Annual Moraine Ridges and Recent Fluctuation of Yala (Dakpatsen) Glacier, Langtang Himal

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Abstract

A series of "annual" moraine ridges are observed on the till surface in the proglacial area of Yala Glacier, Nepal Himalaya. The till surface, often fluted, which distributes between the present glacial margin and the bulky terminal moraine ridges consists of six different till sheets. They correspond to six re-advance stages during the general retreat after the Little Ice Age glacial advance which formed the bulky terminal moraine ridges. Field observations and till fabric analysis suggest that the "annual" moraine ridges of Yala Glacier seem to be formed annually by a advance or ice push. Under the assumption that their annual character was maintained for a long time and that the time span needed for each readvance forming a different till sheet was at most 10 years, the dating of Little Ice Age moraines was attempted. The results indicate that Little Ice Age advances occurred in 1815 and in 1843, therefore roughly simultaneous to those in Europe.

1. Introduction

"Annual" moraine ridges are a series of minor moraine ridges lying on a lodgement till surface which is exposed beyond the present margin of the glacier. There are many kinds of "annual" moraines and various origins have been proposed (Elson, 1968). It is often difficult to distinguish true annual moraines from others, but Worsley (1974) reported the annually formed minor moraine ridges from a Norwegean glacier.

In Nepal Himalaya, Fushimi and Ohata (1980) recognized several minor moraine ridges in front of the terminus of small glaciers in Khumbu Himal and observed that a new moraine ridge was formed within one year on destroying the similar moraine ridge which had already been formed in a year before. This is the first observation in Nepal Himalaya that evidenced an annual character of these minor moraine ridges.

During the work of the boring project '82 in Langtang Himal, I found the well developed "annual" moraine ridges in the proglacial area of Yala (Dakpatsen)** Glacier (Fig. 1) which was chosen for the object of our boring. In this paper, I will describe at first, the proglacial features including "annual" moraine ridges. For this purpose, a detailed geomorphological map was drawn on the basis of the interpretation of air-photographes that were taken by the members of expedition, and the field observation. Secondary, I will discuss the genesis

**Langtang villagers gave no proper name to this galcier. A small snow peak at the southeast end of the glacier is called Yala Peak by trekkers. But, during our boring works, Langtang villagers said that we bored "the ice of Dakpatsen". Dakpatsen is a name of kalka located at the lower edge of the plateau on which the glacier exists. Therefore, we call this glacier Yala or Dakpatsen Glacier. In the following description, we use the names Yala Glacier and Dakpatsen Plateau.

of these moraine ridges. The till fabric analysis and the obesrvation made during the boring works indicate that a single minor moraine ridge is formed by periodical ice-push. Finally, the dating of the "Little Ice Age" moraine of Yala Glacier will be attempted by counting the number of "annual" moraine ridges under the following two assumptions:

1) the "annual" moraine ridges of Yala Glacier are truely annual in character.

2) several re-advance phases which interrupted a continuous retreat of the glacier after the Little Ice Age advance needed at maximum 10 years.

The result of calculation reveals that the Little Ice Age moraine ridge of Yala Glacier was formed around 1815, therefore, fairly contemporaneous to the Little Ice Age glacial advance in Europe.

2. Yala Glacier

Yala Glacier is a small plateau glacier of clean type (Moribayashi & Higuchi, 1977) which covers the upper part of Dakpatsen Plateau dominating Langtang Valley (Fig. 1). This glacier descends from the north eastern margin of the plateau which ends by precipitous rock walls dominating Shalbachum Glacier. This uppermost edge of the plateau consists of several peaks which are almost completely covered by the glacier. The culminating point of Yala Glacier is 5,743 m high (Unnamed Peak), and the glacier flows down to south. The glacier has a steplike longitudinal profile with gently inclined glacial plateaus and steep ice cliffs. There are at least four levels of glacial plateau: 5,600–5,450 m, 5,400–5,350 m, 5,300–5,250 m and 5,200–5,150 m respectively. The terminus of glacier is 5,100–5,200 m in the western part and 5,200–5,300 m in the eastern part. The total surface of Yala Glacier is 2.56 km^2.

At the western end, Yala Glacier contacts with a small ice tongue of the Unnamed Glacier which flows down from Mt. Shalbachum.

