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Mountain hazards in the Kanchanjunga area, eastern Nepal: landslides developed on lateral moraines

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ABSTRACT

We examined the distribution, morphological characteristics, timing of occurrence, and possible causes of the landslides developed on the lateral moraines of Kanchanjunga Himal. Such landslides were found at seven sites. The main possibilities of sliding cause were the unloading due to rapid deglaciation and melting of permafrost. The landslides on the Holocene lateral moraines of the Kanchanjunga Glacier began to occur after the Little Ice Age. This was explained by the following observations: (1) the debris flow deposits after the Little Ice Age cover the morainic material displaced by sliding; (2) the landslide scarp continues along the side and front slopes of the Little Ice Age tributary moraine; and (3) the morainic material and trail on it have slid down at places. The deglaciation in the Holocene age, therefore, was not able to cause the landslides. The ground-temperature and BTS measurements, and seismic sounding indicate that the lower limit of the present permafrost exists between 4,850 and 4,890 m on the south-facing slope in the Nupchu Valley. The landslides on the lateral moraines of the Kanchanjunga Glacier (4,760–5,200 m) may be related to the melting of permafrost or "relict ice" in the moraines.

INTRODUCTION

The Kanchanjunga area was closed to foreign trekkers until 1987. Only few studies such as those of biology have been conducted in the area so far. Khanal (1996) and Watanabe et al. (1998) identified the landslide, rock fall, glacier lake outburst flood, and snow avalanche as the major mountain hazards in this area.

The landslides of the Kanchanjunga area are divided into two types: those in the lower and middle reaches, and those in the upper reaches of the major rivers. The landslide occurrence in the lower and middle reaches seems to be related to geology. The landslides are concentrated in the Main Central Thrust (MCT) zone and Lesser Himalayan meta-sedimentary thrust zone (Arita and Schelling 1999). On the other hand, the landslide occurrence is rather scattered in the upper reaches, where the bedrock is composed of the Higher Himalayan crystallines. The landslides found in the Higher Himalayan crystallines are subdivided into those occurring on steep valley walls and those on lateral moraines in the uppermost reaches.

In order to develop a safe trekking tourism, it is important to study the mountain hazards. This study focuses on the landslides developed on the lateral moraines in the uppermost area of Kanchanjunga Himal, and aims at accumulating basic data useful for mitigating possible future hazards. It also deals with the unloading mechanism by rapid deglaciation and melting of mountain permafrost, which could cause the landslides. There exist a few studies on mountain permafrost in the Himalaya (Fujii 1978; Fujii and Higuchi 1978; Jakob 1992). However, none of them considered the issues of hazard and risk.

GENERAL SETTING

The Kanchanjunga Range (Fig. 1), with the world's third highest mountain peak of Kanchanjunga (8,586 m), meets the international border of Nepal, Sikkim (India), and Tibet (China).

The climate of the area is strongly controlled by monsoon activities. The mean annual precipitation (1988–1997) in Taplejung (1,780 m) was 2,000.8 mm, whereas that in Ilam (1,210 m) was 1,752.6 mm (Central Bureau of Statistics 1999). This suggests the increase in precipitation at higher altitudes, i.e. towards the north.

The territory was designated as a Conservation Area in 1997. Hence, the number of trekkers is expected to increase rapidly. The major trekking trails are usually found on lateral moraines in the uppermost areas. Similar to the previous studies in Khumbu and Shorong Himal by Yokoyama (1978) and in the New Zealand Alps by Blair (1994), landslides are well developed on the lateral moraines in Kanchanjunga Himal as well.

