# CHAPTER VIII

# G E O M O R P H O L O G Y

## GENERAL

The Himalaya has no analogy elsewhere in the earth as regards intensity of geological processes and the changes in their surface forms. The assymmetric ridges, the rejuvenated relief of river valleys and detailed articulation of the intermediate intermontane basins of Lesser Himalaya, reflect the tectonic instability. The development of the river systems in relation to the Cenozoic earth movements, with their expression of antecedence of epigenesis together with complicated patterns of terrace accumulations are the basic elements of geomorphology of the Himalaya. Neotectonism in Himalaya is now an established concept, and all over its length and breadth, the various structural and geomorphic features amply illustrate conspicuous level changes, gradual as well as abrupt, during Pleistocene and Holocene times. While the earlier events of the Himalayan orogeny, that started sometime during Cretaceous and attained maximum intensity during Miocene to Pleistocene periods, are very well preserved in the structural features of the Himalayan rocks, the later and more recent events, are best revealed in the vast network of gravelly river terraces that are encountered in the Lesser Himalaya. The various antecedent rivers flowing almost southwards, cutting across the Main Himalayan strike have given rise to a series of terraces made up of gravel beds deposited during the Quaternary times. Quaternary deposits of Himalaya not only point to the geomorphic activity but also provide a measure of the nature and intensity of the neotectonic processes.

The author during his investigation of the geology of the study area, conducted an exclusive study of the various geomorphic features also. The vast compacted gravel deposits flanking the two sides of Kali Gandaki Valley in the form of step-like terraces, comparatively low lying hill ridges with unusually rugged topographic forms, varying hill slopes and deep entrenched drainage system, are some of the basic geomorphic characteristics of the area. A study of these geomorphic features and their critical evaluation has revealed some interesting facts.

## SALIENT PHYSIOGRAPHIC FEATURES

The area and its neighbourhood, typically represents a characteristic Midland topography. Inspite of a fairly low altitude variation (600 to 2000 m), the area is highly rugged and dissected, with complicated systems of inter-fingering high hills and deep valleys, the Kali Gandaki river providing the base level (730 to 630 m). In its 16 km north-south horizontal coverage, the river loses only 100 m in height. Flanking the river on its either side are the paired, continuous compacted gravelly step-like terrace deposits, which stand out as vertical to sub-vertical cliffs with intervening plains at three distinct levels. The continuity of the terraces is broken by meandering of the river and dissection by the tributaries, which join the Kali Gandaki from either side, forming deep narrow gorges within the terrace deposits. Rising abruptly above from the terraced conglomerate gravels are the higher hills and tributary valleys.

Hill complexes of the study area could be broadly divided into two groups, To the first group, belong the nearly N-S running Balewa-Chokya hills in the west and Gyandikot-Karkinetta hills in the east, which mark the eastern and western limits of the area respectively. They also form the local east-west drainage divide of the Kali Gandaki in the study area. The second group, comprises the roughly east-west trending Thana hill, Purkot-Limikot hill, Gyandikot hill and Ramja hill, and these latter hill ranges form the tributary drainage divide of the river Kali Gandaki. The Sallyan hillspur, inbetween the Kali Gandaki and Modi Khola is a part of a north-south hill range, and forms the drainage divide line for the Kali Gandaki on the west and Modi Khola on the east. A close topographic study of the area and its neighbourhood has shown that the higher summits lie at the intersection of the north-south and east-west running hill ranges. The highest summit of the area is Debithan (2059m).

Located sufficiently higher than the main river valleys of Kali Gandaki and Modi Khola (trending approximately north-south in the study area), are the various east-west tributary valleys; conspicuous amongst them are the valleys of Lamai Khola, Malyangdi Khola and Jare Khola, characterised by deep entrenched stream channels and perfect 'V' shaped valleys profiles.

From the evolutionary point of view, two types of landforms have been distinguished in the study area:

1. Erosional highland comprising high hills and minor valleys.
2. Depositional terraced landforms along the Kali Gandaki Valley.

Elevated erosional landforms provide sloping surfaces with considerable variation in relief. In contrast, the depositional landforms are usually flat. The erosional highlands have been exposed continuously to the agitation and etching of the geomorphic processes since their inception, which have left distinct imprints on the landforms. Man-made activities like cultivation and de~~f~~forestation have also helped in changing the geomorphology of the region.

On the other hand, the depositional landforms indicate a combined history of construction followed by the recent story of erosion - a token of the tectonic instability of the region. The high standing terraced cliffs facing the Kali Gandaki river are the result of these instabilities.

Beside the linear processes activated by neotectonism, the surface degradation and underground water activities have also considerably modified the form of these terraced landscapes. Conspicuous among them are the Karst pillers of the conglomerates on the terrace plains (Plate No.VIII.1), sink holes of considerable diameter on the terrace surfaces, and the underground caves in the compacted gravels.

## DRAINAGE STUDIES

The various morphometric parameters investigated for the drainage evaluation includes linear, aerial and relief aspects. All the variations in these morphometric parameters have been correlated with lithology and structural elements within the study area.

The drainage characteristics have been investigated from the Toposheet 1" = 1 mile enlarged into 4" = 1 mile of the Survey of India, and for this study the author selected seven third order basins and one fourth order basin from the different parts of the study area.

A comparative study of the different basins was taken up applying the Horton's laws of morphometry (1945). Longitudinal profiles for main streams were prepared to bring out the breaks in graded profiles and a correlation with the number of terraces standing on the two sides of Kali Gandaki river was attempted. The various cross profiles were investigated for the generalised slopes and profile irregularities. The slope map was prepared with help of 'Gliding Tangent Scale'. The micro-relief for each generalised slope category was however not taken into account.

The Fig. VIII.1 gives an idea of the drainage network of the area. The classification of the different stream channels within the area shows the main trunk stream Kali Gandaki to be of 7th order. While classifying the channels, it has been presumed that the main channels coming in and out of the study area is of higher order than those counted inside the area. It may however be possible that these channels could be of still higher order or of the same order, when the entire basin is taken into consideration. It is significant that none of the channels exceeding 4th order form one complete basin within the study area.

The main trunk stream Kali Gandaki, flows due south; also the Kali Gandaki and Modi Khola (one of its main tributary), are the only two streams fed by glaciers of the north. These two rivers meet at Modi Beni, a little south of Kusma village. Rest of the other tributaries joining Kali Gandaki and Modi Khola in the study area have their headwaters within or adjacent to the area. All the tributaries above the second order are perennial and fed by springs or rain-water. Seasonal variation in stream discharge is considerable, the ratio of maximum to minimum discharge being more in streams depending mostly on rains.

As the trunk streams Kali Gandaki and Modi Khola are seasonal in their volume of discharge, the widths of the wet channel of these rivers are variable. However, if the dry and wet channels , are taken together, the total widths of the river beds are somewhat narrow and vary from 30 to 150 metres. In the entire stretch of 16 km, in the study area, the Kali Gandaki maintains a constant gradient and flows over the exposed rocky beds comprising mainly quartzites, phyllites and slates (Plate No.VIII.2). Furthermore, the river channel is deeply entrenched leaving the terraced gravels at higher levels. On the other hand, the tributaries joining the Kali Gandaki from its either side, flow over the gravels,

Plate VIII.2

Just exposed rocky bed of the river Kali Gandaki below Jyamir Ghat bridge. $T_3$ gravels are resting on these rock benches. (R = rocky exposures, F = flood plain of river Kali Gandaki, arrow indicates flow direction of Kali Gandaki).

before meeting the Kali Gandaki. These tributaries are entrenched in the gravels forming deep gorges (Plate No. VIII.3 & 4), clearly suggesting the valley-fill nature of these deposits.

