CHAPTER II

PREVIOUS WORK

KUMAON HIMALAYA IN GENERAL

The history of the geological investigations in the Himalayan areas of Kumaon and Garhwal could be divided into following 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 1939 saw a special emphasis being laid on the structural studies of the Himalayas. The development of the concepts of great thrusts in Europe had a

clear impact on the Himalayan studies during this period.

(3) The <u>third and the most recent period</u> 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 recently and the various major engineering projects, expedition, 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 this part of the Himalayas, and he has restricted himself to summarising the salient points of the previous work which have direct bearing on the problems connected with the present study. The interested reader will find excellent accounts of the previous investigations in the works of Vashi (1966), Desai (1968) and Munshi (1972). Keeping in mind the requirements of the present thesis, the author has summarised below a few selected references only.

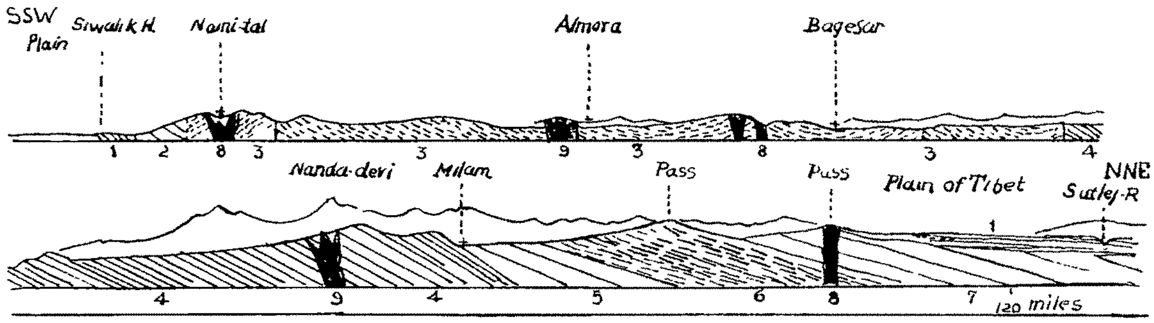
The earliest work that deserves mention is that of Strachey (1851), who conducted a number of traverses in Central Himalaya. His findings clearly established the distinction between the stratigraphical divisions of the high Himalayas from the "Azoic slates". Though his sections (Fig.II.1) did not show any thrusting, but they can certainly be considered as fore-runners of the thrust concept, and a remarkable achievement of his times. Medlicott's (1864) contribution coming out a few years later, marked an important landmark. He gave the first connected account of the geology of the Lower Himalayas between the rivers Ravee and Ganges. His work not only laid down the foundations on which our present knowledge of the Himalayan structure has been built and firmly established, but also his correlation and nomenclature of the rocks of Simla have undergone little alteration at the hands of the subsequent workers. 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:-

Fig. II.1.

The section across Central Himalaya by Captain Richard Strachey



1=Tertiary
2=Secondary & paleozoic ??
3=Metamorphic strata without fossils
4=Crystalline schists
5=Azoic slates
6=Palaeozoic
7=Secondary
8=Greenstone
9=Granite

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 and 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	Lower Gondwana
Infra Krol beds	
Blaini beds	
--------Unconformity--------	
Shali limestone and slate	?
Simla series (Infra Blaini)	
--------Unconformity--------	
Jaunsar series	Purana
--------Unconformity--------	
Chail series	Purana
Jutogh series	Archaeans (?)

