CHAPTER IV

P E T R O G R A P H Y

In the following pages the microscopic characters of the various rock types encountered in the area have been described in detail. The description pertains to the specimens collected from all parts of the ground, whose textural and mineralogical characters were systematically investigated. The study furnishes important clues to the structural and metamorphic evolution of the area.

PILKHOLI SERIES:

Chaubatia schists:

As has been clearly mentioned, this group is seen to consist of following rock types:-

(i) Pelitic and semipelitic schists.

(ii) Psammites.

Rocks in which micas make up about half of the bulk have been called 'Pelites', while rocks where micas form about a third of the whole, have been classified as 'semipelites'. It is rather difficult to draw a definite line to separate the two groups, as gradual gradation exists between them. The pelitic and semipelitic types are petrographically quite identical except in the variation in the relative proportions of the various constituent minerals, and hence they have been grouped together for the purpose of descriptions.

The Semipelites with the decrease of mica content grade into 'psammites'.

Petrographically, these rocks are very important as they reveal an interesting metamorphic history.

A detailed description of these rocks is given below.

PELITIC SCHISTS:

A typical pelitic schist, in hand specimen, is seen to be coarse to medium grained, bronze yellow, foliated rock, spotted with garnet porphyroblasts. These garnets vary in number and size. While some are markedly garnetiferous, others have occasional grains only. As regards the size, they vary from pin-head size to that of a pea. The average sp. gravity of these rocks varies between 2.65 and 2.75.

Texture:

These are coarse to medium grained, foliated rocks. The foliation is characterised by parallel orientation of mica either of individual flakes or of tufts. From the point of view of fabric, the mica schists are seen to belong to the following textural types:-

(1) Rather coarse with tufts or individual well developed micas - biotite and muscovite, occurring in association with elongated aggregates of quartz grains showing

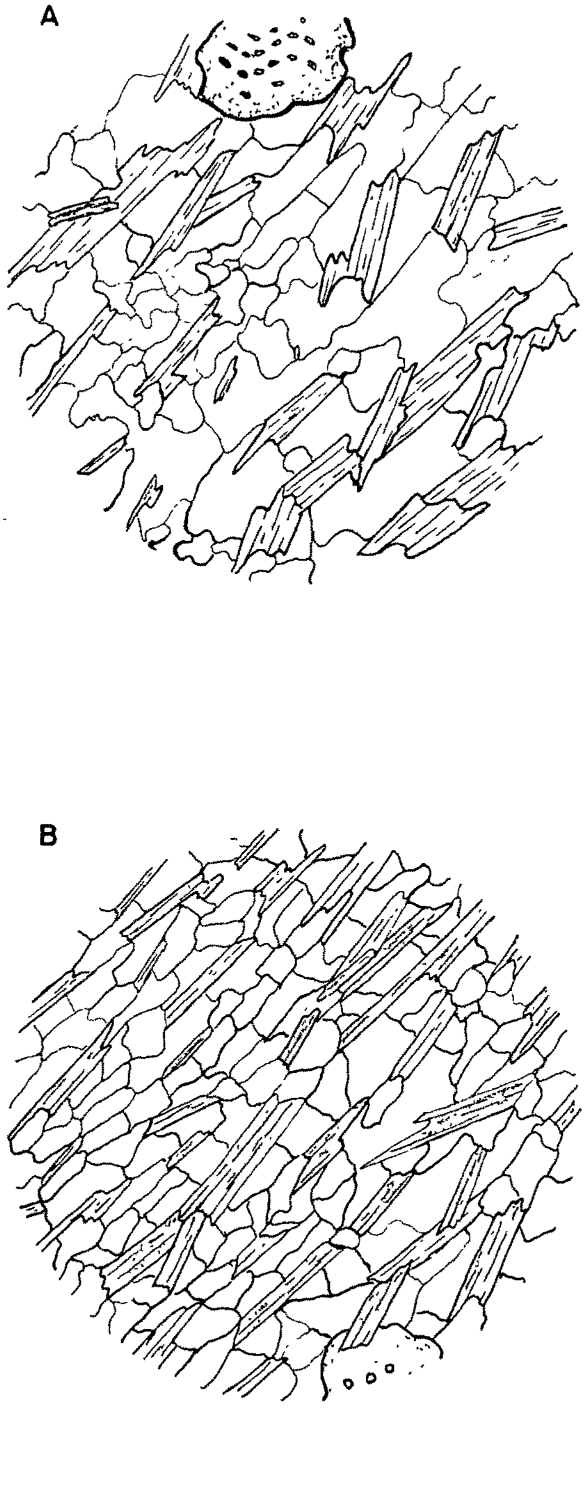


Fig 19

Textures of pelites from Chaubatia schists
(X 30)

sutured and interlocking or sharp and straight mutual junctions. Some quartz grains tend to have elongated shapes, but this is not common (Fig. 19A). Garnets are porphyroblastic, containing quartz inclusions, often crowded near the core. Rotated garnets with a helicoid inclusion pattern are quite often present, suggesting some rotation during their growth.

(2) A medium grained type with uniformly scattered flakes of parallely oriented micas (mostly biotite), interspersed in an equigranular mass of quartz (and stray felspar). The interlocking mosaic is not so common, the quartz grains mostly showing straight borders (Fig. 19B). Garnets are equidimensional, not so idiomorphic, and frequently show rotation.

Mineral assemblages:

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

(ii) Quartz-muscovite-biotite-garnet.

(iii) Quartz-biotite-plagioclase.

Quartz occurs as irregular grains of variable size in the intervening space between the parallely oriented micas.

Generally the quartz-grains show polygonal shapes with sharp junctions with adjoining grains. Frequently, cluster of interlocking grains are also recorded. In most cases the strain shadows are not so well marked. Another mode of occurrence of the mineral is as inclusions in garnet and micas.

Biotite is one of the most important mineral which usually shows a marked parallel orientation unless disturbed by later crinkling. In most cases, the biotite occurs as small elongated flakes, characterising the foliation of the rock. It shows marked pleochroism. $X > Y = Z$, X = straw yellow, $Y = Z$ = Brown. Occasionally, some biotite occurs along the fringes of the garnets and could have possibly derived from the alteration of garnet.

Shreds of colourless muscovite and pale pleochroic ferrimuscovite occur in association with biotite and some chlorite. Almost as much as biotite in quantity, the white mica occurs as slender flakes as well as bigger laths.

Garnet occurs as irregular (i) amaebic patches, (ii) xenomorphic grains as well as big well developed porphyroblasts. The garnet grains are generally well developed, equidimensional and idiomorphic outlines are not uncommon. Its size and content also varies from rock to rock. Faintly pink in colour, it belongs to Almandine group. The garnet porphyroblasts are seen wrapped by micaceous foliae, and thus giving rise to a closed eye structure. The garnets contain inclusions of quartz which are seen arranged in S-shaped pattern. This suggests the rotation of garnet during its growth due to differential movement of the matrix. Iron-oxide and small biotite flakes are also frequently seen to form inclusions in garnet.

Felspar, mostly a plagioclase ($An._{29-31}$), occurs as stray grains of small size. The felspar is rather fresh and characteristically twinned, and free from inclusions. It appears to have developed from the original sediments, during the progressive regional metamorphism.

