CHAPTER IX

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

Introduction

Inspite of its being one of the unique river valleys of Nepal and comprising varied geomorphic features, very little geomorphological work in the Kali Gandaki valley has been done in the past. Detailed gecmorphic studies are essential in understanding one of the most important aspects of Himalaya - the neotectonism. The flat step-like terraces of the river, the sudden uplift-breaks in the river profile, the young stage of topography and the very deep gorge cut by the fast flowing river are some of the clear indications that the Himalaya is still active, and the readjustment process of this part of the earth is still continuing. Study of geomorphology in detail thus provides important clues in the assessment of these recent activities in the Himalaya.

The author, during the present investigation around the villages of Palebas and Bihadi in the Kali Gandaki valley section, therefore, thought it worthwhile to study the main geomorphic features of the area. The river terraces were studied in detail. The drainage analysis and slope analysis were carried out and then an attempt was made to extend these studies to understand the neotectorism of this part of Himalaya. It has also been attempted to study how much the morphology and morphometric parameters of the drainage basins are being controlled by the tectonism and lithology and the combination of the two.

Method of Investigation

In addition to the intensive geological and geomorphological studies of the study area around the Phalebas - Bihadi villages, a N-S traverse was taken from Baglung in the north to beyond Bihadi in the south along the Kali Gandaki river valley. The total area selected for geomorphic and morphometric analysis includes about 475 sq km. The base map utilised for the morphometric and slope analysis was a Four Inch to a Mile scale map enlarged from the original one Inch to a Mile scale

(1 : 63,360) Survey of India toposheet. The result of these studies are therefore, limited to the degree of accuracy of the scale and contour levels of the original map. The stream orders were designated following the method of Horton (1945) and modified by Strahler (1956). Slope map is prepared following the method of Strahler (1956) with the direct slope angles plotted and contoured instead of the sine or the tangent of the angles.

DRAINAGE STUDY

Morphology of the Drainage Basins

The morphometric characters of a basin are directly related to the lithology and structures of the area. Therefore, the variations in lithological characters, dip and strike of the beds, prominent joints, fold axes, thrust planes etc. are very important in the evaluation of the morphometric parameters. The details of the lithological characters of the rocks and the structural geology have been described in detail in the preceeding chapters, and therefore, they are not repeated here.

For the sake of convenience, the area has been divided into three major divisions as under :

1. Kali Gandaki basin
2. Lamai khola basin
3. Seti khola basin

Kali Gandaki basin

A significant portion of the investigated area is occupied by the Kali Gandaki river valley (Fig. IX.1). It is a wide and deep valley, flowing from north to south. In the upper part of the area, the river flows almost in a southerly direction upto Sirkang village and from Sirkang onwards, it takes a south-westerly trend till Bihadi. At Bihadi, the river makes a sudden curvature with its convexity to the west, and after the Seti khola confluence, it again reverts to its N-S trend and flows due south. The widest portion of the valley within the study area is at Phalebas and Bihadi, where they have also developed wide and extensive river terraces. The river flows in the valley bottom about 200 to 300 meters below the river terraces forming steep walls on both sides. The gradient of the valley is very low.

The basins of 3rd, 4th and 5th orders which directly meet the Kali Gandaki valley have been designated as the sub-basins of Kali Gandaki. Eight such sub-basins are taken into account for the morphometric analysis (Fig. IX.1). There are one 5th order, five 4th order and two 3rd order sub-basins.

Size of the basins vary considerably. The sub-basins A, C and D are essentially confined to one single lithological subdivision of Sirkang Unit (Sumsa Formation). The Sub basins C and D are having nearly a triangular shape. Sub-basin B drains the terrain consisting more than one rock type. The NW-SE trending sub-basin E,unlike other sub-basins, is having an elongated shape. It forms deep valley with scarps on both sides before meeting the Kali Gandaki river. This sub-basin predominantly flows in the slate-phyllite-graywacke rocks of Sumsa Formation but near its conflcence with Kali Gandaki, it also drains a small part of the dolomite terrain (Phoksing Dolomite). The sub-basin F is more or less confined in the dolomite rocks whereas, G and H exclusively drain the Bihadi Slates.

Lamai khola basin

The Lamai khola basin roughly trends in E-W direction and consists of two main streams- the Chirdi khola and Lamai khola (Fig. IX.1). They meet each other very near to their Kali Gandaki confluence. Chirdi khcla originates from the Chisapani lekh (2263 m) nearly at the height of 2100 meters. Before meeting Lamai khola, for abcut two kilometers it has a low gradient and forms flat valley bottom with the development of its own terraces. It cuts deep into the Kali Gandaki gravel deposits before joining the main Lemi khola stream. Lamai khola which originates from Bhalu lekh near Karkineta is the major stream of Lamai khola basin. The gradient of this main channel is steep near its source, but after covering about half of its course, the gradient becomes quite low, and forms wide flood plains and terraces of its own, a little east of the Phalebas village. But, as soon as it enters the gravel deposits of the Kali Gandaki, the gradient abruptly becomes higher and cuts deep into it forming gorge of more than 200 meters before meeting Kali Gandaki. Over all, the major portion of the Lamai khola basin lies to the north of the Phalebas Thrust.

Lamai khola basin is divided into four sub-basins as A, B, C and D. All the four sub-basins lie to the north of Phalebas Thrust except basin A which partly lies in the Southern Unit. The sub-basin B which is wholly confined in the Kusma Unit lies partly in the Kusma Quartzite and partly in the Balewa Formation. The C and D sub-basins, however, lie totally within the Balewa Formation of Kusma Unit.

Seti khola basin

Next to the Kali Gandaki basin, the Seti khola forms the main drainage basin of the study area. This basin roughly trends in a NE-SW direction and meets Kali Gandaki at about 7 km SE of Bihadi at Seti Dobhan (Fig. IX.1). The size of the basin is more than twice the size of Lamai khola basin, though both of them are drained by 5th order streams. This basin is almost wholly confined to the south of Phalebas Thrust, and covers all the three major rock types of the Sirkang Unit. For some kilometers before meeting the Kali Gandaki valley, the Seti khola forms broad flood plains with terraces. Near Lame Deorali village, the area is highly affected by landslides and ~~hence,~~ the stream erosion is very high.

The Seti khola basin is divided into seven sub-basins nearly of equal drainage area. Sub-basins A and B are entirely situated in the dolomite with only a part of them lying outside it, whereas the sub-basins C and D occupy the purple slate-phyllite-graywacke sequence of Sumsa Formation. F and G sub-basins are essentially situated on dolomite terrain and E is covering more than one lithology.

Drainage Pattern

A glance at the overall drainage of the entire area (Fig. IX.1) shows that it is very well drained and the drainage is distributed uniformly throughout the area. But the drainage density varies to some extent from basin to basin, as a consequence of the lithological control. The drainage network in the area shows a dendritic to sub-dendritic pattern. The drainage density is higher in softer rocks than in the hard rocks.

Slope Studies

A slope map of the area has been prepared to show the general configuration of slopes that are developed during the course of geomorphic evolution of the region. The slopes of the area have been grouped into seven categories as under (Fig. IX.2):

$< 5^{o}$

$5^{o} - 10^{o}$

$10^{o} - 20^{o}$

$20^{o} - 30^{o}$

$30^{o} - 40^{o}$

$> 40^{o}$

cliffs

A study of the generalized slopes within the basin of Kali Gandaki (Fig. IX.2.) reveals three main categories, according to the position in the landscape:

1. the crests of the ridges
2. the hill slopes
3. the valley bottoms.

The crests of the ridges which mark as the drainage divide between different basins and sub-basins, show a wide range of slope angles. The ridge dividing the drainage of Kalung khola in the north and Chaur khola and Lunwa khola in the south, runs in the ENE-WSW direction. The slope of the ridge is towards ENE and the angle of slope ranges from as low as 5^{0} to as high as 40^{0}, at some places. But the slope angles between 10^{0} to 40^{0} are most frequent, and cover a larger area. The ridge separating the drainage of Seti khola basin and Kali Gandaki also shows much variation in the slope angles. But mostly the slope does not exceed 20^{0}, only with some exceptions which range upto 40^{0}.

The hill slopes constitute a major portion of the area. It can be observed in the slope map that appreciable portions of the valley slopes are covered by the slopes of more than 40^{0} , e.g. in the valley slopes of Chaur khola, Lunwa khola, Palung khola, Khahare khola and Bachha khola. The maximum slope angle obtained in the valley slopes is 54^{0}. However, the larger proportion of the slopes are characterised by the angles between 20^{0} - 40^{0}. Less frequently, the slopes of 10^{0} - 20^{0} are also observed.

The slope of the valley bottom when taken from its source to the point of confluence with the higher order stream, again shows much change. As would be expected, the upper sector of the stream valley starting from its source or from the uppermost first order stream, shows very high angle of slope predominantly more than 40^{0} and sometimes as high as 45^{0}. But when, it descends ~~down~~, near the middle part of the valley bottom, the slope gradually comes down to 10^{0} - 20^{0} and finally towards the end of the valley, the slope angle is reduced to low values- less than 5^{0} to a maximum of 10^{0}. Pain khola for quite a considerable distance before meeting Kali Gandaki, runs in a valley slope of less than 5^{0}, whereas the hill slopes in the same areas have the slope angles of 40^{0} and more.

Morphometric Analysis

The author selected three main basins of the area for detailed study of drainage characteristics. These basins have been further sub-divided into smaller sub-basins of various orders. Out of the total nineteen sub-basins of all the three basins, one is of 5th order, fourteen are of 4th order and four are of 3rd order (Fig. IX.1). Only four sub-basins out of these lie within more than one rock units and rest are more or less confined to single rock unit and hence, make possible for the correlation of the morphometric parameters between the different sub-basins.

The morphometric parameters investigated for each sub-basins include the linear, areal and relief aspects. Among the linear aspects, the relationship of various stream orders (Horton, 1945, modified by Strahler, 1956) with the number of channels and stream lengths have been investigated. The smallest finger-tip tributaries are designated as first order. Where the two first order channels join, the channel segment of second order is formed and so forth. The channels of higher order may also receive the drainage of the smaller order.