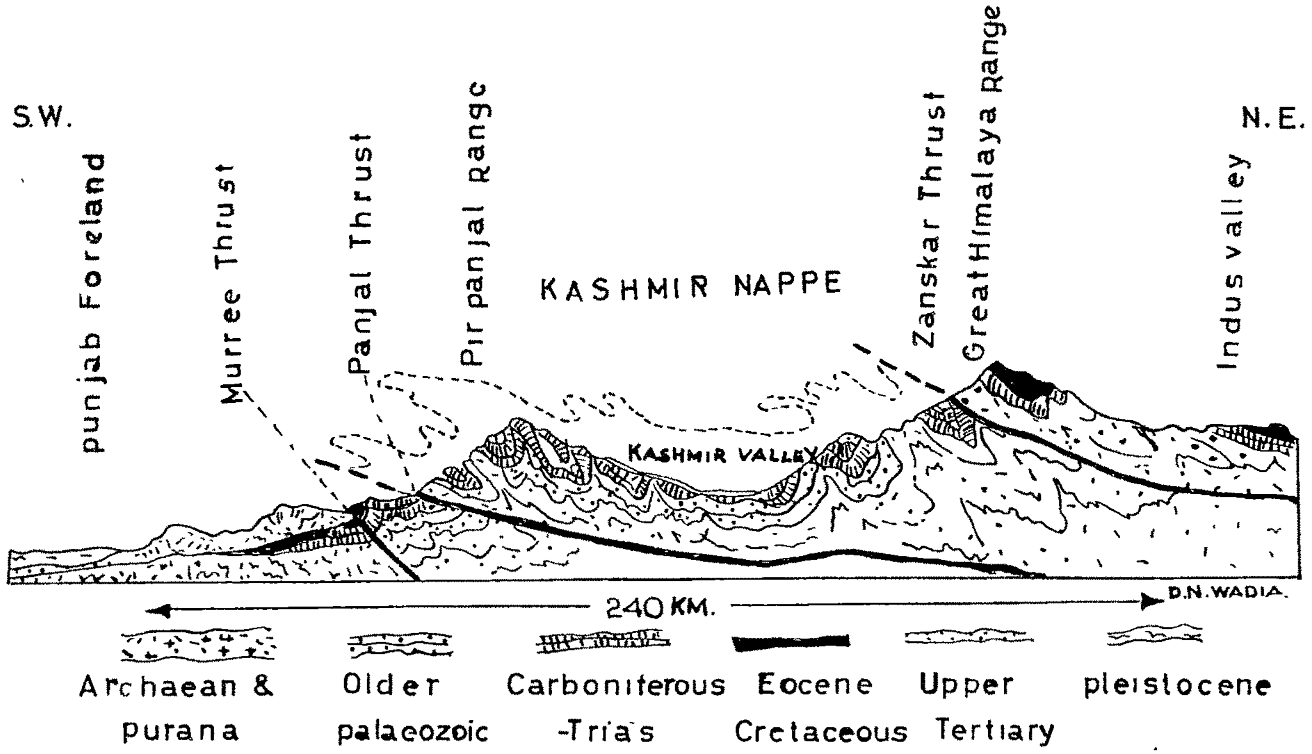
The classical work of Wadia (1931) deals with the syntaxial bend of the Himalayas in Kashmir-Hazara area. He has suggested a single Himalayan movement from the north. According to him, a tongue of the ancient and stable peninsular rocks extended upto the NW beneath a covering of Cenozoic rocks, and this 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 (Fig.II.2).

The most outstanding work on the Himalayas which directly concerns the present study, 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

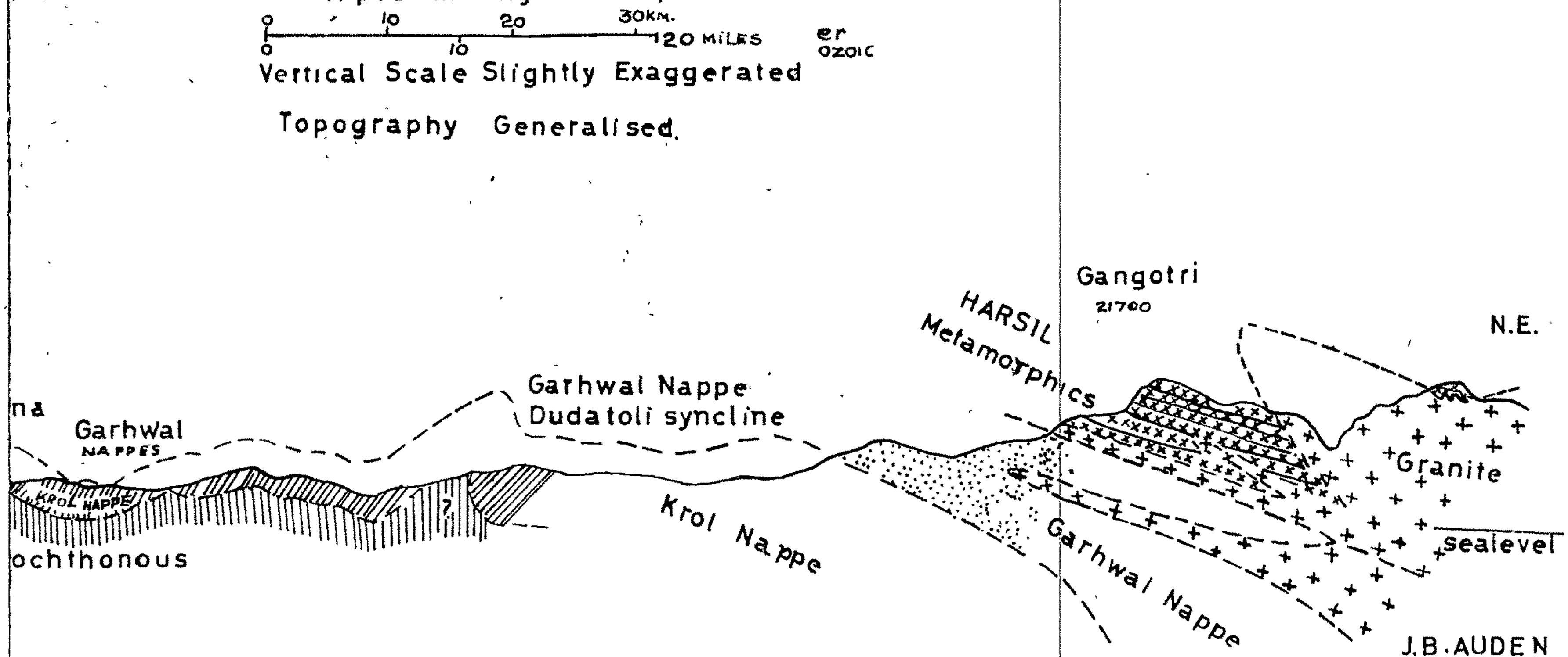
Fig. II. 2.

