CHAPTER V

P E T R O G R A P H Y

MAIN TYPES

The various lithological units that are encountered in the present area range from mica-schists to flaggy quartzites associated with gneissic and granitoid rocks. The quartzites occur as distinct lenses and bands in the mica-schists. The gneisses are the granitised derivatives of the mica-schists. The geological setting of the rocks has already been described in Chapter III, and the present chapter deals with their detailed petrographic studies. This study has very clearly revealed that the rocks of the area have undergone various mineralogical and textural changes during successive periods of deformation and metamorphism. With the help of detailed mapping and an exhaustive study of thin sections, the author has worked out the following classification of the different rock types:

(1) Mica-schists
(2) Gneisses and gneissic granites
(3) Flaggy quartzites
(4) Calc silicate rocks

MICA-SCHISTS

These include schists in which micas make up an important constituent. Those varieties in which the total mica content is more than half of the total bulk, have been designated as mica-schists, while those in which the quartz predominates over micas, are termed as quartzose mica-schists. In most cases, of the two micas, the muscovite content is always higher than that of biotite. Of course, the relative proportions of the two micas are quite variable from sample to sample and at many places the biotite content is appreciably high. But in most cases, it never exceeds that of muscovite, and only occasionally biotite rich schists have been encountered. It is however not possible to delineate and separate the schists of differing mica and quartz contents, as they generally grade into one another.

From the texture point of view, the mica schists and quartzose mica-schists show a number of varieties, though one is seen merging into the other quite imperceptibly. The mineralogical and textural variations, appear to reflect original inhomogeniety of sediments and a subsequent complex metamorphic history. The repeated isoclinal folding of the sequence has further complicated the matter, and as a result the various types of schists are encountered from all over the study area, and transition exists between the various mineralogical and textural types.

Considering the textural and mineralogical characters, the schists have been classified into following four main varieties:

(1) Uncrinkled garnet mica-schists,

(2) Crinkled garnet mica-schists,

(3) Quartzose mica-schists,

(4) Graphitic schists.

A brief textural and mineralogical account of the four varieties is given below:

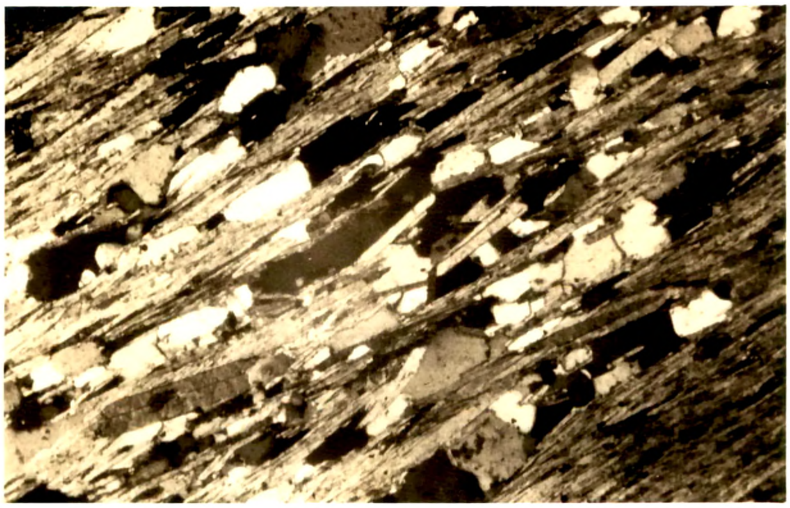
Uncrinkled garnet mica-schists

This variety is the most predominant one and is encountered all over the area. Rocks comprising this variety, show following three textural types:

(i) Coarse-grained schistose rock, wherein the foliation is characterised by alternating layers of micas and quartz. The narrow slender flakes of micas - muscovite and biotite, form elongated and parallel tufts with the intervening spaces between the tufts filled with lensoid aggregates of inequigranular quartz (Plate V.1). The garnets form porphyroblastic grains showing rotation. In some thin sections, the tufts of micas typically reveal a tight microfolding, and such samples provide valuable data on the nature of the main schistosity. It is so obvious that the existing schistosity has developed by a tight folding (Plate V.2) of an earlier cleavage now seen as folded relict.

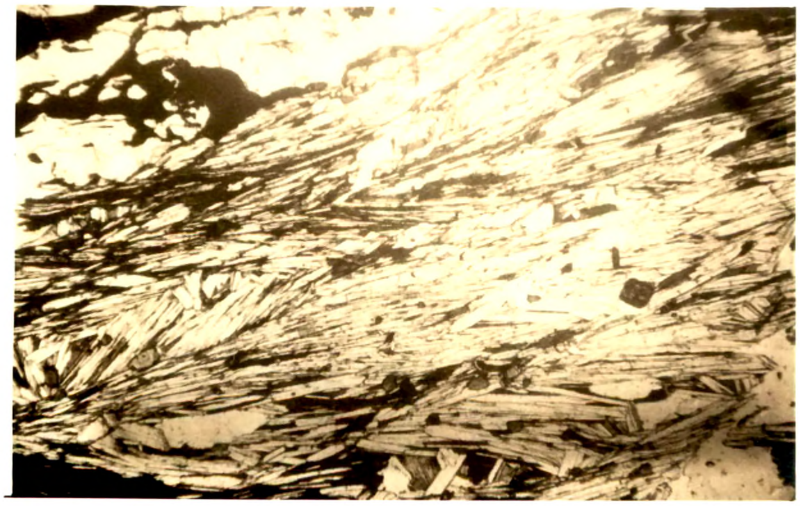
(ii) Fine to medium-grained highly micaceous and strongly schistose rock - the main bulk of which is made up of a foliated mass of small muscovite flakes

PLATE V.1



Texture of coarse-grained garnet mica-schist type (i) (Photomicrograph: crossed nicols X30)

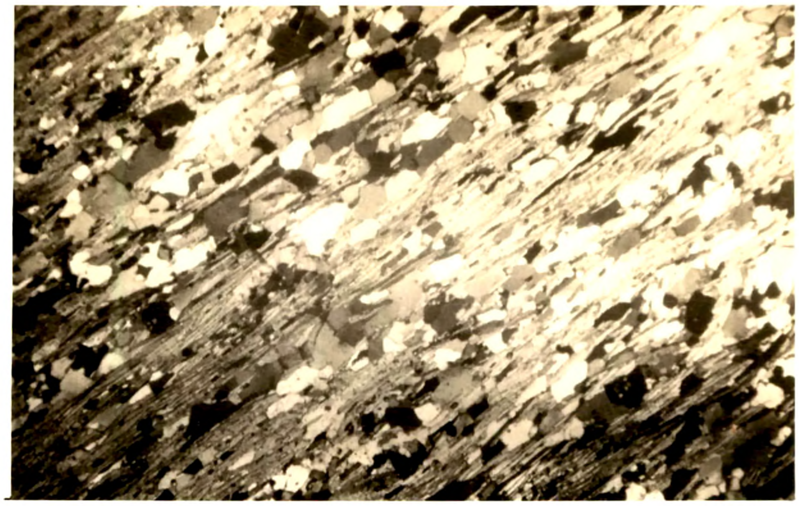
PLATE V.2



Mica flakes showing tight folding of earlier cleavage (Photomicrograph: crossed nicols X30) into which are interspersed biotite and quartz grains. The quartz grains show elongated shapes and have either sharp or smooth margins (Plate V.3). Very finegrained varieties are not uncommon, and they resemble phyllonites in texture. Garnets, in some thin sections show granulated appearance, altering to chlorite, while in others it is fresh, forming idiomorphic porphyroblasts. Obviously, the former appear to have been involved in differential slipping, while the latter grew after the rock had developed this strong shear foliation. The author believes that the coarsegrained schists have changed over to this finegrained variety due to shearing during the flexural-slip at the time of the synformal folding of the Almora nappe. This textural type passes into the crinkled variety with the development of microfolds.

