In the Bhilangna and Balganga valleys the diagnostic field characters and petrography of the main rock types in the Central Crystallines, the Outer Crystallines and the Garhwal Group are described. The main rock types occurring in the area, are as follows:

5.1 SILLIMANITE GNEISS
5.2 AUGEN GNEISS
5.3 STAUROLITE-GARNET SCHIST
5.4 BIOTITE GNEISS
5.5 AMPHIBOLITE
5.6 TOURMALINE GRANITE GNEISS
5.7 PORPHYRITIC GNEISS
5.8 GRANITE GNEISS
5.9 MICA SCHIST
5.10 PHYLLITE
5.11 SLATE
5.12 QUARTZITE
5.13 METABASIC
5.14 CHLORITE SCHIST
5.1 SILLIMANITE GNEISS

This gneiss contains fibrolite and sillimanite as one of the major constituents. The rocks are well foliated, medium to coarse grained and show metamorphic layering. The sillimanite gneiss contains K-feldspar, quartz, muscovite, biotite and subordinate hornblende and tourmaline. It occurs around Kharsoli village near Khatling glaciers in the Bhilangna valley.

Under the microscope, the sillimanite gneiss mainly consist of biotite, muscovite, quartz, microcline, orthoclase, plagioclase and sillimanite as essential minerals, where as apatite, tourmaline, zircon, hornblende, hematite, magnetite, leucoxene and limonite are accessories. The micaceous minerals and sillimanite are arranged in such a manner as to show schistose structure (Fig. 5.1). Occasionally elongated quartz shows linear arrangement. Sometime quartz and feldspar exhibit granoblastic texture. Veins of fine mats of fibrolitic-sillimanite often meander in sinus waves through the micaceous foliae of the rocks. Sillimanite is usually intergrown intimately with and apparently replacing biotite.

5.1.1 Biotite

Biotite occurs as irregular flakes which often have a linear arrangement and foliation plane ($S_1$) is mainly governed by biotite, muscovite and sillimanite. Biotites are strongly pleochoric of reddish brown and greenish brown in
colour. Its pleochroism being X=pale greenish or yellowish brown, Y= Z= Dark greenish brown. Flakes of biotite often show inclusions of long needles of fibrolite which are lighter in colour than the host biotite (Fig.5.2). They probably represent the earliest stage in alteration of biotite to fibrolite. In some of the strongly foliated varieties, biotite aggregates are completely replaced by brown to dirty brown fibrous aggregates.

5.1.2 **Muscovite**

Muscovites are usually better developed than biotite. Parallel growth of the two micas is not uncommon. Often the muscovite flakes lie across the alignment of biotite flakes and sometimes the continuation of biotite cleavage can be seen in the enclosed muscovite either as fine microscopic lines or as accicular inclusions or even as thin biotitic shreds running in that direction. These observations suggest that though most of the muscovite might have originated simultaneously with biotite, but some is formed at the expense of biotite. Inclusions of sillimanite needles are quite common in muscovites. Muscovites are forming the primary schistosity plane and crenulation foliations (Fig.5.3). Two generations of muscovite are observed. The first generation muscovites are aligned parallel to sub-parallel to the foliation plane. The second generation muscovite prophyroblasts grow across the schistosity.
Fig. 5.1 Sillimanite gneiss showing the schistosity, which is defined by parallel arrangement of sillimanite needles and micas. Crossed polars x 63.

Fig. 5.2 Long slender needles of fibrolite replacing the host biotite grains. At the top corner quartz grain is seen. Crossed polars x 63.

Fig. 5.3 Sillimanite gneiss showing two sets of schistosity. The earlier schistosity (North-South) is folded, forming a crenulation cleavage trending nearly (East-West). In top left corner broken K-feldspar grains are seen. Crossed polars x 63.

Fig. 5.4 Felted mats and fine needles of sillimanite. Crossed polars x 63.
5.1.3 Sillimanite

Sillimanite occurs as mat (Fig. 5.4) and fine needles as fibrolite enclosed in biotite, muscovite and quartz. The biotite is bleached and give rise to a dirty grey colour or colourless fibrous aggregates having slightly lower refringence and higher birefrinences than those of the clear sillimanite. In some specimens felts of dirty grey fibrolite pass into the prisms of colourless sillimanites which are elongated along the same direction. It appears that most of sillimanite, may have been derived directly from biotite.

