CHAPTER II

PREVIOUS WORK

KUMAON AND GARHWAL IN GENERAL:

The past record of the Himalayan investigation can be classified as belonging to three periods: (1) An early period of sixty years, beginning with 1860. This period is noteworthy, for during this the foundations of Himalaya's stratigraphy were laid. (2) The period between 1920 and 1939 is the one during which the structural aspects of the Himalayas received greater attention. The impact of the concepts of large scale thrusts developed in Europe is discernible in the structural studies of the Himalayas during this period. (3) The period from 1939 - 1965, particularly after the second world war, during which considerable knowledge of the local structures in the Himalayas has been added, both by Indian and foreign geologists.

During the last few years, Himalayas have received greater attention from the geologists and large amount of data has been made available. Recent work on Himalayas, comprises investigations by a number of agencies. Apart from the systematic mapping by the G.S.I., much information is available from the following sources as well:-

(1) Studies carried out in connection with major engineering projects and prospecting for oil.

(2) The mountaineering expeditions and traverses in isolated parts of the Himalayas.

(3) Research work in various Universities.

Large Himalayan tracts are still lying virgin. However, the work done by previous investigators in the accessible parts is of great interest and help to the future workers in understanding the complex geology of the Himalayas.

The author does not propose to deal with the contributions of all the workers in detail. An excellent summary of the Himalayan studies has been given by Vashi (1966) to which the reader is referred.

In the following pages, the author has discussed briefly only those contributions which are relevant to the present investigation.

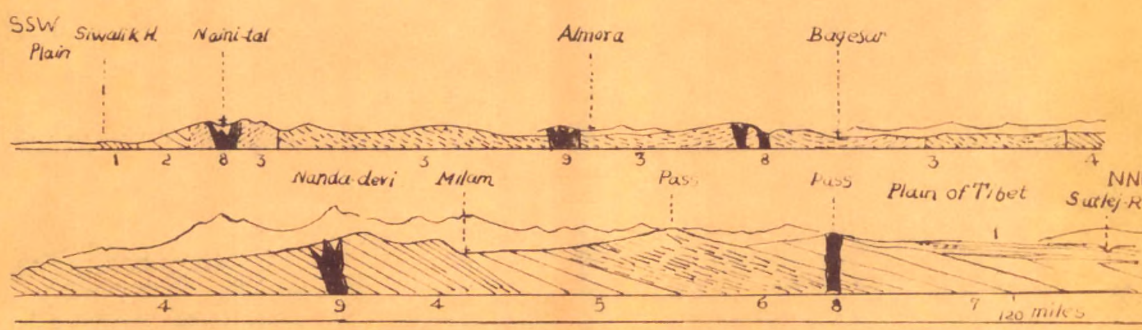
STRUCTURE AND STRATIGRAPHY:

The earliest work that deserves mention is that of Strachey (1851), who conducted a number of traverses in Central Himalayas. His findings clearly established the distinction between the stratigraphical divisions of the high Himalayas from the "Azoic slates". Though his sections (Fig. 7) 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 contribution. 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

Fig 7

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

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 subdivisions, 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 Himalayas 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.

The first modern section of thrust folding over the entire width of Himalaya, although done in a schematic way, was presented by Loc'zy (1907), a Hungarian geologist. He traversed the Eastern Himalayas, and his section of Kanchenjunga showing an enormous overfold with huge reversed series, thrust for 150-200 km. towards the Indian plains.

Burrard (1912) in an interesting paper on the origin of the Himalayas, suggested that the Himalayan folds overthrust towards south, could be on account of the movement of the subcrust towards north, and the subsequent overbalancing of the folds towards south.

Another noteworthy contribution towards the structural interpretation of the 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 Himalayas:-

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 has been resolved into a NE-SW direction in Kashmir and a NW-SE in Hazara (Fig. 8).

