CHAPTER IV

P E T R O G R A P H Y

In this chapter a detailed petrographic description of the various rock types encountered in the study area, has been given. The megascopic and microscopic characters, together with the mineralogy of different rocks, have furnished important evidences towards the structural and metamorphic evolution of the terrain.

ROCKS OF ALMORA NAPPE

The constituent rock types that make up this nappe, are as under:

(1) Mica schists,
(2) Migmatitic gneisses,
(3) Flaggy quartzites,
(4) Chlorite schists,
(5) Phyllonites.

The quartzites occur as distinct lenses and bands in the mica schists. The gneisses, being the migmatised derivatives of the mica schists show rather transitional contacts with the latter. Similarly, the change over of mica schists through chlorite schists into phyllonites is gradational, being due to the retrogression caused by the South Almora thrust.

MICA SCHISTS

These include schists in which micas make up almost 1/2 of the bulk. With decreasing mica content (about 1/3 of the total bulk) the rock could best be called as quartz mica schist. In hand specimen, a typical mica schist is a coarse to medium grained bronze-yellow foliated rock, spotted with brown garnets. The quartz rich mica schist is of light grey colour and is comparatively more compact.

Texture:

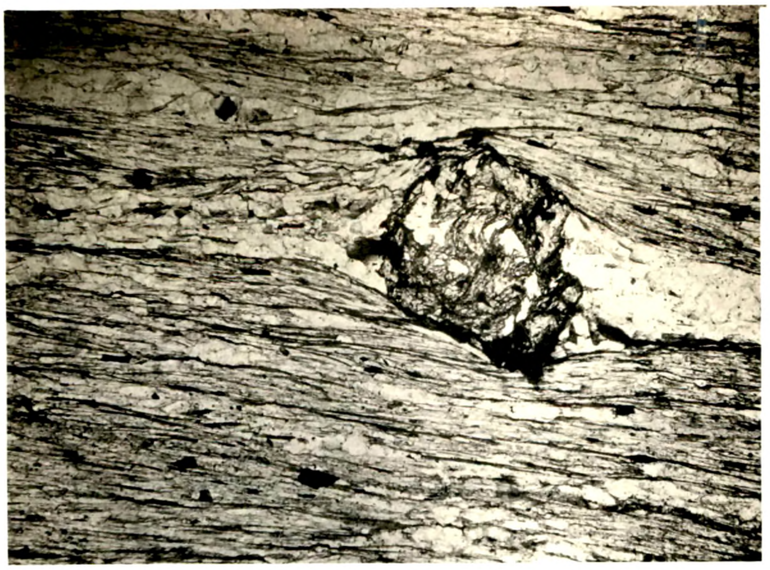
These are coarse to medium grained foliated rocks, the foliation characterised by the parallel orientation of mica flakes. Thin section study reveals following three main textural types;

(1) Uncrinkled coarse-grained mica schists in which foliation is marked by tufts or individual well developed

flakes of micas, occurring in close association with streaky aggregates of quartz grains. These elongated aggregates of quartz show suturing and interlocking, or sharp and straight mutual junctions. Porphyroblasts of garnet are common and mostly show spiral inclusions of quartz, indicating rotation during their growth (Plate IV.1A). Quite often, the phenomenon of 'garnet in garnet' is also recorded, the inner and earlier garnet being static while the enclosing later one having grown in a dynamic matrix (Plate IV.1B). Such garnets afford a convincing evidence of two distinct phases of regional metamorphism undergone by these schists. Another important textural feature of the rock is the presence of stray well formed muscovite, biotite and chlorite flakes, lying oblique to the main schistosity. These indicate incipient stages of a late superimposed cleavage.

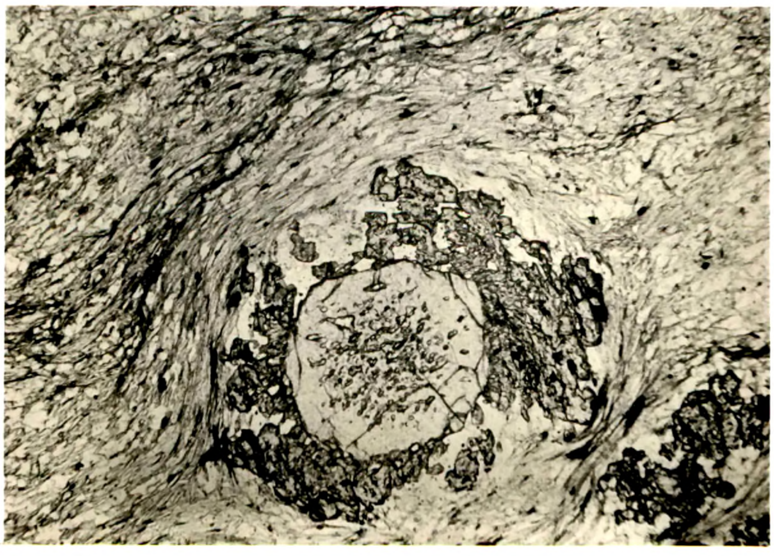
(2) Uncrinkled medium grained mica schists in which foliation is characterised by a uniform scattering of parallel mica flakes, interspersed in an equigranular mass of quartz. This variety is slightly less micaceous than the previous one. The quartz grains show considerable interlocking and suturing, and tiny flakes of muscovite are seen caught up along the grain junctions. The garnet

PLATE IV.1A



Rotated garnet in mica schist.
(Photomicrograph X30)

PLATE IV.1B

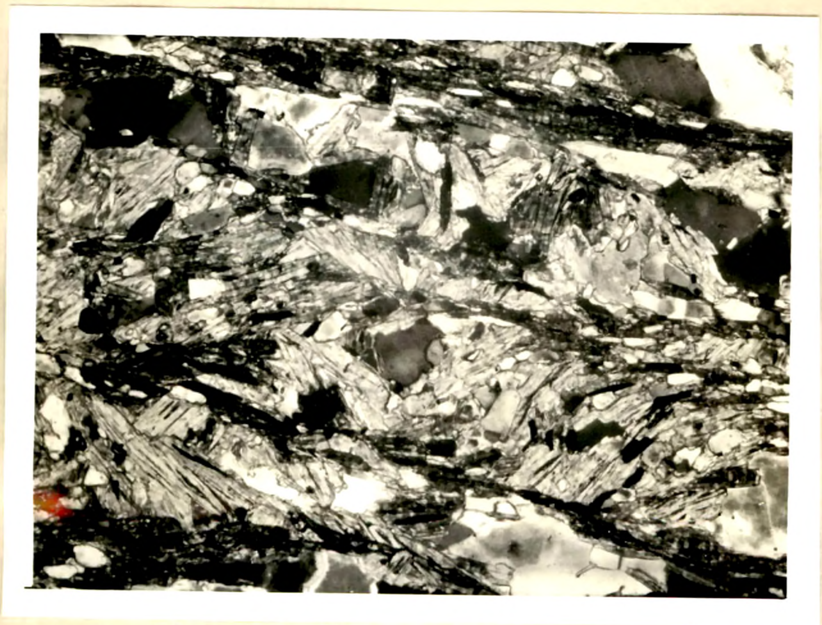


Garnet in garnet - static enclosed within rotated
(Photomicrograph X30)

porphyroblasts are of reduced size, but show the usual helicoid quartz inclusion pattern. Two generations of garnet-static enclosed in dynamic, are frequently present. This variety occurs in close association with the previous one as intercalations, and in the field it is not possible to delineate and separate the two varieties.