Tourmaline, Apatite and Epidote are the common accessory minerals. Tourmaline occurs as bluish grey or light brown tiny laths. Apatite occurs as colourless needles characterized by high R.I. and shows first order polarisation colours. Epidote occurs as small grains with second order polarisation colours.

Graphite schist$:

It occurs as streaks and patches in garnet mica schists of Ranikhet and is easily recognised in field by its dark grey colour and soapy touch.

Texture:

Texturally it is fine grained. This schistosity is marked by the linear arrangement of graphite and mica flakes. Sometimes graphite is segregated into small bands in the direction of schistosity.

Mineral assemblages:

Quartz-graphite-muscovite.

Quartz mostly occurs as small grains and shows recrystallisation.

<u>Graphite</u> occurs as black and opaque dusted mass and occasional flakes, sometimes segregated in streaky patches. The streaks and flakes mark the schistosity. It is well recognised by its pleochroic tendency in reflected light.

<u>Muscovite</u> occurs as elongated small thin flakes and shows parallel arrangement with graphite.

<u>Hematite</u> occurs as small granules, intimately mixed with foliated mass.

<u>SEMIPELITIC SCHISTS</u>:

More siliceous varieties of schist have been classified as semipelites. With the increasing quartz content, garnet mica schists change over to the semipelitic variety. On the other hand, some of the micaceous quartzites could also be included under semipelites. The average sp. gravity of semipelites is about 2.75. These are compact and siliceous rocks with silvery grey colour and form thick slabs.

<u>Texture</u>:

Texturally, these belong to two types. Garnet bearing variety is rather coarser grained with a mosaic of

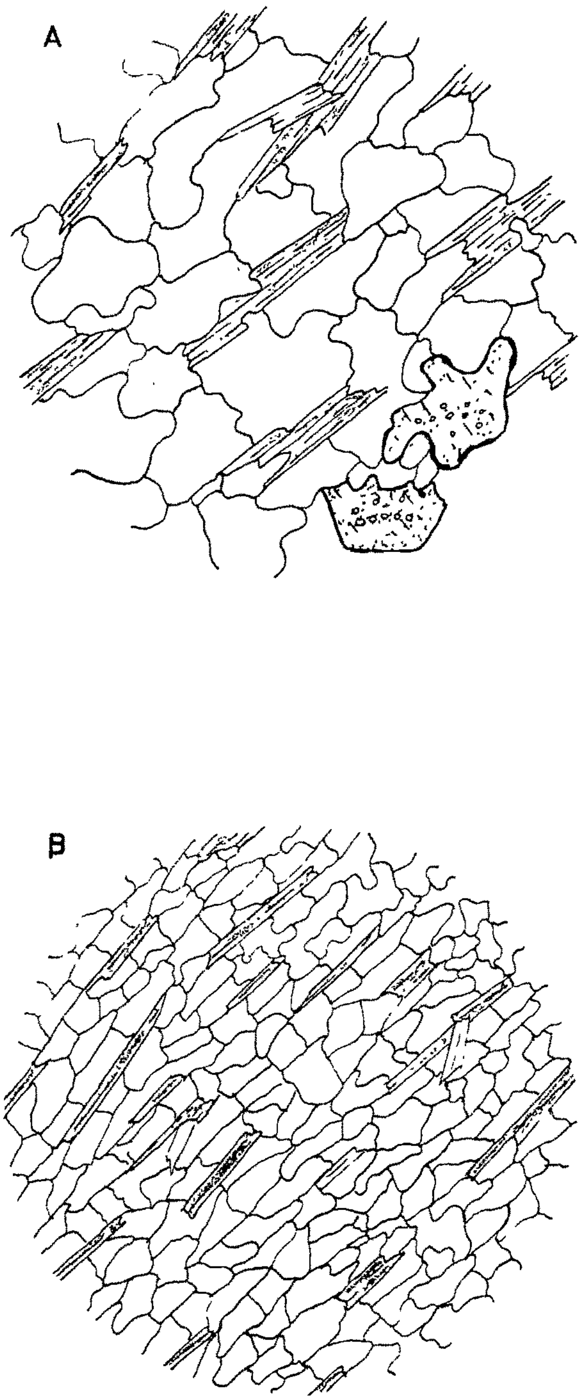


Fig 20

Textures of semi-pelites from Chaubatia schists (X30).

interlocking quartz grains, in which are interspersed slender flakes of parallel oriented biotites (Fig.20A). The other variety consists of a finegrained mass of rather polygonal unsutured quartz and small flakes of biotite (Fig. 20B).

Mineral assemblages:

(i) Quartz-biotite-plagioclase-garnet.

(ii) Quartz-biotite-muscovite.

Quartz occurs as clear grains which quite often tend to possess a flattened shape and show a faintly undulatory extinction. Quartz occurs as (i) a mosaic of interlocking sutured grains (granulated type), (ii) an aggregate of grains - having smoother junctions (tesselate type) and (iii) patches of granulated type in a tesselate mass. Quartz also occurs as inclusions in garnet, sometimes so big that the garnet assumes rather skeletal appearence.

In variety (i), biotite occurs as rather elongate parallel flakes marking the schistosity. It shows marked pleochroism, $X > Y = Z$, X = light brown, $Y = Z$ = dark brown. In the variety (ii), biotite forms tiny flakes of a rather darker shade.

Muscovite occurs as long slender flakes, intergrown with biotite in variety (ii).

Garnet is typically of a light pink variety, and generally present as fair sized amaebic grains with irregular outline and riddled with quartz inclusions.

Plagioclase (An_{30-38}) occurs as small irregular grains, occuring in association with quartz. The felspar is unaltered and shows the usual lamellar twinning.

Clinozoisite, Tourmaline, Apatite and Ironoxide are the accessory minerals, of which the clinozoisite is most striking. Its grains are recognised by high R.I. and typical anomalous blue polarisation colours. Tourmaline occurs as grey and brown tiny laths showing straight extinction and characteristic pleochroism. Apatite is only occasionally seen as colourless needles. Magnetite occurs as inclusions in garnet and biotite.