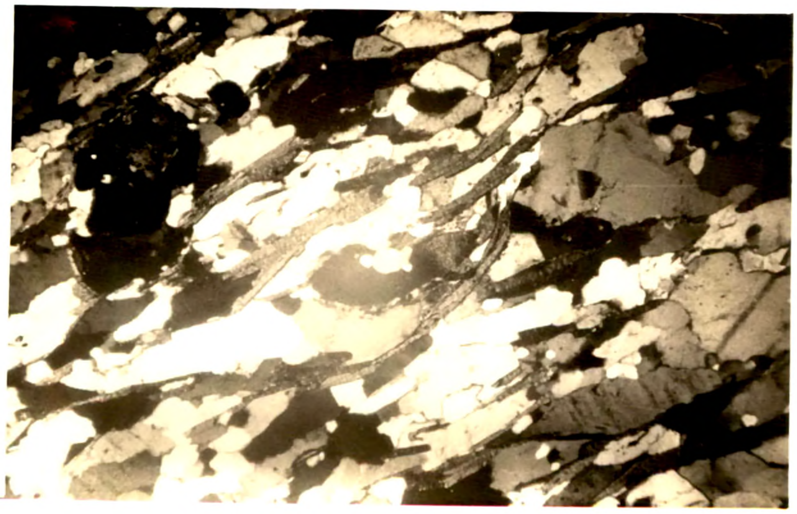
(iii) Coarse to medium-grained rock comprising an equigranular aggregate of quartz with an uniform scattering of individual flakes or small tufts of micas. There is no layering or banding and the foliation is characterised by the elongated quartz grains and the parallel mica flakes (Plate V.4). This texture is transitional between the coarsegrained schistose texture (i) discussed above and that shown by the quartzose mica-schists. Many thin sections show a combination of

PLATE V.3



Texture of medium grained garnet mica-schist type (ii) (Photomicrograph: crossed nicols X80)

PLATE V.4



Texture of garnet mica-schist type (iii) (Photomicrograph: crossed nicols X30) type (i) and type (iii). With increasing quartz content, this type merges with the quartzose mica-schists.

The minerals which are always present in this uncrinkled variety are quartz, muscovite, biotite and garnet; of course, their relative proportions vary from sample to sample. Staurolite is also seen to occur sporadically. The decrease of quartz content results into highly micaceous varieties while with the increase of this mineral, the schists are best included under the third variety, viz., the quartzose mica-schists. Of the two micas, the muscovite generally predominates, though occasionally biotite rich schists (with a small muscovite content), are also recorded. Chlorite is also present in most of the sections, but it appears to be a retrograde product after garnet and biotite.

Quartz is always present, and shows variety of occurrence. Mostly, it forms lensoid aggregates of inequigranular anhedral grains alternating with micaceous layers. This mode of occurrence is more common in the textural type (i). In the type (ii), this mineral is seen as small elongated grains with unsutured boundaries, and uniformly interspersed in a micaceous mass. In the type (iii) the quartz forms an equigranular mass of grains sometimes equidimensional and sometime elongated. In all the types, the quartz is free from strain shadows. This clearly indicates post-deformational recrystallisation. Quartz also occurs as inclusions in bigger flakes of micas and garnet.

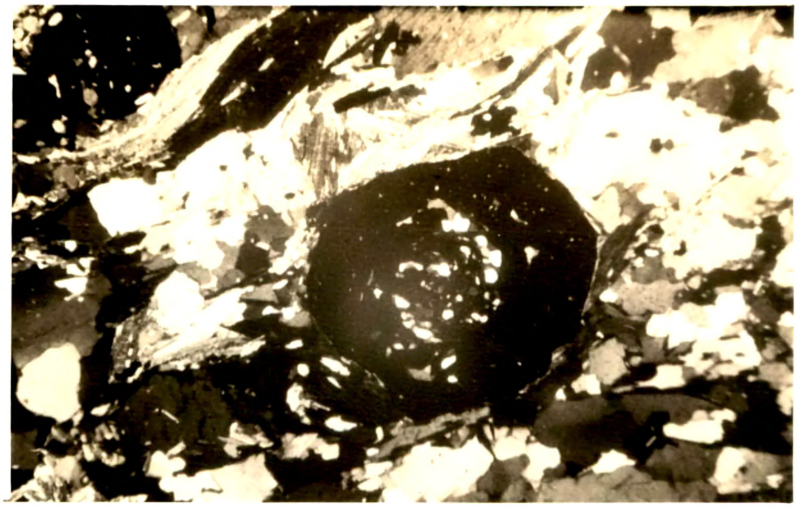
Muscovite forms long slender flakes and in close association of biotite, it characterises the schistosity. In the type (i), it occurs as parallel tufts separated by quartz aggregates. In type (ii), it is most abundant and makes up the main bulk consisting of almost a felted mass of small slender flakes. In type (iii), it occurs as small flakes interspersed in a granular mass of quartz. Parallelism of these flakes characterises the schistosity.

Biotite generally forms smaller flakes though the rocks of a few localities show bigger flakes also. It occurs in close association with muscovite. In the type (i) and (ii), it intergrows with muscovite, while in the type (iii), it occurs independently, forming scattered flakes. It shows the usual pleochroism (yellowish brown to dark brown; $x < y = z$, x = yellowish brown, $y = z$ = dark brown). At several places is seen to be somewhat greenish and chloritic. Occasionally, biotite occurs as discontinuous rims around the garnets, indicating its development at the cost of garnets.

Garnet is an almandine - a common garnet of mica-schists. It is almost invariably present, and its content is variable. While in some samples, it is only sporadic, in others its proportion is quite high. The grain size also varies ranging from 0.5 to 2 mm. It forms porphyroblasts - quite often idiomorphic. Garnets of irregular or amoebic shapes riddled with quartz inclusions are also encountered. In the type (i), the garnet grains commonly show spiral inclusions of quartz within them, indicating a rotational growth (Plate V.5). At times, this mineral is seen changing to chlorite and biotite - the former being more common. In the type (ii), garnets of two generations sometimes occur. The early garnet shows rotational growth and some crushing and alteration, while the late garnet forms well developed idiomorphic grains - fresh and intact within a strongly foliated and sheared (phyllonitic) mass.

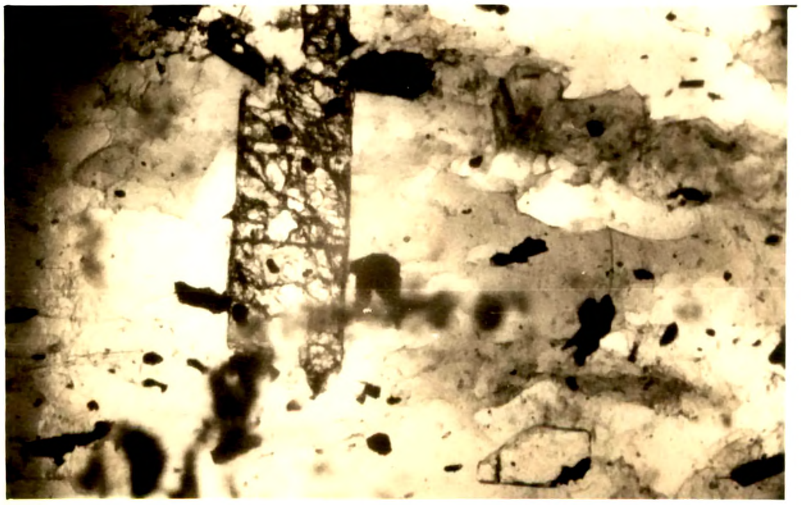
Staurolite is seen in two thin sections only. In one it occurs as well formed tabular crystal (Plate V.6), while in the other, it is seen forming irregular patchy grains. In both cases, it shows the usual colour and pleochroism (pale yellow to golden yellow, $z > y > x$; x = pale yellow, y = yellow, z = golden yellow) and is

PLATE V.5



Garnet grain in mica-schist showing rotational growth (Photomicrograph: crossed nicols X30)

PLATE V.6



Staurolite crystal in garnet mica-schist (Photomicrograph: crossed nicols X80) riddled with quartz inclusions. It is recognised only in the rocks of textural type (i) and (iii).