(3) Crinkled mica schists in which the foliation is characterised by mica flakes and shows intense micro-folding. In thin sections, it is evident that the original flakes of micas were bent into tiny folds and during this bending, they have quite often fractured and recrystallised. The crystallised fractured hinges characterise the super-imposed cleavage, which at many places is of strain-slip nature. A second generation of mica flakes are seen to have crystallised along the fractured hinges and indicate a new foliation (Plate IV.2A). The quartz which occupies the intervening spaces between folded mica tufts, comprise fresh aggregates of unstrained grains, which show much less interlocking. The garnets are less frequent, and when present they are porphyroblastic. These garnets do not show any rotational growth and are perhaps of a later generation, having developed at the time of crinkling.

PLATE IV.2A



New micas along fractured hinges of microfolds.
(Photomicrograph X60)

Minerals:

The mica schists have been found to consist of following mineral assemblages:

1. Quartz-biotite-muscovite-garnet-chlorite,
2. Quartz-muscovite-biotite-garnet-plagioclase,
3. Quartz-muscovite,
4. Quartz-muscovite-biotite-garnet-staurolite-kyanite.

The assemblages (1) to (3) are recorded almost all throughout, but the assemblage (4) is seen to occur in the schists below the gneisses.

Quartz is the most dominant mineral and occurs as irregular grains of variable size (0.5 to 2 mm) occupying the intervening spaces between micas. Bigger grains contain tiny inclusions of micas. The mineral tends to form streaky aggregates of small grains in the lower portions of the formation, nearer to the South Almora thrust. Strain shadows are quite common, and are obviously a result of deformation due to the thrust. Quartz also occurs as tiny inclusions in micas, garnet and staurolite.

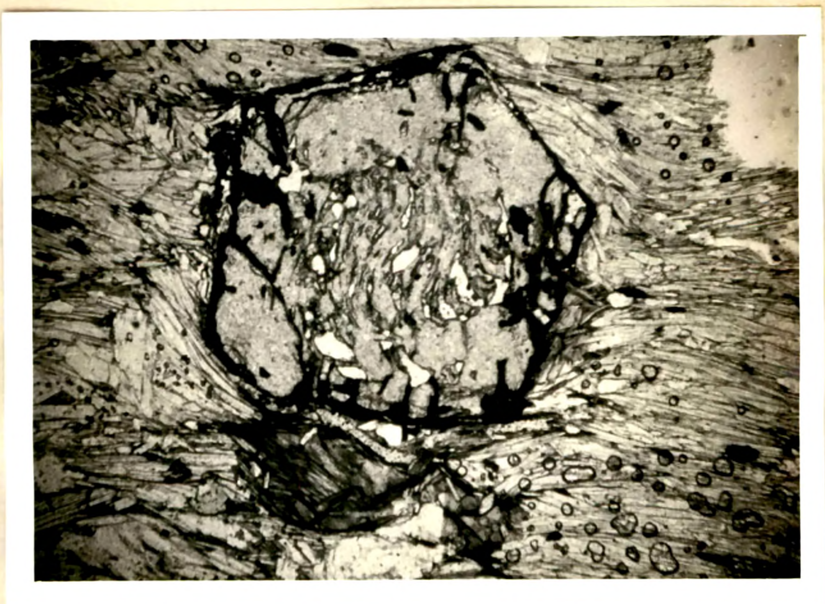
Biotite is generally the dominant of the two micas. It occurs as long (2 mm to 6 mm) slender flakes, mostly intergrowing with muscovite. Its pleochroism is from straw-yellow to brown ($X > Y = Z$, X = straw yellow, $Y=Z=$brown).

Scattered porphyroblasts of biotite, occurring oblique to the schistosity, are obviously of a second generation, and characterise an incipient later cleavage. Some small flakes of biotite also occur, around the margins of garnet as the alteration product of the latter. The biotite is at several places altering to green chlorite. This alteration is more pronounced in the rocks nearer to the thrust.

Muscovite is almost always present and in some cases, dominates over biotite. It forms smaller flakes (0.5 to 1 mm long) as compared to biotite, occurs in close association with the latter and very often shows a yellowish tint and faint pleochroism. Such occurrences have been considered as ferrimuscovite. Some muscovite in the schists below the gneisses and nearer to the thrust, are seen to have developed at the cost of biotite. Also, intense shearing due to the thrust, has at many places changed muscovite into sericite. Muscovite porphyroblasts of late generation, having developed during the crinkling, are seen lying oblique to the foliation.

Garnet is an almandine and occurs as light pink porphyroblastic grains. Its forms either well defined crystals or as amoebic patchy grains riddled with quartz inclusions. Its size and proportion is variable. The garnet porphyroblasts are seen wrapped by micaceous foliae. The amoebic garnet is more common in siliceous varieties. A careful scrutiny of a large number of thin sections has revealed at least three generations of garnet. Most of garnet grains show helicoid pattern of quartz inclusions, but occasionally a 'static' garnet with quartz inclusions in straight lines is seen included within a rotated garnet showing spiral quartz inclusions. Obviously, the 'static' garnet is older to the 'rotated' garnet, the latter having developed at the time of the dynamic metamorphism that synchronised with the isoclinal folding. On the other hand, a few occurrences show a 'rotated' garnet within a 'static' garnet (Plate IV.2B). It appears that the enclosing 'static' garnet developed at some date later than the main metamorphism during the crinkling. The garnets show two-fold alteration. Some grains have mantles of biotite, (and sometime chlorite) and such alteration is mainly confined to the schists above the migmatites. Obviously, this alteration of garnet to biotite or chlorite is related to a hydrothermal activity perhaps of the migmatising emanations. Another mode of alteration is a phenomenon of retrogression due

PLATE IV.2B



Garnet in garnet - rotated enclosed with static.
(Photomicrograph X60)

to thrusting. Garnet grains involved in shearing are seen crushed and granulated, and simultaneously changed to chlorite. The alteration of garnet in both cases, has liberated considerable iron oxides.

Staurolite is recorded only sporadically from the mica schists just below the gneisses. The mineral is seen as porphyroblasts with six-sided basal sections (about 1 mm in width) or elongated prismatic sections (0.5 to 2 mm in length). It shows pleochroism from pale yellow to golden yellow ($Z > Y > X$, X = pale yellow Y = yellow, Z = golden yellow). The staurolite crystals are riddled with quartz inclusions, imparting a 'sieved' appearance. In some sections, the porphyroblasts of staurolite lie obliquely to the foliation, having grown across by pushing apart the micas (Plate IV.3). The mineral is seen altering to sericite.

Kyanite is only occasionally recorded in association with staurolite, and when present, it forms small blades, occurring sometimes in clusters. It is identified by its high R.I., one set of cleavage and oblique extinction, as much as 30° on the cleavages.

PLATE IV.3

Staurolite porphyroblast in mica schist.
(Photomicrograph X60)

Plagioclase is rare and is seen to occur in a few sections only. When present, it is in a very small amount and forms tiny grains. It is identified by its lamellar twinning, and in composition approximates to oligoclase (An_{25-30}).

