

## 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

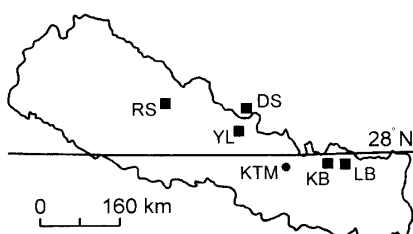


Fig. 1. Locations of glaciers (solid squares) where ice cores have been extracted around the Himalayas. Abbreviations denote Rikha Samba Glacier (RS), Yala Glacier (YL), Dasuopu Glacier (DS), Khumbu Glacier (KB), Lower-Barun Glacier (LB) and Kathmandu (KTM), respectively.

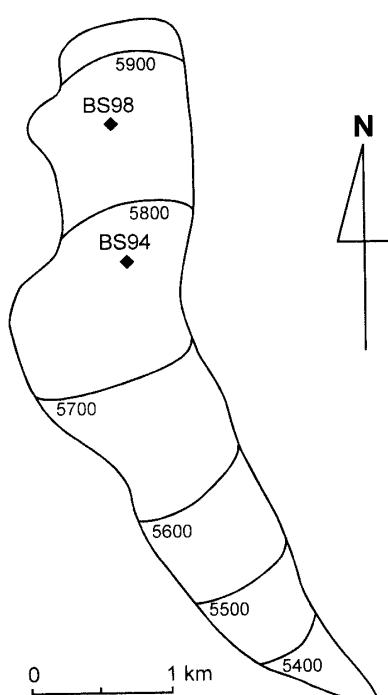


Fig. 2. Map of Rikha Samba Glacier. Rhombuses denote the boring site in 1994 (BS94) and in 1998 (BS98).

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 <i>et al.</i> (1984)  |
| 1982 | Yala        | 5405          | 60         | Watanabe <i>et al.</i> (1984)  |
| 1985 | Yala        | 5350          | 6          | Iida <i>et al.</i> (1987)      |
| 1987 | Yala        | 5350          | 5          | Ozawa (1991)                   |
| 1992 | Yala        | 5350          | 6          | Shiraiwa (1993)                |
| 1994 | Yala        | 5390          | 7          | Yoshimura <i>et al.</i> (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   | $32.3 \pm 9.4^*$ cm        | $33.9 \pm 11.0^*$ cm       |
| Length of ice pieces | $3.2 \pm 5.6^*$ cm         | $24.8 \pm 13.8^*$ cm       |
| Sample No.           | 116                        | 229                        |
| Sampling interval    | $20.0 \pm 5.8^*$ cm        | $6.2 \pm 1.4^*$ cm         |

\* Standard deviations

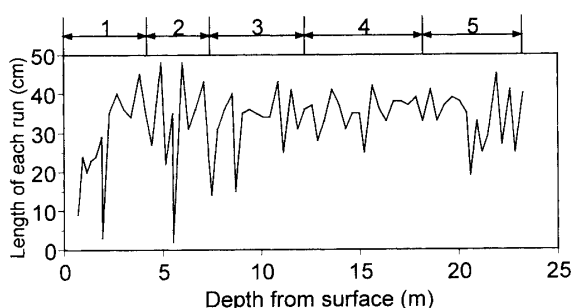


Fig. 4. Depth of ice core vs. length of each run in 1994. Numbers above the figure denote the day of drilling.

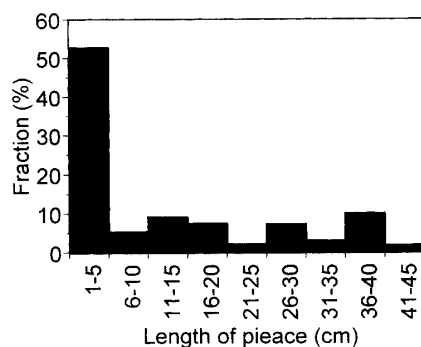


Fig. 5. Histogram of fractured ice length in 1994. The vertical axis denotes the fraction of sum of each fractured ice among certain lengths to the whole core length (23.25 m).

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.