The ratio between the number of segments of a given order to the number of segments of the next higher order gives the bifurcation ratio. Weighted-mean bifurcation ratio (Strahler, 1953) is obtained by multiplying the bifurcation ratio for each successive pair of orders by the total number of streams involved in the ratio and taking the mean of the sum of these values. This is more useful than the bifurcation ratio. Because of chance irregularities, bifurcation ratio between successive pairs of orders differs within the same basin and therefore, the weighted-mean bifurcation ratio gives more representative value. The mean stream length of a channel segment is the cummulative lengths of all the channel segments of that order divided by the number of such segments.

Amongst the areal aspects of the drainage basins, the catchment area for the channels of different orders are measured to investigate their relationship with the various orders of channels. The quantitative expression of the basin shape is expressed as elongation ratio (Schumm, 1956) which is defined as the ratio of the diameter of a circle of the same area as the basin, to the maximum basin length. The drainage density is the ratio of total channel segment lengths cummulated for all orders within a basin to the basin area as projected on the horizontal plane. The stream frequency (Horton, 1945) is the number of stream segments per unit area and which measures the texture of the drainage net, has also been calculated for the various sub-basins.

Amongst the relief aspects, the channel gradient, maximum basin relief (elevation difference of lowest and heighest points of a basin), relief ratio (Schumm, 1956) have been calculated. The relief ratio is defined as the ratio between the total relief of a basin (maximum basin relief) and the longest dimension of the basin parallel to the principal drainage line. It is a measure of overall steepness of the drainage basin.

Kali Gandaki Basin

Kali Gandaki basin which drains major part of the study area is the highest order drainage basin of the region. It also receives many lower order streams from both sides of the valley, which range from the 1st order to 5th order streams within the present area, and some still higher order streams are present in other parts of this basin. The number of 5th order basins within the limits of the study area are comparatively less, and only three such 5th order basins are studied which join Kali Gandaki viz., the Lamai khola and Seti khola from the left side and Palung khola from the right side of the valley. Out of these three 5th order basins, Lamai khola and Seti khola are taken as separate basins for the morphometric analysis as they have quite large drainage area and form within themselves a number of smaller sub-basins of 3rd and 4th order. Therefore, these basins are dealt with separately. The Kali Gandaki basin passes through all the lithostratigraphic and tectonic units of the area.

Drainage

The morphometric parameters determined for all the eight sub-basins of Kali Gandaki are given in the accompanying table (Table IX.1).

The bifurcation ratios of all the sub-basins when compared, show that the third order basins like A and H have very high values. The weighted-mean bifurcation ratio of A is 9.5, which is very high compared to the mean values. The sub-basins of 4th order and 5th order do not show such high value and they range between 3.3 and 4.7. The high bifurcation ratio is attributed to the (?) immature nature of the sub-basins. Due to the sudden termination of the basin limit by the Kali Gandaki valley, the sub-basin A has very small length of the highest order stream section, which is even less than the average length of the first order streams. The drainage densities of the sub-basins vary from 2.1 to as high as 4, and the common values being 3.1 to 3.9. The drainage density of this

Index for tables IX.1, IX.3 & IX.5

1. Channel order
2. Number of channels
3. Total drainage area (sq km)
4. Average drainage area (sq km)
5. Bifurcation ratio
6. Stream length ratio
7. Total length (km)
8. Average length (km)
9. Total length of streams of all orders (km)
10. Weighted mean bifurcation ratio
11. Total drainage area of the sub-basin (sq km)
12. Drainage density
13. Length of the basin (km)
14. Maximum basin relief (m)
15. Stream frequency
16. Elongation ratio
17. Mean stream slope (m per km)
18. Relief ratio

area is typical of the hilly terrain having moderate to high rainfall, the minor variation is due to the differences in lithology. Hard rocks tend to give lower values of drainage density as compared to the softer rocks.

Longitudinal profile

The longitudinal profile of the Kali Gandaki river is prepared between the sector Theule khola in the north and Seti khola to the south (Fig. IX.3A). The drop in vertical height is only 135 meters in a horizontal distance of about 28 km (1 : 207) which shows that the river has reached nearly a mature stage, There are no visible breaks in the profile unlike other stream profiles of its own tributaries (Fig. IX.3B, 4A, 4B). Even in the vicinity of the Phalebas thrust, there is no profile break. It may probably indicate that the fast erosional activity of the river far exceeded the amplitude of the tectonic rejuvenation or perhaps the scale of the profile does not reflect the breaks.

Analysis of Drainage Channels

The set of points obtained when the numbers of the streams of each order are plotted on a logarithmic scale on the ordinate against order numbers on an arithmetic scale on the abscissa, show a straight linear relationship atleast for the lower order streams (Fig. IX.5). This confirms Horton's

(1945) first law; the Law of Stream Number.

However, as shown by the plots of the channel order vs. number of channels of various sub-basins, out of eight only two show linear relationship for all the orders. But in rest, the highest order streams do not observe this rule and hence, form a up-concavity at the lower end. Schumm (1956, P.603) too observed similar deviation from first law of Horton and pointed out that though there is general agreement with the Horton's first law, the geometric progression is not closely observed in the higher orders.

The plots of channel order against average length, obviously do not show the linear relationship so well, and sometimes they are even randomly distributed (Fig. IX.6). Out of the eight basins, four show somewhat linear relationship, but rest do not show any regularity. Thus the second law of Horton (1945, P.291); the Law of Stream Length regarding the composition of stream drainage net are not followed satisfactorily by the streams of the Kali Gandaki basin.

Chansarkar (1974, P.80) also found that the streams of the sub-basins of Kosi, do not confirm in most of the cases, the second law of Horton. He gives the following two explanations for such deviation from the general law :

1. Before these smaller order channels unite with the next higher order within their own catchment, they attain a higher stream frequency and form a small basin controlled by joints and higher relief, pointing towards an indirect tectonic rejuvenation.

2. It is also probably due to the length of a second order stream being taken from the confluence of two first order channels, and its headward continuity being not considered.

The plots of channel order vs. drainage area also do not show a linear relationship (Fig. IX.7). This deviation too may be explained as above in the case of channel length.

Lamai Khola Basin

Lamai khola basin, situated in the NE corner of the study area almost exclusively lies in Kusma Unit situated to the north of Phalebas Thrust. It is a fifth order basin with a basin area of nearly 50 sq km and a maximum length of 11.4 km along the E-W direction. Four sub-basins of Lamai Khola have been selected for the morphometric analysis, out of which three are of 4th order, and one of 3rd order. The basin meets the Kali Gandaki river just south of Phalebas village.

Analysis of drainage channels

The drainage analysis has been carried out for the sub-basins which drain almost 3/4th of the basin area. The morphometric parameters of the Lamai khola basin as a whole is shown in table IX.2. The morphometric parameters of all the four basins are given in the accompanying table (Table IX.3). The orders of the drainage channels against the number and average lengths are plotted on the semilog paper (Fig. IX.8,9). As in the case of sub-basins of Kali Gandaki, here too, the linear relationship of the channel orders and number of channels, is shown only by the smaller order streams, the highest order streams show the deviation forming a concavity upwards at the lower end. Out of the four basins, only one shows a near linear relationship and the rest do not strictly follow Horton's first law. The second law of Horton is also not observed by streams of sub-basins of Lamai khola (Fig. IX.9). Similarly, the plots of channel order vs. average drainage area (Fig. IX.10) do not show the linear relationship. This may indicate the instability in the basin, and that the Lamai khola has not reached to its equilibrium position to follow Horton's laws. The location of the basin near the vicinity of Phalebas Thrust must have also influenced the basin character to some extent.

The drainage densities of the sub-basins of Lamai khola are higher as compared to the other basins, ranging from

Table IX.2 Morphometric parameters of Lamai Khola basin

Total basin area	:	49.21 sq.km	
Order of the basin	:	5th order	
No.of sub basins	:	4	
Total 1st order streams	:	190	113.25 km (cummulative length)
Total 2nd order streams	:	46	27.05 km " "
Total 3rd order streams	:	10	10.54 km " "
Total 4th order streams	:	3	8.51 km " "
Total 5th order streams	:	1	0.64 km " "
Highest level	:	2262.53 m	
Base level	:	609.6 m	
Elongation ratio	:	0.68	
Total length	:	11.43 km	
Stream frequency	:	5.08	

Table IX.3 Morphometric par

1	2	3	4	5		15	16	17	18
Sub-basin A (Chirdi Khola)									
1	44	9.39	0.21						
				4.4					
2	10	1.13	0.11						
				5.0					
3	2	0.20	0.10		3.3	4.66	0.59	202.06	0.21
				2.0					
4	1	1.50	1.50						
Sub-basin B (Khalti Khola)									
1	31	6.25	0.20						
				2.8					
2	11	1.84	0.17		3.8	4.74	0.69	239.16	0.239
				11.0					
3	1	0.97	0.97						
Sub-basin C									
1	20	3.47	0.17						
				2.8					
2	7	0.78	0.11		2.6	6.44	0.84	299.05	0.33
				3.5					
3	2	0.10	0.05						
				2.0					
4	1	0.32	0.32						
Sub-basin D									
1	28	5.34	0.19						
				4.0					
2	7	0.59	0.08						
				3.5	6.3	5.64	0.66	260.84	0.27
3	2	0.12	0.06						
				2.0					
4	1	0.69	0.69						

3.1 to 4.25. The drainage density is mainly controlled by lithology. Those basins which entirely lie within the softer rocks like quartzose phyllites and quartz-sericite-phyllites (sub-basins C and D) show higher drainage density values in comparison to the basins (A and B) situated in more than one type of lithology or mixed lithology. The weighted-mean bifurcation ratio varies from 2.9 to 4.5.

Longitudinal Profile

Longitudinal profiles of trunk stream of Lamai khola basin (Fig. IX.11A) and also of the streams draining the sub-basins have been plotted, (Fig. IX.12A, B). The Lamai khola profile which is about 13.5 km long shows atleast seven breaks in its profile indicating tectonic rejuvenation. The break near the Kali Gandaki confluence is due to the river terraces, where the stream cuts very deep into the gravel beds due to their comparatively softer nature. Towards upstream direction, the next sudden break in profile significantly coincides with the trace of the Phalebas Thrust. The fourth profile break numbered from the down stream side, marks the change of lithology. The part of the Lamai khola lying between the 2nd and 3rd break is relatively flat and forms wide valley. The down slope angle is very low and also the river terraces of Lamai khola are confined to this sector of the stream. Above the 4th profile break, there are atleast three more sharp breaks in the headward portion.