Chlorite is occurring in subordinate amount in all types, and is mostly an alteration product of garnet and biotite. It is typically light green and pleochroic (pale green to green, $x > y = z$, x = pale green, $y = z$ = green) and shows low order grey polarisation colours.

In addition to the above the accessory minerals in the various thin sections are small grains of magnetite, zoisite, epidote and sometimes tourmaline.

Crinkled garnet mica-schists

This variety is also quite common and is characterised by an intense microfolding of the foliation and fineness of grainsize. Though obviously it is derived from the coarse-grained (uncrinkled) variety, having been granulated and crinkled during the late fold episode F_2, its texture and mineralogy deserves separate description.

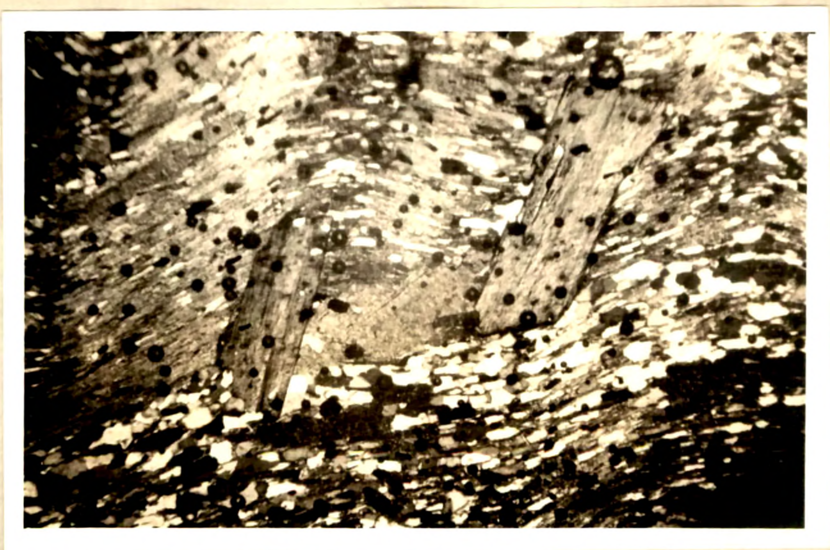
Texturally, the rock is medium to fine-grained, comprising a highly foliated and crinkled micaceous mass interspersed with streaky aggregates of quartz or individual elongated quartz grains. The original tufts of micas were bent and flexured into tiny folds, and during this bending, quite often the flakes have fractured and recrystallised, giving rise to a late superimposed crenulation cleavage. In some sections obliquely growing porphyroblasts of biotite and chlorite (Plate V.7) indicate second generation of these minerals. Garnet is typically euhedral in most sections.

The minerals in these crinkled schists are quartz, muscovite, biotite and garnet. In some thin sections chlorite also occurs. Muscovite is the dominant mineral. Quartz content varies, but it never exceeds that of micas. Garnet is always present.

Quartz occurs as small grains forming streaky aggregates within the micaceous mass. It also occurs as individual grains somewhat elongated in the foliation direction. Streaks of quartz grains suggest crushing and granulation of bigger crystals during the microfolding.

Muscovite is the most important mineral comprising the main bulk. Two generations of this mica are recognised. In most sections, it forms thick tufts of long slender flakes, all arranged parallel to mark the schistosity. The microfolding of this tufted mass has

PLATE V.7



Crinkled garnet mica-schist with porphyroblasts of chlorite (Photomicrograph: crossed nicols X30) extensively flexured and broken the micas, such that a new incipient cleavage, oblique to the main schistosity has developed. Occasionally late muscovite flakes, of somewhat porphyroblastic habit are seen to grow oblique to the schistosity. Sometimes, these grow along the new cleavage.

Biotite is always subordinate to muscovite, and occurs as small flakes intergrown with muscovite. Occasional bigger flakes also are encountered. Biotite is seen to be of two generation. The earlier one of smaller dimensions lies parallel to the foliation. The late biotite is porphyroblastic and always grows oblique to the foliation. Obviously, this later biotite is related to a metamorphism that coincided with the microfolding. In both cases, the biotite is the usual reddish brown, pleochroic from yellowish brown to reddish brown ($x < y = z$; x = yellowish brown, $y = z$ = reddish brown).

Garnet forms well developed grains - quite often idiomorphic. Unlike the garnets of the uncrinkled variety, these contain inclusions of quartz which do not indicate rotational growth. The inclusions show the same trend as that of the enclosing foliation and clearly suggest a static growth (Plate V.8). Most of these garnets appear to be of a later generation. The garnets are strikingly fresh and unaltered.

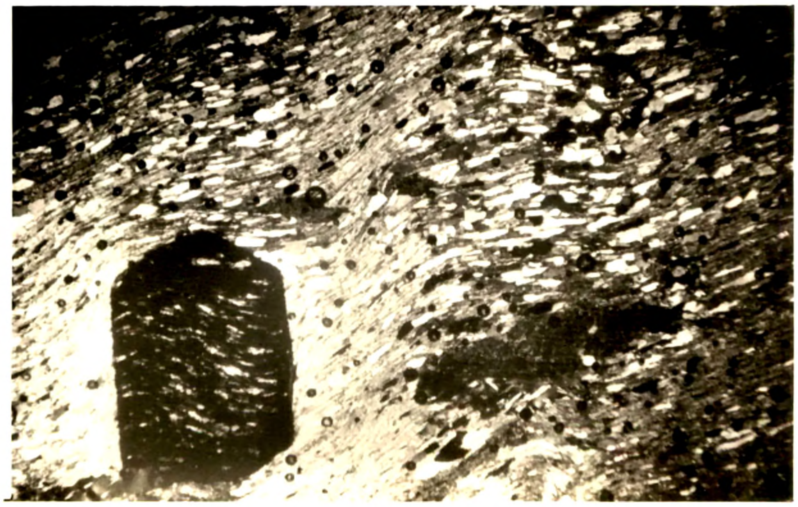
Chlorite is only occasionally recorded, and when present, it forms distinct broad flakes, lying oblique to the foliation. It shows usual pleochroism (pale green to green; $x > y = z$, x = pale green, $y=z$=green) and very low polarisation colours. Its occurrence typically indicates a late origin during the metamorphism that accompanied the microfolding. This chlorite is clearly not a retrograde product after garnet or biotite, but is of 'primary' origin suggesting a superimposition of second metamorphism.

Accessory minerals, present in small amounts are magnetite, epidote and tourmaline.

Quartzose mica-schists

This variety has a larger percentage of quartz, as compared to the other two varieties, and obviously, represents a transitional rock between mica-schists and flaggy quartzites. With decreasing quartz content, it merges into variety (i), and with increase in quartz, it changes into flaggy quartzites.

PLATE V.8



Crinkled garnet mica-schist with static
garnet (Photomicrograph: crossed nicols X30)

Texturally, this variety is quite different from the other two. It is seen to consist of a medium-grained equigranular mass of quartz within which the flakes of micas are uniformly scattered. Tufts and clusters are less common, and there is no layering or banding of mica and quartz. The quartz grains are either equidimensional or elongated. The parallelism of micas and the elongation of quartz characterises the schistosity (Plate V.9).

