Journal of Nepal Geological Society, 2000, Vol. 22, pp. 505–512

Landslides on the late Quaternary deposits in the Bhote Koshi area, central Nepal

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ABSTRACT

The origin and age of piedmont talus slopes and their relationship with present landslides are studied in the Bhote Koshi area of central Nepal. The talus slopes near Lamosanghu consist of 7–15 m thick boulder-rich colluvium overlying the Middle terrace deposits of the Sun Koshi River. The organic debris within these layers was dated 12,745±160 years BP (Nu-967) and 12,970±100 years BP (Beta-130478). The pollen analysis of the sediments revealed that a cool temperate to subalpine conifer forests existed in the adjacent area, and marshland was formed near the Sun Koshi River. According to the limited distribution of glacial landforms above 4,000 m in the upper Bhote Koshi watershed, the upper talus slope deposits had not originated from glaciation, but from frequent landslides on the higher slopes 12,000–13,000 years ago, presumably during the latest Last Glacial time and the early Holocene.

The talus deposits were formed by block sliding on the alternating bands of phyllite and quartzite. On the other hand, near the Main Central Thrust, abundant groundwater is available to trigger present frequent landslides on the talus slopes.

INTRODUCTION

Landslides are the main disastrous phenomena in Nepal (Upreti and Dhital 1996). Quaternary geomorphological processes influenced both by climate change and crustal movement might have played a great role in the formation of landslides in Nepal.

Along the Bhote Koshi River and the upper Sun Koshi River in central Nepal, the Arniko Highway connecting Tibet and Nepal was periodically damaged by many landslides on thick colluvial deposits, which form piedmont talus slopes. Recent studies found Quaternary glacial deposits at low altitude in Nepal (Osmaston 1989; ICIMOD 1996; ITECO Engineering Ltd. 1996). The thick Quaternary deposits along the upper Sun Koshi and Bhote Koshi Rivers too were pointed out to be of glacial origin (ICIMOD 1996) during the Workshop on Hazard Mitigation in the Northern Sun Koshi and Bhote Koshi Water Catchment Areas (HMWA). However, recent geomorphological studies (Shiraiwa 1993) obtained the altitude of past maximum glaciation at a significantly higher level than that of the presumably glacial deposits of the Sun Koshi–Bhote Koshi area.

This paper describes the origin and ages of the piedmont talus slopes and their relationship with present landslides in the Sun Koshi–Bhote Koshi area. It covers the area between Lamosanghu and ten kilometres ahead of Barabise towards Kodari in the Sindhupalchowk District (Fig. 1). The piedmont talus slopes consist of more than 15 m thick upper Quaternary deposits. According to the results of C^{14} dating and pollen analysis, frequent landslides on the valley-side slopes formed the talus slopes during the late Quaternary.

GEOMORPHOLOGICAL CHARACTERISTICS

The study area has the altitude of 800–2,500 m and consists mainly of phyllites and quartzites (Upreti and Dhital 1996), and sandstones and calcareous rocks (Maruo et al. 1973) of the Lesser Himalaya. The mountain height increases towards the Main Central Thrust (MCT) located about 15 km north of Lamosanghu. The thick Quaternary deposits are distributed on the valley bottom of the Sun Koshi River (below 1,000 m) and on the piedmont talus slopes. Landslides frequently occur on these deposits. There is a low-relief surface, which might have originated from remnants of uplifted peneplain above 1,800 m on the right bank of the Sun Koshi River. Deep V-shaped or U-shaped valleys are developed below it.

A geomorphological map (Fig. 2) was prepared based on the interpretation of the 1:50,000 aerial photos taken in 1993 and 1:50,000 topographical maps published in 1996 both by

