CHAPTER IX

R E S U M E

GEOLOGICAL FRAMEWORK

In the foregoing pages of the thesis, the author has attempted to provide details of the various aspects of the geology and geomorphology of the Kusma-Phalebas section of Kali Gandaki Valley region of Nepal Midlands. Though, he has covered relatively a very small area, his findings are of considerable regional significance. The entire story of the geological evolution built by the author, adequately provides glimpses of the various geological events, including Pre-Himalayan, that have given rise to the lofty mountain chain.

The present study reveals for the first time, the structural and stratigraphic complexities of the part of Nepal Midlands.

The area has been found to comprise two tectonic units, separated by a prominent thrust running WNW-ENE across the south-western corner of the area along the village of Phalebas. This dislocation (referred to as Phalebas Thrust) dips due NE and separates the more metamorphosed unit of the north from the incipiently metamorphosed unit of the south. A high angled reverse fault cutting the Northern Unit at Kusma extends almost parallel to the Phalebas Thrust. On account of this fault (referred to as Kusma Reverse Fault), the rocks to its north have been pushed up. The present author has mainly restricted his studies to the Northern Unit, which consists of low grade metamorphic rocks mainly represented by slates, sandstones, phyllites and quartzites. These major groups show variation within themselves, giving rise to a number of lithological types. The lenses of basic volcanics add to the variety. The intermixing of the coarse and fine components in all proportions has very often produced an imperceptible gradation from the most micaceous to the most quartzose type. Apart from the variation due to the original nature of sediments, the varying effects of metamorphism and deformation have also influenced the rocks producing distinct varieties.

Taking into consideration the rocks of the Southern Unit as well, the author has arrived at the following succession of the rocks from south to north:

Kusma Unit (Northern Unit)	Balewa Formation	Quartzose phyllites, gritty quartzose phyllites, micaceous quartzites
	Kusma Quartzites	White to light brown coloured quartzites with lensoid intercalations of spilites
	- - - - - Kusma Reverse Fault - - - - - - - - - - -	
	Balewa Formation	Quartzose phyllites, gritty quartzose phyllites, micaceous quartzites
	Kusma Quartzites	White to light brown coloured quartzites with lensoid intercalations of spilites
	Phalebas Thrust	
Sirkang Unit (Southern Unit)	Sumsa Formation	Purple, green and grey slates, slaty phyllites with thin layers of dolomites and sandstones (graywacke)
	Phoksing Dolomites	Bluish grey to dark grey stromatolitic dolomites with minor intercalations of carbonaceous slates and intraclastic dolomites
	Bihadi Slates	Carbonaceous slates and shales with occasional layers of sandstones and dolomites

A close study of the various rock types of the area, their petrography and metamorphic characters, points out following two conspicuous features:-

1. The sequence shows a feeble metamorphic inversion, the lowermost formation being almost unmetamorphosed but grading upward into somewhat metamorphically high grade rocks.

2. A repetition of the sequence is observed in the upper half of the succession, and this repetition is due to a high angled reverse fault at Kusma.

Once these facts were understood, the rock formations could be adequately arranged in the following stratigraphic order:

3. Slaty phyllites, purple, grey and green coloured slates, dolomites and impure feldspathic sandstones (graywacke)	Sumsa Formation
2. Quartzose phyllites with layers of gritty quartzose phyllites; gritty quartzose phyllites with layers of micaceous quartzites	Balewa Formation
1. Quartzites with lenses of spilites	Kusma Quartzites

In the past, ages ranging from Precambrian to Jurassic, have been assigned to these rocks. But generally, there seems to be an agreement among most of the earlier workers in respect of the Precambrian to Early Palaeozoic age of the rocks of Kusma-Phalebas area. The stromatolitic dolomites (Phoksing Dolomites) outcropping south of the author's Sumsa Formation, according to B.N. Upreti (Personal communication) show the stromatolitic algal structures characteristic of Upper Precambrian to Middle Precambrian age. The combined stratigraphy of the present author and those of Upreti, shows the following sequence.

5. Sumsa Formation
4. Phoksing Dolomites
3. Bihadi Slates
2. Balewa Formation
1. Kusma Quartzites

Hence, if the contention of Upreti regarding the stromatolites is correct, the rock formation of the Kusma-Phalebas area represent a Pre-Palaeozoic sequence.

Though the entire succession points to deposition of sediments in an unmistakable marine environment, it is clearly borne out that all the time shallow water conditions prevailed. However, the conditions fluctuated from relatively deep shallow to almost subaerial, and at the same time the rate and nature of sediment influx also fluctuated. The entire sequence typically points to a succession of deposits that characterise partly cratonic and partly geosynclinal.

STRUCTURAL CHARACTERS

As already stated, the rocks of the area belong to two tectonic units separated by the Phalebas Thrust.

From the structural point of view, the study area comprises three sub-divisions as under:

Sub-division I	Rocks to the south of Phalebas Thrust (Sirkang Unit)
Sub-division II	Rocks between the Phalebas Thrust and the Kusma Reverse Fault (Kusma Unit)
Sub-division III	Rocks to the north of Kusma Reverse Fault (Kusma Unit).

The Phalebas Thrust that separates the Kusma Unit from the Sirkang Unit has been found to be repeating the rock sequence of same stratigraphic age. It is not comparable to the Chail Thrust of Indian Himalaya. It is, on the other hand, of a restricted regional significance, and is more or less a moderately dipping reverse fault.

