CHAPTER V

P E T R O G R A P H Y

MICROSCOPIC CHARACTERS:

Microscopic studies have very clearly revealed that the rocks of the study area have undergone various mineralogical and textural changes during successive periods of deformation and metamorphism. The author therefore proposes to describe briefly the petrographic characters of the various lithological types before building up a sequence of mineralogical and textural changes that the rocks underwent during the past.

The samples were collected from all parts of the ground and their textural and mineralogical characters were investigated. As has already been mentioned, the rocks of the area belong to a pelite-psammite sequence and all gradations from highly micaceous to highly siliceous types exist. Still, however, detailed field mapping supported by exhaustive study of thin sections, has enabled the author to work out a classification for proper and detailed description of the different rock types.

Pelitic and Semipelitic schists:

Rocks wherein micas form half of the bulk have been called "pelites", while rocks where micas make up about one-third of the whole, have been classified as 'semipelites'. With further decrease of mica content and increase of quartz, the rock tends to become almost quartzitic, and wherever significant flakes of micas mark the foliation, they can best be described as siliceous mica schists. It is rather difficult to always demarcate the boundaries of the various groups, as the transition is quite often gradual.

A typical pelitic schist, in handspecimen, is coarse to medium grained, bronze yellow, foliated rock, spotted with garnet porphyroblasts. These garnets vary in size and number. Other varieties have occasional grains only. On account of microfolding, at many places the schistosity has developed herringbones and crinkles, and a frequent resultant strain-slip cleavage. This deformational phenomenon has been responsible for the development of a number of textural and mineralogical features characteristic of the crinkled variety. Detailed microscopic study led the author, therefore to describe the uncrinkled and crinkled varieties separately.

Normal (uncrinkled) schists: These are coarse to mediumgrained, schistose rocks, the foliation characterised by parallel orientation of mica flakes, occurring either as individual flakes or in tufts, with the intervening spaces occupied by quartz. Two distinct textural types are recognised.

(i) Rather coarsegrained with tufts or individual well developed mica flakes - both biotite and muscovite, occurring in association with elongated aggregates of small quartz grains. The quartz grains show rather sharp and straight mutual boundaries. Of course, occasionally, portions richer in quartz do show an interlocking mosaic. Some quartz grains tend to have elongated shapes but they are not very common. Garnets are generally porphyroblastic, containing quartz inclusions. (Plate 12A)

(ii) A mediumgrained type (somewhat less micaceous) showing uniform scattering of parallel flakes of micas (mostly biotite), interspersed in an equigranular mass of quartz. The interlocking mosaic is not so common, the quartz grains mostly showing straight borders. Garnets though porphyroblastic are of reduced size, equidimensional, not so idiomorphic. More micaceous and less micaceous layers occur commonly intermixed and even in a single specimen, very often some parts are highly micaceous while the rest is relatively richer in quartz. This mineralogical variation reflects in the texture also. (Plate 12B)

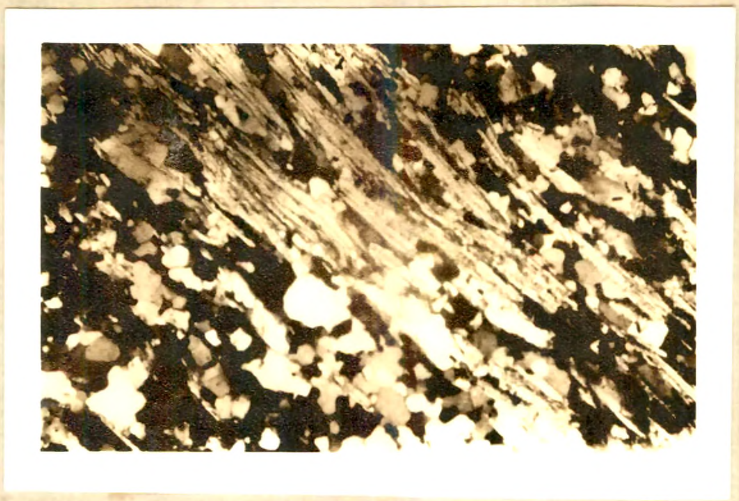
Mineral assemblages:

(i) Quartz-biotite-muscovite-garnet-chlorite

(ii) Quartz-muscovite-biotite-garnet

(iii) Quartz-biotite-muscovite-plagioclase.

PLATE 12A



Textural characters of uncrinkled schists
(Photomicrograph, x30)

PLATE 12B

Textural characters of uncrinkled schists
(Photomicrograph, x30)

Quartz occurs as irregular grains generally equidimensional (varying in size between 0.1 to 2 mm.) filling up the intervening space between the parallely oriented micas. The strain shadows are not so well marked. Mostly they show sharp junctions with the adjoining grains. Another mode of occurrence of the mineral is as inclusions in garnets, micas and felspars.

Biotite occurs as long slender flakes (varying in size from 0.12 to 3 mm.) mostly intergrowing with muscovite. It shows marked pleochroism from straw yellow to chestnut brown ($X > Y = Z$, X = straw yellow, Y = Z = chestnut brown). Stray grains of zircon and quartz are its common inclusions. Small flakes of biotite occurring along the fringes of some of the garnets, appear to have possibly derived from the garnet.

Muscovite almost as much as biotite in quantity, the white mica (muscovite and ferrimuscovite) occurs as shreds and slender flakes. Colourless muscovite and pale faintly pleochroic ferrimuscovite occur in close association with biotite, often intergrowing. Sometimes it is seen that the white mica has developed at the expense of biotite.

Garnet typically of almandine variety, it occurs both as xenomorphic grains as well as amoebic patches. The porphyroblasts of garnet (of sizes 0.8 to 2 mm.) show clear idiomorphic shape in most cases. Of course, some grains have only partly developed crystal faces. In a broad way, well formed garnets are confined to more micaceous portions. The most common inclusions are those of quartz. As a rule the garnet porphyroblasts show S-shaped (helicoid) trails of quartz inclusions (Plate 13), suggesting their rotation during growth due to differential slipping of the matrix along the planes of schistosity.

Chlorite well formed flakes of chlorite are occasionally present. Typically showing light green colour, and low birefringence (almost isotropic), this chlorite, in most cases is seen to be derived from biotite.

Felspar is only occasionally present, in small quantity and is mostly a plagioclase (An_{26-30}). It appears to have developed from the original sediments, during the progressive regional metamorphism. Usually

PLATE 13

Garnet showing helicoid trails of quartz inclusions

(Photomicrograph, x 30)

the grains of plagioclase are small (0.15 to 0.2 mm) and twinned on Albite law (010, composition plane).

