CHAPTER 6.

M E T A M O R P H I C   H I S T O R Y

Only small portions of the Almora and Baijnath nappes fall within the study area and thus they fail to reveal all the metamorphic events that have affected the nappe as a whole. Previous work by a number of investigators in different areas, has established an interesting and varied metamorphic history, extending over a considerable period of geological time. A number of sequentially connected metamorphic episodes have affected the rocks which clearly bear the imprints of a succession of regional metamorphisms of different types. It has further been established that the gneissic rocks of the Almora nappe are migmatised derivatives of mica schists, and that the migmatisation preceded, synchronised with, and even outlasted the main orogenic events. Thus the deformation, regional metamorphism, and migmatisation formed an inter-related sequence of orogeny.

In the present area, unlike those investigated by the previous workers, all the representative rock types are not present, and hence the history of metamorphism and migmatisation could not be built on the basis of the available evidences. The author, however, has succeeded in fitting in the various rock types of the study area into the regional metamorphic framework.

Pande (1963), Powar (1965) and Das (1966) were the first to work out the metamorphic history of the Almora nappe rocks. They have, working in different areas of Kumaon, postulated six metamorphic episodes:

Episode I : Load Metamorphism.

Episode II : Progressive Regional Metamorphism.

Episode III : Retrograde Regional Metamorphism.

Episode IV : Progressive Regional Metamorphism and Migmatisation.

Episode V : Retrograde Regional Metamorphism.

Episode VI : Dislocation Metamorphism or Late Cataclasis.

Vashi (1966) and Desai (1968) have also, working in Ranikhet and Majkhali areas, arrived at similar conclusions. These two workers have suggested that a close synchronisation existed between the various metamorphic and structural events. They worked out the following metamorphic history:

I. The earliest metamorphism of the geosynclinal sediments due to vertically directed load, prior to the main upheaval and folding.

II. Regional metamorphism that accompanied the main orogenic upheaval and the isoclinal folding of the metasediments.

III. Retrogressive changes brought about by intense shearing during the Almora Thrust movement.

IV. Mineralogical and textural changes during the folding of the Almora nappe.

V. Late hydrothermal changes.

The important events of metamorphism have been ideally described by Desai (1968,pp 201-203) in the following words, "After the deposition, the sandstone-shale sequences underwent some load metamorphism on account of the weight of the overlying sediments in a sinking geosynclinal basin. The only evidence of this early metamorphism is at present seen in the form of ill-preserved bedding schistosity (S). Perhaps during this stage, the metamorphosed sediments that sank deeper got granitised also."

"With the first main orogenic upheaval, the metasediments were subjected to severe deformational stresses resulting into a series of recumbent isoclinal folds. During this episode, the existing metamorphic characters for the most part were impressed on the rocks (and the mineral assemblages characteristic of pelites, semipelites and psammites belonging to "almandine" zone of Barrow came into existence). The principal foliation - the main schistosity - was the result of this progressive regional metamorphism that accompanied the isoclinal folding and marked the axial plane direction of the folds. The folding seems to have continued for a considerable time and synchronised with the main period of migmatisation. Transformation of schists into gneissic rocks, proceeded mostly along the axial plane schistosity."

"The continued activity of the deformational stresses, ultimately culminated into the Almora thrust. In the Majhkhali area, a number of shear planes, parallel to the main dislocation developed during this thrusting, and along narrow zones of slipping, phyllonitic rocks with retrograde mineral assemblages are seen to have formed. This phase of retrogressive metamorphism which immediately followed the 'progressive' phase obviously crushed and granulated the rocks, and brought down the metamorphic grade of the rocks, along these planes of shearing."

"During the next upheaval, the area was affected by another folding during which the Almora nappe was synformally folded (F_2). In the Majhkhali area, during this deformation, the main axial plane schistosity (S_1) was crinkled and microfolded, giving rise to a strain-slip cleavage (S_2) at many places. The effects of this folding are very well preserved in the central portion of the area. Metamorphic changes that accompanied this folding consist of

(i) bending and breaking up of earlier mica flakes and their subsequent recrystallisation.

(ii) granulation of quartz grains and their recrystallisation.

(iii) formation of a new (static) garnet.

(iv) The development of biotite porphyroblasts almost parallel to the axial plane of the microfolds and crinkles."

"The next conspicuous event is characterised by a N-S folding (F_3) giving rise to open flexures on various scales."

The retrogressive metamorphism caused by the Almora thrust is described in greater detail by Vashi (1966) from Upradi area south of Ranikhet. He has shown a progressive downgrading of garnet-mica schists to phyllonites through various intermediate stages.