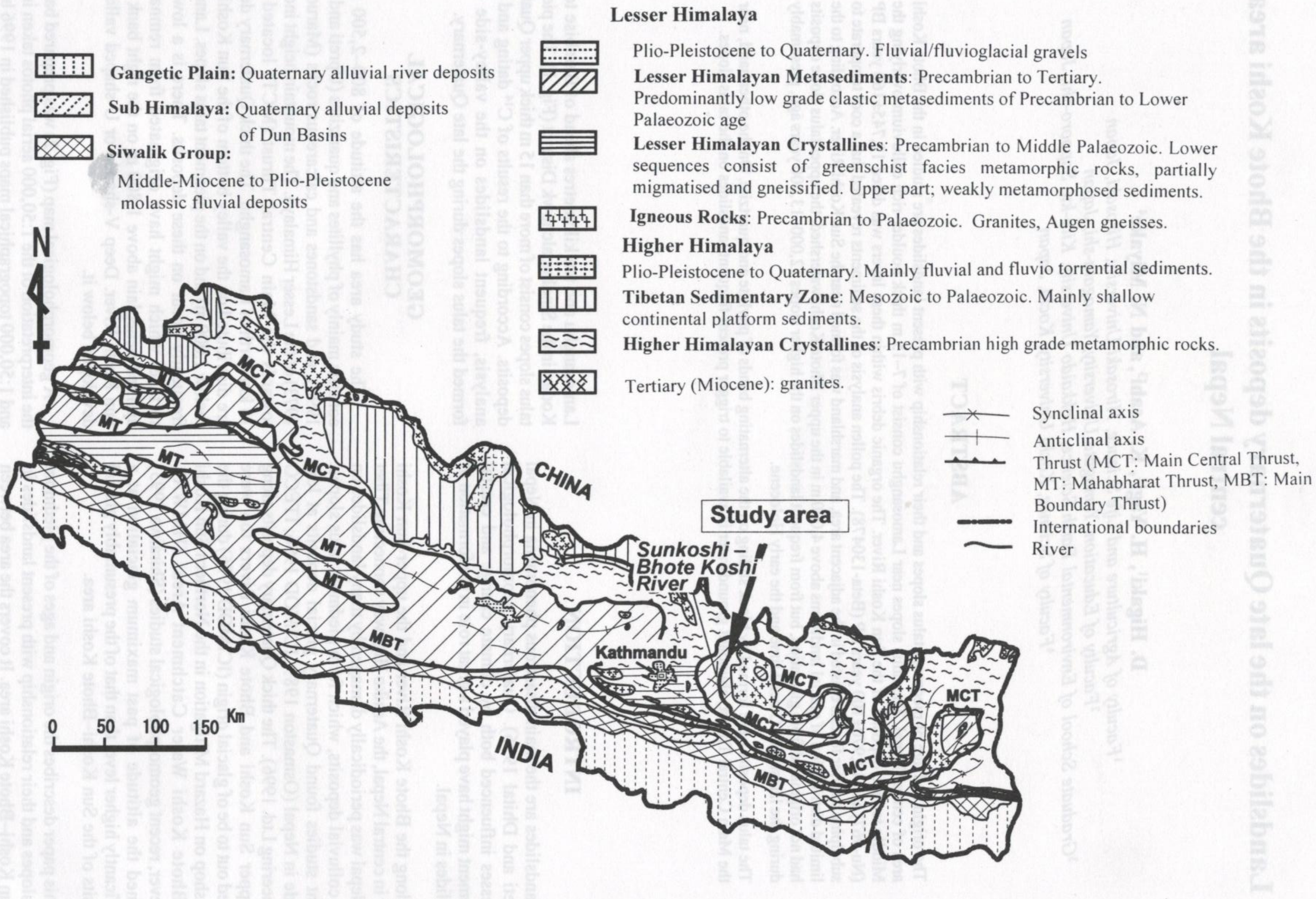

Fig. 1: Geological map of Nepal showing the location of the study area (simplified from ESCAP 1994)

