Journal of Nepal Geological Society, vol.2, Special Issue, 1982, 81－94

GLACIAL LANDFORMS AND RIVER TERRACES IN THE THAKKHOLA REGION, CENTRAL NEPAL

Shuji IWATA[1], Hidetsugu YAMANAKA[2], and Mitsuo YOSHIDA[3]

1 *Department of Geography, Tokyo Metropolitan University, Setagaya, Tokyo, 158, Japan.*
2 *Department of Geography, Tohoku University, Sendai, 980, Japan.*
3 *Department of Geology and Mineralogy, Hokkadio University, Sapporo, 060, Japan.*

ABSTRACT

In order to clarify the relationship between the river terraces and the glacial landforms, and the deformation of the river terraces, a series of field surveys was carried out in the upper course of the Kali Gandaki. Between Ghasa and Marpha, there are many ried out in which were formed by the glaciers from the tributaries. These moraines dammed up the Kali Gandaki, and accordingly, conspicuous terraces are developed upstream. The Middle Terraces are considered to correlate with the Last Glacial age by the paleomagnetic measurements of the deposits at Kingar in the Muktinath basin. Along the Kali Gandaki, the river terraces increase their relative heights above the river bed towards the Great Himalayan Range. This suggests that the uplift of the Great Himalayan Range have continued up to present.

INTRODUTION

The Kali Gandaki (or Krishna Gandaki), in Central Nepal, is an important river in studying the crustal movement of the Himalayas, because it traverses the Great Himalayan Range and it develops river terrace systems along the considerable course of the river.

The upper basin of the Kali Gandaki, called the Thakkhola region, is situated at the north of the Great Himalayan Range. In this region, wide accumulation terraces stretch along the river (Hagen, 1968; Bordet *et al.*, 1971; Fort, 1976), but their ages are not known. The geomorphological interest in the Thakkhola exists in the fact that one can study the relationship between the terraces and glacial landforms. This is one of the possible ways of finding out the ages of the river terraces along the Kali Gandaki. The reason is that the glacial landforms are separated from the river terraces by the steep gorges in the southern side of the Himalayan Range, while the glacier landforms extend on flat plains or uplands and continue to the river terraces in the northern side. Such a situation is widely developed in Tibet, but it is still difficult to work in Tibet. Only the Thakkhola is the easily accessible place which can provide informations on the relationship between glacial stages and the sequence of the river terraces.

The main purpose of the present paper is to describe the river terraces and glacial landforms in the Thakkhola region and to discuss their age and the aspects of the tectonic movement of the Great Himalayan Range.

STUDY AREA AND FIELD SURVEY

The Kali Gandaki originates in the semi-arid region on the northern part of the Himalayan range in

the kingdom of Nepal where the high and open basin was formed in the marginal part of the Tibetan plateau. The basin is more than 3,500 m in altitude and is bordered by two north-south ridges with small glaciers. From Tangbe, 5 km upstream from Kagbeni, to Tukche the Kali Gandaki flows gently on a wide flood plain towards the southwest direction. The river terraces are developed in this section. The Kali Gandaki crosses the Great Himalayan belt from Lete to Dana in a narrow V-shaped gorge cut deeply between the Dhaulagiri and Annapurna Ranges. It descends about 1,300 m in about 13 km, while the climate changes from semi-arid to sub-tropical humid one. Tributaries in this section drain from glaciers covering on the high valley-side slopes.

The field survey was carried out for 10 days in November (Iwata and Yamanaka) and from the end of November to the beginning of December (Yoshida), in 1980. Unfortunately, we were not allowed to enter the upstream region from Kagbeni where it is the restricted area for foreign people. Air photographs, taken by the Indian Air Force in the 1950's, 1 : 60,000, were available only of downstream from Tukche.

GLACIAL LANDFORMS BETWEEN GHASA AND TUKCHE

The geomorphological map along the Kali Gandaki between Ghasa and Tukche indicates the complicated features of glacial, fluvio-glacial, and non-glacial topography (Fig.2). In spite of the prior descriptions (Hagen, 1968; Bordet *et al.*, 1971; Fort, 1976) and present field survey, any direct information about the age of the depositional landforms has not been obtained.

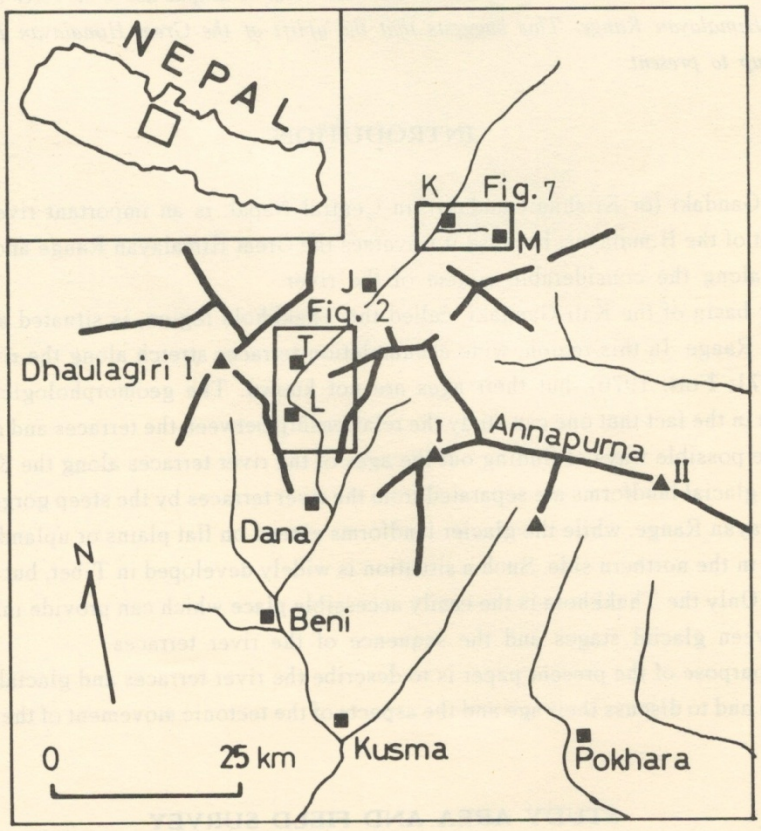

Fig. 1. Study area and the index of the figures.
L: Larjung, T: Tukche, J: Jomosom, K: Kagbeni, M: Muktinath.

