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Distribution of periglacial landforms in the Langtang Valley, Nepal Himalaya

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Abstract

The spatial and altitudinal distribution of the active periglacial landforms such as earth hummocks, solifluction lobes, turf-banked terraces, sorted polygons, talus slopes, and striated ground, were mapped in the Langtang Valley, central Nepal Himalaya. Several inactive landforms such as rock glaciers, block streams, and protalus ramparts were also mapped. The periglacial belt of the Langtang Valley which spreads between the timberline and the equilibrium line, can be subdivided as follows: belt I (3,600 m – 3,920 m: lowermost periglacial belt of patchy distribution of earth hummocks and vegetated solifluction lobes); belt II (3,920 m–4,700 m: lower periglacial belt with a more continuous distribution of earth hummocks and vegetated solifluction lobes); belt III (4,700 m–5,000 m: middle periglacial belt of vegetated solifluction lobes, turf-banked terraces and sorted polygons); belt IV (5,000 m–5,200 m: upper periglacial belt of sorted polygons).

The wide extent of rocky walls and glaciers above 5,000 m and the relatively high snowfall make the belt IV narrow. The sunny aspect and the snowfall seem to elevate the lowest limit of alpine permafrost on the south-facing slope.

1. Introduction

The periglacial landforms of the Langtang Valley have never been studied in detail. Usselman (1980) first made a geomorphological map of the valley, but he mapped only avalanche couloir, avalanche cones, and periglacial slides as being the periglacial landforms. Ono and Sadakane (1986) described the occurrences of earth hummocks, solifluction lobes, patterned ground, and frost shattered-rocks, which become predominant on the debris-covered mountain slopes above about 4,650 m in the valley. In relation to the yak transhumance, they tentatively defined the periglacial belt in the valley as one belt higher than this altitude, which roughly corresponds to the upper limit of shrub vegetation. However, they mentioned that the earth hummocks also occur below this altitude. It is, therefore, necessary to define the periglacial belts of the valley more precisely from geomorphological and geoecological viewpoints.

The periglacial landforms in the Nepal Himalaya were mainly studied in the Khumbu and Mukut Himal (Fujii, 1976; Iwata, 1976), and were focused on the patterned ground. Iwata *et al.* (1976) attempted the comparison of periglacial zonation between the European mountains, Himalaya and Japanese Alps. However, as they stated, the Khumbu Himal is relatively dry in the Nepal Himalaya. This area, consequently, is not representative of the Nepalese slopes of the Himalaya.

The purpose of this paper is to describe the various periglacial landforms in the Langtang Valley, and to discuss their vertical zonation. For this purpose, we mapped the major periglacial landforms in the valley. Figure 1 shows their spatial distribution. Since the periglacial landforms occur mainly on the debris-mantled slopes at a higher elevation, we concentrated the field research on the Dakpatsen Plateau,

