First Results from Himalayan Glacier Boring Project in 1981–1982

Part I. Stratigraphic analyses of full-depth cores from Yala Glacier, Langtang Himal, Nepal.

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Abstract

The first full-depth boring to the Himalayan glacier was attempted in 1981. After reaching the bed at a depth of 30 meter in the ablation area (5180 m a.s.l.), complete 60-m length core sampling was porformed in 1982 in the accumulation area (5400 m) of Yala (Dakpatsen) glacier in Langtang Himal, Nepal. Various data were obtained by measurements and analyses: the anual unit of layering, dirt horizon layering, $\delta\,^{18}O$, ^{3}H and the gross β activity, chemical concentrations of index species of sea salt, and analyses of dust particles composed of the dirt horizon.

The latter a deposition of dry fallout during the dry season, is composed of inorganic materials, soil, rock fragments and also organic materials, aquatic argal, aquatic phyte plankton, and pollen. More than 70 annual units are recognized in the 1982 core.

Due to melt water infiltration during summer, no seasonal oscillation in the vertical $\delta\,^{18}O$ profile is noted. The ^{3}H profile, revealed a marked increase after a thermonuclear weapons test series in the 1950s. Observation disclosed a 6–9 years difference between the ^{3}H age and layering sequence of the dirt horizon.

Among the chemical concentrations, NH_4^+, SO_2^{--} and NO_3^- levels in the 1982 core were ten times higher than in the 1981 core possibly indicating that a drastic environmental change in this region occurred 100 years ago or more.

I. Introduction

In the Nepal Himalaya, the first systematic investigation of glaciers was organized by Nagoya University and Kyoto University of Japan, in co-operation with the meteorological department of Tribhuvan University. The first phase of this multi-year research program was under taken during the period from 1973 to 1978. In this program, a series of field studies in the Khumbu, Shorong, Hink and Hunk region in the eastern part and Mukut region in the western part were carried out and fruitful results were obtained on the fundermental knowledge of distribution and present condition of the existing glaciers and the relation between glaciers and climate. As the second phase of the program, an attempt at reconstruction of the glacial environment during the monsoon in the Himalaya during the last 100 or so years was planned. The attempt at glacier core sampling to the bottom was one of the central objecttives of the second phase program among other investigations such as boring core sampling from glacial lake deposits and geomorphological investigation on the glacial landforms. This is also the first attempt at glacier boring through the full depth in the Himalaya. In addition to these scientific aims, technical improvment and acquiring of experience is another objective, to prepare for more large scale glacier boring in the Himalaya in the future.

In this report, the first results on the stratigraphic analyses of glacier cores which were obtained from both the ablation and accumulation area on Yala Glacier during the autumn of 1981 and 1982 are presented. The results on physical properties deduced from the core analyses and also a technical report on this boring operation are to be presented separately in this issue.

II. Outline of the glacier boring project

II-1 Site selection

In the autumn of 1981, the preliminary operation for the glacier boring was attempted on the ablation area of Yala (Dakpatsen) Glacier, in the right bank of Langtang Valley in the Langtang region. The location of this glacier is shown in Fig. 1. As shown in Fig. 1, the Langtang region is a part of the central Nepal Himalaya and is located in a remote area about 60 kilometers north-west of Kathmandu. From the capital via Trisuli Bazar it takes about 10–14 days on foot to reach the remotest village, Kyangchen Gompa (3,920 meters a.s.l.), which is in a U-shaped valley of the middle stream of the Langtang River. A map of the Langtan region with distribution of glaciers is shown in Fig. 2. All of the equipment including the boring machine, fuel for the electric generator and logistic gear, the weight of which totaled more than 500 kg, was transported by porters.

The major objectives of the 1981 pilot expedition are as follows;

(i) finding a suitable site for glacier boring including exploration of access routes and logistics.

(ii) testing of a boring machine and estimating of the generator power by actual driving at an elevation higher than 5,000 m a.s.l.,

(iii) investigation of supra- and en-glacial conditions relating to the meltwater phenomena and debris distribution.

First, a reconnaissance flight to the Langtang region was made and Yala Glacier was found. The glacier is the only one in this region satisfying the following logistic conditions:

i) it is easy to access the glacier,

ii) easy to climb up the accumulation area, and

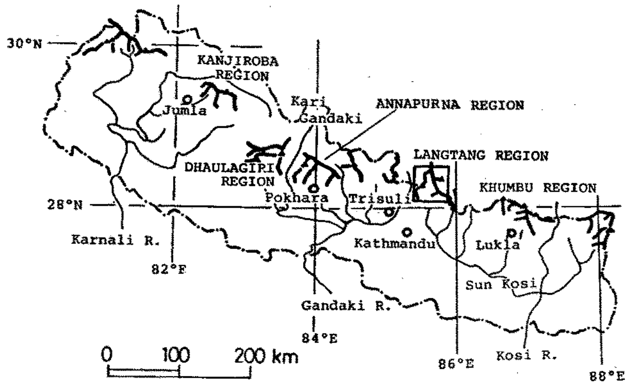


Fig. 1. Langtang Himal in Nepal.

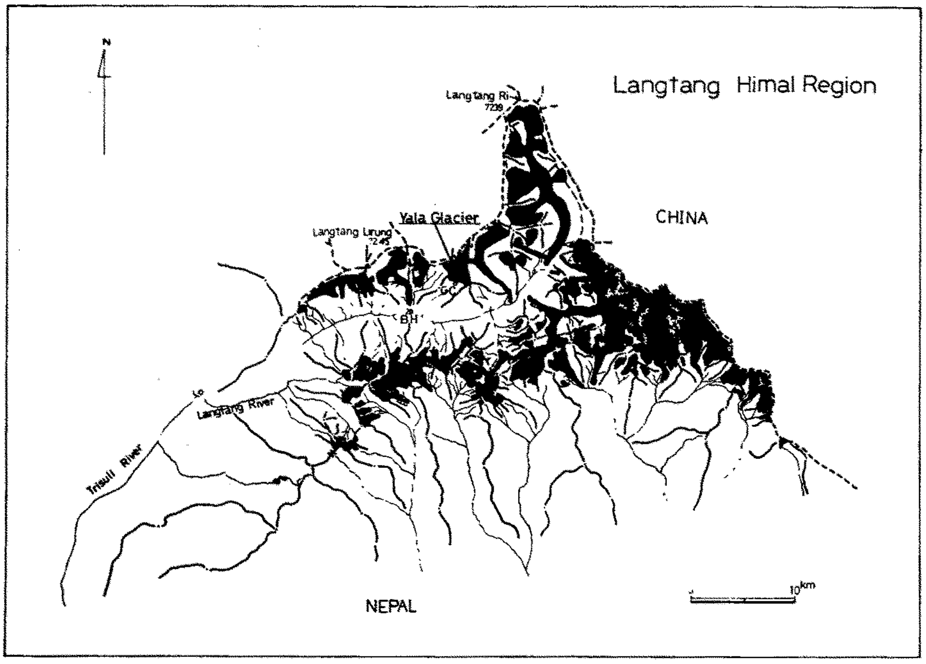


Fig. 2. Glacier distribution in the Langtang Himal.

