# GEOMORPHOLOGY OF THE THAKKHOLA-MUKTINATH REGION, CENTRAL NEPAL, AND ITS LATE QUATERNARY HISTORY

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*Abstract* Glacial and mass-movement landforms, river terraces, and the sediments forming these landforms were surveyed in the field, and the origin, relative chronology and crustal movement were discussed in the upper basin of the Kali Gandaki River. Large scale landslides and glacial deposits around Larjung played an important role for making up the geomorphology of the Thakkhola basin: These landslides made a distinct basin-form and the glacier deposits dammed up the Kali Gandaki and then formed the Paleo Marpha Lake, in which the Marpha Formation accumulated. These occurred in the Pre-Last Interglacial period. The Marpha Formation was entrenched and filled with fluvioglacial materials in the Early and Late Substages of the Last Glacial.

## 1. Introduction

Many people believe that the Himalayan mountains have experienced severe crustal movements since the Miocene, especially during the Quaternary. In order to study the mode and intensity of the crustal movement in this area, investigations of Quaternary deposits and landforms, especially investigations of glacial landforms and lake deposits, are indispensable. Athough favorable fields for the study are widely distributed in the Southern Tibet (Iwata, 1980), it is still difficult for foreigners to work there because of political reasons. Pleistocene glacial deposits, river terraces and lake deposits are extensively distributed in the Thakkhola region, the upper basin of the Kali Gandaki, Central Nepal. The Thakkhola region is one of the most accessible places among the places behind the Himalayas for foreign scientists.

There have been many works on the Quaternary deposits and landforms in Thakkhola-Muktinath region (Fort, 1976; 1980; Fort *et al.* 1981; 1982; Kuhle, 1982). However, the comprehensive history of the Quaternary geomorphological development has not been traced yet. The author has studied geomorphology of the region for three years, and he described the glacial and terrace landforms of this region, according to the results of the field survey carried out from 1980 to 1981 (Iwata *et al.*, 1982).

The second successive field work was carried out in 1982. The field work was focused on the relationship between geomorphic surfaces and deposits. In particular, the internal structures of the terrace deposits were intensively surveyed.

The main purpose of the present paper is to discuss the origin of landforms and their Late Quaternary history of the Takkhola-Muktinath region with describing glacial and mass-movement landforms, river terraces and their deposits.

## 2. Regional Geomorphology and Geology

The Kali Gandaki[1)] originates in the high and open basin situated on the northern side of the Himalayan Range in the Kingdom of Nepal. The basin is called the Mustang region, and it altitude exceeds 3,500 m. From the Tangbe village, 5 km upstream from Kabgeni, the Kali Gandaki flows on a wide flood plain down to Lete and Ghasa. It flows in a relatively open valley at first, but below Marpha it crosses the Great Himalayan Range in a wide but deep valley between the Annapuruna and Dhaulagiri Himal. The Kali Gandaki valley between Kagbeni and Ghasa is called the Thakkhola region. The altitude of the region ranges from 2,400 m to 2,600 m. At Ghasa, the Kali Gandaki flows in a narrow V-shaped gorge, and it descends about 1,300 m over the distance of about 13 km to the low Midland. The Muktinath basin is a small tributary basin situated on the east of Kagbeni. Holy Muktinath Temple, 3,600 m in altitude, gathers many pilgrims and tourists.

Geology of the region was well studied by Hagen (1968) and Bordet *et al.* (1971). The most part of the area belongs to the Tibetan Tethys zone which is composed of calcareous sedimentary rocks of the Paleozoic age. Mesozoic sedimentary rocks are also found in Muktinath basin. The southern end of the Thakkhola region is in the Himalayan gneiss zone where calcareous gneiss and granitic gneiss rocks expose. The Mustang basin and the Thakkhola valley form a continuous north-south intramontane basin, which was termed "the Thakkhola-Mustang graben" (Fort *et al.,* 1981; 1982). In the Mustang area, the graben is filled with the thick Plio-Pleistocene lacustrine and fluvial sediments.

The Great Himalayan Range prevents invasion of moist monsoonal air currents from the south into the north side and the wide deep valley of the Thakkhola causes convectional downdrafts in the valley center. This means that the whole region is in a semiarid environment. However, the discharge of the Kali Gandaki often becomes extremely large, and the water flows all over the wide flood plain, because glaciers supply a large amount of melt-water in summer and precipitation concentrates.

## 3. Geomorphology and Materials

The geomorphological map of the Muktinath basin and the area along the Kali Gandaki between Ghasa and Kagbeni is shown in Fig. 1. This map is based mainly on the field observations of the landforms and materials. Aerial-photographs of 1:60,000 scale, which were taken by the Indian Air Force in the 1950's, were used only for the area south of the Tukche village.

The map indicates a complicated feature of the landform in this area. Various kinds of landforms, such as glacial, fluvial, and gravitational landforms are compounded in the area. The characteristics of the landforms and materials are mentioned under the following