The overall drainage pattern of the area is dendritic. However, the first and second order stream channels show somewhat trellis network, as these minor streams are seen to follow quite often localised joint patterns. In terms of Drainage Density, the area is close textured with higher Stream Frequency in the erosional highland and lower Stream Frequency in the depositional landforms. The overall drainage is controlled by the structural features of the area.

Longitudinal profiles

The trunk stream, Kali Gandaki characteristically, does not show any break in the profile within the limits of the study area. It is characterised by a constant gradient of 1 km : 5.625 metres (Fig. VIII.2). The absence of break in the major trunk stream can be attributed to the homogeneity of the study area and high erosional capacity of the stream.

In contrast, the longitudinal profiles of the major tributary streams like Lamai Khola and Malyangdi Khola

Plate No. VIII.3

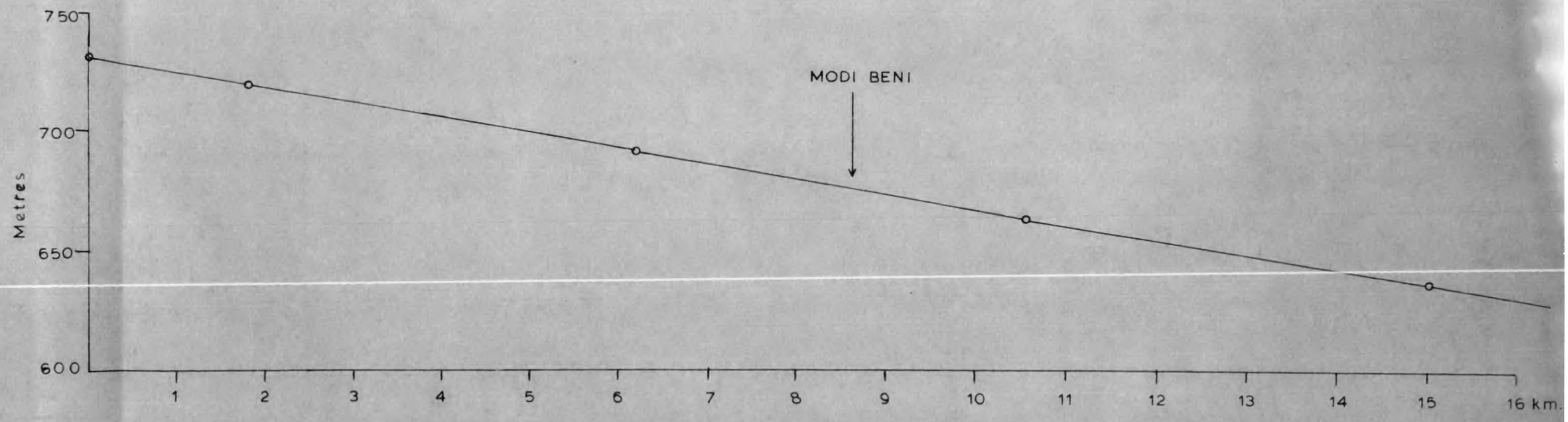

A view overlooking SW from Ghore Dhunga showing deeply entrenched Lamai Khola cutting the gravels; in the background are seen $T_1$ terraces of Phalebas and Thana. ($T_1$ = highest terrace, $T_2$ = terrace of Lamai Khola comparable to the second highest terrace of Phalebas), arrow indicates flow direction of Lamai Khola)

Plate No. VIII.4

Showing narrow gorge of Lamai Khola in the gravels NE of Dhumple Daha (arrow indicates flow direction of Lamai Khola).

Fig.VIII.2

LONGITUDINAL PROFILE OF RIVER KALI GANDAKI



(Fig. VIII.3a & b), show more diverse features, which include (i) steep gradient towards headwater regions, (ii) long flat profiles alternating with short steep profiles with three to four distinct breaks. These breaks in profile, have been attributed to neotectonism, and are correlatable with the terraces of Kali Gandaki.

Cross-profiles

Three superimposed cross-profiles across the trunk stream Kali Gandaki are shown in Fig. VIII.4. The slopes are 20° to 25° in the upper reaches of this valley, while in the immediate vicinity of the drainage channels they are almost vertical. This steepness indirectly points to the rejuvenation of the area in the recent past. The elevated land summits on either side of the Kali Gandaki Valley, if joined together provide a flat datum. This feature together with the gentler hill slopes and the convex flat topped summits point to a marked linear degradation and fast and strong peneplanation of the area in the geological past. The dip direction slopes are of the order of 15° to 20°, whereas the slopes opposite to dip are short and steep. In many cases it has been noted that the slopes opposite to the dip are gentler, obviously showing a phenomenon of debris slope covering the midslopes (hill slopes), thus bringing the slope retreat to maximum. Most valleys are assymetric in shape, and this assymetry appears to be due to structural complexities.

## Drainage Channel Analysis and Comparison of Morphometric Parameters

All together eight basins were chosen, amongst them, two flow over the gritty quartzose phyllites, one over quartzites, three over gritty quartzose phyllites and quartzites and two over gritty quartzose phyllites and gravels.

The plots of the Channel Orders Vs Number (as taken from the Toposheet No. 62P/12, prepared by Survey of India), show a somewhat straight linear relationship (Fig.VIII.5). The discrepancies noted in the equilibrium relationship is mainly due to the higher number of the first order channels as compared to the geometrical number of second order channels. The deviation is also due to the fact that stream channels become immediately of third order. This is also suggestive of the structural control and tectonic rejuvenation of the area.

Channel Order against Average Length, do not show linear relationship (Fig. VIII.6). The discrepancies are seen specially in first and second orders. This implies that before the first order streams unite and become second order within their own catchment, they attain a higher Stream Frequency and Density whereas the second order channels attain lower Stream Frequency as well as Density. This phenomenon shows a marked deviation from the Horton's law of Stream Length (Horton, 1945), and as observed by the author, point to the control of these small order channels by the structural features like joints and by relief, thus pointing to an indirect tectonic rejuvenation.

A comparison of the various morphometric parameters for each of these smaller order basins (Table VIII.1), of the area reveal diverse changes. The values for the Bifurcation Ratio vary from 2 to 6, but most of the common values are between 2 to 4, maximum being 3. The Drainage Density vary between 3 to 5,but in two of the basins, this value lies below 3. This is because, channels in both these basins have travelled a greater distance over softer lithology like gravels and have minimum Relief Ratio. The values of Stream Frequency vary to a great extent i.e.

between 3 to 8.5 and show a conspicuous relationship with lithology and structure. The stream channels flowing through softer lithology show low Stream Frequency. In contrast, the channels flowing through the harder lithology of highly jointed quartzites and gritty quartzose phyllites, display Stream Frequency variation as high as upto 8. However, the overall Stream Frequency variation is not distinctive, as the study area comprises the rocks having hardly any difference in their hardness and resistance. The apparent variation is mainly a structural phenomenon.

## Geological Control on Drainage

The foliation trends of the rocks of the study area (Fig. V.1), when compared with the drainage map (Fig.VIII.1), show a very close relationship with that of the regional structures. The Kali Gandaki flows along the axial trace of a N-S antiform ($F_2$) in the central and southern part of the study area. But in the northern extremity of the area, the river takes a sharp turn at Chhamerke and follows the WNW-ESE Kusma Reverse Fault. Whereas, Modi Khola aligns itself with a NNE-SSW strike-slip fault (Modi Khola Transverse Fault). The other minor tributaries such as Lamai Khola, Malyangdi Khola and Jare Khola more or less flow along the axial planes of the antiformal E-W structures ($F_3$).

In case of others, it has been observed that, when the channels cut across the strike, they follow a narrow path, whereas the reverse case is noted in the channels following the strike. Besides the structural control, lithology is also seen controlling the channel characteristics. It has been observed that in the harder lithology, the channel bed is somewhat narrower than in the softer lithological types. The first and second order stream channels in the study area are seen controlled by the joints trending NNE-SSW or N-S which are prominently developed in the area.