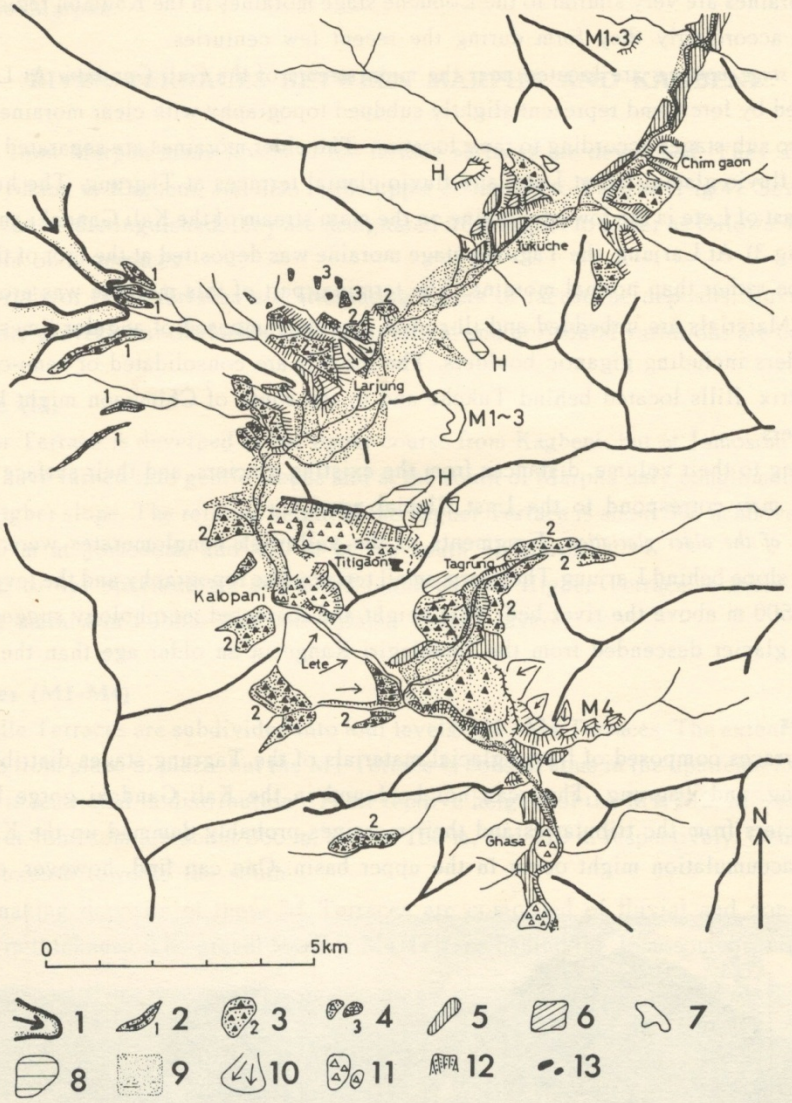

Fig. 2. Geomorphological map in the area between Ghasa and Tukche. 1: Existing glacier, 2: Recent moraine, 3: Tagrung stage moraine, 4: Moraines of the older glaciation, 5: Lower Terrace, 6: M4 Terrace, 7: M1-3 Terrace, 8: Higher Terrace, 9: Alluvial plain, 10: Alluvial and talus cones, 11: Landslide deposits, 12: Landslide and landcreep scar, 13: pond.

Moraines

There are many moraines which were formed by the glaciers from the tributaries and valley slopes. They are classified into three groups as below by the difference of their situations and freshness of morphology:

1) Recent Moraines
2) Tagrung stage moraines
3) Moraines of the older glaciations.

Recent Moraines are situated close to the debris covered snouts of the existing glaciers, or at the

margins of the fresh bedrock topography formed by the recent glacial erosion. Morphological features of the Recent Moraines are very similar to the Lobuche stage moraines in the Khumbu region, Eastern Nepal (Iwata, 1976), accordingly they form during the recent few centuries.

Tagrung stage moraines are located near the main stream of the Kali Gandaki. At Lete and Tagrung they are covered by forest and represent slightly subdued topography with clear moraine ridges. They are divided into two sub-stages according to their location. The older moraines are separated from the younger moraines by a fluvio-glacial fan at Lete, and fluvio-glacial terraces at Tagrung. The huge morainic hill located southeast of Lete is the lowest moraine on the main stream of the Kali Gandaki and the steep gorge begins here (Fig.3). At Larjung, the Tagrung stage moraine was deposited at the foot of the steep rockwall in a cone shape rather than normal moraine. The terminal part of this moraine was eroded away by the Kali Gandaki. Materials are unbedded and ill-sorted gravels composed of angular limestone, gneiss, and quartzite boulders including gigantic boulders. The gravels are consolidated or semi-consolidated with calcareous matrix. Hills located behind Tukche and to the south of Chimgaon might be formed by the tributary glaciers.

According to their volume, distances from the existing glaciers, and their surface morphology, the Tagrung stage may correspond to the Last Glacial age.

