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# Characteristics of snowcover and formation process of dirt layer in the accumulation area of Yala Glacier, Langtang Himal, Nepal

**Hajime Iida[1], Yasoichi Endo[2], Shiro Kohshima[3], Hideaki Motoyama[4] and Okitsugu Watanabe[5]**

1 Water Research Institute, Nagoya University, Nagoya 464 Japan
2 Tokamachi Experiment Site, Forestry and Forest Products Research Institute, Tokamachi City, Niigata 948 Japan
3 Department of Zoology, Faculty of Science, Kyoto University, Kyoto 606 Japan
4 Institute of Low Temperature Science, Hokkaido University, Sapporo 060 Japan
5 National Institute of Polar Research, Tokyo 173 Japan

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## Abstract

Observations of accumulation-ablation and formation process of the dirt layer and annual accumulation of Yala (Dakpatsen) Glacier in Langtang Himal of the Central Nepal were carried out throughout the year from summer, 1985 to spring, 1986. This is a first long term observation in the accumuration area of the glacier in the Himalayas. On the basis of results of these observations, it is considered that distinct dirt layers are formed by dry fallout during the dry period from the post-monsoon season to the pre-monsoon season. However, thin dirt layer can be formed in the post-monsoon season, if there is a large amount of snow accumulation as was seen in the winter season 1985–1986, the total snowfall at B. H. (3850m a. s. l.) from Dec. 1985 to Feb. 1986. was 142 mm in water equivalent Contents of the dirt layer consist of organic materials, such as micro-plants and bacteria, and minerals. It is found that the rate of organic materials content is relatively high. Micro-plants can be seen growing in the dirt layer. We are sure that our results of observation will be very helpful to core analysis in Glacier Boring Investigation in the Himalayas.

## 1. Introduction

Few observations on the accumulation-ablation process in the accumulation area of glaciers have been made as yet in the Himalaya Mountains, espe-cially in the Nepal Himalaya. Furthermore, fewer observations have been made on the formation of dirt layers which are considered annual layer boundaries. Clarification of the accumulation-ablation process and the formation of dirt layers are, however, essential for the reasonable interpretation of stratification of ice core.

As a part of "Langtang-Project" of Glaciological Expedition of Nepal (Leader keiji Higuchi), glaciological and meteorological observations were made at the upper reaches of Yala (Dakpatsen) Glacier in Langtang Himal of the Central Nepal, throughout a year from summer of 1985 to spring of 1986. This is the first long-term observation in an accumulation area of a glacier in the Himalayas. We, hereinafter, present some preliminary results of what we clarified about the formation process of dirt layers and the accumulation-ablation process of Yala Glacier.

## 2. Method and site of observation

Following glaciological and meteorological observations were made at 11 stations distributed from S 1 (5083m a. s. l.) to S 11 (5500 m a. s. l.) on Yala (Dakpatsen) Glacier in Langtang Himal throughout a year from summer of 1985 to spring of 1986. Figure 1 shows locations of observation sites on the glacier. The contents of observations are as follows :

(i) Measurement of accumulation and ablation of snow at the glacier surface with stakes.
(ii) All-year-round measurement of snow depth with