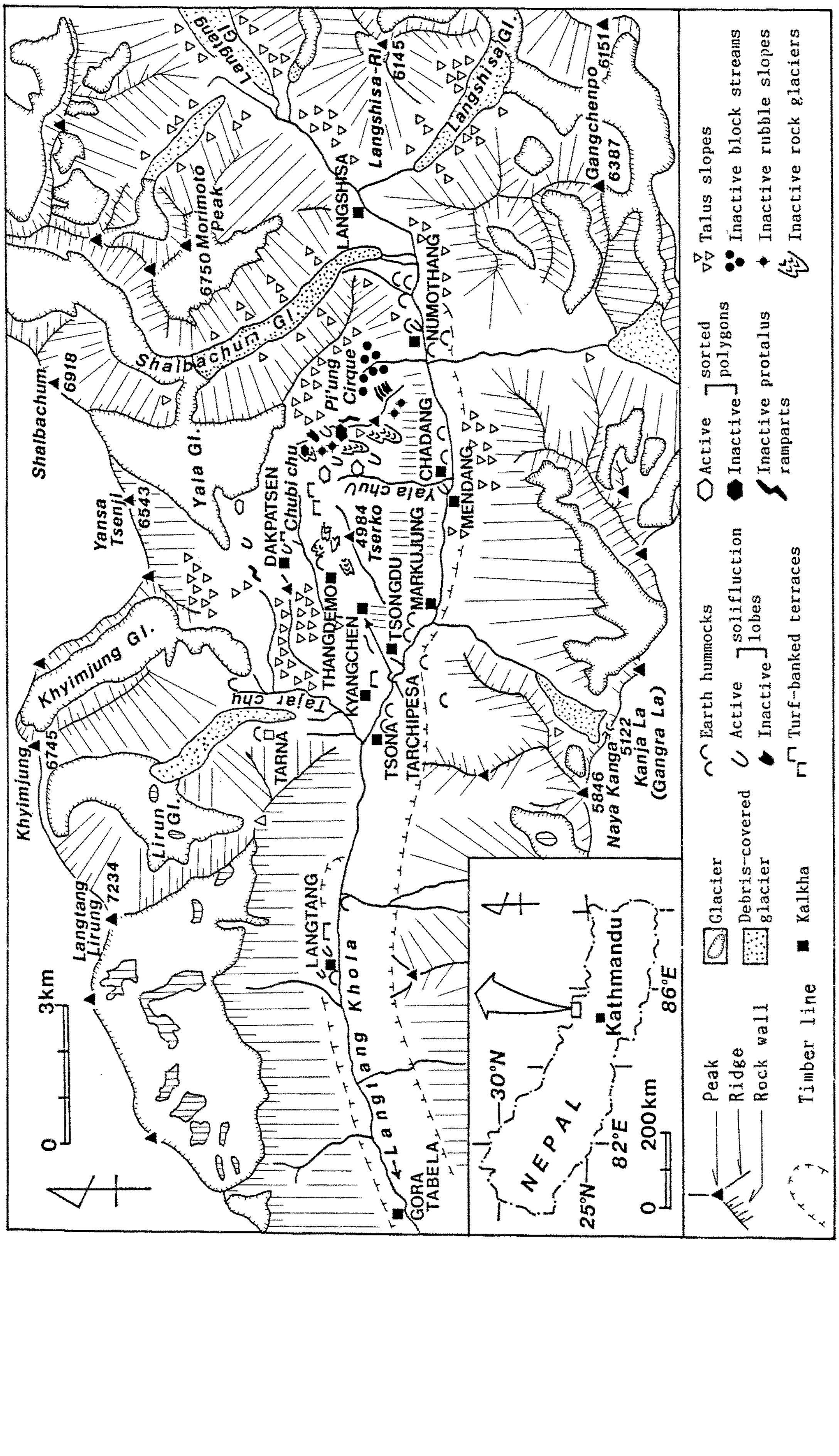


Fig. 1. Study area and the distribution of periglacial landforms.

a high plateau located on the northern side of the main valley, which is believed to have been formed by a huge landslide (Heuberger *et al.*, 1984). Inactive periglacial landforms, such as rock glaciers, block fields, protalus ramparts, rubble slopes, and various patterned ground, were also mapped in the field (Fig. 1). Since the mapping of the inactive landforms is still in progress, they will be described and discussed in a future paper.

The field was visited in the post-monsoon season in 1982, monsoon and post-monsoon seasons in 1987, and pre-monsoon season in 1988.

2. Study Area

The Langtang Valley is located at about 60 km north of Kathmandu (Fig. 1). The valley, stretching from east to west, is dissected by the Langtang Khola. A typical U-shaped configuration develops upvalley from Gora Tabela (3,017 m)*, and the upper reaches of the valley have several tributary glaciers including the Lirung, Shalbachum, and Langshisa. The uppermost part of the main valley is also occupied by the Langtang Glacier. All of these are debris-covered glaciers (Fig. 1). Several sets of moraines occupy the valley bottom; they have been correlated to the Little Ice Age, Neoglacial, Late glacial younger and older, and the advance older than Late glacial (Heuberger *et al.*, 1984; Ono, 1986).

The geology of this area belongs to the Main Central Thrust Zone, which consists of granite, gneiss, and schist.

The climate of the Langtang Valley is moist, with strong influences of the summer monsoons which come from the south. The annual precipitation at Kyangchen, located on the valley bottom at the altitude of 3,920 m, was 1,224.5 mm in 1985 – 1986 (Takahashi *et al.*, 1987). Although the monthly precipitation was zero in November and January, the total precipitation from December to May amounts to 271.1 mm at Kyangchen (Takahashi *et al.*, 1987). Most of it falls as snow at higher altitudes. Even at Kyangchen, the mean monthly air temperature is below 0 °C from December to March. Therefore, the snow accumulation is significant on the valley bottom at the altitude of Kyangchen.

The relatively moist climate of the Lantang Valley is explained by the narrow frontal range in the south of the valley; the humid air from the south easily penetrates the valley. This situation is quite different from that of the Khumbu region, where the large frontal mountains prevent the invasion of the moist air mass (Ageta; 1976; Yasunari and Inoue, 1978). The precipitation map of Nepal (1971–1985) clearly shows this difference; the annual precipitation amounts to about 1,500 mm in the Langtang Valley, but only several hundred mm in the Khumbu region (Department of Hydrology and Meteorology, Nepal Government, 1988).

3. Description of periglacial landforms

3.1. Earth hummocks

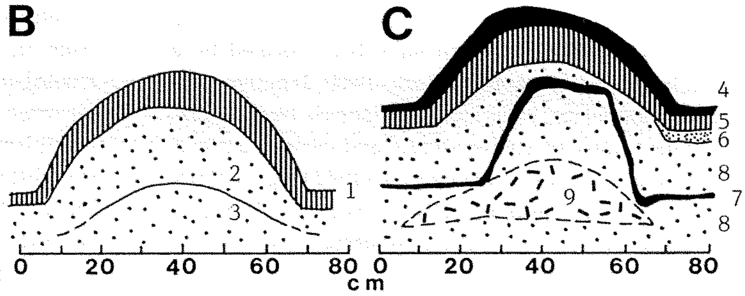
Earth hummocks are spread widely on the moist surface above the level of the Langtang Village (3,410 m). They develop mainly at Tsona (3,780 m), Tarna (4,165 m), Tsongdu (3,800 m), Thangdemo (4,620 m), and Numothang (4,050 m; Fig. 2A). The general dimensions of the earth hummocks in the Langtang Valley are 20–70 cm in diameter and 10–35 cm in height. The surface of the mound is usually covered with *Rhododendron setosum* and *R. anthopogen* of 20 – 40 cm in height, whereas the surrounding surface is covered with grasses and forbs such as primrose.

Trench sections of earth hummocks were observed at the Langtang Village (Fig. 2B) and Tarna Kalkha (Fig. 2C). The latter section, cut on 27 April 1988, revealed the existence of a frozen lense-shaped core at the depth of 37–53 cm. Similar frozen cores were also observed in the earth hummocks at the south of Numothang Kalkha on 16 May 1988.

