CHAPTER II

BACKGROUND INFORMATION

HIMALAYA IN GENERAL

The Himalayan range forms the northern part of the Indian sub-continent and is called as Extra-Peninsula (Krishnan, 1968). The Tibetan Highland borders it in the north, and the Indo-gangetic Plain in the south. Himalaya in its clean sweep from Assam to Kashmir, maintains the strike of SE-NW, but swings its strike from SE to SSW towards Arakan Yoma range in the east, and from NW to SW towards Sulaiman and Kirthar ranges in the west. These arcuately reflexed bundles of mountain folds termed as syntaxial bends of the Himalaya, arch around the edge of the Indian peninsula. The arcuate belt, over its 2,400 km length has a radius of curvature of 1700 km. The width of the belt varies from 230 km to 320 km with an average of 270 km. The average height of the southern margin of the belt is 100 m, and that of the northern margin is 4,500 m; about 5% of its total land surface lying above 6,000 m. The southern boundary of this orogenic belt is much more clearly defined while the northern margin is broadly gradational.

Physiographically, the Himalaya comprises the following four longitudinal zones, each extending parallel to one another throughout the length, and exhibiting a characteristic step like arrangement from south to north:

1. Sub-Himalaya (Siwalik foothills)
2. Lower Himalaya (Lesser Himalaya)
3. Higher Himalaya (Greater Himalaya)
4. Tibetan Himalaya (Tethys Himalaya).

Geographically, excluding Karakorum and Salt Range, Himalaya have been divided (Burrard & Hayden, 1934; Bordet, 1961 and Gansser, 1964) into the following regional units (Fig. II.1).

1. Punjab Himalaya
2. Kumaon Himalaya
3. Nepal Himalaya
4. Sikkim-Bhutan Himalaya
5. Nefa Himalaya.

More recently, Valdiya (1978,p.80) has classified the Himalaya into four contrasted latitudinal lithotectonic sub-provinces or units, each characterised by its own distinctive structural architecture, lithological composition and stratigraphic setting. These four sub-provinces are:

1. The Tethys Himalaya to the north of the Great Himalaya-Pir Panjal Range and comprising fossiliferous sediments that range in age from Late Proterozoic to Cretaceous or even Eocene.
2. The Great Himalaya, "Central Crystalline" sub-province that forms the Great Himalaya Range in Kumaon and Garhwal, but also Dhauladhar-Pir Panjal in Kashmir and Kanchanjanga and Mahabharat Range in Nepal and beyond.
3. The Lesser Himalayan Sedimentary subprovince consisting of complexly folded and faulted Purana and younger sedimentaries.

4. The Outer Himalayan Siwalik subprovince of Cenozoic sediments.

The Main Boundary Fault marks the Lesser Himalaya from the Outer Himalayan Siwalik subprovince. The Main Central Thrust separates the Greater Himalaya from the Lesser Himalaya, whereas the boundary between the Great Himalaya and the Tethys Himalaya is gradational to thrusted.

ORIGIN AND EVOLUTION

Till recently, the Himalayan mountain chain was supposed to have arisen out of the two geosynclines parallel to and separated by a Crystalline axis. The two geosynclines have been referred to as northern and southern geosyncline. The southern geosyncline represented a shallow continental type, in which the environmental conditions for the existence of life were not favourable, whereas the northern geosyncline was favourable for the growth of life and was characterised by faunal growth right from Cambrian to Cretaceous. This supposition of Himalayan evolution is mainly supported by Pande (1967) and Pande & Saxena (1968). Saxena (1971), re-emphasising the concept, suggested that the two geosynclines were separated from each other in every period of sedimentation by Central Crystalline axis, acting as a barrier. The two geosynclines according to him, postulate the contrast in lithology, biogenic conditions, structures and stratigraphy of the zones, lying north and south of the Main Crystalline axis.

Gansser (1964), did not believe in the two geosyncline theory. According to him (op.cit. p.253) "Except in Kashmir area, the Sub-Himalayas, Lower and Higher Himalayas are made up of elements formerly connected to the marginal part of the Indian Shield. Only in the Tibetan Himalayas we do find a geosynclinal influence in the sediments formed in a shallow, gradually sinking Tethys sea. We thus realise that the main Himalayan range has not developed from a geosyncline and also does not therefore conform to the classical theory of Alpine mountain building".

Ohta & Akiba (1973), envisage two sedimentary basins in Himalaya. The unfossiliferous sediments of the Midland basin represents the basin of Eocambrian age. The fossiliferous Tibetan Tethys zone represents the sedimentary basin during Palaeozoic and Mesozoic time. According to them, gradual uplift and emergence of the Midland basin

(Lesser Himalayan basin) in the Upper Eocambrian was accompanied with the gradual subsidence of Tibetan Tethys basin. This northward migration of the basin accounts for the absence of fossils in the Midland zone and luxuriant faunal growth in Tibetan Tethys zone.

On the other hand, the Russian geologist Talalov (1972), postulated the non-geosynclinal development of the Himalaya. According to him, Himalayas are the mobile marginal part of the Hindustan Shield, where the sedimentation progressively shifted from south to north.

Jhingran et al. (1976, p.29) wrote, "Tethyan Himalaya represents platform or cratonic type conditions for sedimentation and not true geosynclinal conditions. ... If the contentions of Gansser about Lesser Himalaya and Shah and Sinha (1974) about Tethys Himalaya are true, then both of these basins i.e. Lower Himalayan and Tethys Himalayan, are not true geosynclines in the classical sense".

The uplift of the Himalaya has been attributed either to continental drift or to the vertical uplift. The supporters of drift theory suggest that the northward drift of Indian block against the Asian block, pushed up the geosynclinal sediments into a series of folds and thrust masses of huge dimension, gave rise to Himalaya. Those who believe in vertical uplift have suggested the evolution of Himalaya to be due to the uplift of the crustal blocks along deep fractures and faults.

Emile Argand (1924), was the first man to apply the concept of continental drift to evaluate the tectonics of Himalaya. He suggested that the Indian sub-continent has drifted towards north to the Asian continent and folded and thrusted the Himalayan geosynclinal sediments. Owing to the rise of the northern continental mass (Tibetan plateau), the overthrust of nappes were directed towards south.