PSAMMITES

These are the siliceous rocks with an average sp. gravity 2.95, occuring as layers in the schists. Based on

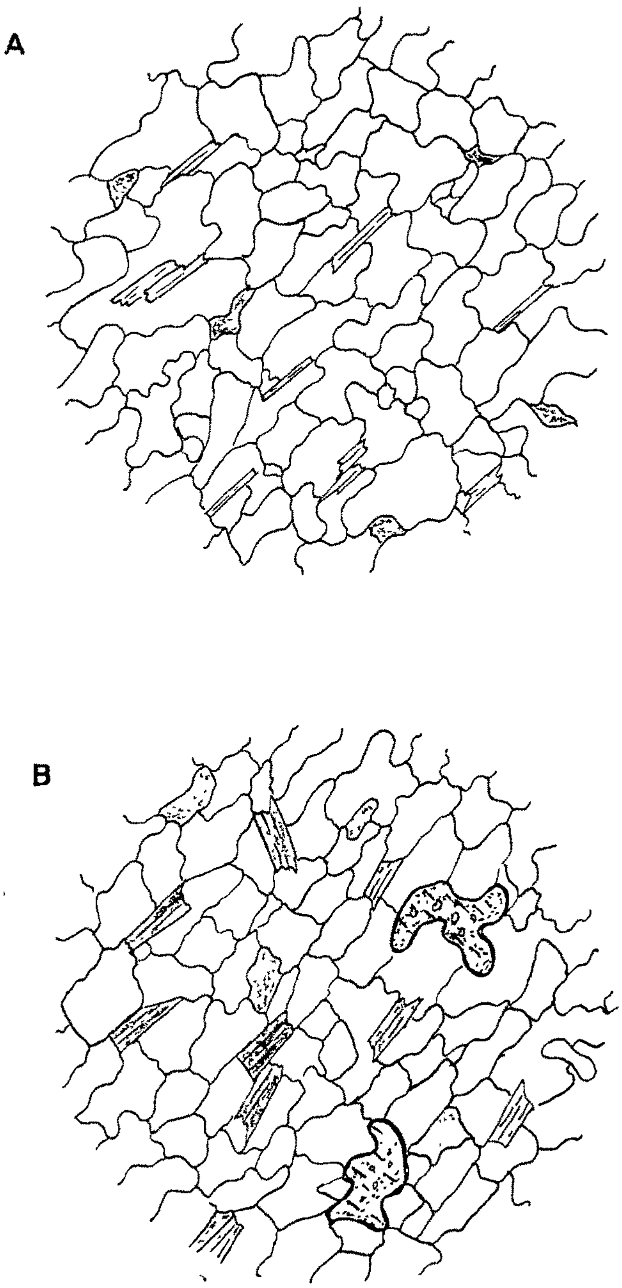


Fig 21

Textures of psammites of Chaubatia schists (X 30).

the study of their thin sections, the psammitic rocks can be classified into two main types:

Type I

Texture:

An interlocking mosaic of quartz grains showing considerable variation in shape and size. The felspar - microcline, is interspersed as irregular grains. Small flakes of muscovite show a parallel orientation (Fig.21A).

Mineral assemblage:

Quartz-microcline-muscovite-(biotite).

Quartz is the dominant mineral. It occurs as highly sutured interlocking grains with undulating extinction. There is a great variation in grain size from as big as 2 mm. to fine aggregates of 0.5 mm.

Microcline occurs in subordinate amount and either forms recognisable grains or as cusp-shaped infillings in the interstitial space between bigger quartz grains. It generally does not show any twinning and is recognised by its low refractive index.

Mica, mostly muscovite, occurs as slender flakes interspersed in the mass and shows a roughly parallel orientation.

Type II

Texture:

These show a rather even grained less sutured texture, and consist of somewhat uniform aggregate of quartz grains with some plagioclase and mica flakes. Though grains do show certain amount of interlocking but it is much less than that shown by the type I (Fig. 21B).

Mineral assemblage:

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

Quartz occurs as medium sized grains, with partly sutured and partly smooth borders.

Plagioclase (An_{28}) occurs frequently as grains scattered in a quartzose mass, shows characteristic twinning and slight alteration.

The dominant mica is biotite which forms small thin laths and characterises the foliation of the rock. Muscovite is not common.

Garnet is quite often present and is found as fairsized skeletal grains, riddled with big grains of quartz.

In both of the above types tourmaline is the most common accessory mineral. It is obvious that type I represents the quartzite (arkosic) layers in schists while type II is a highly siliceous modification of the pelitic sediments.

Jhuladevi gneiss:

Rocks described under this group are characterised by their felspathic nature. These gneissic rocks which occur below the Chaubatia schists, are light coloured, compact and foliated. Their average specific gravity varies from 2.63 to 2.68.

From the field characters, as well as the microscopic study, these felspathic rocks have been identified to be a group of migmatites. From their petrographic study, a complete picture of the course of migmatisation is obtained. Taking into account the increasing felspar content these rocks have been classified into the following four types which grade into one another:

1. Felspathic schists,
2. Permeation gneiss,
3. Augen gneiss,
4. Porphyroblastic gneiss.

The field occurrence of these types has already been described in Chapter III.

Felspathic schists:

These are transitional rocks, which with decrease of felspar grade into mica schists.

Texture:

Texturally these rocks show a coarser grain than the mica schists. The foliation is characterised by parallel flakes of mica (mostly biotite), the intervening spaces filled with aggregate of quartz and felspar (which is mostly a plagioclase).

Mineral assemblage:

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

Quartz is the dominant mineral, and most of it appears to be the original constituent of the schist. Some quartz, mostly that which is seen to occur interwoven with plagioclase, appears to have been added later on together with sodic solutions.

Plagioclase (An_{26}) occurs as distinct grains with tendency to grow larger, and clearly suggests its introduction in the original schistose matrix. The plagioclase is quite fresh and unaltered except for tiny inclusions of muscovite and shows typical lamellar and carlsbad twinning.

Microcline, the potash-felspar is generally not common. Either it is absent or present only in a small quantity. It is recognised by its characteristic twinning or by its low relief.

Biotite occurs as small flakes, of not very dark colour, and the flakes mark the schistosity. The pleochroism is $X > Y = Z$, X = light yellow, $Y = Z$ = dark yellow, and it shows a tendency of loss of coloration.

Muscovite as slender flakes, occurs in association with biotite, generally parallel to schistosity. Some of the muscovite appears to have derived from the biotite.

Garnet is seen as small equidimensional grains in some of the slides.

Stray crystals of apatite and tourmaline and grains of magnetite constitute the accessory minerals.

Permeation gneiss:

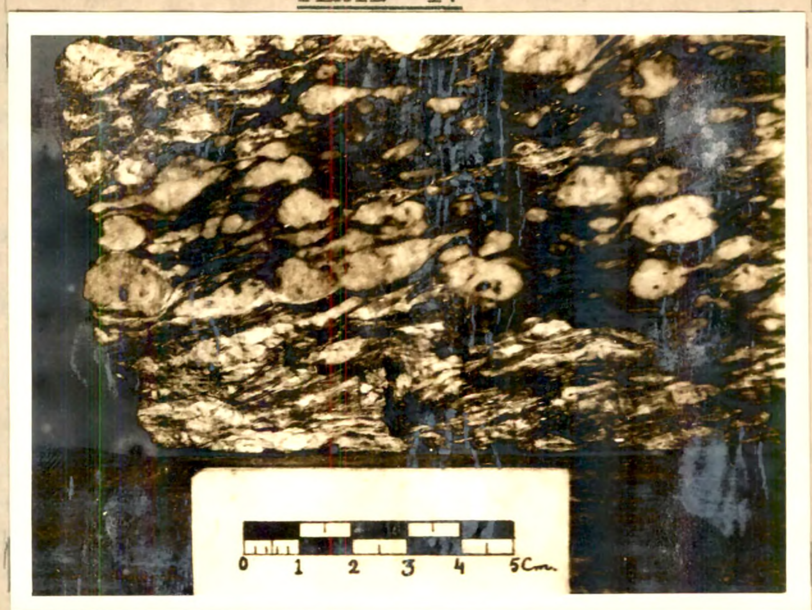
This variety represents yet one further stage of migmatization, more felspathic than the previous variety. In hand-specimen, it shows a uniform scattering of felspar. These are typically a transitional group, which on development of plagioclase pass into the augen-bearing type.