iii) there is no supra-glacial debris on the glacier.

II-2. Glaciological setting of Yala Glacier

A topographic map of the area around Yala Glacier including the operation sites and the route to the glacier is shown in Fig. 3. As shown in this figure, the plateau glacier with a trapezoid shape covering an area of 2.566 km^2, ranges up to 4 km in width (east to west), and up to 1.5 km in length (south to north), and is located 6 km north to north-east of Kyangchen Gompa. The elevation of the snout is 5,090 m and that of the summit ridge ranges from 5,500 to 5,700 meters. The topographical elements of the glacier are summarized in Table 1.

Langtang Himal is situated in the eastern part of the Gandaki River basin. According to the Climatological Records of Nepal published by the Nepal government, the Langtang re-

Table. 1 Topographic and glaciological elements of Yala Glacier.

1) Location: 28°14'–15'N, 85°36'–38'E	
2) Elevation of the snout: 5,086–5,200 m	
3) Uppermost elevation of the accumulation area: 5,500–5,750 m	
4) Elevation of the equilibrium line (1981): (approx.) 5,200 m	
5) Length of the glacier: (approx.) 800–1,500 m	
6) Area of the glacier:	2.566 km^2
(5,000–5,500 m)	2.225 km^2
(5,500–5,750 m)	0.341 km^2
7) Elevation of the observation sites:	
Base House (BH) at Kyangchen: 3,920 m	
Glacier Camp (GC) at the snout: 5,090 m	
1981 Boring Site BS-1981 on the ablation area: 5,180 m	
1982 Boring Site BS-1982 on the accumulation area: 5,405 m	

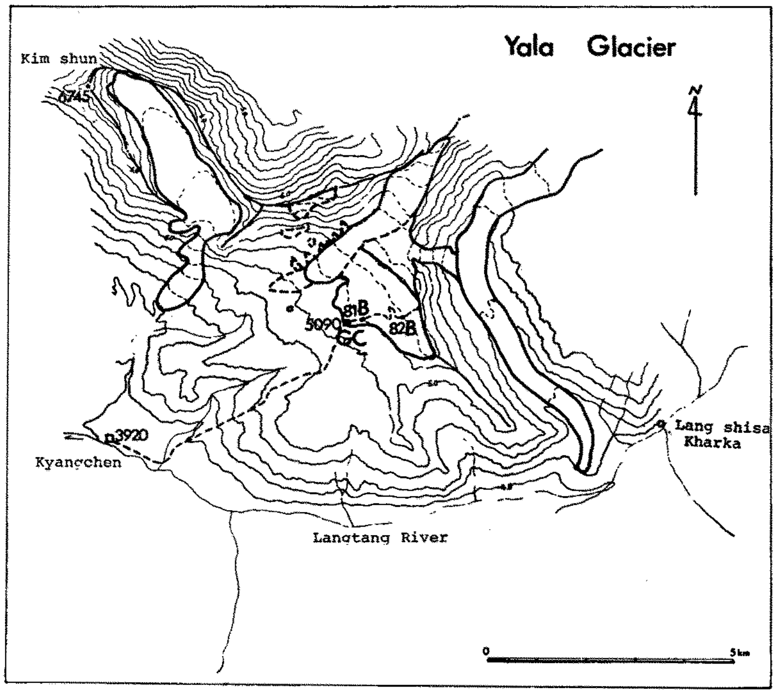


Fig. 3. Topographic map of the area around Yala Glacier.
GC: Glacier Camp (5,090 m), 81B: 1981 Boring site (5, 180 m) and 82B: 1982 Boring site (5,405 m).

gion is a high monsoon precipitation area extending eastward from the Annapuruna region. These areas are characterized by a belt-like area of high concentration of precipitation along the south slope of the main ridge of the great Himalaya. And consequently nourishment of glaciers in these areas is largely supplied by the monsoon precipitation.

Table 2. Meteorological data on the research area.
(I) Meteorological data at Kyangchen (3,920 m a.s.l.)*

1968		M	J	J	A	S	O	N	D
Temperature (°C)	Max.	12.5	11.6	12.5	12.8	11.6	8.5	6.4	4.7
	Min.	1.8	5.6	6.9	6.9	5.4	−0.9	−4.1	−7.1
Precipitation (mm)		—	167	241	160	102	180	0	0
1969		J	F	A	M	J	J	A	S
Temperature (°C)	Max.	1.2	—	9.0	—	13.0	13.0	12.5	11.9
	Min.	−9.9	—	−2.5	1.2	5.6	7.0	6.6	5.8
Precipitation (mm)		—	—	—	29	59	276	179	—

(II) Estimated mean air temperature**

	Glacier snout (5,090 m)	BS-1982 (5,407 m)
May	0.8	−0.9
June	1.6	−0.2
July	2.6	0.9
Aug.	2.3	0.5
Sep.	1.0	−0.8
Oct.	−0.7	−2.5 (−4.3)***

*observed by Dept. of Hydrology and Meteorology, Ministry of Water and Power, Nepal Government.
**using Kathmandu data (1971–1975 mean) and applying a Kathmandu-Lhajung (Khumbu Himal) lapse rate (0.57°C/100 m).
***0900 (LT) mean air temperature during Oct. 1st–23rd, 1982.