Several earth hummocks show an aligned pattern and seem to be related to the yak activity, since the pattern is parallel to the yak trails. They occur especially around Tsongdu and Tarchipesa Kalkha, where many yaks pass through during the transhumance (Ono and Sadakane, 1986). Iwata *et al.* (1976) also reported the earth hummocks related to yak trails in the Khumbu region. They thought that these earth hummocks are basically formed by frost action.

3.2. Solifluction lobes

Active solifluction lobes involve turf-banked and stone-banked types according to the classification of Embleton and King (1968). The turf-banked or the vegetated solifluction lobes occur above 3,425m. They have a steep riser (Fig. 3A) with vegetation cover, and are generally tongue shaped. Each segment of a typi-



1 Brownish Black Humic Soil (10YR2/2, Sandy loam)

2 Brownish Black Sand (10YR2/3, Sandy loam)

3 Brownish Black Sand (10YR3/2, Loam)

4 Black Undecomposed Soil (10YR2/1, --)

5 Brownish Black Humic Soil (10YR2/3, Silt loam)

6 Dark Grayish Yellow Sand (2.5Y5/2, Sandy loam)

7 Brownish Black Buried Soil (10YR2/3, Silt loam)

8 Yellowish Gray Sand with Oxidized Mottles, Unfrozen (2.5Y5/1, Loam)

9 Ditto, Frozen (2.5Y5/1, Loam)

Fig. 2. Earth hummocks near Numothang (A), and the cross sections in the Langtang Village (B), and in Tarna Kalkha (C). Scale length in Photo A is about 70 cm. (Photo: T.W., 9 May 1988).

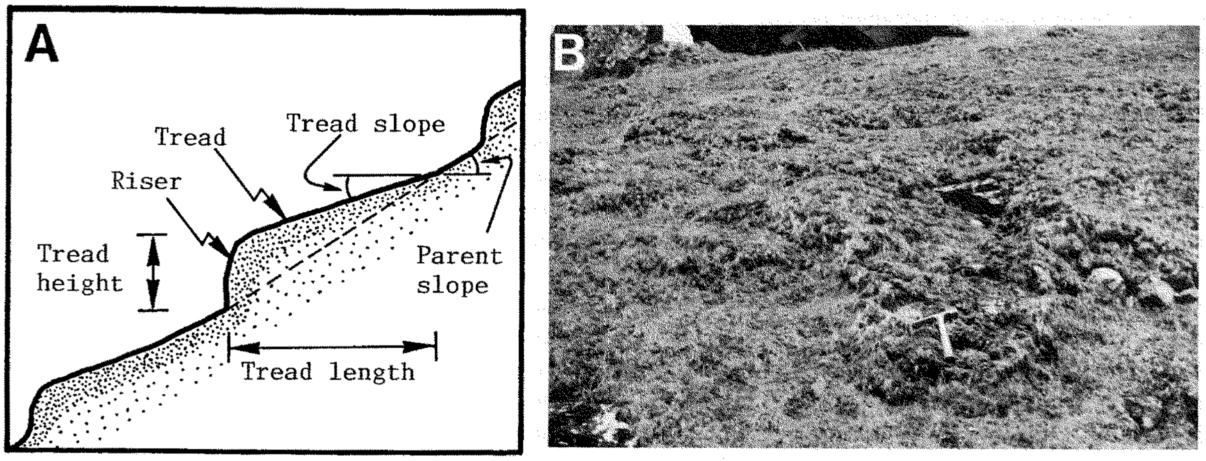


Fig. 3. Schematic longitudinal section of solifluction lobes with terminology by Smith (1987) (A), and the typical vegetated solifluction lobes near the Yala Glacier, 4,920 m (B). (Photo: T.W., 4 May 1988).

cal turf-banked solifluction lobe (Fig. 3A) has the following dimensions: 20−200 cm of tread length and width, and 5−30 cm of tread height. The tread slope varies from 2 to 20 degrees, and the riser slope from 60 to more than 90 degrees. Some lobes have greater tread length than tread width, and vice versa. Although the actual movement rate is not measured in this valley, the surface morphology of the turf-banked solifluction lobes on the Dakpatsen Plateau (4,920 m) cleary shows the present activity (Fig. 3B). The lobes recieve much snow-melt water coming from a snow patch lying upslope in spring (off the photo). The over-saturated lobes seem to move downslope during the snow-melt period. The solid blocks collapsed from the riser strongly suggest this downward movement (Fig. 3B).

Stone-banked or unvegetated solifluction lobes occur above 4,900 m, on the south-west facing debris-covered slope near the Yala Chu (Fig. 1). The upper one-third of this slope seems to be stable, whereas the lower two-thirds suffer from alpine debris flow and solifluction. The stone-banked solifluction lobes observed here, initially formed by alpine debris flows, were subsequently modified by solifluction. Such solifluction lobes have a tread width of less than 2 m and a tread height of 5−10 cm. Similar features are also observed on the steep side-slope of the Little Ice Age moraines in front of the Yala Glacier.

3.3. Turf-banked terraces

Well-developed turf-banked terraces are observed on a moraine to the north-east of Mt. Tserko (Figs. 1 and 4). The boundary between the active turf-banked terraces and the terrace-like features completely covered with vegetation (possibly fossil terraces; hatched area in Fig. 4A) roughly corresponds to the moraine ridge, although the latter becomes wider with increasing elevation. The cross section (Fig. 4B) shows that the B and C horizons are parallel to the slope surface, whereas the A horizon changes its thickness by solifluction movement. A fresh gravel-and-sand layer of 2 to 6 cm in depth (reworked till with loess) mantles the A horizon. Partly frost-shattered sub-angular gravel varies in size from 1 to 200 cm. The existence of this surface layer over the A horizon, the vertical heave of the gravel on the tread surface, and the collapse of soil blocks at the terrace edge indicate the actual solifluction movement.