Accessory minerals tourmaline, zircon and magnetite are usually present in small amounts and occur as tiny grains. Tourmaline occurs as bluish grey or light brown small needles and laths. Magnetite grains are seen scattered all over the rock mass. Also it occurs as inclusions in garnets. Zircon is somewhat rarer and is occasionally seen to occur as tiny inclusions in biotite.

Crinkled pelitic schists: The microfolding of the above described mica schists has given rise to a variety of crinkled rocks, showing characteristic textures, and microstructures. Essentially a phenomenon connected with one folding superimposed on an earlier one, this microfolding has resulted into widespread development of a strain-slip cleavage and a new schistosity (S_2). Depending upon the intensity of the superimposed folding and the lithology of the pelites, the late cleavage (S_2) has developed in a number of varieties, and each variety is ideally recorded in the thin sections of the pelites and semipelites. (Plates 14A, B)

PLATE 14A

Textural characters of crinkled schists
(Photomicrograph, x30)

PLATE 14B

Textural characters of crinkled schists
(Photomicrograph, x30)

These schists also show considerable variation in mica content, depending on which the intensity, and the nature of microfolding and related strain-slip cleavage varies from place to place. The micas occur as tufts, streaks and individual flakes, in a quartzose mass. The quartz grains show a tesselate texture having smooth and sharp junctions, somewhat elongated in the foliation direction.

A close examination of these crinkled schists in handspecimens and in thin sections, has led to the following interesting observations:-

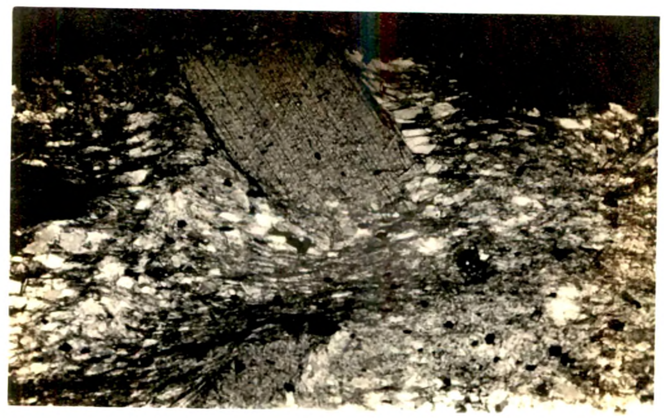
(1) Highly micaceous portions, when affected by intense deformation, have developed numerous very sharp chevron folds. In most cases, the hinges of these tiny folds have broken along the axial planes, giving rise to herringbone structure and a well defined cleavage ~~(Plate 13~~). The size of these microfolds generally vary between 10 mm to 2 mm. With the decreasing intensity of deformation, the tightness and fracturing of the microfolds gradually diminishes, and moderately crinkled schists show only a large number of continuous microfolds. Such

pelites which have been but only slightly affected show a wavy foliation, giving rise to faint puckering of the main schistosity.

(2) Some of the finegrained phyllonitic pelites, show a moderate crumpling and microfolds, but are characterised by widespread development of biotite porphyroblasts growing oblique to the schistosity (S_1) and marking the superimposed cleavage (S_2). In such examples, the orientation of the biotite porphyroblasts clearly indicates the incipient strain-slip direction S_2, the porphyroblasts having developed along the axial planes during the late folding (Plate 15).

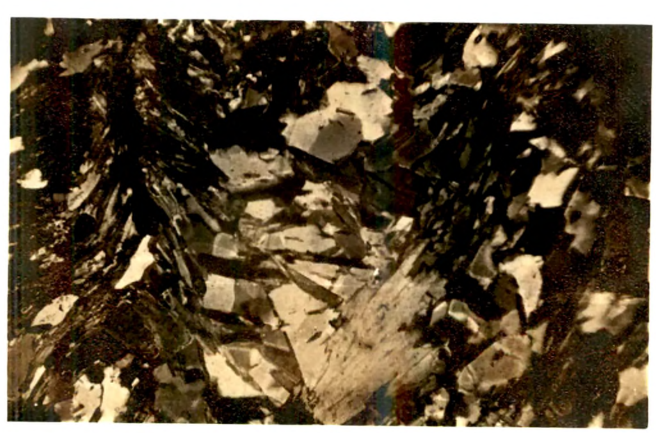
(3) Wherever, the less micaceous (and more siliceous) mica schists have been subjected to this late folding, instead of distinct microfolds, the rock has developed a large number of fine shear planes in S_2 direction. On account of slipping along these planes, the schistosity S_1 shows folding of a different type - a large number of microfolds essentially of the drag type, with resultant strain-slip cleavage (Plate 16).

PLATE 15



Biotite porphyroblast across the schistosity
(Photomicrograph,x30)

PLATE 16



Microfolds of the drag type in schists
(Photomicrograph,x30)

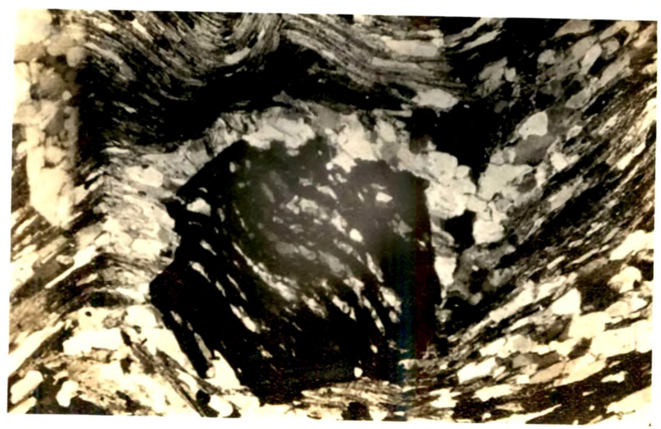
Mineral assemblage:

Quartz-muscovite-biotite-garnet-chlorite.

Quartz occurs as equigranular aggregates with smooth and sharp junctions. The slight elongation of the grains generally follows the microfold trends and it is obvious that considerable granulation and recrystallization took place during the microfolding. It is very interesting to note that in case of highly pelitic varieties, the quartz aggregates are usually confined to the crests of the microfolds. This mode of occurrence suggests that the quartz has accomodated itself to the deformation which caused the crinkling by recrystallizing in this manner. The quartz grains do not show much strain shadows.