Mineral assemblage:

It continues to be Quartz-plagioclase-(microcline)-biotite-muscovite-garnet. Relatively the proportion of felspars, mainly the plagioclase, has slightly increased, and so has the muscovite.

The quartz and felspar form a sutured aggregate. Micas form slender elongated flakes and muscovite and biotite both are present in almost equal proportion, and tend to intergrow as tufts. Garnets when present are well developed and rather unaltered.

PLATE IV



A. Augen gneiss from Jhuladevi showing augens of felspars.

B. Porphyroblastic gneiss from Jhuladevi showing porphyroblast of felspar across the foliation.

<u>Tourmaline</u> and <u>apatite</u> are the most striking accessory minerals.

<u>Augen gneiss</u>:

As already mentioned earlier, the augen-bearing type occurs on the two flanks of the porphyroblastic gneiss (Plate IVA) and in turn, with the disappearence of felspar augens, merges into the Permeation gneiss. The average sp. gravity of this type varies from 2.62 to 2.65.

<u>Texture</u>:

These are medium to coarse grained gneissic rocks containing numerous "eyes" or "augen" of felspar. The micas mark the principal foliation and characterstically wrap~~ped~~ round the felspar augens. The texture of the groundmass is rather gneissic, parallel flakes of micas interspersed in a granoblastic aggregate of mainly quartz and felspar (mainly plagioclase An_{28} and some microcline). Porphyroblastic eyeshaped plagioclase (An_{28-31}) are seen developing at a number of centers.

<u>Mineral assemblage</u>:

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

<u>Quartz</u> shows a variety of modes of occurrence. Its size varies considerably from tiny grains (0.05 mm.) to rather large 3.5 mm. ones, and is seen to form (i) elongate aggregates of sharp polygonal grains (ii) undeformed aggregates of small grains, and (iii) rather fair sized intergrown sutured masses. It is generally free from inclusions, and shows slight shadowy extinction.

<u>Plagioclase</u> occurs both in the ground mass as well as augen shaped porphyroblasts. In the ground mass it occurs in association with quartz, and is quite easily recognised on account of its characteristic twinning, and slight alteration. In composition it is nearly Andesine (An_{29-31}). The augens of plagioclase (An_{28-30}) are also very striking. They seem to have grown along the foliation and mica flakes tend to wrap round these augens. Quartz grains very often crowd around the 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.

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

Microcline is seen in a subordinate quantity, and is confined, mostly to the ground mass, forming irregular grains. It is recognised mostly by its twinning and low refractive index. 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.

Rather well developed garnets with fair sized inclusions of quartz are occasionally recorded. The garnets tend to develop numerous fractures along which they alter into a yellow indefinite substance.

As usual apatite, tourmaline, and iron oxides are the accessory minerals.

Porphyroblastic gneiss:

These are medium to coarse grained greyish rocks - containing porphyroblasts of felspar. These gneisses represent an advanced stage of transformation of mica schist to felspathic rocks, and are typically migmatitic in nature. Their study in thin section, has revealed two main types: Type (I)-with dominant porphyroblasts of plagioclase. Type (II)-with dominant porphyroblasts of microcline.

All gradations exist between type I and type II and it is obvious that with the gradual increase of potash in type I,the potash-felspar content has gone up, the potash-felspar having replaced plagioclase porphyroblasts.

Texture:

The texture is typically a 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 the foliation. The porphyroblasts lie haphazardly.

Mineral assemblages:

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

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

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

Quartz occurs as both small as well as big grains, the sizes very variable. Obviously much of the quartz represents the original constituent of these rocks, which later on recrystallized during migmatisation. The larger grains which mostly occur in augen shaped aggregates shows corroded outline and sutured junctions with mica and felspar. Late quartz contains muscovite and iron oxide as inclusions. Quartz also occurs as inclusions in felspar - porphyroblasts and in garnets.

Plagioclase felspar (An_{30}) occurs in the gneissic ground mass as well as well formed porphyroblasts. In the main body of the rock it forms irregular grains, big as well as small, and is recognised by its characteristic twinning and slight alteration. The plagioclase