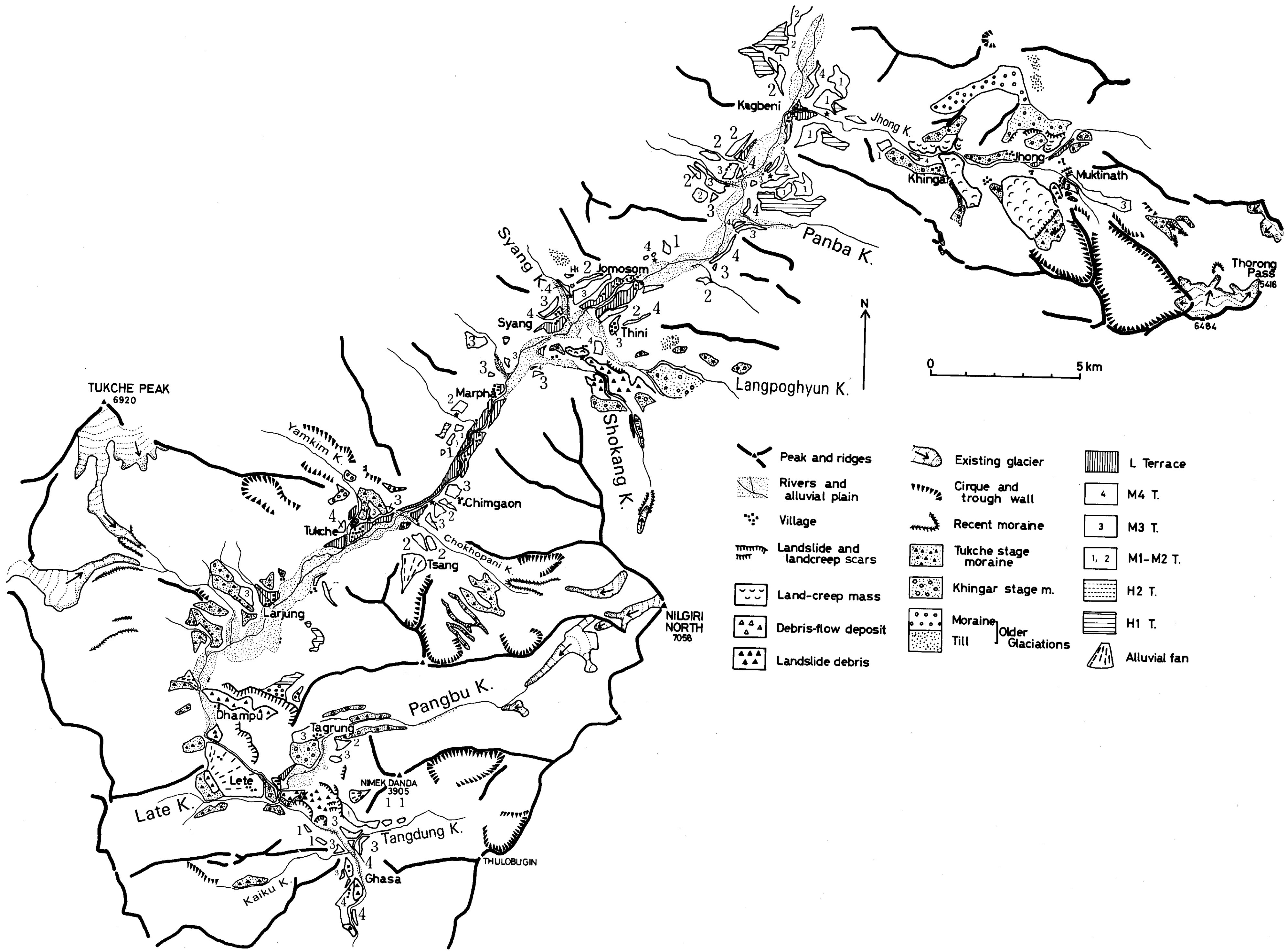


**Fig. 1** Geomorphological map of the area along the Kali Gandaki between Ghasa and Kagbeni and in the Muktinath basin.

headings; glacial landforms; mass-movement forms; river terraces; and Marpha Formation.

**Glacial landforms**

Existing glaciers and fresh glacial landforms are observed in the Muktinath basin and on valley side slopes between Ghasa and Tukche. A well-developed cirque and a glacial trough with an existing glacier are rarely found in the studied area. Glaciers are distributed in the deep valley bottoms or on the steep mountain slopes. Moraines formed by the glaciers from tributaries are distributed at the present Kali Gandaki river bed near Jomosom and between Ghasa and Tukche. In these places, landslide, debris-flow, and/or glacier-avalanche deposits are also frequently observed. The high and steep mountain walls of Dhaulaghiri and Nilgiri provide a favourable topographical situation for this kind of deposition. The mass-movement deposits are hardly distinguished from the glacial till. Although a large quantity of till is found in the Muktinath basin, the morphology of moraines is not clear because most of them have been deformed by large scale landcreeping[2)].

The distinction between the glacial depositional landforms and other landforms, and the classification of the moraines themselves appeared to be difficult in this area. In this area, the moraines are classified into four groups as below by the difference of their spatial sequence and freshness of morphology:

1) Recent Moraines;
2) Tukche stage moraines;
3) Khingar stage moraines;
4) Moraines and till of the older glaciations.

*Recent Moraines*

Recent Moraines are situated near the glacier snouts and show very fresh morphology with sharp ridges. The recent morains of glaciers on the eastern slope of the Dhaulagiri develop close to the debris-covered glacier snouts which extend on the gentle slope above the Larjung village. Other Recent Moraines are distributed in the deep valley on the west and north slopes of Nilgiri, and just below the Thorong Pass in the Muktinath basin. The Recent Moraines are likely to be formed during the Neoglacial stage judging from their locations, morphology, and surface features (Iwata *et al.*, 1982).

*Tukche stage moraines*

Tukche stage moraines correspond with those of the younger Tagrung stage and the Thorong stage in the previous report (Iwata *et al.*, 1982). They are located near the main stream of the Kali Gandaki between Tukche and Lete, and in the tributary valleys such as the Kaiku and Lete Khola. In the Muktinath basin, their development is restricted within a small area to the south of the Muktinath temple. At Lete and Tagrung Tukche stage moraines are covered with forest, but they have clear moraine ridges with slightly subdued morphology.

Moraines behind the Tukche village were formed by the glacier which flowed down the Yamkim Khola (Fig. 3). The moraine ridges of the Tukche stage rise nearly 200 m above the present river bed of the Kali Gandaki. Internal structures of the morainic hills are as follows: The consolidated fluvioglacial gravels abut the unconsolidated till which constitutes the moraine ridges of the Tukche stage (Fig. 2). Smaller moraine ridges composed of unconsolidated younger till cut the fluvioglacial gravels.