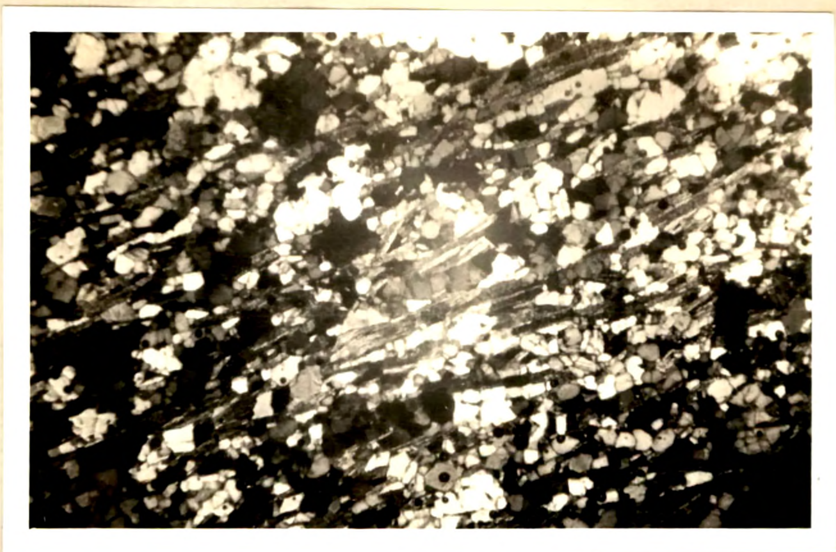
Minerals are quartz, biotite and muscovite. Garnet may or may not be present. It is interesting to note that in this variety biotite either predominates or equals muscovite.

Quartz is equigranular and is either equidimensional or elongated. In most cases, the quartz grains show sharp and straight mutual junctions, interlocking being rare. It also occurs as inclusions in garnets.

Biotite is the dominant mica and forms medium sized flakes, interspersed in the quartzose mass. It is the usual brown variety (pleochroic from yellowish brown to brown, $x < y = z$; x = yellowish brown, $y = z$ = brown).

Muscovite is subordinate to biotite, and has the same mode of occurrence as that of biotite. Usually,

PLATE V.9



Texture of quartzose mica-schist
(Photomicrograph: crossed nicols X30)

it forms smaller flakes, but at places clusters of a few long slender muscovite flakes are recorded.

Garnet is not always present. In some sections it is totally absent, while in others it is seen to occur as well formed grains. It forms both round anhedral and euhedral grains. Quartz inclusions are common, and at times indicate a rotational growth. Generally, the garnet is fresh and unaltered.

Other minerals present as accessory in small amounts are grains of magnetite, zircon and epidote.

Graphitic schists

These occur as layers within mica-schists and comprise a finely foliated grey coloured rock. In thin section, these show a fine to medium-grained aggregate of micas and quartz with thin streaks of dusty graphite. Both uncrinkled and crinkled varieties are recognised. Some of the tightly crinkled varieties might indicate the relict earliest schistosity (S) (Plate V.10).

The minerals are quartz, muscovite, biotite and graphite. Sometimes a few garnet grains are also present. The relative proportions of these minerals are however quite variable and following assemblages

PLATE V.10

Texture of graphitic schist showing relicts of earlier schistosity.
(Photomicrograph: polarised light X30)

are recorded:-

(1) Muscovite and graphite with very little biotite and quartz.

(2) Biotite, quartz and graphite with very little muscovite.

(3) Quartz and graphite with very little muscovite and biotite.

Muscovite: In muscovite rich varieties, it forms almost unbroken foliated mass of slender flakes, within which the dusty graphite granules occur as streaks. Crinkled variety typically shows crenulation cleavage. In muscovite poor varieties, it forms tiny flakes and shreds and shows a scattered occurrence.

Biotite always occurs as tiny flakes either intergrowing with muscovite or interspersed in a quartzose mass. It is brown and pleochroic (yellowish brown to brown, $x < y = z$; x = yellowish brown, $y = z$ = brown).

Graphite forms thin streaky masses of dusty granules, parallel to the foliation. Its content is variable. While in some rocks, it is the predominant mineral, in muscovitic and quartzitic varieties, its percentage is quite low.

Quartz occurs as lensoid aggregates in micaceous variety and as equigranular equidimensional mass in quartzose varieties.

Garnet always forms small rounded grains containing quartz and graphite inclusions.

GNEISSES AND GNEISSIC GRANITES

These include felspathic schists, augen bearing and porphyroblastic gneisses and gneissic granites. Their petrographic characters vary from band to band. Textural and mineralogical characters of these have been described depending on their field occurrences.

Gneissic rocks from the smaller lensoid bands at Sainar, Phalsimi, Bintola, Gajaul, Sheora and Kasaun villages

From the texture point of view in general, the rocks appear to be an intermediate variety between coarse schist and augen gneiss. These are typically a medium grained rock, showing well defined foliation characterised by tufts and individual flakes of micas. The intervening space is filled with an equigranular mass of quartz with some felspar. Considerable intergrowth and suturing is recorded. The plagioclase and occasionally microcline tends to form bigger crystals showing a porphyroblastic tendency (Plate V.11). The minerals are the usual quartz, muscovite, biotite and the two felspars. Some sections contain garnet, while in some, prolific development of tourmaline is noted.

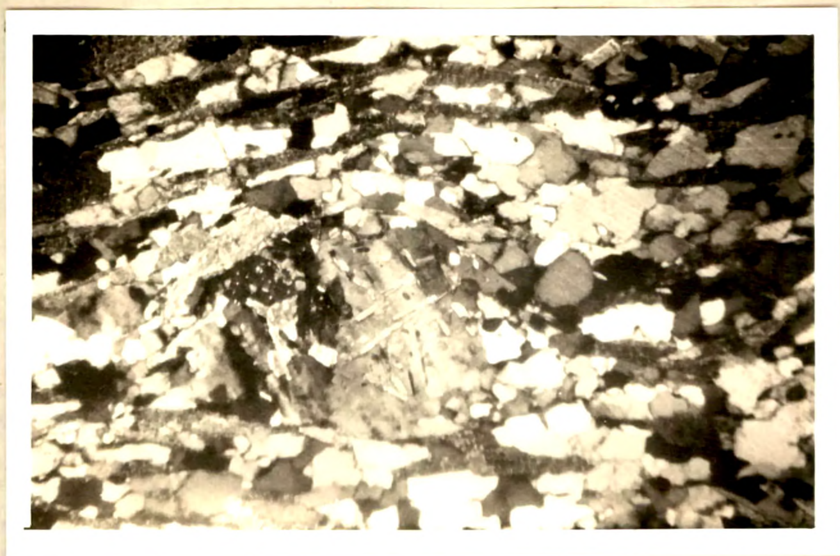
Quartz occurs as inequigranular aggregate showing outlines which are partially straight and partially sutured.

Muscovite is the dominant mica and forms long slender flakes. It occurs as tufts or as individual flakes, but always shows a well defined parallelism. It also occurs as inclusions in felspar porphyroblasts.

Biotite is much less as compared to muscovite. It occurs as small stubby flakes - either independent or intergrowing with muscovite. It shows pleochroism from yellowish brown to brown ($x < y = z$; x = yellowish brown, $y = z$ = brown).

Felspars are both microcline and oligoclase (An_{28-30}). In most cases, the plagioclase predominates over the microcline, but varieties containing an appreciable amount of microcline are also encountered. Microcline shows cross-hatching. Some of the plagioclase tends to form equidimensional bigger crystals (showing a

PLATE V.11



Plagioclase in augen gneiss showing a porphyroblastic tendency
(Photomicrograph: crossed nicols X30)

tendency towards being porphyroblastic). Occasionally, augen shaped porphyroblast of microcline (showing relict carlsbad twinning) are present. The potash felspar may include smaller plagioclases or even replace the latter, but in no case the reverse relationship is seen.