Chlorite is present in most of the samples in variable proportion. It is the most important alteration product of biotite and garnet. Chlorite is seen to form small flakes and shreds of light green colour, which occur in small patchy clusters. Its pleochroism is typical, $X > Y = Z$, X = pale green, Y = Z = light green. Polarisation colour is diagnostic berlin blue. Scattered porphyroblasts of well formed chlorite flakes lying oblique to the main foliation and showing ample pleochroic haloes represent altered porphyroblasts of the late biotite.

Accessory minerals are tourmaline, apatite and iron oxides. Tourmaline is seen to occur in almost all rocks, and forms tiny needles and laths of slaty blue colour. Apatite is also universally present and forms tiny prisms and needles. Iron-oxide is mostly magnetite and occurs in chlorite rich schists.

GNEISSES

The gneisses occur in the mica schists as bands, and their field characters and petrography reveal a metasomatic origin. The following three main petrographic types indicating increasing migmatisation are recognised:

1. Felspathic schist,
2. Permeation gneiss,
3. Augen and porphyroblastic gneiss.

Felspathic schist:

This variety is confined to the marginal positions of the main gneissic bands, and almost resembles the mica schists, except in its felspar content.

Texture:

In thin sections, the rock is seen to consist of a well foliated mass made up of parallel mica flakes and grains of quartz and felspar.

Minerals:

Quartz-muscovite-biotite-plagioclase-garnet.

Permeation gneiss

This variety shows increased felspar content and is a medium grained gneiss.

Texture:

Under the microscope, the rock shows a typically gneissose texture containing granoblastic aggregates of quartz and felspar with parallel tufts and flakes of micas.

Minerals:

Quartz-plagioclase-microcline-muscovite-biotite-garnet.

Augen and porphyroblastic gneiss

These gneisses are highly felspathic and coarse-grained. Felspars occur as distinct augens and idiomorphic porphyroblasts in a gneissic foliated groundmass. It is clear that the augens, due to increased felspathisation change over to well-formed porphyroblasts. The felspars are both plagioclase and potash, and potash felspars dominate over plagioclase.

Texture:

Texturally, these rocks are gneissic and show eye-shaped porphyroblasts of quartz and felspars embedded in a faintly foliated coarse matrix (Plate IV.4A).

Minerals:

Quartz-potash felspar-plagioclase-muscovite-biotite-garnet.

PLATE IV.4A

Augen of a plagioclase in gneissic groundmass.
(photomicrograph X30)

PLATE IV.4B

Rim of quartz-plagioclase around potash felspar porphyroblast with myrmekite.
(Photomicrograph X30)

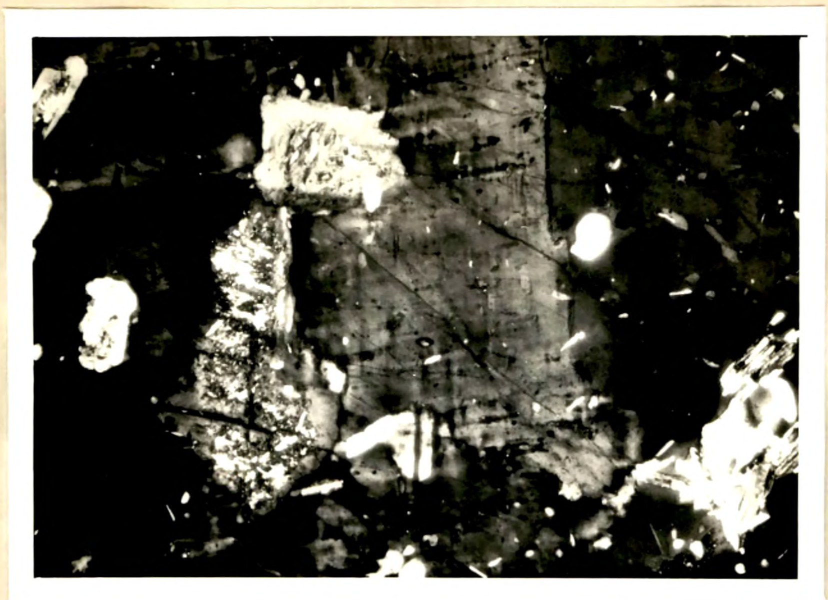
Description of minerals

Quartz is the main constituent and its content shows a gradual increase from felspathic schist to porphyroblastic gneiss. It also shows increase in grain size. In felspathic schist, it forms small xenomorphic grains and occurs as streaky aggregates and most of it represents recrystallised original quartz of the mica schist. In permeation gneiss, it tends to form rather bigger grains, often in association with the felspars. Finally, in augen bearing and porphyroblastic gneiss, its size grows considerably and it occurs as sutured grains often intergrowing with micas and felspars. Porphyroblasts are also common. Quartz evidently is introduced together with felspars. Quartz also occurs as small inclusions in micas, garnet and felspars.

Plagioclase is an oligoclase (An_{25-35}), and its content is variable. It first appears in felspathic schist as small discrete grains (1 to 3 mm long) and becomes quite abundant in the permeation gneiss. It constitutes an important constituent of the equigranular foliated gneissic mass, and also forms somewhat bigger grains (showing a tendency towards augen and porphyroblastic growth). In augen gneiss, the content of plagioclase is much reduced at the expense of increasing potash felspar. It is mainly confined to the foliated groundmass though occasional augens are not uncommon; but these augens almost invariably show replacement by microcline. In the porphyroblastic variety, the plagioclase is much reduced and seen in subordinate amount in the groundmass, or as relicts and inclusions in porphyroblasts of potash felspar. Plagioclase grains of perhaps a younger generation frequently form rims round potash felaspar porphyroblasts, accompanied by a development of myrmekite (Plate IV.4B). The plagioclase is easily recognised by its lamellar twinning.

Potash felspar is the most important mineral of the whole gneissic group, and its both varieties - microcline and orthoclase, are present. In felspathic schist, this felspar is practically absent, and only occasionally tiny cuspate grains of microcline in some thin sections are recorded. In permeation gneiss microcline is invariably present, though subordinate to plagioclase. The augen bearing and porphyroblastic gneisses dominate in potash felspar, which comprises both microcline and orthoclase. The augens and well formed porphyroblasts of microcline and orthoclase are abundant, and these are seen replacing at many places an earlier plagioclase, relicts of which are commonly recorded. An interesting and striking feature of the potash felspar porphyroblasts is that (i) some grains show typical cross-hatching only (ii) while other grains show either a distinct and sharp carlsbard twin or a superimposed cross-hatching over carlsbard twins (Plate IV.5A). This phenomenon affords a very clear evidence in respect of the temperature conditions prevailing during the formation of these porphyroblasts. While the smaller grains of microcline in the permeation gneiss as well as augen and porphyroblastic gneiss indicate a relatively low temperature origin, the orthoclase porphyroblasts suggest origin under high metamorphic conditions. It is obvious that the porphyroblasts originated as orthoclase at high temperature and later on quite a few of them inverted to microcline. All stages of inversion of orthoclase to microcline are recorded. Metasomatic growth of the porphyroblasts is supported by numerous inclusions of early quartz, micas and plagioclase in them. Another important feature of these porphyroblasts is the presence of thin and discontinuous rims of quartz-oligoclase aggregates around their peripheries (Plate IV.5B). Myrmekites have developed along the contact of the two felspars. It is seen that while the porphyroblasts show considerable effect of deformation in the form of strain shadows and

PLATE IV.5A



Porphyroblast of potash felspar showing superimposition of cross hatching over carlsbad twins.
(Photomicrograph X60)

PLATE IV.5B

Rim of quartz-oligoclase around orthoclase porphyroblast with myrmekite.
(Photomicrograph X30)

bending of crystals, the quartz-oligoclase rim is totally unaffected. Obviously, this indicates a late growth of quartz-oligoclase around potash-felspar porphyroblasts during post-Almora thrust period.