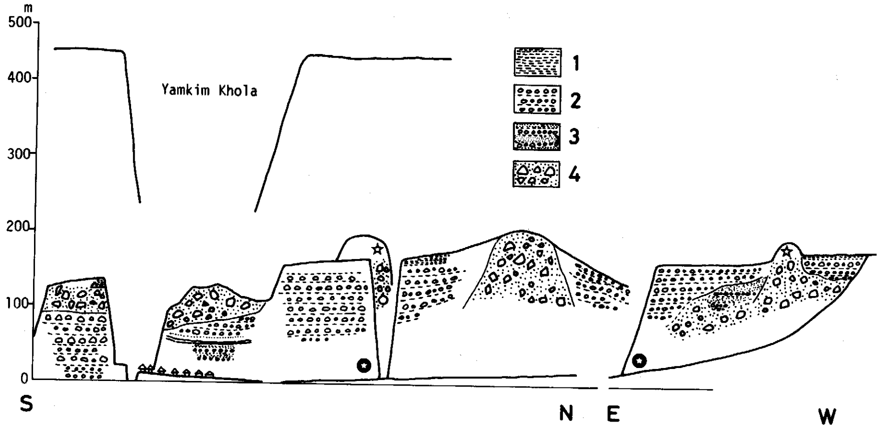


**Fig. 2** Moraines and fluviogracial deposits behind the Tukche village. Geological section in the right shows the internal structure along the small gully. 1: Sandy silt, 2: Fluvioglacial gravel (Angular gravel with stratification), 3: Sandy layers, 4: Till.

Topographic features of the hills behind the Larjung village and the hill on which the Sokung village are the same as those behind Tukche. They were formed by glaciers from the east wall of Dhaulagiri, and they had probably once filled up the Kali Gandaki valley.

*Khingar stage moraines*

Khingar stage moraines, named by Iwata *et al.,* (1982), are distributed at Khingar, and they also develop extensively to the north of the Jhong Khola in the Muktinath basin. They are correlated with the Early Substage of the Last Glacial by the paleomagnetic chronology of the lake deposits at Khingar (Iwata *et al.,* 1982). The distribution of the moraines in the Muktinath basin were largely revised by the field survey in 1982. It became clear that the terrace-like topography of the moraines to the north of the Jhong Khola were formed by slumping occurring in the same stage moraines, i.e. the cliffs are landslide scarps.

A Khingar stage moraine, situated to the sourth of the Thini village in the opposite side of the Syang village, was considered to be formed by the ancient main valley glacier from its lithology (Hagen, 1968, p. 152). Its topographical situation, however, suggests that the moraine may have been formed by the tributary glacier which flowed down from the east (Fig. 6).

The older Tagrung moraines around the Tagrung village were correlated with those of the Khingar stage from their spatial sequence and morphology.

*Moraines and till of the older glaciations*

Moraines of the older glaciations in the Muktinath basin occupy the foot of the mountain slopes in the north of the basin. Subdued and slope-like landforms is clearly distinguished from the Khingar stage moraines and this suggests a great time interval between them.

Yellowish consolidated till constitutes terrace-like moraines, is exposed in high positions behind the Tukche village (Fig. 3). The surfaces are over 400 m above the flood plain of the Kali Gandaki, and they were completely subdued. A similar moraine is found on the ridge to the northeast of the Dhampu village. The surface is gently sloping to the north and its

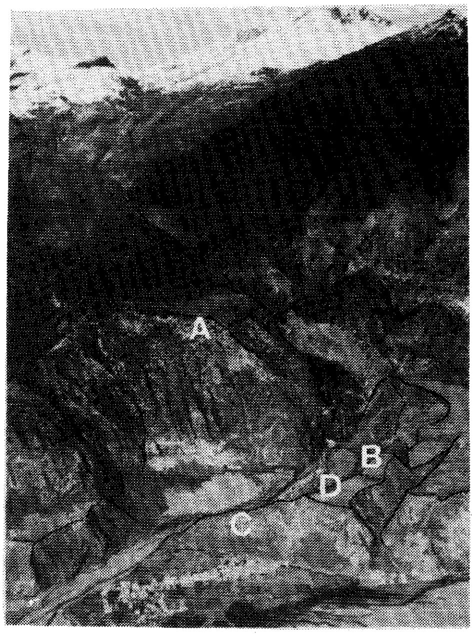

**Fig. 3** Moraines and Terraces behind the Tukche village. A: Terrace-like moraine of the older glaciations, B: Tukche stage moraine, C: Younger moraine, D: M3 Terrace.

relative height ranges from 430 to 460 m above the Kali Gandaki river bed. A thick loess layer covers and smooths the surface, while several huge boulders of calcareous gneiss, the surface of which is etched by chemical weathering, project from the land surface.

Glacial deposits which cover slopes were observed in some places in the studied area. Glacial sediments including exotic angular gravels were found on the mountain slopes to the north of the Muktinath and on the valley slopes of the Syang Khola. On the south facing slope of the Langpoghyn Khola, completely consolidated till, which was smoothed by the posterior glacier, was observed (Fig. 4).

Buried till was found in the study area. The Khingar stage moraine on the west of the Jhong village in the Muktinath basin, represents a large ridge-like topography. At least two till layers are exposed below the Khingar stage till in the south facing cliff of the ridge. Such buried till or morainic sediments occur below the lake deposits of Marpha (Marpha Formation) along the Kali Gandaki main valley between Kagbeni and Marpha (Fig. 11).

The ages of these older moraines and glacial sediments have not known yet. The time interval between these older moraines and the Khingar stage moraines, which is considerably large, indicates that they formed in the pre-Last Interglacial period. This, however, does not necessarily mean that these landforms are contemporaneous with the deposition of the sediments during the glaciation or cold period.