SLOPE STUDIES

The generalised slope pattern study (Fig.VIII.7) of the higher ground reveals three main groupings, according to the position in the landscape:

(i) the crest of the ridges

(ii) the hill slopes and

(iii) the valley slopes.

The crests have low dips of around 5° - 10° sloping towards west, north and south. In comparison the hill slopes, which show a considerable variation in the slope angles, can be sub-divided into two types, viz., (i) debris covered slopes and (ii) steeper rocky slopes.

The debris covered slopes show moderate slope angles ranging from 15°-20°, and are on account of the fact that the process of transportation on these slopes is less effective than the process of ercsion. These moderate slopes are extensively utilised for cultivation, and hence this slope landscape is characterised by flights of man-made terraces.

Most of steeper slopes which are free from debris, occur as crescentic to linear stretches merging immediately with the low dipping waxing slopes at the crests. The distribution of the cliff-like slopes depend on the lithology and structures. These usually have a thin vegetation cover on account of their steepness.

In general, the hill slopes, to some degree, show a close relationship with the structural set-up of the area. The generalised dips of strata are 25° - 40° due NE, SW and W, whereas topographical slopes in dip direction are also 15° - 20° (Plate No.VIII.5). In cases, where the slopes are opposite or oblique to the dip direction, the angle of slope reaches upto 55° (in the quartzites of

Plate No. VIII.5

Convex crest of hills and moderately gentler dip direction hill slopes of the westerly spur of Gyandikot hill, looking N from Limikot.

Lamai Khola and Dobilla). This phenomenon is shown by the east-west running Hogbacks.

In some places like Balewa, even though the dips are opposite to the topographical slope, this slope has angles ranging from 15° - 20°, but these anomalous slopes opposite to dip direction are obviously due to the debris cover on the slopes and thus have no structural control.

The valley slopes are mostly steep with angles usually more than 35°. A clear picture of the valley slopes is not reflected in the slope map of the study area, because of their small amounts and linear pattern. The valley sections of the minor tributaries are extremely steep because of the entrenchment of these streams (Plate No.VIII.6). These entrenchments are irrespective of the lithology of the bed rock and this indirectly reflects the tectonic rejuvenation of the area after a prolonged period of effective weathering and erosion. It is because of this,that at places, the debris covered valley hill sides are seen sliding down the valley slopes.

Slopes in the depositional landforms emphasize a flatness in comparison to erosional landforms. Terraces are very flat or gently sloping down the valley of

Plate No. VIII.6

Vertical entrenchment of the small tributary forming cliff at the valley section.

Kali Gandaki (Plate No.VIII.7). The slope angles in these terraced flats do not exceed 5°. The intervening cliffs between the successive terraces are very conspicuous, and stand out as vertical to sub-vertical cliffs, bordering the gorge of Kali Gandaki. Cliffs with slopes as much as 90° and as high as 300 metres are encountered (Plate No. VIII.8). At places, even overhanging cliffs are met with, which have facilitated the rock falls and slides of the conglomerated gravels.

## Slope Evolution

In Himalaya, relief is always the main controlling factor in the slope evolution apart from differences in lithologic competencies and magnitude of eroding agents. In the study area, all these factors have contributed equally and have given rise to a slope pattern that is quite distinctive. The slope variation from one part to the other, are essentially controlled by geologic factors. Assuming the magnitude of fluvial processes to be uniform all over, the slope evolution in the study area could obviously be attributed to the linear and surface degradation. Of course, the response of varying lithology to this process has been different and steeper slopes are attributed to the structural set up and tectonic processes.

Plate No. VIII.7


A view of gently sloping $T_1$ terrace of Balewa (Balewa Air-port), In the background are $T_1$ and $T_2$ terraces of Pang and Kusma. ($T_1$ = highest terrace, $T_2$ = second highest terrace, arrow indicates the position and flow direction of Kali Gandaki).

Plate No. VIII.8


A view of the vertical cliff of 300 m facing Kali Gandaki looking west from Kusma ($T_1$ = highest terrace, $T_3$ = third highest terrace, C = intervening cliff between $T_1$ and $T_3$, D = debris of gravels covering $T_3$ terrace, F = flood plain of river Kali Gandaki, arrow indicates flow direction of Kali Gandaki).

Geomorphic Processes

The polyphase landscape of this portion of Kali Gandaki Valley has preserved within it an admirable and rather well defined imprints of the various weathering and denudational agencies. Obviously, the entire landscape of the study area is youthful and is under constant attack of processes of active erosion, transportation and deposition. These processes include the various phenomenon like weathering of rocks, mass wasting, stream load discharge, formation of flood plains and terraces and river entrenchment.

In the past also, the similar processes were in play, as no clues are available suggestive of the other processes. The imprints of the processes like glacial and fluvioglacial have not been recorded from the erosional landforms. It has been observed that in this part of Nepal Himalaya, the imprints of glacial activity do not lie below 3000 metres altitude (Hagen, 1969). However the boulders of considerable diameter and of the far of places of Central Crystallines, in the terraced conglomerated gravels of Kali Gandaki amply suggest their fluvioglacial origin. This indicates that though the area itself was never subjected to the glacial condition, but was the depositional ground for the products of the effect of glacial action further north, which provided the gravel deposits in the low lying areas.

## TERRACED GRAVEL DEPOSITS

The terraced gravel deposits have revealed a unique geomorphic history related to the neotectonic activity in this part of Nepal Himalaya. The study has revealed sequential events of deposition, erosion and transportation.

## Kali Gandaki Consolidated Gravels

Flanking the river Kali Gandaki and Modi Khola are the huge compacted gravel deposits throughout their course. The aggregate thickness of the gravel amounts to around 350 metres. Two distinct types of gravel deposits have been observed.

1. Calcareous gravel deposits - the gravelly material comprises big boulders and pebbles of Dhaulagiri contorted limestones, central gneisses, mica schists, quartzites and phyllites, and the matrix of these gravels is also seen to be the finer particles of the same materials (Plate No.VIII.9).

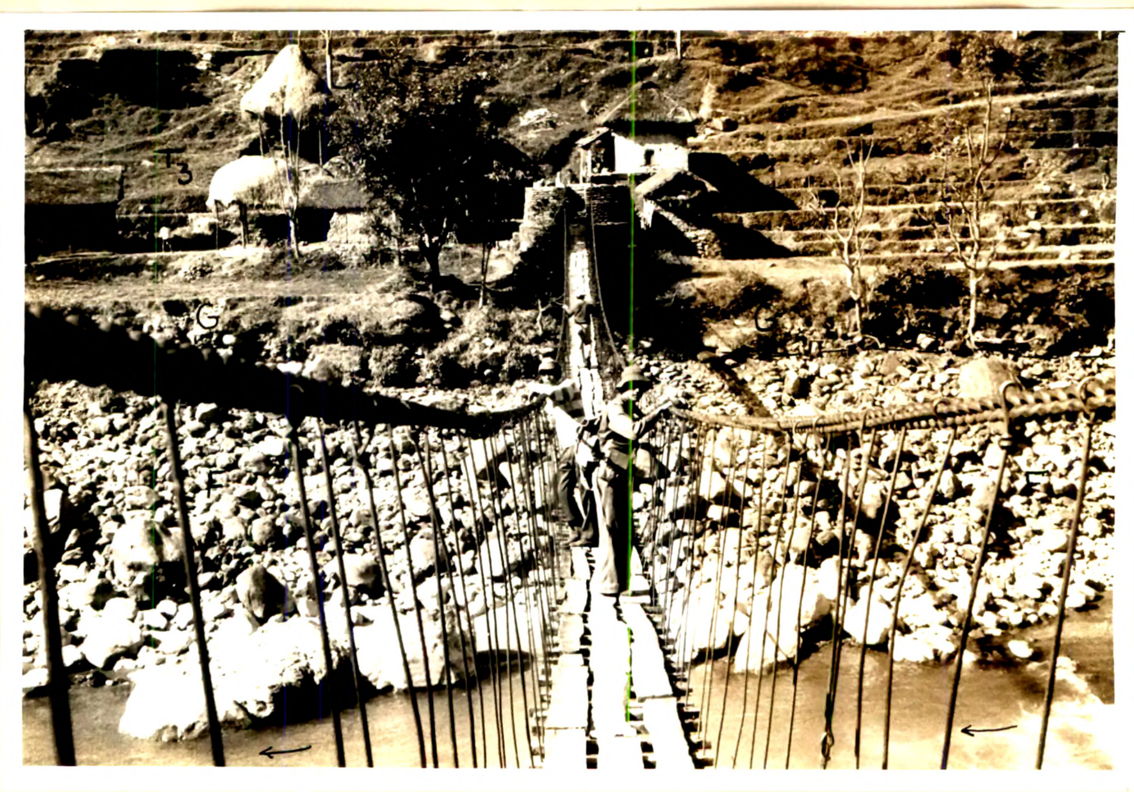
2. Unconsolidated loose gravels, comprising the gravelly materials of quartzites, schists and phyllites of the adjacent area and even the boulders of the calcareous gravels (Plate VIII.10).