Micas are biotite and muscovite, of which the latter predominates. Both occur as discrete flakes singly or in parallel clusters. On the whole, muscovite forms big and slender flakes while those of biotite are small and stubby. The two micas also occur as tiny inclusions in felspar porphyroblasts, while biotite alone is seen inside garnet grains.

Garnet though much less in proportion, is almost always present and forms rounded grains - cracked and altering to biotite. Inclusions are of quartz, biotite and iron oxide.

Zircon, apatite, sphene and tourmaline are the common accessory minerals.

FLAGGY QUARTZITES

These represent sandy layers and lenses in original argillaceous rocks.

Texture:

Texturally, the quartzites show two main types:

(1) Somewhat compact quartzite of greyish white colour, whose texture is characterised by an interlocking mosaic of sutured quartz grains. The grain size of quartz shows much variation.

(2) Comparatively less compact grey quartzite. It is seen to consist of even grained quartz with smoother outline, showing tesselate texture.

Minerals:

Quartz-muscovite-biotite- (garnet-tourmaline).

Quartz is the most dominant mineral and forms either sutured grains of variable size (0.25 mm to 1 mm) in type (1), or equigranular aggregate of grains with smoother outlines in type (2).

Micas are both muscovite and biotite, but in a very small proportion. These form tiny flakes (0.5 mm to 1 mm long) and specks interspread in the quartzose mass and show a faint parallelism.

CHLORITE SCHISTS

Chlorite schists are strongly foliated fine grained rocks of greenish colour. These are retrograde transitional rocks between mica-schists and phyllonites.

Texture:

In thin section, the rock shows a strong foliation and consists of streaky aggregates and bands of tiny flakes of chlorite, muscovite and biotite. The intervening space is filled with granules of quartz. Some sections show microfolding of the foliation.

Minerals:

Quartz-chlorite-muscovite-biotite-garnet.

Quartz occurs as (i) tiny elongated grains and streaks of fine granules and (ii) eye shaped aggregates of a few bigger interlocking grains. All these typically indicate intense shearing and granulation. While the thinner streaks represent originally small grains, the 'eye shaped' aggregates are derived by the crushing of bigger grains.

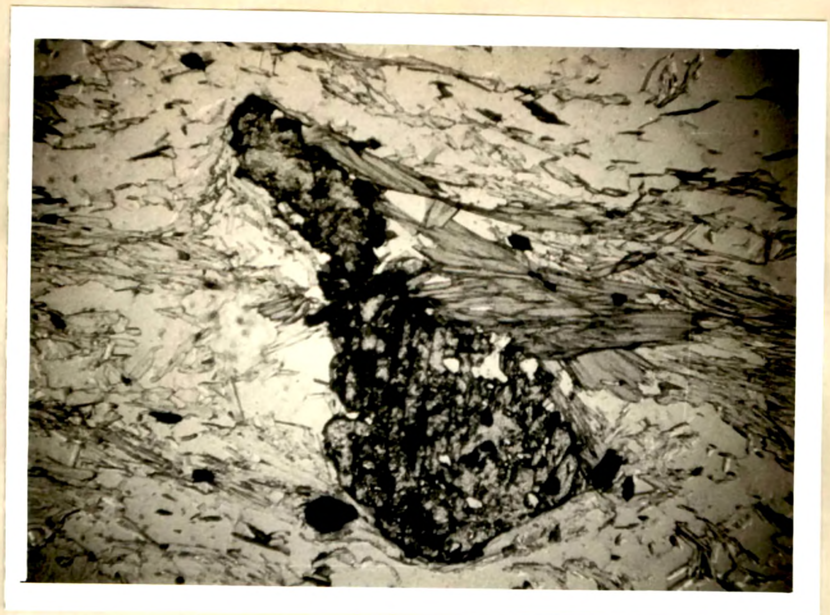
Chlorite is the most prominent mineral and a typical retrograde product after garnet and biotite. It forms tiny flakes, occurs in close association with quartz and muscovite, and shows a strong parallelism. It is characteristically pleochroic in shades of green (X > Y = Z, X = light green, Y = Z = dark green) and shows the usual low polarisation colours. All stages of transformation of garnet and biotite to chlorite are recognised in various sections, and the chlorite content is seen to increase with increasing nearness to the thrust.

Muscovite and biotite are the relicts of the original constituents of mica-schists and are much reduced in amount. Muscovite is seen as tiny flakes, obviously crushed due to shearing. Biotite also forms small flakes, showing alteration to chlorite.

Garnet occurs as (i) granulated streaks (0.25 to 1 mm long) and (ii) rotated relicts (0.25 to 1.5 mm in dia) changing extensively to chlorite (Plate IV.6A). It is obvious that intense differential slipping either crushed the garnets or rotated them, side by side with their alteration.

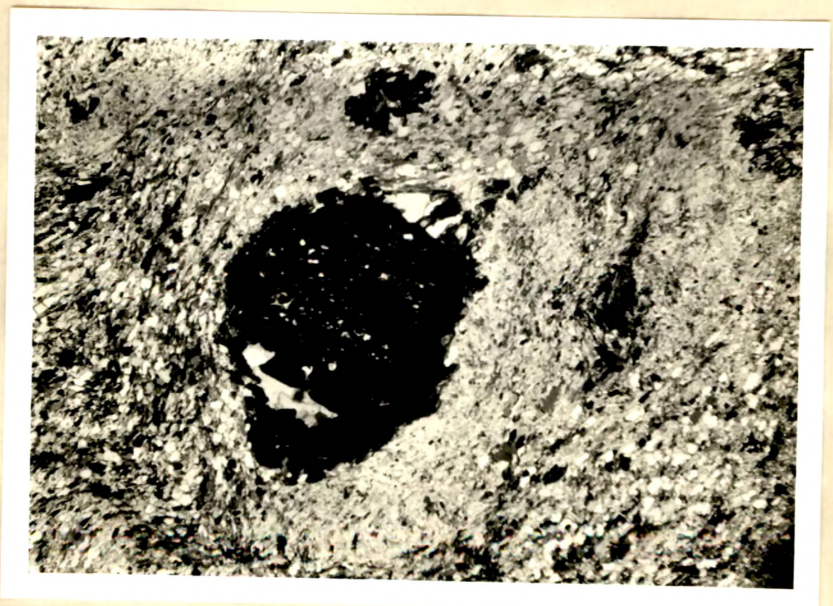
Magnetite is the important alteration product, released from the garnet and biotite. It occurs (i) as elongated grains parallel to the schistosity intergrowing

PLATE IV.6A



Garnet alters to chlorite.
(Photomicrograph X30)

PLATE IV.6B



Taxture of phyllonite.
(Photomicrograph X30)

with chlorite, and (ii) discrete idiomorphic grains, clustered around garnets.

Apatite and zircon are the usual accessory minerals.