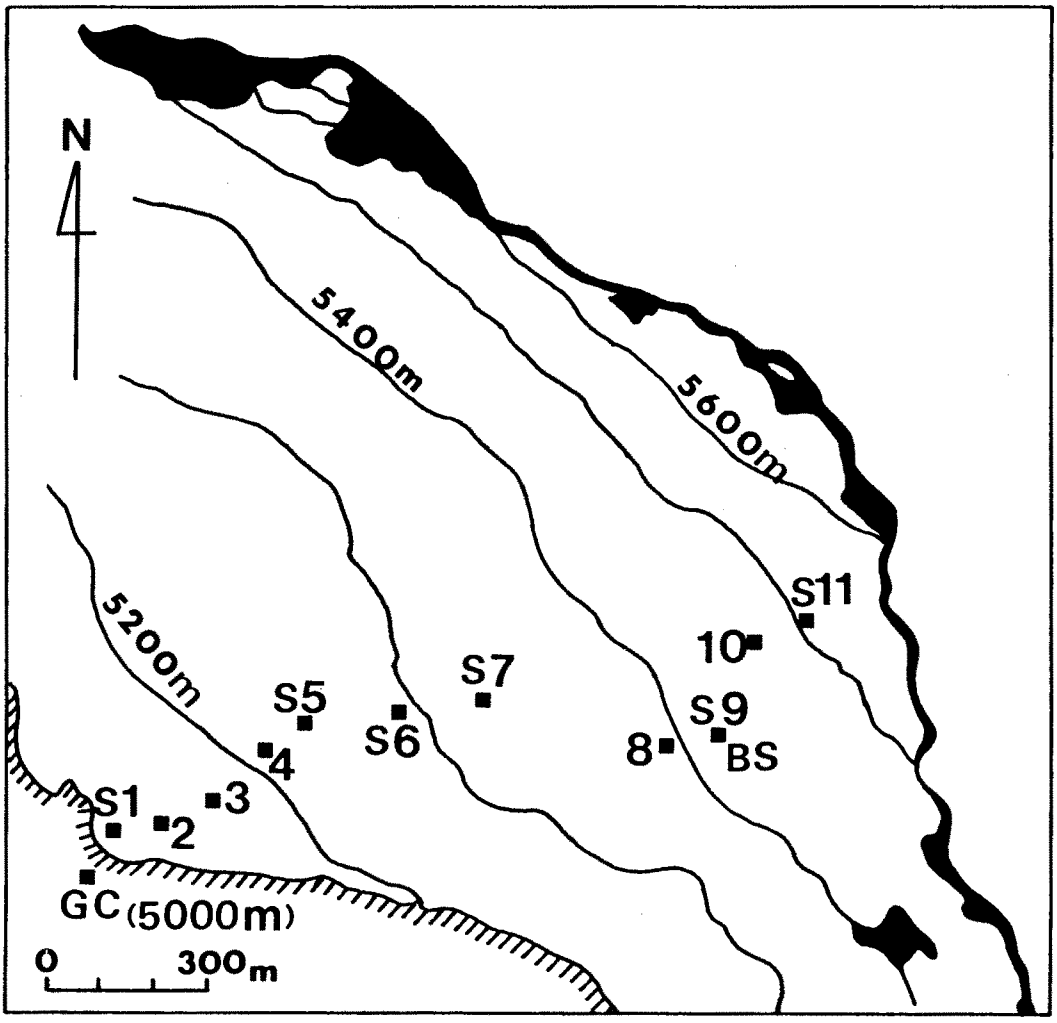


Fig. 1. Locations of observation sites on Yala Glacier. GC: Glacier Camp, BS: Boring Site, S1-S11: stakes for the observation of mass balance.

an automatic snow recorder, snow pressure, air temperature and snow temperature at S 5 (5250m a. s. l.).

(iii) Pit-work of snowcovers on the following items at each station (S 1-S 11) on the glacier.
- Stratigraphic observation of snow layers, especially paying attention to dirt layers and ice layers.
- Measurements of density and grain size.
- Sampling of dust particles, organic materials and living micro-plants in dirt layer.

(iv) Sampling of dry fallout at each observation site.

(v) Meteorological observation at the terminus of glacier.

Similar observations on the Yala Glacier were made in autumn, 1982. (Watanabe *et al.*, 1984). However, only one season of observation is too short a period to clarify the process of accumuration and ablation of the glacier, and all-year observation is required.