The most outstanding work on the Himalayas which directly concerns the present study, came from Auden(1937), who gave an excellent account of the structure and stratigraphy of the Garhwal region (Fig. 9). In this work, he

Fig 8

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

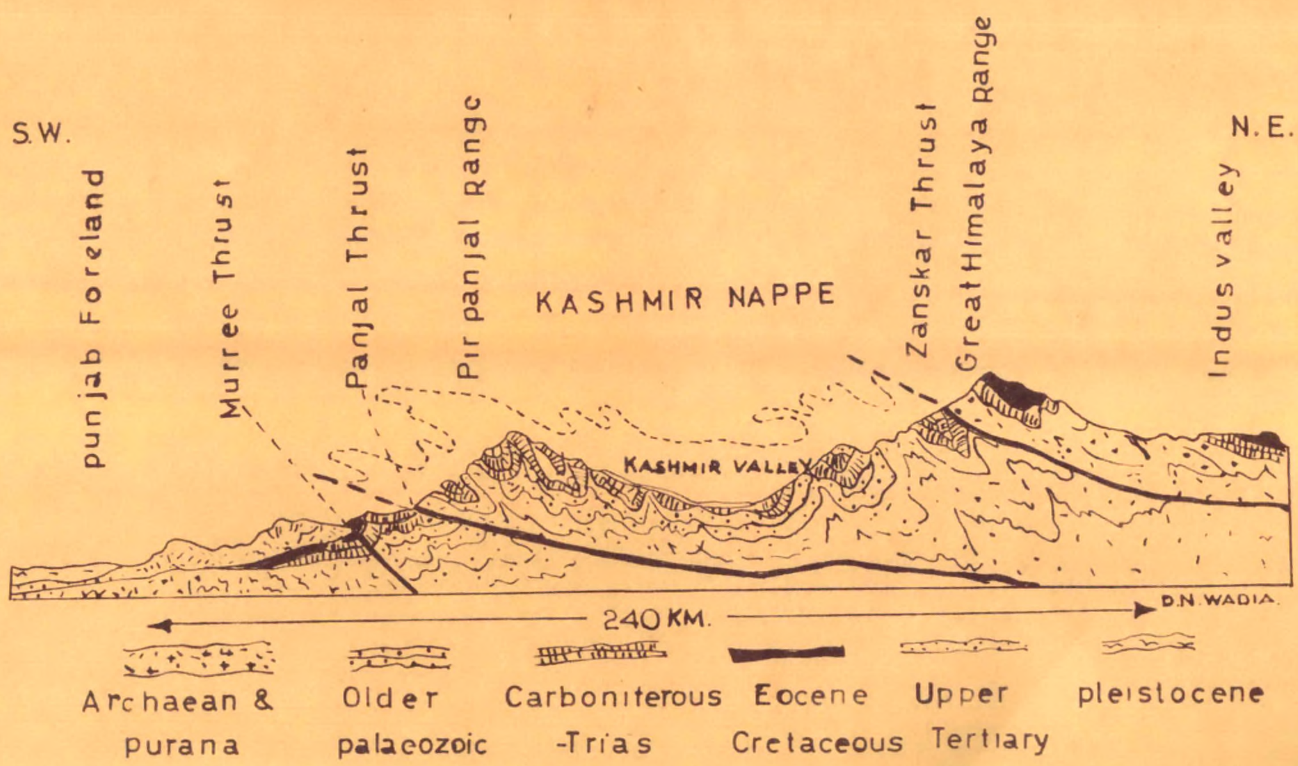
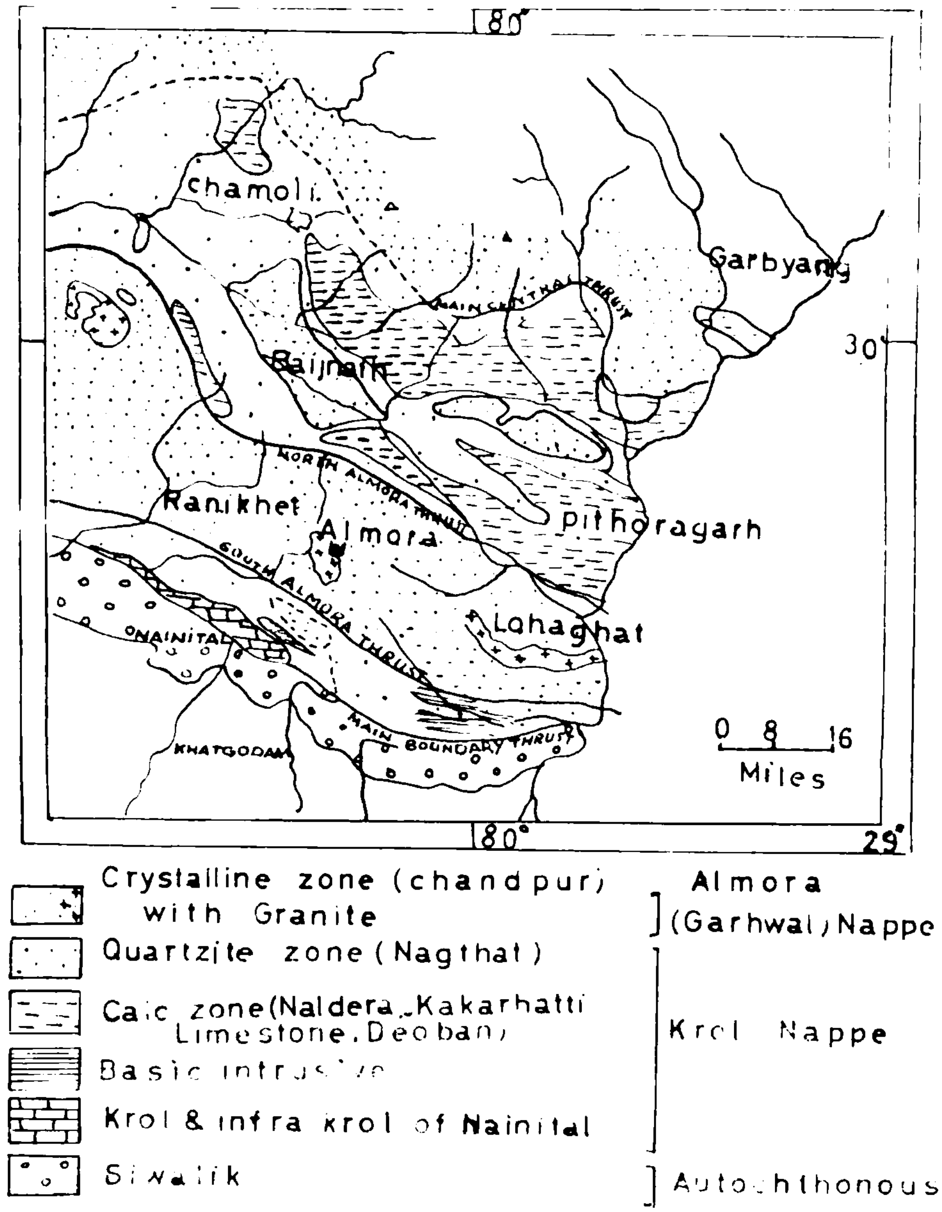