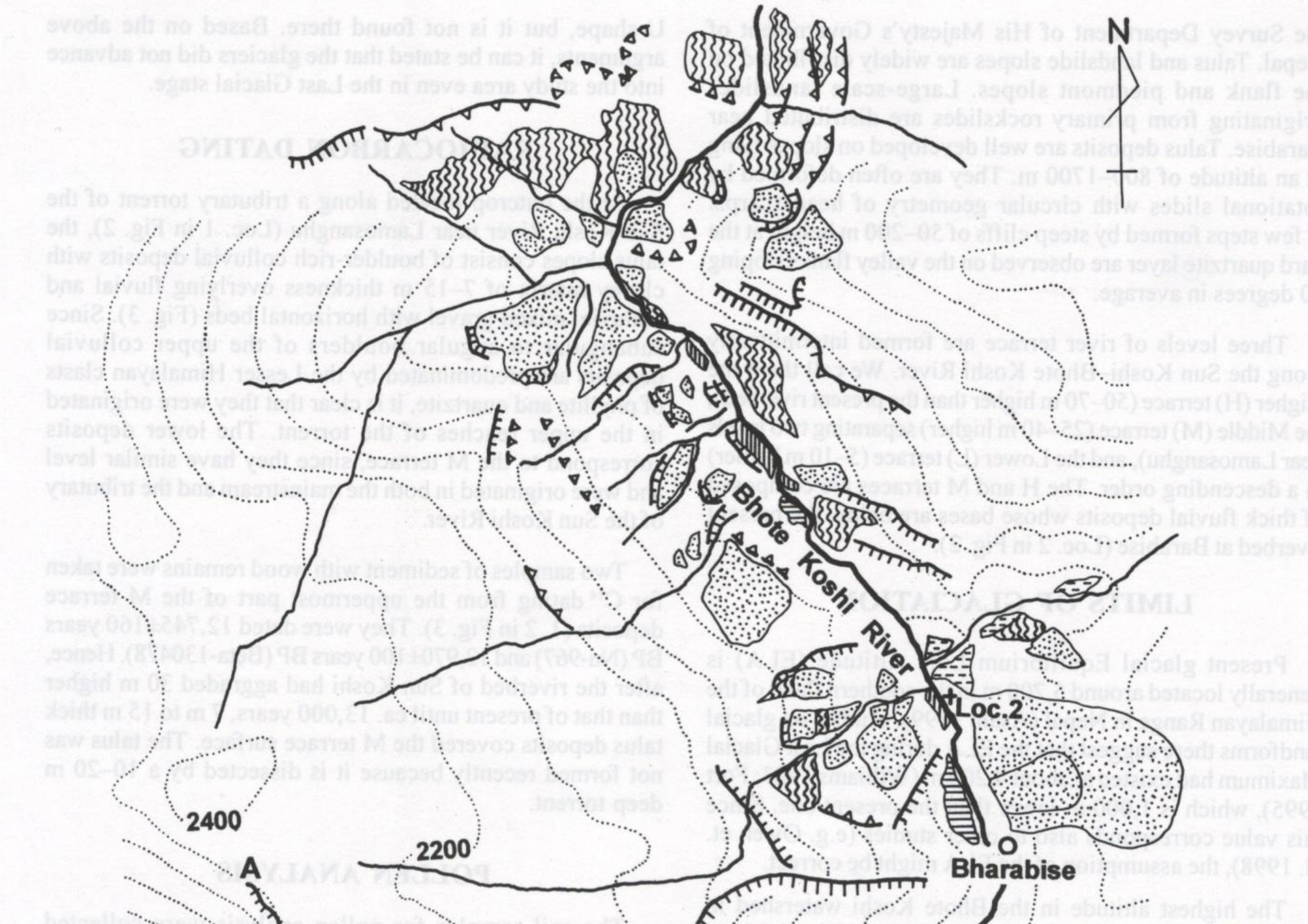

Fig. 2: Geomorphological map of the study area (Loc. 1 and Loc. 2 indicate the locations of outcrops

the Survey Department of His Majesty's Government of Nepal. Talus and landslide slopes are widely distributed on the flank and piedmont slopes. Large-scale landslides originating from primary rockslides are distributed near Barabise. Talus deposits are well developed on slopes lying at an altitude of 800–1700 m. They are often deformed by rotational slides with circular geometry of head scarps. A few steps formed by steep cliffs of 50–200 m height at the hard quartzite layer are observed on the valley flanks sloping 30 degrees in average.

Three levels of river terrace are formed intermittently along the Sun Koshi–Bhote Koshi River. We call them the Higher (H) terrace (50–70 m higher than the present riverbed), the Middle (M) terrace (25–40 m higher) separating two levels near Lamosanghu), and the Lower (L) terrace (5–10 m higher) in a descending order. The H and M terraces are composed of thick fluvial deposits whose bases are below the present riverbed at Barabise (Loc. 2 in Fig. 2).

LIMITS OF GLACIATION

Present glacial Equilibrium Line Altitude (ELA) is generally located around 5,200 m in the southern flank of the Himalayan Range in Nepal (Asahi 1999). Studies on glacial landforms there suggest that the ELA during the Last Glacial Maximum had existed at about 4,200 m (Williams 1983; Fort 1995), which is 1,000 m lower than the present one. Since this value corresponds also to other studies (e.g. Owen et. al. 1998), the assumption of the ELA might be correct.

The highest altitude in the Bhote Koshi watershed in Nepal is 5, 542 m, which lies southeast of Jugal Himal, 10 km northwest of Kodari (Fig. 5). There are only five glaciers smaller than 1 km^2. Small but typical shapes of glacial cirque are continuously distributed on the slopes between the altitudes of 4,000 and 4,200 m. Similarly, glacial cirques exist in the altitudinal zone of 4,000–4,200 m on the left bank of the Bhote Koshi. No glaciated landforms can be found below it. Hence, these landforms indicate a maximum extent of the glaciers and they might have formed in the Last Glacial Maximum (18,000–22,000 years ago). Yagi and Minaki (1991) mentioned that the glacier that flew down to 3,600 m during the Last Glacial Maximum had retreated before 12,000 years in the vicinity of the Siptong Pass, eastern Nepal.