DIAGRAMMATIC SECTION ACROSS THE KASHMIR HIMALAYA, SHOWING THE BROAD TECTONIC FEATURES



TECTONIC SECTION ACROSS THE GARHWAL HIMALAYA

A preliminary attempt.



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

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

------------------Garhwal Thrust------------------

Nummulitic

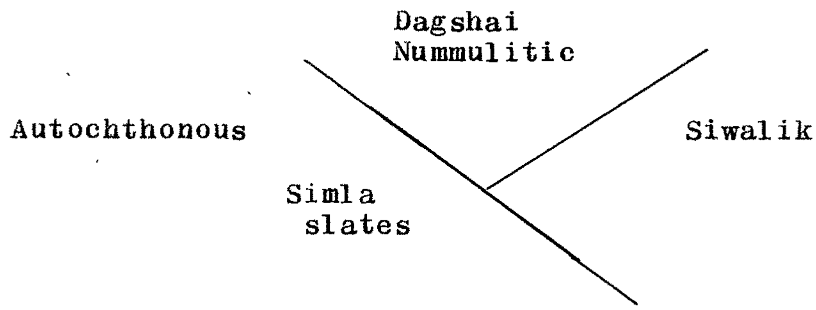
Tal

Krol

Blaini

Nagthat, Chandpur — metamorphosed and unmetamorphosed

------------------Krol Thrust---------------------



According to Auden, in the eastern Himalayas, also, there are two main thrusts: (1) one causing the Gondwana rocks to come over the Siwaliks and (2) 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.