Fig 9



Regional tectonic map of kumaon (after Auden (1937), Heim and Gansser (1939) and Valdiya (1962).

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:-

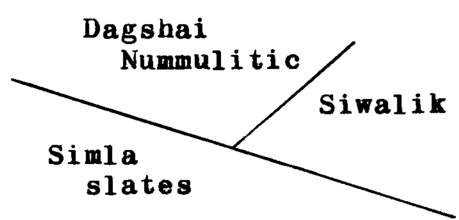
Garhwal Nappe	Chandpur (metamorphosed) ------- Thrust --------- Nagthat, Chandpur — Little metamorphosed Boulder beds, slates and limestones of uncertain stratigraphical horizon occur in one outlier below metamorphosed Chandpurs

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

	Nummulitic	
	Tal	
	Krol	
Krol Nappe	Blaini	
	Nagthat	metamorphosed and unmetamorphosed
	Chandpur	

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

Autochthonous

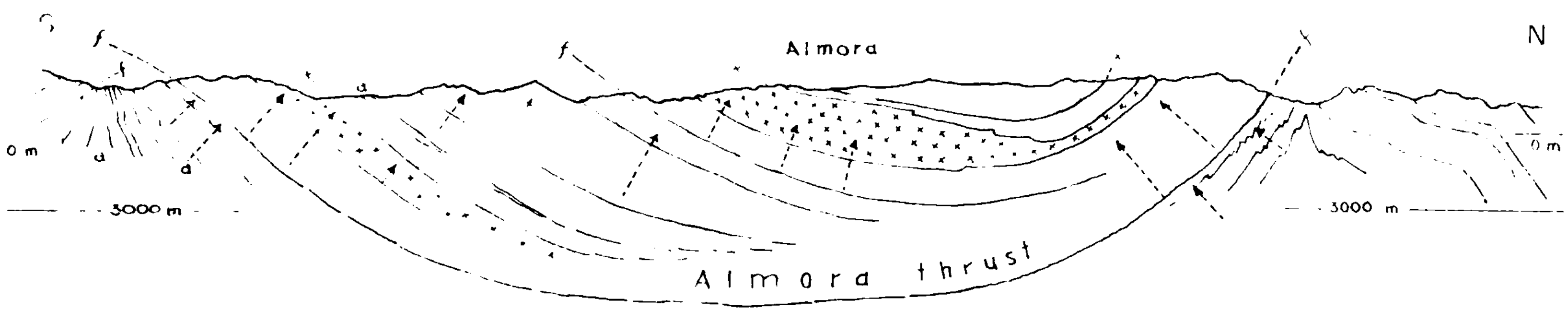


According to Auden, in the eastern Himalayas, also, there are two main thrusts: (1) One causing the Gondwana rocks to come over the Siwaliks and (2) the thrust separating the Daling series from the underlying Gondwana. He further correlated these two thrusts with the Krol and Garhwal thrusts of the Garhwal 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 Himalayas (mainly Kumaon, NW part of Nepal and Tibet Himalayas). 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, where it has been termed 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 their southern limb of the folded Almora Thrust (Fig. 10).

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,Tals(Permian to Cretaceous).

Fig 10



The crystalline thrust masses in the Kumaon Lower Himalayas Almora, Baijnath and Askot, (A. Gansser 1964)

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 as well. According to him, the South and the North Almora Thrusts of Heim and Gansser continued eastwards where they are 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. 11).

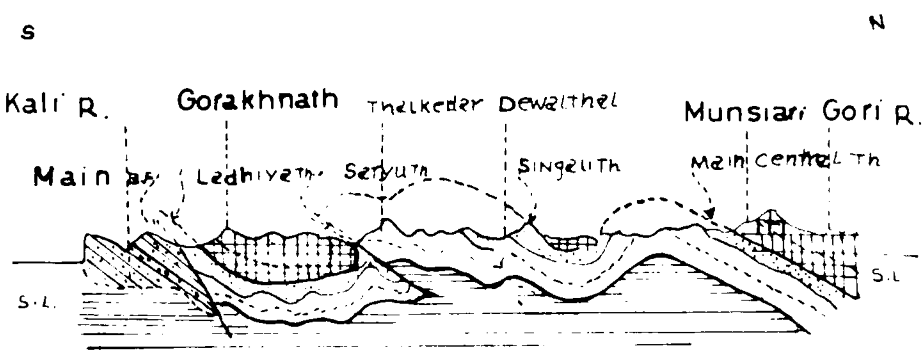
Recently Merh (1968) has suggested that the North Almora Thrust synformally joins up with the South Almora Thrust and not the Ramgarh Thrust (Fig. 12).

GRANITIC ROCKS:

Apart from the structure and stratigraphy, the associated granitic rocks have also been studied in the various parts of Central Himalayas. The earliest work is that of McMahon (1887) on the Chor Granites near Simla in Punjab Himalayas. He first regarded the granites as highly metamorphosed sediments but later on revised his views and considered them to be of intrusive nature. In this later work he has summarised his view on the origin of the Himalayan gneissose granite and contended that they

Fig 11

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



Lower Siwaliks of Tanakpur Area

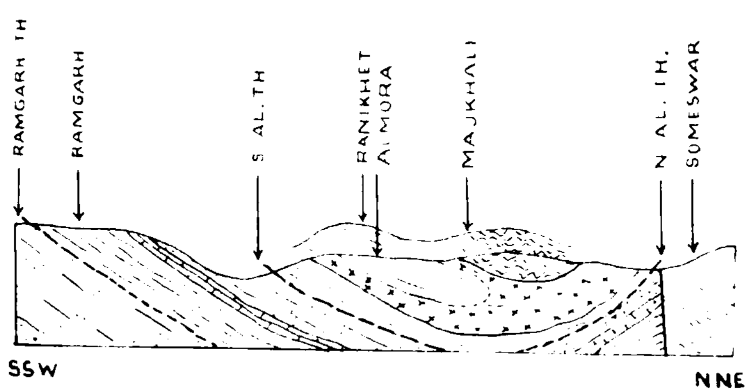
Unknown Autochthonous

Calc zone of pithoragarh
Quartzite zone
] Krol Nappe

Crystalline zone of
Askot & Lohaghat
] Garhwal Nappe

0 5 10 MILES

Fig 12



MERH (1968)

THE SECTION BETWEEN BHOWALI
AND SOMESHWAR

were all identical and of Tertiary age and definitely of igneous origin.