All over the area, in both the units, effects of four episodes of folding are recognised. The present study has revealed the existence of Pre-Himalayan folds belonging to two generations - the early (F_1) tight isoclinal to reclined and late (F_2), rather open, and seen on both microscopic and regional scale. The F_1 is not always N-S, and its trend and orientation considerably vary depending on the effects of the superimposition of F_2, F_3 and F_4. Such behaviour of F_1 folds is ideally seen in the Sub-division II of the study area.

The F_3 folds were generated during the main Himalayan uplift. This folding was obviously caused by the southward pushing of the rocks along the longitudinal thrusts and faults. The F_4 folds, almost normal to the Himalayan strike, have to be explained by a mechanism related to the last phase of the Himalayan orogeny. The present author, is more inclined to attribute these F_4 folds and the various transverse strike-slip faults to the differential movements of the underlying mass, rather than that of the overlying crystalline mass, because these flexures and faults have been recorded even in the Post-Tertiary deposits, viz. Siwaliks and Sub-Recent formations in the south, across the Main Boundary Fault.

SPILITES

The spilitic rocks are found to occur in the quartzites and gritty quartzose phyllitic rocks, north of Phalebas Thrust, as concordant lenses ranging in extension from 100 m to as much as several km, with varying thickness. The frequency of the spilitic rocks (as lenses) is high in the quartzites of Kusma Quartzites and low in the gritty quartzose phyllites of Balewa Formation. These represent contemporaneous volcanism. On the basis of petrographic characters, the spilitic rock has been classified into following three types:

1. Spilitic diabase
2. Spilitic basalt
3. Spilitic tuffs

LANDFORMS

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 deeply entrenched drainage system, are some of the basic geomorphic characteristics of the area. 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 interfingering 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.

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.

DRAINAGE

The overall drainage pattern of the area is dendritic. 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. The 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.

In contrast, the longitudinal profiles of the major tributary streams like Lamai Khola and Malyangdi Khola 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 profiles, have been attributed to neotectonism, and are correlatable with the terraces of Kali Gandaki. As regards the cross profile of the river, 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.

A comparison of the various morphometric parameters for each of these smaller order basins 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 values vary between 3 to 5, but in two of the basins, this value lies below 3. 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 structures. 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.

SLOPE STUDIES

Slope studies have revealed following three groups:

(i) the crest of the ridges

(ii) the hill slopes

(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. Slopes in the depositional landforms emphasize a flatness in comparison to erosional landforms. Terraces are very flat or gently sloping down the valley of Kali Gandaki. 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. At places, even overhanging cliffs are met with, which have facilitated the rock falls and slides of the conglomerated gravels.

Obviously the entire landscape of the study area is youthful and is subjected to the 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.

GRAVEL DEPOSITS

The terraced gravel deposits of Kali Gandaki valley have revealed a unique geomorphic history related to the neotectonic activity in this part of Nepal Himalaya.

Flanking the river Kali Gandaki and Modi Khola, are the huge compacted gravel deposits throughout their courses. 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 consists of big boulders and pebbles of contorted Dhaulagiri 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.
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.

None of the gravel types show any stratification, and are characteristically unsorted. In the calcareous conglomeratic gravels, a sort of gradation is seen in their grain size - lower part being coarser than the upper. 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. 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 (Bihadi 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. T_3, the lowermost terrace and least developed, rises about 10 to 15 metres above the river bed, and at most places it rests directly over the rock benches.

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

The formation of the huge pile of the gravelly material in the form of extensive T_1 terrace flats is attributed to a process of damming of the river Kali Gandaki due to the sudden uplift of the Mahabharat Range in the late Pleistocene time. The entire thickness, thus comprises a valley-fill deposit, having accumulated in lake like water bodies all along the river course, on account of the sudden drop in the velocity of torrential flowing waters.

The formation of T_2 terrace is attributed to the rejuvenation of the river and increase in the rate of flow. This 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, due to shifting of its course, the river laterally cut the gravels, and gave rise to the T_2 surface. The existing configuration of the river points to another period of uplift and degradation, but the associated T_3 level has a somewhat different mode of origin. The unconsolidated material of this terrace, is resting directly over the rocky bench, and is of much younger age. It is interesting to note that at the moment, the river is again seen cutting the rocky bottom vertically, and is passing through a period of rejuvenation.

These gravel beds appear to have been formed 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 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.

CONCLUDING REMARKS

The present investigation by no means, can be considered as exhaustive. The author has merely attempted to reconstruct in outline the sequence of various geological processes and events that operated from Precmabrian to Sub-Recent times -

all culminating into the birth of the Himalaya. On going through the pages of this thesis, one would quite clearly get a fleeting glimpse of the major stages of Himalayan deposition and uplift, manifesting themselves now in the diverse lithology, structural pattern and geomorphic features. No doubt, a host of questions remain unanswered, a variety of problems yet defy solutions, but the author's all pervasive approach has certainly thrown considerable light on the geological evolution of the Nepal Himalaya - especially the Midlands. It is only hoped that systematic studies on identical lines are taken up all over Nepal, so that an integrated and convincing picture of the geological evolution of Nepal, finally emerges, and provides answers to various unsolved problems of Nepal geology.