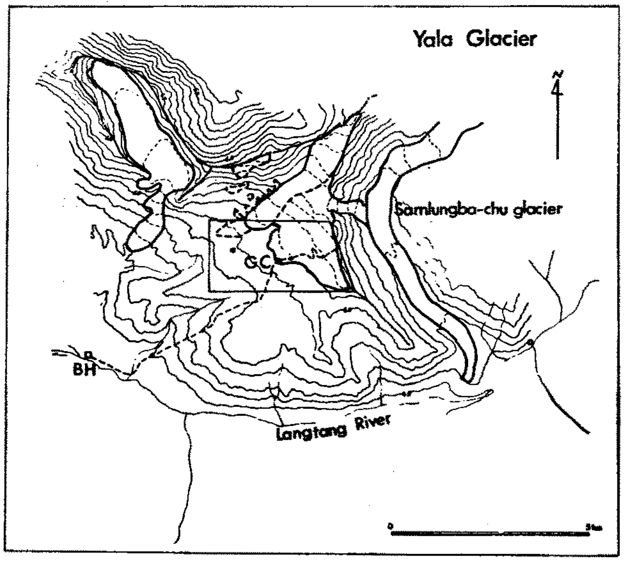

Fig. 1. Location map of Yala Glacier.
A square indicates the area shown in Appendix 5.

3. Proglacial features of Yala Glacier

Proglacial features of Yala Glacier were mapped by means of air-photo interpretations and field observations (Appendix 5). They consist of the following four landforms: (1) rocky surface with steps and roches moutonnées field; (2) lodgement till surface which are often fluted and accompanied with "annual" moraine ridges; (3) bulky terminal moraine ridges and (4) outwash fan plains. They are distributed from the present glacial margin toward the lowest edge of Dakpatsen Plateau in the order described above. In convenience of the further description, the proglacial area on the plateau is divided into three parts as follows:
(1) western part: area from the valley head of Ladzo chu to the junction of Yala and Unnamed glaciers.
(2) central part: area from the junction above stated to the course of one of the uppermost reach of Chubi chu which atteins to a small pond near the Glacier Camp.
(3) eastern part: area east of the central part.

3.1. Proglacial features of the western part

Most of the plateau surface is occupied with a debris-covered terminal part of the Unnamed Glacier which extends to the lowest edge of the plateau, cut by the gully head of Ladzo chu. Glacially scoured rocky surface exposes only slightly near the junction between Yala and Unnamed Glaciers. Bulky terminal moraine ridges constitute a well preserved arc accompanying a small lake in the proximal side. The crest of the highest ridge is very sharp and has nearly no vegetation (Fr. 3). The westernmost morainic arc is destroyed by erosion of Ladzo chu, but lateral moraine ridges are still well preserved especially on the western side of the valley (Appendix 5; leftend).

By its freshness and many geomorphological resemblances to the Little Ice Age lateral-terminal moraine ridges in European Alps and in Khumbu Himal (Iwata, 1976), I correlate the highest sharp ridge of bulky terminal moraine complex to the Little Ice Age maximal advance. The chronological problems will be discussed in the later section.

Till surface distributes widely between the Little Ice Age moraine ridges and the present glacial margin. It consists of five different till sheets (A to E) with or without flutes. The terminal moraine limiting the outer margin of the till sheet A overrides partially the Little Ice Age moraine. Fluting is best developed on a relatively convex plateau surface (Fr. 3). On the other hand, no flutes are observed on the till surface near the margin of the Unnamed Glacier where the till surface is characterized by a series of small cliffs subparallel to the present glacial margin and by several irregular mounds. They should be a feature of final stage of ice-cored moraine in which the ice has been already melted away.

Beyond the distal side of the Little Ice Age moraine, outwash fan plains extend to the surface of Dakpatsen plateau, on which several degraded moraine ridges are found. These ridges are much more smoothened than the ridge of Little Ice Age maximum advance and covered with vegetation. By their geomorphological resemblances to the Neoglacial moraines in Europe and Khumbu Himal (Iwata, 1976), I correlate these moraine ridges to the Neoglacial advances whose chronology will be discussed later.

The outwash fan plains are subdivided into three geomorphic surfaces: present, Little Ice Age, and Neoglacial (or older).
(1) Present outwash fan plain: the fan suface on which the fluvioglacial processes are still in active.