Wadia (1931), Gansser (1966), Ahmed (1968) and others, have also postulated that the northward drift of the peninsular Indian block pushed the geosynclinal pile into a series of folds that gradually rose higher and higher as the landmass moved northwards. This movement of the Indian peninsula is supported by the palaeomagnetic studies in Deccan basalts, which reveal that the Indian peninsula has drifted about 5,000 km in a northerly direction since the end of Cretaceous at the rate of 7 cm per year (Holmes, 1965).

Holmes (1965) recently expressed his view that the uniform and very high altitude in Tibet, is due to underthrusting of India beneath the whole of the Tibet. During this movement, the Pre-Cambrian Shield material were thrusted upon the younger formations, forming the world's largest nappes.

Gansser (1966) regards the "Indus Suture Line" as a sudden root-like downbuckling in which a great length of original crust has disappeared due to the underthrust by the northward drifting mass of the main Indian Shield. This also produced the huge thrust sheets over the shield material forming the largest mountains of the globe, which are restricted to the Himalayas, north of the Indian Shield. Gansser (op.cit.), estimated the crustal shortening due to this orogeny to be of the order of about 500 km.

Pande (1967) and Pande & Saxena (1968), hold that the northward drift of Indian sub-continent and thereby underthrusting of shield material in the sedimentary prism of geosynclines caused thrusting and uplift along the pre-existing faults. According to Eremenko & Datta (1968), and Murthy (1970), thrusting was due to the gravity gliding and tilting of sediments after vertical uplift. Qureshy (1969) has envisaged the uplift of the Himalaya to be due to the injection of the basic material from the Upper Mantle. Ohta & Akiba (1973), postulated the block upheavals in the younger geological periods. Talalov (1972), invoked the block folding as the main cause of Himalayan uplift. Hagen (1969), attributed the nappes of Nepal Himalaya to the uplift of the crustal blocks along deep fractures and faults. Recently, Mehdi et al. (1972), have explained the evolution of Kumaon Himalaya due to progressive uplift with the formation of grabens and horsts.

More recently, with the understanding of the mechanism of seafloor spreading and the concept of plate tectonics the controversy on Himalaya has taken quite a dramatic turn.

Dewey & Bird (1970), have explained the origin of the Himalaya by the collision of two continents - India and Eurasia with Indus suture line as the plate boundary. Fitch (1970), suggested that the origin of Himalaya was due to the convergence at shallow depth of the Indian and Eurasian plates along the Himalayan mountain front. Powell & Conaghan (1973) postulated that the present elevated Himalayan mountain chain is not a direct result of the continent to continent collision, but of uplift during underthrusting along the deep crustal fracture that is now marked by the Indus suture line. Since ophiolites are considered as indicative of the former existence of oceanic crust (Hess, 1955), most of the supporters of the continent to continent collision and underthrusting of Indian sub-continent under the Tibetan or Asian plate, regard the Indus suture line as the relic of a closed ocean.

According to Crawford (1974), the two facts - Indus suture line as a plate boundary and the height of Tibetan plateau are incompatible. He has considered the Indus suture line as a relic of fracture in the mantle and not the junction between the Indian and Asian plates. He has postulated the northern boundary of the Indian plate to be beyond Tibet on the north side of Tarim basin block and the Tienshan. Tibet, originally being the part of the Indian plate.

Kaila & Hari Narain (1976) as Crawford, proposed the northern boundary of the Indo-Tibetan plate along the southern margin of Tien-Shan-Nan-Shan mobile belt. They (op. cit. .) postulated that Himalaya are formed due to the block uplift against steep angled faults running almost parallel to the Himalayan mountain system rather than continent to continent collision as proposed by many workers causing underthrusting of the Indian Shield below Tibet, resulting in large crustal thickness in this region. On the contrary, the great thickness of the crust under Trans-Himalayan Tibet region might be due to normal processes of crustal formation and the consequent overloading might be the cause for creating structural failure in the Himalayan region'.

PREVIOUS WORK

Himalayas have attracted geologists since the middle of the 19th century, and the entire record of the geological studies in the Himalayas can be said to belong to three periods.

(1) The first period of sixty years, beginning with 1860 was instrumental in laying the foundations of Himalayan stratigraphy.

(2) The second period between 1920 and 1930 saw a special emphasis being laid on the structural studies of the Himalayas. The development of the concept of great thrusts in Europe had a clear impact on the Himalayan studies during this period.

(3) The third and the most recent period from 1939 to this date has witnessed the beginning of intensive areal studies of structures and their regional correlation.

A number of agencies have been paying attention to the study of Himalayan geology, and recently the various major engineering projects, expeditions, traverses and academic research have given added impetus to a gradual clarification of concepts about the stratigraphy, structure and metamorphism of the Himalayas.

The author does not propose to deal here with all the important works on Himalayas, and he has restricted himself to summarising the salient points of the previous work which have direct bearing on the problem connected with the present study. Keeping in view the requirements of the present thesis, he has described the subject matter under the following three heads:

1. Outline of Geology of Himalaya
2. Previous work in Nepal Himalaya
3. Previous work in the study area and neighbourhood.

1. OUTLINE OF GEOLOGY OF HIMALAYA

The earliest work that deserves mention is that of Strachey (1851), who conducted a number of traverses in Central Himalaya. His findings clearly established the distinction between the stratigraphical divisions of the high Himalayas from the "Azoic slates". Though his sections (Fig. II.2) did not show any thrusting, but they can certainly be considered as fore-runners of the thrust concept, and a remarkable achievement of his time. Medlicott's (1864) contribution coming out a few years later, marked an important milestone in the geological history of Himalayas. He gave the first connected account of the geology of the Lower Himalayas between the rivers Ravee and Ganges. He classified the Himalayan rocks of the area into two series:

1. Sub-Himalayan series
2. Himalayan series.

These two series, classified into various sub-divisions, formed the following sequence:

1. Sub-Himalayan series

Upper	Siwaliks	
Middle	Nahan	Kasauli
Lower	Subathu	Dagshai

2. Himalayan series

A. Unmetamorphosed:

Krol	-	Limestone
Infra Krol	-	Carbonaceous shale
Blaini	-	Conglomerate
Infra Blaini	-	Slates

B. Metamorphics:

Crystalline and sub-crystalline rocks.