ICIMOD (1996) and ITECO (1996) pointed out that, huge boulder of augen gneiss called Pancha Kanya (whose weight is estimated at 70,000 t and is located near Km 71 of the Arniko Highway) could not be transported without glaciation. However, a boulder denuded from rock wall in the glacial ablation area must be sheared off in the process to reach the glacier. It is impossible to find a huge boulder up to 70,000 t on the surface of existing valley glaciers in the Nepal Himalaya such as the Khumbu Glacier. Although there are some U-shaped parts of the Bhote Koshi Valley having wide bottom and steep side slopes composed of bedrocks, most of the valley morphology is V-shaped. One of the characteristics of a glaciated valley is the continuity of the U-shape, but it is not found there. Based on the above arguments, it can be stated that the glaciers did not advance into the study area even in the Last Glacial stage.

RADIOCARBON DATING

At the outcrop located along a tributary torrent of the Sun Koshi River near Lamosanghu (Loc. 1 in Fig. 2), the talus slopes consist of boulder-rich colluvial deposits with clayey matrix of 7–15 m thickness overlying fluvial and colluvial mixed gravel with horizontal beds (Fig. 3). Since subangular to angular boulders of the upper colluvial deposits are predominated by the Lesser Himalayan clasts of phyllite and quartzite, it is clear that they were originated in the upper reaches of the torrent. The lower deposits correspond to the M terrace, since they have similar level and were originated in both the mainstream and the tributary of the Sun Koshi River.

Two samples of sediment with wood remains were taken for C^{14} dating from the uppermost part of the M terrace deposits (1, 2 in Fig. 3). They were dated 12,745±160 years BP (Nu-967) and 12,970±100 years BP (Beta-130478). Hence, after the riverbed of Sun Koshi had aggraded 30 m higher than that of present until ca. 13,000 years, 7 m to 15 m thick talus deposits covered the M terrace surface. The talus was not formed recently because it is dissected by a 10–20 m deep torrent.

POLLEN ANALYSIS

The soil samples for pollen analysis were collected from four horizons (i.e. A-1, A-2, A-3, and C) containing organic material (Fig. 3). All samples were prepared by successive treatment with 40% HF and hot 10% KOH, sieving through a 0.2-mm mesh, and separation using saturated $ZnCl_2$ and acetolysis solution.

Among the 48 identified taxa, 23 belonged to the arboreal pollen (AP), 22 to the herbaceous pollen (HP), and 3 to the fern spores (FS). Out of them, 33 genera or families are shown in Fig. 4. The percentage of AP grains was calculated based on the total AP grains, while those of HP and FS were expressed using the sum of pollen grains and spores, respectively. The results of A-2 horizon are not shown owing to the recovery of few pollen grains. In the samples from A-1, A-2, and A-3 horizons, the percentage of AP grains is only 3–7%. This suggests that the study area was covered by grassland with isolated small forest patches. However, in these samples, most pollen grains and spores were affected by biological corrosion or mechanical damages. Therefore, much of the pollen might have disappeared due to decaying. On the other hand, in the samples from C Horizon, pollen grains and spores were well preserved, and more than 300 arboreal pollen grains could be counted.

We reconstructed palaeovegetation and palaeo-environment in the study area based on the data of C, A-1, and A-3 Horizons, noting especially that the