5.1.4 Quartz and Feldspar

Two types of quartz are observed. The first type quartz is often xenoblastic. Whereas the second type quartzs are stretched and elliptical in shape. Quartz often shows slight undulose extinction. In the K-feldspar (orthoclase and microcline) bearing gneisses, the bigger plates of microcline sometimes contain inumerable inclusions of quartz giving rise to poikiloblastic textures. Microcline shows incipient twinning and perthitic stringers (Fig. 5.5). K-feldspars are mainly sercitized and kaolinized. Plagioclase feldspar occurs usually in big plates, showing albite twining.

Among the accessory minerals zircon and apatite are very common. Tourmaline and variety of Fe-oxides have been observed in several sections. Zircon is colourless or brown
and occurs as small rounded irregular grains enclosed in biotite, fibrolite or sillimanite or quartz. Inclusions of zircons in biotite are usually surrounded by pleochoric halos (Fig. 5.6). Apatite occurs as sub-hedral prismatic to anhedral grains. Magnetite occurs as irregular mass and sometimes forms the nucleous of the pleochoric or circular halos in biotite.

5.2 AUGEN GNEISS

Augen gneiss is coarse grained and consists of quartz, feldspar, biotite and muscovite. Augens of quartz and feldspar, 1-3 cm long and eye shaped are aligned with their long axes subparallel to the foliation plane.

Under the microscope, augen gneiss consists of quartz, K-feldspar, plagioclase, biotite, muscovite as essential minerals and sericite, apatite, magnetite, zircon, hornblende, epidote, clinozoisite, tourmaline as the accessory constituents. Quartz, feldspar and micas rich layers define the schistosity. Myrmekitic texture is common (Fig. 5.7).

5.2.1 Quartz

Two types of quartz are observed. First type quartz are sub-rounded to rounded in shape while second type quartzs are mainly angular to anhedral in shapes and highly recrystallized. Limonitic material occurs along the fracture plane of the first type quartz grains. Under the crossed polars...
Fig. 5.5 Microcline microperthite with a coarse albitic lamellae. At the bottom a twinned albite grain occurring as inclusion. Crossed polars x 63.

Fig. 5.6 Sillimanite gneiss shows pleochoric halos in biotite. Crossed polars x 63.

Fig. 5.7 Augen gneiss showing myrmekitic plagioclase. At the left hand side K-feldspar porphyroblast is seen. Crossed polars x 63.

Fig. 5.8 Saussaritized plagioclase and matrix are mainly made up of quartz and fine grained feldspars. Crossed polars x 63.
quartz often exhibits widely spaced lamellae subparallel to the primary foliation (S₁) of the rock. At some place these quartz grains show well developed twin lamellae.

5.2.2 **K-Feldspar**

Orthoclase is present in augen gneiss and occurs as porphyroblasts. The size of K-feldspar grains ranges between 0.5 mm to 2.5 mm. K-feldspar shows the cross hatched twinning. At some places antiperthitic intergrowth is also seen.

5.2.3 **Plagioclase**

Among the feldspar Na-plagioclase ranges up to 60-70% where as Ca-plagioclase ranges up to 15-20%. Albite and oligoclase are the main plagioclase. Myrmekitic intergrowth is quite common. The veinlets of plagioclase crystal between various crystals of K-feldspars. Saussritisation is quite prominent, showing alteration of plagioclases into epidote. Sericitization and kaolinization are also common phenomena in this rock type (Fig.5.8).

5.2.4 **Biotite**

The biotite is usually reddish brown in colour and shows very high degree of pleochroism, X= yellowish brown and Y=Z= dark brown. Some of the the biotite flakes show deeper shades of colour irregularly distributed along the margin.
5.2.5 **Muscovite**

Muscovite is comparatively poorer than biotite in this rock. The muscovite flakes lie across the alignment of the biotite as well subparallel to biotite where schistosity plane is defined by biotite.

Among the accessories, apatite appears as small prismatic or subrounded inclusions in quartz and feldspar. Epidote occurs as irregular grains as well as associated with biotite.

5.3 **STAUROLITE-GARNET SCHIST**

In hand specimen staurolite-garnet schist contains porphyroblasts of garnet and staurolite together with micas, quartz and feldspars. The micaceous band alternate with quartz and feldspar rich layers. Well developed biotite lineation is observed.