Garhwal Himalaya received attention of Middlemiss (1887), whose classical work established the following succession of the rocks in the Garhwal region:

	Sub-Himalaya (Siwaliks)
Outer formation	Nummulites Tal Massive limestone Purple slate Volcanic breccia
Inner formation	Schistose series with intrusive gneissic granites

He invoked reverse faulting to explain the presence of schistose rocks over nummulites.

Another noteworthy contribution towards the structural interpretation of Himalayas, came from Pilgrim & West (1928). They mapped the Simla region and suggested that the rocks of Simla-Chakrata area, are not in their normal position, but they have undergone thrusting and inversion. They gave the following stratigraphic sequence of Simla Himalaya:

Dagshai series	Lower Miocene
- - - - - - Unconformity - - - - - -	
Uppermost Subathu beds	Upper Oligocene
- - - - - - Unconformity - - - - - -	
Subathu series	Middle Eocene
- - - - - - Unconformity - - - - - -	
Krol series	
Infra Krol beds	Lower Gondwana
Blaini beds	
- - - - - - Unconformity - - - - - -	
Shali limestone and slate	?
Simla series (Infra Blaini)	
- - - - - - Unconformity - - - - - -	
Jaunsar series	Purana
- - - - - - Unconformity - - - - - -	
Chail series	Purana
Jutogh series	Archaeans (?)

The classical work of Wadia (1931), deals with the syntaxial bend of the Himalayas in Kashmir-Hazara area. He has suggested a single Himalayan movement from the north. According to him, a tongue of the ancient and stable peninsular rocks extended upto the NW beneath a covering of Cenozoic rocks, and this formed the obstacle to the folding movement coming from the north so that original north and south direction of movement was resolved into a NE-SW direction in Kashmir and a NW-SE in Hazara.

The most outstanding work on the Himalayas came from Auden (1937), who gave excellent account of the structure and stratigraphy of the Garhwal region (Fig. II.3). In this work, he gave the following sequence of rocks in Garhwal:

Formation	Thickness	Probable age
Siwalik	4864 m	Upper Miocene to Pleistocene
Nummulitic	-	Eocene
Tal	1976 m	Upper Cretaceous
Krol	1216 m	Permian to Triassic
Blaini	608 m	Talchir (Uralian)
Nagthat	912 m	Devonian
Chandpur	1216 m	Lower Palaeozoic or Pre-cambrian

According to Auden, the above mentioned rocks are tectonically arranged to show the following structural succession:

Chandpur (metamorphosed)

——————— Thrust ———————

	Nagthat Chandpur	Little metamorphosed
Garhwal Nappe	Boulder beds, slates and limestones of uncertain stratigraphical horizon occur in one outlier below metamorphosed Chandpurs	

——————— Garhwal Thrust ———————

	Nummulitic Tal Krol Blaini	
Krol Nappe	Nagthat Chandpur	Metamorphosed and unmetamorphosed

——————— Krol Thrust ———————

Dagshai

Nummulitic

Autochthonous — Siwalik

Simla slates

According to Auden, in the Eastern Himalayas also, there are two main thrusts: one causing the Gondwana rocks to come over the Siwaliks, and the other separating the Daling series from the underlying Gondwanas. He further correlated these two thrusts with the Krol and Garhwal thrusts of the Garhwal Himalayas.

The work of Heim & Gansser (1939) forms another landmark in the study of Himalayas. They have dealt with various geological aspects such as petrology, stratigraphy, and the structure of the Central Himalaya (mainly Kumaon, NW part of Nepal and Tibet Himalaya). Their regional correlation and tectonic interpretation is unique and of great value. These two authors have traced the eastern extension of the Garhwal Thrust of Auden into Kumaon, and called it as 'Almora Thrust'. The stratigraphical ages assigned to the various tectonic units in Kumaon by Heim & Gansser (1939), more or less coincide with those given to the comparable units in Garhwal and Simla areas by Auden (1937). According to these two authors, the rocks of Almora Nappe are perhaps equivalent to the Chandpurs of Jaunsar series (a succession resting over the younger rocks of Krol Nappe). The Krol Nappe includes a succession of Nagthats (Upper Jaunsar) through Infra Krols, Krols and Tals (Permian to Cretaceous).

A subsequent publication by Gansser (1964), follows more or less the same correlation, but deals with the entire Himalaya.

The structural data furnished by Valdiya (1962b) on Champawat and Pithoragarh area in the Eastern Kumaon is of considerable use in the regional study. According to him, the south and north Almora Thrusts continue eastwards. He has assigned identical stratigraphical ages to the various tectonic units in that area.

The volume of the geological data furnished by Hagen (1969), Ohta and Akiba (1973), Fuchs (1967), and Talalov (1972) on Nepal Himalaya is of considerable importance in the regional study.

PREVIOUS WORK IN NEPAL HIMALAYA

The available record shows that prior to the middle part of this century, the various geologists since 1848, visited one or the other area in Nepal, but none provided any coherent geological account. Hooker (1848), Meddlicott (1875), Mallet (1889), Jones (1889), Loc'zy(1907), Holland (1908), Reed (1908), Deiner (1912), Heron (1922), Wager (1934, 1937,1939) and Bowman (1933) were the early workers who contributed on one or the other aspect in a limited manner. It was Auden (1935), who for the first time conducted a systematic study of Nepal geology, and found that the structural concepts developed by him for Garhwal Himalaya (Auden, 1934), were valid for Nepal as well. Accordingly, he recognised three thrust planes (Fig. II.4.A & B) as under.

1. One separating Nahans (Lower Siwaliks) from the overlying Upper Siwalik conglomerates. It occurs near Hitaura (in the Kathmandu section).

2. The Main Boundary Thrust, which separates the Pre-Tertiaries from the underlying Lower Siwaliks, was observed just north of Sonatar (north of Hitaura), and again on the first col east-north-east of Udaipur Garhi.