**Mass-movement landforms**

Three different types of mass-movement landforms occur in three separate areas depend-

**Fig. 4** Completely consolidated till on the south facing slope of the Longpoghyn Khola. The surface was smoothed by the posterior glacier.

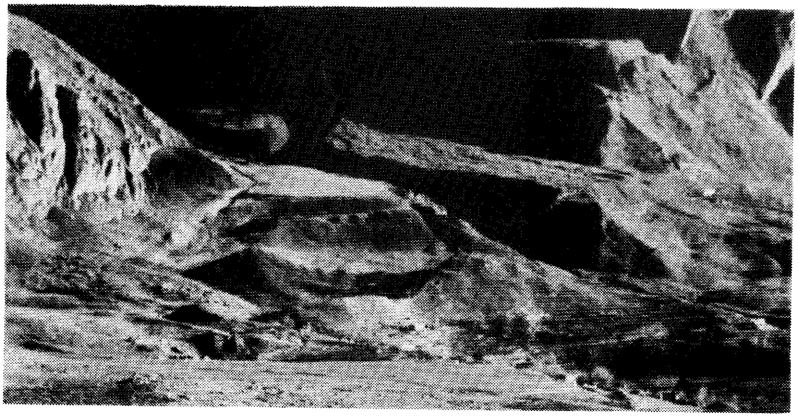

**Fig. 5** Slumping features at the lower end of the valley which leads to Thorong Pass, in the Muktinath basin.

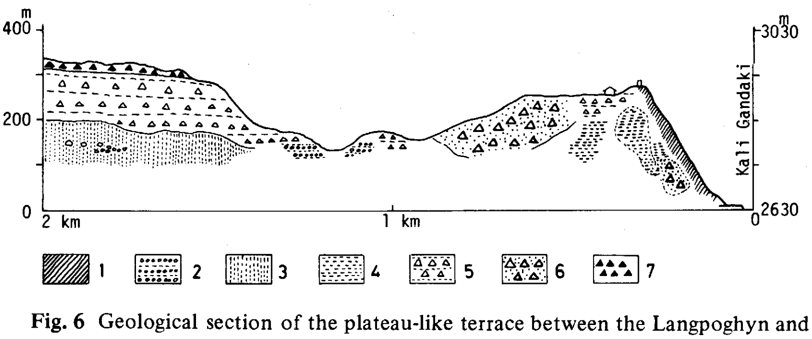


**Fig. 6** Geological section of the plateau-like terrace between the Langpoghyn and Shokang Khola. 1: Bedrock, 2: Fluvial gravel, 3: Massive gray clay, 4: The Marpha Formation, 5: Subangular and subrounded gravel with stratification, 6: Till, 7: Debris-flow deposit.

ing on differences in bedrock lithology and topographic situation: Large-scale landcreep masses in the Muktinath basin; depositional forms of debris flows related to glacier avalanches around Jomosom; and landslides between Dhampu and Ghasa.

The southern part of the Muktinath basin is occupied by large landcreep masses, forming a chaotic topography. On the north of the Jhong Khola, the Khingar stage moraine was torn to several steps by landcreeping. The occurrence of the landcreep masses coincides with the distribution of black splintery shale which contains many fossiles such as ammonites. A valley train, which slid down in the glaciated valley leading to Thorong Pass shows typical features of slumping at the lower end of the valley where the black splintery shale appears (Fig. 5).

In the opposite side of the Syang village, there is a plateau-like terrace between the Langpoghyn (Thini) and Shokang Khola. The main body of the terrace is composed of fluvial and fluvioglacial gravels, and a thin debris layer (1 to 2 m thick) covers the surface (Fig. 6). The layer contains large angular blocks of limestone consolidated with bluishgray matrix. The terrace surface, on which many flow mounds occur, is situated just downstream the valley which flow down from the steep north face of the Nilgiri North peak. The layer seems to be a debris flow deposit related to glacier avalanching as illustrated in the geological map (Bordet *et al.*, 1971).

The similar material constitutes low terraces of the Kali Gandaki in a section between Jomosom and Syang, and in the upper section of Tukche. These terraces rapidly decrease their relative height above the present river bed both downstream and upstream. The debris-flow facies are also recognized in many outcrops between Jomosom and Marpha (e.g. Fig. 11-c). The debris-flow deposit is distinguished from glacier till by the homogeneity of boulders (most boulders are limestone) and the limited quantity of the matrix (Fig. 7). These facts indicate that the debris-flow repeatedly flowed down from the tributaries and deposited on the old valley floor in this region. The high steep wall of the Nilgiri provoked

**Fig. 7** Debris-flow deposit at Jomosom. Most boulders are limestone and the layer is completely consolidated.

glacier avalanches repeatedly, and the hard consolidated nature of the deposit due to limestone made it resistent to erosion.

Although it is well known that large landslides occurred in the area between Larjung and Ghasa (Hormann, 1974; Fort, 1976, 1980; Fort *et al.*, 1981), their precise locality has not been illustrated clearly. The author recognized several landslide scarps and deposits mainly by aerial photograph interpretation.

The most notable landslide scarp is situated behind the Dhampu village. At the foot of the scarp, a furrow accompanied by a few small lakes with the deposition of huge blocks of granitic gneiss is observed. It is probable that the huge bedrock hill, situated on the southeast of the furrow, entirely slumped down to the Kali Gandaki.