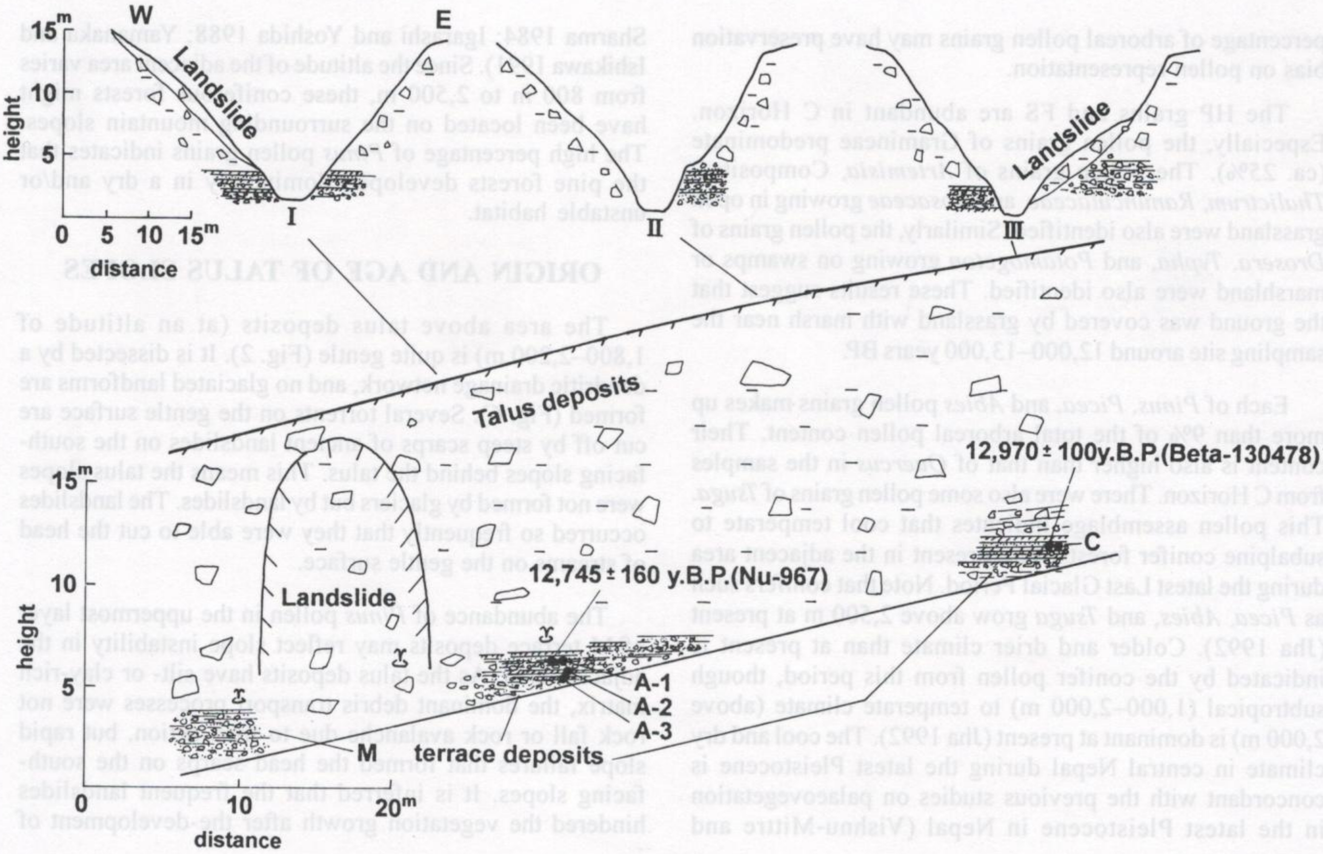

Fig. 3: Exposure of the talus slope at Loc. 1 in Fig. 2 (A-1, A-2, A-3, and C indicate the sampling points for pollen analysis).