3. A third thrust was seen 2.5 km east-northeast of Udaipur Garhi, which marked the boundary between the garnet schists of Darjeeling gneiss and the underlying "possibly Krol rocks".

Heim & Gansser (1939), investigated the geology of the westernmost part of Nepal and their work comprises an attempt to extend the structural concept of Garhwal and Kumaon upto the western boundaries of Nepal.

After 1950, a number of geologists have worked in the various areas of Nepal and their contributions are noteworthy. In 1950, Hagen began his field work for the Government of Nepal and during ten years of intensive investigations, he practically covered all parts of the kingdom. He accumulated a wealth of geological facts, unequalled in the history of geological explorations. Hagen (1969), published a comprehensive account of the geology of Nepal, and more or less extended the nappe concepts of Auden to Nepal geology (Fig. II.5.B). In his own words (op. cit. p.34-35) "As in the Alps, a number of nappe groups were found in Nepal, each of them consisting of several nappes of similar type of lithology and structure. Three of these nappe groups consist dominantly of crystalline formations, namely, from top to bottom: the Kangchendzonga-Lumbasumba nappes, the Khumbu nappes and the Kathmandu nappes. Two of the nappe groups are dominantly formed of palaeozoic sediment - formations, with minor crystalline bodies (Hiunchuli nappes, Jajarkot nappes). A further two nappe groups contain mostly carboniferous-mesozoic formations (Bajang nappes, Nawakot nappes). The latter group however undergoes considerable changes in lithology and stratigraphy in the direction of the strike. They show a kind of transitional character, consisting in the south and in central Nepal dominantly of young formations (permian - triassic), while consisting in eastern Nepal almost entirely of palaeozoic formations. The Nawakot nappes thus show gradual development to the type of the Kathmandu nappes".

Hagen has postulated totally 22 nappes throughout the Napalese territory as under:

Crystalline nappes:	Kanchendzonga nappe (1) Lumbasumba nappe (1) Khumbu nappes (3) Kathmandu nappes (5)
Nappes of dominantly Palaeozoic sediments:	Hiunchuli nappes (2) Jajarkot nappes (2)
Nappes of dominantly Carboniferous - Mesozoic sediments:	Bajang nappes (4) Nawakot nappes (4)

The Fig. II.5.A gives the schematic sketch of the distribution of various tectonic units and their correlation with each other. The two tectonic zones, the Tibetan sediment zone in the north and Siwalik zone in the south, extend throughout the whole country, without interruption.

Hagen (op.cit.), has envisaged the Kathmandu nappes to be the real backbone of Nepal Himalaya. Most of the higher peaks of Nepal are shown situated in the roots of these nappes or in the adjacent marginal schuppen on the backside of its roots. Considering the distribution of the lower nappe groups in the Western Nepal and the higher nappe groups in the Eastern Nepal, he has concluded that the region of the Kali Gandaki Valley forms the pivot from which the main tectonic units have been separated towards the east and the west.

On the overthrust distances of various nappe groups, Hagen (1969, p.38) writes "... the Kathmandu nappes developed the longest overthrusts. ... The maximum overthrust of the Kathmandu nappes are found in the Kathmandu section where they are almost 100 km. The Nawakot nappes have their maximum thrust of 90 km in the section of Kali Gandaki river. The remaining nappe groups in western Nepal do not exceed 50 km of overthrust".

The Siwaliks have been divided into two main groups:

1. Thrusted Siwaliks - near and along Main Boundary Thrust
2. Folded Siwaliks - in the deep south.

Structurally, in the Midlands of Nepal, he has shown a weakly developed fore-anticline south of the root zone.

The other prominent structure is the Midland anticline, which in the Eastern Nepal is called as Sun Kosi anticline, and in the Western Nepal as Kali-Trisuli anticline and Bheri anticline. This structure terminates near Jajarkot after covering a distance of nearly 500 km from east to west. The southern most structure - Mahabharat syncline runs for a distance of 400 km from Udaipur Garhi in the east to Kanchikot in the west. All these structures, running E-W, following the general trend of Himalaya are considered to be the younger structures than the overthrusts of the nappes from their roots southwards.

The cross structures, e.g. Arun anticline, Thak-Khola graben zone etc., are regarded to be the older structures than the thrust of the nappes. According to Hagen (op. cit.), these transverse structures play the main role in the primary layout of the structures of Nepal Himalaya.

Hagen has also made an attempt to correlate the Nepal rocks with the rocks outside Nepal. The rocks of Kathmandu nappes, he writes (op. cit. p. 36) "... continue even far beyond Nepal into the Kumaon and Garhwal Himalayas, where they are identical to the "Garhwal nappes" of J.B. Auden and the "Central Gneiss" and the "Almora Thrust mass" of

Heim & Gansser. The Bajang nappes, uderlying the Kathmandu nappes also continue to the west beyond Nepal. They correspond to the Krol nappes and Tejam zone of the authors mentioned above. Since the Nawakot nappes in central and eastern Nepal correspond to the Bajang nappes (lithologically and tectonically) they can also be considered as equivalent to the Krol nappes of Auden".

Lombard (1958), who accompanied the first Swiss Mount Everest expedition of 1952, introduced for the eastern part of the Nepalese Lower Himalaya a new structural element, the crystalline Khumbu nappe corresponding to the Hagen's Kathmandu nappe No. 5. Lombard considered the Everest limestone group to be of Devonian age. According to him, intrusion of the Nuptse granite took place before the overthrust. But unlike Hagen, Lombard recognised lesser number of nappes in the Eastern Himalaya of Nepal.

Hashimoto (1957, 1959), who worked along Kathmandu to Manasulu along Buri Gandaki, rejected the notions of nappes in Nepal Himalaya. According to him, the Kathmandu and Nawakot nappes of Hagen, represented a successive series of metamorphism as a whole, being separated from Kathmandu basin by a steep fault running through the northern slope of Sheopuri Lekh. Further, he postulated that an apparent reverse distribution of metamorphic rocks has resulted from the multiple repetition of various rock units.