(2) Little Ice Age outwash fan plain: the fan surface which continues to the Little Ice Age moraine. The braided channel patterns are well preserved on the fan surface.
(3) Neoglacial (or older) outwash fan plain: the fan surface connecting to the Neoglacial moraines and other older outwash surface on Dakpatsen plateau. The surface is covered with vegetation and channel patterns are not visible.

3.2. Proglacial features of the central part

As in the western part, rocky surface exposes only near the junction of Yala and Unnamed Glaciers. Bulky terminal moraine complex is, here, made up of two ridges. The higher one is very sharp and keeps a fresh topography as in the western part (Fr. 4). The lower one is located on a distal side of the former and more or less buried under the distal slope of higher ridge. If the higher ridge corresponds to the Little Ice Age maximum advance, the lower one should be correspond to the early advance in the Little Ice Age.

On the other hand, the higher moraine ridge is sometimes overriden, in its proximal side, by a newer till sheet (Till sheet A). Till surface between the Little Ice Age moraine ridges and the present glacial margin consists of six different till sheets (A to F), with or without flutes.

Beyond the distal slope of the Little Ice Age moraine, the outwash fan plain of Little Ice Age develops widely. Present outwash fan plain downcuts the former by 1.5–2 m in the upper reach of the Chubi chu, while it superposes on the older surfaces in several streams which have not enough discharge to downcut the floor. Neoglacial moraine ridges are found among the outwash fan plain, but the corresponding outwash fan plain is less preserved than in the western part.

3.3. Eastern part

Glacially scoured rocky surface develops widely in this part. The direction of rock steps is controled by the joint system in which the directions of NW-SE and NE-SW are dominated. Relatively gentle rocky slopes between steps are transformed into the roches moutonnées field. Some temporary or permanent small lakes are formed in the depressions among them. The eastern end of the plateau is bordered by steep rock walls of the Pi'ung Cirque.

The bulky terminal moraine ridge of the Little Ice Age maximal advance continues to the eastern part, but, here, it is accompanied with two lower ridges at its distal slope. Their ridges are less sharp than the highest ridge and more or less overriden by the latter. As in the central part, they should correspond to the early advance stages of the Little Ice Age.

Till surface is relatively narrow, but extends between the rocky surface and the Little Ice Age moraines. At least two till sheets (A and B) can be recognized. Beyond the Little Ice Age moraines, the present outwash fan plain extends widely downward.

4. Till sheets

4.1. Differentiation of till sheets

The lodgement till surface extending between the Little Ice Age moraine and the present glacial morgin consists of at most six different till sheets as stated earlier. They are called Till sheets A, B, C, D, E, and F in this paper, from the older to younger. Their differentiation was made by air-photo interpretation, on the basis of the existence of moraine ridges showing the re-advance, the difference of flutes pattern on the till surface and the different surface textures. The boundary of each till sheet was usually defiend easily and could be traced for a long distance as shown in Appendix 5.

The moraine ridges limiting the outer edge of the till sheet are very similar, in form, to the "annual" moraine ridges which will be described in the next section. But they are usually higher than the ordinary "annual" moraine ridges. In Appendix 5, they are classified as high annual moraine ridges. They often show a small lobate feature which cuts a parallel or subparallel distribution pattern of common "annual" moraine ridges. Thus, they represent the re-advance stages which interrupts the continuous retreat of the glacier represented by a tightly spaced ordinary "annual" moraine ridges.

The thickness of till sheet is different. Their thickness estimated from the hight of terminal moraines is as follows: Till sheet B: 5–6 m; C: 3–4 m; D: 1.5–2 m; E: 1–1.5 m; F: 2–2.3 m.

The thickness of till sheet A is difficult to be determined. The terminal moraine of till sheet A is sometimes higher and sometimes lower than that of till sheet B. Especially, when the till sheet overrides the Little Ice Age moraine, till sheet A seems to be much thickened. It is probably by the damming effect (Karlén, 1973) of the large Little Ice Age moraine which had been already existed in front of a glacier which re-advanced. In this paper, the mean thickness of the till sheet A is estimated as 7–8 m.