Moraines of the older glaciation: Fragments of the yellowish conglomerates were found in a high position on the slope behind Larjung. They form small terrace-like topography and the level of their surface is higher than 500 m above the river bed. This height and dissected morphology suggest that they were formed by the glacier descended from the Dhaulagiri Range in an older age than the Tagrung stage.

River Terraces

River terraces composed of fluvio-glacial materials of the Tagrung stages distribute in patches at Tukche, Larjung, and Tagrung. They can not be found in the Kali Gandaki gorge below Ghasa.

The glaciers from the tributaries and their moraines probably dammed up the Kali Gandaki and, consequently, accumulation might occur in the upper basin. One can find, however, only fragmentary

Fig. 3. Large morainic hill between Lete and Ghasa is the lowest moraine on the main stream of the Kali Gandaki. The Kali Gandaki gorge begins.

remnants of terraces or sloping planes. Most of accumulated materials were eroded away in the section downstream from Marpha.

RIVER TERRACES BETWEEN MARPHA AND KAGBENI

Upstream from Marpha many levels of the terrace surfaces are developed. They are continuously distributed from Shang to Kagbeni, and also in the upper course up to Tangbe (Fig.4). Seven levels of the terrace surfaces can be distinguished; they are designated from higher to lower as follows: H, M1, M2, M3, M4, and 2 levels of L terraces.

The materials of these terraces are alternating layers of lacustrine deposits, fluvial gravels, and non-fluvial angular gravels, but the facies and their vertical and horizontal variations are complex (Fig.5).

Higher Terrace (H)

The Higer Terrace is develped in the upper course from Kagbeni, but at Jomosom and Shang, the terrace surfaces have turned into gentle slopes and at the south of Marpha only conglomerate deposits are preserved on a higher slope. The relative height of the Higher Terrace is about 360 m above the flood plain at Kagbeni, 370 m at Jomosom, and 400 m at the south of Marpha.

According to our observations at limited outcrops, the Higher Terrace is made up of stratified rounded gravels mainly in cobble size intercalated by silt layers.

Middle Terraces (M1-M4)

The Middle Terraces are subdivided into four levels: M1 - M4 Terraces. The extent of the surface of each level varies from place to place, but the M1 Terrace is conspicuous in the upstream from Kagbeni and the M3 Terrace is restricted in distribution . Their relative heights of the M1, M2, M3, and M4 Terraces above river bed at Jomosom are about 260 m, 200 m, 150 m, and 110 m respectively. Generally speaking, these heights increase towards the south.

Surface-making deposits of these M Terraces are composed of fluvial and non-fluvial gravels, having 30-40 m in thickness. The gravel layer of M4 Terrace behind the Jomosom airport is composed of

Fig. 4. River terraces around at Kagbeni. River terraces continue upstream.

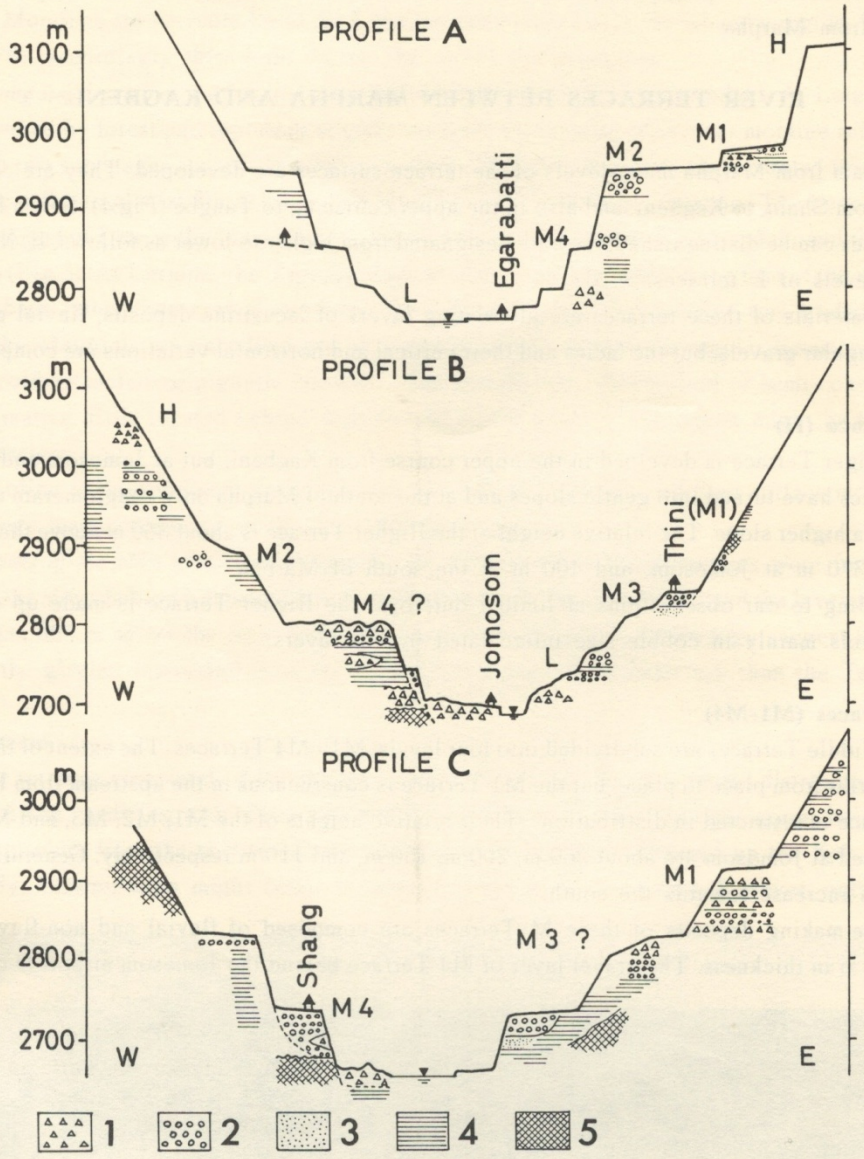

Fig. 5. Cross sections of the river terraces of the Kali Gandaki. 1: Angular gravels, 2: Fluvial gravels, 3: Sands, 4: Alternate layers of fine sands and silts, 5: Bedrock.

large angular boulders and formed small hills on its surface. This angular gravels seem to be glacial desposits or debris flow sediments from the tributary. Below these gravel layers there exist horizontal layers of yellowish fine sands and silts. This sedimentological facies indicate that these materials deposited in quiet conditions.