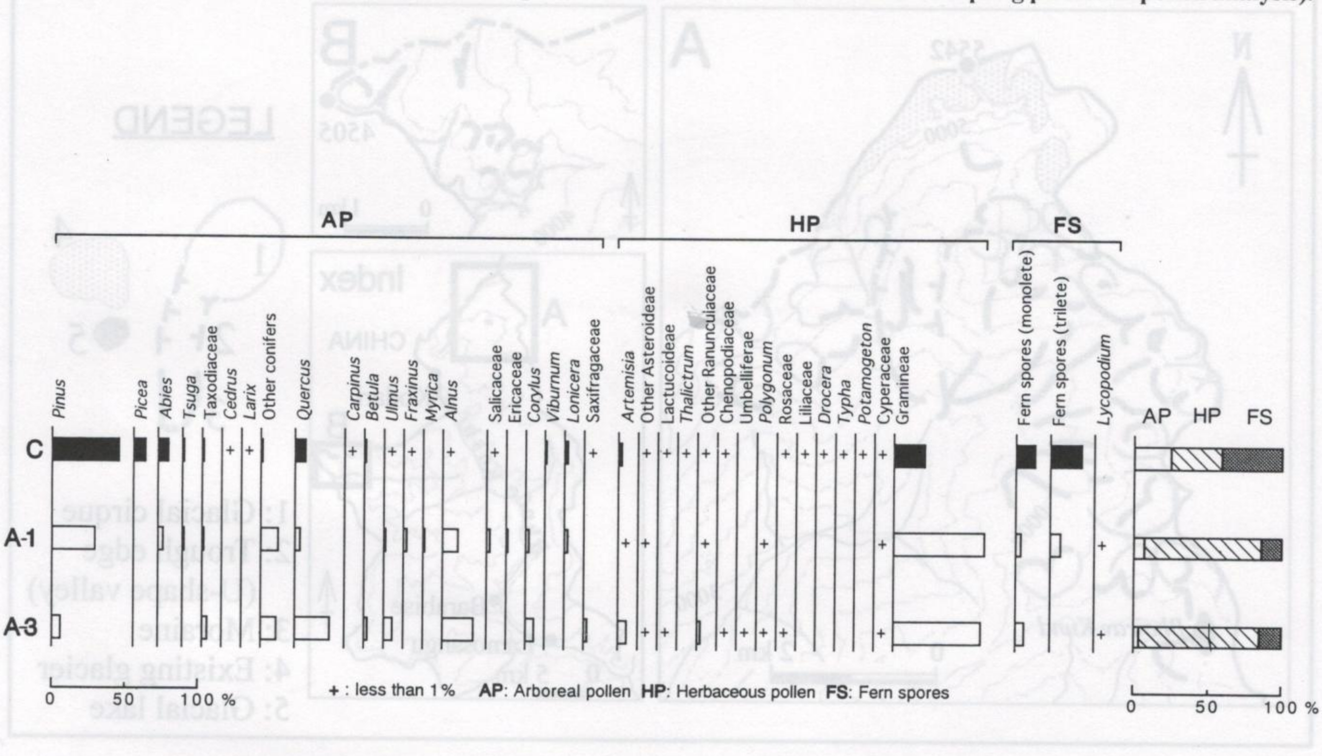

Fig. 4: Pollen diagram of the M terrace deposits

percentage of arboreal pollen grains may have preservation bias on pollen representation.

The HP grains and FS are abundant in C Horizon. Especially, the pollen grains of Gramineae predominate (ca. 25%). The pollen grains of *Artemisia*, Compositae, *Thalictrum*, *Ranunculaceae*, and *Rosaceae* growing in open grassland were also identified. Similarly, the pollen grains of *Drosera*, *Typha*, and *Potamogeton* growing on swamps or marshland were also identified. These results suggest that the ground was covered by grassland with marsh near the sampling site around 12,000–13,000 years BP.

Each of *Pinus*, *Picea*, and *Abies* pollen grains makes up more than 9% of the total arboreal pollen content. Their content is also higher than that of *Quercus* in the samples from C Horizon. There were also some pollen grains of *Tsuga*. This pollen assemblage indicates that cool temperate to subalpine conifer forests were present in the adjacent area during the latest Last Glacial Period. Note that conifers such as *Picea*, *Abies*, and *Tsuga* grow above 2,500 m at present (Jha 1992). Colder and drier climate than at present is indicated by the conifer pollen from this period, though subtropical (1,000–2,000 m) to temperate climate (above 2,000 m) is dominant at present (Jha 1992). The cool and dry climate in central Nepal during the latest Pleistocene is concordant with the previous studies on palaeovegetation in the latest Pleistocene in Nepal (Vishnu-Mittre and Sharma 1984; Igarashi and Yoshida 1988; Yamanaka and Ishikawa 1991). Since the altitude of the adjacent area varies from 800 m to 2,500 m, these coniferous forests might have been located on the surrounding mountain slopes. The high percentage of *Pinus* pollen grains indicates that the pine forests developed dominantly in a dry and/or unstable habitat.

ORIGIN AND AGE OF TALUS SLOPES

The area above talus deposits (at an altitude of 1,800–2,200 m) is quite gentle (Fig. 2). It is dissected by a dendritic drainage network, and no glaciated landforms are formed (Fig. 6). Several torrents on the gentle surface are cut off by steep scarps of ancient landslides on the south-facing slopes behind the talus. This means the talus slopes were not formed by glaciers but by landslides. The landslides occurred so frequently that they were able to cut the head of streams on the gentle surface.