None of the gravel types show any stratification and are characteristically unsorted. In the calcareous

Plate No. VIII.9

A block of consolidated unsorted unstratified $T_2$ gravelly material lying on the flood plain of Kali Gandaki.

Plate No. VIII.10




Unconsolidated $T_3$ gravels at Jyamir Ghat ( G = unconsolidated gravels of $T_3$, $T_3$ = third highest terrace, F = flood plain of river Kali Gandaki, arrow indicates flow direction of the river).

conglomerate gravels a sort of gradation is seen in their grain size - lower part being very coarser than the upper. The gravel deposits also do not show any indication of tilting. To the present date the gravelly materials express topographically three distinct levels.

## Criteria for the Terrace Classification

The river Kali Gandaki and its main tributary Modi Khola have cut deep narrow gorges in the gravel material itself, bounded on either side by hanging terraces one above the other. Most of terraces are paired, and only occasionally along the meander points of the river, some terraces are unpaired. The river beds of the Kali Gandaki and Modi are however rocky and show a very low almost negligible (1° or so) gradient, the terraces standing out as vertical to subvertical cliffs. Three distinct levels on either side of the deep gorges of Kali and Modi have been recorded, and the aggregate thickness of the three terraces varies from 300 to 500 metres. These form extensively wide belts at the major stream confluences, at Baglung (Kanthe Khola and Kali Gandaki), Balewa, Kusma and Gyandi (Modi and Kali Gandaki) and Phalebas (Lamai Khola and Kali Gandaki). The various previous workers (Nanda and Nadgir, 1966; Fuchs, 1967, Fort, 1976;Hagen,1969), have observed such aggradational river terraces all along the course of Kali Gandaki from Mahabharat Range in the south to as far as Thak Khola in the north.

The vast gravel beds filling up the Kali Gandaki valley, point to an interesting genesis. Thick deposits, several hundred metres high, flanking the river valley, show typical terraced topography, the successive terraces, revealing a phenomenon of deposition and erosion during Quaternary times. The area affords a good example of valley-fill deposition caused by the damming of the river due to uplift in its lower course, followed by a series of tectonic events resulting into successive rejuvenation of the river. The net result of the various tectonic events is reflected in the carving out of the various terraces.

The terraces hanging on either side of the Kali Gandaki have been classified and correlated mainly on the basis of following two factors:

1. <u>Relative heights of the successive terraces</u>: At most places, three well defined levels have been recognised. In cross-section (Fig.VIII.8), the levels of the terraces are almost identical,

while in the longitudinal profile sections (Fig.VIII.9), the successive terraces show a progressive decrease in heights (Plate No. VIII.11, 12, 13 & 14).

2. The particle size, composition and degree of compaction of the terrace material: The terrace material is composed of unsorted materials ranging from big boulders to sand and silt, layering or bedding being inconspicuous at most places. The infilling matrix is impure calcareous in nature.

At least, three types of the gravel material - each typically diagnostic of the three terraces have been recorded:

(1) Fairly hard and compacted aggregate of angular to sub-rounded pebbles of quartzites, phyllites, gneisses and contorted limestone (of Dhaulagiri). The compacting cement is impure calcareous (Terrace $T_1$).

(2) The terrace material identical to (1), but much coarser, i.e. the large fragments of gneiss, quartzite, Dhaulagiri limestone of bouldary to

