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Characteristics of cryoconite holes on a Himalayan glacier, Yala Glacier Central Nepal

Nozomu TAKEUCHI[1], Shiro KOHSHIMA[1], Yoshitaka YOSHIMURA[2], Katsumoto SEKO[3], and Koji FUJITA[3]

1 Basic Biology, Faculty of Bioscience and Biotechnology, (c/o Faculty of Science), Tokyo Institute of Technology, 2-12-1, Ookayama, Meguro-ku, Tokyo 152-8551 Japan

2 Mitsubishi Institute of Life Sciences, 11 Minamiootani, Machida, Tokyo 194-8511 Japan

3 Institute for Hydrospheric-Atmospheric Sciences, Nagoya University, Nagoya 464-8601 Japan

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Abstract

Cryoconite holes, water-filled cylindrical melt-holes on ice, are common features of glaciers. Morphology, distribution, stability, and organisms of cryoconite holes on a Himalayan glacier (Yala Glacier, Langtang region of Nepal) were investigated. On this glacier, cryoconite holes were distributed in the bare-ice area from 5110 m to 5240 m a.s.l. in altitude. Their size ranged 3.0 - 12.0 cm in depth (mean 5.3 cm), 1.0-36.0 cm in diameter (mean 7.0 cm). At flat bottom of the holes, dark colored mud -like material (cryoconite) was deposited. The material contained much filamentous blue-green algae and organic matter. Besides the blue-green algae, green algae, copepods, and insect larvae were found in the holes.

Twenty-five days observation of 17 holes revealed that cryoconite holes on this glacier were short -lived and unstable; 13 holes were broken during the observation period. Hole-depth increased as albedo of the ice surface surrounding the holes increased by snowfall. Altitudinal increase of hole -depth and relationship between hole-depth and heat balance at the glacier surface, both of which have been reported on glaciers of other region, were not observed in this glacier. Negative correlation between hole-diameter and surface inclination suggests that life span of the holes on steep slopes is shorter than those on gentle slopes. Results suggest that cryoconite holes of this glacier were shallow and unstable because albedo of the glacier surface was reduced by much dark-colored material and it could drastically change by snow falls and/or relocation of the material.

1. Introduction

Cryoconite holes, water filled cylindrical melt -holes on ice, have been reported from glaciers in many parts of the world: Arctic, Antarctic, Greenland, Canada, Tibet, and Himalayas. (Willem and Els, 1994; Wharton *et al.*, 1981; Wharton *et al.*, 1985; Gribbon, 1979; Kohshima, 1989; Kohshima, 1987b). At bottom of the cryoconite holes, dark colored material called cryoconite is deposited. As the cryoconite absorbs solar radiation and promotes melting of the ice beneath it, the cylindrical holes are formed (Fig. 1).

Cryoconite holes have been suggested to play important roles in the glacier ecosystems because many kinds of living organisms have been reported from this structure on the glaciers, for example, algae, rotifer, tardigrada, insects and ice worm. Wharton *et al.* (1985) suggested that cryoconite holes are individual ecosystems with distinct boundaries, energy flow, and nutrient cycling. Cryoconite holes of Himalayan glaciers were also reported to provide semi-stagnant aquatic habitats to various organisms on the glacier such as algae, insects and copepods (Kohshima, 1987b; Yoshimura, 1997). Thus, it is important to know the basic characteristics of Himalayan cryoconite holes, such as morphology, distribution, and stability, to

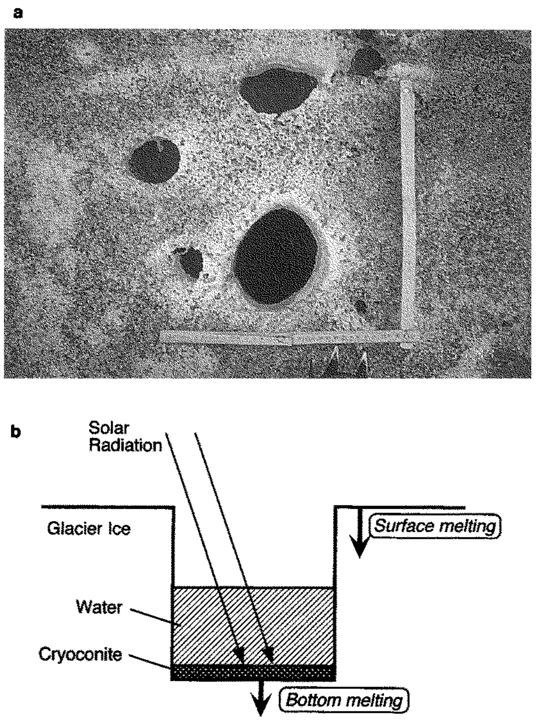

Fig. 1 Cryoconite holes on Yala Glacier (**a**; 5240 m; 31 July 1994) and schematic cross section of a cryoconite hole (**b**).