5.3.1 **Quartz**

Quartz is the most abundant mineral in this rock. Two generation of quartz are observed. The first generation quartz is usually recrystallized and is subrounded in shape. The second generation grains are mainly stretched and elongated in nature and anhedral in shape, showing undulose extinction and deformed twin lamellae. The first generation quartz are full of inclusions.
5.3.2 **Staurolite**

Two generations of staurolite are observed in the rock. The first generation staurolites are skeletal in shape. The second generation staurolites are prismatic and euhedral in habit with quartz and magnetite inclusions.

5.3.3 **Garnet**

Garnets occurs as porphyroblasts ranging in size from few milimeters to centimeters. They are euhedral to subhedral in shape but also show a tendency for elongation in the direction of schistosity. Garnets also occur enclosed in big idioblastic crystals of staurolite. Two generation of garnets are observed in the rock type. First generation garnets are skeletal to subrounded in outline and pink in colour and fractured (Fig.5.9). Si trail is sub parallel to Se external fabric. The second generation garnets are mainly fresh in nature and mainly appear in the form of euhedral crystals and enclosed in staurolite and garnet.

5.3.4 **Plagioclase**

Plagioclase appears in the form of porphyroblasts that are wrapped by micas. Albite twinning is quite common.

5.3.5 **Muscovite and Biotite**

The length of biotite flakes are ranging between 0.5 mm. to 2.0 mm. and usually of reddish brown in colour.
Fig. 5.9 Photomicrograph of staurolite-garnet schist showing 1st generation garnet porphyroblasts with inclusions of quartz and magnetite and the garnet is fractured. Crossed polars x 63.

Fig. 5.10 Photomicrograph of staurolite-garnet schist showing two sets of schistosity. The primary schistosity $S_1$ (North-South) is defined by parallel arrangement of biotite and muscovite and the later schistosity $S_2$ (East-West) is mainly of crenulation. Crossed polars x 63.

Fig. 5.11 Photomicrograph of staurolite-garnet schist showing tightly appressed isoclinal fold. Crossed polars x 63.

Fig. 5.12 Photomicrograph of biotite gneiss showing the two generation of biotite; the first is parallel to $S_1$ (North-South) and the second is developing at the hinge of crenulation fold $S_2$. Crossed polars x 63.
At some places biotite have released iron giving rise to iron oxide minerals like magnetite, hematite and limonite. The primary schistosity plane \((S_1)\) is governed by both biotite and muscovite flakes which are folded (Fig. 5.10). At some places big porphyroblasts of staurolite and garnet grow across the primary foliation defined by micas. Both the biotite and muscovite flakes are folded into tightly appressed isoclinal folds (Fig. 5.11). The micas are of two generations, the first generation micas are subparallel to the metamorphic layering and the second generation micas define the AP schistosity.

5.4 BIOTITE GNEISS

Biotite gneiss occur in the lower unit of Central Crystallines zone of Bhilangna valley. Gneissosity is defined by the biotite and muscovite. Quartz and feldspar grains are highly recrystallized and aligned along the foliation. Their porphyroblasts are wrapped by the biotite. The rock is greyish black in colour and normally medium to fine grained.

The essential minerals in this rock type are quartz, biotite, K-feldspar, plagioclase, muscovite, and chlorite. Magnetite, hematite, epidote, leucoxene and limonite occur as accessory minerals. The cleavage cracks of the biotite are filled by minute opaque inclusions. Intergrowth of feldspar and quartz show myrmekitic texture.
5.4.1 **Biotite**

Biotite is yellowish brown or greenish brown in colour. The grain size varies between 0.15 mm and 2.5 mm and forms the $S_1$ plane. Biotite is normally altered to chlorite. Crenulation foliation is also seen, where the second generation biotite are formed at the hinge of the crenulation fold and perpendicular to the first generation biotite (Fig.5.12).

5.4.2 **Quartz**

Quartz occurs as anhedral, stretched and mostly elongated in nature. The quartz grains are usually, coarsely crystallized and show undulose extinction and sutured contact (Fig.5.13). Some of the quartz grains are recrystallized, fine grained without undulose extinction.

5.4.3 **Feldspars**

Both the varieties of feldspar (K-feldspar and Plagioclase) are observed. They mainly appear in the form of porphyroblasts and aligned along the $S_1$ plane. Often they are surrounded by the small second type quartz grains. The feldspars are altered to sericite and kaolinite, suggesting a retrogressive phase of metamorphism. Plagioclases exhibit albite twining. Perthitic intergrowth is quite common.
5.5 AMPHIBOLITE

Amphibolites occur as concordant bodies in the form of bands and sheets like isolated bodies. Sometimes they cut across the foliation of the country rocks.