LONGITUDINAL PROFILE ALONG PHALEBAS AND KUSMA

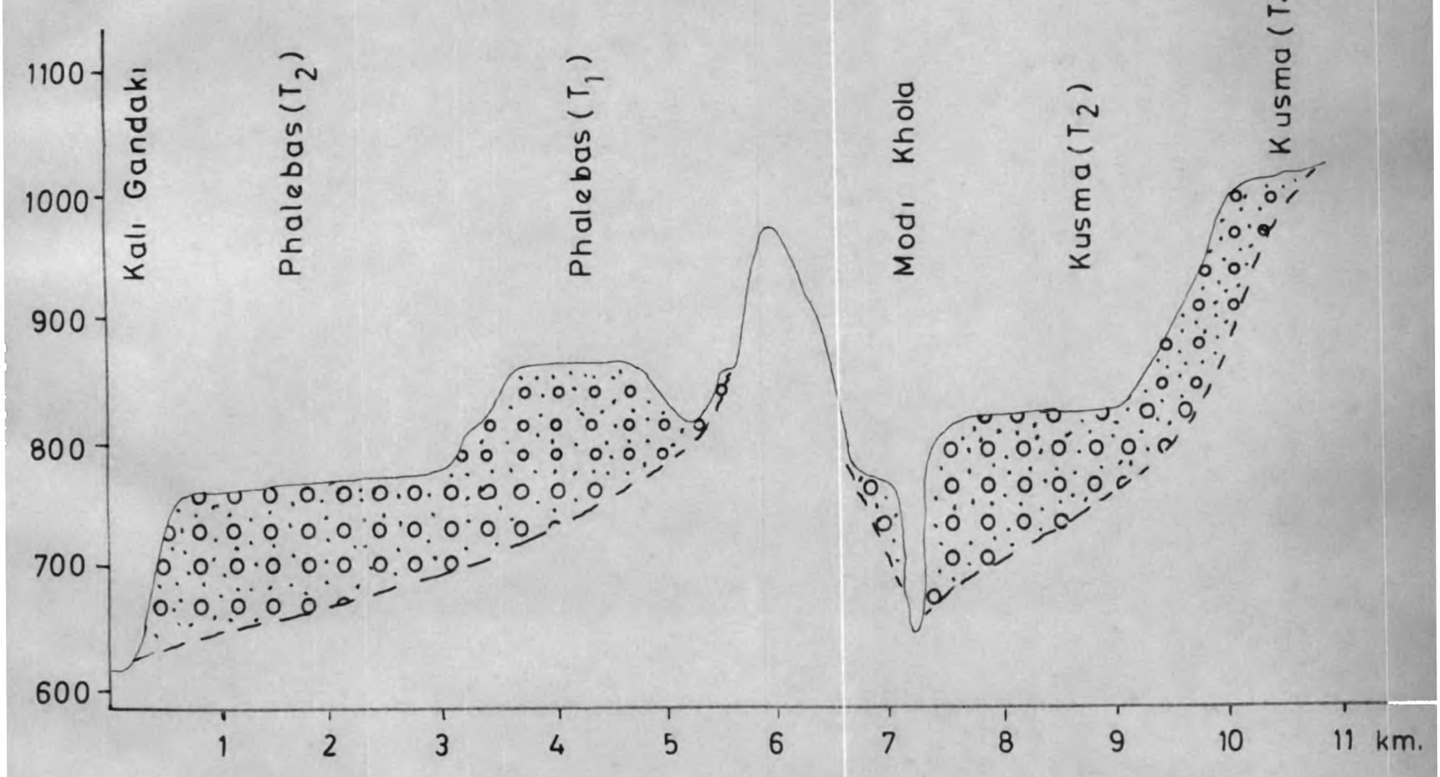
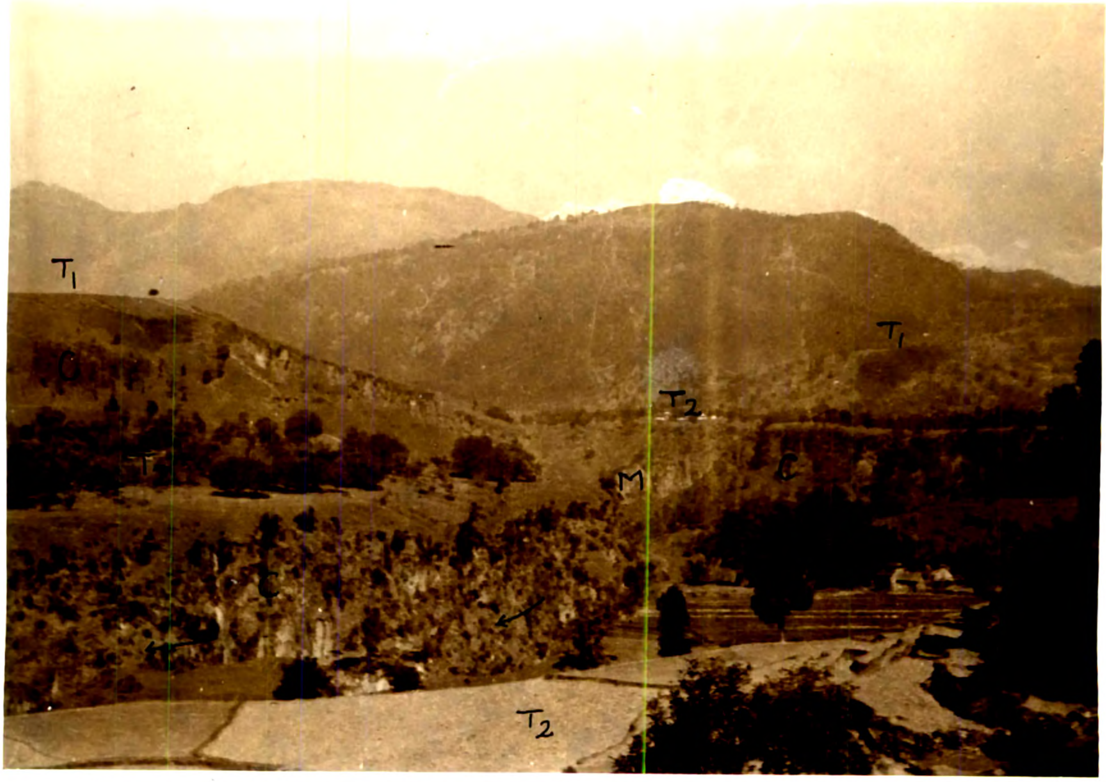
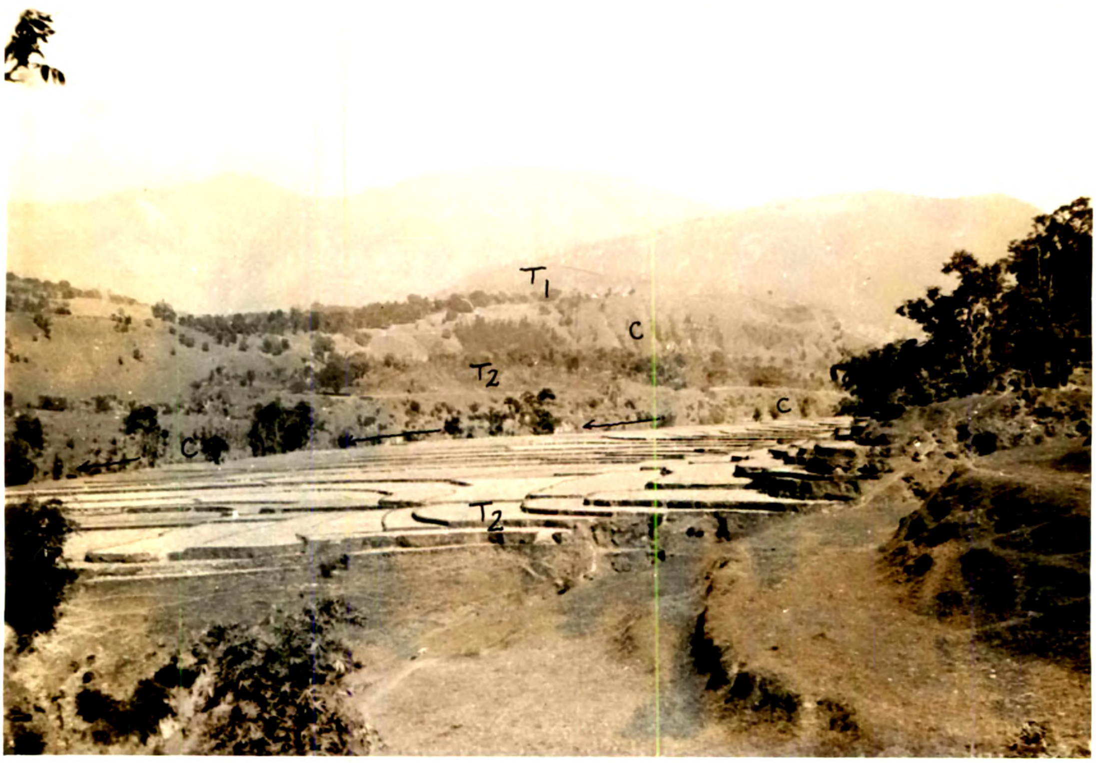