Lower Terraces (L)

The Lower Terraces are distributed as narrow strips and two levels of surfaces are recognized. In most cases, they are composed of non-consolidated fluvial gravels, but the lowest terrace at Jomosom and

Shang is composed of consolidated angular gravels with dark colored calcareous matrix. On the terrace surface there are many mounds. The materials are considerd as debris flow deposits transported from the north wall of Nilgiri (Bordet, *et al.*, 1971).

LANDFORMS IN THE MUKTINATH BASIN

Topography in the Muktinath basin is not simple; morainic hills, fluvio-glacial terraces, bedrock knolls, and large landcreep masses are mixed in confusion(Fig.6). The geomorphological map in the area is shown in Fig.7. Crossing the basin, the Jhong Khola, which springs at the holy Muktinath temple, flows towards the west and joins the Kali Gandaki at Kagbeni. The topography in the north of the Jhong Khola are different from that in the south of the Khola. In the southern part of the basin large landcreep masses represent chaotic topography, on the other hand in the northern part of the basin wide terrace-like platforms are distributed.

Moraines

Moraines in the area are classified into three stages as: Thorong stage moraines, Kingar stage moraines, and Moraines of the older glaciation.

Thorong stage moraines are distributed in the large, shallow cirque to the south of Muktinath, just north of Muktinath, and the north bank of the Jhong Khola. They have sharp ridges on which huge blocks are scattered. According to their distributional sequence and their morphology, the Thorong stage moraines are considered to correspond to the Periche stage moraines in the Khumbu region (Iwata, 1976).

Distribution of the Recent Moraines corresponded to the last few centuries are restricted within narrow areas over 4,500 m in altitude. The slopes around Muktinath are covered with mature soil. Humic soil was sampled from the bottom of the soil layer, 4,300 m in altitude, at the point of 3.5 km north of Muktinath(B in Fig.7), and its ^{14}C age was measured 8.670 $\pm^{210}_{200}$ yr.B.P. (TH-728)(Yamanaka, 1982, in prep.). It indicates that the slope has not been occupied by glaciers at least during Holocene.

Kingar stage moraines occupy at Kingar, Jarkot, and to the northeast of Jhong. A typical lateral moraine stretches to the southeast of Kingar. At Kingar the moraines are composed of mostly cobble size subangular to angular gravels of columnar shale. Most of the Kingar stage moraines have been deformed widely by landcreeping to the east of Kingar and to the south of Jarkot. Their materials are composed of subangular to angular gravels of quartzite, sandstone, limestone, and columnar shale of cobble to boulder size.

The Kingar stage moraine situated to the north of Jhong forms notably terrace-like topography of which relative height from the Jhong Khola is about 280 m near Jhong. Many mounds and ridges are found on the surface. It consists mainly of boulder size angular gravels of limestone, quartz sandstone and shale.

Moraines of the older glaciation distribute at the foot of the mountain slopes. The surface is about 30 m higher than that of the Kingar stage moraine. The surface is nearly flat, but there exist winding subdued

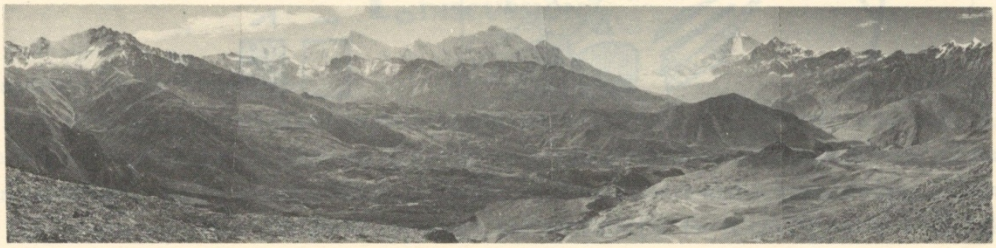

Fig. 6. The Muktinath basin viewing from north. Dhaulagiri I (8,167 m) is far beyond.