Garnet occurs in some sections and is always seen as fresh but anhedral grains.

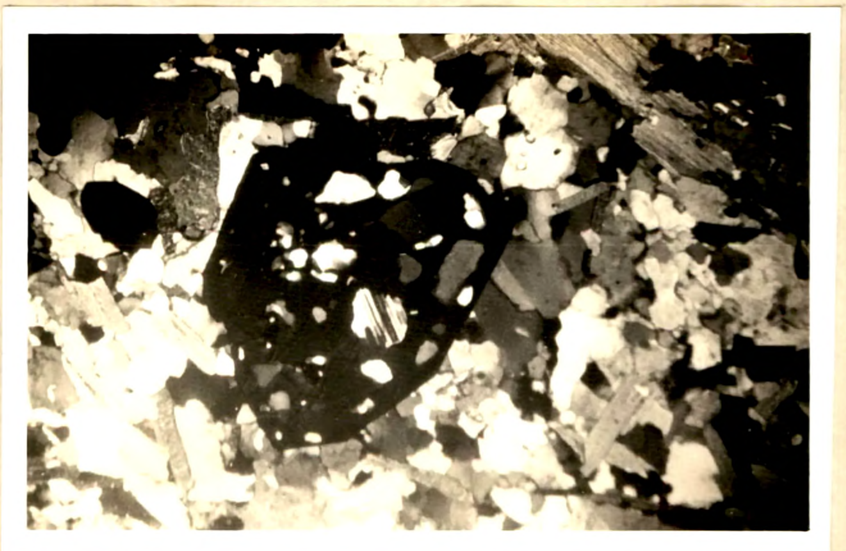
Tourmaline is recorded in the specimens from the Sainar and Sheora gneissic bands. It occurs as prisms, the basal sections of which typically remain isotropic and show numerous inclusions of quartz and plagioclase (Plate V.12). It is pleochroic from light blue to deep blue ($\omega > \varepsilon$; ω = deep blue, ε = light blue).

Accessory minerals present are zircon, magnetite and apatite.

Gneissic rocks from the Chaunsali band in the SW

Rocks from this band belong to two categories: (1) A thin fringe of felspathic schist and (2) the main mass comprising an augen bearing and porphyroblastic gneiss.

PLATE V.12



Basal section of tourmaline with inclusions of quartz and plagioclase
(Photomicrograph: crossed nicols X30)

Felspathic schist

This rock which forms a very narrow fringe on the two flanks of the main gneissic band, is seen to be a coarse schistose rock mainly containing an equigranular aggregate of quartz and micas. The presence of occasional plagioclase indicates the earliest stage of the granitisation. The foliation is characterised by the parallel orientation of micas. The minerals are quartz, muscovite, biotite, plagioclase and garnet.

Quartz shows an occurrence almost identical to that in the schist, except a little suturing and coarse grain size.

Muscovite forms long slender flakes and occurs as tufts and clusters.

Biotite is generally subordinate to muscovite and forms smaller flakes in close association with the latter.

Felspar is sporadically seen and is generally an oligoclase-andesine (An_{30-35}). It is recognised by its characteristic twinning. Microcline is generally not seen but occasionally it occurs as small cuspate interstitial grain within the quartzose mass.

Garnet is always present, it is quite fresh and rounded with distinct quartz inclusions.

Accessory minerals are stray grains of apatite, magnetite and zircon.

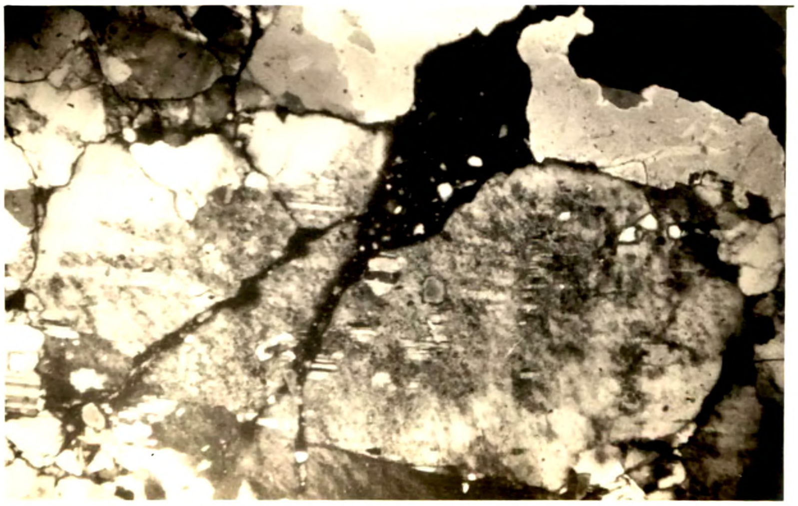
Augen gneiss

It is a more felspathic variety and comprises a medium-grained gneissic rock with small (2 to 4 mm long) augens of plagioclase. The main mass of the rock is coarsely foliated, the foliation characterised by the micas (Plate V.13). The intervening space is occupied by an aggregate of quartz with some felspars. Interlocking and suturing is quite common. The minerals are quartz, micas, felspars (both oligoclase and microcline), garnet and tourmaline.

Quartz typically occurs as inequigranular aggregates showing considerable intergrowth and suturing. It also occurs as inclusions in felspar augens and in garnets.

Felspars are both oligoclase (An_{28-30}) and microcline, the former is predominant. Oligoclase occurs both in the groundmass as well as in the form of augens. It shows usual lamellar twinning. Its augens contain inclusions of muscovite and quartz. Microcline is always subordinate

PLATE V.13



Texture of augen gneiss with augen of plagioclase (Chaunsali band)
(Photomicrograph: crossed nicols X80)

to the plagioclase but its proportion is variable. Very rarely it forms bigger grains and in most cases it is seen as fine to medium sized grains occurring in association with quartz.

Micas are both muscovite and biotite. The muscovite content is always high. It shows usual tufts and individual flakes.

Garnet is not always seen but when present, it forms rounded and fresh grains.

Tourmaline is always present but in small proportion. It forms small prisms and pleochroic (light blue to deep blue, $\omega > \varepsilon$; ω = deep blue, ε = light blue). In some cases it is quite abundant, and then the rock could best be described as a tourmaline gneiss.

Accessory minerals present are mainly zircon, apatite and magnetite.

Porphyroblastic gneiss

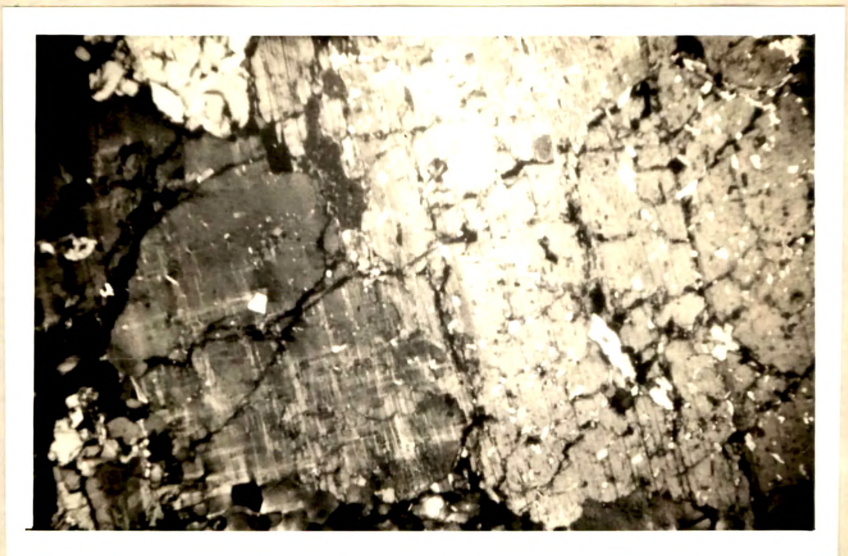
It is a medium-grained gneissic rock containing porphyroblasts of felspar lying haphazard in a gneissic matrix. In thin sections the groundmass shows a gneissic texture, with numerous anhedral to subhedral porphyroblasts of potash felspar (microcline) (Plate V.14). Augens are less numerous. Foliation as usual is indicated by the parallelism of micas. Minerals present are quartz, felspars, micas and garnet.