Plate No. VIII.11



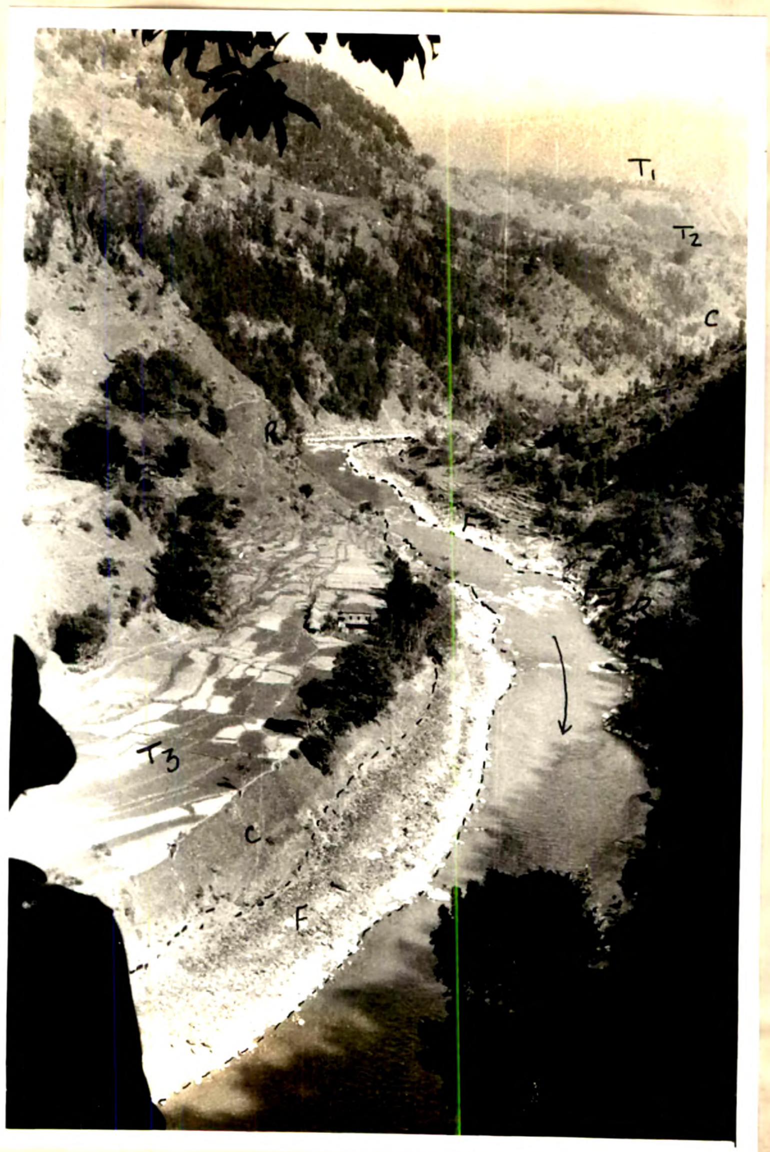

$T_1$ and $T_2$ terrace flats of Balewa on the left and $T_1$ and $T_2$ terrace flats of Kusma on the right as viewed northward from Phalebas $T_2$ terrace ($T_1$ = highest terrace, $T_2$ = second highest terrace, C = cliff intervening between the terraces and facing the gorge of Kali Gandaki, M = Modi Beni - confluence of Kali Gandaki and Modi Khola, arrow indicates the position and flow directions of Kali Gandaki and Modi Khola).

Plate No. VIII.12



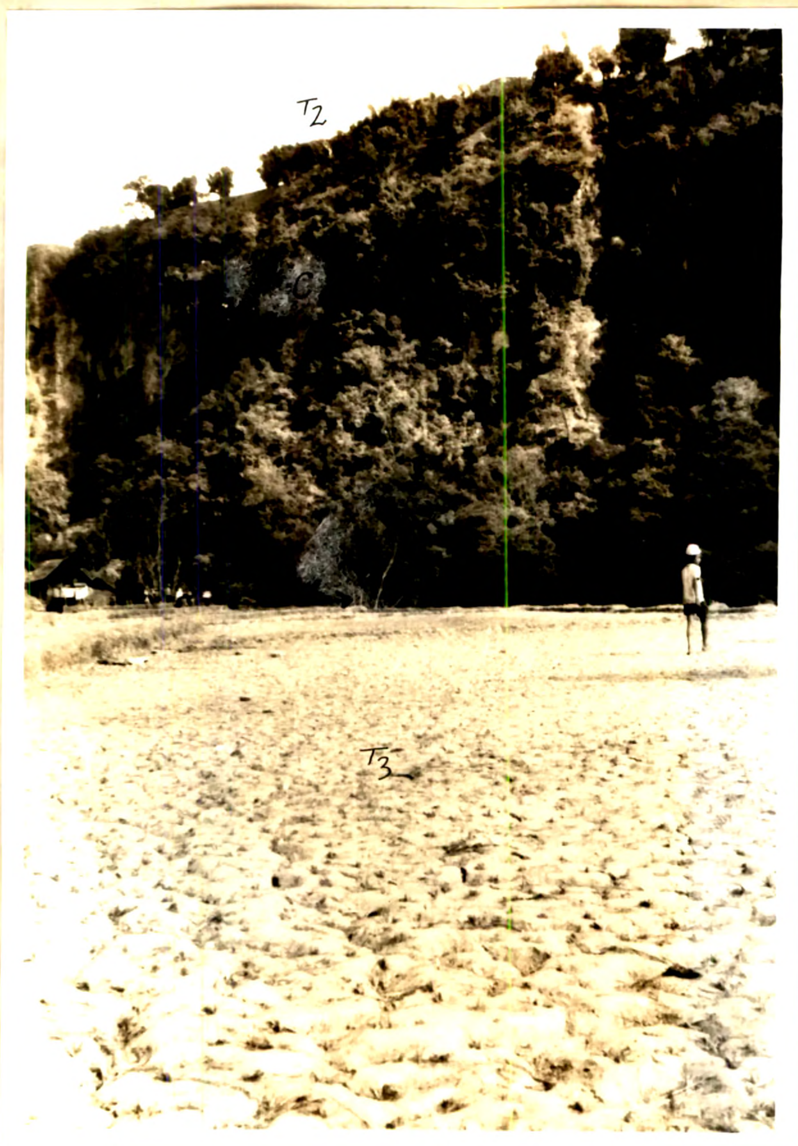

$T_1$ and $T_2$ terrace flats of Balewa looking north of Phalebas $T_2$ terrace ($T_1$ = highest terrace, $T_2$ = second highest terrace, C = cliff intervening between the terraces and facing the gorge of Kali Gandaki).

Plate No. VIII.13




$T_3$ terrace flat of Jyamir Ghat. In the background, are $T_1$ and $T_2$ terraces of Balewa, viewed north from $T_2$ terrace of Phalebas ($T_1$ = highest terrace, $T_2$ = second highest terrace, $T_3$ = third highest terrace, C = cliff separating $T_3$ from the flood plain of Kali Gandaki, F = flood plain of Kali Gandaki, R = rocky exposures, arrow indicates the flow direction of Kali Gandaki).

Plate No. VIII.14




$T_3$ terrace flat of Jyamir Ghat. In the background is the vertical $T_2$ cliff of Phalebas facing Kali Gandaki ($T_2$ = second highest terrace, $T_3$ = third highest terrace, C = $T_2$ cliff facing Kali Gandaki, arrow indicates the position and flow direction of Kali Gandaki).

pebbly size. The cement is calcareous and the rock is much more compacted (Terrace $T_2$).

(3) Unconsolidated mass of boulders and pebbles of quartzite, metamorphic rocks of the neighbourhood and also blocks derived from the $T_1$ and $T_2$ terraces (Terrace $T_3$).

$T_1$ is the highest and the earliest formed terrace standing out at heights varying from 400 metres to 300 metres from the river bed. It generally shows an altitude variation from 1150 metres (Balewa in the north) to 775 metres (Behadi in the south). The height difference between the $T_1$ and the next lower terrace $T_2$, varies from 70 to 200 metres, and at some places $T_1$ gradually slopes down to $T_2$ while at other places, steep scarps separate the two. The $T_2$ terrace is very well defined and well developed all along the river course. The height difference between $T_2$ and $T_3$ is usually 150 to 200 m (Plate No.VIII.14). $T_3$, the lowermost terrace, rises about 10 to 15 metres above the river bed (Plate No. VIII.13), and at most places it rests directly over the rock benches, and this youngest terrace is least developed.

The material of $T_1$ and $T_2$, is a product of one single depositional sequence, the coarser in the lower part (now making up the $T_2$) and the finer in the upper part, making the $T_1$.

## Distribution and Morphology of Terraces

From north to south, the gravel beds as revealed by the successive terraces (Fig. VIII.10), have been investigated in the vicinity of the following villages:

1. Gijjan and Pakuwa around Dobilla in the NE (between the Modi and Jare Kholas).
2. Kusma and Pang (north of the confluence of Kali Gandaki and Modi Khola).
3. Balewa (on the western bank of Kali Gandaki)
4. Gyandi (on the eastern bank of Kali Gandaki, in between Jare and Malyangdi Kholas).
5. Phalebas (on the eastern bank of Kali Gandaki, in between Malyangdi and Lamai Kholas).