The hill located to the southeast of Lete between the Pangbu Khola and Kali Gandaki was specified as a huge morainic hill (Iwata *et al.*, 1982), but it has landslide scarps at the junction between the hill and the back mountain (Nimek Donda). Large exposures facing to the Kali Gandaki (about 330 m in height), provided the author some new information. The upper part of the western half of the exposures seems to contain glacial till and fluvioglacial deposits, but the lower and eastern parts are composed of weathered and/or brecciated calcareous gneiss. Many furrows which may relate to landslides occur on the hill and a mineral spring was found in a small valley situated to the east boundary of the hill. These features also suggest that the hill may be a landslide block. These large scale landslide might occur not only due to the regional tectonic movement related to the uplift of the Great Himalayan Range (Fort, 1980; Fort *et al.*, 1981), but also due to the deep down cut by the Kali Gandaki. The hill is entirely covered with large blocks of granitic gneiss which derived from relatively recent landslide.

**River terraces**

River terrace surfaces in the study area can be grouped into seven levels. They are designated H1, H2, M1, M2, M3, M4, and L Terraces from higher to lower. Except the L Terrace, they are unevenly distributed in the two separate river courses between Ghasa and Tagrung, and between Marpha and Kagbeni. Between these two courses, only several M Terraces are distributed in patches at Larjung, Tukche, and Chimgaon. The Kali Gandaki terrace stretches up to the moraine at Khingar, and many remnants of the terraces are distributed along the Jhong Khola, in the Muktinath basin. Most of them are covered with colluvium or deformed by landcreeping. No river terrace was found in the Kali Gandaki gorge below Ghasa, while the terraces are continuously distributed in the upper course from Kagbeni up to Tangbe in Mustang.

The Kali Gandaki terrace is characterized by fresh morphology with nearly vertical cliffs and sharp edges. This is due to the consolidated nature of the materials including calcareous component and the semiarid climate. Narrow gullies cutting into the terrace provided some information about the internal structure of the terraces.

Longitudinal profiles of these river terraces along the Kali Gandaki is illustrated in Fig. 8.

*River terraces around Ghasa and Tagrung*

River terraces and their materials around Ghasa were reported by Fort (1976). The terrace deposits contain well-stratified fine materials which are likely to be deposited in a

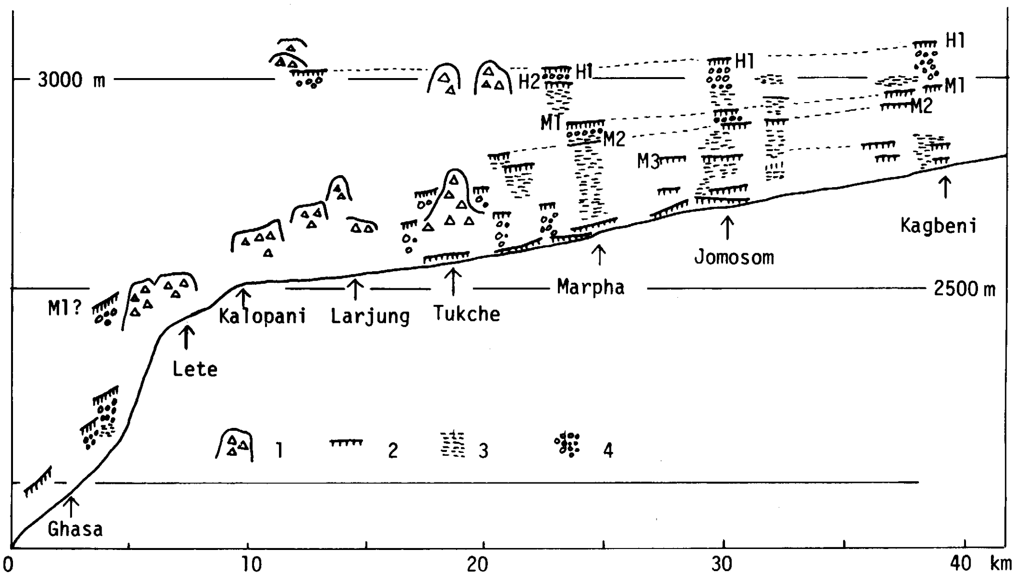


**Fig. 8** Longitudinal profiles of river terraces along the Kali Gandaki between Kagbeni and Ghasa. 1: Moraine, 2: Terrace surface, 3: Lake deposit, 4: Fluvial and fluvioglacial gravel.

quiet condition. This sedimentary environment may have been provided by the blocking by the landslides which occurred below Ghasa.

The M3 Terrace at the Tagrung village developed in front of the Tukche stage terminal moraine with fluvioglacial terracing. The alluvial fan, on which the Lete village was settled, is composed of outwash materials from the old Lete Khola Glacier.

*River terraces between Larjung and Chimgaon*

River terraces, which have sloping surfaces, occur at the lower ends of the tributary valleys along the river course between Larjung and Chimgaon. They are fluvioglacial terraces formed in front of the moraines (e.g. Fig. 2), or alluvial cones or fans. Because the correlation of the fragmented surfaces was not easy, the moraines were used as a reference in some cases to correspond to the others in addition to the spatial sequence, morphological features, and relative height. Of course, their surfaces were controlled by the main steam river bed at that time.

The M3 Terraces around Chimgaon are composed of well stratified rounded cobble layers (Fig. 9), while those at Tukche and Larjung are composed of ill-sorted angular gravels with some stratification.