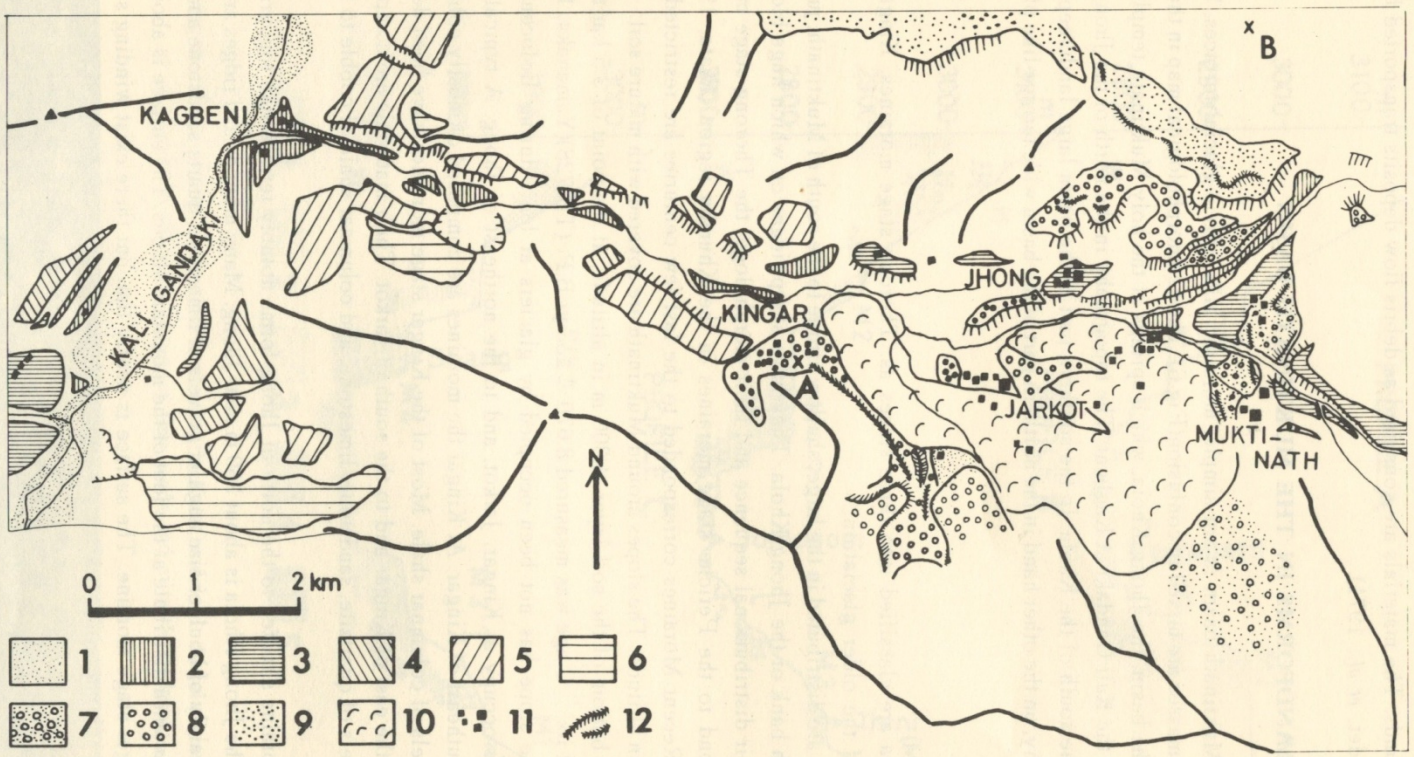

Fig. 7. Geomorphological map in the Muktinath basin. 1: Alluvial plain, 2: Lower Terrace, 3: M4 Terrace, 4: M2 Terrace, 5: M1 Terrace, 6: Higher Terrace, 7: Thorong stage moraine, 8: Kingar stage moraine, 9: Moraines of the older glaciation, 10: Landcreep mass, 11: Village, 12: Moraine ridges, A: Sampling point for paleomagnetic measurements, B: Sampling point for ^{11}C dating.

ridges. The topographic features and situation are similar to the platform topography in the Khumbu region (Iwata, 1976).

River Terraces

Many fragments of the river terraces are distributed along the Jhong Khola. Most of them are covered with the materials derived from the back slopes and turn to gentle slopes. Among them the M1 Terrace is important from the chronological view point. The M1 Terrace extends upstream from Kagbeni up to Kingar where it connects with the Kingar stage moraine. Therefore, the M1 Terrace can be considered to the fluvio-glacial terrace of the Kingar stage.

Paleomagnetic Measurements

About the age of the glacial advance we obtained an indirect information at Kingar. Lake deposits, with 5 m in thickness, were found in the depression on the Kingar stage moraine (A in Fig.7). For the purpose of the paleomagnetic investigation, oriented samples were collected from the deposits (Fig. 8). These samples are suitable for the determination of direction and intensity of the remanent magnetization. Oriented cores, 3.2 cm in diameter, are covered with a non-magnetic acryle tubes. A total 24 samples, 4 cores at about 100 cm intervals in each site, were collected.

The remanent magnetizations are measured using an automatic astatic magnetometer (Fujiwara and Yoshida, 1981). The stability of the remanence were assessed by stepwise demagnetization in a 400 Hz alternating field without specimen rotation (Creer, 1959; Snape, 1967). Mostly natural remanent magnetization (NRM) are very stable and weak. Generally, 200 Oe field strength was chosen for magnetic cleaning. After magnetic cleaning, directions of the remanent magnetizations in each site show relatively well concentration (Fig. 8). The intensity of remanent magnetizations after cleaning are within the range of 10^{-6} and 10^{-7} emu/cc.

Directions of magnetization before and after magnetic cleaning are summarized in Fig. 8. Site mean direction and intensities are shown in Table 1. Change of the virtual geomagnetic pole position (VGP) inferred from several stratigraphic units are plotted in Fig. 9. A paleomagnetic polarity obtained from this lake deposits are intermediate. Latitudes of VGPs are extremly low. These trends may represent that the remanent magnetization of the lake deposits are probably acquired during the geomagnetic transition age.

In the Brunhes Normal Epoch, several reversed polarity events or excursions have been detected. During the Last Glacial age (late Brunhes Normal Epoch), the Laschamp Event is known (Bonhommet and Zahringer, 1969). In recent years, the Laschamp Event is investigated fully in detail, and detected at many districts. The radiometric dating places the Laschamp Event between 15,000 and 50,000 yr. B.P.; the values of these dating seem to concentrate around at 35,000 yr. B.P. (Gillot,*et al.*1979). The age of the lake deposits indicates that the Kingar stage moraine was made in the Last Glacial period, most of all, in the older stage of the Last Glacial period.