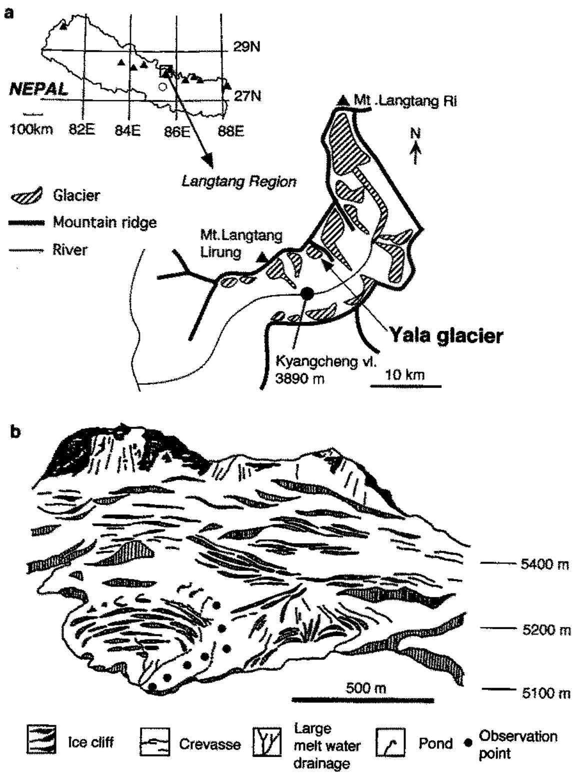

Fig. 2 Location (**a**) and a schematic map (**b**) of Yala Glacier showing observation points of cryoconite holes.

understand the glacier ecosystem of this region. However, no study has been done on cryoconite holes in Himalayan glaciers.

This study aimed to clarify the characteristics of cryoconite holes observed on a Himalayan glacier. Their morphology, distribution pattern on the glacier, daily change in their size, and organisms living in the holes were investigated. Based on the results and heat balance observation, stability and factors affecting size of Himalayan cryoconite holes were discussed.

2. Field description and methods

2.1 Study site

Research was carried out in Yala Glacier (5110 m -5700 m a.s.l. in altitude, Fig. 2), Langtang region, Central Nepal, between 28 July and 21 August 1994 during monsoon season. This glacier is a plateau shaped small glacier without rock debris cover. The equilibrium line in the study period was at about 5300 m in altitude. The ice surface was exposed at the ablation area (5110 m-5240 m a.s.l.) during the study period. In this glacier, 11 species of snow algae, 2 midge species and 1 copepod species have been reported (Kohshima, 1984a; 1984b; 1987a; and 1987b; Yoshimura *et al.*, 1997).

2.2 Observations of cryoconite holes

Maximum diameter, depth, water-level from bottom, and deposit thickness of cryoconite holes were measured with a scale at 7 areas of different altitude (5110 m, 5130 m, 5150 m, 5160 m, 5180 m, 5210 m, and 5240 m a.s.l.). At each area, 10-14 holes larger than 1 cm in diameter were measured. The measurements were carried out in the morning (9 : 00-12 : 00). At the observation areas, maximum inclination of the glacier surface was measured with a portable clinometer (mean of five points).

The size of 17 cryoconite holes (11 at 5150 m a.s.l. and 6 at 5240 m a.s.l.) was monitored from 28 July to 21 August (25 days). Longest diameter, depth, water level, and deposit thickness were measured once a day in the morning (7 : 00-11 : 00).

Sediments of cryoconite holes (cryoconite) were sampled with a pipette and kept in plastic bottles with

3 % formalin solution. The samples were transported to Japan. Organisms (microbes) and structure of the cryoconite were analyzed with a microscope.

2.3 Meteorological measurement and heat balance calculation

Air temperature (Pt thermo-sensor), and upward and downward short-wave radiation were measured at 5240 m on the glacier during the observation period. These sensors were installed at 100 cm above the glacier surface. The average values of every 10 minutes were logged with a data-logger (DATAMARK 3000ptv, Hakusankogyo Co.).