*River terraces between Marpha and Kagbeni*

River terraces formed by the main stream appear on the right bank just downstream the Government Agriculture Farm, 1 km downstream from the Marpha village, and they are distributed more or less continuously up to Tangbe. They are mainly the H1, H2, M1, and M2 Terraces, and the M3 Terrace develops in the area around Jomosom (Fig. 10). Upstream from the confluence of the Panda Khola, the terraces are widely extended. The H1, M1, and M2 Terraces represent typical plan form of the accumulation terrace, which stretches into

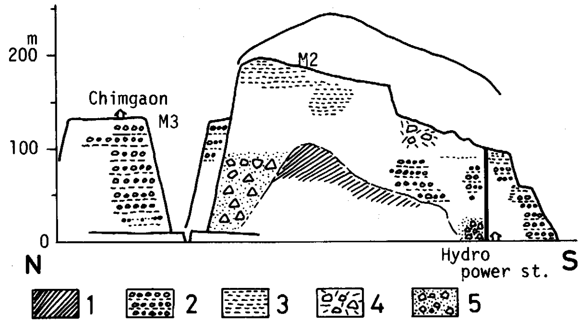


**Fig. 9** Geological section along the Kali Gandaki around Chimgaon. 1: Bedrock (Phyllitic sandstone), 2: Fluvial gravel, 3: The Marpha Formation, 4: Silt layers with large blocks (The Marpha Formation ?) 5: Till.

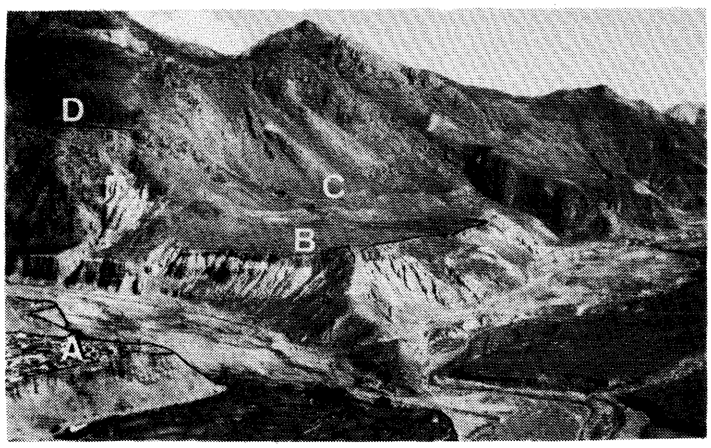


**Fig. 10** Terraces around Jomosom. A: M4 Terrace at Syang, B: M3 Terrace, C: M2 Terrace, D: H1 Terrace.

the tributary valley. These terrace surfaces have great relative height above the river bed, and the maximum attains up to an altitude of nearly 400 m. The terraces are formed with large amounts of deposits.

As illustrated by Fort (1976, 1980) and Iwata *et al.* (1982), the deposits of these terraces are composed of alternating layers of fluvial gravels, lacustrine deposits, and fluvial and non-fluvial angular gravels. Their facies vary vertically and horizontally in a short distance complicatedly.

Several geologic sections of the terraces observed by the author, are shown in Fig. 11. The investigation of these sections revealed the followings:

i) At least between Marpha and Jomosom, the main body of river terraces are composed of the lacustrine deposits which was designated "les formations lacustres de la bases Thakkhola" by Fort (1980).

ii) The H1 Terrace seems to be a filltop terrace of the lacustrine deposits (Fig. 11-c) and

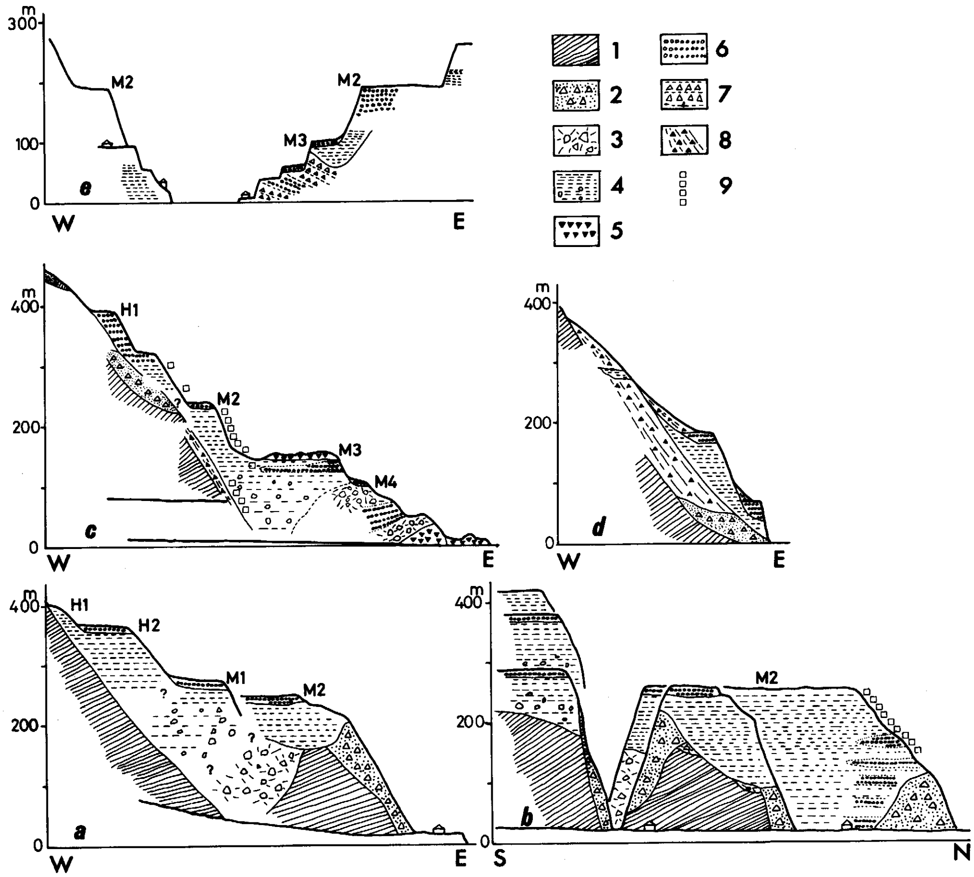


**Fig. 11** Geological sections of the terrace deposit between Marpha and Kagbeni. a: Transverse section, behind the Government Agriculture Farm, Marpha, b: Section along the Kali Gandaki at Marpha, C: Section along the Syang Khola, d: Section, 2 km upstream from Jomosom, e: Section at Egarabatti, 2 km downstream from Kagbeni. 1: Bedrock, 2: Till, 3: Muddy layer with large blocks, 4: The Marpha Formation, 5: Debris-flow deposit, 6: Fluvial gravel, 7: Angular gravel with stratification, 8: Talus deposit, 9: Sampling points for paleomagnetic measurements.