They are dark coloured, fine to coarse grained rocks. Schistose structure is more commonly developed in fine and medium grained varieties than in the coarse grained ones. The amphibolites contain elongated prismatic needles as well as stout prisms (Fig. 5.14). Occasionally, the rock exhibits bands rich in feldspathic material varying from 1 mm. to 5 mm. in thickness.

Petrographically three types of amphibolite are recognised, viz.

5.5.1 Plagioclase amphibolite

5.5.2 Biotite amphibolite

5.5.3 Garnetiferous hornblende gneiss

5.5.1 Plagioclase amphibolite

This rock is essentially composed of hornblende, plagioclase, quartz, epidote, clinozoisite, magnetite and chlorite. Zircon and leucoxenes are the accessory minerals.

The most abundant mineral is hornblende which occurs in variable amount. The hornblende appears in the form of porphyroblasts of irregular outline, and the linear and planar elongation of these minerals is observed in fine grained schistose variety. In general, greenish and bluish
Fig. 5.13 Biotite gneiss showing deformed quartz grains with undulose extinction, and recrystallized grains of formed along the grain boundaries. Crossed polars x 63.

Fig. 5.14 Amphibolite showing prismatic grains of hornblende. Crossed polars x 63.

Fig. 5.15 In biotite amphibolite big porphyroblast of biotite shows inclusions of apatite and epidote. The dark grain at the centre of the porphyroblast is the basal section of apatite. Crossed polars x 63.

Fig. 5.16 Garnetiferous hornblende gneiss showing myrmekitic texture; the myrmekitic quartz occurs in triangular shapes, indicating that myrmekite probably formed due to exsolution. Crossed polars x 63.
hornblende show strong pleochroism. The scheme of pleochroism is \( X= \) yellow or greenish yellow, \( Y= \) green or bottle green, \( Z= \) greenish blue, the absorption being \( X<Y<Z \). In some specimens, the hornblende is brownish green and absorption is \( X<Y>Z \). Prismatic sections of hornblende show positive elongation and maximum values of extinction angle \( X\psi C \), from 18° to 23°.

The hornblende crystals include inclusions of small second generation quartz, ilmenite, sphene, leucoxene, chlorite and limonite. Often they show sieve texture. They alter into biotite and chlorite.

The plagioclase feldspar varies in composition from andesine nearly (An-40) to labradorite (Apx.An-70) as determined from maximum \( X\angle 010 \) in sections normal to 010. It is usually fresh to altered. Some of the sections are highly kaolinized and sericitized. There is no definite relation between basicity of feldspar and the amount of quartz present in specimen. Some of the amphibolites containing basic andesine or labradorite have quartz content almost equal to plagioclase. Sometime plagioclase shows undulose extinction and deformed twin like structure under crossed nicols. The grain size of the plagioclase is mainly medium to fine grained, laths and as sub-idioblastic to xenoblastic grains with ill defined and corroded margins. Sericitization along the cleavages and twin planes are very common and most of grains are clouded with clay mineral and iron oxides.
The extinction angle X ranges up to 30°. Sodic labradorite (An-50) are found to replace albite. The other common plagioclases are albite and oligoclase (An-13). The laths of these plagioclases show blasto-subophitic texture with hornblendes. The plagioclase shows lobate relation with hornblende and often the intergrowth between that two is also found. Generally plagioclase contains the inclusions of zoisite, sericite, calcite and apatite.

The amount of orthoclase in amphibolite is very less as compared to plagioclase. The grain are mainly sub-idioblastic. Generally these grains are clouded with development of muscovite, sericite, limonite and hematite grains.

Fibrous faintly pleochoric flakes of chlorite occur along the margin of hornblende, containing inclusions of epidote and sphene. The hornblendes are mainly altered to chlorite.

Magnetite is the most common accessory. This mineral is having irregular outline and usually occurs as inclusions in hornblende. Most of the sections are containing variable amounts of leucoxene which are mainly altered from magnetite. The appearance of leucoxenes are mainly in skeletal form.