The abundance of *Pinus* pollen in the uppermost layer of M terrace deposits may reflect slope instability in the adjacent area. As the talus deposits have silt- or clay-rich matrix, the dominant debris transport processes were not rock fall or rock avalanche due to frost action, but rapid slope failures that formed the head scarps on the south-facing slopes. It is inferred that the frequent landslides hindered the vegetation growth after the development of

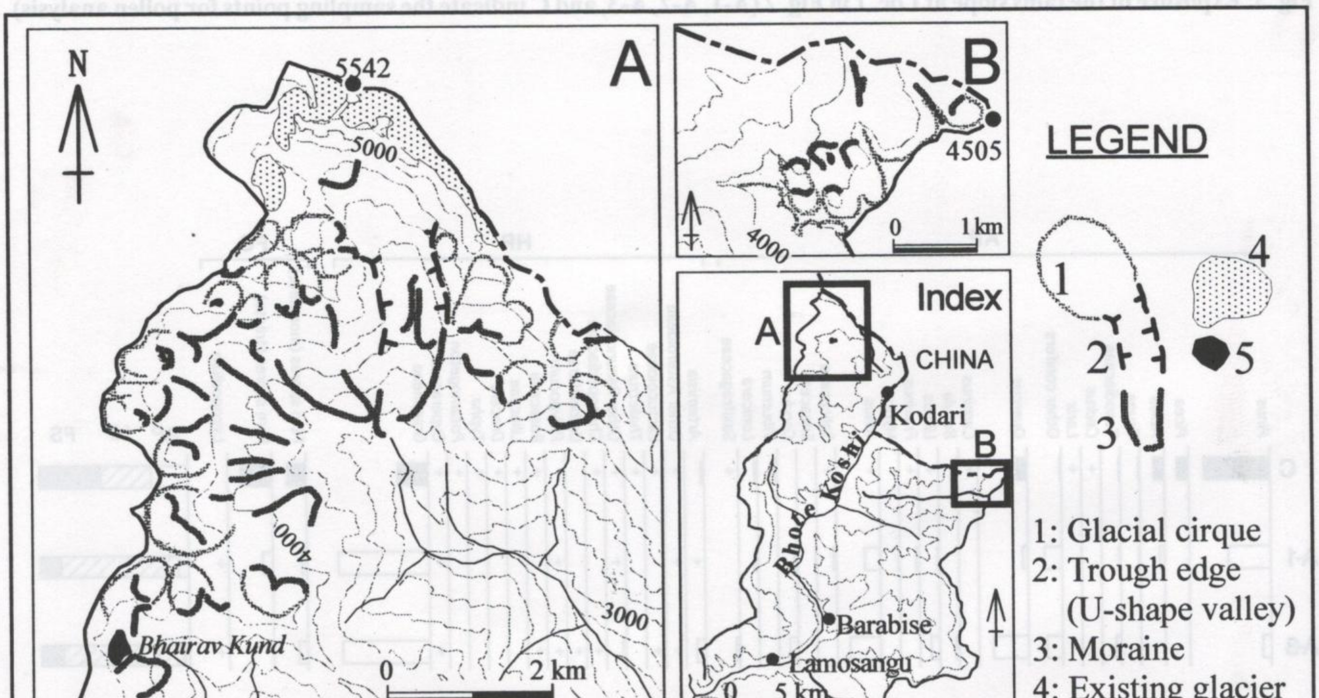

Fig. 5: Distribution of glacial landforms in the Bhote Koshi watershed in Nepal

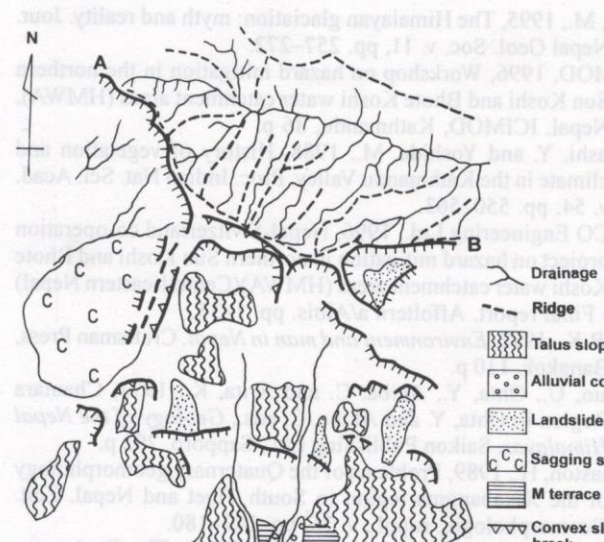

Fig. 6: Morphological difference between the low-relief surface and south-facing slopes (Locations A and B are shown in Fig. 2.)

pine forest on the mountain slopes, and marshland was formed on the foot of talus slopes where the debris was frequently removed by fluvial processes of the Sun Koshi River around 12,000–13,000 years. After that, the talus slopes were formed simultaneously during degradation of the main riverbed.