Daily meteorological observations (surface air temperature, precipitation) were made at Kyangchen Gompa, where a Base House (BH) for this project set up, and the Glacier Camp (GC) at a elevation of 5,090 meters a.s.l. during the autumn of 1981–1982. These records show that the minimum mean air temperature was 1.7°C (Oct. 25th, 1982) and the maximum was 10.3°C (Sep. 3rd, 1982) at BH during Aug. 27th–Oct. 26th, 1982.

The elevation difference between BH and the glacier snout (GC) is about 1,200 m. Appling an appropriate lapse rate (0.57°C/100 m), the climatic condition at the boring site BS-1982 (5,405 m) and the glacier snout (5,090 m) are estimated. The climatic conditions around the glacier are summarized in Table 2.

II-3 Outline of the boring operation

The core borings were performed with an electromechanical machine developed by Prof.

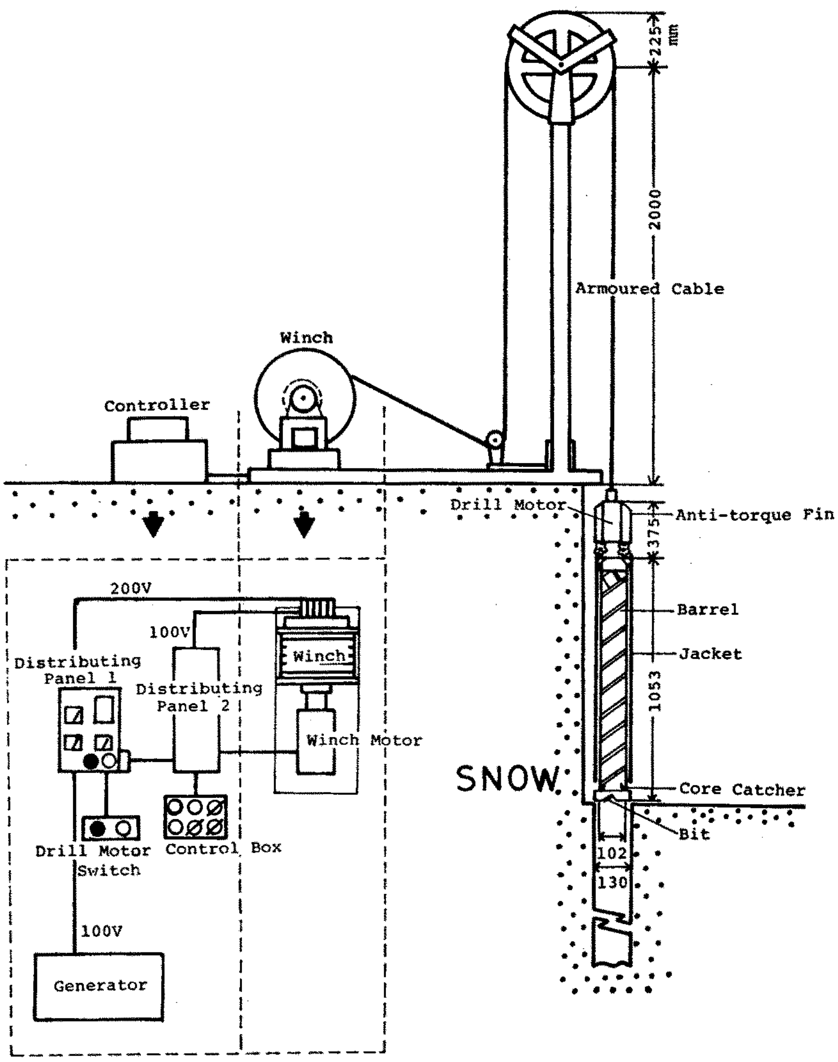


Fig. 4. Schematic diagram of the glacier boring drill system.

Yoshio Suzuki (1982). The machine consists of a core barrel and a driving system with a set of anti-torque fins and is suspended on an armoured cable. The design of the machine is shown in Fig. 4.

This is the first attempt to sample by boring through the full depth of a glacier in the Nepal Himalaya; therefore, many unknown factors for the boring operation were taken into accounit in the preparation. One of the most important problems is the internal conditions of the glacier in the presence of infiltrating melt water and sub-glacial debris. And in regards to mechanical operation, the real power efficiency of a generator at such a high altitude (more than 5,000 m a.s.l.) was still unknown. Usage of a high power generator was not possible due to the weight and the rate of fuel consumption. A gasoline generator of rated output of 1ϕ, 50 Hz, 2 kVA was chosen; it weighs about 40 kg, making the total net weight of the system about 300 kg.

During October and November in 1981, a pilot operation was carried out on the ablation area of Yala Glacier at an altitude of 5,180 m a.s.l.

By boring into the bare ice a full-depth core of 30 m was taken. The temperature in the hole remained slightly below 0°C so that infiltrating of melt water was practically nonexistent. On the other hand, the operation which was carried out during a cold season, to avoid melt water problems, involved such logistic problems as high-atitude porter employment, climbing on a glacier covered with heavy snow, etc.

Immediatly after the 1982 monsoon season was over, the main boring operation on the accumulation area was set up at an altitude of 5,405 m. During the operation, various troubles with the boring arose: a failure condition on the anti-torque fins due to the existence of thick temperate loose firn developed between 1 to 10 meters below the surface, the machine was submerged by an abrupt spouting of infiltrated melt-water at a depth of 27 m, and also many mechanical troubles occurred. On the other hand, under good conditions up to 6–7 m can be bored per day.

At the end of October, the first 60 m full-depth boring in the Nepal Himalya succeeded; 17 m of firn and 43 m of ice were found. The temperature measurements at depth were made in the air of the open bore hole with a thermistor. The bore-hole temperature measurements on the accumulation area indicatate that this area is temperate (the ice temperature below 10 m depth was 0°C).

The glaciological description and the hydrological analyses of the spouting of en-glacial water are to be discussed, in connection with a water table study, in separate paper (Iida et al., 1984).

III. Glaciological research work around Yala Glacier

III-1 Objectives and items of the glaciological research work

The glacier boring project carried out during 1981–1982 is one of the main components of interdisciplinary studies attempting a reconstruction of the climatic history in the Langtang region, central Nepal Himalaya, during the past 100 or so years.

In these studies, stratigraphic and geochemical research on deposited materials in glacier lakes, geomorphological reseach on glaciated land forms and glacial depositions and so on were carried out in collaboration with the glacier boring project.