5. "Annual" moraine ridges

5.1. Characteristics

"Annual" moraine ridges distributing on the proglacial area of Yala Glacier are small accumulation of till, composed of the materials similar to the till forming the till sheet on which develop the ridges. Except the ridges limiting the outer margin of each till sheet and the newest ridge, "annual" moraine ridges are small and usually difficult to be distinguished on the ground. But they are easily recognized on the air-photographes and several ridges can be traced for more than 250 m. They are formed on a flat or relatively convex till surface and lacking on the valley slopes or valley bottom. They are also found on roches moutonnées field. On the till surface, they usually make a grid-iron pattern as they cross the flutes which run roughly perpendicular to them.

The maximum number of "annual" moraine ridges was counted in the central part of the plateau where they develop most tightly. The counting was made on enlarged air-photographes (Frs. 3 and 4). The length of each till sheet was measured in two sections in the central part, from the present glacial margin to the direction of SSW, nearly perpendicular to the direction of "annual" moraine ridges. The mean space intervals between each annual moraine ridge were thus calculated by dividing the till length by the maximum number of ridges (Table 1).

The newest "annual" moraine ridge locating at the east of a small pond near the Glacier Camp is 1.5 m high at its distal side, where it faces to a depression (Pl. 1). Distal slope is very steep (42–48°) and therefore very unstable. Probably the true height of the ridge composed

Table 1. Maximum number of "annual" moraine ridges and mean intervals between each ridge on different till sheets.

Till sheet	Little Ice Age Max. advance	A	B	C	D	E	F	Total
Length of till sheet (m)	50–55	65	45–85	70–90	115–150	20–60	10–20	425–475
Maximum number of ridges	6	8	17	12	30	15	6	94
Mean intervals (m)	8.3–9.1	8.1	2.6–5.0	5.8–7.5	3.8–5.0	1.3–4.0	1.6–3.2	4.02–5.05

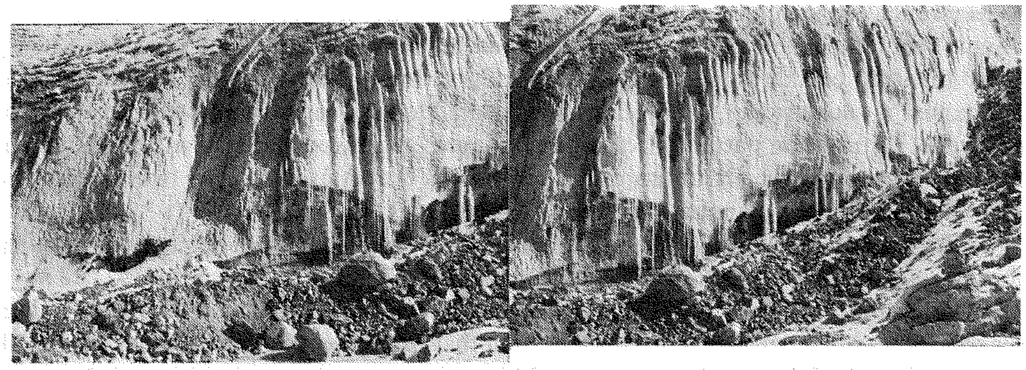

Plate 1. Marginal ice cliff and the newest "annual" moraine ridge of Yala Glacier, at the east of Glacier Camp (Loc. 2 and 4 in Fig. 2).

of blocky till is less than the apparent height, because till materials seem to cover a rocky side-wall of the depression. The height of proximal side is only 0.3 m, where slope is gently inclined to ward the present margin of Yala Glacier. The angle of proximal slope of the ridge is about 16°. The distance between the ridge crest and the glacial margin is about 2.5 m and the width between the ridge crest and the distal foot is about 2 m.

At another point which is nearer to the pond, the ridge height is 0.8–1.5 m on the both sides whose slope angles are about 40°. The distance between the ridge crest and the glacial margin is 3.5 m. The ridge fringes the glacial margin regardless the relief of the ground. The inclination of the ridge crest, in the direction of extension, changes up to 30° where the ridge goes up on the flank of the bedrock protrusion at the east of the pond.