the lower surfaces are their dissection levels.

iii) Surface-making deposits of the lower terraces between Marpha and Jomsom are of typical fluvial gravel veneers composed of cobbles and pebbles in size. They increase their thickness upstream and represents the features of typical valley fills (Fig. 11-e).

iv) The terrace surface are sometimes covered by angular gravels with small hill-like topography or mounds. Some of them are debris-flow deposits as mentioned before (e.g. Fig. 11-c), but others may be glacial deposits.

## The Marpha Formation

The distribution, facies, stratigraphic position, and the origin of the lacustrine deposits in the area was described and discussed by Fort (1980). However, the formation has not been named yet, although the deposits have a geological and geomorphological importance for this region. Here, the author named the lacustrine deposits, Marpha Formation.

The type locality of the Marpha Formation is the exposures behind the Government Agriculture Farm to the south of Marpha (Figs. 11-a and b).

The formation is more than 420 m thick in total at the type locality. It is composed mainly of semi-consolidated yellowish-grey to yellowish-white clay and silt layers, and unconsolidated yellowish-white and bluish-grey sandy (medium to fine sand) layers. Each layer ranges from a few millimeters to a few centimetres in thickness. The layers lie almost horizontally and contain intercalated gravel layers. No organic material was found in the layers.

The distribution of the Marpha Formation shows the domain of the ancient lake which was termed "le paléo lac de la Marpha (the Paleo Marpha Lake)" by Fort (1980). The Marpha Formation was traced to the M2 Terrace situated to the southwest of Chimgaon (Fig. 9) and to the high position of the valley slope just opposit side of Chimgaon. And it was traced upstream as far as the north of Kagbeni.

At the Type locality the Marpha Formation unconformably covers the bedrock, hardly consolidated till, and consolidated mud layers with huge angular blocks (Figs. 11-a and b). At Jomosom it covers the consolidated debris-flow deposits and scree material as well (Figs. 11-c and d).

The Marpha Formation is thought to have accumulated continuously (Fort, 1980). At the type locality, however, the formation may be sub-divided into two types of sedimentary facies. In the south side of the exposure, the Marpha Formation forming the H1 and H2 Terraces are composed mainly of clay and silt layers and contains many large blocks in the lower part (Fig. 11-b). On the other hand, in the north side of the exposure, the Marpha Formation contains many sandy layers (Fig. 12). This more sandy layers look fresher than

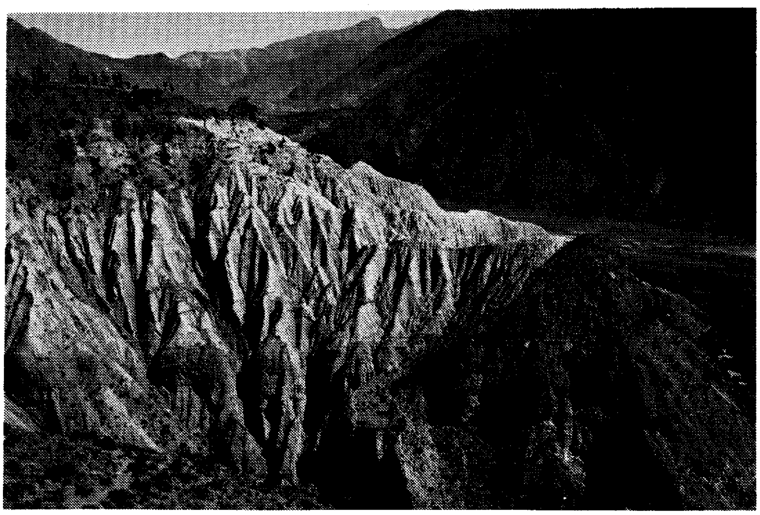

**Fig. 12** Yonger sandy layers of the Marpha Formation behind the Government agriculture Farm, Marpha.

the former muddy layers. The result of the paleomagnetic measurements of the more sandy layers indicates the different inclinations from those of the Marpha Formation at Jomosom, the facies of which are similar to the muddy layers at the type locality (Yoshida *et al.*, 1984). The sandy layers are thought to be younger than the muddy layers. This suggests that the sandy layers may unconformably cover the muddy layers, though no apparent unconformity between these two parts could be found because of existence of a tributary valley.

The age and origin of the Paleo Marpha Lake are discussed below.

## 4. Discussion

### Origin of the Paleo Marpha Lake

Fort (1980) and Fort *et al.* (1981) insisted that the large landslide occured around Larjung and dammed up the Kali Gandaki. However, remnants of the landslide deposits could not be found at higher positions around Larjung. The main body of her "Larjung landslide" seems to be corresponded with the Tukche stage moraine in this paper. The filltop level of the Marpha Formation is coincided with the top positions of the morains of the older glaciations at both Tukche and the opposit side of Larjung (Fig. 8). Accordingly, it can safely be said that the glacier and/or glacial deposits at the older glaciations blocked the Kali Gandaki to form a lake of over 400 m deep. As mentioned above, the Marpha Formation is divided into two sub-formation, and it suggests that the Paleo Marpha Lake occurred during at least two different periods. The younger lake may have occupied only a small area around Marpha.

It is notable that the Kali Gandaki Valley had been widened and deepened before the Paleo Marpha Lake was formed.