5.5.2 Biotite amphibolite

Biotite amphibolites are mainly associated with biotites and the colour of the hornblende varies from blue
to brownish green in colour. Biotite is mainly 0.1 mm. to 0.8 mm. in length and brown in colour. They are highly pleochroic from pale yellow to reddish brown. The biotite are usually free from inclusions, but occasionally some isolated grains of apatite, epidote occur as inclusions in biotite (Fig. 5.15).

The size of the hornblende is comparatively larger here than plagioclase amphibolite and they are brownish green in colour. Some of the hornblende crystals show the inclusions of hornblende which are smaller in size than host hornblende. Sometime twinned hornblende crystal is partly colourless and partially greenish and the boundary between the two types cut across the twinning plane, thus suggesting the change of hornblende composition after the development of the twin. When two hornblendes are in parallel growth they usually extinguish at the same time. The maximum extinction angle (Z\wedge C) being 20°.

In the amphibolites the proportion of quartz varies greatly in different specimens irrespective of the basicity of the plagioclase.

5.5.3 Garnetiferous hornblende gneiss

Occurrence of garnetiferous hornblende gneiss above the MCT-II is quite significant. Thickness of alternating hornblende and micaceous bands is quite variable. Quartz veins are quite significant and mainly appear in the folded
pattern. Essentially the rocks contain quartz, biotite, hornblende, garnet and plagioclase; magnetite, leucoxene and apatite are the accessory minerals. Overall the rock exhibits gneissose structure. Schistosity is well defined and mainly governed by hornblende and biotite. The bands of hornblende and biotite are arranged alternating with quartzo-feldspathic layers.

The porphyroblasts of hornblende occur in the groundmass which is composed of finely recrystallized quartz, feldspar and garnet. They are very strongly pleochroic and the scheme of pleochroism is $X$=yellow or greenish yellow, $Z$=greenish blue and $Y$=bluish green. The absorption being $X<Y<Z$. Prismatic sections of hornblende show positive elongation and they are biaxially negative. The hornblende mainly shows poikiloblastic texture. It is difficult to distinguish the prismatic sections of colourless hornblende from those of diallage but the characteristic basal parting (Salite structure) and the positive optic sign of diallage distinguishes it from the former. Inclusions of iron oxides are developed along the fracture plane of hornblende.

Garnets are mainly small in size, but they are mainly aligned along the foliation plane. The grains of garnets are mainly subrounded to elliptical in shape and generally having inclusions of small grains of second generation quartz and magnetite. At places, the magnetites
are giving rise to spotted leucoxene. Myrmekitic texture appeared in triangular form due to the exsolution (Fig. 5.16). Occurrence of this type of exsolution is just below the thrust plane, deciphered the temperature generated during the thrusting event.

The Outer Crystallines consists of Tourmaline granite gneiss, porphyritic gneiss and granite gneiss.

5.6 TOURMALINE GRANITE GNEISS

This rock is characterized by its granitic composition and well defined foliation. The foliation plane is governed by the biotite and muscovite flakes. The porphyroblasts of quartz and feldspar are aligned along the foliation plane and they are highly recrystallized in nature. The needles of tourmaline are quite prominent and they are randomly distributed in the rock, with often radiating habit. Recrystallized quartz veins traverse through the rock with random orientation.

Under microscope, tourmaline granite gneiss of Bhilanga valley consists of quartz, K-feldspar, plagioclase, biotite, muscovite and tourmaline as essential minerals and chlorite, sericite, apatite, magnetite, hornblende, epidote and zircon as accessory minerals. The biotite rich bands show great variation in grain size of all mineral constituents. At places hornblende shows poikiloblastic texture due to the
inclusions of minute grains of quartz. Myrmekitic texture is quite common in the rocks (Fig. 5.17).

5.7 PORPHYRITIC GNEISS

The porphyritic gneiss overlies granite gneiss and underlies tourmaline granite gneiss in the Outer Crystallines of Bhilangna valley. The quartz and feldspar appear in the form of porphyroblasts. Biotite and muscovite define the foliation plane. The porphyroblasts of quartz and feldspar are wrapped by the micaceous minerals.