PHYLLONITES

Phyllonites are highly sheared greenish - grey sheeny phyllite - looking rocks, confined to the thrust zone.

Texture:

In thin sections, the rocks show a strongly foliated fine grained mass comprising streaky micaceous and quartzose aggregates (Plate IV.6B). Considerable recrystallisation appears to have taken place during the granulation and shearing, because the quartz grains are fresh and free from shadows. Similarly, the sericite tends to recrystallise to tiny muscovite. Sections of the rocks in the immediate vicinity of the thrust, ideally show a fine crinkling and drag folding of the foliation.

Minerals:

Quartz-sericite-chlorite-biotite-garnet-magnetite.

Quartz occurs as (i) fine grained streaky aggregates intimately mixed with chlorite and sericite and (ii) streaks and lenses of coarse interlocking grains within the fine foliated mass. These represent the more quartzose portions in the original rock.

Chlorite and sericite the two important constituents occur intimately mixed and form a strongly foliated mass of tiny flakes. Their relative proportion is variable and perhaps the variation reflects the original mineralogy of the crushed rock. While chlorite is derived from garnet and biotite, the sericite is a product after muscovite.

Biotite shows an interesting occurrence. It forms porphyroblastic flakes (0.5 to 1.5 mm long) growing oblique to the foliation. Obviously, this is a new biotite, developed during a later progressive phase of metamorphism. The orientation of such biotite marks an incipient new metamorphic cleavage. This biotite is fresh and unaltered, and shows the characteristic pleochroism.

Garnet has two modes of occurrence indicating old and new garnet. The earlier garnet, a constituent of the schists occurs as tiny relict fragments extensively altered to and surrounded by chlorite. The late garnet, forms small (0.5 to 1 mm in dia) but well developed grains, fresh and unaltered.

<u>Magnetite</u> occurs as streaks parallel to the foliation or as well developed bigger grains. <u>Tourmaline</u> and <u>zircon</u> occur as <u>accessory minerals</u>.

ROCKS OF KROL NAPPE

Rocks of the Krol nappe, occurring in the various group at different horizons, consist of the following varieties:

(1) Quartzites
(2) Phyllites
(3) Limestones
(4) Mylonitised granitic rocks
(5) Epidiorites
(6) Metabasalts.

QUARTZITES

Nathuakhan quartzites

Quartzites are the most dominant rocks of Nathuakhan formation, immediately underlying the South Almora thrust. These comprise massive beds separated by thin phyllitic layers. Yellowish and greyish in colour, these show faint traces of bedding in handspecimens.

Texture:

Under the microscope, two textural types are recognised - each showing some mineralogical variation also.

Type (i) an equigranular mosaic of interlocking grains of quartz with small amount of interstitial felspar grains (Plate IV.7A).

Type (ii) aggregates of grains of somewhat smoother outlines containing tiny flakes of mica showing a faint parallelism, and streaks of ferruginous dusty material.

Minerals:

(i) quartz-plagioclase-microcline.

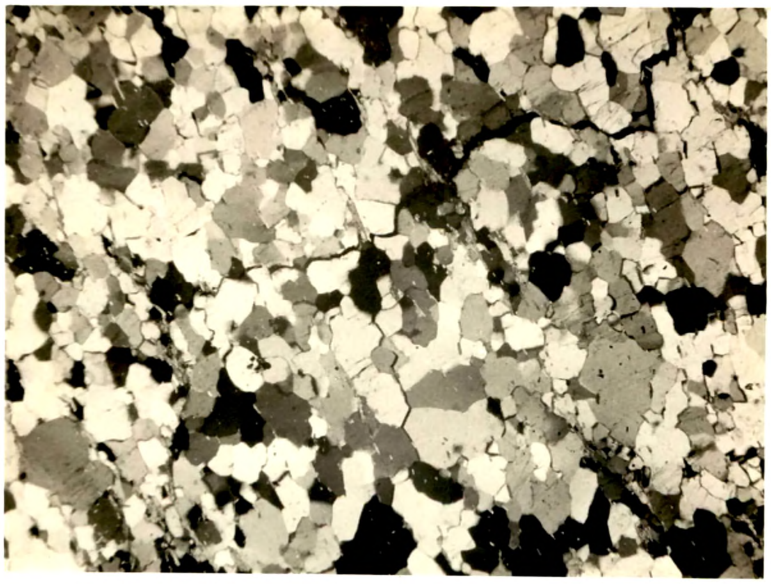
(ii) Quartz-muscovite-plagioclase-microcline-magnetite.

Quartz occurs as equidimensional grains (about 0.25 mm dia) with smooth outlines or as sutured interlocking grains.

Muscovite forms tiny streaks and flakes which are parallel and mark the foliation.

Felspar is both plagioclase (An_{10-30}) and microcline, and occurs as tiny grains interspersed in the quartzose mass. The two felspars together are in a very subordinate amount, but between the two, plagioclase dominates.

PLATE IV.7A



Quartzite shows equigranular mosaic of interlocking quartz grains.

(Photomicrograph X30)

PLATE IV.7B

Texture of Lusgaini quartzite.

(Photomicrograph X30)

Lusgaini quartzites

These quartzites occur interbedded with phyllites. In handspecimens, they are seen as compact greyish and greenish rocks.

Texture:

In thin sections, the rock is seen to consist of quartz grains which show considerable variation in their shape and size. Generally, the same section may show big as well as small grains whose outline may be smooth or sutured. Foliation is marked by tiny flakes of muscovite (Plate IV.7B).

Minerals:

Quartz-muscovite-hematite.

Quartz comprises an inequigranular (0.5 to 2 mm in dia) mass showing much diversity not only in size but also in shape. The sutured aggregates clearly indicate their derivation by the granulation of bigger grains, and always show strain shadows.

Muscovite is much less in amount but significant enough to impart a foliation by the parallel alignment of its tiny flakes.

Hematite forms streaks of dusty aggregates but occasionally small well developed grains are also present.

Chlorite, Zoisite and Tourmaline fragments are commonly recorded.

Quartzites of Ramgarh Group

Within the mass of sheared granitic rocks of Ramgarh group, the quartzites form a big lens. Petrographically the rock is identical to the one described above (i.e. Lusgaini quartzite).

Titoli quartzite

Quartzites that lie below the Ramgarh thrust are seen to comprise of two types.

(1) Pebbly and gritty confined to the upper portion, nearer to the Ramgarh thrust (size of pebbles varies from 0.5 to 6 cm).

(2) Massive even-grained comprising the main bulk.

Texture:

Under the microscope, the rock is seen to consist of sutured interlocking aggregates, which show effects of deformation. Almost all the grains have wavy extinction and bigger grains (small pebbles) not only show cracks but are enveloped in a fine granular aggregate-a product of intense shearing (Plate IV.8A).

Minerals:

Quartz-muscovite-magnetite.

Quartz occurs as strained and sutured grains of variable size (5 mm to fine dust).

Sericite is present in very small quantity. Magnetite is occasionally present.

Zircon is the only accessory mineral.

PHYLLITES

Nathuakhan phyllites

Occurring as thin layers, separating the various quartzite layers, the phyllites are seen as grey shining foliated rocks.