According to Ono and Sadakane (1986) and the GEN members (1988, person. commu.), no yaks are grazed on the above-mentioned moraine ridge shown in Figure 4; therefore, these turf-banked terraces can be regarded as naturally formed features. On the other hand, those in the Langtang village (3,420−3,480 m) and Kyangchen (3,800−3,920 m) are regarded as yak-related forms, although their excavated sections show the similar features.

3.4. Sorted polygons

Sorted polygons occur on a small, shallow, seasonal lake bottom (4,908 m) to the north−east of Mt. Tserko (Fig. 5). They are 100−400 cm in diameter. The central part consists of sand and small gravel on the surface, and fine silt with a small amount of gravel at deeper levels. The margin is surrounded by sub-angular large boulders of 15−100 cm in diameter.

Sorted polygons at this locality are covered with snow from the mid-October to early May. The ground surface was not frozen on 27 May 1988. As the lake is filled with snow-melt water during the early monsoon season, the period available for frost action is short. However, the up-domed shape of the central part and the presence of fresh sand and gravel on the surface suggest current frost activity.

On the other hand, sorted polygons which are located on the gentle ridges in the west of the Pi'ung Cirque, and on the rock glacier near the same cirque (Fig. 1), are partly covered with vegetation. The cross section of their central part shows the undisturbed A and B horizons; therefore, they seem to be inactive.

Sorted polygons also occur, in some cases with stone stripes, on the convex slope in front of the Yala Glacier, above about 5,000 m. Their diameter ranges from 1 to 5 m, and the margin of the polygons is made up of sub-angular blocks of 10 to 40 cm. The polygonal pattern, however, is not so clear as that of the lake bottom near Mt. Tserko mentioned above. The sorted polygons are located on the annual moraines, which are thought to have been formed between 1887 and 1903 (Ono, 1984, 1985). If this idea is supported, the sorted polygons were made within the past 100 years.

Relatively smaller-scale sorted polygons stretch on the pavement-like surface along the Yala Chu (4,820m); the larger of these are about 1 m, and smaller ones are 30−40 cm in diameter.

3.5. Talus slopes

Active talus slopes, with frost-shattered fresh fragments on the surface, fringe the basal part of the steep rocky valley walls above the level of Kyangchen