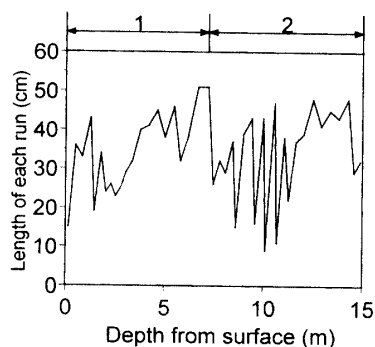


Fig. 6. Depth of ice core vs. length of each run in 1998. Numbers above the figure denote the day of drilling.

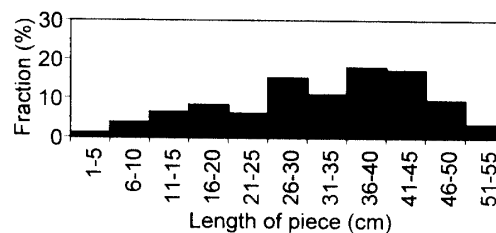


Fig. 7. Histogram of length of ice samples in 1998. The vertical axis denotes the fraction of sum of each fractured ice among certain lengths to the whole core length (14.90 m).

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 ml water sample was filtered through a 25 mm hydrophilic PTFE type membrane filter (pore size of  $0.2 \mu\text{m}$ ) 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-ml 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  $50 \times 30 \times 20$  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.

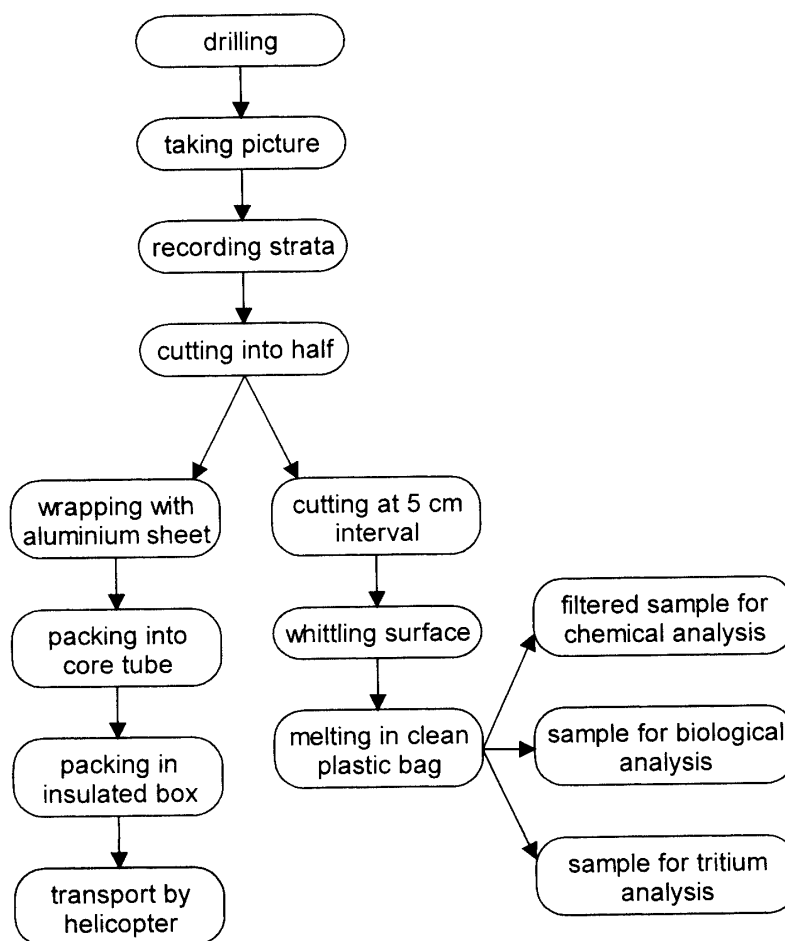


Fig. 8. Schematic flow chart of core process in situ.