## Gijjan and Pakuwa around Dobilla

Around Dobilla the raised river terraces are preserved at Gijjan and Pakuwa. $T_2$ terrace at Gijjan lying between Rati and Modi, extends for 3 km towards N, gradually rising up and merging with $T_1$ at its northern extremity. The $T_3$ flat is seen developed only as a small bench on the eastern bank of Modi west of Gijjan. $T_2$ is again seen at Pakuwa, between Rati and Jare Kholas. Small remnant of $T_2$ is also recognised SW of Jare-Rati confluence at Simle. No development of $T_3$ is observed around Pakuwa and Simle.

The $T_2$ terrace lies about 135 to 165 metres above the present river bed, whereas $T_1$ terrace attains an average height of 260 metres at the northern extremity of Gijjan.

Kusma and Pang

At Kusma, the $T_2$ terrace is extensively developed, and forms a tongue shaped flat, extending N-S for 2 km right from the confluence of Modi and Kali Gandaki upto the Sallyan foot-hills. From the foot-hills, it extends as a narrow strip towards NW and NE along the eastern bank of Kali Gandaki and the western bank of Modi Khola respectively. To the NW, this terrace flat extends for about 6.5 km with a small gap between Pang and Chhamerke. To the NE, it extends for about 4 km upto the confluence of Modi and Sundare Khola. The $T_2$ terrace flat of Kusma and Pang attains the average height of 165 metres from the present river bed.

At Kusma only the remnants of $T_1$ terrace are recognised along the foothill of Sallyan, above the Kusma Bazar. The $T_1$ and $T_2$ flats of Kusma are not separated by any vertical cliff, but instead are joined by a 15° to 20° sloping plain. The $T_1$ terrace of Kusma attains the maximum height of 450 metres, from the river bed, just N of Kusma Bazar. NW of Kusma the $T_1$ terrace remnants are not observed except at the northern sector of Pang. But towards NE the $T_1$ terrace is somewhat better preserved upto Chuwa.

The $T_3$ terrace flat around Kusma is seen developed near Modi Rati confluence, and E of Kusma along the western bank of river Modi. Along the eastern bank of Kali Gandaki, only a small strip of $T_3$ is observed west of Chhamerke. $T_3$ flats are not as extensive as those of $T_1$ and $T_2$ and lie only about 5 to 10 metres above the present flood-plain of the river.

Balewa

The best and most extensive development of $T_1$ terrace is seen at Balewa, where it has attained maximum height of 450 metres above the river bed of Kali Gandaki. It is flanked on its NW and S by $T_2$ terrace flats, but to the E, it faces Kali Gandaki with a vertical cliff of about 300 metres. The $T_1$ terrace slopes about 4° eastward and extends for about 2.5 km in N-S and more than 1.5 km in E-W directions. To the NW, it joins up with $T_2$ flat through a slope of 15°. The $T_2$ terrace also shows a good development, extending all along the Kali Gandaki. To the south, $T_1$ terrace is separated from $T_2$ of Kaiya by a rather very steep cliff like slope. The $T_2$ terrace at Balewa, attains the height of 165-200 metres from the river bed of Kali Gandaki and stands at the same height as the $T_2$ flats of Kusma and Gyandi.

The $T_3$ flat at Balewa is developed only along the Kali Gandaki, west of the confluence of Modi and Kali Gandaki, about 5 to 10 metres above the riverbed of Kali Gandaki.

<u>Gyandi</u>

At Gyandi $T_1$ terrace is observed as a remnant in a small hill lying in between Malyangdi and Chhini Khola. It attains a maximum height of 360 metres from the present river bed. $T_1$ flat gradually slopes down to $T_2$ flat of Gyandi lying about 165-200 metres above the river bed. The $T_2$ terrace of Gyandi faces the gorge of Modi with a vertical cliff, with or without $T_3$ flat at its base. The $T_2$ flat of Gyandi extends for about 2 km in the east-west direction.

<u>Phalebas</u>

At Phalebas all the terrace flats are well developed. $T_1$ flat extends N-S right from Mudkuwa upto the confluence of Lamai Khola and Kali Gandaki. Due to the deep incision of Lamai Khola in the terraced gravels, small portions of $T_1$ and $T_2$ terraces have been separated from the main Phalebas

$T_1$ and $T_2$, whose remnants are still preserved on the northern flank of Thana hill upto Archale nearly 5 km upstream from the confluence of Lamai Khola and Kali Gandaki. The $T_1$ terrace attained its maximum height east of Dhamahadungha, but gradually slopes down to the $T_2$ terrace flat near the Lamai and Chirdi Khola confluence. The $T_1$ terrace flat maintains its average height of 270 metres above the present river bed of Kali Gandaki.

The $T_1$ and $T_2$ of Phalebas in the E-W section are separated by a cliff. The height difference of $T_1$ and $T_2$ is about 65 metres. The $T_2$ extends for nearly about 5 km from the confluence of Modi and Kali Gandaki upto the confluence of Lamai Khola and Kali Gandaki. As such this terrace forms the southern continuation of $T_2$ terrace flats of Kusma, Gyandi and Balewa, at present having been dissected and separated by the deep gorges of Kali Gandaki and Modi. The average E-W extension of $T_2$ terrace at Phalebas is roughly $1\frac{1}{2}$ km.

The $T_3$ flat is not so well developed on the eastern bank of Kali Gandaki, except to the south of the Kali Gandaki-Modi confluence, where it lies about 5 to 10 metres above the river bed, is fairly extensive. Along the western bank of Kali Gandaki, at Jyamir Ghat, this terrace is very well developed (Plate No.VIII.13 & 14). Remnants of older terraces are found in the gently sloping landscape of the villages of Thapathana, Silme and Bajakhet along the western bank of Kali Gandaki opposite to Phalebas.

## Origin of Gravel Beds

The various terraces flanking the Kali Gandaki typically indicate the depositional and erosional phenomena related to the river itself during the Quaternary period. The huge pile of the gravelly material, dissected into successive levels, reveals a series of tectonic changes that affected the morphology of the Kali Gandaki valley. Unlike the extensive plains of Pokhara and Kathmandu, the gravel beds of Kali Gandaki valley, form somewhat narrow linear terraces, showing obvious genetic relationship with the main river as well as the various major tributary streams. In order to properly understand and evaluate the significance of these Quaternary deposits, one has to go back in time and understand the overall drainage pattern of Nepal Himalaya.

A generalised picture of the drainage pattern of Nepal (Fig. VIII.11), shows that most of the rivers including Kali Gandaki originate from the Tibetan Marginal

Range, north of the Greater Himalaya. These rivers cross the Greater Himalaya through the deep narrow gorges and flow due south. This is a clear indication of the ancient origin of the main drainage of Nepal. Thus it is obvious that the Greater Himalaya, south to the main watershed attained their existing heights only after the main drainage was established (Hagen, 1969; Weger, 1937; Fuchs, 1967; Fuchs & Frank, 1970; Wadia, 1975; Holmes, 1965, etc.). The river-cutting kept pace with the gradual rise of the Greater Himalaya.

After crossing the Greater Himalaya, most of the rivers including Kali Gandaki maintain their southern course till they encounter the Mahabharat Range. Here most of these rivers abruptly changes their course nearly at right angles, and flow either E or W along the length of the country until they cross the Mahabharat Range. This deflection of the Nepalese rivers in front of the Mahabharat Range, according to Hagen (1969), was due to the rise of the Mahabharat Range during the late Pleistocene time. He further states that (op.cit. 1969, p.150) "this rise was a relative one; we do not know how much the northern area sank relative to the main Mahabharat Lekh. But the fact remains that a mountain range rose to the south of the Midlands, thus forming the Midlands and giving it a natural barrier to the south".

"The original rivers, which had so far been following directly southwards found their way out of hills dammed. They chose a way along the northern foot of the Mahabharat range in areas of weakness, and crossed through the Mahabharat Lekh in zones weakened by tectonic events. Some of the big transverse rivers found in their longitudinal course (east-west) an easy path for erosion mainly in the Midland anticline. This anticline had by its fault like character destroyed the rocks considerably". This supposition of Hagen is further strengthened by the presence of Upper Siwalik conglomerates in front of the southern prolongations of the present big rivers from the kink point (Fig. VIII.11).