Under microscope, porphyritic gneiss exhibits granoblastic texture. The quartz, K-feldspar plagioclase, biotite and muscovite are essential constituents and magnetite, rutile, and chlorite are accessory minerals in the rock. The porphyroblasts of quartz and feldspar are wrapped by the flakes of biotite and muscovite and exhibit porphyroblastic texture (Fig. 5.18). Intergrowth of feldspar and quartz shows myrmekitic texture. The calcic plagioclases have been altered to albite plagioclase with release of epidote and muscovite. The albite and K-feldspar are highly sericitized and kaolinized and show recrystallization. At some places original brown biotites are replaced by pseudomorphs made of aggregates of chlorite, rutile, titanite and white micas.
Fig. 5.17 Photomicrograph of tourmaline granite gneiss showing myrmekitic plagioclase; the grains in extinction at the top and left are of K-feldspar. Crossed polar x 63.

Fig. 5.18 Photomicrograph of porphyritic gneiss showing typical porphyroblastic texture (augen type). The K-feldspar porphyroblasts are wrapped up by flakes of biotite and muscovite. Crossed polars x 63.

Fig. 5.19 Photomicrograph of granite gneiss showing mylonitic characters. The K-feldspar grains (black and grey) are highly deformed with undulose extinction and irregular fractures. The fractures are filled up by quartz; also some newly formed recrystallized quartz grains at the grain boundary. Crossed polars x 63.

Fig. 5.20 Photomicrograph of granite gneiss showing foliation (Fluxion structure) which is mainly developed due to mylonitization. Crossed polars x 63.
Group. At the thrust contact due to the cataclasis, the rocks are sheared in nature. Recrystallization of quartz and feldspar grains are quite prominent. The granite gneiss is homogeneous in nature without much mineralogical variation.

Under microscope, the granite gneiss exhibits granoblastic texture. The essential minerals are quartz, K-feldspar, plagioclase, biotite, muscovite, sericite and chlorite; whereas hornblende, apatite, zircon, epidote and clinozoisite occur as accessory minerals. The granite gneiss shows textural variation due to varying intensity of mylonitisation (Fig.5.19). Though the major portion of the gneiss is porphyroblastic, but bands of fine grained gneiss devoid of porphyroblasts occur at various levels. This gneiss is well foliated with fluxion structure (Fig.5.20). Another characteristic feature is the development of stretched mineral lineation defined by biotite and quartzo-feldspathic streaks. Strong recrystallization and neomineralization dominate over cataclasis showing development of blastomylonite near the thrust contact.

As mineralogy of all the three rock types of the Outer Crystallines are same, they are described jointly as follows:

5.8.1 Quartz

Two types of quartz are observed. The second type quartz mainly exhibits xenoblastic texture. The grains
elongated, equant, interlock and show optical continuity. The first type quartzs exhibits allotrimorophitic form. Under the crossed polars, the quartz often exhibits widely spaced lamallae, sub-parallel to primary foliation \((S_1)\) of the rock. Occasionally a well developed deformation lamallae has been observed in quartz, signifies syntectonic recrystallization and in some cases the quartz grains do not have any strain effect indicating post tectonic recrystallization (Fig. 5.21).

5.8.2 K-feldspar

Both the variety of K-feldspar (orthoclase and microcline) are present and appear in the form of porphyroblasts. The grain size of K-feldspar varies between 0.5 mm to 2.5 mm. K-feldspar shows perthite films and stringers and some of its grains show only incipient cross hatched twinning especially around the inclusions of quartz. Plagioclases are mostly (0.1-1.5 mm.) acid oligoclase with anorthite content less than 15%. K-feldspars are always turbid with limonite and kaolinite. Some of the K-feldspar grains are highly sericitized and altered; sometime, K-feldspar contain water clear drops of secondary quartz and small inclusions of plagioclase. Perthitic intergrowth is quite common. At some places antiperthitic growth is also observed. Sericitization and kaolinization suggests regional retrograde metamorphic event (Fig. 5.22).
Fig. 5.21 Photomicrograph of granite gneiss showing a quartz porphyroblast with undulose extinction and wrapped up by foliation, indicating its syntectonic nature. At the left hand corner fine grained quartz without strain effect indicate post-tectonic recrystallization. Crossed polars x 63.

Fig. 5.22 Photomicrograph of granite gneiss showing a porphyroblast of plagioclase showing sericitization and kaolinization, which are due to regional retrogression. Crossed polars x 63.

Fig. 5.23 Photomicrograph of mica schist showing $S_1$ foliation defined by elongated biotites. Crossed polars x 63.

