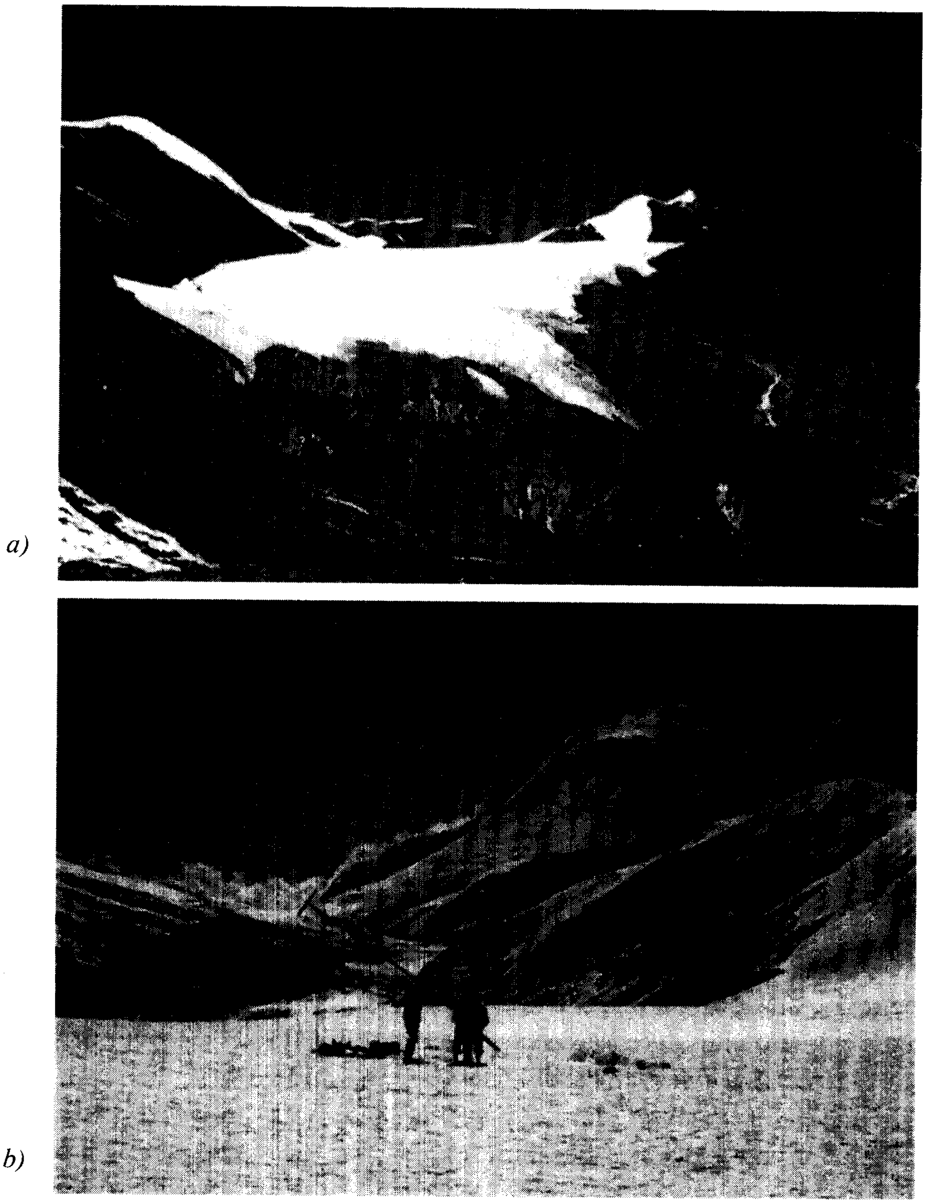

Fig. 3. Photos of Rikha Samba Glacier (a) and the drilling site (b) in 1994.

Table 2. Periods, members, altitudes and core length of operation in 1994 and 1998 at Rikha Samba Glacier in Hidden Valley, Nepal Himalayas.