Before the present work, glaciological research in this region has not been done in detail. Therefore the fundamental knowledge of glacial conditions, mass balance, heat balance and the dynamical condition of existing glaciers in this region were positively necessary for these studies.

In terms of the pilot expedition performed in 1981 and the main operation in 1982, the following glaciological research work was carried out:

i) Photogrammetric and triangular survey of Yala Glacier and surrounding area,
ii) geomorphological survey on the glaciation,
iii) mass balance and heat balance studies on Yala Glacier,
iv) structural and dynamic studies on Yala Glacier,
v) stratigraphic and geochemical researches on deposition of glacier lakes,
vi) glacio-biological studies on the glacier and in the surrounding area,
vii) glacier inventory of glaciers in the Langtang region by means of air photogrammetry.

Preliminary results obtained in these sutdies are to be presented in separte reports in this issue.

III-2 Objectives and contents of the boring core analyses

The 30 m-long core obtained from the ablation area and the 60 m-core from the accumulation area of Yala Glacier were analyzed from two different points of view: one is a stratigraphic analyses and another is studies of the physical properties and on the transformation processes from firn to glacier ice.

Observations, measurements and samplings were carried out in situ, because there were no means for transportation and storage to keep samples in a solid state in such a remote region of the Nepal Himalaya. The following stratigraphic analyses included;

i) visible stratigraphy,
ii) dirt layer analyses.
iii) sampling for stable isotope measurements, radioactive isotopic measurements and chemical composition analyses.

The collected samples were placed in pre-cleaned air-tight polyethylene bottles and carried to the laboratory at Nagoya University and other places.

The physical property measurements included the following:

i) density measurements,
ii) crystal shape and size measurements,
iii) bubble elongation and size measurements,
iv) observations of the micro-texture of firn and ice.

The density measurements were made by means of a volume-weight technique in situ. The measurements and the observations for items ii–iv were analyzed by the use of cross polarized photographs of firn-ice thin sections taken in situ.

These results are reported and discussed in part II of the boring project report in this issue.

IV. Results of stratigraphic analyses of the cores

IV-1. Alalyses of the annual layering

IV-1-1 Dirt layer stratigraphy

On both the cores from the areas of the ablation and accumulation, visual stratigraphy, as shown in Fig. 5, is relatively simple consisting of ice crust, dirt layer, bubbly part and clear part. On the other hand, as shown in Plate 1, the well-developed concentration of dirt parti-

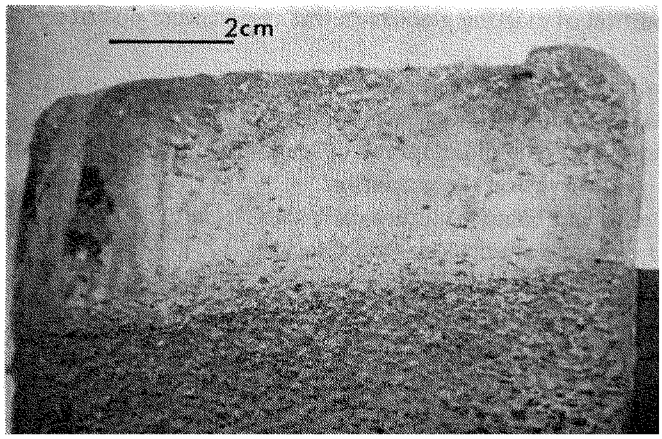
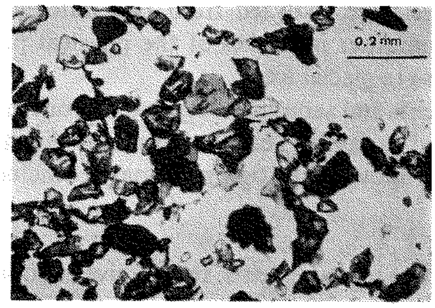
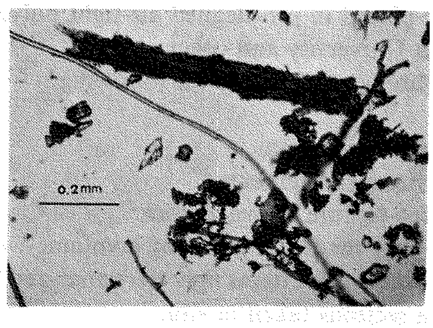


Plate 1. Typical structure of dirt horizon.



(1)



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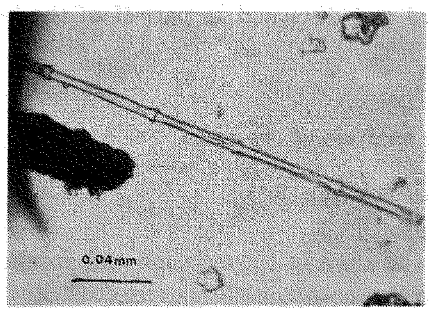
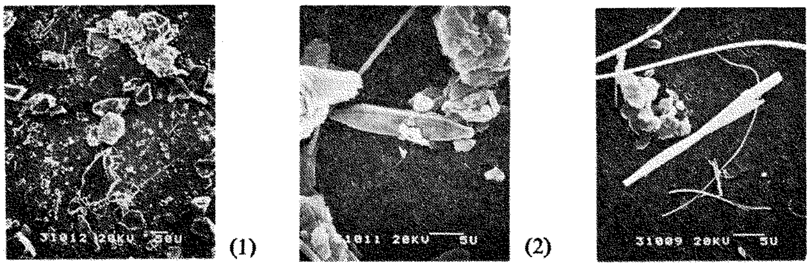


(3)

Plate 2-1. Optical microphotographic data: (1) minerals, (2) and (3) plant fragments.



(1) (2) (3)

Plate 2-2. Electron microphotographic data: (1) minerals, (2) pollen and (3) plant fragments.

cles and their regular existence is a distinctive feature in the visual stratigraphy. The vertical sequences of dirt horizon along the cores are illustrated on the stratigraphic diagram. Origin and kinds of organic and inorganic materials of the contents composed is described in detail in the following paragraph.

Various sorts of dust particle in the dirt horizon can be considered to be brought from the nearby surroundings of the glacier during the dry period from the post-monsoon to the pre-monsoon.