DISTRIBUTION OF LANDSLIDES ON LATERAL MORAINES

The distribution of landslides on lateral moraines was examined using the aerial photographs taken in 1992, and the slides were plotted on the 1:50,000 topographical maps. Such landslides were found at seven sites (Fig. 1). Six of them are on the southwest- to southeast-facing slopes, and the rest on the east-facing slopes (Table 1). The altitude of landslides ranges from 4,400 to 5,200 m and their scarp length varies between 400 and 7,200 m. Among these, the largest

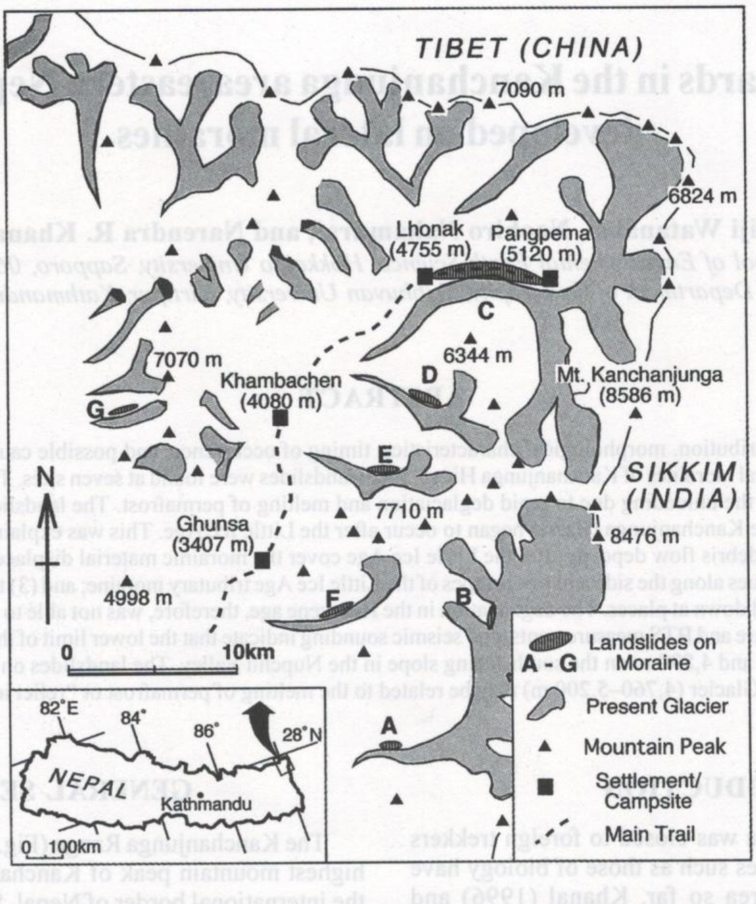

Fig. 1: Location of study area and the distribution of the landslides developed on the lateral moraines, Kanchanjunga Himal, far-eastern Nepal.

Table 1: Distribution of landslides on the lateral moraines in the Kanchanjunga area

Location no.	Name of glacier	Altitude of landslide (m)	Length of landslide (m)	Slope direction
A	Yalung	4,400-4,420	500	S
B	Yalung	4,840	400	E
C	Kanchanjunga	4,760-5,200	7,600	S
D	Ramdan	4,800-5,040	2,200	SW
E	Kumbhakarna	4,640-4,760	1,550	S
F	Yamatari	4,600-4,680	550	SE
G	Unnamed	4,480-4,600	1,100	SSW

landslide, which is developed on the lateral moraines of the Kanchanjunga Glacier (Fig.1C and Table 1), was studied in the field.

Geomorphological classification

The geomorphological map (Fig. 2) of the uppermost area of the Kanchanjunga Glacier depicts an asymmetrical valley configuration. The north-facing slopes (left bank) contain extremely steep rock wall. In contrast, the south-facing slopes (right bank) are relatively gentle. On the north-facing slopes, the distribution of the depositional landforms such as talus cones and rock glaciers is limited to the western half. Lateral moraines can be found only near the terminal area. The south-facing slopes exhibit many kinds of depositional landform (Fig. 2). Although the slopes mantled by debris are presently under the periglacial environments, the vegetated slopes may have been already stabilised by the strong root network of *Kobresia*. Frost cracks are extensively developed on such slopes, but may not be active today. Active periglacial landforms such as sorted polygons and stripes are observed on higher slopes.