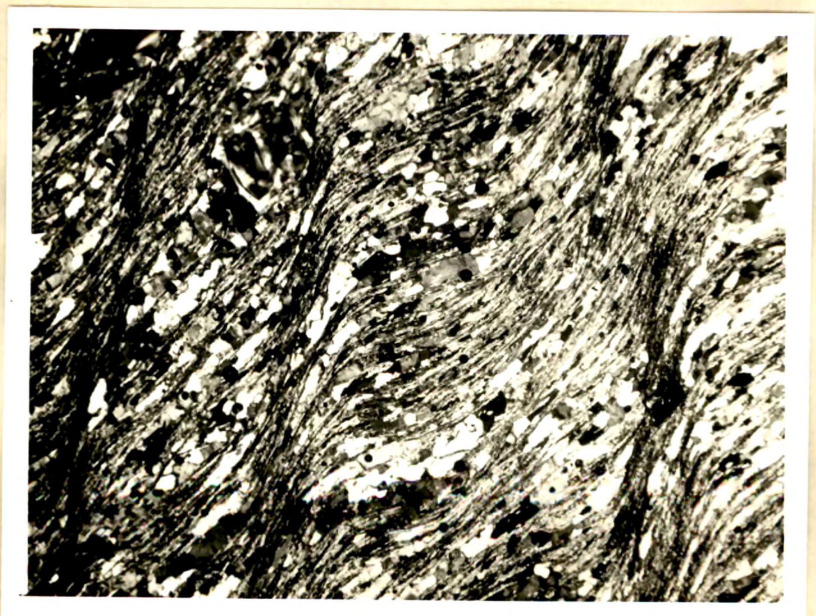
Texture:

Thin sections reveal a strongly foliated mass consisting of alternate bands of fine-grained to medium-grained aggregates of quartz and micaceous minerals. Differential slipping has in many samples given rise to a fine crinkling due to drag effect (Plate IV.8B). Some biotite porphyroblasts are seen growing oblique to the shear cleavage.

PLATE IV.8A

Texure of Titoli quartzite.
(Photomicrograph X30)

PLATE IV.8B



Crinkling due to differential slipping in Nathuakhan phyllites.
(Photomicrograph X30)

Minerals:

Quartz-muscovite-biotite.

The above minerals show their presence in varying proportions, and depending on the abundance of one or the other, the following three types have been recognised:

1. Biotite phyllites,
2. Muscovite phyllites,
3. Quartzose phyllites.

Quartz occurs as small equigranular somewhat elongated grains, forming bands of sutured aggregates, into which are interspersed tiny biotite and muscovite flakes. The quartz grains typically show a very striking flattening along the foliation.

Muscovite forms tiny flakes and is an important constituent, though its content varies. In some varieties, it is most abundant and in association with quartz, makes up the entire mass of the rock.

Biotite also forms very small flakes and lies along the foliation in close association with quartz and muscovite. Biotite porphyroblasts (0.5 to 0.1 mm in width) of a later generation are seen to have grown oblique to the foliation and indicate a new cleavage direction.

Chlorite, Tourmaline, Plagioclase (An_{10-30}) and Magnetite form the accessory constituents.

Lusgaini phyllites

The phyllitic layers of the Lusgaini formation are of dark grey and greenish colour and more towards slate.

Texture:

Under the microscope, the rock is seen to comprise a very fine-grained foliated aggregate of alternating bands of quartz and muscovite-chlorite. The micaceous foliae are extensively crinkled in most samples (Plate IV.9).

Minerals:

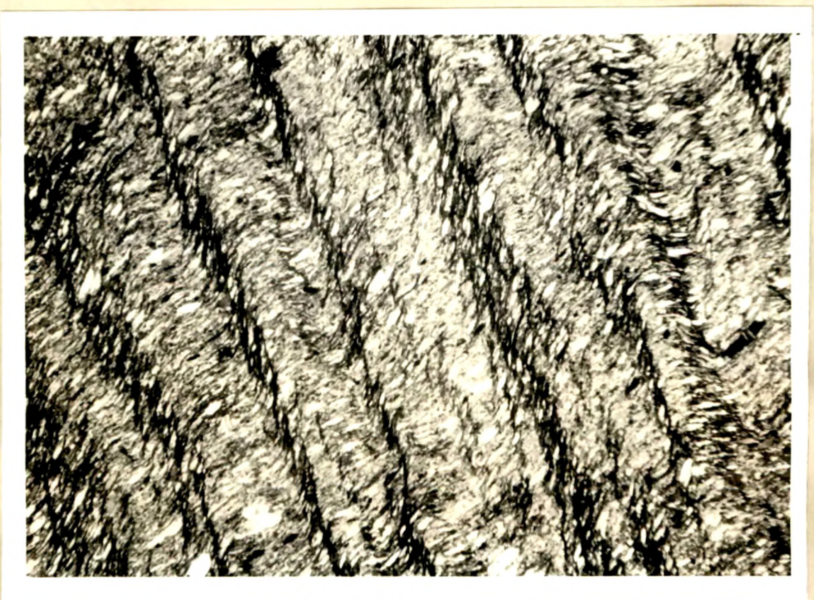
(1) Quartz-muscovite,

(2) Quartz-hematite-muscovite,

(3) Quartz-chlorite-muscovite.

Quartz forms lenticular aggregates (0.5 to 2 mm long) and bands of inequigranular grains of very small size. Generally, the grains show much flattening and elongation in the foliation direction. Somewhat coarser aggregates show suturing and interlocking.

PLATE IV.9



Crinkling of foliation in Lusgaini phyllites.
(Photomicrography X30)

Muscovite is always present but its content varies. It occurs as foliated bands together with quartz granules.

Chlorite occurs as tiny flakes in association with sericite and quartz, and is recognised by its green colour, pleochroism (pale-yellow to green) and very low interference colour.

Hematite occurs as bands of dusty mass parallel to the foliation, in some types.

Magnetite when present is seen to form small euhedral to sub-hedral crystals.

Tourmaline occurs as accessory mineral.

Phyllites associated with Soyalgad limestone

Thin layers of almost slaty phyllites occur in between limestone beds. The rock is grey and petrographically identical with that occurring in the quartzites above.

Phyllites of Ramgarh Group

Phyllites occur as stray patches in the sheared granites and perhaps represent the country rocks in which granites were emplaced.

Texture:

The rock shows a fine-grained foliated mass with usual alternating bands rich in quartz and muscovite-sericite.

Quartz aggregates show much suturing and interlocking. The crinkling of the micaceous bands is conspicuous and widespread, and at several places resulting into a late strain-slip cleavage.

Minerals:

Quartz-muscovite (sericite)-chlorite-biotite.

Quartz occurs in layers of tiny grains - some of flattened habit, though coarser aggregates show suturing.

Muscovite comprises a fairly foliated mass of tiny flakes into which are enclosed quartz, chlorite and biotite. Shearing at some places has changed it to sericite.

Chlorite and Biotite are present in very subordinate amount in association with muscovite, and form small flakes of green and brown colour respectively.

LIMESTONE

Limestone formation comprises alternate layers of white and greyish black colour.

Texture:

In thin sections, the rock is seen to be coarse grained and granoblastic, and made up of mostly equigranular calcite grains. Sometimes, the original bedding is marked by magnetite dust (Plate IV.10A).

Minerals:

Calcite-quartz-muscovite.
(Staining with alizarin red - S has shown complete absence of dolomite).

Calcite is the main constituent of the rock and occurs as colourless equigranular (about 0.5 mm in dia.) grains. Twinkling and lamellar twinning are its characteristic properties.