METAMORPHIC ASPECTS OF THE ALMORA AND BAIJNATH NAPPES

Metamorphically, the portion of the Almora nappe falling within the study area is not much interesting. The prevalent rock is a gneiss and nowhere are the original mica schists encountered. Thus the evidences of load metamorphism and main progressive regional metamorphism are almost non-existent. Of course, there is little doubt in surmising that the gneissic rocks derived metasomatically from the pre-existing mica schists.

The starting point in the study area is the gneissic rocks, and these show only a partial record of the subsequent metamorphic changes. In the following table, the author has given the various metamorphic events recognised in the area:

Vashi (1966) & Desai (1968)	Author's Area
I. Load Metamorphism	Not recognised
II. Main progressive regional metamorphism coinciding with isoclinal folding	Obliterated but recorded in the form of gneissic foliation

III.	Dislocation metamorphism due to Almora thrust.	Mylonitisation of gneisses with retrogressive changes and the development of phyllonites.
IV.	Progressive metamorphism during the folding of the Almora thrust.	Not recognised
V.	Late hydrothermal changes	Present sporadically; Epidioritisation.

From the above, it will be seen that only the retrogression related to the North Almora thrust characterises the dominant metamorphic changes that could be studied in detail. The field mapping has shown that the shearing due to thrusting has affected the rocks in two ways:

(i) Development of numerous zones of mylonitised gneiss.

(ii) Development of phyllonites all along the North Almora thrust.

Mylonitised Gneisses

Intense shearing along narrow zones has resulted into the following retrogressive changes:

Textural changes: (1) Progressively increasing granulation and reduction in grain-size of all minerals. (2) Formation of streaky aggregates of quartz granules and of shreds of sericite, chlorite, epidote grains etc. (3) Development of a very strong shear cleavage indicating slipping.

Mineralogical changes: (1) Diminution in the grain-size of quartz. (2) Progressive destruction of potash felspars to a sericitic mass, and of plagioclase to saussurite and sericite. (3) Alteration of biotite to chlorite. (4) Alteration of muscovite to sericite.

Phyllonites

The phyllonites are the final and end products of retrogression due to the thrust. These highly sheared and cleaved rocks resembling phyllites, typically represent the culmination of a downgrading process brought about by intense shearing. Unlike most other areas where complete sequences of mineralogical and textural changes leading to the phyllonisation of garnet-mica-schists through various intermediate stages can be observed, the phyllonites of the present area do not show any gradation. Occupying a narrow zone beneath a thick quartzite formation, these show a complete transformation with no relicts of parent rock.

It was, therefore, possible to work out the details of this retrogressive metamorphism only on the basis of the studies of Vashi (1966) and Desai (1968). This metamorphic event has been ideally described by these two workers.

Textural and mineralogical changes leading to the development of phyllonites are as under:

(1) The quartz grains finely granulated and arranged in streaks.

(2) Progressive disappearance of the original plagioclase of the schists.

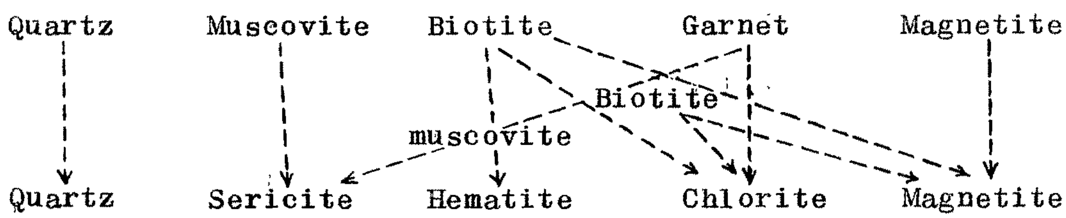
(3) Crushing and granulation of garnet with formation of drawn out streaks and its progressive alteration to chlorite.

(4) Progressive alteration of biotite to chlorite and muscovite.

(5) Transformation of muscovite into sericite shreds.

(6) Generation of hematite and magnetite grains scattered all over the rock, obviously a by-product of the degeneration of garnets and biotites.

The following diagram shows the mineralogical changes leading to phyllonisation:



In the present area as stated already, only the final products of retrogression are encountered.

EVOLUTION OF GNEISSIC ROCKS

It has now been firmly established that the gneissic rocks of Almora nappe are derived from the original mica schists by a process of migmatisation. The schists were gradually transformed into gneisses mainly by the addition of alkalis. The transformation started with the addition of Na_2O which was soon followed by K_2O, the K_2O progressively replacing Na_2O.

The evidences to prove such a migmatitic origin of the gneisses could not be recorded in the study area because nowhere the unmigmatised schists were encountered. It was, therefore, not possible to observe and work out the sequence of textural, mineralogical and chemical changes leading to migmatisation. Such sequence has been ideally worked out in the Ranikhet and Majhkhali area by Vashi (1966) and Desai (1968) and the author has derived much from these works.