Fig. 5.24 Photomicrograph of biotite-muscovite schist showing flakes of muscovite (dark) with cracks along cleavage filled with minute opaque inclusions. Crossed polars x 63.
5.8.3 **Plagioclase**

Plagioclases in granite gneisses are dominant and play a major role in signifying the genetic history of granite. Sodic plagioclases are widely distributed up to 70-80% where as the anorthite content is up to 15%. The plagioclase are mainly albite and oligoclase and appear as porphyroblasts. The protrusion of plagioclase in K-feldspar, which may have irregular or straight margins, show typical myrmekitic quartz. The grain size of the plagioclase mainly ranges between 0.2 and 1.5 mm. At places they are either untwinned or show albite twinning. At places plagioclase shows zoned margin at its contact with K-feldspar. The marginal portion of plagioclase has a lower refringence and a higher birefringence than the central part. Thin veinlets of small plagioclase occur with K-feldspar. They take a peculiar sinuous course along the boundaries between the adjoining K-feldspar and quartz crystals and look like ptygmatic veins. At places, plagioclase exhibits saussuritisation producing epidote. Sericitization is also common in plagioclase.

5.8.4 **Biotite**

Biotite occurs as sub-idioblastic flakes. The size of the flakes varies from 0.1 to 5 mm. They are mainly governing foliation plane. Biotite wraps the feldspar and
quartz grains. At places the biotites appears in the form of aggregates. The biotites are highly pleochoric. They are usually reddish brown (s) type but greenish brown biotite is also observed especially in highly crystalline varieties. Basal flakes of biotite often show inclusions of long needles of biotite which are lighter in colour than the host. These probably represent the early stage of alteration of biotite. Reddish brown colour is due to introduction of limonites along the cleavage planes.

5.8.5 Muscovite

Muscovite is usually lesser developed than biotite. The parallel growth of biotite and muscovite is quite common. Also the muscovite flakes lie across the alignment of the biotite. Most of the muscovites appear to originated simultaneously with biotites, but some have crystallized later than the biotites.

5.8.6 Hornblende

The hornblende laths range between 0.1 and 0.5 mm. in length and usually occur as xenoblastic to subidioblastic elongated plates. Small basal sections of hornblende occur as inclusions in quartz. Pleochoric scheme of hornblende is X=Yellowish green, and Y<Z=dark bluish green of emerald green. The extinction angle ZAC varies with maximum of 18°. The large hornblende prophyroblasts have poikiloblastic
inclusions of quartz, apatite, zircon, magnetite and hematite.

5.8.7 Epidote

Epidote is colourless to dirty grey in colour with grain size ranging between 0.5 mm and 1.5 mm in length. At places, the epidote veins cut across the quartz grains and also occur along the two twin planes of feldspar.

Apatite appears as small prismatic or subrounded inclusion in feldspar and quartz. Some of the basal section of apatite is isotropic.

Iron oxides are widely distributed in granite gneisses. Mainly magnetite, limonite, ilmenite, hematite and leucoxene are present. Occurrence of magnetite is mainly confined to big porphyroblasts of quartz and feldspar and along the fracture planes of these big prophyroblasts. At places blood red colour hematite of rhombic shape occur in quartz grains. Limonite appears mainly at the boundary of quartz and K-feldspar.

5.9 MICA SCHISTS

The rocks are well foliated and schistose in nature and contain porphyroblasts of elongated quartz grains. The porphyroblasts are mainly wrapped by micaceous minerals. Towards NE part of the study area schist becomes rich in biotite forming quartz-biotite schist. This schist at places
contain thin layers of gneissic rocks. The biotite schists is followed by muscovite schists upward in the succession. Appearance of quartz veins following the trend of country rocks is a quite common feature.

5.9.1 Quartz mica schist

The schistosity of the rock is defined by the flakes of biotite and elongated recrystallized quartz grains (Fig.5.23). The quartz is of two types, second type quartz is stretched and elongated, whereas the first type is clean, moderately undulose with straight to scalloped boundaries. The quartz grains also show numerous fractures. Both the varieties of feldspar occur. Medium to fine grained variety appears in porphyroblastic forms. The elongated ends of the porphyroblasts are often found associated with fine grained aggregates of polygonal quartz, in which micas are completely absent. Feldspars are altered to sericite and extensive sericitization effect give rise to cloudy appearance in feldspar grains. Few feldspars contain inclusions of sericite, magnetite, apatite and zircon. Perthitic intergrowth is also observed.