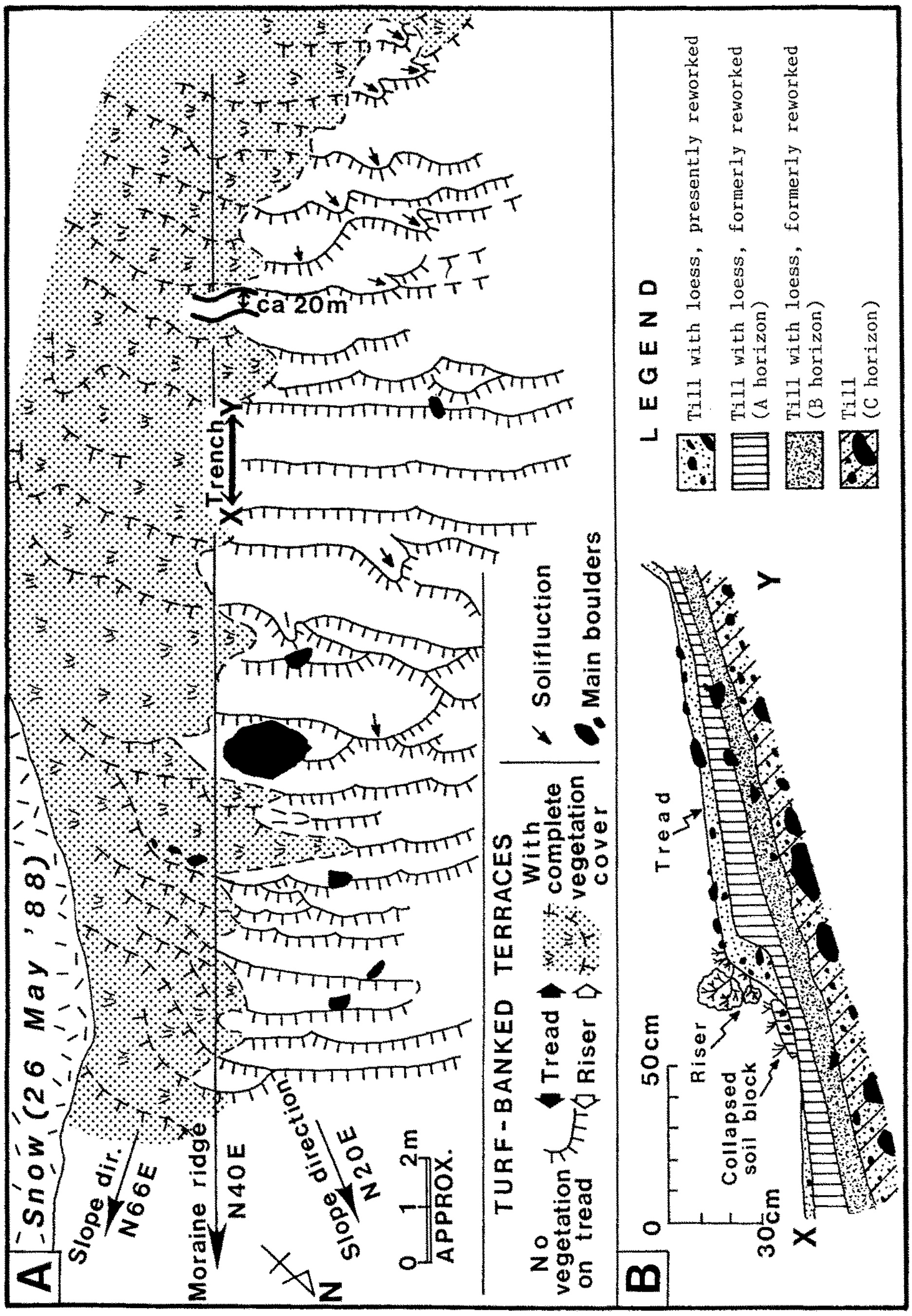


Fig. 4. Turf-banked terraces on a moraine ridge to the north-east of Mt. Tserko (A), and their cross section (B).

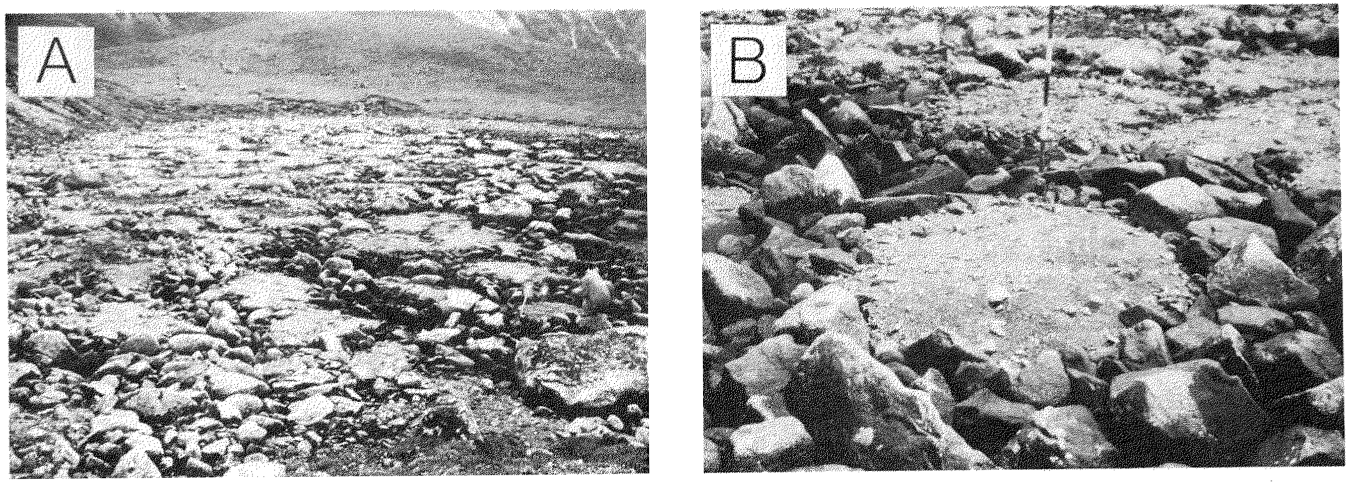


Fig. 5. Sorted polygon nets, located to the north-east of Mt. Tserko (A), and their close-up (B).
These polygons are seasonally submerged under the lake water. The circumference of the seasonal lake is 163.4 m. Water depth on 27 May 1988 was 30–50 cm. The underground coarse particles was partially filled with water on 19 September 1987. Note that some polygons have small-scale polygons inside. The man in Photo A is for scale. Length of the two scales in Photo B is 1 m. (Photos: T.S., 19 September 1987).

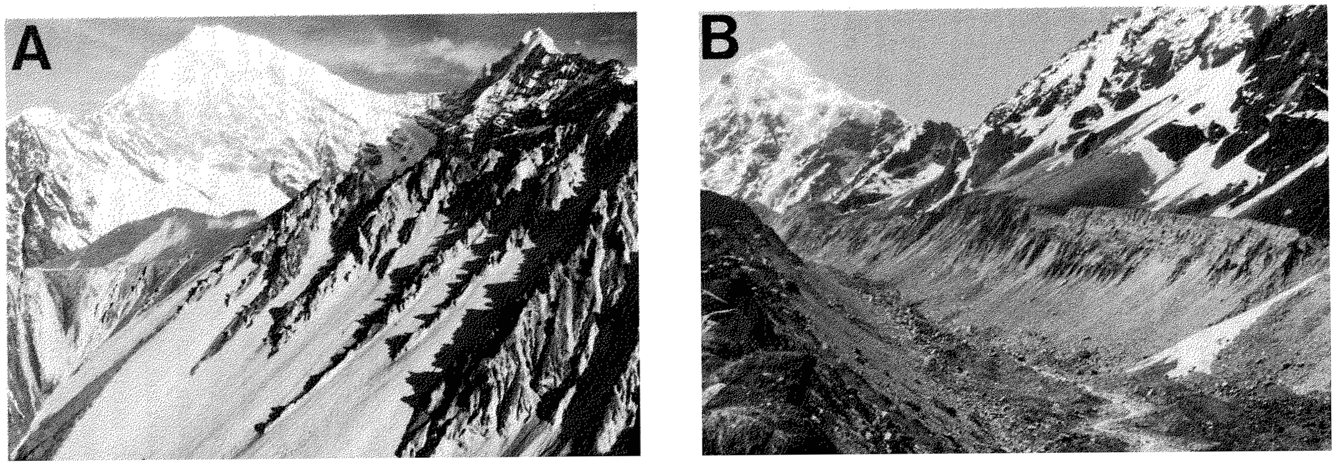


Fig. 6. Typical talus slopes, right bank of the Chubi Chu (A) and left side of the Little Ice Age moraine, Langshisa Glacier (B).
The white peak in the skyline of Photo A is Mt. Langtang Lirung (7,234 m), and that of Photo B is the unnamed peak (6,151 m). (Photo A: T.W., 9 April 1988: B: T.W., 11 May 1988)

(3,920 m).