Middlemiss (1887) however considered the gneisses to be much older and perhaps pre-Triassic.

Pilgrim and West (1926) too, considered the granites of Chor mountain to be of intrusive origin but they considered them to be of Tertiary age.

Burrard, Hayden and Heron (1932) in their work on the geography and geology of the Himalayas putforth a classification, dividing the Himalayan rocks into two groups: (i) metamorphics composed of granite gneiss and crystalline schists and (ii) a series of fragmental rocks of undoubtedly sedimentary origin such as slates, quartzites, conglomerate and limestone. In their opinion, the gneiss was perhaps intrusive in the metamorphics, but whether it was wholly an igneous rock or was a composite gneiss formed by injection and rolling out of granite veins along the foliation of mica schists was uncertain.

Wadia (1932) described the gneisses of Nanga Parbat, as being more or less of the nature of injection or permeation gneisses along the peripheries with the metamorphics into which they are intrusive.

Auden (1933) investigated the problem of the age of the Himalayan granites and concluded that while "in Tibet and the Hindukush, there is indisputable evidence of late Cretaceous or Tertiary granites" those of the Central Himalayas and border ranges closer to the peninsula, which have been considered to be of Tertiary age, were originally intruded in pre-Triassic times and belonged to pre-Himalayan tectonics.

Heim and Gansser (1939) believe that the granites of Almora region were intrusive into the schists. The formation of gneiss according to them, is partly due to a primary marginal facies of granite and partly to tectonical effects.

Petermisch (1949) was the first worker to invoke a metasomatic origin for the granites of Himalayas. He putforth his views on the Nanga Parbat granites, and invoked granitisation of batholithic dimensions. Describing the gneissic granites of that area, he writes (1949,p.207), "These rocks have undergone regional metamorphism during early Tertiary orogeny. Regional metamorphism of argillites progresses from slate and phyllites, though mica schists, biotite para-gneiss, kyanite schist to sillimanite para-gneiss are due to lit-par-lit replacement as against mechanical injection along active foliation planes makes banded gneiss. The metamorphic isograde is seen to be independent of depth and a function of differential introduction of heat from below. The degree of metamorphism and granitisation are systematically linked and connection of heat by the granitisation solution is held responsible for high grade regional metamorphism in the upper part of the crust".

Pande (Pande and others, 1963) considers the granites and gneisses of Kumaon to be of metasomatic origin and he prefers to call them as migmatites. His students have worked in a number of areas in Kumaon, and their work shows that the gneissic rocks are a product of syn- and post-tectonic granitisation of metasediments. Valdiya (1962) however preferred to consider gneissic rocks of Champawat area to be batholiths of granodioritic composition, intruded during the Himalayan uplift.

On the other hand, Sarkar (Sarkar and others,1965) is of the view that the Almora granites are a product of granitisation, a phenomenon connected with the orogeny. Merh and Vashi (1965) also believe that the granitic gneisses of Ranikhet area (and Kumaon region in general) are in fact, migmatites, derived from the pelitic schists by granitisation, which was for the most part syntectonic.

Recently the author has in a paper (Shah, Desai and Merh, 1968) very clearly brought out the sequence of events to explain the origin of the granitic rocks of Kumaon area. They have suggested 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.

WESTERN KUMAON:

The author has summarised below the information available on the rocks of the Ranikhet-Almora region in particular. A brief geological account based on the work of a number of investigators on the areas surrounding Majkhali, provides an ideal background for the present study.