DISCUSSION

a) Correlation of the Landforms

According to the paleomagnetic measurements and the comparison with the moraines in the Khumbu region, we can consider that the Thorong stage and the Kingar stage correspond with the late substage and the early substage in the Last Glacial Stage, respectively. As mentioned above, the age of the accumulation of the M1 Terrace coincides with the Kingar stage, and accordingly, the Higher Terrace is older than the Kingar stage. There is a possibility that the Higher Terrace corresponds to the older glaciation. Figure 10

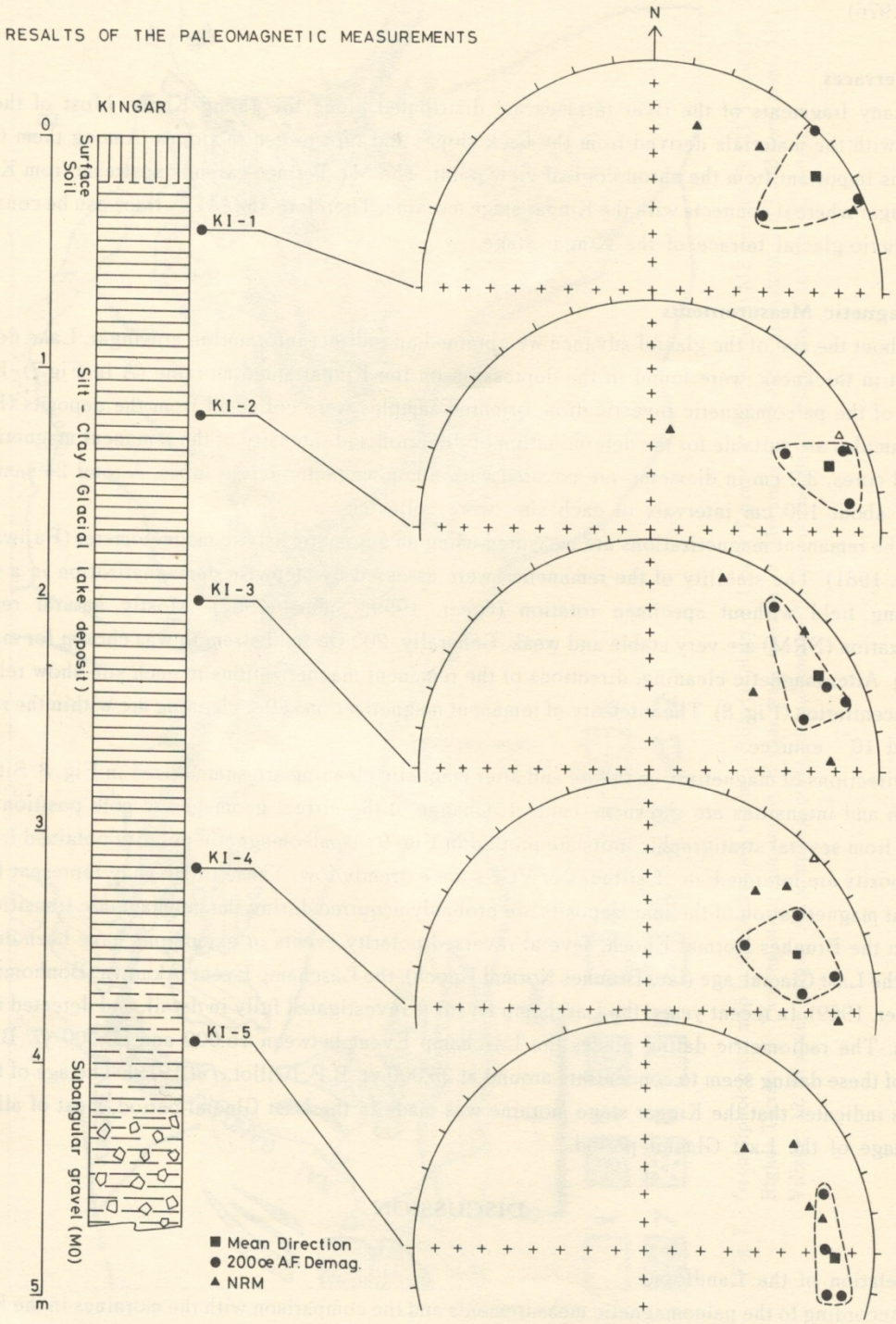

Fig. 8. Equal-area stereographic projection for same specimens showing changes in directions of magnetization at before and after 200 Hz alternating field demagnetization treatment. Closed symbols represent positive inclinations, and open symbols represent negative inclinations.

Table 1. Results of the Paleomagnetic Measurements, Kingar lake deposits (KI-Section). Site mean directions after 200 Hz alternating field demagnetization. ×Ey represents × 10^{y}.

Sample	N	Dec.	Inc.	Intensity	$\alpha 95$	K	VGP (lat.)	VGP (long.)
KI01	3	55	16	7.93E-7	24	10	34	183
KI02	3	71	20	7.36E-7	16	24	21	173
KI03	4	61	19	7.92E-7	15	20	30	179
KI04	4	70	31	7.60E-7	15	21	24	167
KI05	4	87	8	9.12E-7	23	9	4	171
		(°)	(°)	(emu/cc)	(°)		(°)	(°)