## 3. Results and discussion

### *3. 1. Surface mass balance*

Observations on surface mass balance were carried out at each ovservation site, S 1-S 11, by stake method from August to November in 1985 as shown in Fig. 2. Daily precipitation and daily mean air temperature at B. H. (Base House, 3850m a. s. l.) during the

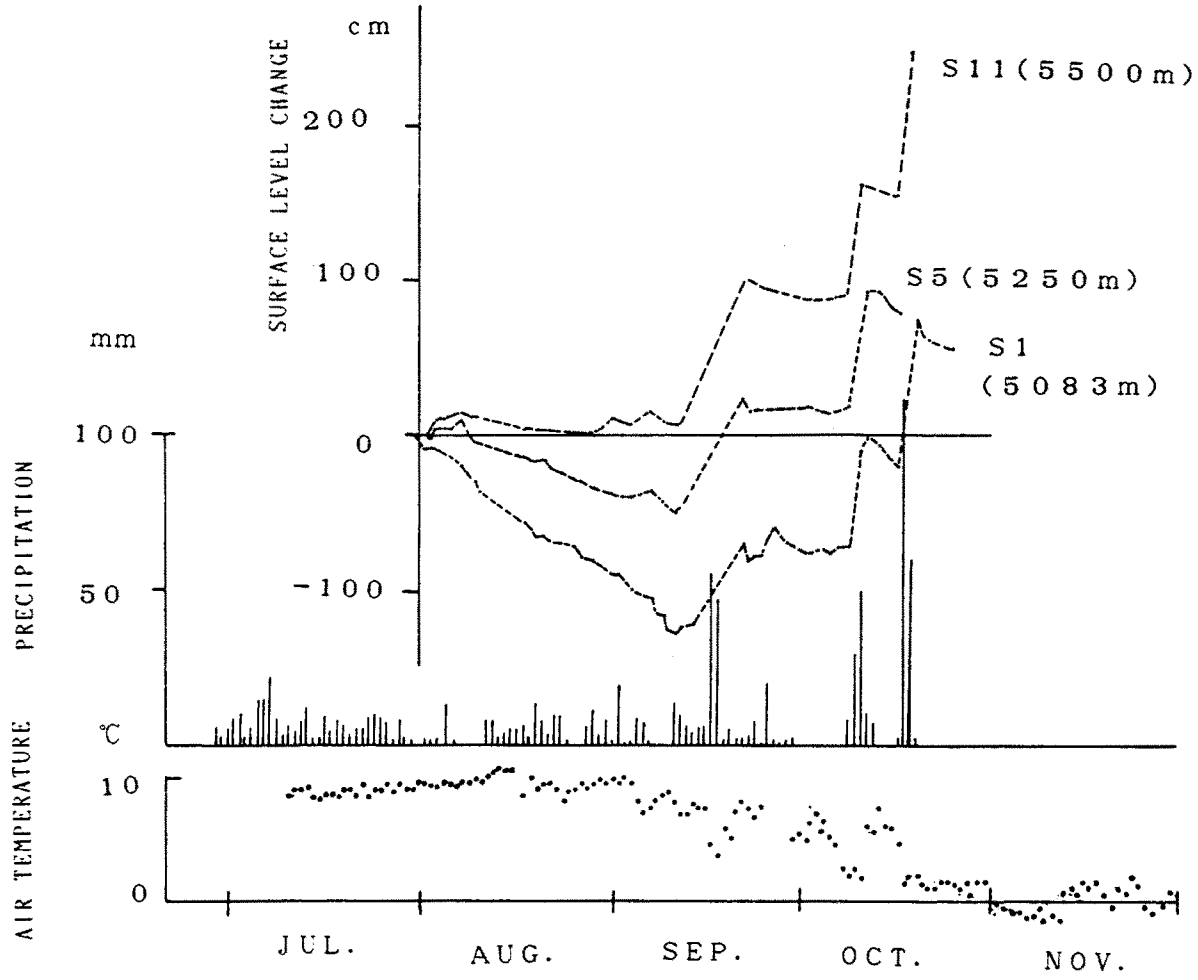


Fig. 2. The level change of the glacier surface and daily precipitation and air temperature at B.H. (Base House : 3850m a.s.l.).

period from July to November are also shown in Fig. 2.

The level of glacier surface decreased more than 100 cm at S 1 (5083m a. s. l.) during the period from the early August till the middle of September because of intense melting in the monsoon season. The level of S 5 (5250m a. s. l.) which is very near to the equilibrium line (5200m a. s. l.) (Watanabe *et al.*, 1984) had also remarkably decreaced until the middle of September. However, little variation of the level can be seen at S 11 (5500m a. s. l.).