Lateral moraines are well developed along the right bank of the Kanchanjunga Glacier. The lateral moraines with several ridges are classified into the higher (older) group and the lower (younger) group belonging to the Holocene and Little Ice Age, respectively (Asahi and Watanabe 2000). Debris flow cones are developed at the foot of the slopes and cover the higher lateral moraines.

Development of the landslides

The landslides are observed only on the right bank of the lateral moraines (Fig. 2). The total length of the landslide scarp attains 7,600 m (Table 1), although some of the scarps are unclear at some sites. The relative height of the scarp ranges from 0.5 to 70 m (Plate 1).

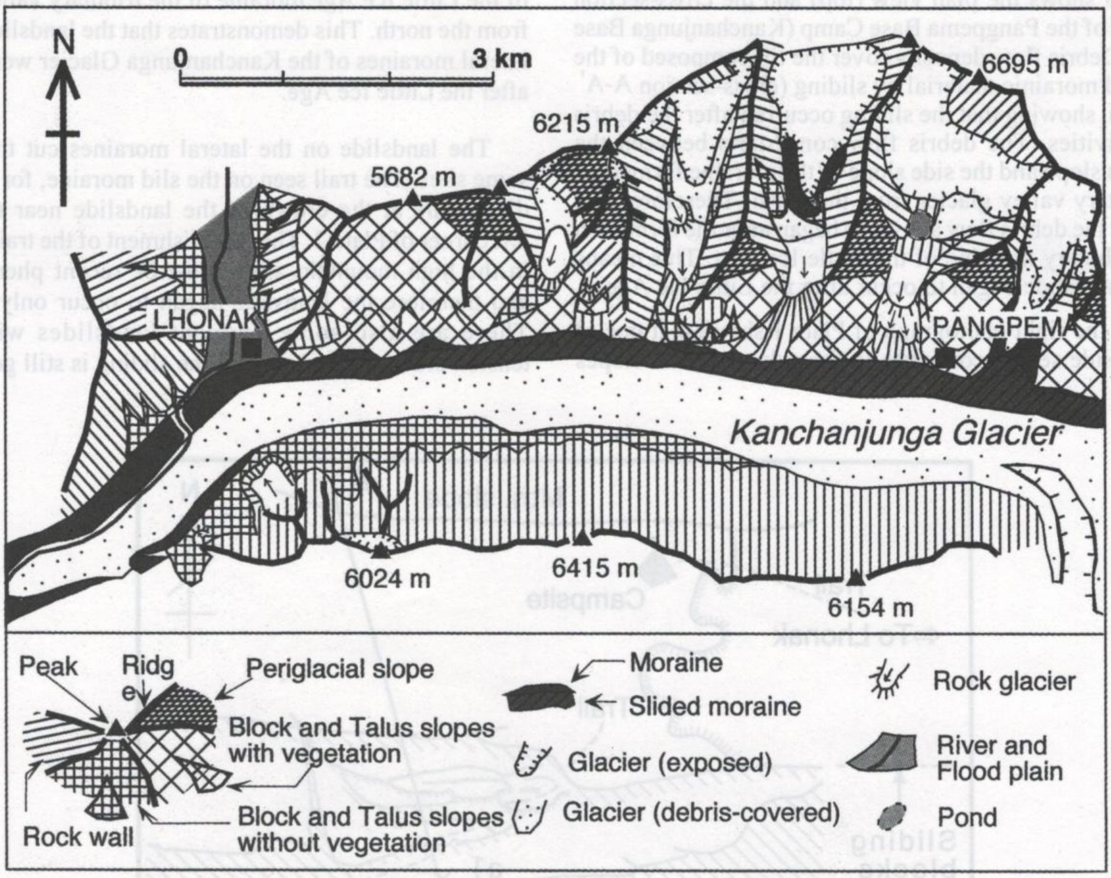

Fig. 2: Geomorphological map of the Kanchanjunga Glacier area

Plate 1: Slipped blocks of the lateral moraine of the Kanchanjunga Glacier at the Pangpema Base Camp. The landslide scarp in the centre is 13.5 m high. Stratified sand deposits are seen on the left of the scarp. The right side of the scarp is composed of morainic deposits.