Thus, it was this phenomenon of the damming of south flowing rivers that was responsible for the aggradational process in the Midlands of Nepal, and it was during this period of aggradation that several lakes were formed in the Midlands of Nepal (Hagen, op.cit.), which are now being represented as big valleys sandwitched between Mahabharat Range and the Greater Himalaya, e.g. Kathmandu valley, Pokhara valley, Tilla valley etc.

The Kali Gandaki, on which the present discussion dwells, also originates in the Tibetan Marginal Range in Mustang, north of Dhaulagiri and Annapurna mountains (both exceeding 8000 metres), and crosses the Greater Himalaya through narrow gorges. The transverse course of the Kali Gandaki is maintained till it drops into the Midland anticline near Riri Bazar, where it aligns itself parallel to the Midland anticline and collects a number of tributaries, major and minor, before crossing the Mahabharat Range at Dev Ghat.

The formation of the huge pile of the gravelly material in the form of distinct terraces along the Kali Gandaki is also attributed to this process of the damming of the river. The author has thus visualised one single period of gravel deposits, the upper limit of which broadly is marked by $T_1$ terraces. The entire thickness comprises a valley-fill deposit, having accumulated in lake-like water bodies all along the river on account of the sudden drop in the velocity of torrential flowing waters. A perusal of the terrace map of the study area, clearly shows that the extent and configuration of the gravel deposits have been which controlled the successive events of aggradation and degradation. For this purpose, two 4th order stream longitudinal profiles were taken (Fig. VIII.3a,b), namely Malyangdi Khola and Lamai Khola which cut gravel materials before meeting the main river Kali Gandaki. Both the tributaries show a flat longitudinal profile at the height of 1133 metres to 1066 metres respectively for a length of 0.8 km tributary course. This section of the profile, if connected with the headward profile forms a concave pattern, and can be very well correlated with $T_1$ flats of Gyandi and Phalebas which show same heights. Lamai Khola shows one major break in its profile at the height of 1200 metres, which cannot be correlated with any of the terrace levels and the author suspects this feature to be either of very recent period or very old.

The flat profile formed between the heights 1133 and 1100 metres in Malayangdi Khola, and 1100 and 1066 metres in Lamai Khola suddenly drops down by 100 metres, forming a steep stream profile within a distance of 0.8 km, after which the streams again show very flat profile for more than 2 km in its course. This sudden drop of the stream profile is correlatable with the height of the cliff intervening $T_1$ and $T_2$, the flat profile with the $T_2$ level.

Again at the height of 900 metres to 833 metres, the stream profile suddenly drops by 166 to 200 metres within a distance 0.5 km. This drop is very well correlated with the cliff between $T_2$ and $T_3$. The break between $T_3$ and the present river level of Kali Gandaki is not reflected in the tributary profiles due to the scale taken.

If one looks to the nature of the breaks in the profile, one would notice that the periods of uplift were very mild during their initial stages but became more intense subsequently. It is also noted that the period of abrupt uplift culminated suddenly into a period of non-uplift, thus giving very flat profiles immediately after the sudden break, which in the gravels are represented as the vertical cliffs and flat terraces.

It is also noted that the major periods of uplift were themselves of oscillatory type, as there are occasional smaller terraces between $T_2$ and $T_3$, which represent relatively minor periods of non-uplift in the major uplift cycle. The breaks in the profiles of the tributaries, as well as the terrace disposition also point to the periods of uplift alternating with those of non-uplift. At least, three periods of major uplift are noticed with intervening two periods of non-uplift in the late Quaternary cycle of movements.

Another important neotectonic feature is the absence of any major tilting of the gravel beds. By and large, the deposited material still shows horizontality and it is presumed that most movements were broadly vertical.

## Nature of Gravel Beds

The huge gravel deposits of Midland Nepal, have intrigued most of the previous workers, and there has been considerable diversity of opinion. Though all agree that the aggradation of this material, was due to the rise of tectonic barriers in the south, some difference of opinion prevails regarding the nature of the depositing agencies. Quite a few (Glennie & Ziegler, cf. Gurung, 1970) believed that the deposition of the gravel beds could be attributed to the normal processes of transportation and deposition by water, but some workers have invoked climatic factors involving glacial or fluvioglacial processes. Hagen (1969), described the Pokhara Gravel beds as comprising accumulation in a lake, filled up by the scree from the nearby Annapurna Range, and according to him, the top bouldary layer consisted of morainic material, resting over normal river alluvium. Gurung (1970) also believed in a combination of ice and water, and suggested the importance of tectonic processes, aided by climatic factors. He has considered the Pokhara valley deposits, to be a legacy of a periglacial past. Fort (1976) has worked on the Quaternary deposits of the Middle Kali Gandaki Valley. She did not believe that the gravel beds of the Kali Gandaki Valley comprised products of a single period of deposition. She has described three basins north of Kusma viz. Kusma, Ghasa and Thak Khola basins, each characterising distinct depositional processes. According to her (1) the Kusma Type (to which belong the gravel beds of the study area) represented valley fills of fluviatile nature, (2) the Ghasa Type pointed to a combination of glacial, alluvial and colluvial processes, and (3) the Thak Khola Type conprised lacustrine accumulation.

So far as the gravel beds of the study area are concerned, the following characters have to be taken into account while considering their nature and mode of origin:-

(1) Uniformity in material and in grain size variation over large areal extent from north to south.

(2) Lack of proper sorting.

(3) Unstratified nature.

(4) Abundance of angular to sub-rounded boulders of Dhaulagiri limestone and gneisses of the Main Central Region.

The present author envisages deposition of the gravel material, by a process of river deposition, where the debris mostly provided from the north had a glacial origin. The study area itself, does not provide any indication of glaciation and it is therefore presumed that this part of the Kali Gandaki valley was never subjected to any glacial action, but the glaciation further north actually contributed in the process of gravel accumulation.

The damming of the river course due to the uplift of the Mahabharat Range took place in the Late Pleistocene period, when the Midlands were practically free from glaciation, but the debris which accumulated in the stagnant water bodies all along the river course, dominantly comprised material of glacial origin coming from the north. The rapidly melting glaciers in the Higher Himalaya further north, must have been feeding the Kali Gandaki and other similar rivers, with torrentially flowing water that carried huge quantities of morainic and other ~~glacial~~ material. The steep gradient from north to south, ideally provided the high energy for the flowing water. It was the accumulation of such fluvioglacial sediments that gave rise to the gravel beds. Considerable non-glacial material (mainly fluviatile, scree etc.) was also added to the site of accumulation by the agency of various tributaries draining the adjoining Midland areas. Thus he has concluded that the gravel beds of this part of Kali Gandaki valley, mainly consist of glacial and fluvioglacial deposits, having been transported southward by the fast moving waters of Kali Gandaki.

The Quaternary gravel beds of the Midland Nepal can, on the basis of their location and nature of accumulated material can be classified into two categories, viz. one identical to those of the study area, and the other where the processes were exclusively lacustrine with little addition of glacial material from the north.

The origin and accumulation of the various gravel beds of Midland Nepal, have to be viewed in the light of the above considerations. No doubt, the initiation of the process of gravel accumulation was due to the uplift in the Mahabharat Range, damming the various south flowing rivers, but the actual process of deposition and the nature of the debris depended on whether the material came from the snow-fed rivers from the north or consisted of material accumulated by the various smaller streams draining the Midland areas all around and dumping the material in the stagnant water bodies. To the former category, thus belong the terraced gravel deposits of Kali Gandaki and Pokhara while the lacustrine to fluviatile deposits of Kathmandu Valley comprise the latter.