Heat balance at 5240 m a.s.l. is calculated. Basic equation of heat balance on the glacier surface is described as:

$$MH = NR + SH + LH,$$

where MH is heat used for melt, NR is net radiation, SH is turbulent sensible heat, LH is turbulent latent heat.

All components in right side are positive when fluxes are directed towards the surface. Heat supplied with rain and heat conducted into/from the glacier are neglected in the equation. Net radiation consists of:

$$NR = SR^{\downarrow} - SR^{\uparrow} + LR^{\downarrow} - LR^{\uparrow},$$

where $SR^{\downarrow}$ is incoming short-wave radiation, $SR^{\uparrow}$ is outgoing short-wave radiation, $LR^{\downarrow}$ is incoming long-wave radiation, $LR^{\uparrow}$ is outgoing long-wave radiation.

Both short-wave radiation were observed at 5240 m a.s.l. Outgoing long-wave radiation is calculated from the temperature of glacier surface as:

$$LR^{\uparrow} = \varepsilon\sigma(T_s + 273.2)^4,$$

where ε is emissivity of ice (1), σ is Stefan-Boltzman constant (5.67×10^{-8} W m^{-2} K^{-4}), T_s is temperature of glacier surface (°C).
Since the surface was always wet ($T_s = 0$) during the calculation period (26 July to 27 August, 1994), outgoing long-wave radiation is considered to be constant as 315.6 W m^{-2}.

Incoming long-wave radiation is evaluated from following equations presented by Kondo (1994).

$$LR^{\downarrow} = \sigma(T_a + 273.2)^4 \left[1 - \left(1 - \frac{R^{\downarrow}_{df}}{\sigma(T_a + 273.2)^4}\right) C\right]$$

$$C = 0.03B^3 - 0.30B^2 + 1.25B - 0.04, \quad B \geq 0.0323:$$

$$= 0, \quad B < 0.0323:$$

with $B \equiv SR^{\downarrow} / SR^{\downarrow}_c$

where T_a is air temperature (℃), $R^{\downarrow}_{df}$ is global long-wave radiation in clear day, and $SR^{\downarrow}_c$ is global solar radiation in clear day. The influence of cloud for $LR^{\downarrow}$ is evaluated by this empirical equation derived on the basis of the ratio, B, of global short-wave radiation observed to that theoretically calculated on clear days.

Turbulent sensible and latent heat fluxes are described by the bulk method as:

$$SH = c_p \rho_a C U (T_a - T_s),$$
$$LH = l_e \rho_a C U (h_r q_a - q_s),$$

where c_p is specific heat for air (1006 J kg^{-1} K^{-1}), ρ_a is density of air (kg m^{-3}), C is bulk coefficient (0.002; Yamazaki *et al.*, 1993), U is wind speed (m s^{-1}), T_a is air temperature (°C), l_e is latent heat for evaporation (2.50×10^6 J kg^{-1}), h_r is relative humidity (non dimension), $q_{a,s}$ is saturated specific humidity of air ($_a$) and surface ($_s$) (non dimension).

Air temperature was observed at 5240 m a.s.l. Wind speed and relative humidity are assumed to be equal to those observed at Glacier Camp (GC, 5100 m a.s.l.). Saturated specific humidities of air and surface are calculated from air temperature. Daily mean value of air temperature, relative humidity, incoming and outgoing short-wave radiations are used as the input variables.

3. Results

3.1 Morphology, size, and distribution of cryoconite holes on the glacier

Cryoconite holes were distributed in the bare-ice area between 5110 m (lower terminus of the glacier) and 5240 m a.s.l. on this glacier. Cryoconite holes observed in this glacier were almost circular or ellipsoid shape in horizontal section. Size of cryoconite holes ranged 3.0-12.0 cm in depth (mean 5.3 cm), 1.0-36.0 cm in diameter (mean 7.0 cm). Water depth ranged 0.1-6.1 cm (mean 1.9 cm).

Number density of cryoconite holes was not uniform on the glacier surface. Cryoconite holes were frequently found (approximately 5-20 holes m^{-2}) on the flat area where inclination of the glacier surface was less than 12 degree, but few cryoconite holes (less than 1 holes m^{-2}) were found on steep slopes where inclination of the glacier surface was more than 17 degree.

Table 1 Data of cryoconite holes in different altitude of Yala Glacier, 1994.