Micas - both muscovite and biotite are present, though the muscovite generally predominates. The micas characterise the foliation of the rock, which is seen crinkled. Flakes of micas - both biotite and muscovite - show a wavy orientation. The flakes themselves are undeformed and evidently suggest that earlier mica flakes were bent or broken and later recrystallised into their new positions. Biotite's

PLATE 17



Static garnet in crinkled pelites
(Photomicrograph, x30)

occurrence is very interesting. It is seen to belong to two types, perhaps representing two distinct origins. One mode of occurrence is that as slender flakes in association with muscovite, characterising the wavy foliation. Perhaps this biotite is the original one recrystallised during crinkling. Yet another biotite, distinct from the above type, is that forming porphyroblasts. These porphyroblasts lie across the crinkled foliation and clearly suggest that most of these (biotite porphyroblasts) were formed at the time of the microfolding of the foliation, porphyroblasts growing in the axial plane direction of the folds.

Garnet is almost always present and forms small porphyroblasts (0.5 to 1.5 mm.). The nature of garnet grains occurring in these crinkled rocks, is very interesting. When occurring in the crests of the folds, it is seen to form idiomorphic grains. The trends of quartz and magnetite inclusions inside these garnets show same fold trends as the surrounding matrix, and it is fairly obvious that the garnets have grown in a static matrix. (Plate 17) These garnets appear to have formed during the later microfolding. On the other hand, garnet grains occurring along the limbs of the folds show helicoid pattern of inclusions, and appear to have rotated during growth. It is quite likely that these rotated garnets also grew during the late microfolding. But the likelihood of these being regenerated early garnet cannot be easily ruled out. It is observed that most of such garnets, which lie as linear clusters on the flanks of the folds, contain considerable biotite and chlorite along their borders, and this is a fairly good indication of granulation and retrogression of an early garnet due to differential slipping during the microfolding ~~(Plates 16 and 17)~~ and its subsequent regeneration.

Chlorite is usually found associated with micas as parallel scattered flakes and appears to be a retrogressive product after biotite. The chlorite is pleochroic from green to light green ($X > Y = Z$, X = green, $Y = Z$ = light green, parallel to C(001). Some chlorite appears to have derived from the garnets also, which is seen along the fringes of the latter.

Accessory minerals magnetite and zircon are the common accessory minerals. Magnetite forms discrete grains scattered all throughout the mass. Zircon occurs as tiny inclusions in biotite flakes.

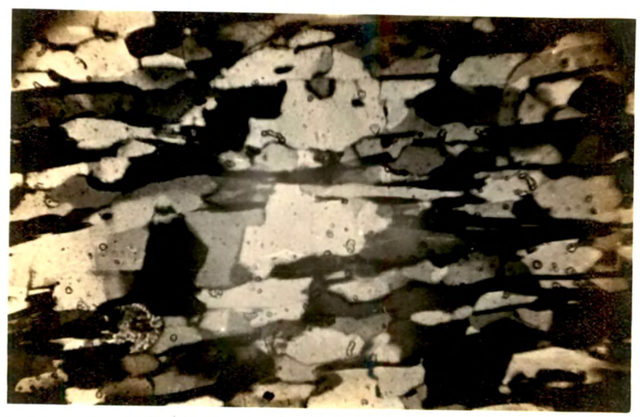
Semipelitic schists: With the increasing quartz content, garnet mica schists change over to the semi-pelitic variety. These are foliated and compact siliceous rocks with silvery grey colour. These semi-pelites are essentially transitional rocks and form distinct bands and lenses in garnet mica schists on the one hand and in quartzite on the other.

On the basis of megascopic and field study, two varieties of the semipelitic schists have been identified.

(1) One variety shows a uniform scattering of mica in a siliceous mass. It differs from the mica schists only in the decreased mica content, and can best be considered as siliceous mica schists(Plate 18).

(2) The other variety consists of rapidly alternating micaceous and siliceous layers. The bulk composition of these varieties of semipelites is intermediate between psammites and pelites.

PLATE 18



Textural characters of semipelitic rocks
(Photomicrograph, x30)

These semipelitic schists also show microfolding but, generally its effect is not so much pronounced. Only the foliation is seen to have developed open crinkles.

Texture: Texturally, these semipelitic (siliceous mica schists) rocks are very interesting. These show foliated structure, characterised by parallel arrangement of mica flakes. The mica flakes are thin and never very long, generally 0.4 to 0.56 mm and lie scattered in a granulitic mass of quartz grains. Quartz forms polygonal grains with rather straight and sharp mutual junctions. Interlocking mosaic is not very common. The relative proportions of quartz and micas, are very variable and layers with varying mica content, are quite frequently recorded. The mica flakes are seen showing preferred orientation in two directions at a slight angle. This phenomenon is ideally seen in such semipelites which consist of rapidly alternating micaceous and siliceous layers. The mica flakes in mica rich portions are parallel to the layering while those in less pelitic bands are somewhat oblique to the layering. This clearly indicates the existence of two schistosities - an early one (S) parallel to the sedimentary layering, and a late one (S_1) oblique to the sedimentary bedding. On a careful study, even the more pelitic layers also show a considerable number of flakes of mica, lying slightly oblique to the main layering.

In the crinkled varieties, the foliation shows some degree of waviness, and occasionally porphyroblasts of muscovite (or rarely biotite) are seen growing oblique to the foliation.

Mineral assemblages:

(i) Quartz-biotite-muscovite-garnet

(ii) Quartz-biotite-muscovite-plagioclase±garnet

Quartz occurs as clear polygonal grains which quite often tend to possess a flattened shape. Mostly quartz occurs as aggregate of grains - having smoother junctions (tesselate type) with occasional sutured patches of interlocking grains. Quartz also occurs as inclusions in garnet.

Biotite occurs as rather slender parallel flakes marking the schistosity. Pleochroism is light brown to dark brown ($X > Y = Z$, X = light brown, Y = Z = dark brown). The biotite flakes either form thin layers and streaks or occur scattered in the quartzose mass.

Muscovite usually occurs as slender flakes very often intergrown with biotite.

Plagioclase is on the whole quite scarce, and is only occasionally seen occurring as small irregular grains in association with quartz. When present, it is fresh and unaltered, and shows the usual lamellar twinning ($An._{25-30}$).

Garnet is typically of pink variety (almandine) and generally present as fairsized xenomorphic grains with rather irregular outine. Inclusions of quartz are numerous and sometimes show distinct helicoid pattern.

Accessory minerals are zircon, apatite, tourmaline, clinozoisite, magnetite. Zircon, as usual forms haloed inclusions in biotite. Apatite forms stray needles. Tourmaline occurs as grey and brown tiny laths showing straight extinction and characteristic pleochroism ($\omega > \epsilon$, pale blue to colourless). Clinozoisite has high R.I. and shows characteristic anomalous blue

blue polarization colours. Magnetite occurs as inclusions in garnet and biotite.