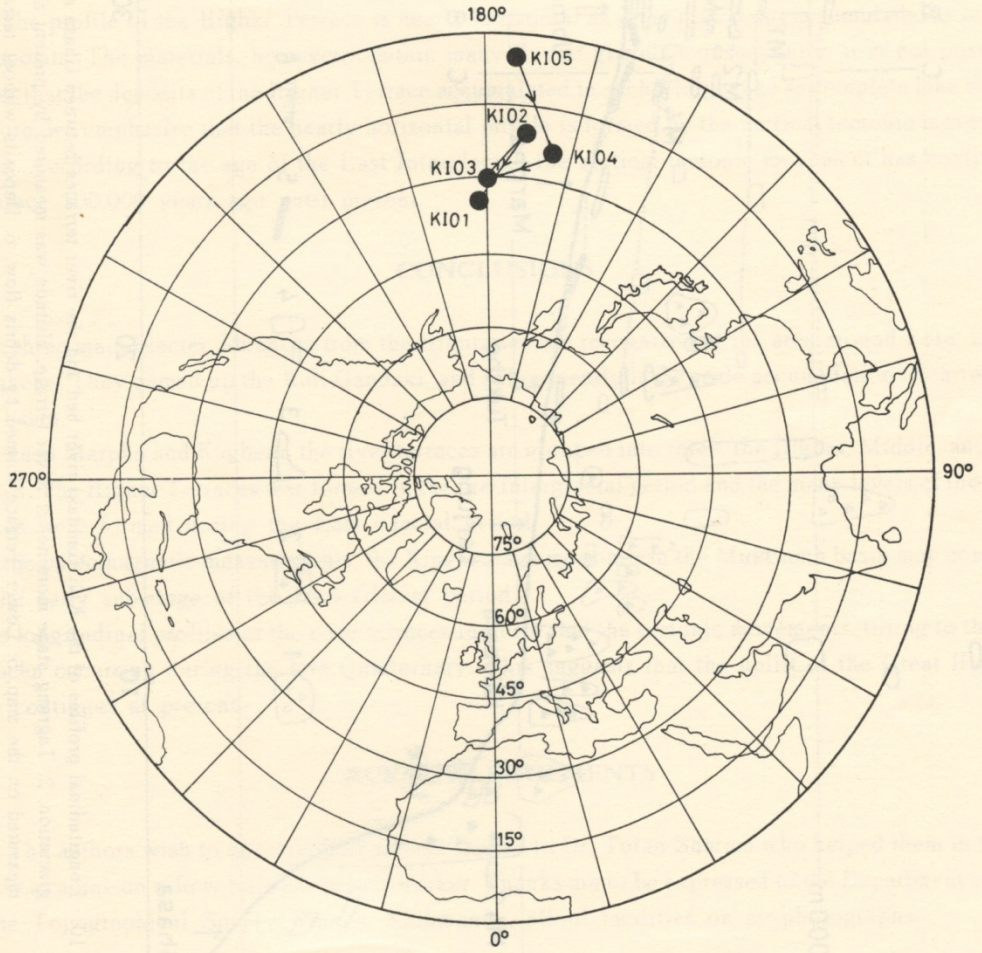

Fig. 9. Distribution of virtual geomagnetic poles (VGP) determined from glacial lake desposits located at Kingar.