Year	1994	1998
Period	16–20, Oct. (5 days)	8–9, Oct. (2 days)
Members for research	3 scientists and 3 Sherpas	6 scientists and 5 Sherpas
Members for drilling	3 scientists and 2 Sherpas	3 scientists and 2 Sherpas
Altitude	5780 m a.s.l.	5880 m a.s.l.
Auger	PICO hand auger	PICO hand auger
Diameter of ice core	7.6 cm (3 inch)	10.2 cm (4 inch)
Core length	23.25 m	14.90 m
Number of operation	70	44
Length of each run	32.3±9.4* cm	33.9±11.0* cm
Length of ice pieces	3.2±5.6* cm	24.8±13.8* cm
Sample No.	116	229
Sampling interval	20.0±5.8* cm	6.2±1.4* cm

* Standard deviations

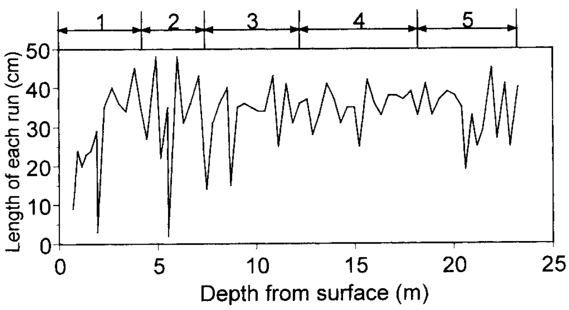

Fig. 4. Depth of ice core vs. length of each run in 1994. Numbers above the figure denote the day of drilling.

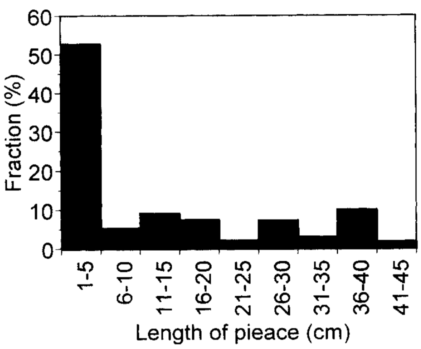

Fig. 5. Histogram of fractured ice length in 1994. The vertical axis denotes the fraction of sum of each fractured ice among certain lengths to the whole core length (23.25 m).

32.3 cm due to a cutter problem. The drilling took 5 days (Fig. 4). Almost all recovered ice consisted of 'potato chip'-like fragments (average of fractured ice length was 3.2 cm, Fig. 5). It is considered that the diameter of the ice core whittled by cutters was the same as the inner diameter of the core barrel because there was no inner bulge of cutters. Therefore, the core was broken at the mouth of barrel. Ice 'cores/chips' were packed at intervals of 20.0 cm in depth. Partly melted water was discarded twice to avoid contamination. After the complete melt, 116 samples were packed in pre-cleaned bottles.

Oxygen isotope ratio, major chemical components and tritium were measured in laboratories in Japan (Fujii *et al*., 1996).

3. Drilling in 1998

In order to obtain a better quality ice core, we drilled again at the same glacier and brought ice samples to laboratory in Japan. The boring site was moved by 100 m in elevation (5880 m a.s.l., Fig. 2, Table 2). Although we planned to go to the col of the glacier (about 5980 m a.s.l.), it was impossible due to crevasses in the accumulation area. Another PICO hand auger with larger barrel (4 inch diameter) was used. Spare cutters, which have enough inner bulge, were prepared by Geo Tecs Co. Ltd., Japan to avoid the core trouble mentioned above.

Three of the scientific members could not join the drilling operation because of health problems. Therefore, the drilling operation was carried out by 3 scientists with the logistic help of 2 Sherpas, as in 1994. Because both members and time were limited, an ice core of 15 m in length was extracted during 2 days of operation. Although the length of each run (33.9 cm, Fig. 6) was the same as in 1994, the quality of the core was significantly improved (average of fractured ice length was 24.8 cm, Fig. 7). The improved cutters with enough inner bulge could whittle the ice core, whose diameter was smaller than the inner diameter of the core barrel, and thus the core could enter the barrel without interference. Superimposed ice appeared again but firn was partly found. We found obvious dirt layers in the ice core with diameters of 0.2 to 2 mm, which were composed of mineral particles, algae and bacteria. Cutters were often chipped by the dirt particles and one member did nothing but sharpen the cutters during the whole operation. In order to avoid cutter chipping trouble, stronger cutters are needed.