Graphite schists: These occur as thin streaks, lenses and bands in pelites. In hand specimen, these graphite bearing rocks are easily identified by their thin finely foliated nature and dark grey colour. Wherever the graphite content is high, the rock has a characteristic soapy touch.

Texture: Finegrained with strong foliation marked by linear orientation of graphite streaks, the intervening space filled with quartz grains. The foliation, as characterised by the streaks of graphite, shows moderate to faint puckering ~~(Plate 22)~~, and very often flakes of biotite are seen growing almost normal to the foliation, signifying an incipient late cleavage.

Mineral assemblages:

Graphite-quartz-biotite-garnet.

Graphite occurs as small thin streaks, parallel to each other. It is as usual opaque.

Quartz forms small grains - all irregular, filling up the intervening spaces between streaks of graphite.

Biotite forms somewhat bigger flakes which mostly lie across the foliation. It is obvious that this biotite has developed during the microfolding of the schistosity and marks the late cleavage (S_2).

Garnet almost always present, it forms well developed grains with quartz inclusions.

Phyllonites (Sericite-chlorite schists): These rocks are confined to a few shear zones in the pelitic and semipelitic schists, and appear to have originated by intense mylonisation due to differential slipping (In most cases, the subsequent metamorphism has resulted into the formation of big biotite porphyroblasts grown across the foliation. The recrystallised and crinkled varieties have been described later) (Plates 15 & 19).

Texture: These phyllonites are finegrained and highly foliated rocks of light grey colour. In thin sections, they are seen to show a strong schistosity marked by tiny flakes of sericite-muscovite and quartz granules.

PLATE 19

Textural characters of phyllonitic rocks
(Photomicrograph, x45)

<u>Mineral assemblages</u>:

Quartz-sericite(muscovite)-biotite-chlorite ± garnet-magnetite.

<u>Quartz</u> occurs as small grains - intimately mixed with micas, very often forming streaky aggregates.

<u>Sericite</u> may be very fine muscovite - tiny flakes marking the foliation.

<u>Biotite</u> always occurs as big porphyroblasts, a late product cutting across the foliation.

<u>Chlorite</u> is only sometimes present and occurs as small flakes in close association with muscovite.

<u>Garnet</u> only occasionally present and is seen to be of small irregular shape.

<u>Magnetite</u> small grains of magnetite occur scattered all over the mass.

<u>Mylonitised quartz - tourmaline rock</u>: This peculior rock type is a hard glassy looking grey in colour and under thin sections, seen to be a partly

recrystallised mylonite.

Texture: Some samples show distinct mylonitic texture - a finegrained matrix into which crushed, augen shaped relicts of quartz are embedded. In case of recrystallised varieties, the matrix is seen to form a fine aggregate of quartz grains and tourmaline needles.

Mineral assemblages:

Quartz-tourmaline-epidote

Quartz occurs as relict augens, fine granules in the sheared and recrystallised matrix.

Tourmaline is seen as small needles pervading the matrix or as somewhat big grains - partly crushed. The bigger grains are typically pleochroic from pale blue to colourness ($\omega > \epsilon$) while the needles and smaller grains are faintly pleochroic and perhaps could be called as (? Dravite).

Psammitic rocks: These are highly siliceous rocks, occurring as layers in the schists and consist dominantly of quartz. Two varieties of these siliceous rocks are recognised: (1) white compact quartzite and (2) grey and foliated quartzite. Both these varieties are somewhat flaggy on account of the frequent presence of thin pelitic layers. Texturally and mineralogically, these two varieties are quite distinct.

White compact variety: This is a biotite free variety, more or less an unfoliated quartzite.

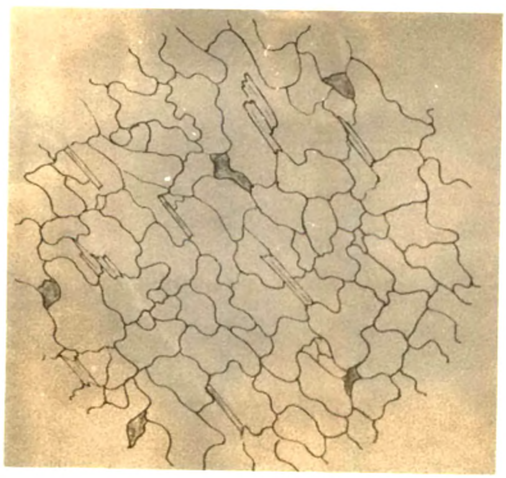
Texture: A medium grained rock consisting of an interlocking mosaic of sutured quartz grains which show considerable variation in shape and size. This texture has been referred to as "granulated type" (Read, 1931, p. 46-48) (Plate 20).

Mineral assemblages:

Quartz-muscovite-microcline

Quartz is the dominant mineral, constituting the main bulk, and occurs as sutured and interlocking grains with undulatory extinction.

PLATE 20



Granulated texture in psammites
(Photomicrograph, x30)

Muscovite occurs as tiny flakes, interspersed in the quartz mosaic. The flakes show a parallel orientation, marking the foliation.

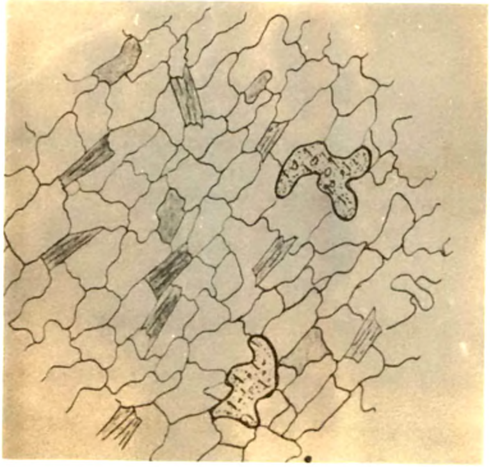
Microcline occurs in subordinate amounts and either forms recognisable grains or as cusp-shaped infillings in the interstitial space between bigger quartz grains.

Accessory minerals are tourmaline, epidote and sphene.

Grey foliated variety: This variety of psammitic rock, is somewhat more micaceous than the previous one, and contains a small proportion of biotite, on account of which the rock has a grey foliated nature.