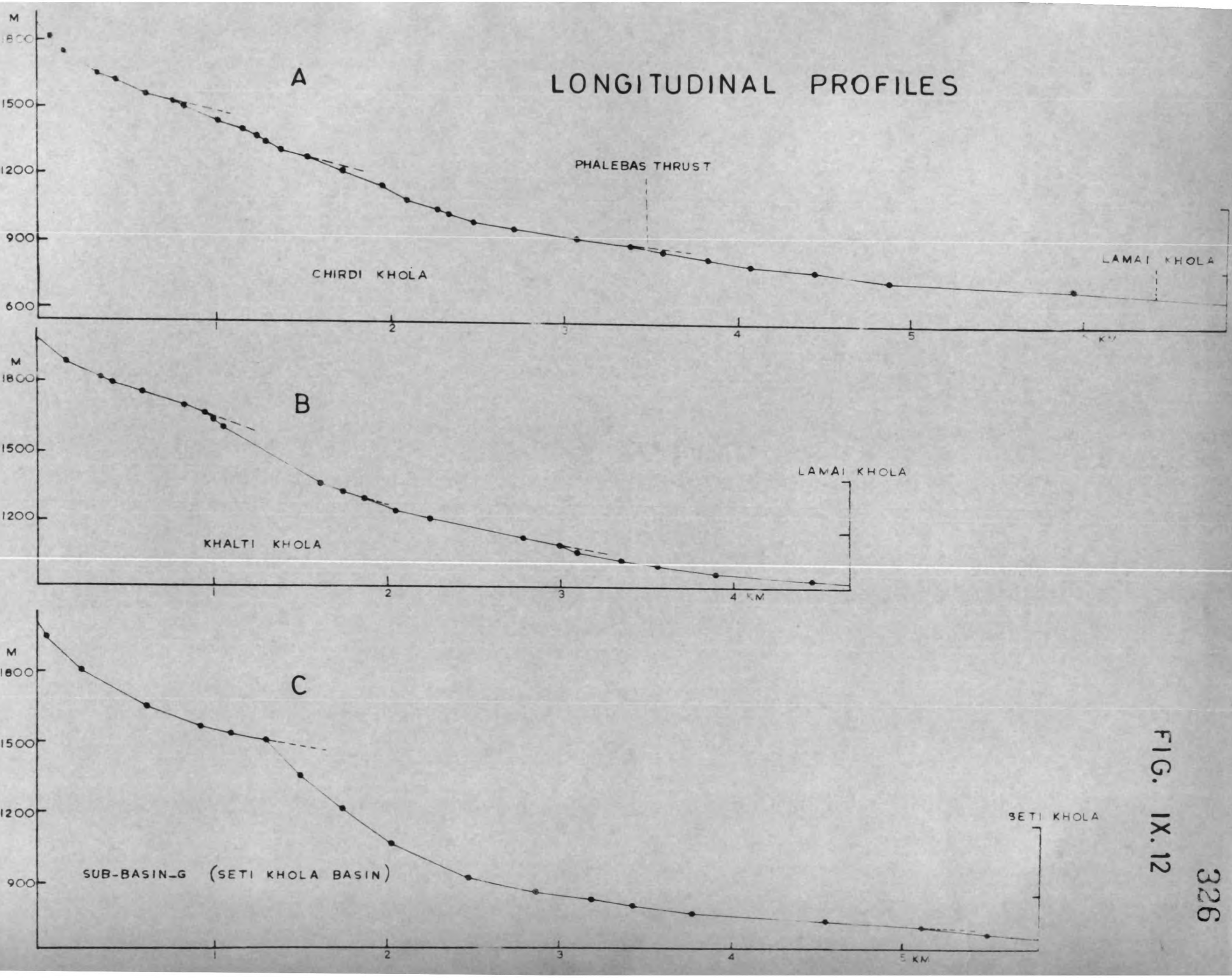

LONGITUDINAL PROFILES
A
CHIRDI KHOLA
PHALEBAS THRUST
LAMAI KHOLA
B
KHALTI KHOLA
LAMAI KHOLA
C
SUB-BASIN_G (SETI KHOLA BASIN)
SETI KHOLA
M
1800
1500
1200
900
600
1
2
3
4
5
KM

FIG. IX.12

The profile of the tributaries of Lamai khola also show similar breaks in profile lines. Chirdi khola (Fig. IX.12A), a main tributary to Lamai khola, which runs for about 6.5 km, shows 3 major breaks in the profile. One of the profile break, in the downstream side, roughly coincides with the trace of Phalebas Thrust as seen in the case of Lamai khola profile. Similarly, Khalti Khola (Fig. IX.12B) shows three breaks before meeting Lamai Khola.

<u>Slopes</u>

Lamai khola basin in contrast with the Kali Gandaki and Seti khola basins, is comparatively milder in topography and slopes (Fig. IX.2). Unlike in other basins here, the slopes with angles exceeding 40^{0} are quite restricted. The hill slopes are dominated by the slope angles between 10^{0}- 30^{0}. However, some parts are also covered by the slope angles between 30^{0}- 40^{0}. The river terraces of Phalebas form practically flat terrain and the average gentle slope towards the Kali Gandaki valley is less than 4^{0} , except a small N-S strip of slope dividing the higher (T_1) from the lower (T_2) terrace which has a slope angle between 5^{0} - 10^{0}. The slope of the valley bottom of Lamai khola varies in different parts. The headward portion has higher slope angles whereas for a length of 8-9 km from mouth upwards, the Lamai khola flows with a slope angle of less than 5^{0}. For a few hundred meters before meeting Kali Gandaki, the Lamai khola in the gravel deposits forms a higher slope angle than upstream. Chirdi khola runs for about 4 km with a slope angle of less than 5^{0} just before joining the Lamai khola. The upper part of the valley bottom of this stream however, has the slope angle as high as 40^{0}.

Seti Khola Basin

Seti khola mainly drains the south-eastern portion of the study area. The total drainage area of the basin is around 115 sq km , and the total basin length is 17.7 km. It is a 5th order basin with a total number of 365 1st order, 90 2nd order, 19 3rd order and 6 4th order streams (Table IX.4). Approximately one third of the studied area is covered by this drainage basin. The basin is divided into seven sub-basins, out of which six are of 4th order and one is of 3rd order. Except for a small part of the upper section of the basin which lies to the north of Phalebas Thrust, the larger portion of the basin is located in the Sirkang Unit.

Drainage

Each of the seven sub-basins of Seti khola were taken for morphometric analysis and the result is presented in table IX.5. These sub-basins lying in different lithological units show variations in morphometric characters. The weighted-mean

Table IX.4 Morphometric parameters of Seti Khola basin

Total basin area	:	115.095 sq km	
Order of the basin	:	5th order	
No. of sub basins	:	7	
Total 1st order streams	:	365	210.24 km (cummulative length)
Total 2nd order streams	:	90	57.24 km " "
Total 3rd order streams	:	19	32.03 km " "
Total 4th order streams	:	6	17.03 km " "
Total 5th order streams	:	1	15.13 km " "
Highest level of basin	:	2262.53 m	
Base level of the basin	:	518.77 m	
Elongation ratio of basin	:	0.72	
Total length of the basin	:	17.70 km	
Stream frequency	:	4.18	

bifurcation ratio varies from 3.5 to 5.6, the highest value being that of 3rd order sub-basin, the most common values lie between 3.5 to 4.6. The drainage density similarly show variations and ranges between 2.7 to 3.8. The variation of the drainage density is obviously due to the corresponding lithological variation. The sub-basins A, B, F and G which drain mainly the harder rocks like dolomite show lower values for drainage density within a narrow range of 2.5 to 2.9, while on the other hand, sub-basins C, D and E, occupying the area covered by comparatively softer rocks like purple slate-phyllite and graywacke sequence have higher values of drainage density which range from 3.1 to 3.8.

The plots of channel order vs. numbers and average lengths show the relationship similar to those of the earlier basins. But here in this case, the linear relationship is better maintained by most of the sub-basins. The plots of channel orders against number of channels (Fig. IX.13) show better linear relationship in case of the sub-basins B, D and G, without any up-concavity at the lower end. But the rest four do not closely observe this relationship for the higher order streams. The plots of channels orders vs. average lengths (Fig. IX.14) do not strictly follow the geometric progression in all the sub-basins. The second law of Horton is not thus, observed by the streams of these sub-basins. This law is more violated by the smaller order streams than by higher orders. The plots of like shales and slates, are dominantly occupied by 10^{0}-30^{0} slopes. The sub-basins D and E have slopes between 20^{0} - 30^{0} and a very small area is occupied by the slopes of 30^{0} - 40^{0}. A significant part of these basins is also covered by the slopes of 10^{0} - 20^{0}. The lower reaches of the valley of all most all the streams of the sub-basins are having the valley bottom slopes less than 5^{0}.

Comparison of Morphometric Parameters of various Sub-basins

The morphometric parameters of various sub-basins of the three major basins of the area are compared to show the relationship of these parameters with the lithological variations and structural discontinuity. In total, there are nineteen sub-basins that have been taken into account for the purpose of comparison, lying in different lithological units and structural set up. The comparision of the various morphometric parameters of the sub-basins reveal the variations in (1) bifurcation ratio and weighted-mean bifurcation ratio, (2) drainage density, (3) stream frequency, (4) relief ratio,(5) elongation ratio,(6) stream length ratio &(7) maximum basin relief.

The bifurcation ratio has been recalculated into weighted-mean bifurcation ratio following Strahler (1953). The values show considerable change from basin to basin. The values

They range from 2.9 to 9.5, but the most common values lie between 3.3 to 4.7. The exceptionally higher values of weighted-mean bifurcation ratio like 9.5 (Kali Gandaki basin, A) and 5.6 (Seti khola basin, B) are restricted to the 3rd order basins, whereas the 4th order and higher order basins have average values. It may be because the 3rd order basins have not reached their equilibrium position of drainage development in comparison to the higher order streams.