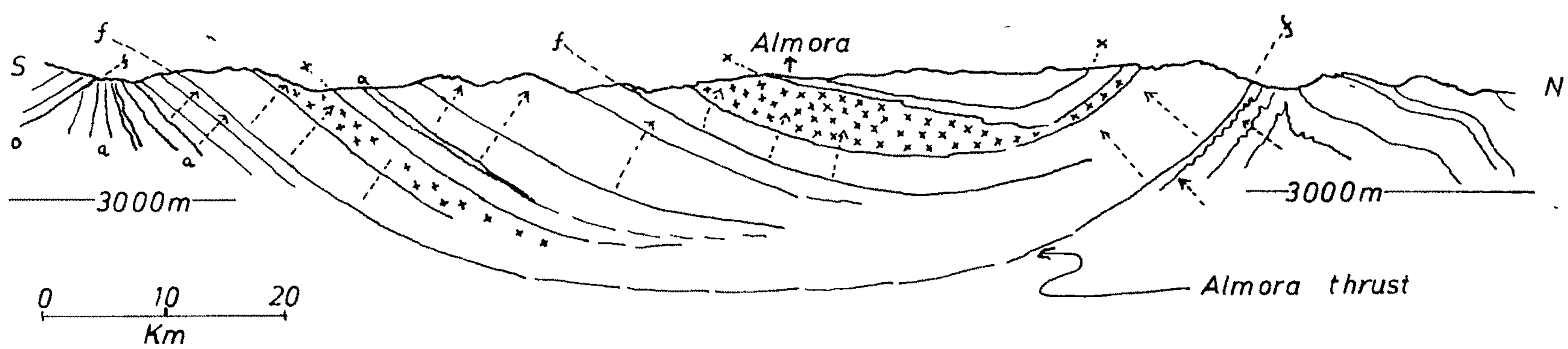
The work of Heim and Gansser (1939) forms another landmark in the study of Himalayas. They have dealt with various geological aspects such as petrology, stratigraphy, and structure of the Central Himalaya (mainly Kumaon, NW part of Nepal and Tibet Himalaya). Their regional correlation and tectonic interpretation 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'. This thrust separates the overlying crystalline rocks termed as Almora nappe (= Garhwal nappe of Auden) from the underlying Krol nappe rocks. The Almora thrust is perhaps synformally folded, outcropping to the south and north of Almora-Ranikhet. The two authors, however, are not clear whether their North Almora thrust joins up in the south with the South Almora thrust or with the Ramgarh thrust. However, in his later work, Gansser (1964) has shown the Ramgarh thrust as the southern limb of the O folded Almora thrust (Fig.II.4).

Stratigraphic ages assigned to the various tectonic units in Kumaon by Heim and Gansser (1939) and Gansser (1964) more or less coincide with those given by the comparable units in Garhwal and Simla areas by Auden and others. According to these workers, the rocks of Almora nappe are perhaps equivalent to the Chandpurs of Jaunsar series (a succession resting over the younger rocks of Krol nappe). Krol nappe includes a succession of Nagthats (Upper Jaunsar) through Infra Krols, Krols and Tals (Permian to Cretaceous).

Valdiya (1962) investigated the areas of Champawat and Pithoragarh in the eastern Kumaon and furnished structural data, which is of considerable use in regional study. According to him, the South and the North Almora thrusts of Heim and Gansser continued eastwards where they have been called as Ladhiya and Saryu thrusts respectively. Valdiya has assigned more or less the same stratigraphical ages to the various tectonic units in the Champawat-Pithoragarh area (Fig.II.5).

Fig. II. 4.

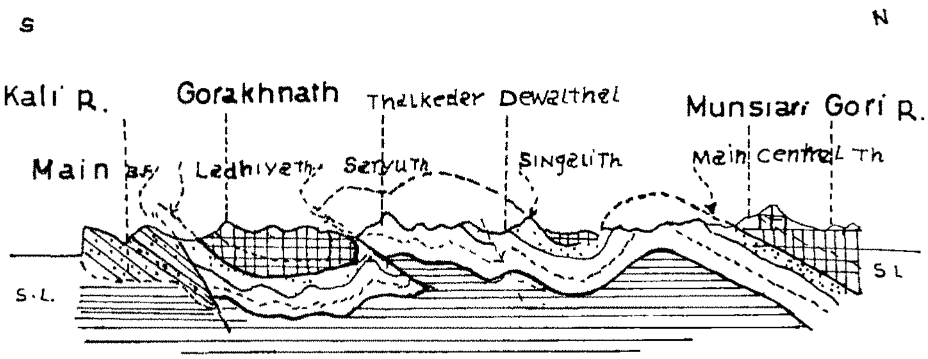
The crystalline thrust masses in the Kumaon Lower Himalayas Almora.



(A. Gansser 1964)

Fig. II. 5.

Tectonic section from Munsiari to Kali Valley near Tanakpur after K.S. Valdiya



- Lower Siwaliks of Tanakpur Area
- Unknown Autochthonous
- Calc zone of pithoragarh / Quartzite zone] Krol Nappe
- Crystalline zone of Askot & Lohaghat] Garhwal Nappe

0 5 10 Miles

Recently Merh (1968) has suggested that the North Almora thrust synformally joins up with the South Almora thrust and not the Ramgarh thrust (Fig.II.6).