Quartz occurs as inequigranular aggregates of interlocking grains. It shows much variation in the grain size. It also forms the usual inclusions in porphyroblasts of felspars and garnets.

Felspars are both plagioclase and microcline. The plagioclase is an oligoclase (An_{15-20}) recognised by the lamellar twinning. It mostly occurs in the groundmass or forms stray augen shaped bigger crystals. Microcline occurs both in the groundmass, as well as in the form of big porphyroblasts. Its smaller grains are typically interstitial and may or may not show cross-hatching. The porphyroblasts are also cross-hatched but most of them in addition show traces of carlsbad twinning indicating the inversion of microcline from orthoclase. At a few places, the microcline is seen replacing the plagioclase. The microcline porphyroblasts contain inclusions of quartz, muscovite and plagioclase.

Micas are mainly muscovite with subordinate biotite. They show the usual occurrence viz., tufts

PLATE V.14



Porphyroblast of potash felspar in porphyroblastic gneiss. Relict carlsbad twin is seen. (Chaunsali band)
(Photomicrograph: crossed nicols X30)

of slender muscovite with intergrown flakes of biotite.

Garnet occurs only occasionally and when present, it forms rounded fresh grains.

Accessory minerals present are *zircon*, *apatite*, *sphene* and *magnetite*.

Gneissic granite mass of Dyolidanda hill

A most characteristic feature of this hill is that its central part is biotitic and shows a high potash-felspar content. Texturally, the rocks of the hill fall into four categories:

(1) Felspathic schist,
(2) Augen gneiss,
(3) Porphyroblastic gneiss,
(4) Gneissic granite.

Felspathic schist

This occurs along the fringes of the hill as discontinuous patches. In texture, it is almost schistose with dominant quartz and micas, and very subordinate felspars. The minerals are *quartz*, *muscovite*, *biotite*, *felspars* and *garnet*.

Quartz occurs as subhedral grain showing characters similar to those of its occurrence in the adjoining schists.

Micas are both muscovite and biotite, of which muscovite predominates. It forms clusters and slender flakes. Biotite forms narrow flakes that are scattered in a quartzose mass, and shows usual pleochroism (straw yellow to reddish brown; $x < y = z$, x = straw yellow, $y = z$ = reddish brown).

Felspars are seen in a subordinate amount, occurring in close association with quartz as anhedral grains. Most of the felspar appears to be a plagioclase (An_{30-36}). It is recognised by the lamellar twinning and staining. Potash felspar (microcline) is only occasionally seen.

Garnet is present and occurs as rounded fresh grains often containing inclusions of quartz.

Accessory minerals are magnetite, zircon and apatite.

Augen gneiss

Augen gneiss represents an advanced stage of granitisation of schists, and in thin section typically shows a gneissic groundmass with numerous felspar augens mostly of orthoclase. The minerals are quartz, felspars, micas and some garnet.

Quartz forms typical irregular grains and shows quite often interlocking and size variation.

Felspars are both orthoclase perthite and plagioclase, the former dominates. It occurs in the main mass of the rock as small untwinned grains, and also forms eye-shaped larger crystals. The augens typically show a carlsbad twinning over which cross hatching is superimposed (Plate V.15). The optic axial angle of this potash felspar (2Vx) is 76° to 84° and thus the mineral is intermediate between orthoclase and microcline. It contains numerous inclusions of muscovite, biotite, quartz and plagioclase. Plagioclase is an oligoclase (An_{25-28}) and it forms quite distinctly twinned grains. Augens of plagioclase are not very common.

Micas are both muscovite and biotite, the muscovite is predominant and form slender flakes and occurs in tufts. Biotite forms discrete flakes. It shows pleochroism from straw yellow to brown ($x < y = z$; x = straw yellow, $y = z$ = brown).

Garnet is generally rare and is seen only occasionally in a few sections.

PLATE V.15

Augen of potash felspar from augen gneiss of Dyolidanda hill band showing superimposition of cross-hatching over carlsbad twinning.
(Photomicrograph: crossed nicols X30)

Accessory minerals are apatite, zircon, and tourmaline.

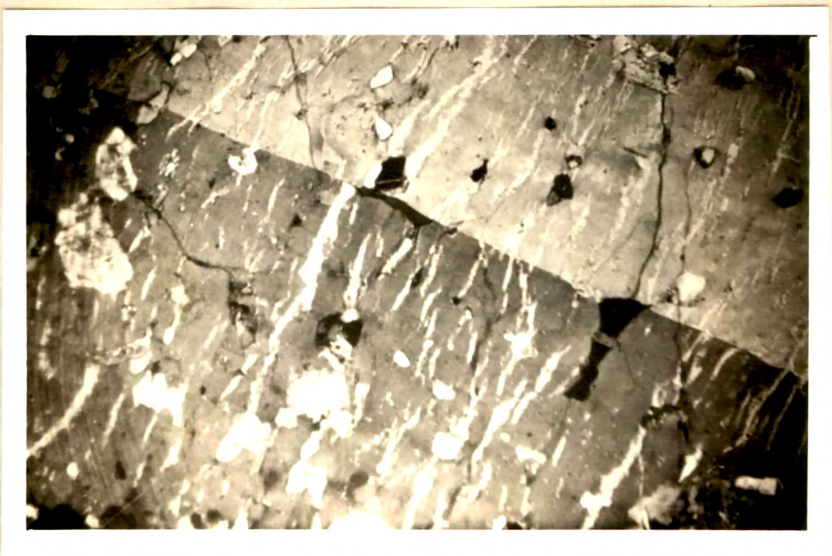
Porphyroblastic gneiss

This gneiss contains a large number of felspar porphyroblasts - rounded as well as subhedral, that lie haphazard along and across the foliation. Under the microscope, the main mass of the rock shows a crude foliation indicated by mica flakes, the quartz-felspar forming a granoblastic aggregate. The porphyroblasts lie in all directions and are mostly of potash-felspar (Plate V.16). The minerals are quartz, potash felspar, plagioclase, muscovite, biotite and stray garnet.

Quartz typically forms inequigranular and somewhat sutured grains of all sizes.

Felspars are both potash felspar and plagioclase. The potash felspar is orthoclase perthite as well as microcline. In the groundmass, mostly it is a microcline, while the porphyroblastic grains show a transition from orthoclase to microcline. Twinning on carlsbad law as well as cross hatching are shown by most of the bigger grains. Their 2Vx is found to vary from 74° to 82°. Plagioclase is an oligoclase (An_{10-18}) and it contains numerous inclusions of mica.

PLATE V.16



Porphyroblast of potash felspar in the porphyroblastic gneiss of Dyolidanda hill band (Photomicrograph: crossed nicols X30)

Micas are the usual muscovite and biotite - the former being predominant. The muscovite forms clusters, tufts and individual flakes. Biotite occurs sporadically as discrete, sometimes quite broad pleochroic flakes (straw yellow to reddish brown; $x < y = z$; x = straw yellow, $y = z$ = reddish brown).

Garnet is seen as well formed fresh rounded grains.