In the middle of September, and around October 10th and 18 th, the surface level suddenly increased because of heavy snowfall of more than 50mm per day at B. H. (Base House, 3850m a. s. l.). These snowfalls increased the level of the glacier surface at S 11 (5500m a. s. l.) by more than 200cm. Air temperature fell drastically in every snowfall and after the snowfall of October 18th the fine weather period of the post-monnsoon season set in.

These results show considerable agreement with results of 1982 (Ageta *et al.*, 1984a), but precipitation during the period from September till October in 1985 is much larger. Heavy snowfalls in the post-monsoon season characterize the meteorological condition of 1985.

### *3. 2. Formation of the dirt layer*

Results of pit work of snowcover at S 7 (5333m a. s. l.) during the period of the monsoon and the post-monsoon seasons are shown in Fig. 3. as well as that at the terminus (5000m a. s. l.) of glacier in winter season. In the Fig. 3, DL indicates dirt layer and i indicates ice layer.

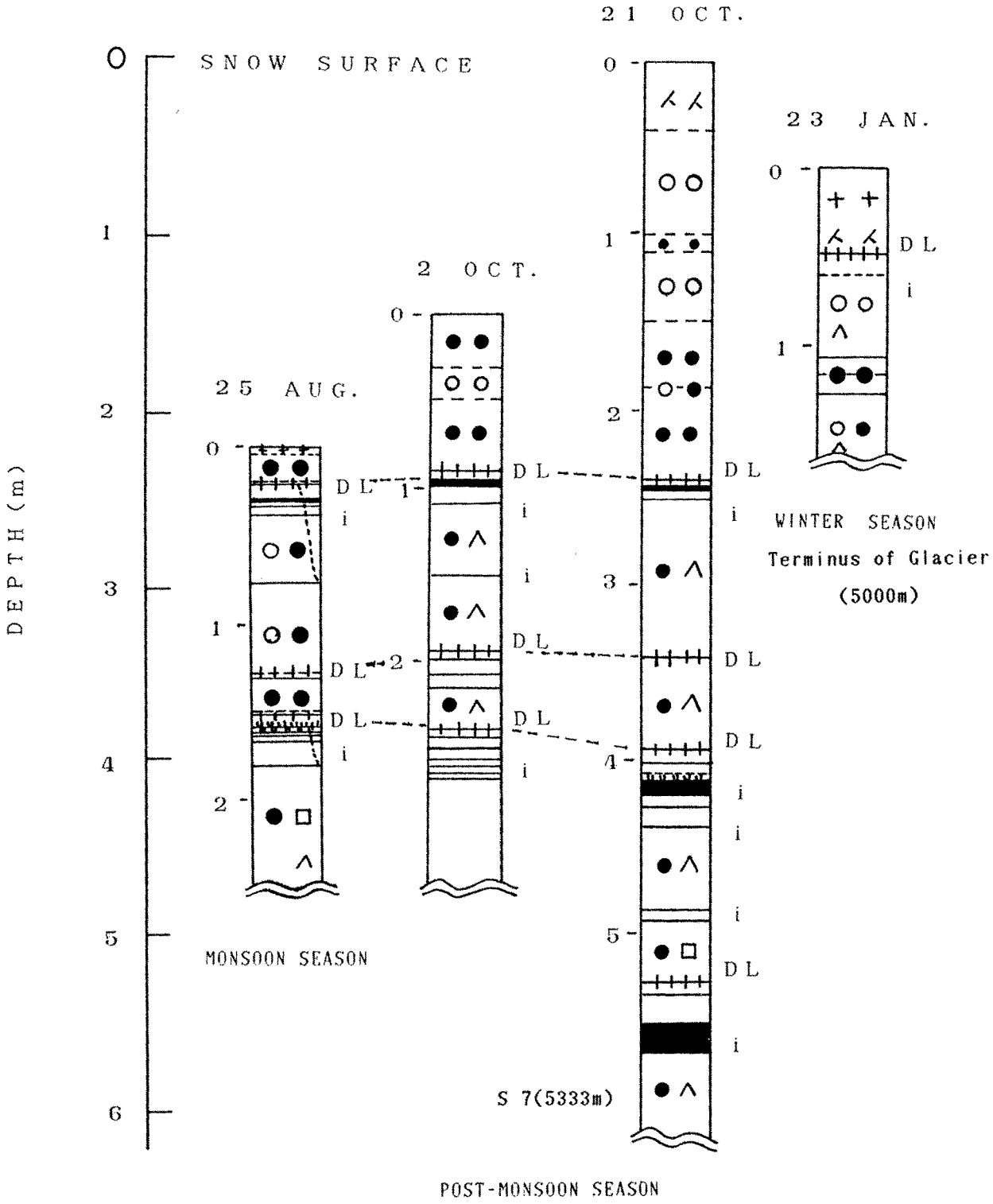


Fig. 3. The results of stratigraphic analysis during the period from monsoon season to winter season.
DL: dirt layer i: ice layer.

Three dirt layers seen within 2 m depth from the surface on 25 Aug. can be identified those in the pit on both 2 and 21 Oct. as shown in the figure. On 25 Aug., snowcover is thin above the uppermost dirt layer, while thick on 2 and 21 Oct caused by heavy snowfall after the end of August.

As seen in the Fig. 3, distinct dirt layer is often seen just above a thick ice layer or a group of ice layers. On the uppermost thick dirt layers of 25 Aug., 2 and 21 Oct. were deposited loose-bonding granular snow layers, composed of spherical snow grains of 1-3 mm in diameter. These results agree with those of the observation on Yala Glacier in Autumn 1982 (Iida *et al.*, 1984). It is considered that ice layers under dirt layers are formed by refreezing of percolated water of melted snow and rain during the pre and the early-monsoon season. Granular snow layers above dirt layers are considered to form through metamorphosis of waterlogged snow in the warm summer monsoon season. Therefore, we may say that distinct dirt layer is formed during the dry period before the early monsoon season. According to Fujii *et al.