Fig. 3 shows the plan view (top) and the cross-section (bottom) of the Pangpema Base Camp (Kanchanjunga Base Camp). Debris flow deposits cover the till composed of the displaced morainic material by sliding (cross-section A-A' in Fig. 3), showing that the sliding occurred after the debris flow activities. The debris flow cone starts between the mountain slope and the side slope of the moraine formed by the tributary valley glacier from the north. Therefore, it is clear that the debris flow activities began after the formation of the tributary moraine of the Little Ice Age. This means that the landslide began to occur after the Little Ice Age.

Also, the right photograph of Plate 1 shows that one of the landslide scarps continues to the side and front slopes of the Little Ice Age moraine of the tributary valley glacier from the north. This demonstrates that the landslides on the lateral moraines of the Kanchanjunga Glacier were formed after the Little Ice Age.

The landslide on the lateral moraines cut the trail at some sites. The trail seen on the slid moraine, for example, disappears at the crown of the landslide near the upper left corner of Plate 2. The establishment of the trail network in the high mountain areas must be recent phenomenon, and therefore the landslide began to occur only recently. There are also some dormant landslides with many tension cracks indicating that the sliding is still going on.

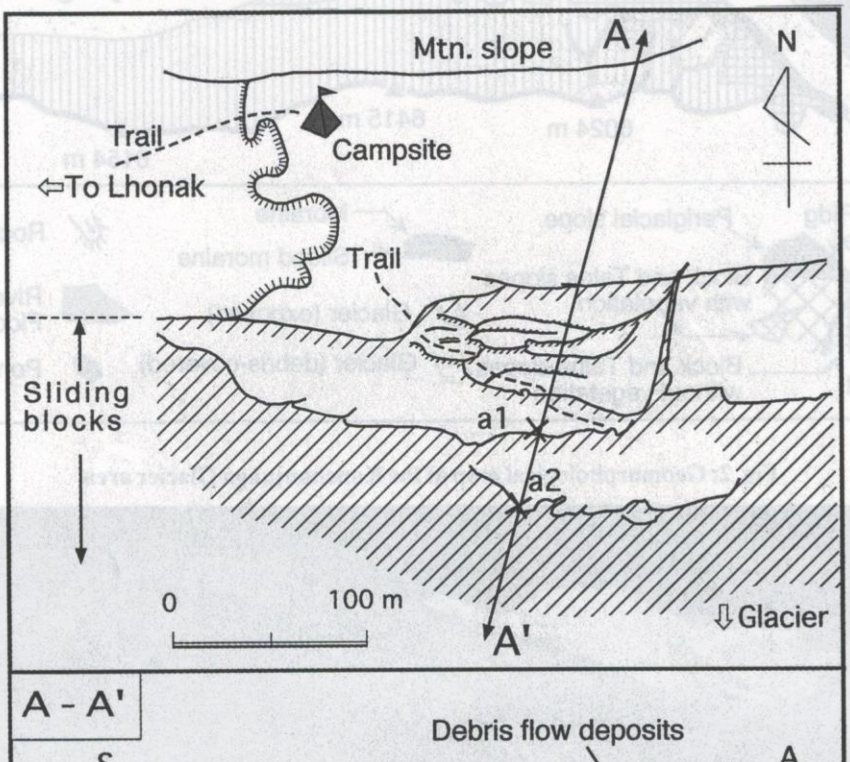

Fig. 3: Plan view (top) and cross-section (bottom) of the Pangpema Base Camp, which show the landslides developed on the Holocene lateral moraine. Relative height of the landslide scarp between Sites A1 and A2 is about 20 m.

Plate 2: A trail to the Pangpema (Kanchanjunga) Base Camp, which is stretching on the morainic material displaced by sliding. Note that part of the trail is buried by rock fall debris from the landslide scarp. The trail abruptly disappears at the head of the scarp near the upper left corner of the photograph, indicating that the landslide occurred after the establishment of the trekking trail between the Lholak and Pangpema Base Camps.