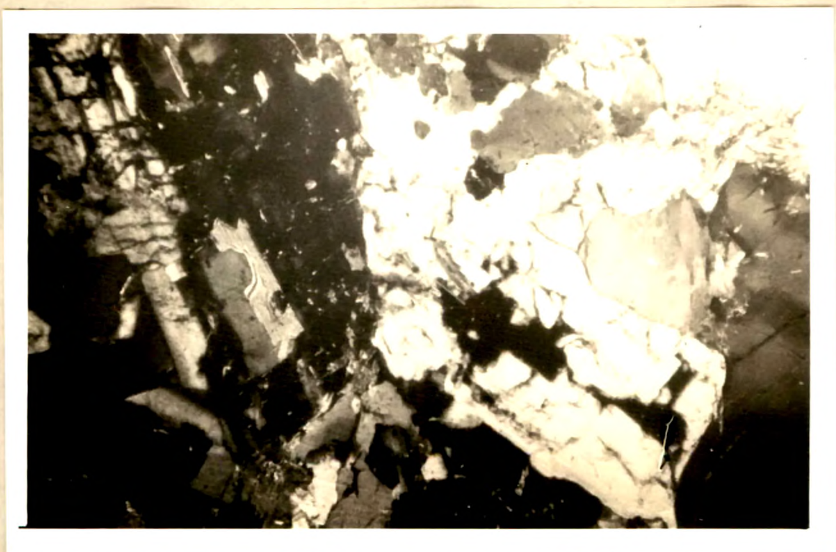
Accessory minerals are apatite, zircon and magnetite.

Gneissic granite

This variety forms the main central portion of the hill and shows a distinct but coarse foliation only in hand specimen. In thin sections, it is seen to exhibit a typical granitic texture (Plate V.17). The minerals present are quartz, felspars, micas and occasional garnet. Fibrolitic sillimanite is also encountered sporadically. A characteristic feature of most of the samples of this rock is the presence of sericite in variable proportion, being an alteration product of felspars.

Quartz occurs as irregular highly sutured grains showing a very wide range of grain size. Bigger grains intergrow with each other or with felspars or micas,

PLATE V.17

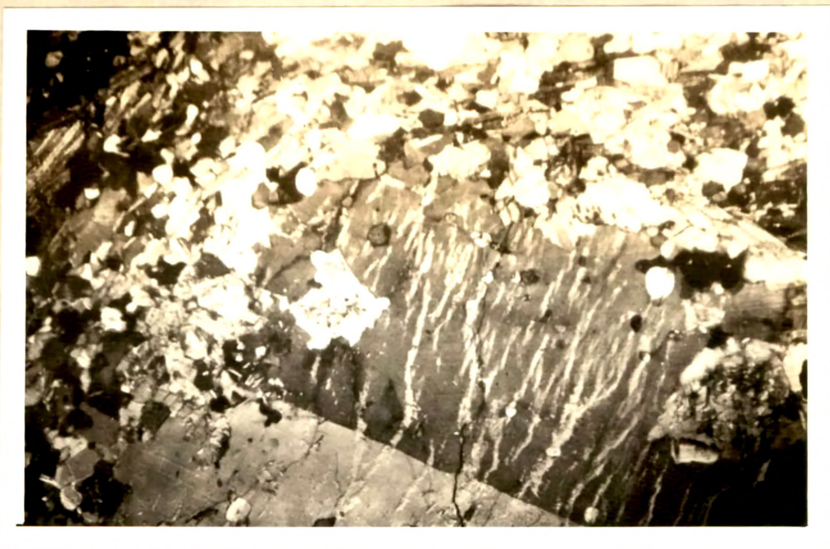


Texture of gneissic granite
(Photomicrograph: crossed nicols X30)

while the smaller ones in addition, show patches and clusters of interlocked grains. It occasionally forms rims of tiny aggregates along the borders of felspar porphyroblasts (Plate V.18). In some sections, the quartz shows distinct strain shadows, while in others it is very fresh and undeformed.

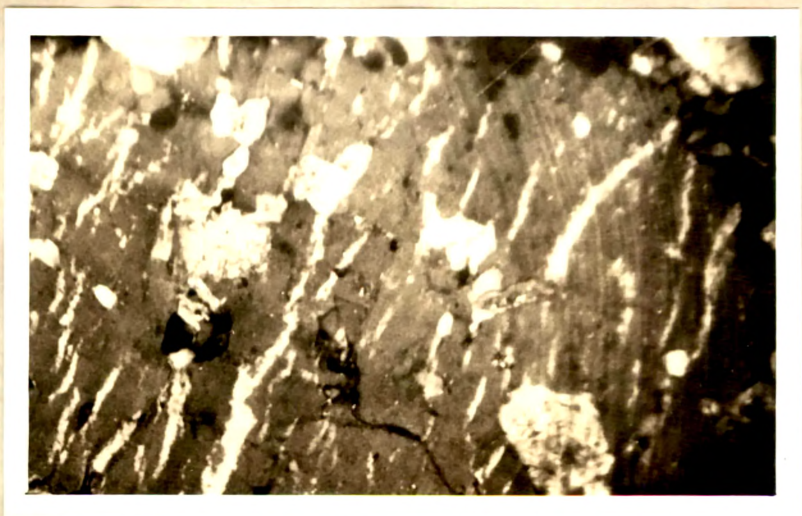
Felspars are both potash felspar and plagioclase. The potash felspar is mostly an orthoclase perthite though microcline too is not uncommon. This mineral also shows a big range of size variation. Smaller crystals occurring in close associations with quartz are generally of microcline. The bigger (suggestive of porphyroblastic origin) felspars are invariably of orthoclase perthite or orthoclase changing to microcline. Carlsbad twinning is always recognised. Veins of plagioclase tend to impart it a perthitic nature (Plate V.19). The superimposition of cross-hatching clearly suggests a progressive inversion of orthoclase to microcline. The 2Vx values (Table V.1) also amply support this observation. These porphyroblastic potash felspars contain numerous inclusions of quartz, plagioclase, muscovite and occasional biotite, Another important feature of these bigger grains is the crowding of small quartz grains along the borders. Quite often the potash

PLATE V.18



Rims of quartz grains along borders of felspar porphyroblasts in gneissic granite.
(Photomicrograph: crossed nicols X30)

PLATE V.19



Perthitic veins in orthoclase of gneissic granite (Photomicrograph: crossed nicols X50)

TABLE V.1

2Vx values of K-felspars in gneissic granites of Dyolidanda hill

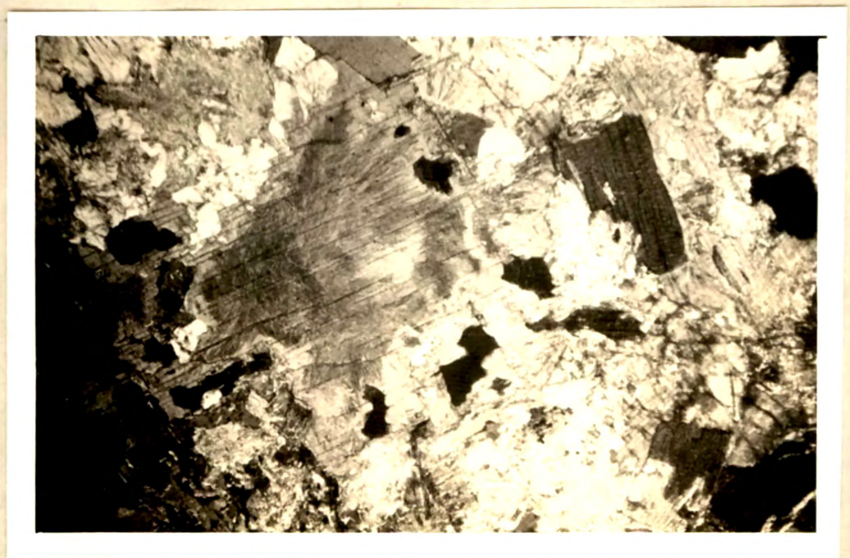
Specimen No.	2Vx values		
	Orthoclase	Orthoclase-microcline (transition)	Microcline
211	-	75°	79°,83°
212	58°	73°	82°
83	72°	76°	79°,82°
183	63°	75°	78°,84°
198	69°	-	-
205	70°	74°	80°,84°
71	64°	-	80°,84°

felspar is seen altering to sericite mass and different stages of sericitisation are recorded.