Bordet (1961), a member of the French Makalu expedition, made structural and petrological studies along the Arun river upto Mount Makalu and presented a profile (Fig.II.6.A) extending from Sagarmatha-Makalu massif to the Ganges plain. The essential points of the Bordet's profile is a stack of large scale nappes (covering a thrusted distance of more than 100 km). He has opined that a large crystalline nappe structure was created by the block movements of the basement.

On the Lower Himalaya of Eastern Nepal, north of the Main Boundary Fault, Bordet (op. cit.) distinguished the Sanguri series which is followed by his Lower Himalayan unit. The Lower and Upper Sanguri series have been folded, forming narrow southward overlying synclines. Folding are strong below the thrust of Lower Himalayan unit. The Sanguri section could be compared to the Nawakot nappes of Hagen, but resembles rather Dalings of Auden, and is unlike his Krol section.

The Lower Himalayan unit has been subdivided into seven lithological units, which according to Bordet (op.cit.)

constitute a normal stratigraphic sequence. A tentative age have been assigned by Bordet to this section of Lower Himalayan unit as under:

Salung Conglomerate	= Permian
Upper Phyllite (with calcareous zone)	= Carboniferous
Upper Phyllite with carbonate	= Devonian
Upper Quartzite	= Silurian-Devonian
Lower Phyllite	= Silurian
Lower Quartzite	= Cambro-Silurian
Schists and gneisses	= Pre-cambrian

In this section of Lower Himalaya, Bordet distinguished major anticlinal features, all of them included in his main thrust sheet of Barunse. This is covered by the next, higher thrust mass of Tinjure, which consists predominantly of schists and gneisses. Northwards, this mass is bordered by main thrust of Higher Himalaya. He has also shown a tectonic window of phyllite and metasediments, a remarkable NNE-SSW striking doubly plunging anticlinal structure along the middle reaches of the Arun river. This transverse structure is thought to be a structure older than the nappe of the crystalline rocks.

Beside this, Bordet (1961), has also carried out work in the Mount Everest region, where he divided the

the contributions of Auden, Hagen, Bordet, Lombard etc. He believes in the uniform continuation of tectonic units and the stratigraphic horizons, all throughout the Himalayan belt, and his discussion are mainly based on the data from the Indian Himalayas.

An altogether new approach to the geology of the Nepal is seen in the work of Nadgir & Nanda (1966), two G.S.I. Officers, who, it seems, did not believe in nappe concept. They have envisaged major structural blocks, bounded by thrust faults of considerable vertical slip components (Fig. II.7). They have accordingly divided the Nepal Himalaya into following four major structural blocks:

1. The southern belt of Siwaliks,
2. The belt of Suparitar autochthonous folds and thrust with Ismakot central massif of Bhimphedi type,
3. Bhimphedi belt of Main Himalaya,
4. The Tibetan sedimentary zone.

The general stratigraphic sequence suggested by Nadgir and Nanda (op. cit.) for the Central Nepal is as under.

7. Mustang Valley lake-fill, River terraces, Terai, Gangetic alluvium	Middle Pleistocene to Recent
6. Siwalik System	Upper Tertiary to Middle Pleistocene
------------ Unconformity	--------------
5. Tansen series (Mahabharat area)	Cretaceous to Palaeozoic
4. Granite intrusive	Mesozoic
3. Thak Khola rocks (Tethyan)	Palaeozoic to Mesozoic
------------ Unconformity	--------------
2. Suparitar series	Pre-cambrian (Delhi ?)
1. Bhimphedi series	Pre-cambrian

Fuchs (1963) visited Nepal as a member of Austrian Dhaula expedition, and carried out the structural studies of Nepal Himalaya in the meridian of Dhaulagiri. He has presented a cross-section along Butwal-Tukucha section in Central Nepal (Fig. II.8). Further details regarding the tectonics and stratigraphy of Central and Western Nepal were furnished by Fuchs (1967), Fuchs & Frank (1970) and Frank & Fuchs (1970). These authors also support the nappe tectonics, but in details, their ideas are very much different from those of Hagen and Bordet. According to these authors, the stratigraphy given by Auden is applicable very well to Nepal and the tectonics described by Pilgrim & West (1928) and West (1939), are surprisingly identical to those observed in Nepal.

Fuchs (Fuchs, 1967; Fuchs & Frank, 1970 and Frank & Fuchs, 1970), recognised six structural zones in Nepal Himalaya - traceable over long distances along the strike of Himalaya, each characterised by specific rock assemblages, grade of metamorphism and tectonic style. The different structural units from south to north is as under:

1. The Tertiary Zone (Siwaliks)
2. The Tansing Unit (= Krol Unit)
3. The Rukum Nappe
4. The Chail Nappe, splitting into three nappes in the NW
5. The Lower and Upper Crystalline Nappes (Kathmandu nappes - Hagen)
6. The Tibetan Tethys Zone.

Tectonically, the rock sequence of Tertiary Zone are thrusted over by Tansing Unit (= Krol Unit), along the Main Boundary Thrust. The rock sequence of Tansing Unit, have been considered to be of parautochthonous character.

Rocks of Tansing Unit are shown to extend from west to east. Beyond the Western Nepal the Pithoragarh-Tejam window rocks form the continuation of (Bajang nappes of Hagen, 1969) Tansing Unit. At the SW front of the Lower Himalaya, rocks of Tansing Unit appear in the region of Piuthan, comprising the Piuthan zone of Hagen (1969). In the Kali Gandaki Valley section, the southern part of Hagen's Nawakot nappes forms the Tansing Unit rocks. In the region of Kathmandu and Eastern Nepal rocks of Tansing Unit are considerably reduced, forming a narrow band south of Mahabharat range.

Rukum Nappe in the region of Rukum (West Nepal), has been correlated to the Simla slate masses in their tectonic situation. The rock sequence of Rukum Nappe are thrusted for about 38 km from their root zone over Tansing Unit.