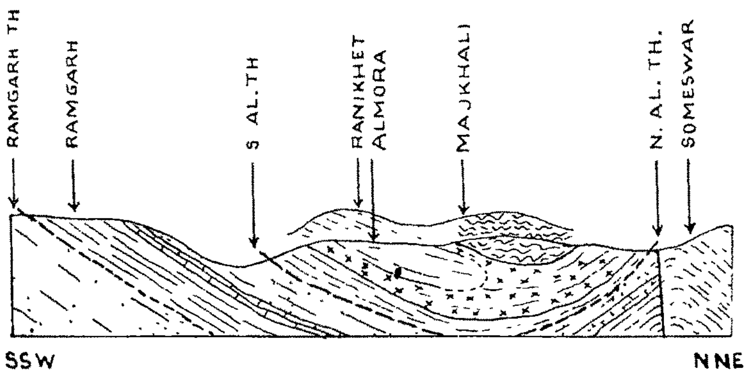
Of late, the metamorphic aspects of the crystalline schists of the Almora (= Garhwal) nappe have received much attention. Pande (1963) after working extensively all over Kumaon, has recognised following episodes in the metamorphic history of the Kumaon Himalayas:

Episode I : Load metamorphism resulting in the formation of first cleavage.

Episode II : Progressive regional metamorphism during which the rocks were folded, related with the development of main schistosity at an angle to first one.

Episode III : Widespread dislocation movement, degeneration of garnet and biotite, and formation of ferrimuscovite and chlorite.

Episode IV : Permeation of fluids from depth along the privileged paths like foliation and cleavage, resulting in the formation of porphyroblastic gneiss



MERH (1968)

THE SECTION BETWEEN BHOWALI AND SOMESHWAR parallel to biotite foliation and development of garnet in garnet.

The Chandpur schists around Ranikhet have been mapped by Vashi (1966) and Merh and Vashi (1965), and their studies have clearly established that the regional metamorphism (including migmatisation) was so closely related to the various deformational episodes that the study of one cannot be accomplished without taking into account the other. Directed stresses acting on the geosynclinal sediments at deeper levels possibly folded them into a big reclined structure. This folding synchronised with progressive regional metamorphism of the rocks. The metamorphic foliation that developed thus coincided with the axial plane of the fold. The metamorphic mineral assemblages that developed, characterise moderately high pressure and temperature. Shearing stress played an important role in the metamorphism as it is clear from the rotated garnets. Occupying the core of the fold are the rocks from the deeper levels. These deepseated rocks, nearest to the theatre of granitisation seem to have afforded easy and direct channels for the migmatising emanations from depth which rose along the foliation. Migmatisation might have immediately followed the folding and metamorphism of the rocks, and formed a part of the same orogenic event.

On account of the continued activity of the deforming stresses, the rocks ultimately ruptured, and the overfold culminated into the thrust. The differential slipping and shearing in the vicinity of the thrust not only crushed and granulated the schists but also brought down the metamorphic grade. The retrogression is characterised by the alteration of garnet and biotite to chlorite and of muscovite to sericite, the resulting rocks being phyllonite.

A short note published by Merh (1968) on the structural and metamorphic aspects of the Central Kumaon gives a clear picture of the geological evolution of the Kumaon region. Merh has come to the conclusion that some of the structural observations of Heim and Gansser are not valid and according to him, the South Almora thrust is in fact the southern limb of the Almora thrust, which joins up synformally with the North Almora thrust in the north. He has completely ruled out the possibility of the existence of a nappe at Ramgarh and has shown the regional structure between Bhowali and Mukteshwar as an uninverted succession. According to him, the Ramgarh thrust is younger to the Almora thrust, and possibly originated during the synformal folding of the latter.

In the same paper Merh has suggested that the Central Kumaon region has been affected by three deformational episodes. The earliest deformation appears to have folded the geosynclinal sediments into several large reclined isoclinal structures. The folding synchronised with the progressive phase of the regional metamorphism. Later, these overfolded rocks ruptured and this resulted in the Almora thrust. The superimposed second folding gave rise to the major structures like the Almora nappe synform and the anticlines at Bhowali and Someshwar. The third major folding has been along a NNW-ESE to N-S axis.

Very recently, Merh (Merh et al., 1972) has revised his opinion and now believes that the Ramgarh thrust is not connected with the folding of the Almora thrust, but is a very late structure.