Vashi (1966) has classified the migmatitic gneisses of Ranikhet into the following four types showing an increasing migmatisation.

1. Felspathic schist
2. Permeation gneiss
3. Augen gneiss
4. Porphyroblastic gneiss.

In the Ranikhet area, the migmatisation is first recorded in the felspathic schists with the appearance of abundant plagioclase in the ground mass, and then as augens and finally as well formed (very often idiomorphic) porphyroblasts. The potassic emanations appear to have followed the sodic ones, and show increasing activity from augen bearing to porphyroblastic variety of gneisses. All gradual stages of replacement of plagioclase by potash felspar are observed in the gneissic rocks. In the augen gneisses the microcline is seen in the ground mass only, but with its increasing content in the porphyroblastic variety, a number of plagioclase porphyroblasts are seen in various stages of gradual replacement by microcline.

Desai (1968) has rallied adequate evidences to suggest that the migmatisation preceded, synchronised with, and outlasted the main deformational events, viz. isoclinal folding, thrusting and folding of the thrust. The earliest phase of migmatisation was initiated before the first folding set in, and was confined to the deeper parts of the geosynclinal basin. This migmatisation broadly coincided with the load metamorphism. The bulk of the synkinematic migmatisation synchronised with the main orogenic upheaval comprising the first and the second foldings.

The gneisses of the study area represent an advanced state of migmatisation and comprise porphyroblastic and augen bearing varieties. Unmylonitised portions very clearly reveal the original structure and texture of the gneisses. Texturally and mineralogically, they compare very well with similar rocks described by Vashi and Desai.

Chemically too, the gneisses, both mylonitised and unmylonitised, are more or less akin to those of Ranikhet (Table 6.1).

An interesting feature of the gneissic rocks of the study area is the sporadic development of quartz tourmaline seggregations. These have metasomatically grown in mylonitised gneisses sometime after the shearing; and these spindle shaped or elliptical bodies lying with their axes along the foliation, typically show rims of quartz and felspar enclosing tourmaline rich cores. These masses

TABLE 6.1

Chemical compositions of Ranikhet and Someshwar gneisses

	Ranikhet (Vashi 1966) (wt %)	Present Area	
		unmylonitised gneiss (wt %)	mylonitised gneiss (wt %)
SiO_2	65.23	64.9200	66.1000
Al_2O_3	15.42	17.4088	14.5834
Fe_2O_3	1.51	1.5532	3.9396
FeO	4.28	2.5800	2.8600
CaO	2.70	3.2266	2.3834
MgO	3.01	1.9182	2.9266
Na_2O	2.97	1.2199	2.9702
K_2O	5.18	5.5536	3.4320
TiO_2	0.036	-	-
P_2O_5	0.052	-	-
MnO	0.003	-	-
Loss of Ignition	-	0.3820	0.6260
Total	100.441	98.7623	99.8262

have grown subsequent to the shearing, perhaps during the waning period of migmatisation, and comprise the "pegmatoid stage" of Mehnert (1968, p.294). The most striking fact about these bodies is their metasomatic differentiation into quartz-felspar-rich, and tourmaline-rich portions. The author is unable to throw more light on the exact mode of origin and mechanism of growth for these bodies. But there is little doubt that they are metasomatic growths related to the final stages of migmatisation.

EVIDENCES OF LATE HYDROTHERMAL CHANGES

Some hydrothermal activity took place after the main orogenic activity when the deformations ceased to be effective. Perhaps this activity was in some way connected with the waning phase of migmatisation and the various mineralogical transformations took place without any shearing.

In the study area, these late hydrothermal changes are sporadically recorded and belong to the following categories:

(1) Sericitisation of potash felspars and chloritisation of biotite in unmylonitised gneiss.

(2) Epidioritisation of the dolerite sills; the original pyroxene has changed to hornblende and chlorite, while the plagioclase has partially been saussuritised.

SUMMARY OF THE METAMORPHIC EVOLUTION

The entire metamorphic evolution including the migmatisation and retrogression, worked out with the help of data from the neighbouring areas, could be summarised into the following series of events:

(1) Load metamorphism; some migmatisation at depth.

(2) The main progressive dynamic metamorphism that synchronised with the isoclinal folding. Lifting up of the gneisses as fold cores; migmatisation culminated into the porphyroblastic gneiss.

(3) Retrogressive metamorphism during the Almora thrusting; mylonitisation of gneisses; downgrading of unmigmatised schists to phyllonites.

(4) Development of quartz-tourmaline bodies sometime during the post thrusting period, perhaps after the folding of the Almora thrust.

(5) Hydrothermal alteration of potash felspar and biotite of gneisses, and epidioritisation of the mafic rock.