Extracted ice cores were processed as shown in Fig. 8. After taking photographs and recording strata of a core on black cloth, it was cut into half with an electric circular saw.

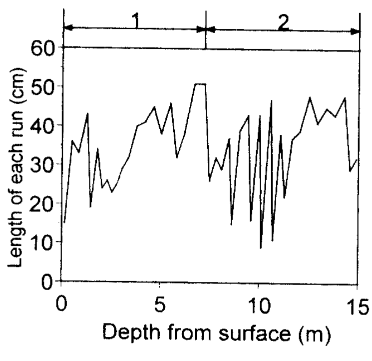

Fig. 6. Depth of ice core vs. length of each run in 1998. Numbers above the figure denote the day of drilling.

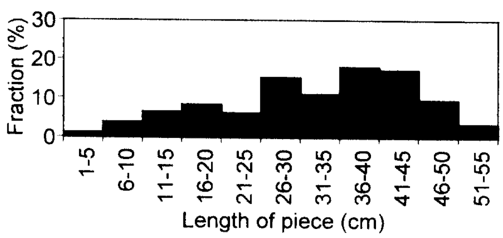

Fig. 7. Histogram of length of ice samples in 1998. The vertical axis denotes the fraction of sum of each fractured ice among certain lengths to the whole core length (14.90 m).

Half of the core was cut in situ at an interval of 5 cm in length. Each sample was shaved with a ceramic knife and melted in a clean plastic bag. After complete melting, each 50 m*l* water sample was filtered through a 25 mm hydrophilic PTFE type membrane filter (pore size of 0.2 μm) and packed in a pre-cleaned polyethylene bottle for chemical analysis. The rest of the water was divided into samples for biological analysis and tritium analysis. The biological samples were kept in 50-m*l* clean polyethylene bottles and preserved as 3% formalin solution to fix biological activity. The other half of the ice was packed in four insulated boxes (inner size of 50×30×20 cm; insulation thickness of 5 cm) and cooled at Base Camp (1 km from the glacier terminus; 5200 m a.s.l.) with river ice. After other observations concerning glacier fluctuation (Fujita *et al*., 2001b), the boxes were brought to Kathmandu by helicopter. After a one hour flight, the ice samples were safely placed in the freezer of a dairy company (BTC Private Ltd.) which has one of the few cold rooms in Kathmandu. For transportation from Nepal to Japan, we had to keep the samples as cold as possible. Therefore, we imported dry ice from India and cooled the samples before leaving for Japan. Although we ordered 30 kg of dry ice, 5 kg was lost in a cooler box during the one week import. More than 5 kg of dry ice was lost in a cold room during the succeeding 2 days. Ice cores with dry ice were transported by air *via* Bangkok (Thai Air). This was the only flight on which dry ice was available from Nepal to Japan.