Texture: The texture of this variety is essentially of the "tesselate type" of Macgregor (1951,p. 56). (Plate 21) The quartz grains show sharp and straight mutual contact. The rock contains frequent thin layers of parallel mica flakes characterising the original bedding. Separated by such micaceous layers, the quartzite bands, dominantly siliceous, contain tiny mica flakes, parallel to each

PLATE 21



Tesselate texture in psammites

(Photomicrograph, x30)

other, but making a slight angle with the bedding cleavage. Thus, these rocks ideally show in thin sections, existence of two cleavages - one early coinciding with the bedding (S) and the other, a late one oblique to the former (S_1).

Mineral assemblages:

Quartz-biotite-muscovite-plagioclase-garnet.

Quartz occurs as medium sized grains with mostly smooth and straight borders. It also occurs as inclusions in garnet.

Biotite-muscovite the dominant mica is biotite, which forms small thin laths, and is seen marking two foliations. Parallel flakes of biotite with muscovite, confined to micaceous layers, marks an early foliation (parallel to lithological banding). Another mode of occurrence is as scattered flakes in quartz matrix, almost all oriented in a direction oblique to the main foliation.

Plagioclase occurs in subordinate amounts as grains scattered in quartzose mass. It shows characteristic twinning and is Andesine ($An._{35}$).

Garnet is present as fairsized skeletal grains, containing inclusions of quartz.

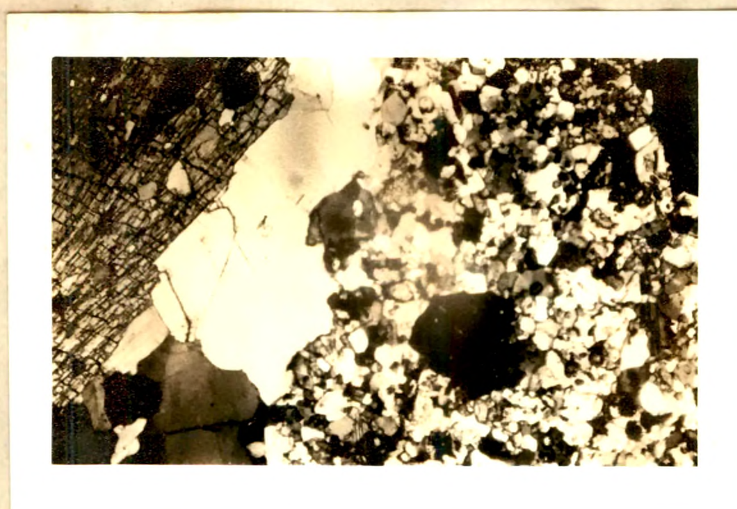
Accessory minerals are tourmaline, epidote and sphene.

It is clearly seen from above that the white compact variety represents arkosic sediments while those giving rise to grey foliated variety were sandy argillaceous.

Calc-silicate rocks: These rocks occur as thin bands (upto 3 cm. wide) mostly in pelites and semi-pelites and are observed throughout the area. They are interesting because of their varied mineral assemblages.

Texture: These rocks are made up of mediumgrained equigranular mosaic of quartz with felspar, zoisite and clinozoisite in which large crystals (2 to 4 cm. long) of actinolite, and garnet (1.12 to 1.36 mm diameter) are seen embedded (Plate 22).

PLATE 22



Textural characters of calc-silicate rocks
(Photomicrograph, x30)

<u>Mineral assemblages</u>:

(i) Quartz-felspar-zoisite-clinozoisite-garnet-biotite

(ii) Quartz-felspar-zoisite-amphibole-garnet

(iii) Quartz-zoisite-garnet-biotite-chlorite.

<u>Quartz</u> occurs as equigranular somewhat interlocking grains and as inclusions in garnet and zoisite.

<u>Felspar</u> is a plagioclase ($An._{45}$) and occurs in close association with quartz. Sometimes its grain size is little larger than that of quartz.

<u>Zoisite</u> usually occurs as irregular grains with frequent inclusions of quartz. It shows the characteristic low order grey polarization colour and commonly is seen intergrowing with garnet.

<u>Clinozoisite</u> is seen as small irregular grains scattered all over and shows anomalous blue polarization colours.

<u>Amphibole</u> is a tremolite-actinolite and forms large broad needles, which lie embedded in the granular matrix with a random orientation. The amphibole is

light green colour, faintly pleochroic. ($Z > Y > X$, Z = emerald green, X = light green). Its extinction angle varies between 10° to 20° in prismatic (110) sections. The crystals contain large number of quartz inclusions.

Garnet occurs as big round grains riddled with numerous inclusions of quartz. Sometimes inclusions of sphene, biotite and clinozoisite are also present.

Biotite small flakes of brown biotite present in some bands, lie scattered all over with a faint parallel orientation. It is associated with hornblende and may be a retrograde product of hornblende.

Chlorite occurs in some rocks associated as long slender flakes with biotite and garnet. It appears to have derived from garnet or biotite.

Accessory minerals grains of sphene, apatite and magnetite constitute the accessory minerals.

Gneisses (Migmatites): From the field characters, as well as the microscopic study, the gneissic rocks of the area have been identified to be a group of migmatites. Their petrographic study furnishes a complete picture of the course of migmatisation. A regular and gradational increase in the felspar content accompanied by appropriate textural changes from pelitic schists to coarse biotite gneisses, ideally illustrates the course of granitisation. Depending on the increasing felspar content and the textural characters, these felspathic rocks have been classified into the following types:-

(1) Felspathic schists

(2) Streaky permeation gneiss

(3) Tourmaline gneiss

(4) Augen gneiss

(5) Coarsegrained porphyroblastic gneiss.

The field characters and distribution of these types have already been described in Chapter III.

Felspathic schists: The felspathic schists are the least felspathized derivatives of mica schists, and indicate the beginning of the migmatisation. These rocks have a restricted occurrence, and are of transitional nature confined to the marginal areas on the two flanks of the gneissic bands. With the disappearance of the felspar, these grade into typical mica schists, on one side, and with the increase of felspar content, these give place to permeation gneisses.

Texture: These rocks show medium to coarsegrained texture. The foliation is characterised by thin parallel flakes of mica (mostly biotite), the intervening spaces filled with granular aggregates of quartz and felspar.

Mineral assemblages:

Quartz-biotite-muscovite-plagioclase-chlorite (garnet).

Quartz is the dominant mineral occurring as polygonal grains generally with smooth outlines, and occasionally forming aggregates of sutured interlocking grains. Much of it constitutes the original quartz of the pelitic schists. Some sutured aggregates and a few larger sized porphyroblasts appear to have been added during migmatisation. Another mode of occurrence is as tiny inclusions in garnet, muscovite and plagioclase.

Biotite occurs as thin flakes, of not very dark colour, and their parallelism marks the schistosity.