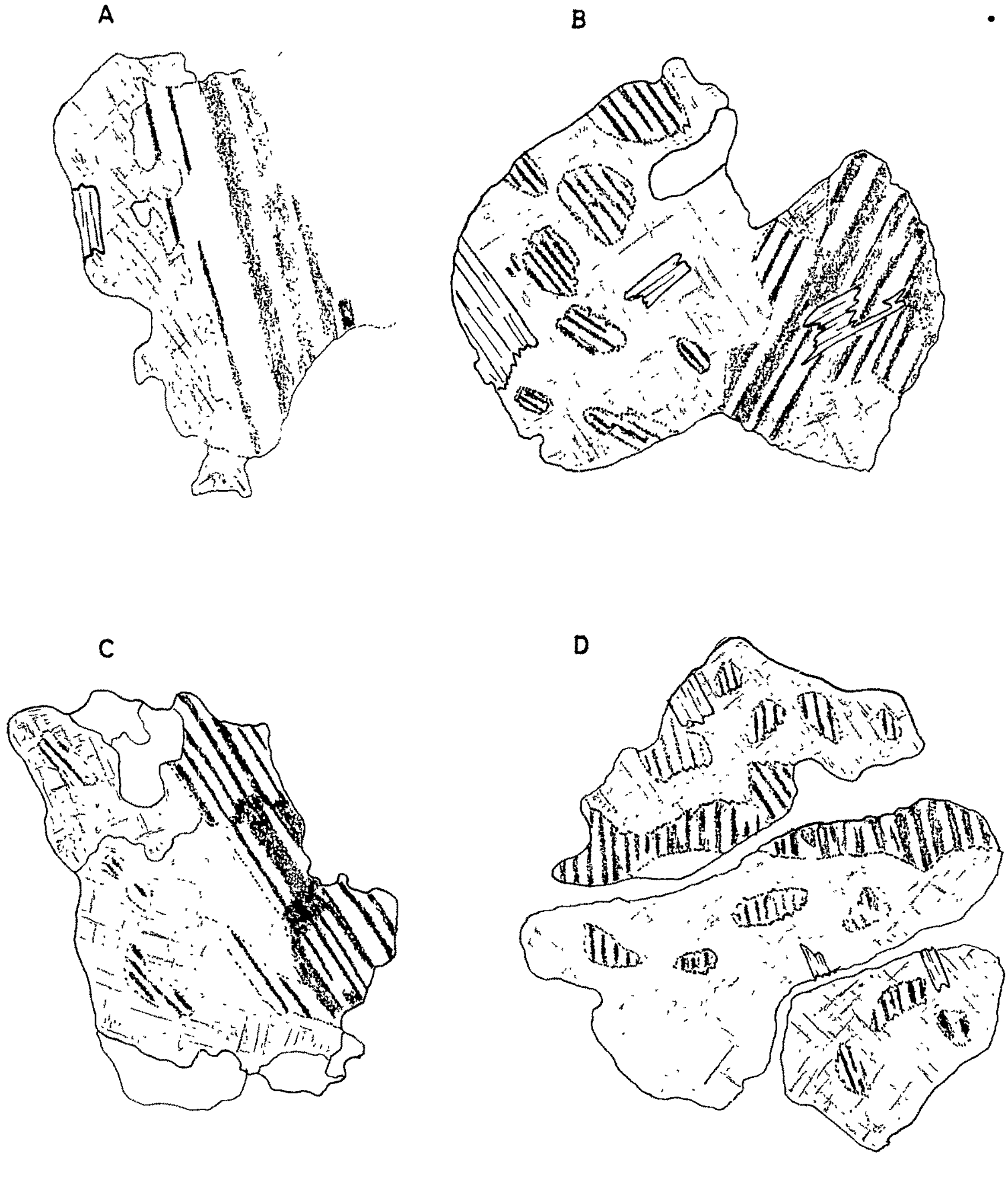


Fig. 22

Felspar porphyroblasts showing different stages of replacement of plagioclase by microcline (X 25.)

porphyroblasts are most striking. These form quite well defined (very often almost idiomorphic) crystals and have grown in the rock without any definite orientation (Plate IV.B).~~megascopic photo)~~. 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 inclusions and some quartz. Their borders are mostly frayed and jagged, on account of the crowding of quartz (and microcline) grains.

An interesting textural phenomenon preserved in these porphyroblasts is of their gradual replacement by potash-felspar. By their study, it is very obvious that with the gradual replacement of sodic-plagioclase by potash-felspar, the type (I) has gradually passed into the type (II). Based on these study of a large number of thin sections, a gradational sequence of the plagioclase being replaced by microcline has been established (Fig. 22). 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.

As already stated above, microcline content is variable. In the plagioclase dominant rock, it is confined only to the ground mass. It is however seen to increase, both in the ground mass as well as in porphyroblasts from type (I) to type (II). In the microcline rich type, it occurs as porphyroblast and in the ground mass.

In the ground mass, microcline occurs in intimate association with quartz, often showing a sutured interesting texture. Twinning is not uncommon, but 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. While those which have developed at the cost of early plagioclase generally contain all the inherited inclusions etc.

Of the two micas, generally the muscovite dominates. On the whole the gneisses are richer in muscovite, though there are some patches, fairly rich in biotite. The micas generally constitute the main foliation and show a somewhat coarse parallelism. The muscovites form long slender flakes - often as tufts with stray intergrown 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 inclusions in the felspar porphyroblasts. Biotite may occur as stray inclusions in the garnet.

Garnets are not very common though are frequently recorded. In some thin sections, they tend to have skeletal shapes, riddled with quartz grains and fractures, but in other thin sections, garnet grains appear to have been well preserved - unaltered. They contain usual inclusions of quartz and biotite and their outer rims tending to be rather heamatitic.

As usual, the apatite is the most common accessory mineral, which occurs in appreciable quantity. Tourmaline is seen only as occasional elongated lath, but at few spots it is seen in larger proportions.

IGNEOUS INTRUSION IN GNEISSES:

Dolerite:

It is a dark, compact, hard rock in which black shining crystals of pyroxene and grey laths of felspar are easily distinguished.

Texture:

Under microscope rock shows typical ophitic texture.

Mineral assemblage:

It mainly consists of plagioclase, pyroxene, olivine and iron oxide.

Plagioclase is labradorite (An_{52}) and mainly occurs as phenocrysts, generally unaltered and fresh. It shows combined carlsbad-albite twin. It is also present in the ground mass.

Pyroxene forms big as well as small grains. Its 2V varies from 18° to 30°. Possibly a pigeonite variety, it is seen sometimes to alter to biotite.

Olivine occurs as colourless, anhedral grains with prominent irregular cracks and high refractive index, typically altering into serpentine along the cracks.

Magnetite occurs in a subordinate quantity as small grains and some of it could be an alteration product of olivine.

Ilmenite occurs as black crystals, with their marginal alteration to leucoxene.

Chlorite mostly occurs as pale green mass as an alteration product.

PANIALI SCHISTOSE GROUP:

This group which underlies the migmatitic gneisses, constitutes an inverted metamorphic succession i.e. shows successive retrogressive stages, when traced from north to south. As has become quite clear from the field study alone, the Upradi thrust is the cause of all these interesting metamorphic variations. In fact, the down-grading of the garnet-mica schists to phyllonites is so gradual that a number of intermediate stages can be recognised, but these are difficult to delineate and classify. Still however, for the convenience of description the various transitional varieties could be grouped into the following main types:-

(i) Garnet-mica-schists
(ii) Chlorite-schists
(iii) Phyllonites.

(i) Garnet-mica-schists:

These are pelitic schists somewhat similar to those of Ranikhet, but with a little greenish tinge.

Texture:

Tufts and individual flakes of micas, show a strong parallel arrangement, and lie in a granular mass of quartz and some plagioclase. A number of thin sections (on going to the south) show interesting textural evidence of slipping.

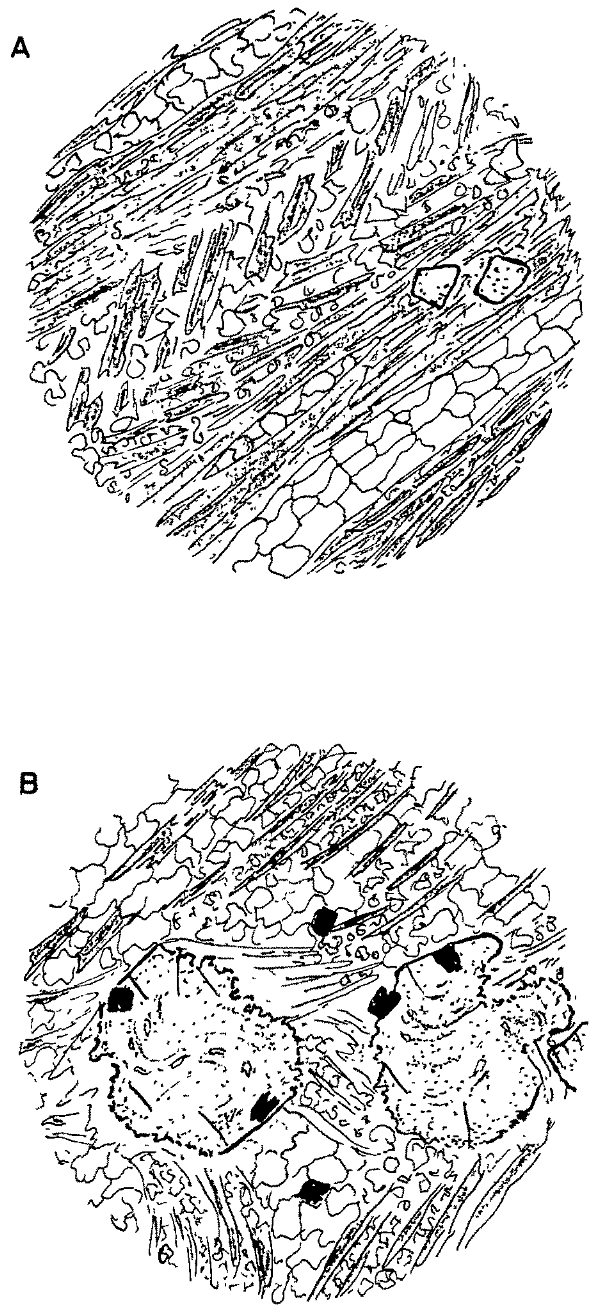


Fig 23

Textural characters of garnet mica schists of Paniali schistose group (X 30).