Along the left bank of the Tajar Chu, many angular granite blocks without lichen cover lie on the large talus slopes (3,985 m). They are currently supplied from the upper bedrock exposures above the altitude of 4,200 m. Other large talus slopes, whose relative height reaches 400−500 m, stretch along the right bank of the Chubi Chu (Figs. 1 and 6A).

In the main valley, the talus slopes are more or less related to avalanches, coming downslope from the hanging glaciers above the steep valley wall.

Near the termini of the Shalbachum and Langshisa Glaciers, some talus slopes cover the lateral moraines of the Little Ice Age and join to the debris-covered glacier surface (Fig. 6B).

3.6. Striated ground

Striated ground occurs above 3,840 m, especially on the moist surfaces around Mt. Tserko and the Yala Glacier. It consists of aligned lumps of sand with narrow channels of only several centimeters in width and length. The features are so minute that they are not shown in Fig. 1. It has been reported in the Andes (Schubert, 1973) and the Khumbu region (Fujii, 1976; Iwata *et al.*, 1976).

4. Vertical distribution of periglacial landforms in the Langtang Valley

The vertical distribution of periglacial landforms in the Langtang Valley can be summarized as in Figure 7.

1) Vegetated periglacial landforms

The *Betula−Rhododendron* forest extends up to 4,200 m at maximum on the north-facing slope, although Ono and Sadakane (1986) gave the height of 4,050 m on the basis of observation around Nääkhng Kalkha near Tsona. On the other hand, the coniferous forest forms the timberline on the south-facing slope and valley bottom, and its upper limit is about 3,600 m (Ono and Sadakane, 1986). Therefore, the periglacial belt basically extends down to these altitudes.

The lower altitude of timberline on the south-facing slope rather than the north-facing one is also reported in the Khumbu region by Iwata *et al.* (1976), and it is likely caused by the difference of topo-climatological conditions on both slopes.

The altitude of timberline is also lower on the bottom of the Langtang Valley. This cannot be explained by the topo-climate, and it is probably caused by the farming and grazing. In fact, the warmth index (cumulative positive monthly air temperature 5 ℃) at Kyangchen approximately amounts to 15 ℃・month. It means that the coniferous forest (*Larix potanini, Tsuga dumosa* and *Abies spectabilis*), which actually spreads up to Nesapali Kalkha (3,627 m), can potentially grow up to the level of Kyangchen (3,920 m). This indicates that the lowest limit of the periglacial belt is artificially lowered on the bottom of the Langtang Valley. In relation to this, earth hummocks and turf-banked solifluction lobes occur occasionally downvalley at much lower altitude than the general timberline on the valley bottom.

Earth hummocks, turf-banked solifluction lobes, and yak-related turf-banked terraces are the most wide-spread periglacial landforms in the Langtang Valley. Among them, the turf-banked solifluction lobes have the widest vertical distribution which ranges from 3,400 m to 4,900 m.

2) Non-vegetated periglacial landforms

The distribution of non-vegetated periglacial landforms is quite limited in the Langtang Valley. As stated above, they occur only around Mt. Tserko and the Yala Glacier, between 4,900 m and 5,100 m. Furthermore, their distribution is not continuous but rather sporadic. Well-developed non-sorted polygons only occur on a temporarily dried shallow lake bottom which favors their development (Ray *et al.*, 1983; Gleason *et al.*, 1986). These limited distributions suggest that the belt of continuous sorted polygons is narrow in the Langtang Valley.

3) Tentative zonation of periglacial landforms

Vertical zonation of patterned ground has been proposed by Höllerman (1967) and Rudberg (1972) for European high mountains. Iwata *et al.* (1976) compared the vertical periglacial zonation of high mountains in the western Europe, Tibetan and Nepalese slopes of the Himalaya, and northern part of the Japanese Alps. They concluded that the Tibetan slopes of the Himalaya are characterized by a vertically wide range of the sorted patterned ground, while the Nepalese slopes are characterized by that of the vegetated patterned ground. They explained this contrast by the basic difference of topography in the Himalaya between the Tibetan and Nepalese sides: the wide extent of a gentle debris-covered slope at a high altitude belt in the former, and the occupation of the same belt by the precipitous rocky walls or glaciers in the latter.