The Chail Nappe, forming an important element of Himalaya, comprising Chail Formation in most part of the Himalaya, are shown to comprise a complete stratigraphical sequence in Hiunchuli region. In the same region, the Chail Nappe is shown to split into three units (designated as Chail Nappe 1, 2 & 3) in the form of plate like sheets. The lower most thrust sheet, Chail Nappe 1, is postulated to be of parautochthonous character, and Chail Nappe 3 to comprise an inverted sequence. The rocks of Chail Nappe are thrusted over the Tansing Unit and Rukum Nappe along the tectonic plane called 'Chail Thrust'. Chail Nappe rocks have vast extension in the Hiunchuli region and in the northern parts of Nepalese Midlands between Kali Gandaki and Nawakot. Here, the 'Series of Kuncha' of Bordet and others (1964) corresponds to the Chail series. East of Kathmandu, Chail Nappe rocks are restricted to a narrow band at the foot of the mountains and to window zones (Okhaldhunga & Angbung of Hagen, 1969). The root zone parts of Hagen's Nawakot nappe correspond to the Chail Nappe of Fuchs (1967).

The Crystalline Nappes are thrusted over these southern tectonic units. The thrust distance of the Crystalline Nappes is postulated to be of the order of 100 km. These nappes are also shown to extend from east to west and roughly correspond to Hagen's Kathmandu and Khumbu nappes.

Stratigraphically, the Lower Himalayan unfossiliferous units, namely Tansing Unit, Rukum Nappe and Chail Nappe are shown to comprise a similar stratigraphic sequence, which differ only in the facies, tectonic development and metamorphic characters. The general stratigraphy presented is very much similar to the stratigraphic sequence presented by Auden (1937) for the Krol rocks of Simla, is as under:

Tansing Unit	Rukum Nappe	Chail Nappe
1. Simla Slates	1. Simla Slates	1. Simla Slates
2. Chandpurs	2. Chandpurs	2. Chail Formation
3. Nagthats	3. Nagthats	3. Nagthats
4. Blaini	4. Blaini	4. Blaini
5. Infra-Krol and Shali Slates	5. Infra-Krol	5. Shali
6. Riri Slates	6. Riri Slates	6. Shali Slates
7. Krol and Shali	7. Krol and Shali	7. Lower Gondwana
8. Tal Formation	8. Tal Formation	
9. Subathu	9. Subathu	
10. Dagshai	10. Dagshai	

Obviously, these authors have not only extended the stratigraphy of the unfossiliferous formation of NW Himalaya to Nepal, but have also extended the same terminologies.

Regarding the age of different lithological horizons, Fuchs (1967) has considered them to comprise a sequence from Cambrian to Eocene; Simla slates being the oldest one, Krol and Shali of Upper Carboniferous to Mesozoic age. Frank (in Fuchs & Frank, 1970), however, doubts in this supposition and believes a larger portion of the stratigraphic sequence to constitute a Pre-cambrian succession.

A Russian geologist, Talalov (1972), reinterpreted Hagen's map on the basis of the concept of oscillatory movements. He has commented (1972, p.611), "none of the propounders of nappe concept show direct stratigraphical proofs of the presence of nappes and the arguments based on different metamorphic grades without revealing the nature of metamorphic alterations of rocks is obviously unconvincing".

In his opinion, the Nepal Himalaya exhibits the "normal" structure postulating the non-geosynclinal development in Alpine cycle.

He has distinguished the following three structural units, which more or less coincide with the geographical units of Gansser (1964):

1. Siwalik fore-deep
2. Lower Himalayas
3. Higher Himalayas.

Talalov (1972), has presented the following stratigraphic sequence for the Lesser Himalayas of Nepal, which is based on the work mainly in the Kali Gandaki region and some of the radiometric datings (Table II.1).

The Japanese geologists Ohta & Akiba (1973), on the other hand, have suggested an altogether different geological framework for the Nepal Himalaya. According to them, the Alpine ultranappe concept could not be applied to Nepal, as there is an essential difference in the geological structures of Indian and Nepalese Himalayas. These authors envisaged that the essential structures of this mountain range have resulted from the longitudinal block movements with vertical displacement. No nappe structures exist in Central and Western Nepal, though some nappes are not ruled out in Eastern Nepal, but they too are quite subordinate, as compared to the vertical movements. They have visualised mainly two major tectonic dislocations in Nepal Himalaya - The Main Central Thrust and The Main Boundary Fault. The Fig. II.9 gives the tectonic section from the Everest to the Ganges plain as presented by these authors (1973).

The sedimentary sequence of Nepal Himalaya has been divided from north to south according to the tectonic divisions and lithostratigraphic characters as follows:

Tibetan Tethys sediments (early Palaeozoic to Eocene) with basement of Himalayan gneisses (Precambrian)

———————— M. C. T. ————————

Midland Meta-sediment group (probably Eocambrian and older)

Kathmandu group (early to middle Palaeozoic)

Younger sediments (late Palaeozoic and Cretaceous to Eocene)

———————— M. B. F. ————————

Siwalik series (Miocene and Younger)

Tectonically, Nepal Himalaya has been sub-divided into three main zones, each of these zones are further sub-divided into smaller tectonic zones as under:

A. The Tethys Himalayan zone

1. The Tibetan Tethys sediment zone
2. The Himalayan gneisses zone
3. The Main Central Thrust zone

B. Midland zone

1. The Midland zone
2. The Mahabharat zone

C. Siwalik zone

Also, the correlation of Nepal rocks with those of Kumaon is not acceptable to Ohta & Akiba (1973), as they were not convinced of the desirability of comparing the lithological units between the remote areas more than several hundred kilometers apart from each other. They established a larger lithostratigraphic sub-division for each of the surveyed areas, and then correlated the units between the adjacent areas within Nepal. After establishing general lithostratigraphy they correlated it to the succession known outside Nepal. The rocks of the Midland Meta-sedimentary group has been very broadly correlated with the rock succession of the Peninsular India by these workers.

Sharma (1973), like Japanese and Russian workers, has invoked the block uplift of the Himalayas, and according to him (1973, p.63), "Nepal Himalayas consists of older rocks of geological time scale, involved in Alpine folding".

Sharma has also recognised the following zones in Nepal Himalaya.

1. Sub-Himalayan zone
2. Lower or Middle Himalayan zone
3. Higher Himalayan zone
4. Tethysian zone

But according to him, the Sub-Himalayan zone was separated from the Lower or Middle Himalayan zone by the Main Boundary Thrust, while the Lower Himalayan zone and Higher Himalayan zone were gradational or occasionally separated by steep angled faults. Sharma, thus did not attach much significance to the M.C.T. and considered the 'Main Central Crystalline' to be the uppermost formation of his Mahabharat Limestone group, now metamorphosed by granites.