It is not uncommon to come across microfolding (due to drag), and slipping, shearing, and granulation along more micaceous layers (Fig. 23A).

Mineral assemblage:

Quartz-biotite-muscovite-garnet-chlorite.

Quartz forms aggregates of rather flat smooth grains, relatively unstrained. Wherever the slipping has occurred, quartz shows intense shearing and granulation and is seen to form a streaky mass of small elongated granules intimately mixed with micas. Another mode of occurrence is as usual inclusions in garnet.

Both muscovite and biotite are present, but in variable proportions. They occur as rather long slender flakes, often intergrown. The micas characterise the principal foliation by their parallel orientation. Muscovites are free from inclusions and at some places seem to merge into biotite. The biotite has rather a greenish tinge, and its tendency to change over to chlorite is recognised occasionally. In some sections, biotite is also seen to form a rim round garnets and it is very obvious that some biotite is developing at the expense of garnet; of course this mode of alteration of garnet is not common. Wherever more micaceous portions have slipped and sheared, the micas are seen to be intimately mixed with quartz granules. The drag folding is ideally exhibited by micas. They exhibit clear microfolds, the axial planes directions, of which are almost identical with that of the trend of the main foliation.

Garnet forms equidimensional well formed grains, containing spiral inclusions of quartz. Almost all garnet grains show a tendency of alteration to light green chlorite (Fig. 23B) (or in some rare cases to greenish biotite).

Chlorite occurs as small flakes - either as patchy clusters of small shreds, near and around the garnets or in association with micas as parallel scattered flakes. Most of it is obviously derived from the garnet, while some chlorite is seen developing at the expense of biotite also. It shows pleochroism, $X > Y = Z$, X = pale green, $Y = Z$ = light green.

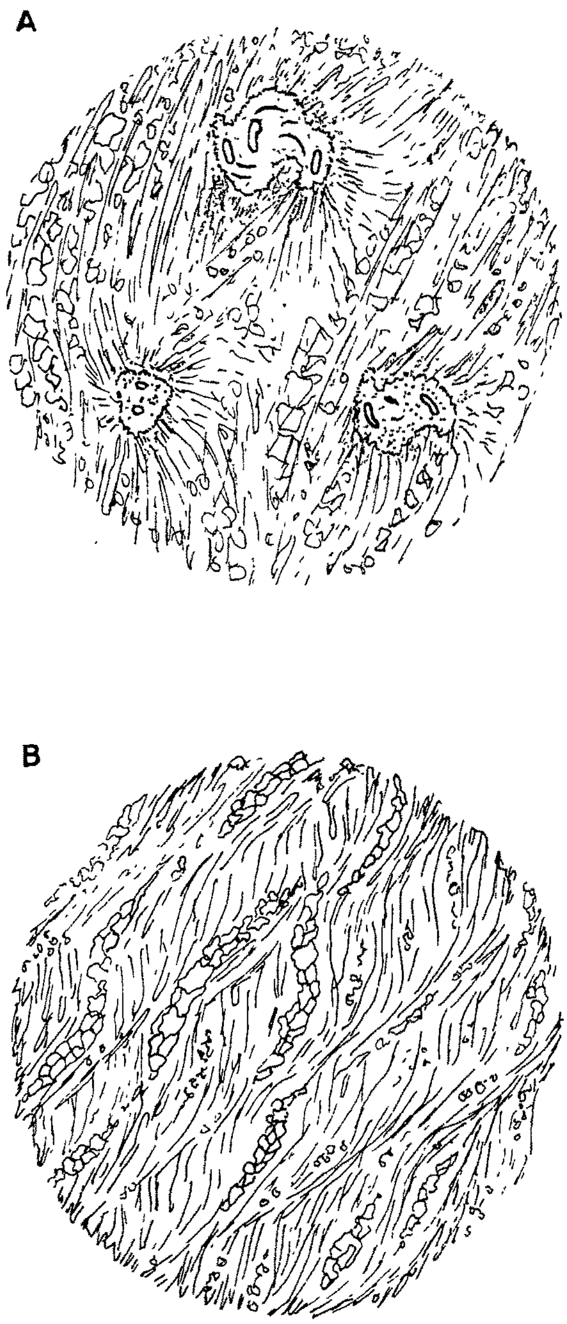


Fig 24 Textural characters of chlorite schists of Paniali schistose group (X 30).

As accessory minerals, present are the needles of tourmaline, apatite and rutile, tiny inclusions of magnetite in micas and garnets, and patches of brown hematite.

These mica schists gradually become fine grained, streaky and more chloritic on being traced southwards, and almost imperceptibly grade into more chloritic schists.

(ii) Chlorite schists:

These are medium to fine grained highly foliated greenish looking schists. It is obvious, even in hand-specimen, that the rock type marks the transition between mica schist at one end and the phyllonitic-sericite-chlorite schist at the other.

Texture:

The rock shows a strong foliation, marked by tiny parallel flakes of chlorite and muscovite generally forming almost continuous streaks. The intervening spaces are filled with granules of quartz (Fig. 24A). Sections of those specimens in which late puckers have developed, show ideal example of the early stage of the development of a strain-slip cleavage (Fig. 24B).

Mineral assemblages:

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

Quartz occurs in two ways: (1) As small granules - with smooth margins; quite often with a tendency for elongated shapes, interspersed and intimately mixed with chloritic and micaceous foliae. (2) Porphyroblastic - eyeshaped aggregates of sutured grains. These possibly represent bigger quartz grains - ruptured and recrystallized due to shearing.

The next mineral in order of abundance is green chlorite. It forms tiny flakes, and occurs in close association with muscovite. It is pleochroic, $X > Y = Z$, X = light green, $Y = Z$ = dark green, and polarisation colours are of second order. The chlorite is seen derived from garnet as well as from the biotite.

Muscovite is almost as abundant as chlorite, and forms slender flakes. In some cases it could be better called ferri-muscovite because of slight pleochroism $X > Y = Z$, X = light yellow, $Y = Z$ = light brown. Biotite is generally scarce, but occasional greenish flakes are not uncommon.

Garnet's occurrence is very interesting and the various stages of its alteration to chlorite can be seen occasionally even in a single thin section. It is not uncommon to find (1) fairly round grains with somewhat uneven borders along which it is altering to chlorite, (2) a considerable portion altered to chlorite and an uneven patchy garnet still remaining, and (3) a mass of chlorite containing small bits of remnant garnet.

Almost all garnets clearly suggest simultaneous rotation and alteration.

Magnetite is present in striking abundance and shows two modes of occurrence: (1) Commonly it is seen as slender elongated grains, intergrowing with, and included in chlorite or occasionally in muscovite. The elongation parallels micas, or it forms tiny irregular grains in vicinity of the altering garnets. (2) Another mode of occurrence is as well shaped porphyroblastic grains.