Altitude (m)	Surface inclination (degree)	Observed date	Number of observed holes	Mean diameter (cm)	Mean depth (cm)	Mean water level (cm)	Mean deposit thickness (cm)
5110	7.6	21 Aug	9	6.3	5.8	2.4	0.3
5130	18.7	21 Aug	4	3.0	5.1	1.0	0.3
5150	11.7	20 Aug	13	6.6	6.8	1.9	0.3
5160	17.4	20 Aug	12	4.1	4.3	0.8	0.3
5180	7.3	17 Aug	11	8.1	4.8	1.9	0.2
5210	23.3	14 Aug	3	4.0	5.2	2.4	1.2
5240	5.0	4 Aug	14	11.4	4.9	2.4	0.3

Table 1 shows the mean size of cryoconite holes observed at 7 observation areas of different altitude. The size of the cryoconite holes differed among the areas, particularly, in diameter, depth, and water level. Thickness of deposits was thin at 6 areas (approximately 0.3 cm), but thick at 5210 m (1.2 cm), where the holes were often connected with melt-water streams and the deposition was probably conveyed from upstream area.

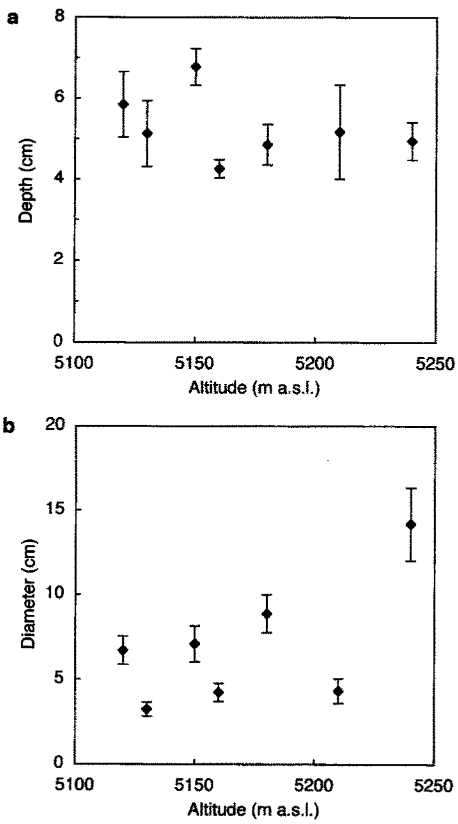

Fig. 3 Altitudinal distribution of depth (**a**) and diameter (**b**) of cryoconite holes in Yala Glacier. (Error bar = standard error, sample number = see table 1)

Figure 3 shows altitudinal change of the depth and diameter of cryoconite holes. A statistical analysis (one-way analysis of variance) revealed that both depth and diameter significantly varied among the observation areas (variance ratio (F) = 2.26, probability (P) = 0.032 < 0.05; F = 2.26, P = 0.000 < 0.05, respectively). However, neither depth nor diameter correlated with altitude (Sperman's correlation coefficient (r_s) = -0.24, P > 0.05; r_s = 0.14, P > 0.05, respectively).

Figure 4 is the relationship between the diameter and the surface inclination of the observation areas. There was a negative correlation (r_s = -0.86, P < 0.05), which means a cryoconite hole with small diameter tended to be observed on a steep slope, and large one is on a flat surface.

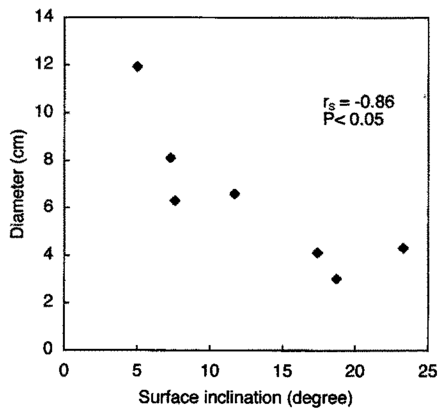

Fig. 4 Relationship between hole-diameter and surface inclination of Yala Glacier.

3.2 Sediments and living organisms in cryoconite holes

At flat bottom of cryoconite holes, dark colored mud-like material (cryoconite) was deposited (0.1–3.0 cm in thickness, mean = 0.3 cm). Most of the cryoconite consisted of dark colored small granules ranging from 0.1 to 3.0 mm in diameter (mean 0.5 mm, standard division=0.2). The dark colored material was also observed on ice surface around the cryoconite holes. The amount of the dirt material on the surface varied from 50 to 900 g m^{-2} in dry weight (mean 300 g m^{-2}). The granules contained organic matter (5.4-9.9 % in dry weight, mean 7.8 %). Microscopy of ultra-sonicated cryoconite revealed that the cryoconite contained 2 kinds of filamentous blue-green algae (Oscillatoriacean algae).