As previously pointed out by Miller et al. (1965) from his investigations on the Khumbu Glacier of Mt. Everest, east Nepal, he succeeded in dating the ice layer with the aid of the trituim content and in demonstrating that two dirt horizons are deposited annually. When a considerable amount of snowfall occurs in winter, two horizons of dirt may be laid down.

As shown in (d) column of Fig. 5-1, these dirt horizons are indicated by lines from the uppermost to down including some of the debris on shear planes thrust up from the glacier basement.

Estimated boundaries for annual layering are indicated by an line in the right column. As shown in Fig. 5-2, the boundaries of the upper 10 meters in the firn layer, where the least occurrence of visible dirt horizons was observed, were estimated by comparing the stratification of the exposed wall of crevasse situated near the boring site of 1982.

Below the depth of 23 meters, two dirt horizons within one annual layer become visible due to increasing density.

In the core from the accumulation area, more than 70 annual units of layering were found.

IV-1-2. Oxygea isotope profile

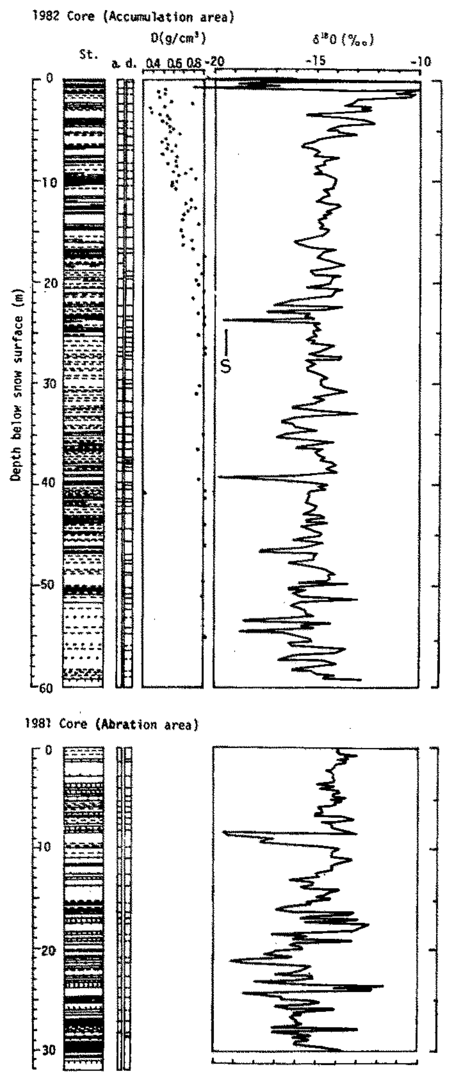
The cores from the ablation area and the accumulation area taken in 1981 and 1982 were analyzed for the oxygen isotope content. The results are shown on the right side of the stratigraphic diagram in Fig. 5-1. Analytical results are given in $\delta\,^{18}O$ notation as follows,

$$\delta\,^{18}O = \frac{(^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{SMOW}}{(^{18}O/^{16}O)_{SMOW}} \times 1000\ (^{\circ}/_{oo})$$

SMOW: Standard Mean Ocean Water

and analytical error is $\pm 0.2^{\circ}/_{oo}$. Cold firn in high mountain and polar region, as is well-known, preserves the seasonal variations of the stable isotope content. In the Himalaya, as reported previously by Wushiki (1977) from his investigation of the annual variation of the deuterium content in the Khumbu region, increasing precipitation with advancing of the monsoon season caused decreaseing duterium content, which increased through the winter to the spring after a temporary decrease in a shorter period at the end of the monsoon.

5-1



5-2

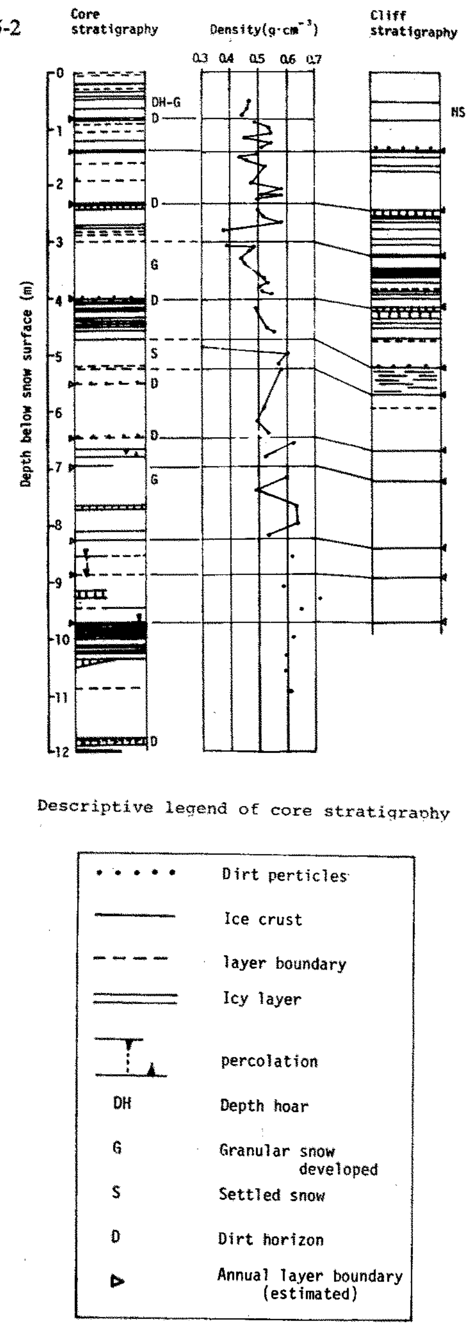


Fig. 5-1. Stratigraphic diagram and $\delta^{18}O$ profile.
St: Stratigraphy, a: Annual layer boundary, d: dirt horizon and D: density.
S in oxygen isotope profile: $\delta^{18}O$ value of spouting water.
Fig. 5-2. Stratigraphic correlation between 1981 core and ice cliff stratigraphy.

As easily visualized from Fig. 5-1, such an expected seasonal oscillation was not found, and, also, there was no relation between the $\delta^{18}O$ profile and the annual layering estimated by the dirt layer sequence.