Accessory minerals are apatite and stray zircon grains.

(iii) Phyllonites:

These are the final downgraded products occurring in the vicinity of the thrust and constitute a group of

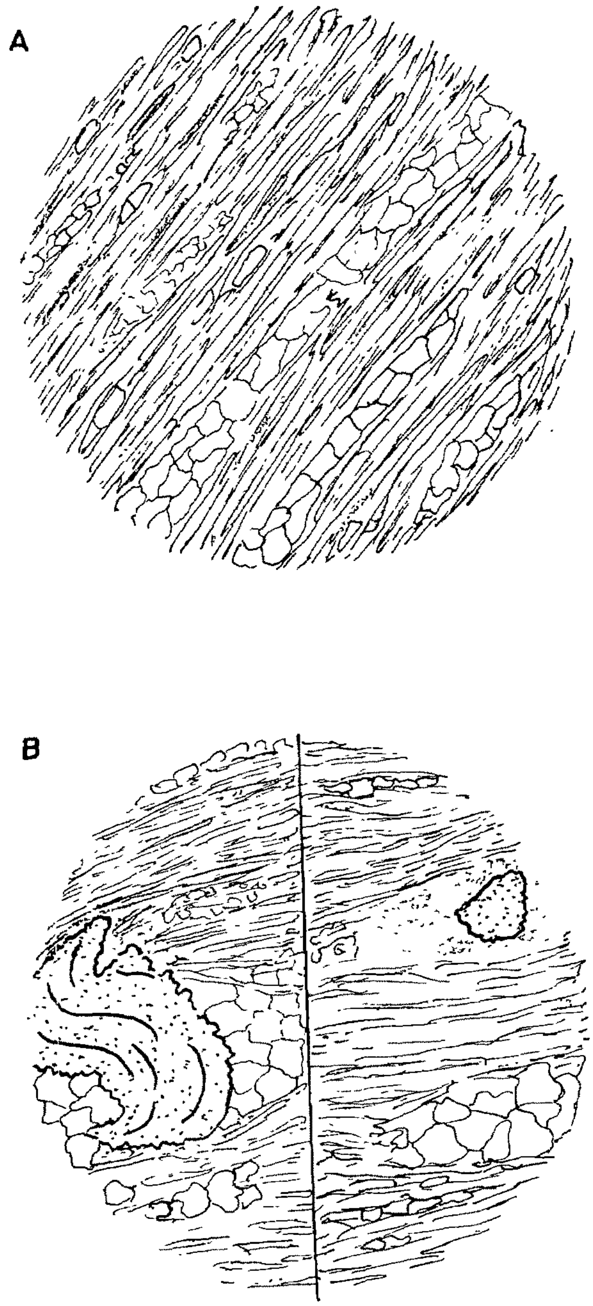


Fig 25 Textural characters of phyllonites of Paniali schistose group (X30)

sheeny phyllite looking rocks of greenish grey colour.

Texture:

Very strongly foliated rocks, the foliation is characterised by streaky micaceous and chloritic patches (Fig. 25A).

Mineral assemblages:

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

Quartz occurs in two ways: (1) As tiny elongated grains, intimately intergrown with and included within tufts of sericite muscovite. This mode of occurrence very clearly illustrates recrystallisation of quartz under conditions of intense shearing. (2) As bands, veins, patches of interlocking bigger grains possibly representing more quartzose patches and layers of the original rock.

Sometimes the quartzose patches contain a few grains of plagioclase which are recognised by their characteristic twinning, and appear to contain (An_{12}). But this occurrence of plagioclase is not universal.

Chlorite and muscovite (sericite) occur in varying proportions, sometimes chlorite and sometimes muscovite dominates. Even the nature of muscovite varies. Often it can still be called a muscovite, while in most cases it could better be referred as sericite. The most characteristic feature of the muscovite and sericite is that they form rather continuous patches in which are intimately interspersed tiny flat granules of quartz, arranged in a parallel orientation. It contains abundant inclusions of magnetite. The chlorite is the usual green pleochroic variety and under cross-nicols tends to remain almost isotropic or shows very low polarisation colours. Some flakes can still be considered as green biotite possibly an intermediate stage in the derivation of chlorite from biotite.

Garnet's proportion is variable. If present, it almost invariably shows alteration into chlorite. With the advanced stage of alteration only small bits of garnet are seen enclosed in a mass of chlorite. Wherever bigger grains are seen, they show the tendency to alter into chlorite, while rotating strongly (Fig. 25B).

Magnetite occurs in the form of small granules scattered in the ground mass or as well developed bigger grains.

Tourmaline is the only accessory mineral.

BAJINA SERIES:

These rocks, which underlie the thrust belong to a younger stratigraphical group, probably Nagthats, and metamorphically too, they show mineral assemblages, characteristic of fairly low grade. It is significant to note that on the whole the grade of metamorphism slightly decreases on going away from the thrust and some interesting conclusions could be drawn from their petrographic studies.

As has already been stated, the rocks to the south of the Upradi thrust, constitute a group of pelites and psammites, underlain by a dolomitic limestone. The three main rock types encountered are thus: (1) Pelites, (2) Psammites, (3) Dolomitic limestones.

(1) Pelites:

These are seen to belong to the following three varieties:-

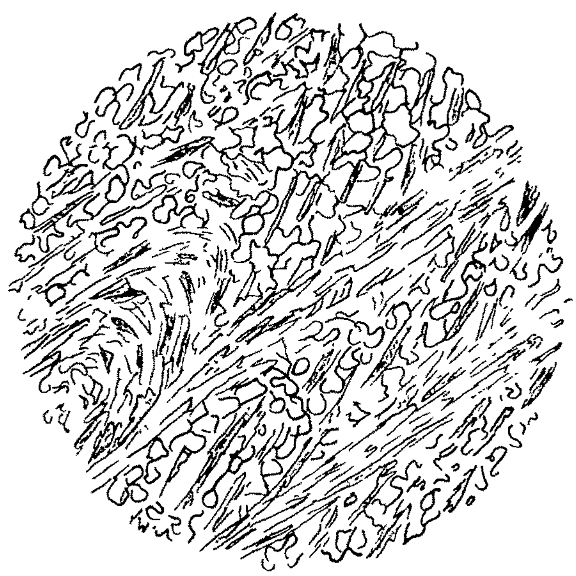


Fig 26

Texture of phyllites of Bajina series near the thrust (X 30).

(i) Green chloritic phyllites.

(ii) Sericitic phyllites.

(iii) Dark coloured siliceous phyllites.

(i) Green chloritic phyllites:

These are seen to occur in the vicinity of the thrust, interbedded as layers in quartzites.

Texture:

Texturally, these are somewhat coarser grained than the phyllites, and contain alternate layers of more micaceous and quartzose layers. The differential slipping along micaceous layers is amply recorded in drag fold and in a strong tendency for the development of a second foliation oblique to the first one (Fig. 26).

Mineral assemblages:

Quartz-chlorite-sericite.