5.2. Genesis

Observation of the newest "annual" moraine ridges above mentioned and the marginal ice cliff of Yala Glacier near by were made at the middle and end of October 1982, namely at the beginning of the post-monsoon season. In this period, the melting of the glacier occurred in daytime from the surface. The marginal ice cliff of Yala Glacier is about 20–30 m high, and apparently has no crevasse at the snout. The ice cliff is almost composed of clean blue ice except the debris laden basal part which is about 60–80 cm thick. This basal part is mainly composed of till involving abundant fine materials and several larger blocks.***

As the clean blue ice exposing at the cliff contains few blocks, the most of till which constitutes the "annual" moraine ridges should be originated from the debris laden basal part of the glacier. But there is apparently no shear planes extending from the bed to surface in the debris laden layer, and it is also quite unlikely that the glacial margin is stagnant. If the "annual" moraine ridges are simply formed through the basal melting and the superposition of englacial debris on the ground, the fabric of till involved in glacier should be preserved in ridges. To examine this possibility, the fabrics of basal till and the till composing the newest "annual" moraine ridge were analysed. The results of measurements of the orientation of a-axis of gravels (cobble and boulder size; Fig. 2) have revealed that (1) the orientation of a-axis of gravels in the basal till is subparallel (Loc. 4) or oblique (Loc. 2) to the direction of

***The detail description of the debris laden basal part of Yala Glacier will be made in another paper.

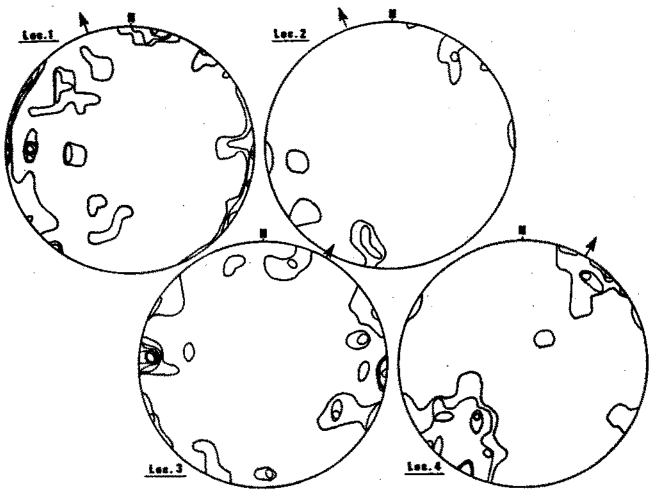

Fig. 2. Contoured stereographic diagrams showing till fabrics of "annual" moraine and basal till of Yala Glacier.
Loc. 1: "annual" moraine (contour lines: 2.5–5–7.5–10% concentration; 40 stones)
Loc. 2: basal till (contour lines: 10–20% concentration; 10 stones)
Loc. 3: "annual" moraine (contour lines: 3.5–7–10.5–14–17.5–21% concentration; 30 stones)
Loc. 4: basal till (controur lines: 3–6.5–10–13% concentration; 32 stones)
Arrows indicate a flow direction of glacier.

glacial flow and (2) that of the till which constitutes the newest "annual" moraine ridge is nearly perpendicular to the flow direction of glacier (Locs. 1 & 3).

Field observations have revealed, on the other hand, that the gravels involved in glacier ice were exposed little by little on the surface and finally fallen down on the foot of ice cliff, as the melting of glacial surface continues at the snout. On falling, gravels usually rolled down at first on a gently inclined short ice slope at the foot of the cliff and then rolled down on the ground for a short distance. The orientation of a-axis of the gravels was changed on these movements. During the melting of glacial snout, the fallen gravels were left on the ground in front of the glacial margin. But, as the glacial snout retreated continuously, no particular accumulation of fallen materials was formed. A short advance or ice push is necessary to result in any accumulation forms such as "annual" moraine ridges. Only by a short advance of glacial front, the gravels and fines left on the proglacial ground are gathered to form a ridge. During such a buldozer action of a short distance, the gravels are not incoporated into the glacier ice but only pushed forward by the advancing glacial front. Therefore, the orientation of a-axis of gravels which has been already subparallel to the glacial margin, is not distorted largely during the buldozing movement.

In Nepal Himalaya, ablation and accumulation of glacier occur simultaneously in the summer monsoon season. Ageta *et al.* (1980) clarified that the summer temperature takes a decisive role for a mass balance of small glaciers of clean type, because it determines whether the monsoon precipitation becomes rain or snow. The small glaciers such as the Yala is, therefore, in a quite delicate steady state in which the annual change of mass balance is controlled by a slight difference of air temperature during the summer monsoon season. Ageta (1983) concluded that a maximum mass balance usually appears in late May in such small glaciers, while it also appears in September to October when there is much snowfall at the end of the summer monsoon season.