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  $19.3 \pm 0.7$  cm in ice thickness between 1963 and 1994, and  $27.2 \pm 1.6$  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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### References

- Ageta, Y., Naito, N., Nakawo, M., Fujita, K., Shankar, K., Pokhrel, A.P. and Wangda, D. (2001): Study project on the recent rapid shrinkage of summer-accumulation type glaciers in the Himalayas, 1997–1999. *Bull. Glaciol. Res.*, **18**, 45–49.
- Fujii, Y., Fujita, K. and Paudyal, P. (1996): Glaciological research in Hidden Valley, Mukut Himal in 1994. *Bull. Glacier Res.*, **14**, 7–11.
- Fujita, K., Nakawo, M., Fujii, Y. and Paudyal, P. (1997): Changes in glaciers in Hidden Valley, Mukut Himal, Nepal Himalayas, from 1974 to 1994. *J. Glaciol.*, **43**, 583–588.
- Fujita, K., Takeuchi, N. and Seko, K. (1998): Glaciological observations of Yala Glacier in Langtang Valley, Nepal Himalayas, 1994 and 1996. *Bull. Glacier Res.*, **16**, 75–81.
- Fujita, K., Kadota, T., Rana, B., Kayastha, R.B. and Ageta, Y. (2001a): Shrinkage of Glacier AX010 in Shorong region, Nepal Himalayas in the 1990s. *Bull. Glaciol. Res.*, **18**, 51–54.
- Fujita, K., Nakazawa, F. and Rana, B. (2001b): Glaciological observations on Rikha Samba Glacier in Hidden Valley, Nepal Himalayas, 1998 and 1999. *Bull. Glaciol. Res.*, **18**, 31–35.
- Iida, H., Endo, Y., Kohshima, S., Motoyama, H. and Watanabe, O. (1987): Characteristics of snow-cover and formation process of dirt layer in the accumulation area of Yala Glacier, Langtang Himal, Nepal. *Bull. Glacier Res.*, **5**, 55–62.
- Ikegami, K. and Azuma, N. (1982): Research of Lower-Barun Glacier, Report of Mt. Baruntse Expedition 1980/81. Academic Alpine Club of Hokkaido, 153–156 (in Japanese).
- Kadota, T., Fujita, K., Seko, K., Kayastha, R.B. and Ageta, Y. (1997): Monitoring and prediction of shrinkage of a small glacier in the Nepal Himalaya. *Ann. Glaciol.*, **24**, 90–94.
- Koci, B.R. and Kuivinen, K.L. (1984): The PICO light-weight coring auger. *J. Glaciol.*, **30**, 244–245.
- Meier, M.F. (1984): Contribution of small glaciers to global sea level. *Science*, **226**, 1418–1421.
- Nakawo, M., Fujita, K., Ageta, Y., Shankar, K., Pokhrel, A.P. and Yao, T. (1997): Basic studies for assessing the impacts of the global warming on the Himalayan cryosphere, 1994–1996. *Bull. Glacier Res.*, **15**, 53–58.
- Ozawa, H. (1991): Thermal regime of a glacier in relation to glacier ice formation. Doctoral dissertation of Hokkaido University, 51 p.
- Shiraiwa, T. (1993): Glacial fluctuations and cryogenic environments in the Langtang Valley, Nepal Himalaya. Doctoral dissertation of Hokkaido University, 227 p.
- Thompson, L.G., Yao, T., Mosley-Thompson, E., Davis, M.E., Henderson, K.A. and Lin, P.-N. (2000): A high-resolution millennial record of the south Asian monsoon from Himalayan ice cores. *Science*, **289**, 1916–1919.
- Watanabe, O., Takenaka, S., Iida, H., Kamiyama, K., Thapa, K.B. and Mulmi, D.D. (1984): First results from Himalayan glacier boring project in 1981–1982: Part I. Stratigraphic analyses of full-depth cores from Yala Glacier, Langtang Himal, Nepal. Report of the Glacier Boring Project 1981–82 in the Nepal Himalaya, 7–23.
- Yoshimura, Y., Kohshima, S., Takeuchi, N., Seko, K. and Fujita, K. (2000): Himalayan ice-core dating with snow algae. *J. Glaciol.*, **46**, 335–340.

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