Quartz occurs as discrete clusters of a few interlocking grains or as tiny veins.

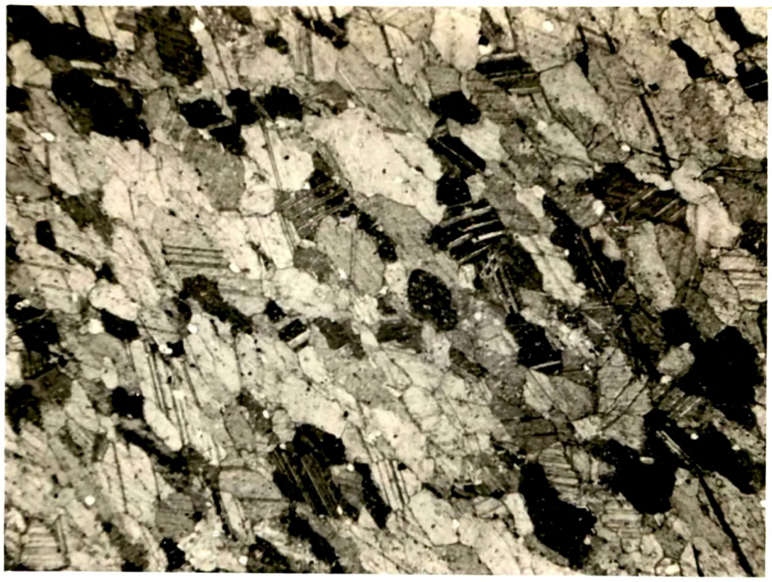
Muscovite is occasionally seen and when present, it forms, small flakes.

Iron oxide, mainly magnetite occurs as a minor constituent and indicates bedding traces.

MYLONITISED GRANITIC ROCKS

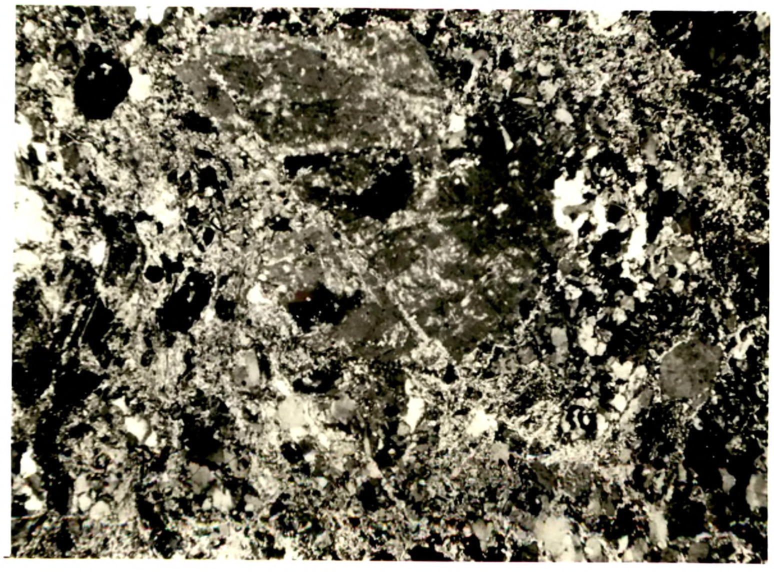
These rocks included in the Ramgarh group are essentially sheared and mylonitised granitic rocks, and depending on the original mineral composition and degree

PLATE IV.10A



Texture of Sayalgad limestone.
(Photomicrograph X30)

PLATE IV.10B



Texture of mylonitised granite.
(Photomicrograph X30)

of mylonitisation, a number of varieties are recognised. Chlorite and sericite are the two most dominant alteration products of shearing, and according to the predominance of one or the other, following two main varieties have been recorded:

(1) Chlorite and biotite rich variety,

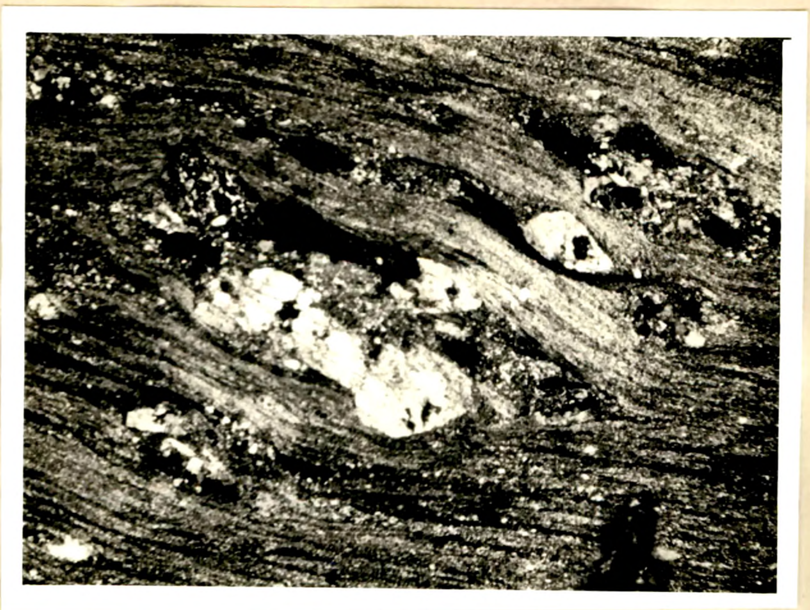
(2) Sericite rich variety.

Texture:

In thin section, the chlorite and biotite rich variety, is seen as a sheared coarse grained rock consisting of broken and partly drawn out grains of quartz and felspar together with biotite and chlorite. This variety represents rocks which have undergone lesser shearing and still clearly show the original granitic nature (Plate IV.10B). Shear planes are characterised by parallel streaks of chlorite.

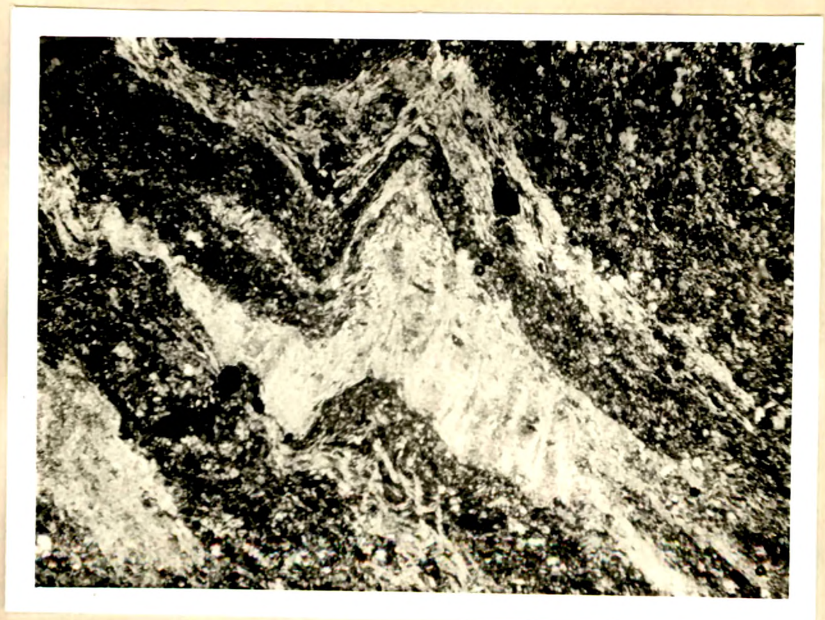
The other variety rich in sericite is fine grained and highly foliated. Obviously, it comprises products of intense shearing, wherein most of the original granitic constituents have been mylonitised and altered (Plate IV.11A). Relicts of altering felspars and granulated quartz are embedded in a streaky and fine groundmass of sericite, chlorite and quartz. This variety also shows extensive

PLATE IV.11A



Typical mylonitic texture in sheared granite.
(Photomicrograph X30)

PLATE IV.11B



Crinkling and strain-slip in mylonitised granite.
(Photomicrograph X30)

crinkling and a late strainslip cleavage oblique to the main foliation (Plate IV.11B).