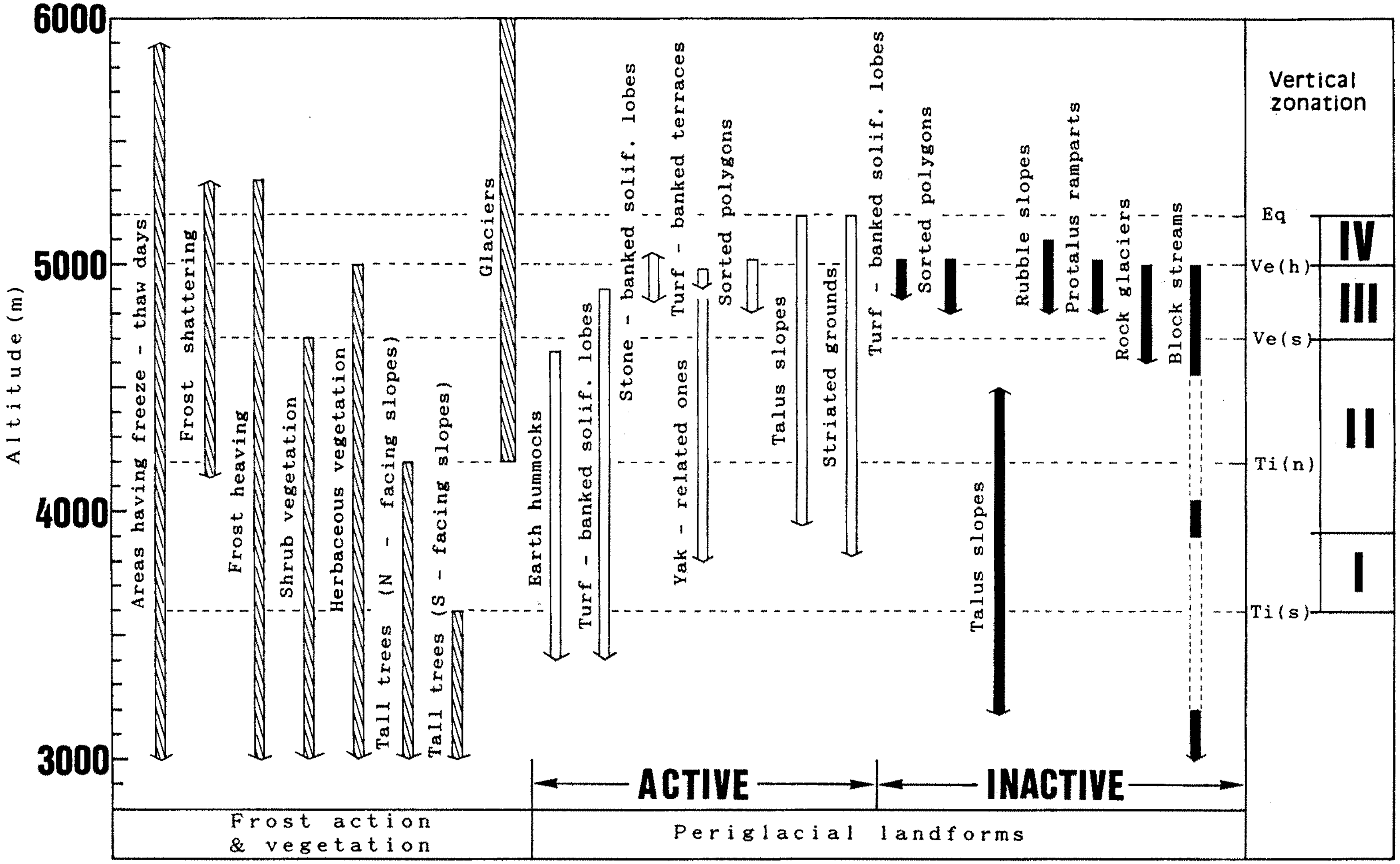


Fig. 7. Vertical distribution and tentative zonation of vegetation and periglacial landforms in the Langtang Valley. Eq: Equilibrium line; Ve(h): Upper limit of herbaceous vegetation; Ve(s): Upper limit of shrub vegetation; Ti(n): Timberline on north-facing slopes; Ti(s): Timberline on south-facing slopes; I – IV: Periglacial belts. Arrows and broken lines indicate the possibility of wider vertical range, and the possible occurrence of block streams, respectively.

Although Iwata *et al.*'s (1976) research was done only in the Khumbu region for the Nepalese slopes of the Himalaya, their explanation is valid for the Langtang Valley. The poor development of the sorted polygons can be attributed to the lack of extent of debris-covered gentle slopes above 5,000 m; the higher slopes are mainly occupied by glaciers and rocky walls. A relatively lower equilibrium line altitude (ELA) of the glaciers in the Langtang Valley also narrows the vertical extent of the belt of sorted polygons.

The low ELA of the Langtang Valley indicates that the area recieves much more snowfall than the Khumbu region. The lack of high frontal mountain ranges, which obstruct the monsoon invasions from the south, favors the snowfall in the Langtang Valley. Ono (1986) estimated the ELA of the Yala Glacier as 5,300 m on the basis of air-photo interpretation. However, according to recent glaciological studies on the Yala Glacier, the ELA of this glacier is about 5,200 m (Ozawa, 1988, person. commu.).

If we apply the zonation of patterned ground proposed by Höllerman (1967) to the vertical distribution of periglacial landforms in the Langtang Valley, the following zonation will be possible (Fig. 7):

(1) Belt I (Lowermost periglacial belt with patchy distribution of vegetation-covered patterned ground): between about 3,600 m (timberline) and about 3,920 m (Kyangchen). The extent of earth hummocks and turf-banked solifluction lobes is rather limited, except for yak-related turf-banked terraces.

(2) Belt II (Lower periglacial belt with completely or partly vegetation-covered patterned ground): between about 3,920 m (Kyangchen) and about 4,700 m (upper limit of shrub vegetation). This belt is characterized by earth hummocks, turf-banked solifluction lobes and yak-related turf-banked terraces, which are much more common than in belt I.