Besides the blue-green algae, four species of algae were observed in cryoconite holes separated from the granules. The algae most commonly observed in cryoconite holes were *Cylindrocystis brēbissonii* (green algae) and *Mesotaenium berggrenii* (green algae). A few cells of *Raphidonema* sp., *Ancylonema* sp. were also observed. These algal communities were similar to the communities which was classified as ice environment algae reported by Yoshimura *et al.* (1997).

Red colored copepods (*Glaciella yalensis*, reported by Kikuchi (1996)) and larvae of midge (insect, *Diamesa* sp. reported by Kohshima (1984a)) were observed in the cryoconite holes located 5110-5200 m a.s.l. of the glacier. They were also observed in melt water streams on the glacier surface. Microscope observation revealed that a rotifer (unknown species) and a tardigrada (unknown species) were also contained in the cryoconite.

3.3 *Daily change of cryoconite holes*

Table 2 shows data of the cryoconite holes monitored at 5150 m (11 holes) and at 5240 m (6 holes) from 28 July to 21 August (25 days). During the monitoring period, 13 of 17 cryoconite holes collapsed. Ratio of the collapsed holes differed between the two sites. All holes (11 of 11 holes) collapsed at 5150 m, whereas 2 of 6 holes collapsed at 5240 m.

Breakdown of the cryoconite holes was mainly caused by melt-water flow on the glacier surface. In the daytime, melt-water streams often flowed into cryoconite holes, melt the wall, and washed out the cryoconite at the bottom. The breakdown by melt-water flow occurred in all of the 11 holes at 5150 m. Another way of the breakdown was caused by depth reduction, which is probably due to the change in melting conditions. This type of breakdown occurred in 2 holes at 5240 m.

After the breakdown of the holes, cryoconite particles were scattered over the surface and they started to form small pits. New cryoconite holes developed again from these small pits.

Figure 5 shows daily change in mean depth and diameter of 6 cryoconite holes observed at 5240 m. The depth and the diameter changed in the range from 2.7 to 6.8 cm (mean 4.0 cm), from 6.5 to 12.2 cm (mean 9.3 cm) during the period, respectively. A statistical analysis (one-way analysis of variance) revealed that the depths were significantly different among the days ($F=1.64$, $P=0.0002<0.05$), but the diameters were not

Table 2 Decay of cryoconite holes monitored during 25 days at 2 altitude in Yala Glacier, 1994.

No.	Altitude (m)	Surface inclination (degree)	Start of observation	Date of decay	Observed span (days)	Mean diameter (cm)	Mean depth (cm)
1	5240	5	28 Jul	–	>25	6.8	3.0
2		5	28 Jul	–	>25	9.9	4.2
3		5	28 Jul	–	>25	7.1	3.7
4		5	28 Jul	7 Aug	11	4.3	3.3
5		5	28 Jul	-	>25	13.6	5.9
6		5	28 Jul	7 Aug	11	3.1	5.0
7	5150	12	28 Jul	30 Jul	3	4.6	2.9
8		12	28 Jul	30 Jul	3	11.3	6.7
9		12	28 Jul	29 Jul	2	4.4	6.0
10		12	28 Jul	2 Aug	6	7.0	6.0
11		12	28 Jul	30 Jul	3	3.8	5.7
12		12	28 Jul	31 Jul	4	6.3	6.3
13		12	8 Aug	15 Aug	10	1.9	5.5
14		12	8 Aug	16 Aug	11	6.3	8.8
15		12	8 Aug	16 Aug	11	3.0	No data
16		12	8 Aug	16 Aug	11	4.4	7.8
17		12	8 Aug	16 Aug	11	2.2	No data