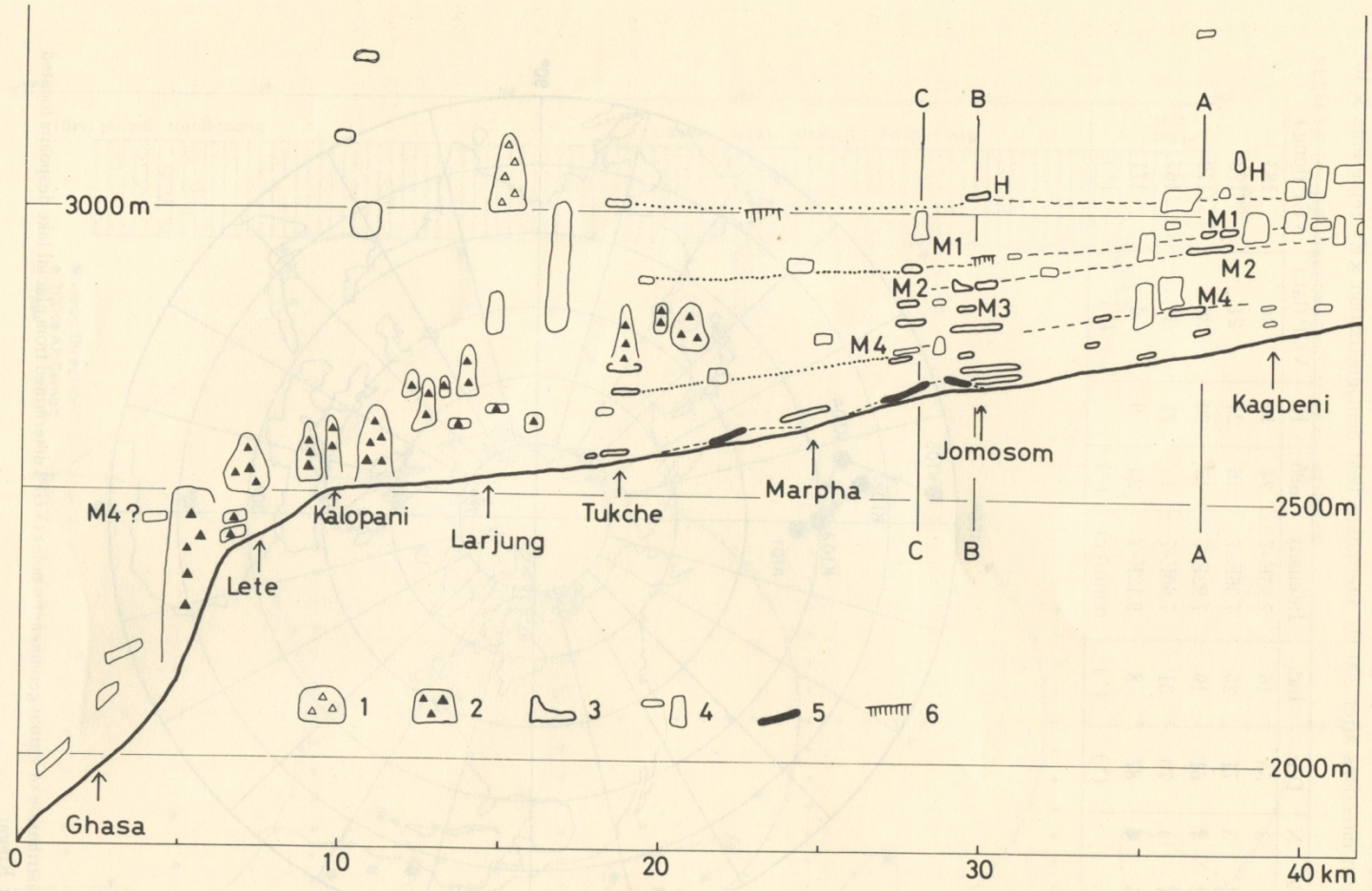

Fig. 10. Longitudinal profiles of the Kali Gandaki river bed and the river terraces between Ghasa and Kagbeni. 1: Moraine of the older glaciation, 2: Tagrung stage moraine, 3: River terrace, altitude was measured by present authors, 4: River terrace, altitude was measured on the map, 5: Lower Terrace formed by debris flow, 6: Deposits without terrace surface.

illustrates the longitudinal profiles of the river terraces between Ghasa and Kagbeni. This shows that the level of the Higher Terrace seems to coincide with the moraines of the older glaciation at Larjung. The M4 Terraces at Tagrung and near Ghasa are fluvio-glacial terraces in the older phase of the glacier advance of Tagrung stage. In Fig.10, the level of the M4 Terraces seems to coincide with the lower level of the Larjung stage moraines. Therefore, we consider that the M4 Terrace corresponds with the late substage of the Last Glacial Stage.

b) Deformation of the River Terraces.

The vertical displacement of a longitudinal profile of river terraces represents the aspects of the vertical tectonic movement, if we can suppose that the river bed profile during the terrace formation is similar to that at present. The relative heights of the H, M1, and M4 Terraces above river bed increase downstream apparently (Fig.10).

The profile of the Higher Terrace is nearly horizontal as if the materiales accumulated as complete lake deposits. The materials, however, contain many fluvial gravels, consequently, it is not possible to consider that the deposits of the Higher Terrace accumulated in such a large lake as complete lake deposits. Therefore, we emphasize that the nearly horizontal profile is formed by the vertical tectonic movement in the area. According to the age of the Last Interglacial, the vertical tectonic movement has continued at least since 100,000 years ago until present.

CONCLUSIONS

1) The three main glacier advances from the tributaries are recognized at the area around Lete, Larjung, and Tukche. They damed up the Kali Gandaki, and subsequently large scale accumulation occurred in the upper basin.
2) Between Marpha and Kagbeni, the river terraces are grouped into three: the Higher, Middle, and Lower Terraces. The Higher Terraces was formed in the pre-Interglacial period and the many levels of the Middle Terraces were formed during the Last Glacial period.
3) By the paleomagnetic measurements, the Kingar stage moraines in the Muktinath basin may correspond with the early sub-stage of the Last Glacial period.
4) The longitudinal profiles of the river terraces indicate that the tectonic movements, tilting to the north, have been occurring during the late Quarternary. This suggests that the uplift of the Great Himalayan Range continues at present.

ACKNOWLEDGEMENTS

The authors wish to express their sincere thanks to Dr. Toran Sharma who helped them in the field not only as a liaison officer but also as a co-worker. Thanks are to be expressed to the Department of Forest and the Topographical Survey Branch, Kathmandu, afford facilities on air-photographs.

REFERENCES

Bonhommet, N. and Zahringer, J. 1969. Paleomagnetic and Potassium argon age determination of the Laschamp geomagnetic polarity event. Earth and Planetary Science Letters, 6, 43-46.

Bordet, P., Colchen, M., Krummenacher, D., Le Fort, P., Mouterde, R., and Remy, M., 1971. Recherches Geologiques dans l' Himalaya du Nepal, Region de la Thakkhola. Ed. du C.N.R.S., Paris, 279p.

Creer, K. M., 1959. A.C. demagnetization of unstable Triassic Keuper marls from southwestern England. Jour. Geophys. Res., 67, 307-312.

Fort, M., 1976. Quaternary deposits of the Middle Kali Gandaki Valley. Himalayan Geology, 6, 499-507.

Fujiwara, Y. and Yoshida, M., 1981. An automatic astatic magnetometer for paleomagnetic studies. Jour. Fac. Sci. Hokkaido Univ., Ser. IV, 19, (4), 519-526.

Gillot, P. Y., Labeyrie, J., Laj,C., Valladas,G., Guerin, G., Poupeau, G., Delibrias,G., 1979. Age of the Laschamp paleo-magnetic excursion revisited. Earth and Planetary Science Letters, 42, 444-450.

Hagen,T., 1968. Report on the geological survey of Nepal, II-Geology of the Thakkhola, including adjacent areas. Memoires de la Société Helvétique des Sciences Naturelles, 86, 1-160.

Iwata, S., 1976. Late Pleistocene and Holocene moraines in the Sagarmatha (Everest) Region, Khumbu Himal. Jour. Japanese Soc. Snow and Ice "Seppyo", 38, Special Issue, 109-114.

Snape, C., 1967. A 500 c/sec alternating field demagnetization apparatus. in Collinson, D. W., (ed.), Method in Paleomagnetism, Elsevier, Amsterdam, 237-240.

Yamanaka, H;, 1982. Racdiocarbon ages of upper Quaternary deposits in Central Nepal. Sci. Rep. Tohoku Univ., 7th ser. (Geogr.), 32(1), in perparation.