As regards the granitic rocks of the Kumaon Himalaya, the earliest investigation was that of Oldham (1883) who gave a general description of the rock types encountered in his traverse from Almora to Mussoorie. He noticed, for the first time the presence of gneissose granites in crystalline schists. More work on these granitic rocks was carried out by Auden (1933) who considered the foliated granites to be of igneous origin, originally intruded in the crystalline Chandpurs in pre-Triassic times. Heim and Gansser (1939) have also considered the granites and gneisses of Almora region to be of igneous origin intrusive into schists. These workers believed that the granitic rocks were perhaps of a higher age than Tertiary as some Himalayan granites are considered to be.

Pande (Pande et al., 1963) was the first worker to suggest that the granites and gneisses of Kumaon were of metasomatic origin, and he preferred to call them as migmatites. His students have worked in a number of areas in Kumaon, and their work has shown that the gneissic rocks are a product of syn- and post-tectonic granitisation of metasediments. Sarkar et al. (1965) are also of the view that the Almora granites are a product of granitisation, a phenomenon connected with the orogeny. Similar views have been expressed by Merh and Vashi (1965) who believe that the gneisses of Ranikhet are (and Kumaon region in general) of migmatitic origin, having been derived by a syntectonic granitisation. Valdiya (1962) on the other hand considers the granitic rocks of Champawat in the east to be a batholith of granodioritic composition intruded during the Himalayan uplift.

The present author (Shah et al., 1968) in a preliminary note on the nature and origin of the granitic rocks of Almora, brought out the following sequence of events:

(1) Regional metamorphism at depth, and the formation of schists.

(2) Permeation of the schists with granitic juices or emanations, in two stages - first, the introduction of soda, and the formation of plagioclase bearing migmatites, then followed by the introduction of potash, resulting in the gradual replacement of plagioclase by microcline.

(3) Squeezing and emplacement of migma, giving rise to intrusive granite masses. The intrusive masses of trondjhemite, granodiorite and potash-granite, represent the different stages of the

migmatites showing progressive enrichment of potash.

PREVIOUS WORK ON ALMORA AREA

The earliest reference to the rocks of Almora area in somewhat detail is in the work of Heim and Gansser (1939). The two authors, took a traverse from Naini Tal to Almora, passing through Ramgarh, Peora and Gurari bridge, and they came across in the vicinity of Almora, an ascending succession of schists with increasing metamorphism upwards from sericite schists to garnet mica-schists. Over these schists further up was seen a muscovite-gneiss which in turn was overlain by mica-schists with quartzite layers. The Almora granite, resting over these schists formed a massive intrusion-coarse grained grey partly gneissic. These granites were again seen to underlie garnetiferous schists. According to these two workers, the Almora granite, which forms an intrusive mass, corresponds tectonically to the gneissic rocks of Ranikhet, the latter, in their opinion being a real ortho-gneiss.

Describing the granitic rocks of Almora, they have written (Ibid, p.54-55), "In contrast to the gneissified ortho rocks of Ranikhet, we found south of Almora town a large complex of massive muscovite-biotite-granite. The wooded Granite Hill shows clear outcrops including its northern contact. The large idiomorphic felspar (2 cm) gives the rock a porphyritic appearance. Inside the granite mass there are often more basic inclusions with biotite of a pre-granitic schisty relic structure. The composition of the granite is as follows: Large perthitic orthoclase and quartz of a slightly undulous extinction are the main components. Plagioclase of the oligoclase-andesine type is less abundant. Twin lamellas are usually indistinct. Occasionally the plagioclase shows zonar growth with a somewhat more acid core. Muscovite and biotite are well defined. The biotite, of a pleochroism from brown to reddish brown, frequently contains inclusions of zircon. Their pleochroitic haloes may have some bearing on the age of granite. The relatively large diameter of the haloes points to a higher age than Tertiary as some Himalayan Granites are considered to be."

Nautiyal (1941) too considered this granite mass as an igneous intrusion.

Pande et al. (1963) in his paper on the gneisses of the Kumaon region as a whole, suggested a metasomatic origin of the Almora granites. In a later paper written in collaboration with Powar (Pande and Powar 1968), he provided more details on the Almora granite mass. He has written that, "The Almora granite occurs in the form of NW-SE trending, concordant sheet like mass within an envelope of garnetiferous mica-schist with subordinate intercalations of micaceous quartzites and is exposed between the Kosi and Sual rivers. To the east of Sual river, the granite disappears under a capping of the metasedimentary rocks."