* (1976), the dirt layer should be formed during the period from the post-monsoon season to the pre-monsoon season, containing the dust particles blown from the dry ground in the surface snow layer. It is considered that the distinct dirt layer on Yala Glacier is formed by such a process.

However, there are some indistinct dirt layers, such as the second dirt layer of 2 and 21 Oct., and the first dirt layer nearest to the surface of 23 Jan.. The dirt layer of 23 Jan. are examined as follows :

It is generally considered that accumulation and ablation occur almost at the same time in the monsoon season in the Nepal Himalayas, winter being the dry season (Ageta, 1983). The winter season of 1985-1986, however, was very extraordinary, because there were three heavy snowfalls in Langtang Valley during the winter due to the passage of developing westerlies trough. The snowfall of December 25-27, 1985 recorded 81.7 mm and total snowfall of winter of 1985 -1986 amounted to 142 mm in water equivalent at B. H. (Base House, 3850 m). Stratigraphy on 23 Jan. shows the states of one month after the snowfall. On 23 Jan., a thin dirt layer was found 50cm below the glacier surface, granular snow and depth hoar were observed below the dirt layer and fresh and settled dry snow were observed above the dirt layer, water equivalent of snow above the dirt layer being 148 mm. Therefore, snow with high density below the dirt layer is considered to have deposited in Autumn, while snow above the dirt layer deposited in winter of 1985, that is, from 25 to 27 December.

Therefore, it came clear that every dirt layer is not formed by same process, but thin dirt layer is formed during the dry period of the post-monsoon season if a large amount of snow accumulation occurs in winter. In this case we expect the dirt layer has no granular snow layer above it and that dry fallout of the post-monsoon season is the main component of the dirt layer.