Sharma (1973), has proposed the following stratigraphy for the rocks of Nepal Himalaya (Table II.2).

More recently, an entirely new approach is seen in the work of Remy (1975). His work pertains to the major structural elements of the Western and Central Nepal. He has invoked the nappe concept and has worked out the following lithostratigraphic and tectonic units in Central and Western Nepal:

1. The Nepalese series
2. Salyan series

3. Nepal Nappe series
4. Tibetan series
5. Tertiary formation
6. Siwalik formation

The Main Boundary Thrust is supposed to separate the Siwalik series from the zone of Nepalese series, Nepal Nappe series, Salyan series and Tertiary series. The Main Central Thrust separates the latter from the Tibetan series.

The rocks of the Nepalese series, and Nepal Nappe series have been correlated with the older formations of Kumaon. The Salyan series have been correlated with the Blaini-Krol-Tal sequences.

On the basis of some geochronological measurements, he has shown two distinct phases of metamorphism in Nepal Himalaya, the oldest being the Precambrian and the youngest being the Mio-Pliocene period.

A valuable contribution to Nepal geology has been made by Stocklin & Bhattarai (1977), who in an unpublished report, have summerised the results of their photogeological and regional geological work of the area between Seti-Trisuli

Ganga confluence in the west to Sindhuli Garhi in the east, in the Central Nepal. Like Hagen (1969), these workers have also visualised the nappe nature of the Kathmandu crystalline, which according to them has been thrusted far to the south and has remained as klippen in the core of the E-W Mahabharat syncline in the region of Kathmandu. However, they do not agree in the multiples of nappes within the Kathmandu crystalline as envisaged by Hagen (1969).

In this section of Nepal Himalaya, Stocklin & Bhattarai have recognised three main orographic and tectonic zones as under:

1. The High Himalaya, composed of Tibetan sedimentary zone and the underlying Central Crystalline zone.
2. The Lesser Himalaya, composed of the Midland sedimentary zones of Nawakot and the Sun Kosi, separated by the gneiss zone of Sheopuri-Gosaikunda; the Kathmandu crystalline zone that includes the Kathmandu Valley area and the Mahabharat Range; and the Suparitar sedimentary zone.
3. The Sub-Himalaya or Siwalik foothills.

In the Lesser Himalayas, apart from the Quaternary deposits, they have recognised only two largest litho-units -

1. Nawakot Complex and 2. Kathmandu Complex. The essential difference between the two complex is the grade of metamorphism. The Kathmandu Complex comprises high grade metamorphics in contrast to the low metamorphic grade of the Nawakot Complex. Physically, the Kathmandu Complex overlies the Nawakot Complex and shows inverse order of metamorphic grading along the contact that is in most places steeply inclined. This contact is tectonic one, and is supposed to be related to reverse or thrust faulting rather than normal faulting. This contact has been designated as "Mahabharat Thrust Fault", which have been named differently in south, northwest and northeast.

Stratigraphically, the rocks of Kathmandu Complex and Nawakot Complex have been taken as separate stratigraphic entities and are further subdivided into number of lithostratigraphic units as under (Table II.3).

On the basis of the stromatolitic structures, some of the radiometric age determination and broad lithological similarity to dated rocks of Middle East and Western Himalaya (Pakistan), the upper Precambrian age has been assigned to the rocks of Lower Nawakot Group, however, the age of the Upper Nawakot Group is very arbitarily fixed to Palaeozoic.

The bulk of Bhimphedi Group have been placed in the Precambrian, for it is overlain conformably and without sedimentary break by the fossiliferous Phulchoki Group of Early - Middle Palaeozoic age. These authors, from the lithological comparisons with the dated sedimentary sequence of Pakistan and Middle East, suggest that the Precambrian-Cambrian boundary lies somewhere within the Tistung Formation of Bhimphedi Group.

The following deformational history has been established by these authors (1977, p.77):

1. Regional metamorphism and related primary schistosity.

2. Main orogenic phase: drag and shear foldings of small and medium scale, secondary schistosities; syn or post-tectonic granitization, superimposed heat metamorphism; all possibly related to thrusting (Mahabharat Thrust).

3. Large scale folds and related longitudinal faults; Main Boundary Thrust.

4. Megafolds and transverse faults.

5. Sub-recent reactivated faults both longitudinal and transverse, probably related to continuous uplifting of Himalayan Range.

PREVIOUS WORK IN THE STUDY AREA AND NEIGHBOURHOOD

In the geological accounts of almost all the previous workers, brief reference have been made to this area, but no detail description is available anywhere.

In the tectonic map of Hagen (1969), the study area is shown to form a part of Nawakot nappes. The Nawakot nappes covering a distance of 550 km from Uttar Ganga in the west to Arun river in the east are shown best developed in the region of Kali Gandaki, where they cover the whole area from the root zone at the southern flank of Greater Himalaya right down to the Main Boundary Thrust on to the Siwaliks. In this region, the Nawakot nappes have been divided into four nappes. The Pokhara window zone, considered to be the lowest tectonic unit of Nepal Himalaya, is also shown in this region.

The study area has been shown in the Nawakot nappe No.3, a little SW of the Pokhara window zone. Hagen has not shown any thrust major or local in the study area. Hagen (from Gansser 1964, p.147) has proposed the following stratigraphical succession for the Nawakot nappe rocks:

Calcareous polygenic breccia	= ? Rhaetic
Dolomites	= ? Triassic
"Veruacano" conglomerate	= ? Permian

Carbonaceous phyllites	= ? Carboniferous
Sandstones	= ? Lower Palaeozoic
Phyllites, mica schists and gneisses	= ? Precambrian

Obviously, the rock succession comprises a sequence from Precambrian to Rhaetic, which is very broadly correlated with the Krol sequence of Auden (1937). According to Hagen (1969), the rocks of Krol sequence occur only in Central and Southern Nepal, but towards the north and east in the root zones, the rocks change entirely; the Permo-Carboniferous and Triassic formations are underlain and partly even replaced by undoubtedly older rocks, which show a greater similarity to the overlying Kathmandu nappes.