They further write (Ibid, p.58), "A traverse from south to north, shows garnetiferous mica-schists grading through felspathic garnetiferous mica-schists to well fôliated granite, a medium grained rock. This foliated granite, in turn, shows a transition to gneissose granite in which the felspar grains are augen to oval in shape and are aligned with their longer axes parallel to the mica foliation. In the central portion, the felspar becomes rectangular and larger and the gneissose granite grades into a crudely foliated or non-foliated rock. This is the main Almora granite.

Towards the north-east side, the gneissose granite shows stress effects and grades to garnetiferous mica-schist with interbedded quartzites. Structural studies indicate that the north-eastern margin of the granite mass corresponds to a tectonic contact. Xenoliths of schist and quartzite with the same structural trends as shown by country rock are present. Clots of mafic material, mainly biotite have been observed. In one zone within the gneissose granite, there is abundant development of garnet. A few quartz rich nodules have been noted projecting as 'knobs' on the weathered surface of granite. These almost invariably show, in thin sections, the development of sillimanite. Irregular quartz and pegmatitic veins, upto a foot in width, are seen cross cutting the granitic mass. Within the enclosing schist are present some felspathic patches".

As regards the mode of origin of the granitic rocks, the two authors have written (Ibid, p.61), "On the basis of the field characters supporting graniti-sation and the lack of evidence favouring forceful injection or magmatic stopping, it is concluded that the Almora granite is the product of the transformation of the metasediments."

On the basis of their study of zircon crystals, they concluded that the granitising fluids were magmatic in nature. Further according to them, "In all probability a dislocation zone, corresponding with the position now occupied by the main granitic gneisses provided the main channel along which the migmatitic material was repeatedly introduced, and on incorporating the country rocks gave rise to the main granite characterised by the presence of large porphyroblasts of felspar. The upward and outward diffusion of the granitic solutions resulted in the formation of the gneissose and foliated granites."

Gansser appears to have since revised his earlier opinion (Heim and Gansser, 1939) and in his later work (Gansser, 1964), he has described the Almora granitic rocks in the following words (Ibid, p.100), "South of Almora, instead of the granite gneisses, there are outcrops of a coarse to medium-grained muscovite-biotite-granite - the Almora granite. It appears in a thick lenticular sill like position, and does not cut throgh its surrounding gneisses and schists. It seems to correspond to a syngenetic granitisation without discordant offshoots in the form of dykes and apophyses. The massive granite includes frequent xenoliths of psammitic biotite rocks."

The structural aspects of the Almora area were investigated by Sarkar et al. (1965). These workers, after a detailed mapping of the various structural elements, concluded that the country rocks which mainly include garnetiferous mica-schists, quartzites, graphite schists, granite gneisses and granites, are characterised by three S-planes and four types of linear structures. S_2 (axial-plane cleavage) transects S_1 (bedding) near fold hinges, but is subparallel to S_1 on the limbs. S_3 is a later strain-slip cleavage on puckered S_2. Linear structures include L_1 - axes of recumbent and isoclinal folds of first generation; L_2 - intersection of S_1 and S_2; L_3 - slickenside, groove and mineral lineation on S_1 and S_2; and L_4 - minor puckers on S_2. They have suggested that the recumbent folds of the first generation developed by translatory movement varying in direction between north and west.

Describing the granite hill, they have written (Ibid, p.672), "An elongated granite body mantled by granite gneisses occupy the south western part of the area and gradational variation is noticeable from the schists through granite gneisses to granites. The granite gneiss, with well developed gneissic foliation and banding containing quartz, felspar and mica, exhibits different stages of transformation to coarse biotite granite and porphyritic biotite granite with felspar phenocrysts (porphyroblasts) upto 2.5 cm in diameter. Relicts of mica-schists and quartzites upto 10 meters thick are seen in the granite and granite gneiss, with their schistosity direction being subparallel to that of the gneissic banding and regional foliation. Locally, however, relics of meta-sediments within the granite show haphazard orientation suggesting mobilization of granite. In the southernmost part of the area the augen gneisses with similar regional orientation as above exhibit various transitional stages of granitisation of mica-schists and quartzites.

Based on A^{40}/K^{40} age data, these granites, according to Sarkar, et. al. (1965) ~~Polkanov and Gerling (1964)~~ originated during Lower Oligocene period by granitisation.