(3) Belt III (Middle periglacial belt with both sorted and partly vegetation-covered patterned ground): between about 4,700 m (upper limit of shrub vegetation) and about 5,000 m (upper limit of herbaceous vegetation). The lower part is similar to belt II, however, above about 4,850 m, the sorted polygons and stripes increase. The turf-banked terraces and stone-banked solifluction lobes also characterize the upper part of this belt.

(4) Belt IV (Upper periglacial belt with sorted patterned ground): between about 5,000 m (upper limit of herbaceous vegetation) and 5,200 m (equilibrium line). As the margin of the Yala Glacier descends to 5,090 m, there remains actually only 90 m for the vertical range of belt IV. Frost shattering becomes more active in this belt and more than a few blocks are sharply broken on the ground (Fig. 8). Frost-shattered blocks and sorted polygons, sometimes associated with sort-

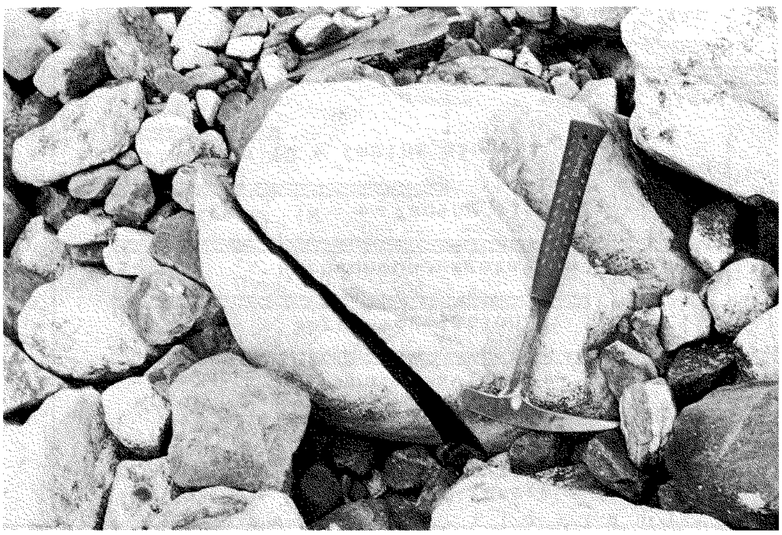


Fig. 8. Frost-shattered boulder on a debris-covered slope near the margin of the Yala Galcier. (Photo: Y.O., 28 October 1982).

ed stripes, occur on the moist debris-covered slopes where snow covers the ground for a longer time than below. Melting of snow patches and ground ice should be the main source of the water supply.

In opposition to the above, however, a deep freezing of the ground seems to be obstructed by a thick snow cover. On 25 May 1988, the snow depth exceeded 100 cm at 5,090 m near the Yala Glacier. The result of the measurement of the ground temperature at 5,070 – 5,090 m in September 1987 (Fig. 9) suggests a lack of permafrost at this altitude. The sunny aspect of the slopes and the relatively high snowfall probably prevent sufficient freezing to form alpine permafrost. The limited extent of belt IV also seems to reflect the lack of permafrost at the altitude around 5,000 m; however, since the number of measurement sites is only three, further investigation is definitely necessary to determine the permafrost condition of belt IV.

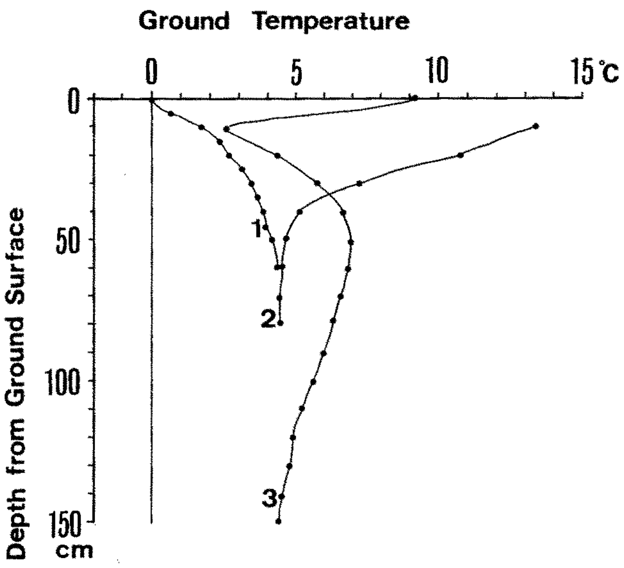


Fig. 9. The ground temperature profiles around the margin of the Yala Glacier.
Altitude, weather, time, and date of the measurements are as follows:
1: 5,090 m, snow, 16:40, 11 September 1987.
2: 5,070 m, clear, 16:14, 16 September 1987.
3: 5,090 m, clear, 11:30, 29 September 1987.

*Note

The altitude of each location was determined by Thommen pocket altimeter during the fieldwork. The control point of the altitude is the Glacier Camp (5,090 m), located near the margin of the Yala Glacier. The height of this camp was determined by Prof. Y. Ageta of Nagoya University in 1982 by triangulation involving the summits of Mt. Tserko (4,984 m), Mt. Langtang Lirung (7,234 m), and Mt. Gangchenpo (6,387 m). The altitudes of locations cited in this paper, therefore, do not necessarily coincide with those indicated by contours in the one inch to one mile map by the Survey of India, although the heights of the mountain summits in this paper follow the map.

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