### Relative chronology

Chronological frameworks in this area were proposed by Fort *et al.* (1982), Kuhle (1982), and Iwata *et al.* (1982). Fort's work forcused on the tectonic evolution during the entire period of the Late Cenozoic, and the ages of the glacial and terrace deposits were not discussed in detail. Kuhle (1982) classified the moraines and the river terraces into eighteen chronological stages, but his classification is largely different from the present author's interpretation. Although any important absolute dating has not been obtained yet in this area, the relative chronology was made in this study on the basis of the geomorphological and morphostratigraphic methods. In particular, in addition to the relative chronology of the moraines, which was discussed by Iwata (1984), paleomagnetic chronology has played an important role to establish the regional chronology.

The glacial landforms were directly correlated with the river terraces in several places: The Khingar stage moraine joins the M1 Terrace in Jhong Khola between Khingar and Kagbeni (Fig. 13) and the M3 Terrace joins the Tukche stage moraine at Tukche (Fig. 2). The extended line of the longitudinal profile of the H1 Terraces accords with the moraines of the older glaciations at Tukche and in the opposit side of the Larjung (Fig. 8), and it indicates that the H1 Terrace gravels are likely to have deposited during the pre-Last Inter-

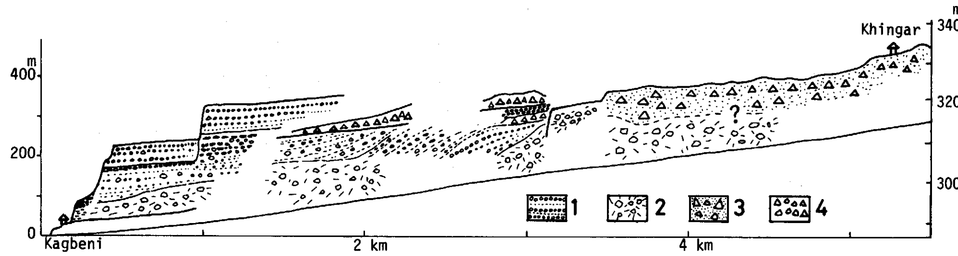


**Fig. 13** Geological section along the Jhong Khola between Kagbeni and Khingar. 1: Fluvial gravels, 2: Muddy layers with large angular blocks, 3: Till, 4: Colluvium.

| Estimated age x $10^4$y.BP | Moraine stages | River terrace | Paleo-Marpha Lake | Mass-movement forms |
|---|---|---|---|---|
| | Recent | L | | DF |
| 0.5 | | | | Landcreep |
| 1 | | M4 | | DF |
| 2 | Tukche | M3 | | DF |
| 3 | | | | |
| 4 | | M2 | | |
| 5 | Khingar | M1 | | |
| 10 | | H2 | | |
| 15 | Older | H1 | | DF? |
| 50 | | | | Landslide |

DF: Debris-flow

**Fig. 14** A tentative correlation of landforms and deposits in the Thakkhola – Muktinath basin.

glacial period.

The results of the paleomagnetic investigation indicate that the Marpha Formation accumulated during the Brunhes Normal Epoch, and that the accumulation had ended before the Laschamp Event (Yoshida *et al.,* 1984). The intermediate polarity of the Laschamp Event, which was detected from the lake deposits at Khingar (Iwata *et al.,* 1982), has not been measured. These facts do not conflict with the age which the Paleo Marpha Lake was formed by the blocking of the glacier or glacier deposits during the pre-Last Inter-glacial time. The ages of the large scale landslides at Dhampu and Lete are completely unknown, but they may have occurred successively after the extreme down-cutting of the Kali Gandaki.

The above discussion is summarized in Fig. 14, which shows a tentative correlation of the landforms in this area.

## Crustal movement

The vertical displacement of longitudinal profiles of river terraces can be considered to represent the aspects of the vertical tectonic movement, if one can suppose that the river bed profile during the terrace surface formation is similar to that at present. The relative heights of the H1, M1, and M2 Terraces above river bed apparently increase downstream (Fig. 8). The older the terrace is, the gentler the profile becomes. This indicates the river terrace deformation due to the uplift of the Great Himalayan Range. A gentle profile of the H1 Terrace, however, may have also been caused by sedimentation of the Marpha Formation. The terrace gravels of the H1 Terrace at Jomsom which are smaller than those of the present river bed and a large amount of sand in the layer (Mezaki, personal communication), indicate that the gradient of the river bed at the time of the terrace surface formation was gentler than that at present.

## 5. Summary

The author may summarize the relative chronology of the above mentioned events as follows:

1. As the Himalayan Range began to rise and the Thakkhola-Mustang graben appeared, the Kali Gandaki Valley was formed.
2. The Himalayan Range grew higher and the Kali Gandaki downcut to make a gorge and wide valley. A knickpoint separated them.
3. Large scale landslides occurred at the knickpoint under the influence of the regional tectonic movement as well as the gravitational instability due to the steep slope of the deep gorge. The basin shape of the wide valley above the knickpoint was enhanced by the landslide and glacial erosion.
4. A glacial advance blocked the valley around Larjung before the Last Interglacial period, and the Paleo Marpha Lake was formed. This glacial expansion was larger than the following expansions.
5. The Marpha Formation filled the lake and the H1 surface was formed.
6. In the Last Glacial, entrenching and glaciofluvial filling of the valley were repeated: The M1 and M3 Terraces gravels were deposited in the Early and Late Stage of the Last Glacial respectively.
7. The uplift of the Great Himalayan Range may more or less continues at present.

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The author would like to dedicate this paper to Professor T. Nakano in commemoration

of his refirement from Tokyo Metropolitan University.

## Notes

1) "Gandaki" means a large river in Nepalese, while "Khola" means a river smaller than Gandaki.
2) An imperceptibly slow, more or less continuous downward movement of a considerable mass of bedrock and/or sediments.

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(* in Japanese)