POSSIBLE CAUSES OF THE LANDSLIDE

The previous studies conducted elsewhere in the world indicate that rapid deglaciation can trigger landslides (Yokoyama 1978; Blair 1994). Rapid melting of mountain permafrost may also initiate sliding. The main triggers of landslide in the Kanchanjunga area are summarised below.

Deglaciation

The photograph taken in 1899 (Freshfield 1903) shows that the glacier surface of the Kumbhakarna (Jannu) Glacier, located about 9 km south of the Kanchanjunga Glacier, was close to the level of the lateral moraines. Today, the surface of the glacier is lowered by about 100 m. Although the accurate lowering amount of the glacier surface for all the glaciers (Table 1) is not known, they seem to have experienced great lowering of their ice surface since the end of the Little Ice Age glacial advance. Thus, it is inferred that the lateral moraines lost the support of glacier ice due to its rapid melting during the last 100 years, and consequently the landslides occurred in those areas.

However, as shown in cross-section A-A' (Fig. 3), the present glacier is located far down the sliding blocks at the Pangpema Base Camp. The younger (lower) moraine is a Little Ice Age moraine, and hence the rapid deglaciation (after the Little Ice Age advance) took place only in the younger moraines of the Kanchanjunga Glacier.

Permafrost in the Kanchanjunga area

Melting permafrost is another possible cause of the landslides. The existence of rock glaciers with no vegetation cover indicates the permafrost development in the area. In order to identify the lower limit of permafrost, ground temperatures and basal temperature of snow (BTS) were measured. A seismograph equipped with a sledgehammer was also used for this purpose.

Ground temperature profile

Ground temperatures have been measured on the Nupchu Rock Glacier at an altitude of 4,997 m since September 1997. This rock glacier was selected because it forms a sequence of multi-unit of different ages (Fig. 4), because it is formed on a south-facing slope, and because it is a glacier-derived one.

Fig. 5 summarises the one-year record of temperatures at the depths of 30, 50, 70, 110, and 150 cm from the ground surface. The temperatures are automatically recorded in small data loggers (T and D Co., TR-51 and 52; Onset Co., Optic Stowaway) at an interval of one hour. The ground temperature profile shows that the permafrost table exists at the depth of 220 cm (Fig. 5).

Measurement of BTS

The BTS measurement is another way of estimating the existence of permafrost (Haeberli 1973). This method has been used mainly in the Alps. According to Haeberli (1973), the ground surface temperature under snow cover with certain thickness in late winter to early spring should be above -2° C if no permafrost exists, and it should be less than -3° C if permafrost exists.

At an altitude of 4,990 m (Site BTS-1) on the newest rock glacier, the BTS values were below –3° C (A in Fig. 6), and at an altitude of 4,890 m (Site BTS-2), they were higher than those at Site BTS-1 but were well below –3° C (B in Fig. 6). These data support the existence of permafrost at these altitudes.

Seismic sounding

Barsch (1996) carried out seismic sounding with a sledgehammer in the Alps to determine the existence of permafrost. For this purpose, we used a handy seismograph (OYO Co., McSEIS-3). At Site N1 (5,996–4,997 m), the velocity of the uppermost layer (V1) ranged from 275 to 458 m/sec, whereas that of the second layer (V2) from 1,572 to 3,301 m/sec