The pleochroism of biotite is from dark yellow to light yellow ($X > Y = Z$, X = dark yellow, $Y = Z$ = light yellow). Occasionally inclusions of sphene, apatite, zircon, magnetite are seen inside the biotite flakes, Some sections, especially those which are somewhat crinkled, contain a few biotite flakes broad and stubby lying oblique to the main foliation. These biotites are of a later generation having grown along the axial plane direction of the microfold.

Muscovite occurs as long slender flakes in association with biotite (In some specimens, it almost equals or even dominates over biotite). Some muscovite appears to have been derived from the biotite.

Plagioclase occurs as distinct grains and is seen developing along the foliation scattered all over the mass, with a tendency to grow larger. This clearly suggests its metasomatic introduction in the original schistose matrix. The plagioclase is quite fresh and unaltered and shows characteristic twinning on Albite (Twin-plane 010) and Carlsbad laws (Parallel to 001, twin axis) and is an andesine ($An._{35}$). The plagioclase grains contain inclusions of muscovite and quartz.

Chlorite is of minor occurrence, and is associated with biotite and probably is an alteration product of biotite. Chlorite forms light green distinct flakes, showing very low birefringence(and almost isotropic). A few broad flakes are also noticed to grow across the foliation.

Garnet occurs as distinct but xenomorphic grains riddled with quartz inclusions.

Accessory minerals stray needles of apatite, tourmaline and grains of magnetite and zircon constitute the accessory minerals.

Streaky permeation gneisses: These represent one further stage of migmatisation and are more felspathic than the previous variety. In handspecimen, these show a uniform scattering of felspar along the foliation, and are typically a transitional group, which with an increase in felspar content passes into the augen variety.

Texture: Somewhat coarser than the previous variety, the rock still distinctly exhibits a schistose structure, which is marked by the parallel flakes of micas. The quartz grains tend to become somewhat irregular in size and sutured.

Mineral assemblages:

(i) Quartz-plagioclase-microcline-biotite-muscovite-garnet

(ii) Quartz-plagioclase-microcline-muscovite-biotite-tourmaline-garnet.

Quartz occurs as somewhat sutured grains, and also as inclusions in plagioclase and garnet.

Plagioclase somewhat prophyroblastic, the plagioclase grains are seen growing along the foliation. These tend to force apart the micaceous foliae, though partly enclosing the micas and quartz. Inclusions of muscovite and quartz are common. Almost andesine ($An._{30-35}$) in composition, these show characteristic usual twinning.

Microcline is only occasionally seen in a few sections. When present it is seen confined to the groundmass.

Biotite-muscovite these micas occur as slender flakes - often intergrowing. The proportion of muscovite and biotite is almost equal.

Tourmaline present in some varieties only. It occurs as small neeules very often forming radiating clusters; otherwise they lie oriented in the foliation characterising a distinct lineation (The muscovite and microcline content is very high in tourmaline bearing variety of gneiss).

Garnet present as well developed and unaltered grains with magnetite and quartz inclusions.

Accessory minerals apatite and zircon are the most striking accessory minerals.

Augen gneiss: The streaky permeation gneisses with increase in the content and size of the felspars, merge into the augen variety.

Texture: Texturally, these are medium to coarse-grained gneissic rocks containing numerous "eyes" or "augens" of felspar ~~(Plate 27)~~. The micas mark the main foliation and characteristically wrap round the felspar augens. The texture of the groundmass is rather gneissic, parallel flakes of micas interspersed in a granoblastic aggregate of quartz and felspar (mainly plagioclase ($An._{27-30}$) and some microcline). Porphyroblastic eye-shaped plagioclases are seen developing at a number of places.

Mineral assemblages:

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

Quartz shows various modes of occurrence. Its size varies considerably from tiny to large grains and is seen to occur as (i) elongate aggregates of sharp polygonal grains, (ii) rather fairsized intergrown sutured masses. Its extinction is generally shadowy.

Plagioclase occurs both in the groundmass as well as augen shaped porphyroblasts. In the groundmass, it occurs in association with quartz, and is quite easily recognized on account of its characteristic twinning and slight alteration. In composition, it is nearly Andesine ($An._{30-35}$). The augens of plagioclase are very striking. They seem to have grown along the foliation planes and mica flakes. Quartz grains very often crowd around their periphery. The twins shown by these augen-shaped plagioclases are of the albite as well as the carlsbad types. The most characteristic feature of these plagioclase crystals is the large number of inclusions of tiny muscovite flakes and some quartz grains.

Biotite-muscovite of the two micas, muscovite predominates and forms long flakes. Quite often it shows faint pleochroism from colourless to light brown and could best be termed as ferrimuscovite. Some of the muscovite appears to have been derived from the biotite. Biotite is seen to occur in a subordinate quantity and forms scattered small flakes, often intergrown with muscovite.

Microcline is seen in a subordinate quantity and is confined mostly to the groundmass forming irregular grains. It is recognised mostly by its twinning and low R.I. In some thin sections, however, the proportion and size of potash-felspar is considerably increased, and occasionally the tendency of potash-felspar to invade the plagioclase porphyroblast is clearly recognised.

Garnet rather well developed garnets with fairsized inclusions of quartz are occasionally recorded.

Accessory minerals tourmaline, apatite and ironoxides are the accessory minerals.

Coarsegrained porphyroblastic gneiss: These gneisses represent an advanced stage of transformation of mica schists to felspathic rocks. These medium to coarsegrained gneissic rocks contain abundant porphyroblasts of felspar.

Texture: The texture is typically gneissic-porphyroblastic. The main (ground) mass constitutes a granoblastic aggregate of quartz and felspar of very variable grain size, interspersed with tufts, streaks and laths of micas which impart a coarse foliation. The porphyroblasts lie haphazardly and consist of both plagioclase and microcline.

<u>Mineral assemblages:</u>

(i) Quartz-plagioclase-muscovite-biotite-muscovite-(garnet)

(ii) Quartz-plagioclase-microcline-biotite-muscovite-(garnet)

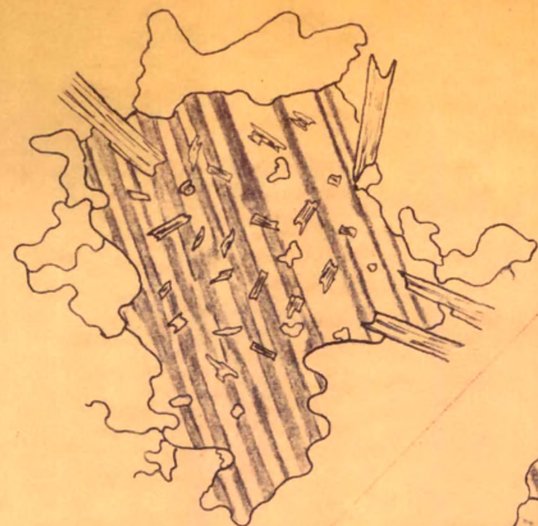
(iii) Quartz-microcline-plagioclase-muscovite-biotite-(garnet).