The drainage density, another important parameter of a drainage basin is the quantitative measure of the drainage of a basin in contrast to the qualitative expressions as poorly drained or well drained basins. According to Horton (1945, P. 283), the well drained basin has the drainage density more than 2.74. The drainage density of the sub-basins of the present study area varies from as low as 2.1 (Kali Gandaki, D) to a maximum of 4.3 (Lamai khola, C). Therefore, except only two sub-basins (Kali Gandaki, D and Seti khola, B), out of nineteen sub-basins, all are well drained. The most common values of the drainage density lie between 2.7 to 4.0. The variations in drainage density of the area obviously, as observed, is under the direct control of the corresponding change in lithology. The drainage density of the study area can be grouped into the following three main divisions:

(a) Low 2.1 - 2.9

(b) Medium 3.0 - 3.8

(c) High 3.9 - 4.3

These three divisions of the values of drainage density can be very well correlated with the different lithological units of the area. It is observed that the lower values of drainage density are found to be confined in the dolomite terrain (Seti khola basin, A, B, F) which is a hard rock compared to other rocks of the area. Secondly, the medium values of the drainage density are more or less restricted in the rocks of purple slate-phyllite - graywacke rock sequence of Sirkang Unit (Seti khola, C, D and E; Kali Gandaki, A and B). But sometimes they show lower values (Kali Gandaki, D) perhaps due to the predominance of arenaceous rocks and also due to their partial lying in harder rocks. Finally, the highest value of the drainage density is observed in the Balewa Formation of Kusma Unit (Lamai khola, C) which is a well foliated soft rock, and in the black shales and slates of Sirkang Unit (Kali Gandaki, G and H), in the extreme south of the area. The basins which lie in more than one lithological units tend to show an intermediate value.

The stream frequencies i.e. the number of channels per sq. km , vary from 3.1 to 6.9. But the average values are in-between 4.3 to 5.7. The stream frequencies do not seem to be much controlled by lithology as is the case of drainage density. Relief ratio which is a measure of overall steepness of the drainage basin has also been calculated. The values range from the minimum of 0.14 to as high as 0.42. However, the most common values are between 0.20 to 0.34. From this, it is evident that most of the drainage basins are having high steepness values, and there is a sudden drop of height from the head of the basin to its mouth within a very short horizontal distance. The sub-basins A and B of Seti khola show comparatively low values of relief ratio as the topography of this area is milder and therefore, the maximum basin relief is not very high and basin length too is more. The highest value of relief ratio is shown by the sub-basin H of Kali Gandaki which has 1526.7 m drop of height within a short horizontal distance of 3.6 km. The exceptionally short length of the basin before it reached to its mature stage is due to the abrupt termination of the sub-basin by the Kali Gandaki valley.

The elongation ratio an expression of the basin shape has also been determined. As the value of elongation ratio is nearing unity, the basin shape tends to be more circular in shape. The values calculated for various sub-basins of the present area, show that they range from a minimum of 0.5 to the highest value of 0.84. The most common values lie between 0.61 to 0.76. The values indicate that the basins are not very elongated, rather they are more or less of oval shape .

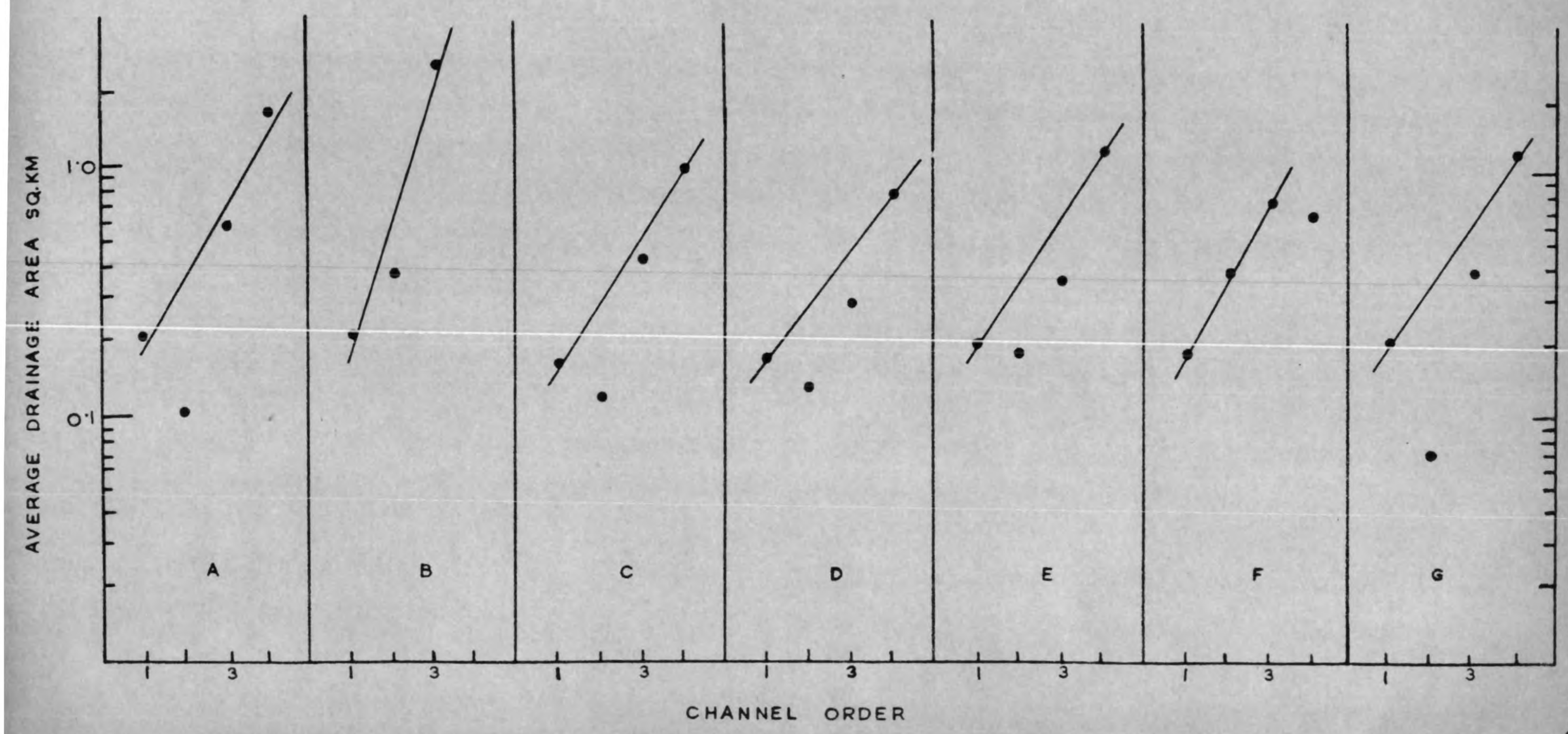
GRAVEL DEPOSITS

Neotectonism in Himalaya is now an established concept, and all over its length and breadth, various structural and geomorphic features amply illustrate the conspicuous level changes, gradual as well as abrupt, during the Pleistocene and Holocene times. Himalaya is still active, comprising a dynamic portion of the earth's crust. While the earlier events of the Himalayan orogeny that started sometimes during Cretaceous and attained maximum intensity during Miocene to Pleistocene periods, is 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 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 gravels deposited during the Quaternary times. Quaternary deposits of Himalaya, not only point to the geomorphic activity, but as well provide a measure of the nature and intensity of the neotectonic processes. The terraced gravel deposits of the study area between Baglung and Bihadi reveal geomorphic features that have got direct bearing on the neotectonism. From north to south, the successive terraces show variable development and at most places three distinct levels on either side of the deep gorges of Kali Gandaki and its major tributaries have been recorded (Fig. IX.16).

FIG. IX. 15

RELATION BETWEEN AVERAGE DRAINAGE AREA & CHANNEL ORDER

(SETI KHOLA BASIN)



channel order vs. drainage area (Fig. IX.15) also do not observe a linear pattern.

Longitudinal profile

The longitudinal profile of Seti Khola shows at least five profile breaks (Fig. IX.11B). The river originating at an altitude of about 2,000 m suddenly drops down to a height of about 1,000 m within a horizontal distance of only 5 km. Further down, the river profile follows a very gentle slope till it joins the Kali Gandaki valley. It is in this section of the river that it forms wide valley with river terraces. The stream profile of the sub-basin G (Fig. IX.12C) shows one very striking break, with a sudden drop of height, indicating a tectonic rejuvenation.

Slopes

The slope map of Seti Khola basin (Fig. IX.2) clearly indicates that the valley slope angles are essentially controlled by lithology. The dolomite terrain of sub-basin F and G exhibit higher slope angles than in other parts of the basin. Here the valley slopes are predominantly occupied by the slope angles between 30^{0} - 40^{0} and above 40^{0}. The area covered by the slopes between 10^{0} -30^{0} is very less. The valley slopes of sub-basins A and B which mostly lie in the soft rocks

RELATION BETWEEN NUMBER OF CHANNELS & CHANNEL ORDER

(SETI KHOLA BASIN)