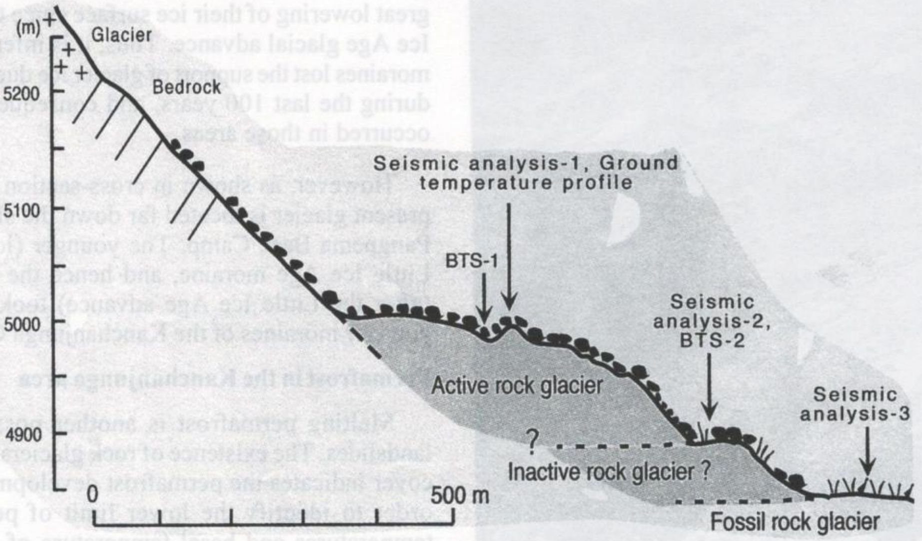

Fig. 4: Longitudinal profile through the multi-unit of the Nupchu Rock Glacier. The locations of BTS measurement and seismic sounding sites are also indicated.

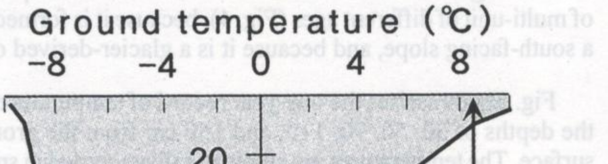

Fig. 5: Ground temperature profile of the Nupchu Rock Glacier (4,997 m) from October 1997 to 18 September 1998

(Table 2). The velocity ranges confirmed the existence of a permafrost layer at 1.5 to 2.8 m below the ground. At Site N2 (4,888–4,890 m), the velocity of the second layer (V2) ranged from 786 to 1,572 m/sec (Table 2), and it was not possible to ascertain the existence of permafrost there, whereas at Site N3 (4,850 m), no permafrost was detected (Table 2).

Lower limit of permafrost

The results of BTS measurements and seismic sounding indicated that the lower limit of the present permafrost existed between 4,850 and 4,890 m in the Nupchu Valley. On the other hand, in the lateral moraine of the Kanchanjunga Glacier, the temperatures on 19 November 1998 at the depths of 20, 50, 80, 100, 130, 180, 200, and 225 cm from the ground indicated that no permafrost existed at 4,900 m. Both the Nupchu Rock Glacier and the lateral moraine of the Kanchanjunga Glacier with the landslide are located on the

Table 2: Results of seismic sounding on the Nupchu Rock Glacier

Location no.	Altitude (m)	Run	V1 (m/sec)	V2 (m/sec)	Depth (m)
		1-1	458	1,572	2.8
N1	4,996–4,997	1-2	275	3,300	2.2
		1-3	314	3,301	1.5
		2-1	550	1,572	2.8
		2-2	314	917	2.1
N2	4,888–4,890	2-3	324	786	1.9
		2-4	262	1,100	2.4
N3	4,850	3-1	786	917	-