On the other hand, the rate of glacial flow is accerelated in the beginning of the summer monsoon season while the ablation rate becomes larger than the former in the middle of the summer monsoon season, especially in July (Kodama & Mae, 1976). As stated earlier, Fushimi & Ohata (1980) observed in July 1976, that a new "annual" moraine ridge had been formed on destroying partly the similar ridge which had already existed in November 1975. This fact suggests that a short advance of glacier or ice push occurs most likely in the beginning of the monsoon season, for the dry and cold climate during the winter monsoon season is not favorable for the glacial advance.

6. Recent fluctuation of Yala Glacier

By the geomorphological characteristics such as sharpness of ridge form and the degrees of preservation, weathering and vegetation cover, two groups of larger moraines of Yala Glacier were tentatively correlated to the Neoglacial and Little Ice Age glacial advances respectively. In the following sections. I discuss the chronology of these two major glacier advances.

6.1. Neoglacial advances

The distribution of Neoglacial moraine ridges on Dakpatsen Plateau seems to suggest that there are at least two different stages in the Neoglacial advance (Appendix 5). In Khumbu Himal, Neoglacial advance, called Thuklha stage (Iwata, 1976) shows only one advance. But in Tibetan Plateau, Zhen & Li (1982) reported two Neoglacial stages whose C^{14} ages are 2,980$\pm$150 y.B.P. and 1,920$\pm$110 y.B.P. respectively. The older stage was called the Xuedang advance and the younger the Ruoguo. Two Neoglacial stages of Yala Glacier might correspond to these advances, for the latters were recognized at the northern foot of Mt. Xixabangma (Gosaintang), which is not far from Langtang Himal.

6.2. Little Ice Age advances

In Khumbu Himal, Iwata (1976) recognized three moraine stages corresponding to the Little Ice Age advances. The newest moraine ridge, called Lobuche I stage, was correlated to a glacial advance during 19 C. and early 20 C. The older moraine ridges, called Lobuche II and III, were regarded as to correspond the early advances of Little Ice Age which occurred between 15 C. and 17 C. in Europe (e.g. Le Roy Ladurie, 1967; Karlén, 1973).

On the other hand, Fushimi (1977) divided the younger moraine ridges into six substages in Khumbu Himal. He found a wood sample at the bottom of the moraine of the oldest substage mentioned above and this wood gave a C^{14} age of 410$\pm$110 y.B.P. (Fushimi, 1978). According to this age, the earliest stage of Little Ice Age advance occurred in 16 C. in Khumbu Himal.

In Yala Glacier, two lower moraine ridges located at the distal side of the highest sharp moraine ridge should correspond to the early advances of Little Ice Age. As shown in Appendix 5, the magnitude of these advances were slightly more extensive than that of the later maximum Little Ice Age advance represented by the highest moraine ridge in the central and eastern parts.**** But in the western part, the moraine ridges of early stages are com-

****In these parts, therefore, the use of expression of "maximum" advance to the highest moraine ridge is not appropriate.

pletely buried under the higher moraine ridge. These facts suggest that the magnitude of glacial advances was not different greatly between the early stages and the later maximum stage during Little Ice Age.

The maximum advance of Little Ice Age in Khumbu Himal has been believed to have occurred simultaneously to that in European Alps, namely around 1850 (Heuberger, 1956; Muller, 1959). But, in fact, there has been no dating concerning the age of this maximum advance. In the following discussion, the dating of the Little Ice Age maximum advance is attempted by counting the "annual" moraine ridges.

6.3. Dating of Little Ice Age maximum advance

As stated in previous sections, "annual" moraine ridges of Yala Glacier seem to be formed by a glacial push which occurs annually according to delicate changes of mass balace, glacial flow rate and ablation rate. Although there is no evidence that such ice pushes occurred annually over a long time span, there are some reasons to consider that the tightly spaced "annual" moraine ridges are truely annual in character:

(1) If these ridges have a true annual character, the time span of continuous retreat is measured by counting the number of ridges. The mean intervals of each annual moraine which were shown in Table 1, thus indicate the mean retreating speed of the glacier. The values range from 1.3–9.1 m/year which are just in the same order as the actually measured retreating speed of several small glaciers in Khumbu Himal (Fushimi & Ohata, 1980).