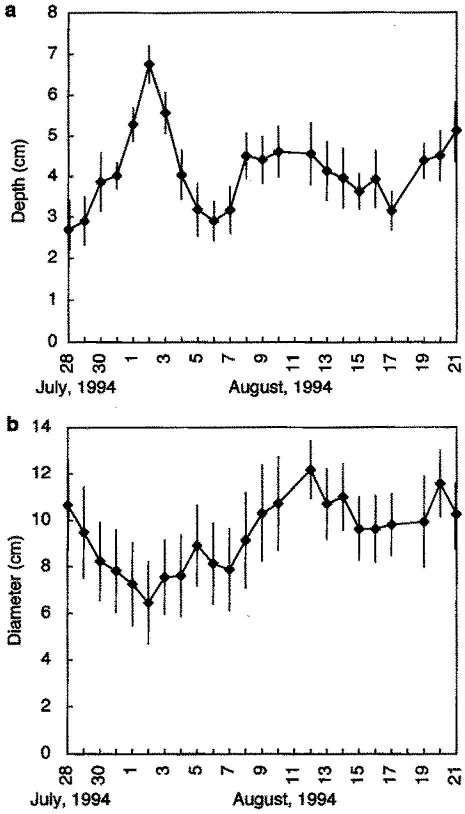

Fig. 5 Daily depth (**a**) and diameter (**b**) change of cryoconite holes at 5240 m. (11 Aug: no data; Error bar=standard error; sample number=6 (28 Jul-6 Aug), =5 (7 Aug-21 Aug))

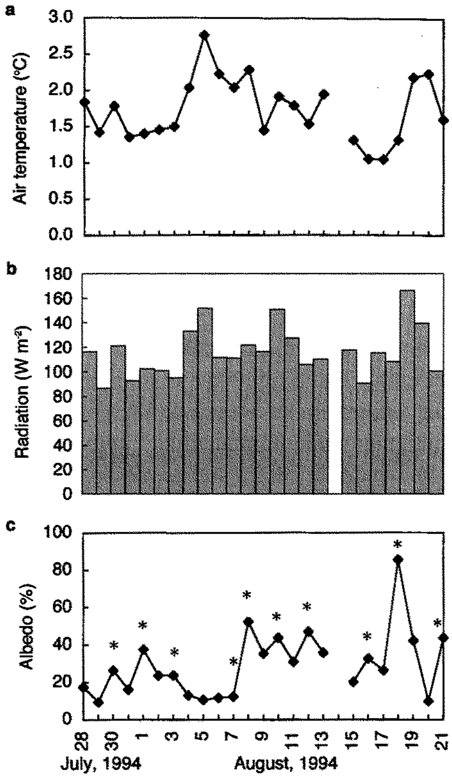

Fig. 6 Meteorological data at 5240 m in Yala Glacier (14 Aug: no data). Daily mean air temperature (**a**), daily mean downward short-wave radiation (**b**), and daily mean albedo of the glacier surface (**c**). Asterisks (*) denote the day when the glacier surface was covered with snow.

significantly different among the days (F=1.64, P=0.872>0.05).

3.4 Meteorological data and heat flux at glacier surface

Figure 6 shows the changes in daily mean air temperature, solar radiation and surface albedo at 5240 m. Daily mean air temperature, solar radiation, and surface albedo during the study periods ranged from 1.1 to 2.8 °C (mean 1.7 °C), from 87 to 166 W m^{-2} (mean 116 W m^{-2}), from 9 to 86 % (mean 29 %), respectively. Sudden increase of albedo was due to snowfall, which occurred when the surface was covered with new snow.

Figure 7 shows the heat flux components at the surface of 5240 m, calculated from the meteorological data. Net radiation, sensible heat, latent heat varied from 32.1 to 150.9 W m^{-2} (mean 62.5 W m^{-2}), from 0.3 to 10.4 W m^{-2} (mean 2.3 W m^{-2}), from -1.9 to 8.8 W

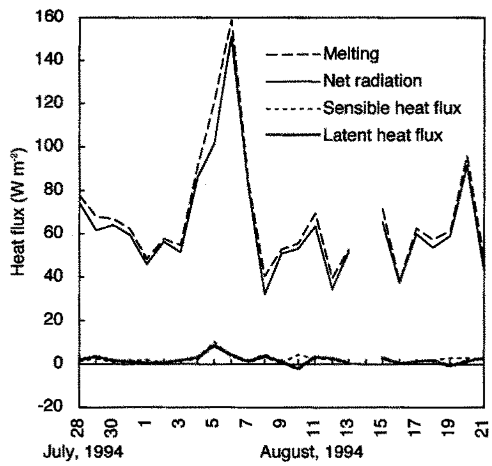

Fig. 7 Changes in daily mean of heat balance components at 5240 m in Yala Glacier, 1994 (14 Aug: no data).