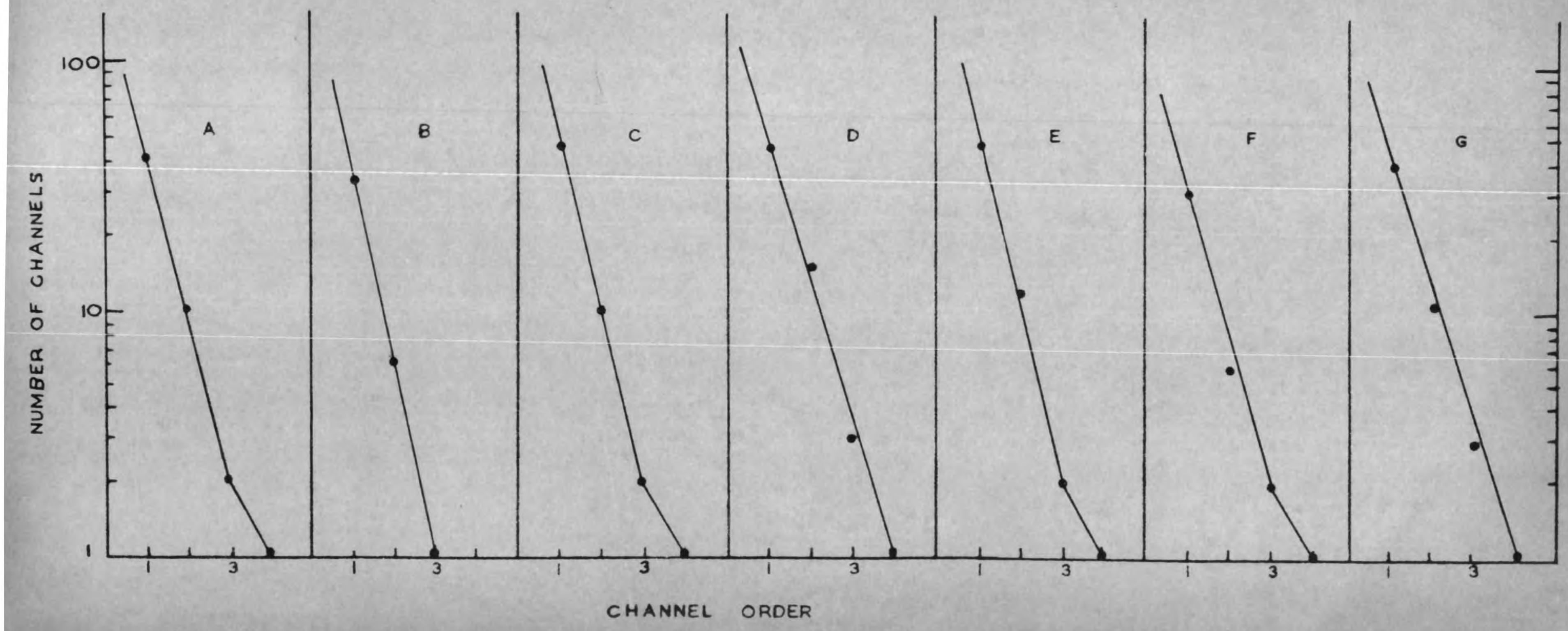
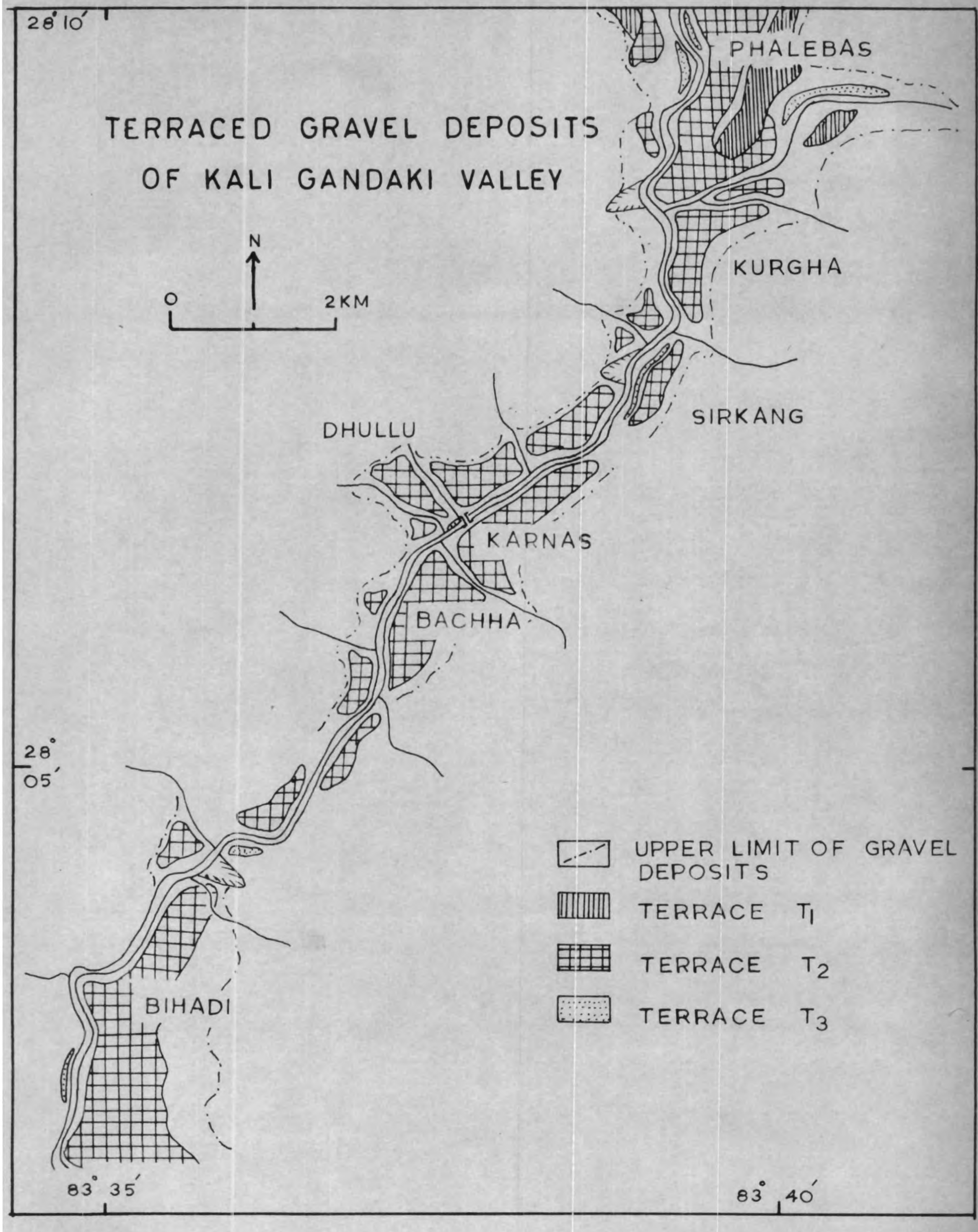


FIG. IX.13

FIG. IX.16



28°10′
TERRACED GRAVEL DEPOSITS
OF KALI GANDAKI VALLEY
N
0
2KM
PHALEBAS
KURGHA
SIRKANG
DHULLU
KARNAS
BACHHA
28°
05′
BIHADI
UPPER LIMIT OF GRAVEL DEPOSITS
TERRACE T1
TERRACE T2
TERRACE T3
83°35′
83°40′

Kali Gandaki and 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 the 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 (1^o or so) gradient, the terraces standing out as vertical to subvertical cliffs. The three levels on either side of the deep gorges of Kali Gandaki and Modi have an aggregate thickness varying from 300 to 500 m . These terraced gravel beds form extensively wide belts at the major stream confluences at Baglung (Kanthe Khola and Kali Gandaki), Balewa, Kusma and Gyandi (Modi and Kali Gandaki), Phalebas (Lamai Khola and Kali Gandaki), and Karnas and Bachha (Bachha Khola and Kali Gandaki).

Terrace Classification

The vast gravel material filling up the Kali Gandaki valley, point to an interesting genesis. Thick deposits, several hundred meters 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 to be followed by a series of tectonic events resulting into successive rejuvenation of the river. The net result of the various tectonic events are reflected in the carving out of the various terraces in the valley fill gravels.

The terraces have been classified and correlated mainly on the basis of following two factors:

1. Relative heights of the successive terraces. At most places, three well defined levels have been recognised. In cross sections the level of the terraces are almost identical, while in the longitudinal profile sections, the successive terraces show a progressive decrease in heights.

2. The size, composition and degree of compaction of the terrace material. It is composed of unsorted materials ranging from big boulders to sand and silt, and layering or bedding is inconspicuous at most places. The infilling matrix is impure calcareous material. At least, following three types of the gravel material - each typically diagnostic of the three terraces have been recorded :

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

Plate IX.1 A view of the erosional features in T_1 terrace. The comparatively finner material of T_1 is cemented by lime. Location: 0.5 km E of Phalebas viewed towards west.

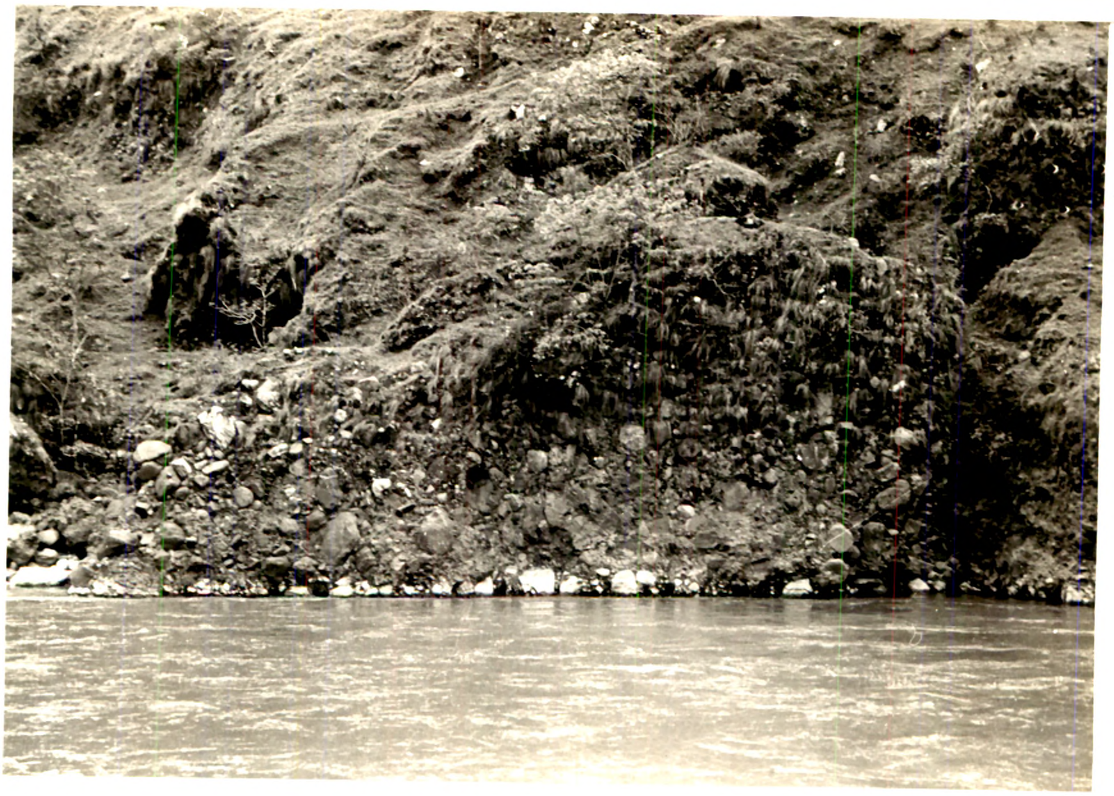
(b) The terrace material is identical to (a), but much coarser and highly unsorted i.e. the large fragments of gneiss, quartzite, Dhaulagiri limestone of bouldary to pebbly size and intimately mixed with finer material. The cement is calcareous and the gravels show well compacted nature. (Terrace T_2 , Plate IX.2).