### *3. 3. Contents of the dirt layer*

Sampling of dust particles on the glacier surface of the ablation area and in dirt layers of the accumulation area were carried out. Our preliminaly results show that dust particle in the thick dirt layer consist of micro-plants, such as phormidium sp., and bacteria, not so different from those of the surface dust of the ablation area, and that about 10% of its dry weight is carbon (Kohshima, 1987).

It is likely that percolated water of melted snow and rain during the monsoon season estimated 74 cm water in all (Iida *et al.*, 1984) and shortwave radiation proliferate micro-plants in the dirt layer formed before the early monsoon season.

Micro-plants can be seen growing in the dirt layer formed during the post-monsoon season, but the amount is not so much as that before the early monsoon season. It is also expected that amount and species of plant in the dirt layer formed before the ealy monsoon season are different from those in the dirt layer formed during the post-monsoon season. We count it possible that components of the dirt layer may indicate the period of its formation (Khoshima, 1987).

### *3. 4. Accumulation-ablation process on Yala (Dakpatsen) Glacier*

Figure 4 is a diagram of estimated accumulation-ablation and formation of the dirt layer at S 9 (5417 m a. s. l.), S 7 (5333 m a. s. l.) and S 5 (5250 m a. s. l) on Yala Glacier throughout the year. Air temperature at S 9 (5417 m a. s. l.) is estimated by consulting air temperature at Kathmandu with the assumptions of sine curve seasonal variation, 13.0 ℃, annual range of July and January being the warmest and the coldest months, 0.6℃/100m of lapse rate of air temperature. As for precipitation as well, by consulting changes of precipitation in Timure (1676 m a. s. l., 23km west from Yala Glacier) (Ageta *et al.*, 1984b), sine curve