Table 3. $\delta^{18}O$ of solid precipitation and the spouting water.
(I) 1982 Boring site (5,405 m)

1982		1982		1982	
Oct. 8	−7.3‰	Oct. 17	−19.0‰	Oct. 22	−31.8‰
9	−8.8	18	−19.6	23	−16.8
10	−7.2				
11	−5.1				

(II) Kyangchen (3,920 m)
1981 Nov. 14, −9.5‰

(III) Spouting water from 1982 bore hole
5 samples mean −19.5‰
(Tritium content 40TU)

The oxygen isotope content varies between −10‰ and −22‰, with a mean value of −15.0‰ (1982-core) and −15.1‰ (1981-core). And the range of oxygen isotope value does decrease with depth.

For reference, oxygen isotope content of solid precipitation during the term of the boring operation in 1982 is given in Table 3. From these data, it can be pointed out that the oxygen isotope content of precipitation varies greatly in a relatively short period.

The $\delta^{18}O$ value of spouting water at the depth of 27 meters is also shown in Table 3.

IV-1-3 Tritium profiling

Vertical profile of tritium concentration in the firn and ice are presented in Fig. 6 with a simple stratigraphic diagram. The measurements were carried out in the laboratory of Kyoto University. The tritium concentration is given in Tritium unit (1 TU = $T/H \times 10^{-18}$). It is well-known that tritium concentration peaks in firn and ice layer of glacier, due to the production of tritium by thermonuclear weapons tests since 1953, are good means for hydrological dating up to 30 years ago. In the northern hemisphere, these distinct peaks in the glacier plofile (Valnajobull Glacier, Ice land) and that of the ice sheet (Greenland, Dye 3) analyzed by Theodorssen (1975) are found in 1954, 1956, 1959, 1963, 1964 horizon and so on. In contrast with these high (less or more than 10^3 TU) concentration, the value in the pre-bomb years is on the order of 10 TU. These high tritium concentrations are also found in Grenz Glacier, Swiss Alps (Oeschgen et al., 1977) and Vernagt ferner, Austria Alps (Stichler et al., 1983) indicating the value of 10^3 TU in 1963 horizon.

In the Himalaya, the first measurement of tritium concentration were made by Miller et al. (1965) on the firn of the Westen Cwm of the Khumbu Glacier in 1963. About 500–800 TU concentrations were found in the layers deposited during 1954–1962. As pointed out by Kamiyama and Kitaoka (1984) from the distribution of mean tritium value during the periods 1963–1964 and 1974–1975 surrounding the Nepal Himalaya by IAEA network, the higher concentrations occur in the deeper inland region and the reverse in the coastal area. In contrast with these higher level, more than the 3,000 TU average of 1963–1964 precipitation, is found in Karizimir (Afghanistan), while that of New Delhi (India), in a maritime climate, shows a relatively lower value of less than 1,000 TU. The lower value of less 1,000 TU found on Mt. Everest implies that climatic conditions are considerably by a maritime monsoon.

In the vertical profile of tritium obtained from Yala Glacier, several peaks and troughs are found. Distinguishing figures among them are indicated alphabetically (A–G) from bottom to top. To date, the peak E can be presumed most probably to be precipitation during the 1963–1964 period. The profile obtained from the ablation area ranging 1–10 TU may correspond

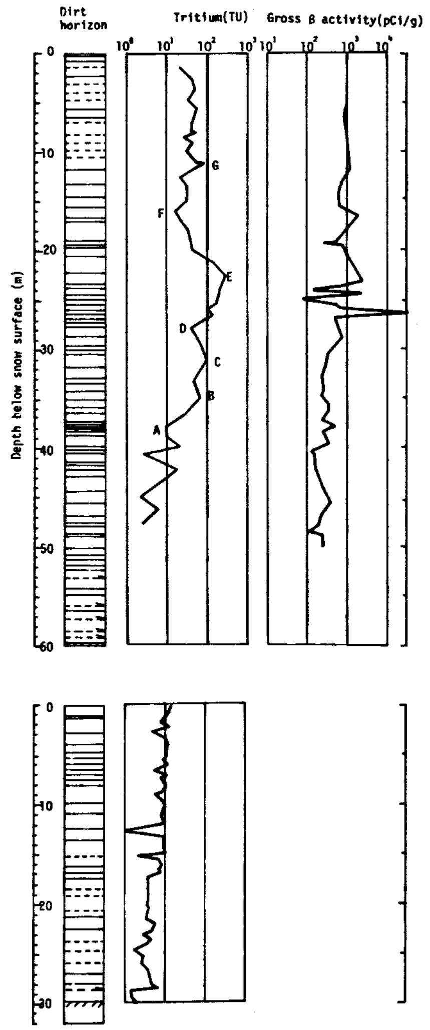


Fig. 6. Profile of Tritium content and Gross β activity.
Alphabet in the Tritium profile is temporary indication.

to pre-1954 precipitation. The spouting water at the depth of 27 meters was found to be 40 TU.

IV-2 Analyses on depositional environment

IV-2-1 Chemical composition

Some 90 samples and 145 samples obtained from the 1981-core and 1982-core, respectively, were brought to Nagoya University (Japan) for analysis. The glacier firn and ice samples were melted at the sampling sites and kept in pre-cleaned air-tight polyethylene bottles. The bottles were cleaned with nitric acid and rinsed with deionized water. To measure mainly the sea salt index species, F^-, Cl^-, NO_3^-, SO_4^{2-} of anion and Na^+, K^+, NH_4^+, Ca^{2+}, Mg^{2+} of cation were analyzed by the following methods; Dionex Model 10 Ion Chromatograph was used for the determination of the anion. The samples were filtered with millipore filter before analysis.