The plagioclase (An_{10-15}) is subordinate to the potash felspar, and occurs in the main mass of the rock. Its mode of occurrence is identical to that of potash felspar, except that it very rarely forms porphyroblastic grains. It is recognised by lamellar twinning and is quite fresh on the whole. Sometimes it contains inclusions of muscovite and quartz.

Micas are both biotite and muscovite. The relative proportions of the two is quite variable. On the whole, the biotite predominates over muscovite, but in some cases, the two may be present in equal amounts. Biotite form typical broad tabular flakes, showing a pleochroism from straw yellow to reddish brown. It contains inclusions of zircon occasionally. The occurrence of muscovite is quite interesting, and this mica appears to be of two generations. Muscovite occurring as small flakes in close association with biotite, appears to be of the same generation as the biotite, but bigger flakes (0.2 to 0.5 mm) of porphyroblastic habit are seen to have developed at the expense of sericite by recrystallisation (Plate V.20). Thin sections typically

PLATE V.20



Porphyroblastic muscovite after sericite
(Photomicrograph: crossed nicols X30)

reveal this second generation of muscovite having been developed from the sericite, the alteration product of felspars. It is therefore likely that the muscovite rich variety represents rocks which contain recrystallised sericite. Muscovite also occurs as tiny inclusions in felspars.

Garnet is only occasionally present. It is seen in a few sections only, forming imperfect but fresh crystals.

Sillimanite: This mineral recorded in some sections only is of fibrolite variety. It is seen as hairlike needles forming inclusions within quartz.

Accessory minerals are apatite, zircon and tourmaline.

FLAGGY QUARTZITES

These micaceous quartzites have been classified into two main types: (i) white muscovite bearing and (ii) light grey biotitic bearing. The texture and mineralogy of the two types are rather different.

White muscovite bearing quartzites

These micaceous quartzites in thin sections show a medium-grained aggregate of equigranular quartz into which are interspersed thin streaks of muscovite flakes. The quartz grain aggregates show more or less straight contacts, though suturing and interlocking is not uncommon. The minerals are quartz, muscovite and a little biotite (Plate V.21).

Quartz is the most dominant constituent and occurs as somewhat elongated grains. Interlocking is not very common and the mutual junctions are quite often straight.

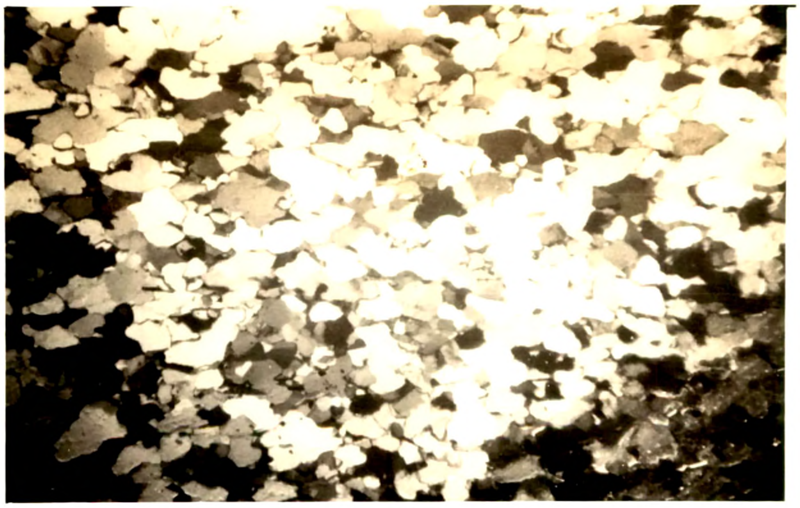
Micas is mostly muscovite. It forms discontinuous thin parallel streaks of muscovite interspersed in the quartzose mass. Biotite is only occasionally present as tiny flakes.

Grey biotite quartzite

It is slightly more micaceous than the previous type, and in thin sections shows a "granulated" aggregate of quartz (Plate V.22) with some potash felspars into which tiny flakes of biotite lie scattered showing a well defined foliation. The mineral content comprises quartz, potash felspar, biotite and a little muscovite.

Quartz is the dominant mineral and occurs as somewhat interlocking grains of lensoid shapes.

PLATE V.21



Texture of quartzite type (i)
(Photomicrograph: crossed nicols X30)

PLATE V.22

Texture of quartzite type (ii)
(Photomicrograph: crossed nicols X30)

Potash felspar is untwinned (microcline) and forms cuspate grains that occupy interstitial spaces between quartz.

Biotite occurs as slender small flakes interspersed uniformly and showing a parallelism.

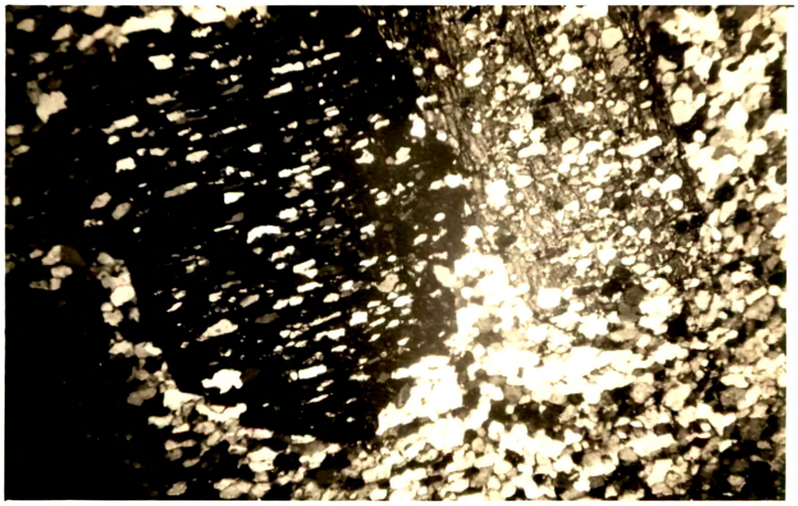
Muscovite is only occasionally seen as tiny flakes.

CALC-SILICATE ROCKS

It is a light grey compact rock crowded with actinolite needles and cinnamon coloured garnets. In thin sections, it shows a 'granulated' porphyroblastic texture comprising a medium-grained groundmass of flattened lensoid quartz grains and plagioclase, embedded in which occur broad plates of actinolite and rounded grains of garnet porphyroblasts.

Quartz forms an equigranular mass of slightly flattened lensoid grains. It also occurs as inclusions within the actinolite and the garnet, and a typical feature of these inclusions is that their orientation cuts through these porphyroblasts uninterrupted (Plate V.23), suggesting growth of porphyroblasts after the foliated mass of quartz had originated.

PLATE V.23



Porphyroblasts of actinolite and garnet with inclusions of quartz and showing a late growth
(Photomicrograph: crossed nicols X30)

Felspar is a plagioclase (An_{40-45}) and occurs as distinct grains in close association with quartz. It typically shows lamellar twinning. It never occurs as inclusion in actinolite or garnet.

Actinolite occurs as broad plates. Its extinction angle varies between 10° to 20° on (110). It shows pleochroism from pale green to emerald green ($z > y > x$; z = emerald green, x = light green). The crystals contain large number of quartz inclusions.

Garnet forms as big round grains riddled with numerous inclusions of quartz.

Chlorite (clinochlore) occurs as distinct crystals with a faint pleochroism from colourless to green ($x > y = z$; x = colourless, $y = z$ = green). It shows polysynthetic twinning and low order grey polarisation colour. It occurs in association with actinolite.

Accessory minerals are mainly magnetite and some grains of apatite.