Since at present the river is actively undercutting the talus slope, there was a past (12,000–13,000 years ago) stage of talus formation. Saijo (1991) assumed that the colluvial slopes in the southern part of the Kathmandu Valley were formed during the warmer stage from the latest Last Glacial Periord to the early Holocene. In this area, we also infer an equivalent stage of talus formation by landslides.

The alternating phyllite and quartzite bands facilitated the talus formation. Extensive landslide scars were observed in the similar rocks around the Kathmandu Valley (Yagi 1995). The slope instabilities triggered by the Sun Koshi–Bhote Koshi River induced gravitational deformation in the phyllite that had well-developed foliation and higher ductility than quartzite. The quartzite, which was less susceptible to internal rock deformation, acted as a counterweight on the phyllite. They together finally fell down as block slides giving rise to talus slopes (Fig. 7).

RELATIONSHIP BETWEEN TALUS DEPOSITS AND PRESENT LANDSLIDES

Within a span of one kilometre, there are seven debris slides less than a few metres deep on the valley side of the torrent (Fig. 3). Many active debris slides occur on talus slopes along the highway. As the relative relief near the MCT is higher than in any other areas of the Lesser Himalaya, a large amount of debris and groundwater can accumulate on the piedmont slopes. The weathered soil from phyllite is also transported downhill constituting the debris matrix. Moreover, the toe of talus slopes is being eroded by streams and has become unstable.

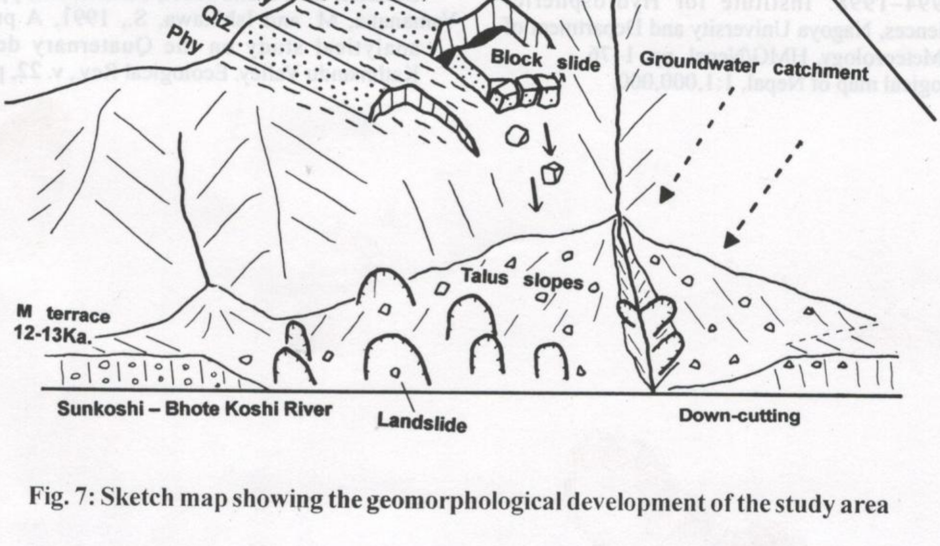

Fig. 7: Sketch map showing the geomorphological development of the study area

CONCLUSIONS

Landslides frequently take place on the thick Quaternary deposits of the Sun Koshi–Bhote Koshi Valley. Since glaciated landforms are limited above 4,000–4,200 m in the Bhote Koshi Watershed, the glaciers were not present in this area even in the Last Glacial period. The talus slopes near Lamosanghu are composed of 7–15 m thick colluvial deposits and they overlie the fluvio-colluvial deposits of the M terrace. The organic debris within these layers was dated 12,745±160 years BP (Nu-967) and 12,970±100 y BP (Beta-130478).

The result of pollen analysis revealed that there were temperate to subalpine conifer forests in the adjacent area and marshland near the Sun Koshi River 12,000–13,000 years ago. The occurrence of abundant pollen grains of *Pinus* indicates slope instabilities.

The talus deposits were not transported by glaciers, but by frequent landslides on the upper slopes presumably during the latest Last Glacial Period and the early Holocene. They were formed by block slides on the alternating bands of phyllite and quartzite, which might had been preceded by gravitational deformation due to river undercutting after 12,000–13,000 years ago. Near the MCT, abundant groundwater is available to trigger present frequent landslides on the talus slopes.

ACKNOWLEDGEMENTS

The authors are thankful to the staffs of the Water Induced Disaster Prevention Technical Centre/HMG Nepal/JICA for the help provided to this study. They also thank the Paleo Labo. Ltd., Japan for C^{14} dating.

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