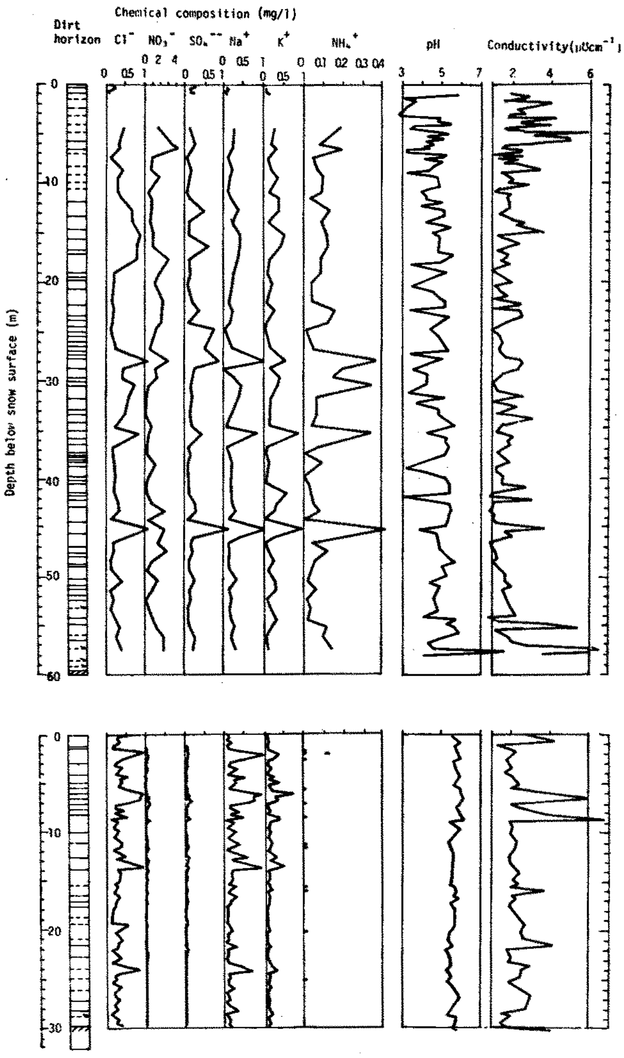


Fig. 7. Profile of chemical composition, pH and Conductivity.

Chromatographic conditions were: eluent, 0.003M $NaHCO_3$ and 0.0024M Na_2CO_3; flow rate, 138 ml/hr; separate column, 3×500 mm anion first separator; suppressor column, 6× 250 mm anion suppressor; injection volume, 100 μl.

The concentrations of Na^+, K^+, Ca^{2+} and Mg^{2+} in samples taken from 1981-core were determined by atomic absorption method, while those of Na^+, K^+ and NH_4^+ in samples taken from 1982-core were determined by ion chromatographic method.

All results for the 1981-core and part of those for 1982-core are shown in Fig. 7. Mean concentrations and standard deviations of each chemical species in these samples are shown in Table 4. The order of the concentrations was comparable to that of Greenland ice core taken at Site 2 (Langway, 1970).

A comparison of the two plofiles in Fig. 7 revealed that high NO_3^-, SO_4^{2-} and NH_4^+ concentrations occur in the 1982-core which was deposited during the last several years. It reflects

Table 4. Mean of chemical composition (mg/litter).

1982 Core						
	Cl^-	NO_3^-	SO_4^{--}	Na^+	K^+	NH_4^+
$\bar{x}$	0.35	1.3	0.23	0.25	0.24	0.10
s	0.26	1.0	0.21	0.22	0.19	0.095
n	55	54	55	55	55	52
1982 Core						
	Cl^-	NO_3^-	SO_4^{--}	Na^+	K^+	NH_4^+
$\bar{x}$	0.33	0.071	0.033	0.23	0.11	$\fallingdotseq 0$
s	0.19	0.072	0.028	0.22	0.11	—
n	85	84	84	85	84	15

$\bar{x}$: mean, s: standard deviation, n: number of samples.

a different depositional environment surrounding Yala Glacier from that in the period when the 1981-core was deposited.

IV-2-2 Dirt horizon particle analysis

As mentioned before, distinctly developed dirt horizons were found in both cores. Observations of the surface forming process in situ and the stratigraphic occurrence made it obvious that these particles originate from a fallout during the dry season. In the winter, the core of the westerly jet stream is above the Himalaya mountains, resulting in very strong winds. Particles, which are products of weathering processes from surrounding rock wall and glaciated plateau without snow cover, are blown upward and fall to the glacier surface. Some of them can be presumed to be carried in from the Tibetan plateau and the Takla Makan desert.

Particles consist of inorganic materials such as rock fragment, soil, chips of mineral etc. and also include (c.f., K. Koshima in this issue) organic materials such as aquatic argal, aquatic phyte plankton, pollen. Particle analyses, type determination and investigation on their origin, are still in progress. Microphotograph data results dealing with the various type of particles from optical and electron microscopy are shown in Plates 3 and 4, respectively.

Sixty-two dirt horizon and 6 shear planes including rock fragment are found in the 1982-core obtained from the accumulation area of Yala Glacier. On the core stratigraphy, the dirt horizon in the upper 10 meters is not distinct or invisible except for the uppermost horizon formed during the dry season of 1981–1982. Below a depth of 12 meters with an average density of 0.6 $g{\cdot}cm^{-3}$, the dirt horizon again became distinctly visible below a below the depth of 22 meters with an average density of 0.8 $g{\cdot}cm^{-3}$. Other horizons within an annual unit appear due to densification of the firn.

Figure 8 shows vertical distribution of the dirt horizon and weight amount of the particles per 80 cm^2 area. Two different modes of particle occurrence were found in the core; the one is a concentration pattern to a horizon surface and the other a scattered pattern at a certain depth range. The weights could be divided two groups; namely 1–10 mg/80 cm^2 and 20–40 mg/80 cm^2. A peak of 60 mg at a depth of 39 meters was exceptional. Weight comparison along the vertical profile is only for reference because of the greater elongation with increasing depth.

The results of the gross β activity measurements of the filtered dust particles are shown in the right in Fig. 6. The general trend of the porfile indicates a linear increase in the semilogarithmic graph from 10 p Ci/g down to 10 p Ci/g in the upper frame above the depth of 28 meters some unusual increased trends are noted.

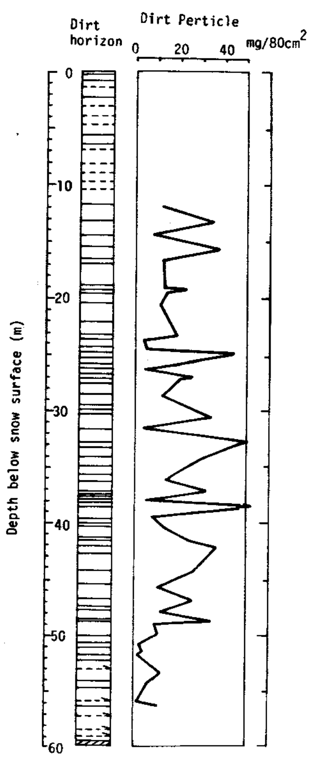


Fig. 8. Profile of dust particle concentration per unit area.