(c) 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 300 to 400 m from the river bed (Plate IX.3). It generally shows an altitude variation from 1150 m (Balewa) to 775 m (Behadi in the south). The height difference between the T_1 and the the next lower terrace T_2 , varies from 25 to 60 m. At some places T_1 gradually slopes down to T_2 while at other places, steep scarps separate the two (Plate IX.3). The T_2 terrace is very well defined and well developed all along the river course. T_3 the lowermost terrace rises about 5 to 15 m above the river bed (Fig. IX.4) and at most places it rests directly over the rock benches, and this youngest terrace is least developed.

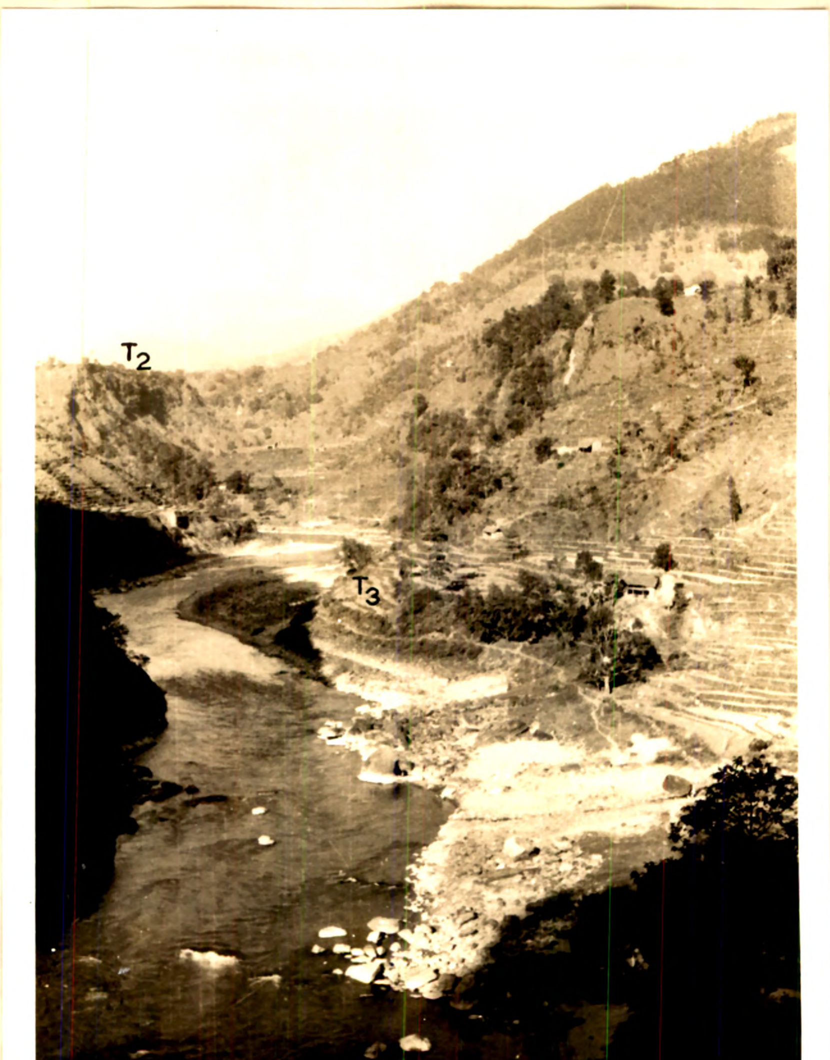
Plate IX.2 A view of the material of T_2 terrace. very coarse,highly unsorted bouldary material.

Location: At the right bank of Kali Gandaki Opposite of Kusma.




T1
T2
T2
T3

Plate IX.4 A view of the Kali Gandaki Valley showing development of T_3 terraces. Location: About 0.5 km N of Ragmas village. In the background is seen T_2 terrace of Kurgha. Viewed north from Ragmas.



T2
T3

The material of T_1 and T_2 , comprises one single depositional sequence, the coarser in the lower part (making up the T_2) and the finer in the upper part (making up the T_1).

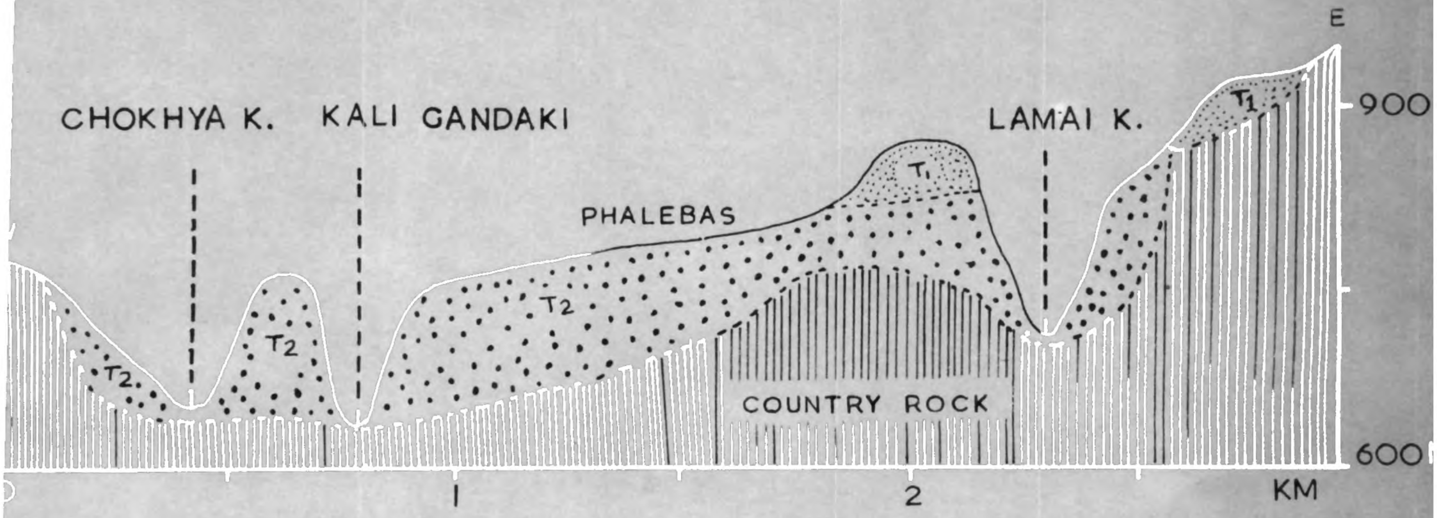
A brief area-wise description of terraces that are developed in the study area is given in the following pages.

Phalebas - Kurgha Terraces

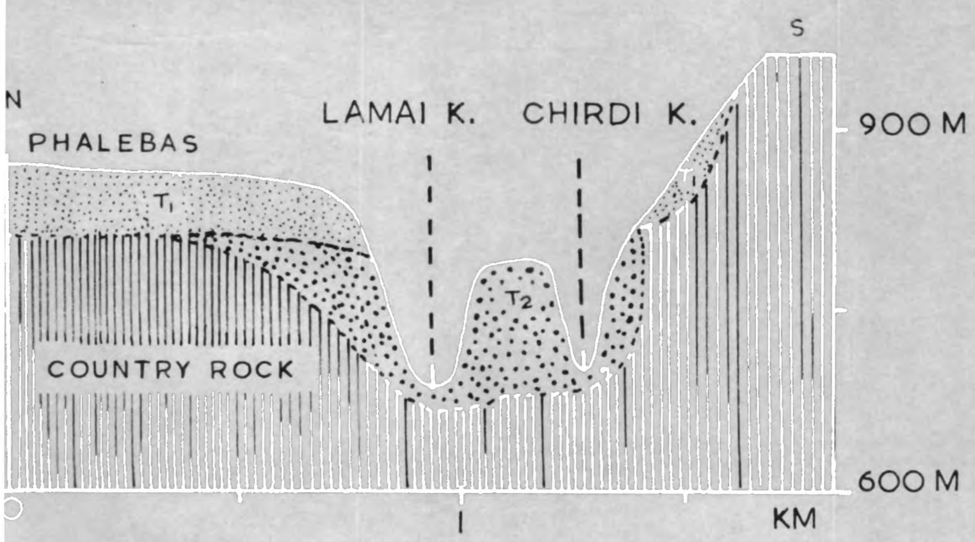
The extensive gravel deposit of Phalebas-Kurgha forms one of the many major terraces of Midland Kali Gandaki valley (Fig. IX.16). The terraces T_1 and T_2 are ideally developed in this sector. The cross-sections of the gravel deposits of this area (Fig. IX.17A , 17B) show the disposition of the T_1 and T_2 flats. The T_1 is separated from T_2 flat by a cliff of about 50 m. In the southern part, however, the T_1 flat gradually merges with T_2 . The Phalebas terrace extends towards north (from the Lamai Khola-Kali Gandaki confluence) for nearly 6 km uninterrupted. In fact, the Phalebas and Kurgha terraces were once continuous, and only later on they were dissected by Lami and Chirdi Kholas. In Kurgha, the T_1 terrace flat is not well preserved. On account of the somewhat looseness of the gravels of T_2 terrace due to leaching out of the carbonate cementing material, many depressions of a few meters to tens of meters diameter have developed in Kurgha - (analogous

FIG. IX.17

CROSS-SECTION OF GRAVEL DEPOSITS



A



B

T_1 – TERRACE T_1

T_2 – TERRACE T_2

to Karst topography). It is a common feature of T_2 gravel deposits to form numerous caves in its basal part.