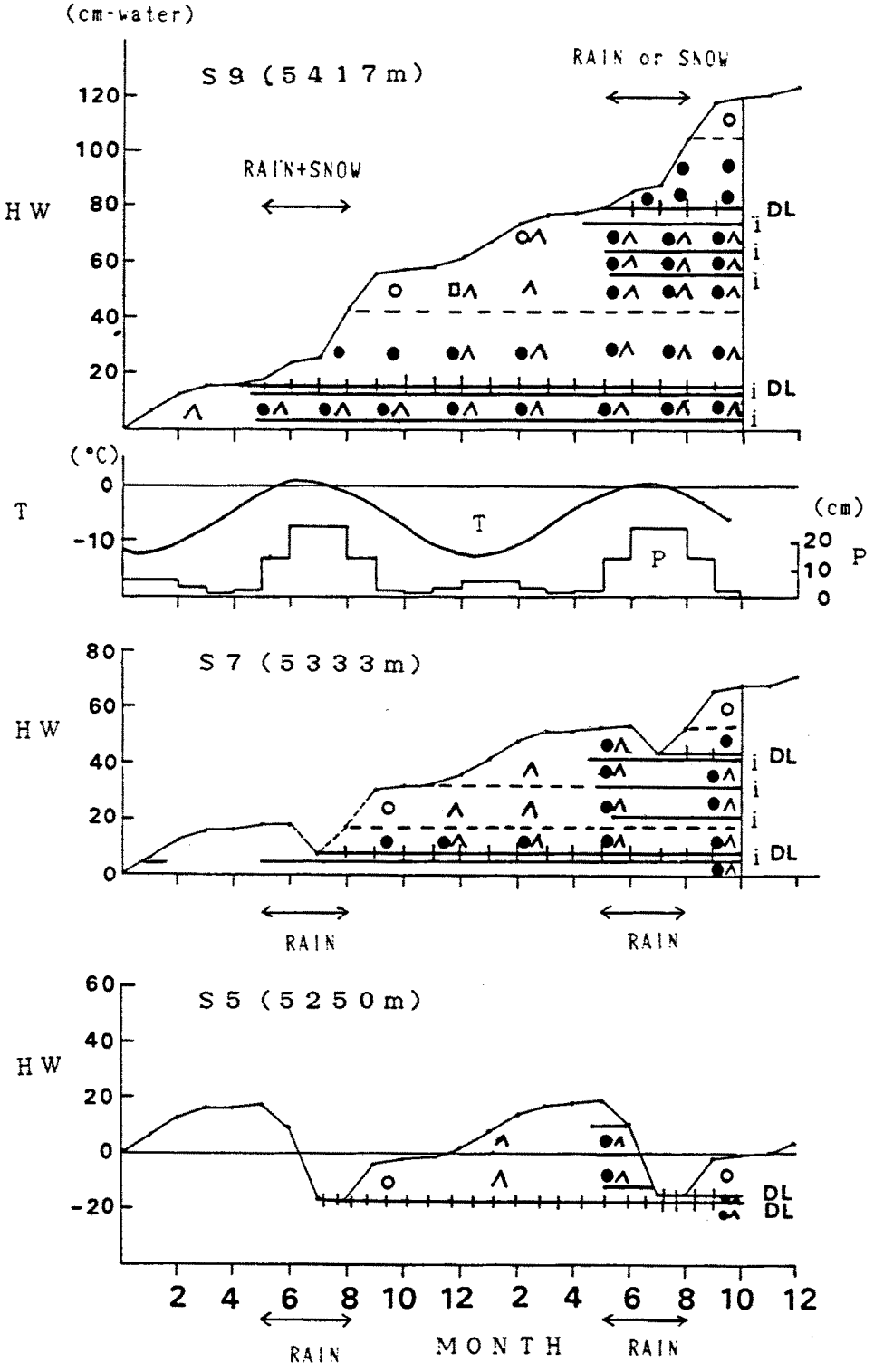


Fig. 4. Schematic diagram of accumulation-ablation and formation process of the dirt layer on Yala Glacier throughout the year.
DL: dirt layer i: ice layer

seasonal variation was adopted on the presumption that precipitation is 50cm and 20cm-water in summer and winter, and annual precipitation being 100cm-water.

On the basis of these models of annual changes in air temperature and precipitation, and Ageta's formula (Ageta, 1983), monthly accumulation, $c_m$ : and monthly ablation, $a_m$ ; can be expressed as below.

$c_m=0$ $T_m>3.5$℃
$c_m=p_m\ (0.85-0.24T_m)$ $3.5$℃$\geqq T_m\geqq -0.6$℃
$c_m=p_m$ $T_m<-0.6$℃
$a_m=-0.3(T_m+3.0)^{3.2}$ $T_m>-3.0$℃
$a_m=0$ $T_m\leqq -3.0$℃

Mass balance at each observation site on the glacier is calculated, shown as curves of water equivalent of snow on the diagram.

Judging from the diagram, at S 9 (5417 m a. s. l.) in the accumulation area dry fallout of the dry priod of the previous post-monsoon, winter and the pre-monsoon season forms thick dirt layer and accumulation occurs above this dirt layer in the monsoon season. The similar process is thought to occur at S 7 (5333m a. s. l.), while a considerable amount of ablation occurs in the monsoon season and the glacier surface rapidly becomes dirt. At S 5 (5250m a. s. l.) which is very near to the equilibrium line, ablation increases in the monsoon season and the dirt layer became difficult to recognize as annual layer.

It can be said that thin dirt layer, which the authors observed in winter of 1985−1986, formed by dry fallout in the dry period of the post-monsoon season, is formed at the plateau stage of the post-monsoon season on the curve in Fig. 4. In case of a large amount of snowfall in winter like the winter season 1985−1986, it seems that the dirt layer formed in the post-monsoon season is distinguished from the one formed during the dry period of winter and the pre-monsoon season.

Miller *et al.* (1965) indicated the possibility of two strata being deposited annually in Nepal Himalayas by their observation of the Khumbu Glacier of Mt. Everest (Chomolongma massif). He explains that there are two main accumulation processes. In the monsoon season the deposition is by direct snowfall, in winter, the lesser direct snowfall is sapplemented by the wind of jet stream deposition of the winter snow from the exposed faces of the surrounding Chmo-longma massif.

In the case of Yala Glacier, there is a possibility that formation of the dirt layer occurs twice a year by direct snowfall in the monsoon season and winter. Accumulation process on Yala Glacier is differrent from that of Miller's result.