Considering the works of Auden (1937) and Heim and Gansser (1939), the rocks of the area forming the western part of the Kumaon belong to two distinct structural units - the Krol and the Almora Nappe. In the south, the town of Bhowali is situated on an anticline in Krol Nappe. From Bhowali, northwards, the rocks almost uniformly dip to ENE or NE as far as a little to the south of Someshwar, after which the other limb of the synform is encountered which dips in the opposite sense. The Almora Thrust (Garhwal Thrust of Auden) which separates the underlying younger rocks of the Krol Nappe (from those of Almora Nappe) is also synformally folded.

Heim and Gansser (1939) have termed its northern flank as the North Almora Thrust. They are, however, not clear about the exact location of the southern flank of this folded thrust. Between Bhowali and Ranikhet, the two authors have shown two thrusts dipping to the NE, and the one near Ramgarh, in their opinion, joins up with the North Almora Thrust. The other one at Upradi (8.5 air km. south of Ranikhet) is their South Almora Thrust. According to them (1939, p.28) the region between Bhowali and the South Almora Thrust forms a recumbent syncline overturned to the NE.

Merh (1968), however, does not believe in the existence of such an inverted syncline. His investigations in the Ramgarh-Bhowali area, south of South Almora Thrust, clearly rules out any recumbent folding. The uniformly NE dipping rocks hardly show any evidence of a inverted fold. He is more inclined to consider the thrust at Upradi (South Almora Thrust) as the southern limb of the folded Almora Thrust, joining up synformally with the North Almora Thrust in the north. He considers the thrust at Ramgarh to be of later date than the Almora Thrust, and in some way connected with the synformal folding and Kroi Thrust movement (Fig. 12).

Much information is available from the Ranikhet and Almora areas which have been investigated quite in detail by a number of workers.

Pande (1963) who has worked extensively all over Kumaon, has recognised the 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 parallel to biotite foliation and development of garnet in garnet.

Sarkar and others (1965) investigated the structural geology of the rocks around Almora. According to them 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 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 are developed by translatory movement varying in direction between due north and west. Sarkar (1965) has considered the age of regional metamorphism in this part of Himalaya as Lower Oligocene and has also concluded that the granitisation is also of the same age.

Powar (1966) has studied the granitic rocks of Almora in detail, and has come to the conclusion that they are the products of granitisation.

The Ranikhet area, to the west and southwest of Majkhali has been mapped by Vashi and Merh in considerable detail (Merh and Vashi, 1965; Vashi, 1966). Their study has clearly established that the regional metamorphism both progressive as well as retrogressive, and the migmatisation as shown by the rocks of Ranikhet area, are intimately related with the orogenic movements, which deformed the geosynclinal sediments. According to these two authors, the Ranikhet area constitutes a big recumbent structure, reclined to the north, and its core is occupied by the migmatitic gneisses. It has been pointed by them that the regional metamorphism (including migmatisation) is 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 assemblage that developed, characterises 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 deep-seated 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.

On account of the continued activity of the deforming stresses, the rocks ultimately ruptured, and the overfold culminated into the (South Almora) thrust. In another paper, Merh and Vashi (1966) have described the structural elements of the rocks in the vicinity of the South Almora Thrust, recorded near Upradi, South of Ranikhet. Considering the dragfold axes in the thrust zone, they have tentatively surmised that at least in this part, the movement along the thrust has been due WNW.

Sarkar, Kumar and Roy (1966) in their paper on Ranikhet have also described the tectonic pattern of the area. Their work is to a certain extent identical to that of Vashi (1966). They have mapped 3 S-planes and three types of lineations and suggest that the recumbent folds of the first generation are developed by translatory movement mostly along directions between E and ESE.

Preliminary studies of the author himself in the Majkhali area, have been published in the form of short note, wherein the significance of the widespread strain-slip cleavage of Majkhali pelitic rocks has been discussed (Merh and Desai, 1966). In a recent paper Merh (1966) has suggested that the area has been affected by three deformational episodes. The earliest deformation appears to have folded the geosynclinal sediments into several big reclined isoclinal structures. This folding synchronised with the progressive phase of regional metamorphism. With the increasing intensity of the stresses, the overfolded rocks ruptured and culminated into Almora Thrust. The retrogression in metamorphism due to this dislocation, has given rise to an apparently inverted sequence of metamorphic zones.

The superimposed second folding gave rise to major structures like the synform at Almora and the anticlines at Bhowali and Someshwar. The third and possibly the last major folding, has been responsible for the development of folds on all scales along NNW-SSE to N-S axes.