(2) In Gyajo Glacier, Khumbu Himal, Fushimi & Ohata (1980) recognized distinctive glacial advances in 1970 and in 1976. These two advances are of nearly same magnitude and the "annual" moraine ridge of 1976's advance destroys the 1970's ridge in some parts. If the till sheet F which corresponds to the newest re-advance stage in Yala Glacier is correlated to the glacial advance of 1976 in Gyajo Glacier, the continuous glacial retreat after 1960's which has been evidenced in Khumbu Himal is well proved by tighty spaced fifteen "annual" moraine ridges on the till sheet E of Yala Glacier.

Under the assumptions that the "annual" moraine ridges of Yala Glacier are truely annual in character and the newest re-advance stage corresponds to 1976's re-advance, the dating of the Little Ice Age maximum advance was made by the following procedures:

(1) Time span of continuous glacial retreat from the outer to the inner edges of each till sheet was calculated by counting the maximum number of "annual" moraine ridges left on the till sheet.

(2) Time span of continuous retreat which should have occurred upglacier, until the onset of next re-advance, beyond the position which is now occupied by the terminal moraine of the newer re-advance, was supposed to be equal to the time span needed for a re-advance (broken line in Fig. 3.)

(3) Time span needed for a re-advance of each till sheet was estimated by a height of each terminal moraine limiting the till sheet. The height of "annual" moraine ridge reflects the volume of till left on a proglacial area during the retreat. When the glacier advances for the longer distance, it buldozes the more materials, thus forms the higher ridge. The height of the moraine ridges limiting each till sheet should be, therefore, propotional to the distance of glacial advance which is again proportional to the time span of advance, if the advancing speed is constant.

Under the assumptions that the terminal moraine of till sheet F, 2.3 m high, was formed by a re-advance of 3 years (1973–76), the time span needed for building of terminal moraine of each till sheet was calculated.

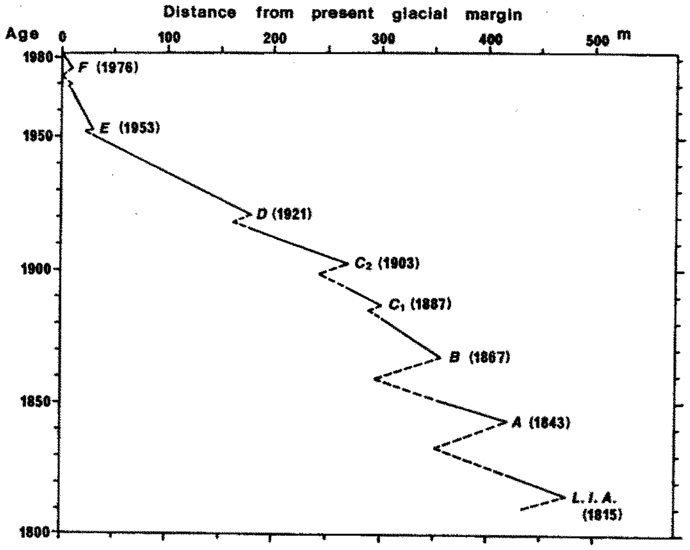

Fig. 3. Recent fluctuation of Yala Glacier reconstructed by "annual" moraine ridges.
Solid line: time span of continuous retreat represented by "annual" moraine ridges.
Broken line: time span of continuous retreat not represented by "annual" moraine ridges and time span of re-advance estimated by the height of terminal moraine of each till sheet.

Figure 3 shows the result of these calculations.***** Though they are based on many assumptions stated above, this figure indicates that Little Ice Age maximum advance occurred in 1815, that is to say, roughly simultaneous to one of the maximum advances in Little Ice Age in Europe (e.g. Le Roy Ladurie, 1967). Furthermore, the first re-advance of the glacier after 1815's advance is dated as 1843, which also roughly corresponds to the advance in 1850 in Europe. In Appendix Map 2, moraines limiting the till sheet A is classified into the recessional moraines. But in reality, the till sheet A should be included into the Little Ice Age advances in the European chronology. The younger re-advance stages are also nearly correlatable to the advance stages known in Europe. These facts suggest that the recent glacial fluctuation in Nepal Himalaya would be roughly parallel to those of other high mountains in Northern Hemisphere, if the assumptions made for the present calculation were appropriate, and inversely, if the recent glacial fluctuation occurred roughly contemporaneously both in Himalaya and in European Alps, the present assumption would be appropriate.

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