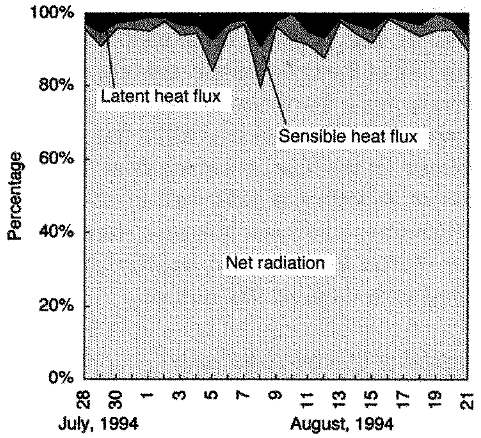

Fig. 8 Change of percentage of heat balance components in total heat income flux at 5240 m in Yala Glacier (14 Aug: no data).

m^{-2} (mean 2.0 W m^{-2}), respectively. Heat for melt was ranged from 34.3 to 158.9 W m^{-2} (mean 66.8 W m^{-2}).

Figure 8 shows the percentage of each heat source in the total income heat-flux to the glacier surface. Although the percentage of sensible heat and latent heat changed slightly, net radiation kept dominant in the income heat flux (more than 80 %) throughout the study period.

3.5 Correlation between hole size and heat-flux conditions

Table 3 shows Pearson's (liner) correlation coefficients between hole size (daily mean at 5240 m) and heat flux conditions. The hole-depth was not correlated with the percentage of net radiation, sensible heat, nor latent heat. However, the hole-depth was positively correlated with albedo of the glacier surface, and negatively correlated with the net radiation and the melting heat. In contrast, the hole-diameter showed no correlation with any meteorological factors studied.

Table 3 Correlation coefficient between sizes of cryoconite holes and meteorological conditions on Yala Glacier. Asterisks (*) denote $P<0.05$.

	Depth	Diameter
Net radiation (%)	0.033	−0.129
Sensible heat (%)	0.043	0.149
Latent heat (%)	−0.110	0.082
Net radiation (W m^{-2})	−0.464*	−0.253
Sensible heat (W m^{-2})	−0.227	0.015
Latent heat (W m^{-2})	−0.367	−0.093
Melting heat (W m^{-2})	−0.473*	−0.240
Downward short -wave radiation (W m^{-2})	−0.114	0.265
Albedo (%)	0.461*	0.292
Air temperature (°C)	−0.194	0.040

4. Discussion

4.1 Size of cryoconite holes

4.1.1 Hole-depth

According to McIntyre (1984), depth of cryoconite hole increases as net radiation become dominant in heat-flux at glacier surface. Hole-depth increases when hole-bottom melts faster than the ice surface surrounding the hole (see Fig. 1). Because of lower albedo at the hole-bottom relative to the ice surface surrounding the hole, melting by radiation at the hole -bottom is larger than that of the ice surface. On the other hand, sensible and latent (condensation) heat are added to heat budget on the ice surface around the holes, but not on the hole-bottom. Therefore, hole -depth increases when radiation is dominant in income heat-flux, whereas, it decreases when sensible and/or latent heat is dominant. According to this consideration, hole-depth would increase with altitude because sensible heat decreases with altitude as air temperature decreases with altitude, but radiation is almost independent of altitude. In fact, hole-depth in Greenland glaciers was reported to increase with altitude (Gribbon, 1979). However, in Yala Glacier, such tendency of hole-depth increase with altitude was not observed. Furthermore, daily change in hole -depth was not related with the ratio of heat budget components. Since the radiation always dominated in the total heat flux (more than 80 % of heat input, Fig. 8), it is expected that the hole-depth would keep increasing during the observation period. However, the hole-depth did not keep increasing (Fig. 5). These facts suggest that hole-depth is controlled by other factors in this glacier.

The positive correlation between hole-depth and albedo of the glacier surface suggests that variation of surface albedo is responsible for hole-depth change. Since the radiation was the main heat source for melting at the glacier surface, the albedo change could affect melting speed of the ice surface surrounding the cryoconite hole. Therefore, albedo change at the glacier surface is likely to cause the daily change in the hole-depth. Negative correlations of the hole-depth with melting heat and with net radiation income at the surface also support this idea.

The daily albedo change is likely due to snowfall on the glacier surface. Just after the surface is covered with new snow, which has high albedo (70-90 %), the albedo would be high, and would decrease as the snow cover melts. In fact, the timing of albedo increase well agreed with the timing of snowfall events (Fig. 6). This means that cryoconite holes on this glacier tend to become deeper just after snowfall and become shallower as the snow cover melts.