Although the gross β activity not only results from the radioactive isotope of thermonuclear weapon test products but also from natural ones such as ^{40}K from rocks, these broad peaks seen in the upper layer of core may well result from the artificial products of radioactive isotopes as seen in polar ice and firn.

IV-2-3 Measurements of pH and the electrical D.C. conductivity

The pH and the electrical D.C. conductivity were measured in situ, employing a UC-23 digital pH/ORP meter (Central Kogaku Co., Ltd.) and a portable conductivity meter, model CM-1K (TOA Electronics, Ltd.), respectively. The results are plotted versus depth on the right in Fig. 7 along with the chemical content. The core sample was melted in the pre-cleaned polyethylene bottle by means of warm water bathing after removing the mantle to prevent of contamination.

The mean pH and electrical conductivity level in the 1981 and 1982 core were 5.6, 2.39 $\mu℧\cdot cm^{-1}$ and 4.7, 2.01 $\mu℧\cdot cm^{-1}$ respectively. In comparison with those in other regions, one-tenth of level of the Alps (Oeschger et al., 1977) and equivalent to that of central Greenland (Hammer, 1976).

V. Concluding remarks

The results described in the previous chapters are preliminary and further studies are still in progress.

With regard to the accumulation process on Yala Glacier, characteristics can be pointed out; the most important among them is the infiltration of abundant water originating from snow melting and liquid precipitation during the monsoon season. During the glacier boring operation in 1982, an abrupt spouting occurred at a depth of 27 m. Although this spouting can be presumed to be an aquifer due to its nature, a free water table may develop, reaching an upper level of a depth of 17 m and so, in the height of the melting season. When this phenomenon is possible, the mass balance process in firn layer becomes complicated. It is suggested that the mass balance process should be divided into two stages, the initial stage at the surface and the secondary stage in the level of the water table at a certain depth. On the other hand the characteristics of the temperature profile of this glacier, a slightly negative profile in the ablation area and 0°C throughout the full depth in the accumulation area, should require an other approach for understanding the ice formation mechanism in such infiltrated water.

The various vertical profiles in 1981 and 1982 cores, as shown in the previous chapters, lead to the following simple conclusions:

(i) The dirt horizons are a clear criteria for the boundaries the annual layers in the core obtained from the glacier. Increasing density with depth makes clear the existence and occurrence of dirt particles and below a certain depth two such horizons within one annual layer were found.

(ii) Relatively small scale oscillation is a characteristic of the oxygen isotope profile. This homogenization may be considered to result from the infiltration of water. A small difference (0.1‰) of the mean value between 1981 and 1982 cores is also interesting.

(iii) In profiles of both ^3H and the gross β activity, a striking increase due to thermonuclear weapons tests in the 1950s is found. At present, observation disclosed a several years difference between the ^3H age and dirt horizon sequence. The reason is still under study.

(iv) The finding of living things in the dust horizon will lead interesting information on the environmental conditions in the area around the glacier.

(v) A marked difference in the concentration of NO_3^-, SO_4^{2-} and NH_4^+ between 1981 and 1982 cores may suggest that a drastic environmental change in this region occured 100 years ago or more.

The final report of this study is to be given in a separate paper.

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References

Ageta, Y., (1983): Characteristics of mass balance of the summer-accumulation type glacier in the Nepal Himalaya, Seppyo, Vol. 45, No. 2, 81–105.

Ageta, Y. H, Iida and O. Watanabe, (1984): Glaciological studies on Yala glacier in Langtang Himal, in this issue.

Hammer, C. U., (1976): Greenland ice sheet chronology and past volcanism as inferred by impurity analyses of glacier snow and ice. Licentiat afhandling, University of Copenhagen.

Iida, H., O. Watanabe and M. Takikawa, (1984): First results from Himalayan Glacier Boring Project in 1981–1982; Part II. Studies on internal structure and transformation process from snow to ice of Yala Glacier, Langtang Himal, Nepal, in this issue.

Kamiyama, K. and K. Kitaoka, (1984): Characteristics of Yala Glacier on the viewpoint of tritium content, in this issue.

Koshima, K. (1984): Living micro-plants in the diry layer dust of Yala Glacier, Nepal Himalaya, in this issue.

Lambert, G., B. Ardouin, J. Sanak, C. Lorius and M. Pourchet, (1975): Accumulation of snow and radioactive debris in Antarctica: a possible refined radiochronology beyond reference levels, Symposium of Grenoble. IAHS-AISH, publication No. 118, 146–158.

Langway, C. (1970): Stratigraphic analysis of a deep ice core from Greenland, The Geological Society of America, Special paper 125. p. 186.

Miller, M. M., J. S. Leventhal and W. F. Libby, (1965): Tritium in Mt. Everest ice—Annual glacier accumulation and climatology at great equatorial altitudes. J.G.R., Vol. 70, No. 16, 3885–3888.

Oeschgen, H., U. Schotterer, B. Stauffer, W. Haeberli and H. Rothlisberger, (1977): First results from Alpine core drilling projects. Z. Gletscher K. Glazialgeol. 13, H. 1/2, 193–208.

Stichler, W., W. Ravert, H. Oerter and D. Baker, (1983): Dating of an ice core from a temperate Alpine glacier (Vernagt ferner, Austria), XVIII IUGG Assembly (Hamburg), Symposium.

Suzuki, Y. and K. Shiraishi, (1982): The drill system used by the 21st Japanese Antarctic research expedition and its later improvement. Mem. Natl. Inst.: Polar Res. Spec. Issue No. 24, 259–273.

Theodorsson, P., (1975): 40-year tritium profiles in a polar and a temperate glacier. Symposium of Grenoble. IAHS-AISH publication No. 118, 393–398.

Vallon, M., R. Petit, and B. Fabre, (1976): Study on an ice core to the bedrock in the accumulation zone of an Alpine glacier, Jour. Glacio. Vol. 17, No. 75, 13–28.

Wushiki, H. (1977): Deutrium content in the Himalayan precipitation at Khumbu district, observed in 1977/1975, Seppyo, 39, special issue, 50–56.