Karnas - Bachha Terraces

Compared to the extensive gravel deposit of Phalebas and Kurgha to the north, the gravel deposits near Sirkang are very much constricted. Only small patches of terraces T_2 and T_3 have developed. To a little south, in the Karnas - Bachha area again, a wide belt of the terraces is developed. Mostly, the T_2 terraces have been well preserved, whereas T_1 terrace flats are nowhere found, though the uppermost boundary of the higher terrace could be marked on the basis of the nature of gravelly material. The T_2 terrace around this locality is about 6 km in length and lies at a height of about 930 m above M.S.L. i.e. about 250 m above the present Kali Gandaki river bed. This, once a continuous gravel terrace has been transversely cut by the Bachha khola forming a deep gorge near its confluence with the Kali Gandaki. The terrace T_2 around this area has a gentle slope towards Kali Gandaki (Fig. IX.18B) and forms a much less pronounced step like terrace.

The terraces on the west side of the river Kali Gandaki are less extensive than their counterparts in the east. Here also, T_2 is well developed forming paired terraces. T_1 flats are not developed, but their upper boundary could be easily demarcated. A very small patch of T_3 (lowest terrace, few meters above the river bed) is developed a little south of the Karnas bridge.

Bihadi Terraces

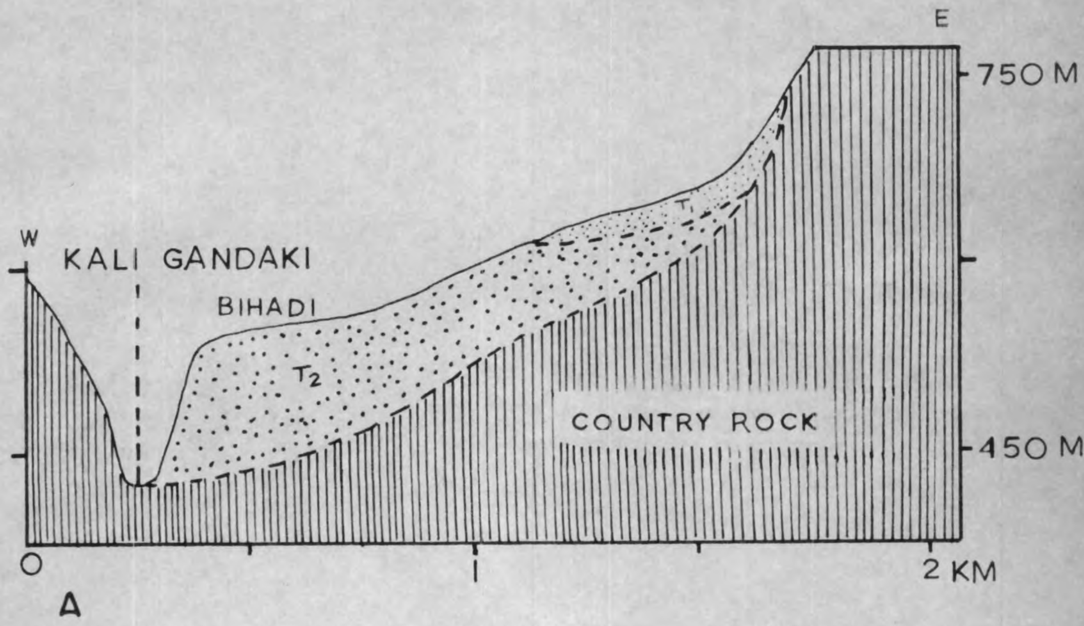
The wide development of terraces in Karnas-Bachha area pinches out at a place little south of Bachha village and is interrupted by a cliffy exposure of dolomite rock. In between Jimire and Sakuni villages, very narrow, unpaired and discontinuous T_2 terraces have developed. At places, a small deposition of terrace T_3 is also found.

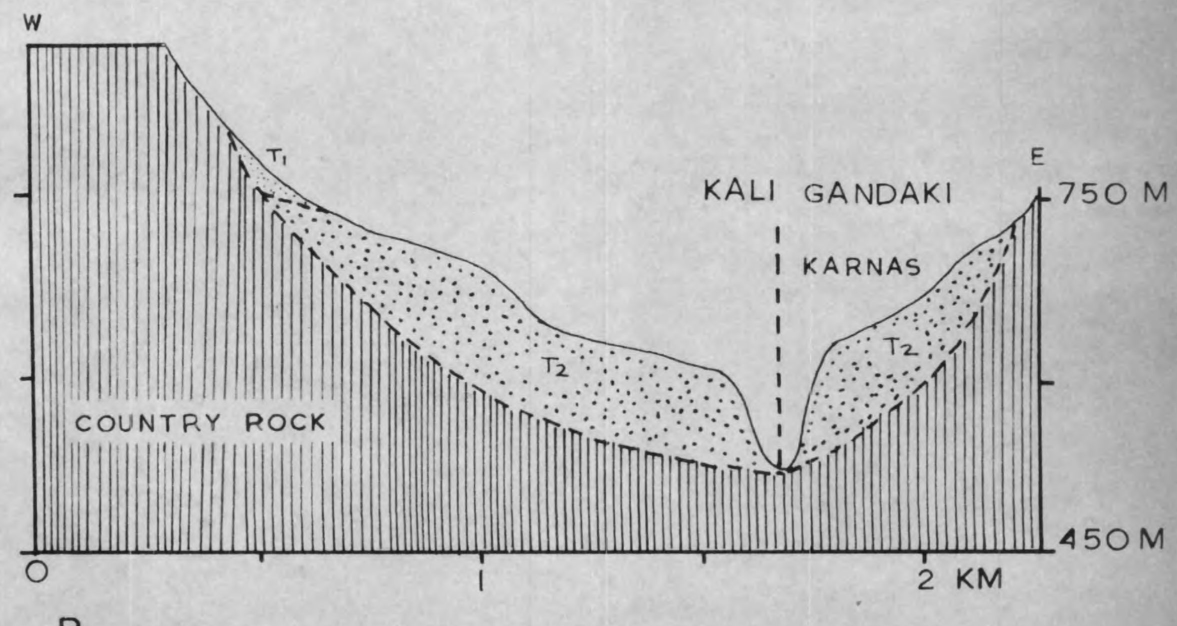
The vast T_2 terrace deposits of Bihadi starts from Sakuni southwards all along the concave side of the meander of Kali Gandaki (Fig. IX.16). This graval deposit is comparable with the Phalebas terrace in its extension. Except Khahare khola and very small seasonal tributaries no major streams cut this terrace at Bihadi. Like the Phalebas terrace, here also the terraces are unpaired and the gravel deposits are exclusively on the left side of the river. The length of the terrace is more than 8 km and maximum width is one km.

The T_1 terrace flat at Bihadi is not well developed. They show a very gentle slope towards Kali Gandaki river and imperceptively grades into the terrace T_2(Fig. IX.18A). The

FIG. IX.18

CROSS-SECTION OF GRAVEL DEPOSITS





T_1 – TERRACE T_1

T_2 – TERRACE T_2

highest trace of terrace level lies at about 800 m above M.S.L. The terrace flat T_2 ~~which~~ is at a height of nearly 600 m. (above M.S.L.) or about 200 m above the present river bed. Near Purti Ghat, there is a development of third terrace level which lies about 50-70 m below T_2 terrace having more or less same constituent material as T_2 . This terrace level is not developed in other areas so conspicuously, and appears to be a part of T_2 terrace itself. Near Purti Ghat bridge on either banks of the river, there is a development of T_3 terrace as well.

Profile Studies

A critical evaluation of the cross-sectional and longitudinal profiles of the Kali Gandaki and its main tributaries (Fig. IX.11, 12) provides information about the nature of the uplifts which controlled the successive events of aggradation and degradation. For this purpose, a few longitudinal profiles of 4th order and 5th order streams were taken, which cut gravel materials before meeting the main river Kali Gandaki.

The flat profile formed between the heights 1450 and 1200 m in Lamai Khola (Fig. IX.11A) suddenly drops down by 150 m, forming a steep stream profile within a distance of 1.5 km after which the stream again shows very flat profile for more than 3.7 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 corresponding with the T_2 level. Near Phalebas Thurst, the profile of Lami Khola shows a sudden break, possibly due to the effect of the thrust.

‾he 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. It is further observed that the periods of uplift were essentially of oscillatory type, as there are occasional smaller terraces between T_2 and T_3 (Bihadi), which represent the minor fluctuations with periods of relative non-uplift within the major uplift cycle.

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

Depositional History and Neotectonism

The various terraces flaking 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 deposits 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.

A generalised picture of the drainage pattern of Nepal (Fig. I.1) shows that most of the rivers including Kali Gandaki originates 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 (Wager, 1937 ; Holmes, 1965 ; Fuchs, 1967 ; Hagen, 1969 ; Fuchs & Frank, 1970 ; Wadia, 1975 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 (Fig. I.1). Here most of these rivers abruptly change 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 Range during the Late Pleistocene time. He (1969, P.151) further states that "this rise was a relative one; we do not know how much the northern area sank relative to the 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 flowing directly southwards found their way out of the hill 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."

The 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 points.

The Kali Gandaki originates in the Tibetan Marginal Range in Mustang, north of Dhaulagiri and Annapurna mountains (both exceeding 8000 meters), and crosses the Greater Himalaya through narrow gorge. 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 Deo Ghat. Thus, the phenomenon of the damming of south-flowing rivers was responsible for the aggradational process and it was during this period of aggradation that several lakes were formed in the Midlands of Nepal, which are now being represented as big valleys like those of Kathmandu, Pokhara and Tila, sandwiched between Mahabharat Range and the Greater Himalaya.