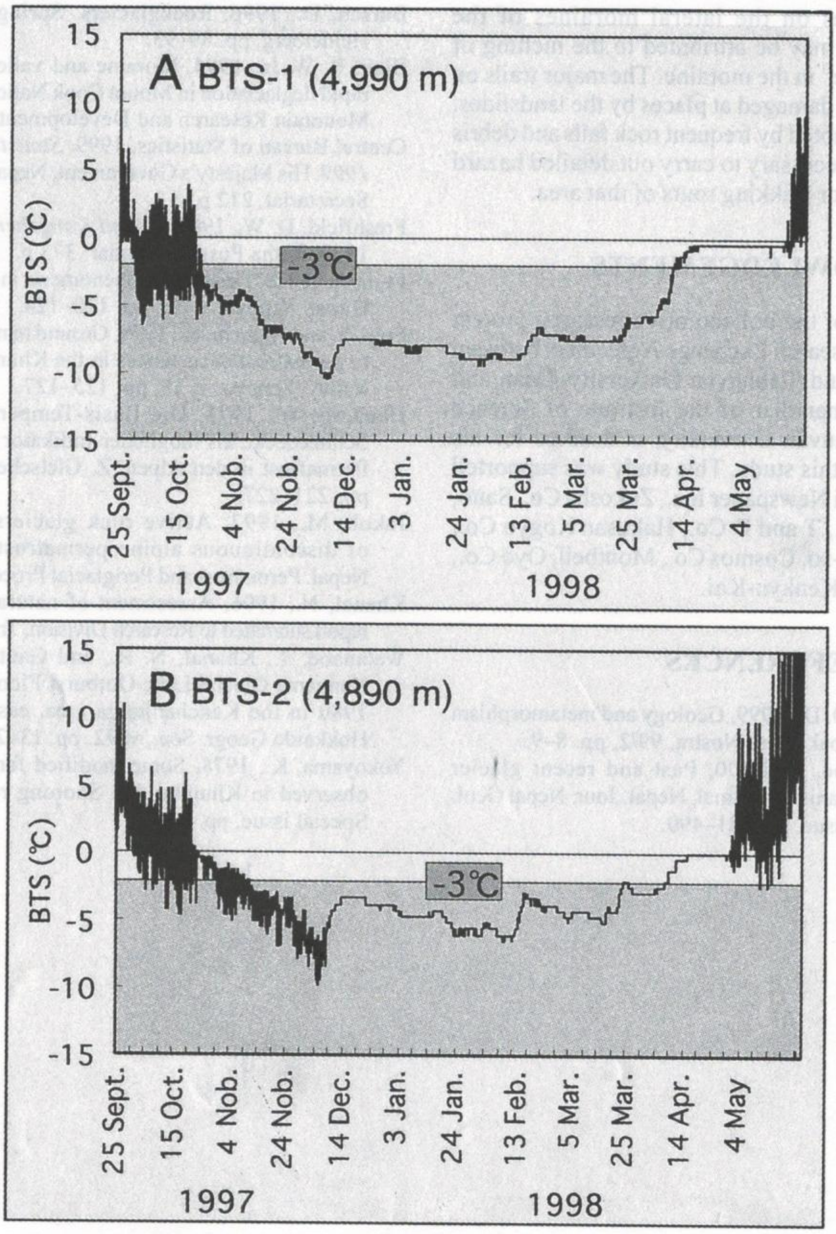

Fig. 6: BTS values in the winter of 1998 for the Nupchu Rock Glacier. Locations are shown in Fig. 4.

south-facing slope. The lower limit of the present permafrost may be higher in the rock glaciers of periglacial origin. The permafrost of glacier ice origin or "relict glacier ice", however, may remain in the lateral moraines.

The lateral moraines are not composed of homogeneous materials (besides tills, debris flow deposits fill the upper part of the moraines at places). There are also some laminated sand layers (Plate 1) with frequent seeps. Table 1 shows that the altitude of the landslide occurrence ranges from 4,400 to 5,200 m. If the lower limit of the present permafrost lies between 4,850 and 4,890 m, the landslides at Sites A, E, F, and G appear to have occurred when the permafrost existed at the lower altitudes.

CONCLUSIONS

The landslides developed on the Holocene lateral moraines of the Kanchanjunga Glacier began to occur after the Little Ice Age. This is explained by: (1) the debris flow deposits after the Little Ice Age cover the morainic material displaced by sliding; (2) the scarp continues on the side and front slopes of the Little Ice Age tributary moraines; and (3) the morainic material with trails on it have slid down at places. The rapid deglaciation in the Holocene age, therefore, was not able to cause the landslides.

The lower limit of the present permafrost exists between 4,850 and 4,890 m on the south-facing slope in the Nupchu

Valley. The landslides on the lateral moraines of the Kanchanjunga Glacier may be attributed to the melting of permafrost or "relict ice" in the moraine. The major trails on the lateral moraines are damaged at places by the landslides. Such trails are also disrupted by frequent rock falls and debris flows. Therefore, it is necessary to carry out detailed hazard mapping along the major trekking routs of that area.

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