<u>Quartz</u> occurs both small as well as big grains, the sizes very variable. Obviously much of the quartz represents the original constituent of these rocks, recrystallised during migmatisation. Some quartz also appears to have been added to the rock along with felspars. Most of the quartz grains - though variable in size and shape, show sutured outline, and very often occur as elongated aggregates. Individual porphyroblasts of quartz are not common. Intergrowth of quartz with felspar and micas, is frequently seen. This mineral also occurs as inclusions in felspar porphyroblasts and garnet.

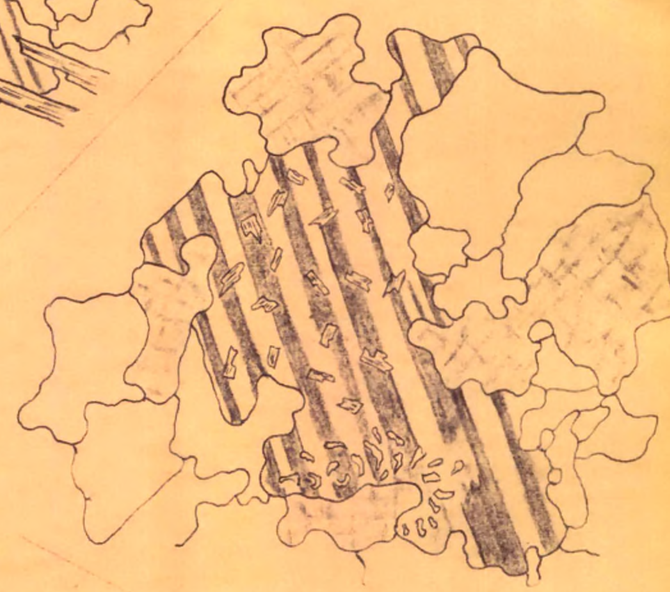
Plagioclase (An_{25-30}) occurs as small grains in the gneissic groundmass as well as wellformed porphyroblasts. In the main body of the rock it forms irregular grains, and is recognised by its characteristic twinning and slight alteration. The porphyroblasts are most striking, and it is amply recorded that augens have grown into these porphyroblasts. These form quite well defined (very often almost idiomorphic) crystals and have grown in the rock without any orientation. In thin sections, these porphyroblasts show very interesting textural phenomenon. All show the characteristic lamellar twinning, some show in addition twinning on the carlsbad law also. They universally contain large number of tiny muscovite and quartz inclusions. Their borders are mostly frayed and jagged, on account of the crowding of quartz grains and replacement by microcline.

An interesting textural phenomenon preserved in these porphyroblasts is their gradual replacement by potash-felspar. Based on the study of a large number of thin sections, a gradational sequence of the plagioclase being replaced by microcline has been established(Fig. 24).

Fig.24



[X 30]



[X 30]

[X 30]

Replacement of plagioclase by microcline

It can be clearly seen that there are:-

(i) Plagioclase porphyroblasts almost intact.

(ii) Plagioclase just beginning to be replaced by microcline - either along a portion of the borders or along a few stray centres within the main crystals.

(iii) Porphyroblast - almost half microcline and half plagioclase.

(iv) Porphyroblasts - almost consist of microcline with a few skeleton patches of plagioclase.

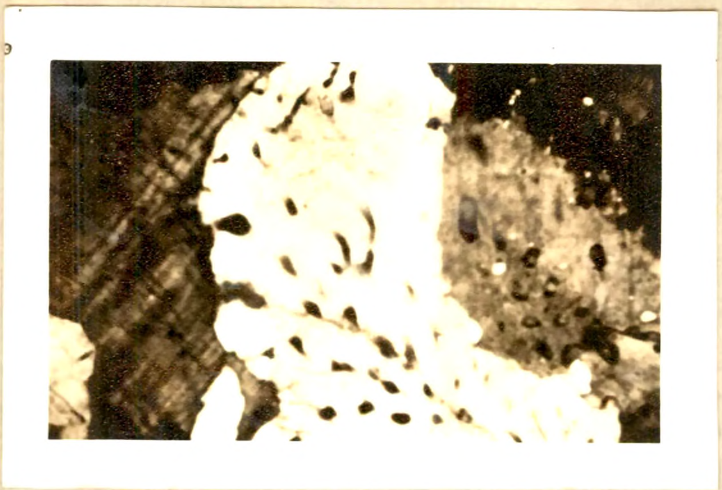
It is noteworthy that with the increasing replacement of plagioclase porphyroblasts by microcline, the proportion of latter increases in the main mass of the rock too.

Microcline content is variable. In the plagioclase dominant rock, it is confined to the groundmass. It occurs as porphyroblastic grains also. In the groundmass, microcline occurs in association with quartz often showing sutured texture. Cross-hatched twinning is not always seen. In its porphyroblastic mode of occurrence, the mineral shows either a single grain or a group of a few grains, and appears to have developed by replacing the plagioclase or grown independently. Those which have developed at the cost of early plagioclase generally contain a few relics of plagioclase and inclusions of mica, and quartz inherited from the original plagioclase. Myrmekitic texture is frequently developed at the junction of microcline with plagioclase (Plate 23).

Muscovite-biotite on the whole, relative proportions of the two micas are variable sometimes biotite predominates, while at other places rocks are rich in muscovite. The two micas generally mark the main foliation and show a somewhat coarse parallelism. The muscovites form long slender flakes occurring often in tufts with stray intergrown reddish brown biotite flakes. Biotite forms rather small size flakes. In a few thin sections, it appears that some muscovite at least, has been derived from the biotite.

In addition, tiny flakes of muscovites are seen to occur as inclusion in the felspar porphyroblasts.

PLATE 23



Development of myrmekitic texture at the junction of microcline with plagioclase

(Photomicrograph, x30)

Biotite may occur as stray inclusions in the garnet.

Garnets are not very common, though frequently recorded. In some thin sections, they tend to have skeletal shapes, riddled with quartz grains, iron-oxides and fractures, but in other thin sections they are seen as well formed crystals with inclusions of quartz and biotite.