The irregular altitudinal distribution of hole-depth observed in the glacier may be due to spatial variation of surface albedo. In this Glacier, surface albedo of the ablation area is substantially decreased by dark-colored material, and varies from 5 to 30 % depending on density of the material (material amount per unit area, Kohshima *et al.*, 1993). The irregular altitudinal distribution is probably due to the density variation of the mud-like material on the glacier surface.

4.1.2 Hole diameter

According to Wharton *et al.* (1985), diameter of a cryoconite hole is enlarged by radiation absorbed by water in the hole. However, significant enlargement was not observed in this glacier in spite of high radiation input during the study period. Furthermore, the daily variation of hole-diameter was not correlated with radiation, any other meteorological conditions, nor heat balance compornents. These facts suggest that the effect of these heat factors on hole-diameter was small.

Horizontal growth of cryoconite holes has been reported to occur through fusions of holes locating close each other (Gerdel and Drouet, 1958; McIntyre, 1984). In this glacier, such hole-fusions were often observed at 5150 m during the 25 days observation. In many cases, small cryoconite holes (1-2 cm in diameter) was observed to fuse into an enlarged hole (3-9 cm in diameter) within several days. Therefore, the diameter of cryoconite hole on this glacier likely grows by fusions. Since fused holes are not divided again and remarkable decrease in hole-depth was not observed, diameter of cryoconite holes are likely to enlarge with time.

The negative correlation between hole-diameter and inclination of glacier surface observed in this glacier can be explained by the different life span of the holes among observation areas. The cryoconite hole on a slope seems to be shorter life span than the holes on flat surface. Because the cryoconite holes on a slope were fed by much melt-water from upstream of the slope. The inflow of much melt-water is likely to cause loss of the cryoconite in the hole and collapse of the hole-wall. Furthermore, since the bottom of cryoconite holes is horizontally flat, horizontal enlargement of the hole on a steep slope should cause collapse of downstream-side wall of the cryoconite hole. Therefore, cryoconite hole on a steep slope tends to have shorter life span and smaller hole-diameter compared with those of flat surface.

4.2 Instability of cryoconite holes

Our observation revealed that life span of the cryoconite holes on this glacier was much shorter than those reported on glaciers in other regions. For example, a life span of 100-200 years was suggested to be possible for cryoconite holes on Greenland glaciers (Nobles, 1960). In contrast, in Yala Glacier, 7 of 11 holes (76 %) collapsed and 5 new holes formed in the observation area during 25 days. These facts suggest that cryoconite holes on this glacier are unstable and repeat collapse and formation.

The life span of cryoconite holes on this glacier is so short probably because their hole-depth is very shallow and largely changes. The amplitude of daily change in hole-depth was similar to the mean depth of the cryoconite holes at 5240 m during the study period (4.1 versus 4.0 cm). It means that the cryoconite holes were easy to collapse by daily variation of the hole-depth. Furthermore, the shallow cryoconite holes seem to be easy to collapse by melt water flows on the glacier surface. In contrast, cryoconite holes of Greenland glaciers with long life span were reported to be much deeper (10-60 cm in depth, Gerdel and Drouet, 1958; Gribbon, 1979) than those of the Yala Glacier.

The shallow depth and large depth change of the cryoconite holes are probably due to low albedo of the glacier surface. As mentioned above, surface albedo of this glacier is substantially decreased by dark colored material (Kohshima *et al.*, 1993). The low albedo is responsible for high melting speed of the ice surface. Since hole-depth is determined by difference of melting speed between hole-bottom and ice surface around the hole, the high melting speed of the ice surface may cause shallow hole-depth. Furthermore, albedo of the bare ice surface covered with the dark colored material can drastically change by snowfalls and/or relocation of the material. The drastic change of surface albedo is likely to cause the large depth change of the cryoconite holes. Especially, this glacier suffers from frequent snowfall in summer because the region of this glacier is affected by Asian monsoon. The frequent snowfall in summer may also cause the instability of cryoconite holes in the glacier.

Since cryoconite holes housed many kinds of organism living in the glacier, instability of the cryoconite holes on this glacier may affect various biotic activities in the glacier. Though more investigations are necessary to understand ecological roles of cryoconite holes, it is possible that instability of the cryoconite holes on this glacier affects primary production and/or species composition of the glacier ecosystem.

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