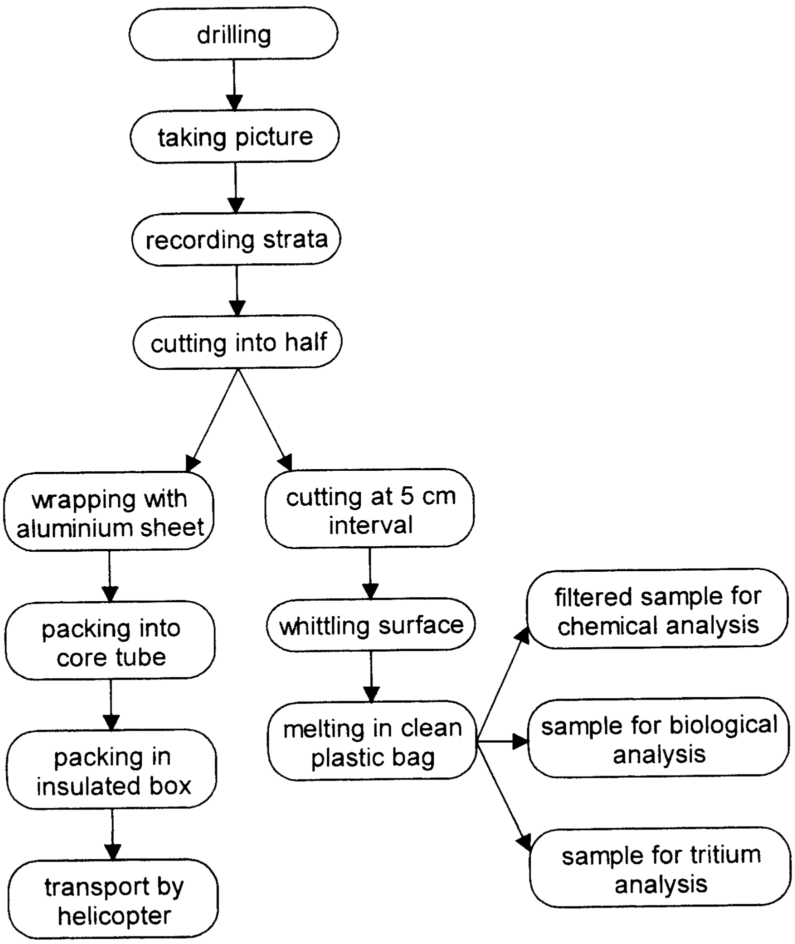

Fig. 8. Schematic flow chart of core process in situ.

Twenty hours after leaving Kathmandu, the ice samples were finally placed in a freezing room of the Institute for Hydrospheric-Atmospheric Sciences, Nagoya University.

4. Features of ice cores

For the ice core taken in 1994, the oxygen isotope ratio, major chemical components and Tritium were measured in the laboratory (Fujii *et al.*, 1996). The tritium peaks of 1963 and 1958–59 are found at 5.80–6.19 m and 7.10–7.34 m below the surface, respectively. Mean annual net balance is calculated as 19.3±0.7 cm in ice thickness between 1963 and 1994, and 27.2±1.6 cm in ice thickness between 1958/59 and 1963. The 23.25 m length core is expected to cover the past several decades assuming 30 cm of ice as the mean annual net balance. Since an ice core consists of superimposed ice, climatic information is disturbed by melting and refreezing as well as possible loss of annual layers by high melting.

The ice core taken in 1998, in which better quality was expected at higher altitude, still consists of superimposed ice with a few firn layers. No tritium peak was found in the ice core and thus the annual net balance is considered to be more than 44 cm in ice thickness. Although superimposed ice is also dominant in the core, a sampling interval of 5 cm in ice will give high resolution in the analysis. Further analysis is still continuing on for dirt concentration, inorganic and organic chemical components, pollen, micro plants in dirt, bubble density, grain size and stable isotope ratio.

5. Concluding remarks

Locations appropriate for better quality ice cores are limited at high altitude since we found heavy melt and refreezing features even at 6000 m a.s.l. Because capacity for work decreases at high altitude, light weight instruments are required. On the northern slope of the Himalayas in China, three ice cores were extracted in 1997 (Thompson *et al.*, 2000; Dasuopu Glacier; DS in Fig. 1). The relatively gentle slope of the northern side of the Himalayas, good accessibility to the field by car, availability of cold cars for core preservation and their large experience at high elevation made it possible to take the cores of excellent quality at high altitude around 7000 m a.s.l. On the other hand, the approach to high altitude requires climbing past dangerous ice falls and crevasses due to the steep slopes in Nepal. Ice cores without melting and refreezing, therefore, have been extracted only at Khumbu and Lower-Barun Glacier by hand auger in the southern side of the Nepal Himalayas (Table 2). Ice cores from the southern side of the Himalayas, however, are considered to be significant because the climatic environment changes drastically across the Himalayan range from south to north.

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