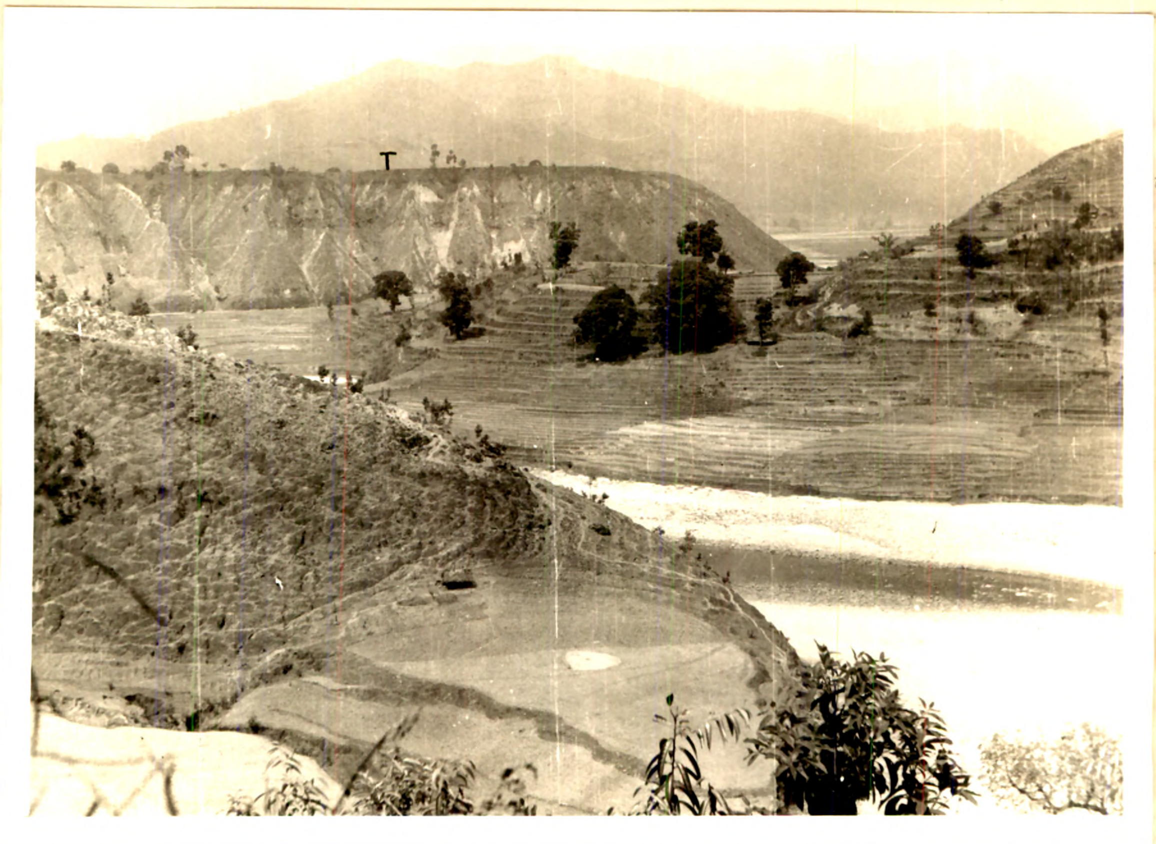
The formation of the huge pile of the gravelly material in the form of distinct terraces along the Kali Gandaki is attributed to the process of the damming of the river. The author has visualised one single period of gravel deposition, the upper limit of which is broadly marked by T_1 terraces. The entire 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 terrentialy flowing waters. The terrace map of the study area (Fig. IX.16) clearly shows that the extent and configuration of the gravel deposits have been controlled by the tributary streams, i.e. they are widest at the confluences.

Similar observations were also made by Holmes (1965) in Arun valley in Eastern Nepal where, gravel deposits which are quite similar to Kali Gandaki area have developed. He writes (Holmes 1965, P.598) "Like the Colorado river the Arun has not continuously maintained its course against the rising ground. Locally and at times it has been what Hunt would call an anteposed river. About half-way between the great gorge and the Ganges plain the Arun has cut a channel 500 ft deep through a broad plateau of sediments. These appear to be the infilling of a lake formed at a time when the uparching of one of the Middle Himalaya branches was sufficiently active to pond back the river untill it could spill over and resume its downward erosion."

The present author has also observed such thick gravel deposits in Buri Gandaki (Arughat area), Bagmati river (south of Kathmandu), Trisuli area (Plate IX.5). These gravel terraces are in many respect similar to the terraces developed in Kali Gandaki river valley and point to a similar mode of origin. The extension, thickness and steep cliffs on both banks are characteristics of all these river sections. A comparative study of such gravel deposits of different rivers would be of great value for better understanding of the neotectonic activity in Himalaya.

The formation of T_2 terrace is attributed to the rejuvenation of the river and the increase in the rate of flow, which in turn initiated processes of degradation again. As a result, the river excavated a valley within the gravel deposits themselves. During the next phase of relative quiescence, it is envisaged that due to shifting of the river course, it laterally

Plate IX.5 A view of the gravel deposit of Trisuli river. Note the terraced gravel deposit (T) cut by Tadi river (tributary to Trisuli) In the foreground flows a small tributary of Tadi Khola. In the far background lies Nawakot village at the hill top.


T

cut the gravels, and gave rise to the T_2 surface. Obviously, the T_2 material would represent the lower portion of the initial accumulation of the gravel beds, and this level is essentially a product of lateral erosion.

The existing configuration of the river points to another period of uplift and degradation. The associated T_3 level has somewhat different mode of origin. The unconsolidated material of this terrace, is seen resting directly over the rocky bench, and is of much younger age and it is interesting to observe that at the moment, the river is again cutting the rocky bottom vertically, and is passing through a period of rejuvenation.

Nature of the Gravelly Material

The huge gravel deposit 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 exists regarding the nature of the depositing agencies. Quite a few (Glennie and Ziegler ; cf. Hagen 1969) believe that the deposition of the gravels ~~beds~~ could be attributed to the normal processes of transportation and deposition by water, but some (Gurung, 1970) invoke climatic factors involving glacial of fluvioglacial processes. Hagen (1969) has 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 consists of morainic material, resting over normal river alluvium. Gurung (1970) also believes in a combined action of ice and water, and has suggested the importance of tectonic processes, aided by climatic factors. He considers the Pokhara valley deposits, to be a legacy of a periglacial past.

Fort (1974, 1976a,b) has worked on the Quaternary deposits of the Middle Kali Gandaki and Buri Gandaki valleys. She believes that the gravelly materials of the Kali Gandaki valley do not comprise 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 deposits of the study area) represents valley fills of fluviatile nature, (2) the Ghasa Type points to a combination of glacial, alluvial and colluvial processes, and (3) the Thak Khola Type comprises lacustrine accumulation.

So far as the gravels of the study area are concerned, the following characters exhibited 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 Thrust region.

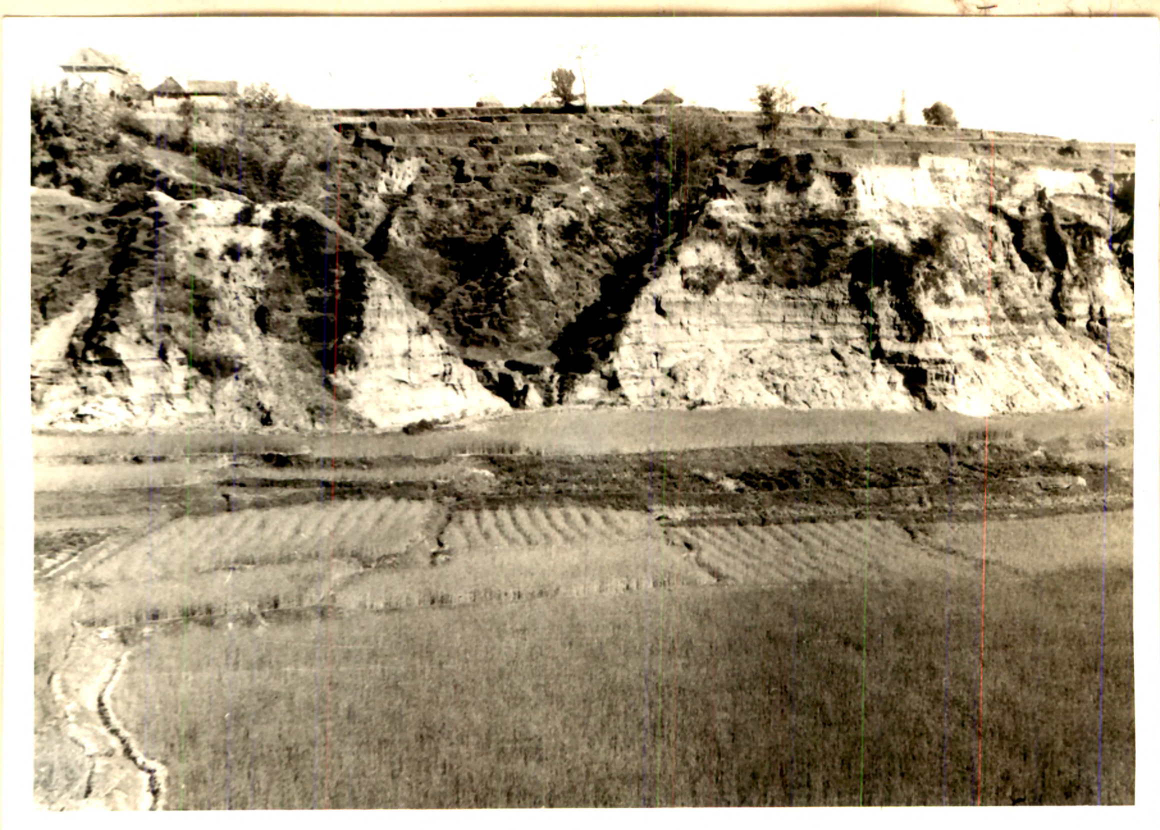
The author envisages the gravelly materials of the study area to have developed by the process of river deposition, where the debris mostly provided from the north had a glacial origin. The study area itself, does not provide any indication of glaciation and it is therefore presumed that this part of the Midland was not 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 materials 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 these gravel deposits. The author further envisages that 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 the author has concluded that the gravels of this part of Kali Gandaki valley, mainly consist of glacial and fluvioglacial deposits, having been transported southward by the fast flowing rivers.

The Quaternary gravel beds of the Midland Nepal, 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 are exclusively lacustrine with little addition of glacial material from the north (Plate IX.6).

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

Plate IX.6 A section of lacustrine deposit of Kathmandu valley, exposed in a wide abandoned stream Channel; made up of sand, silt and clays.



whether the material came from the snow fed rivers from the north or comprised material added 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.