### *3. 5. Annual accumulation on Yala (Dakpatsen) Glacier*

Table 1 ( i ) shows water equivalent of snow between dirt layers, which was obtained through pit work of surface snowcover at each observation site on Yala (Dakpatsen) Glacier. Table 1 ( ii ) shows precipitation at each observation site of 9−10 Oct. and 17−18 Oct.. Little dependence of precipitation upon the altitude can be seen. According to the table, on the assumption that thick dirt layers are formed once a year, annual accumulation at a site with an al-titude of 5333m a. s. l. is estimated as follows.

1984 44.6 g/cm²
1983 21.7 g/cm²
1982 65.0 g/cm²

Extremely little accumulation occured in 1983.

Table 1.(i) Water equivalent of snow between two neighboring dirt layers at each observation site on Yala Glacier.

| | SNOW SURFACE ~ THE 1ST.DL | THE 1ST.DL ~ THE 2ND.DL | THE 2ND.DL ~ THE 3RD.DL | THE 3RD.DL ~ THE 4TH.DL |
|---|---|---|---|---|
| | (g/cm²) | | | |
| S 11 | 97.5 | 65.2 | 30.7 | 60.2 |
| S 10 | | 57.0 | | |
| S 9 | | 49.6 | | |
| S 8 | | | | |
| S 7 | 77.0 | 44.6 | 21.7 | 65.0 |
| S 6 | 63.7 | 25.9 | | |
| S 5 | | | | |
| S 4 | | | | |
| S 3 | 50.5 | | | |
| S 2 | 52.1 | | | |
| S 1 | 46.2 | | | |

Table 1.(ii) Precipitation of October, 9-10 and October, 17-18 at each observation site on Yala Glacier.

| OBSERVATION SITE | 17 OCT. ~ 18 OCT. | 9 OCT. ~ 10 OCT. | THE 1st.DL ~ 8 OCT. |
|---|---|---|---|
| | ($g/cm^2$) | | |
| S 1 1 | 21.5 | 15.2 | 60.8 |
| S 1 0 | | | 44.6 |
| S 9 | | | 48.3 |
| S 8 | | | |
| S 7 | 21.9 | 16.3 | 38.8 |
| S 6 | 19.6 | 12.1 | 32.0 |
| S 5 | 21.8 | 12.6 | 20.0 |
| S 4 | | | 22.9 |
| S 3 | 18.5 | 13.1 | 18.9 |
| S 2 | 19.0 | 15.8 | 17.3 |
| S 1 | 18.2 | 10.8 | 17.2 |

Similar characteristics of the accumulation is shown at the uppermost site S 11 (5500m a. s. l.). The stratigraphic diagram around the second dirt layer (Fig. 3) shows the second dirt layer, which is thin, has no ice layers below it. At S 6 (5300m a. s. l.), there is a possibility that the second dirt layer was absorved in the third dirt layer. Therefore, the second dirt layer is thought to be formed in the dry period of the post-monsoon season that was previously mentioned above. If the second dirt layer is the dirt layer formed in the post-monsoon season, it follows that annual accumulation in the period of 1984 at S 7 (5333m a. s. l.) is 66.3 $g/cm^2$, and this numeral value is near 65.0$g/cm^2$.

## 4. Concluding remarks

It is considered that distinct dirt layers are formed by dry fallout during the dry period from the post-monsoon to the pre-monsoon season on Yala (Dakpatsen) Glacier. However, thin dirt layer can be formed in the post-monsoon season, if there is a large amount of snow accumulation in winter.

Contents of the dirt layer consist of Micro-plants, such as *phormidium* sp., bacteria, and minerals. It is found that the rate of organic materials content is relatively high. Micro-plants can be seen growing in the dirt layer.

Annual accumulations at a site of 5333m a. s. l. on Yala (Dakpatsen) Glacier are estimated 65.0$g/cm^2$ in 1983 and 66.3$g/cm^2$ in 1984 by mesurering water equivalent of snow between distinct dirt layers.

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