Accessory minerals as usual, zircon, apatite, sphene, tourmaline, are the most common accessory minerals. At few spots tourmaline is seen in larger proportions.

CHEMICAL CHARACTERS

Chemical compositions of the various rock types were determined, in order to fully understand the nature of the rocks, and also to make out the chemical changes that were brought about during metamorphism and migmatisation. In the following tables, the chemical analyses have been summarised.

TABLES OF CHEMICAL ANALYSES

PELITES (GARNET MICA SCHISTS) AND SEMI-PELITES (SILICEOUS MICA SCHISTS)

Percentage	M 209	M 145	M 199	M 74	M 200
SiO_2	61.42	67.82	64.04	65.07	66.97
Al_2O_3	20.17	17.30	19.72	18.06	19.17
Fe_2O_3	5.26	1.95	4.22	1.60	4.04
FeO	2.40	4.67	1.40	3.43	0.72
Na_2O	2.11	2.47	2.62	2.80	2.16
K_2O	3.99	2.66	3.34	3.68	3.36
MgO	1.67	0.54	1.80	1.95	1.44
CaO	1.42	1.52	1.34	2.38	1.26
MnO	0.35	0.35	0.65	0.50	0.50
TiO_2	0.92	1.04	0.96	0.96	0.74
P_2O_5	0.03	0.02	0.06	0.05	0.09
Total	100.04	100.34	100.15	100.48	100.45

Percentage	M 141	M 142	M 127	M 205	M 165
SiO_2	63.89	62.11	68.86	55.19	65.90
Al_2O_3	20.71	21.01	17.01	25.16	21.36
Fe_2O_3	2.04	4.75	1.36	1.20	1.20
FeO	4.37	1.11	2.11	6.45	3.10
Na_2O	2.27	3.27	3.58	2.06	2.27
K_2O	3.25	3.24	4.12	4.20	4.24
MgO	0.99	1.62	0.18	1.81	0.78
CaO	1.12	1.21	1.54	1.26	0.84
MnO	0.35	0.35	0.67	0.15	0.35
TiO_2	0.82	0.88	0.63	1.54	0.89
P_2O_5	0.03	0.03	0.06	0.01	0.03
Total	99.84	99.58	100.12	99.83	100.16

Siliceous mica schists and phyllonitic rocks:

Percentage	Siliceous Mica Schists		Phyllonitic Rock
	M 206	M 210	M 191
SiO_2	70.77	70.43	60.48
Al_2O_3	10.57	12.97	24.27
Fe_2O_3	1.92	1.28	1.96
FeO	5.36	5.39	6.08
Na_2O	2.84	2.64	1.32
K_2O	2.57	3.14	2.68
MgO	3.81	2.21	1.10
CaO	1.82	1.26	1.40
MnO	0.35	0.15	0.35
TiO_2	0.62	0.59	0.69
P_2O_5	0.02	0.03	0.03
Total	100.65	100.09	100.36

Calc-silicate rocks:

Percentage	M 122	M 123	S 13	S 15
SiO_2	70.53	67.17	56.30	73.06
Al_2O_3	15.66	19.06	20.47	11.47
Fe_2O_3	0.99	1.68	3.12	1.60
FeO	4.17	4.05	5.45	5.13
Na_2O	1.16	1.00	2.30	0.14
K_2O	0.53	0.62	2.80	0.14
MgO	1.70	1.61	1.83	0.97
CaO	4.21	5.61	6.86	6.72
MnO	1.00	0.35	0.17	0.19
TiO_2	0.79	0.54	0.75	1.31
P_2O_5	0.09	0.031	0.02	0.07
Total	100.83	101.72	100.07	100.80

Flaggy Quartzites:

Percentage	M 134	M 128	M 111	M 210	M 108
SiO_2	74.23	76.00	82.40	85.02	84.00
Al_2O_3	20.46	16.41	12.46	10.43	10.24
Fe_2O_3	0.57	1.21	0.63	0.99	0.43
FeO	0.19	1.59	0.59	1.33	0.69
Na_2O	0.82	0.21	0.65	0.47	0.64
K_2O	0.73	0.12	0.42	0.31	0.55
MgO	1.73	1.26	1.64	0.72	1.15
CaO	0.74	1.40	0.84	0.12	0.12
MnO	0.67	0.67	0.67	0.82	0.84
TiO_2	0.27	0.42	0.31	0.29	0.30
P_2O_5	0.06	0.06	0.06	0.07	0.07
Total	100.47	99.35	100.67	100.57	99.03

Migmatites:

Percentage	Felspathic Schist	Streaky permeation gneisses	
	M 153	K 18	M 169
SiO_2	66.45	67.14	71.76
Al_2O_3	15.97	17.01	16.75
Fe_2O_3	2.30	2.41	0.99
FeO	5.26	2.99	0.72
Na_2O	3.30	3.18	3.29
K_2O	2.96	2.91	2.27
MgO	1.32	0.80	1.01
CaO	2.24	2.66	0.56
MnO	0.07	0.35	0.57
TiO_2	0.72	0.67	0.52
P_2O_5	0.03	0.03	0.09
TOTAL	100.62	100.15	99.93

Augen gneisses:

Percentage	M 173	M 174	M 175	M 154	M 157
SiO_2	67.94	72.14	70.81	73.89	66.58
Al_2O_3	17.16	16.56	14.06	12.46	16.10
Fe_2O_3	1.85	1.39	1.03	0.60	4.62
FeO	2.39	1.76	2.99	4.04	2.19
Na_2O	4.49	3.16	4.08	2.95	3.18
K_2O	3.27	2.56	3.12	3.37	3.43
MgO	0.31	0.40	1.53	0.30	0.71
CaO	0.84	0.98	2.24	0.98	2.24
MnO	0.67	0.57	0.15	0.57	0.50
TiO_2	0.63	0.64	0.61	0.55	0.62
P_2O_5	0.06	0.04	0.03	0.09	0.09
TOTAL	100.61	100.20	100.65	100.04	100.36

Porphyroblastic gneisses:

Percentage	M 158	M 160	K 17
SiO_2	74.48	73.20	74.45
Al_2O_3	12.50	12.50	14.11
Fe_2O_3	0.78	1.30	0.11
FeO	0.59	1.48	0.39
Na_2O	3.28	4.60	4.11
K_2O	5.78	4.90	5.24
MgO	0.52	0.20	0.35
CaO	0.66	0.50	0.52
MnO	0.67	0.20	0.25
TiO_2	0.52	0.42	0.69
P_2O_5	0.09	-	-
TOTAL	99.87	99.90	100.24