Quartz occurs as small equidimensional grains, forming bands of sutured aggregates into which are interspersed the chlorite and sericite flakes. Wherever the second foliation is better developed, it tends to form flattened grains, parallel to foliation.

Chlorite occurs as bluish green tiny needles and flakes, either in association with white mica or as scattered flakes. It conspicuously characterises the early foliation by forming well defined layers, and also the second foliation by lying oblique to the former as scattered isolated flakes.

Sericite forms tiny needles and flakes, and occurs in close association with chlorite. Its mode of occurrence is identical to that of chlorite. Some of the sericite could better be considered as tiny muscovite even.

Accessory minerals are tourmaline and magnetite.

(ii) Sericitic phyllites:

Away from the thrust, the phyllites tend to be more slaty and fine grained.

Texture:

It presents a more slaty texture-a very streaky mass consisting of fine mica and lensoid grains of quartz.

Mineral assemblages:

Quartz-sericite-(chlorite).

Quartz occurs in intimate association with sericite as tiny flat grains, characterising the foliation. Interspersed in the foliated groundmass, are small flat eyeshaped aggregates of sutured grains of quartz.

Sericite forms a rather continuous foliated mass, in which are interspersed quartz and magnetite. In some of the thin sections, some greenish undefined chloritic material is also recorded.

Magnetite occurs as small grains scattered in the ground mass, and also as thin streaks of tiny granules (a magnetite dust), occurring along the foliation.

Accessory minerals are Tourmaline and stray grains of felspar (An_{26-32}).

(iii) Dark coloured siliceous phyllites:

These are transitional rocks - tending to be more towards psammitic variety; but having enough micaceous minerals to impart thin cleavage. The dark shade of the rock is on account of the presence of iron-oxide as fine dust.

Mineral assemblage:

Quartz-sericite-plagioclase.

Quartz occurs as very fine tiny elongated grains.

Plagioclase is recorded occasionally and is recognised by its characteristic twinning.

Sericite: Interspersed within the quartzose mass, are very tiny flakes of sericite. These characterise the cleavage of the rock by a parallel orientation.

Stray tiny laths of tourmaline and iron oxide occur as common accessory minerals.

(2) Psammites:

The psammitic rocks of the Bajina series are more or less quartzitic. These form thick layers as well as thin layers in pelitic portion. In the field they have been recognised as belonging to two types: (1) Buff coloured and (2) Pink coloured. In thin sections, this distinction is not clearly marked.

Texture:

Quartz, together with felspars, forms a granular

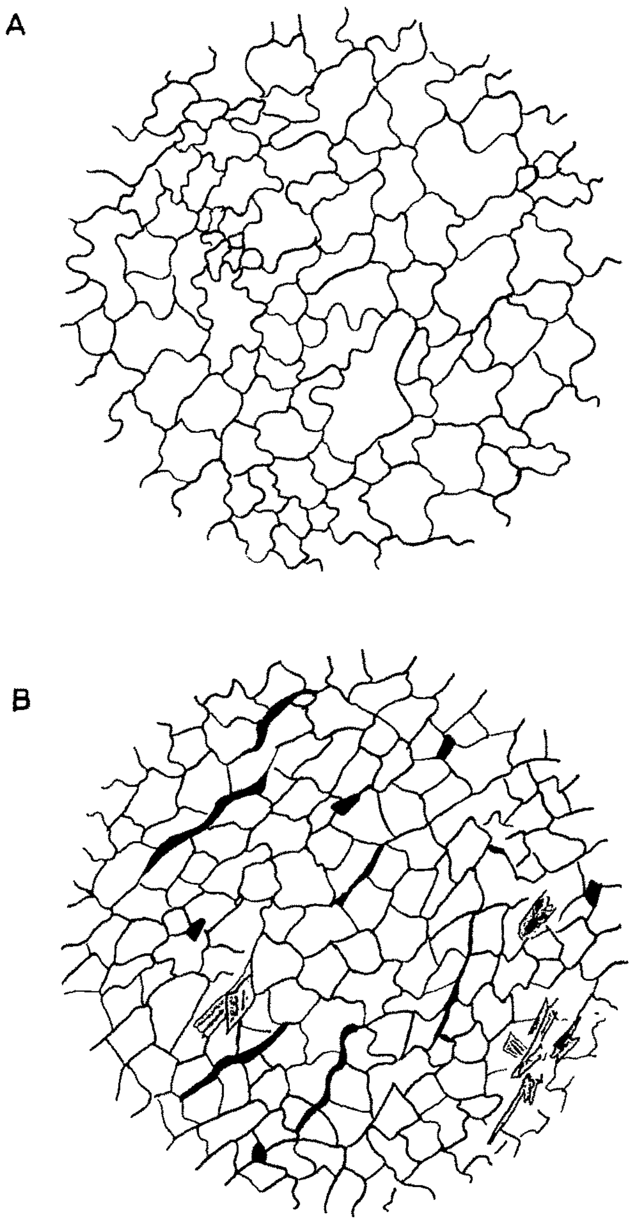


Fig 27

Textures of psammites of Bajina series (X30).

aggregate. In most thin sections, the texture consists of a mosaic of sutured somewhat interlocking grains, suggesting recrystallisation. But in some other thin sections (Fig. 27A), the original coarse sandy matrix is partly recognised, and smooth sand grains cemented by an indefinite ferruginous dusty material. The recrystallisation of impure ferruginous matrix has given rise to magnetite - and in some cases flakes, streaks and clusters of biotite (Fig. 27B).

Mineral assemblages:

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

Quartz occurs as irregular grains either with smooth or sutured borders, depending upon the degree of recrystallisation.

Both plagioclase (An_{26-32}) and microcline are present, occurring as irregular grains interspersed in quartzose mass.

Sericite occurs interstitially as ill-defined streaks and tiny flakes.

<u>Biotite</u> is not always seen. When present it forms cluster and individual flakes of dirty brown colour. It is obvious, that the ferruginous argillaceous cementing material, wherever recrystallised, has given rise to biotite.

Streaks and patches of dirty opaque dust and granules of <u>hematite</u> and some grains of <u>magnetite</u> are scattered throughout the mass, and possibly mark the original bedding.

Accessory minerals are commonly <u>tourmaline</u> and <u>zircon.</u>

(3) <u>Dolomitic limestone</u>:

The dolomitic limestone as discussed earlier occurs below quartzite and varies in colour from buff to dark grey.

<u>Texture</u>:

Under microscope it is fine to medium grained and shows granoblastic texture. The rock is essentially formed by carbonate minerals - both calcite and dolomite. Quartz is present in considerable amount. Iron oxide occurs as a minor constituent.

<u>Mineral assemblage</u>:

Calcite-dolomite-quartz.

<u>Calcite</u> is dominant and occurs mainly as colourless equigranular grains. Small crystals show twinkling. The cleavage is parallel to longer diagonal of the grain.

<u>Dolomite</u> is invariably present and can be distinguished by its relief, polarisation colours and twinning. Twin lamillae are parallel to shorter diagonal.

<u>Quartz</u> occurs as small rounded grains and at times as aggregates, characterised by its low relief and first order grey polarisation colours.

<u>Iron oxide</u> occurs as minor a constituent~~s~~.