On the other hand, Bordet (1961), and Bordet and others (1964), postulated that this part of Nepal belongs to a wide autochthonous zone and is devoid of any regional nappes. They did not visualise the Pokhara window zone and successive sheets of Nawakot nappes as was done by Hagen. In this region of Kali Gandaki Valley, Bordet (1961), and Bordet and others (1964), envisaged a progressive northward younging succession comprising a sequence ranging from Silurian to Jurassic age, as under:

Thick succession of arkosic flysch type sediments (Series de Kuncha)	= ? Jurassic
Yellow dolomites	= ? Triassic
"Verrucano"	= ? Permian
Banded schist with white dolomite	= ? Carboniferous
Dolomite with Collenia	= ? Devonian
Black phyllites	= ? Silurian

More recently, Bordet (1973), has however correlated his 'Series of Kuncha' with the Chail series (Devonian) of Fuchs (1967) and the 'Stromatolitic dolomites' with stromatolitic rocks of Valdiya (1962), of Riphean age of the Kumaon Himalaya.

A somewhat detailed account of the geology of the area is given by Nadgir & Nanda (1966), who surveyed the Kali Gandaki Valley in connection with Cobalt-Gold investigation. But their findings are totally different from Hagen and Bordet. As already stated earlier, they envisaged a number of structural blocks in this part of Kali Gandaki Valley, delineated by sharp vertical to sub-vertical faults. In the study area, they have shown a high angled E-W thrust fault called Lame Deorali Thrust passing along the southern corner of the area and a steep fault in the line of Kusma. According to Nadgir & Nanda

(1966), the rocks of the study area constituted a part of their Suparitar series of Precambrian age, and in this region of Kali Gandaki Valley, they have shown a stratigraphically younging sequence from north to south as under:

S	8.	Carbonaceous shale with dolomitic limestones
U	7.	Stromatolitic dolomites cherty in upper part
P	6.	Purple formation
A	5.	Grey shales grading into purple formation
R	4.	Crystalline limestone and phyllites
I	3.	White quartzites with discontinuous basal
T		pebble beds
A	2.	Basic volcanic facies, Sub-marine (?)
R	1.	Grits and phyllites with occasional limestone
		and basic igneous bands,(Flysch?)

These two officers of Geological Survey of India did not see any reason to correlate these formation with Palaeozoic formation outside Nepal, nor did they agree to the age correlation made by Bordet and others (1964). They have correlated these rocks with the rock sequence of Delhi System in Peninsular India.

<u>Fuchs & Frank</u> in a series of publications (Fuchs, 1967; Fuchs & Frank, 1970; and Frank & Fuchs, 1970), have given some details of the geology of the Kali Gandaki Valley. They have shown a NW-SE thrust dividing the area into two tectonic units, the Chail Nappe in the north, resting over the Tansing Unit (= Krol Unit) in the south. Fuchs (1967) with some doubt has shown the tectonic line of separation between the two units. On the broad basis of epizonal metamorphic characters of the rocks north of Sirkang, he postulated a tectonic contact near Sirkang, in order to overcome the difficulties posed by the high metamorphic grading up in the succession. On the same basis, he commented on Bordet and others (1964, who have also shown a stratigraphic boundary between the 'Series of Kuncha' and 'Yellow dolomite'), that it was very difficult to explain the increase of metamorphism at the border in the above deposited younger formation of 'Series of Kuncha'.

These workers did not agree on the tectonic set up of the region presented by Bordet and others (1964) and Hagen (1959). Fuchs (1967) has also ruled out the possibility of Pokhara window zone; he believed in the continuation of Chail rocks of Chail Nappe from Kusma to Pokhara.

In this region of Central Nepal, Fuchs & Frank (1970), have postulated the tectonic contact between the Chail Nappe and Tansing Unit to lie in the rocks of the same age i.e. Chandpurs and Chail series, which can be differentiated by the metamorphic characters, Chandpurs being unmetamorphosed and the Chail series being epi-metamorphic in character.

In Kusma-Pokhara sections, Fuchs (1967), has shown his Chail series rocks to attain a maximum width of 35 km, which according to him can be very well recognised by the metamorphic characters and the usual occurrence of the basic lenses. Fuchs considered the Chail series rocks to be Devonian mollasses, deposited after the Caledonian orogeny. On the other hand, Frank has suggested the possibility of these rocks being Precambrian.

Talalov (1972), postulated the vertical uplift and block faulting to explain the structural complexities of this part of Nepal. His geological map of Nepal shows a number of transverse and longitudinal faults in the study area. The conspicuous faults are the E-W fault passing along the line of Kusma and a transverse fault running through the village of Balewa and Baglung. The rocks of the area according to Talalov comprise the Cambrian sequence belonging to his Okharbot and Tara suites.

The Japanese workers Sako, Ishida & Ohta (From Ohta & Akiba, 1973), have suggested a structural framework identical to that of Nadgir & Nanda and Talalov. According to these authors, the structures of the study area are guided by the schuppen faults. The characteristic high angled faults in the area are passing through Kusma and south of Phalebas. The rocks of the study area, according to them, comprised the sequence of their Midland Meta-sediment group. The stratigraphy presented to the Midland Meta-sediment group is as under:

Lowermost subgroup	...	argillaceous succession
Lower subgroup	...	arenaceous succession
Middle subgroup	...	siliceous succession
Upper subgroup	...	calcareous succession.

Remy (1975), on the other hand, has shown a number of transverse faults in the Kali Gandaki region belonging to his Nepalese series, the important faults being the transverse fault passing along the Modi Khola and along the line of Karkinetta. An acute schuppen fault traverses the area along Kali Gandaki in the Baglung and Kusma section.

The stratigraphy presented by Remy (1975) to the rocks of Nepalese series is as under:

5. Carbonaceous schists and sandy carbonaceous
   upper series
4. Red schists and limestones and dolomites series
3. Grey schists and limestones and dolomites series
2. Quartzite series
1. Quartzo pelite series.