All transitions exist between the above varieties, and the various stages of increasing mylonitisation are recorded in thin sections.

Minerals:

Quartz-potash felspar-plagioclase-chlorite-sericite.

Quartz occurs in two ways. Either, it forms tiny granules arranged in drawn out patches and streaks, a product of extensive granulation, or it occurs as 'porphyroclasts', relicts of partly granulated bigger quartz grains of the original rock. The latter are characteristically associated with tiny quartz granules that occupy cracks or surround them. The relicts typically show strain-shadows. While the 'relicts' are more predominant in the variety (1), they progressively disappear towards the variety (2).

Potash felspar is another mineral which is seen as big relicts (0.2 to 5 mm) in variety (1) and gradually tend to diminish towards variety (2). Microcline, orthoclase and perthite are recognised, of which the former is more common. These porphyroclasts show all stages of alteration to sericite, and with increasing shearing effect, they show more and more sericitization and diminution in size. Finally they disappear, leaving behind streaks of sericite. Considerable rotation during alteration is also seen.

Plagioclase is also a mineral of the original granitic rocks, and approximates to an oligoclase(An_{10-45}). Its content is less than potash-felspar, and shows identical mode of occurrence and alteration. It not only forms broken and altered porphyroclasts, but is also seen as small grains in the groundmass. Plagioclase is invariably altered, and the alteration product is saussurite and sericite.

Biotite is more common in variety (1), having escaped mylonitisation and alteration. In the other variety, it has been completely destroyed and altered to chlorite and sericite. The relicts of biotite, occur as patches of small flakes of greenish colour. They are pleochroic from greenish yellow to brownish yellow ($X > Y = Z$, X = greenish yellow, Y = Z = brownish yellow). Its alteration to chlorite is widespread. The biotite is much reduced in the variety (2) and if present it forms tiny shreds in association with chlorite.

Chlorite and Sericite are the two main alteration products derived due to shearing and mylonitisation. While chlorite is more abundant in the less crushed variety (1), the sericite is dominant in the more crushed variety (2). Chlorite is seen as tiny flakes together with biotite in variety (1) and with sericite in variety (2), the entire mass, highly foliated and occupying the zones of slipping. The increase in the sericite content towards more mylonitised rock is clearly due to the increasing destruction of felspars, at the expense of which the sericite has developed. Some sericite is also seen to have derived by the destruction of biotite.

Tourmaline and apatite occur as tiny grains and comprise accessory minerals. Zoisite, epidote and magnetite in small amounts, are the released minerals during shearing.

EPIDIORITES

These are sills of mafic rocks occurring within Ramgarh group and Titoli quartzites. As these show little effects of deformation, their emplacement must have taken place after the Ramgarh thrust. Mineralogically, these show only hydrothermal alteration. Plagioclases have survived while the pyroxenes have fully or partially changed to hornblende (Plate IV.12A). The plagioclase is an oligoclase, and thus the original rock must have been fairly sodic. Considering the textures, and mineralogy this mafic rock could have been originally an oligoclase dolerite.

Texture:

The texture is typically epidioritic. Unaltered plagioclases are seen embedded in a hornblendic matrix and the original coarse to medium subophitic texture is easily recognised.

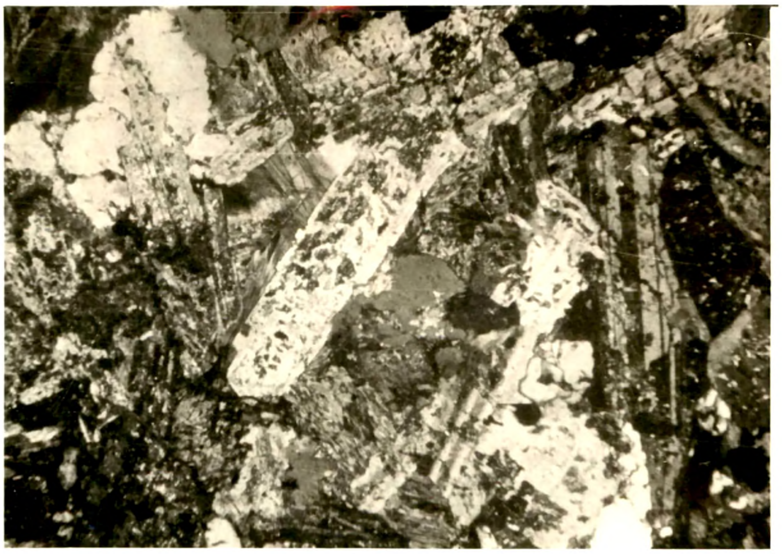
Minerals:

Oligoclase-hornblende-augite-chlorite-ilmenite-epidote-biotite.

Oligoclase (An_{30-45}) forms prismatic laths lying haphazardly in a hornblendic groundmass. It is somewhat altered to saussurite but the alteration is never so much as to obscure its original nature, and twinning is still clearly recognised.

Hornblende a product of alteration of original pyroxene, occurs as anhedral plates or fibrous aggregates. The bigger crystals show the characteristic amphibole

PLATE IV.12A



Texture of epidiorite.
(Photomicrograph X30)

PLATE IV.12B

Texture of metabasalt.
(Photomicrograph X30)

cleavage. Pleochroism is conspicuous and shows variation in shades of green (X = pale yellow, Y = yellowish green, Z = green; X > Y = Z).

Augite occurs as light pink coloured relict fragments in some sections, enclosed within hornblende mass. It shows extinction angle of about 32° on (110).

Ilmenite is the original constituent of the igneous rock and occurs as irregular patches with associated leucoxene.

Chlorite and Biotite are the products of alteration of hornblende. These occur in small amounts, and form stray flakes and aggregates.

Epidote and quartz are the released minerals.

Quartz occurs in and around altered felspars.

Apatite forms stray tiny needles.

METABASALTS

These somewhat foliated rocks occupy the core of the Bhowali anticline and are encountered in the extreme SW corner of the area. In hand-specimen, the rocks are seen as foliated light green rocks which could be easily mistaken for chlorite schists.

Texture:

Under the microscope the rock clearly reveals its volcanic nature and is seen to show typical porphyritic texture with phenocrysts of plagioclase embedded in a basaltic groundmass.(Plate IV.12B). Frequent amygdales of quartz and calcite also indicate volcanic nature.

Plagioclase (An_{20-45}) forms small laths with haphazard orientation, and considerably alterated to saussurite. It shows twinning on carlsbad and albite laws.

Hornblende and Chlorite comprise the groundmass and occur together forming a fibrous gronndmass of green colour.

Quartz and Calcite occur as secondary amygdaloidal minerals.