Biotite is next abundant mineral which shows greenish brown to deep brownish colour with strong pleochroism. The biotites are mainly aligned along the foliation planes. Often biotites show release of iron giving rise to magnetite. These magnetite changes to leucoxene. Colourless
small grains of zircons are widely distributed. Tourmaline grains are also associated with the rock.

5.9.2 Biotite-muscovite schist

Biotite-muscovite schists are widely distributed in Bhilangna valley. Both the biotite and muscovite define the schistosity plane. Quartz grains are recrystallized and the grain size is mainly medium to fine. Iron oxides are leached along the foliation plane. In association with biotite, greenish chlorite also govern the foliation plane. The cleavage cracks of muscovite are widely opened and are sometimes full of minute opaque inclusions (Fig.5.24). Myrmekite texture is quite common. Marginal granulations signifies that the rock has undergone recrystallization.

5.9.2.1 Biotite

Biotite is yellowish brown or greenish brown (Z) in colour, the size of the grains ranging between 0.1 mm and 2.5 mm. and forms the S₁ schistosity plane. Sometime they contain interlacing accicular, semi-opaque crystals of tourmaline. Both the biotite and muscovite are of two generations. Alteration of biotite to chlorite is significant. At some places the biotites have free growth and appear in the form of aggregate masses. Biotite shows pleochoric halos with altered apatite. Association of limonite with biotite is also observed. At some places muscovite flakes of first
generation show kink type (Fig. 5.25), crenulation foliation (Fig. 5.26).

5.9.2.2 Quartz

The grains are 0.1 to 1.5 mm. to size and usually coarsely crystallized and often show undulose extinction and deformed twin lamellae. The quartz are of two types. Second type quartz are elongated, stretched in shape and aligned along the foliation planes. The first type quartzes are strained and have numerous fracture.

5.9.2.3 Feldspar

Both the variety of feldspars (K-feldspar and plagioclase) appear in the rock in the form of porphyroblasts as well as aligned along the schistosity plane (S₁). They are mainly wrapped by micas and small second generation crystals of quartz. Some of the porphyroblasts show inclusions of flaky and platy minerals. K-feldspars are altered to sericite, suggesting retrograde metamorphism. Limonite is quite widespread along the fracture planes of K-feldspars. Plagioclases are also a dominant mineral in the rock showing albite twinning. Often the twin lamellae are either broken or bent due to the mechanical stresses. Quartz, magnetite and micaceous mineral inclusions are quite common in plagioclase. Feldspars show perthitic intergrowth. Myremekitic texture is widely observed. Plagioclase ranges
Fig. 5.25 Photomicrograph of biotite-muscovite schist in which flakes of muscovite show kinks. At the left top recrystallized quartz grains occur at triple point. Crossed polars x 63.

Fig. 5.26 Photomicrograph of biotite-muscovite schist showing two sets of foliation. The $S_1$ foliation (North-South) is folded and a new crenulation foliation is developed (nearly East-West). Crossed polars x 63.

Fig. 5.27 Photomicrograph of phyllite showing well marked foliation with abundant graphite. Crossed polars x 63.

Fig. 5.28 Photomicrograph of schistose quartzite along MCT-I showing granulation and recrystallization of quartz grains typical of a mortar texture. Crossed polars x 63.
between oligoclase to andesine. Often they exhibit poikiloblastic texture.

Zircon, apatite, magnetite, limonite, chlorite are common accessories. Zircons are colourless, small ovoids having high relief and are found scattered in the quartz mass or along the interface of quartz, muscovite and biotite. Apatite usually occurs as small prismatic crystals. Magnetite, leucoxene and limonite occur as small irregular grains. Tourmaline is also associated with the schist. Tourmaline occurs as short prismatic needles showing pleochroism from greenish yellow(e) to brown(w). Dichroism is also observed in tourmaline.

5.10 PHYLLITE

Phyllite occurs interbeded with the quartzites and slate. It is fine grained and greenish grey in colour. Some strained quartz are aligned along the schistosity plane.

Under microscope, the phyllite is characterized by well developed schistosity imparted by the preferred orientation of flakes of chlorite and muscovite. The schistosity surface exhibits a silky luster due to muscovite. The foliaceous minerals alternate with thin streaks of quartzofeldspathic minerals which are aligned parallel to the schistosity. Occasionally pyrite crystals have developed in small lenticular cavities which lie oblique to the plane of schistosity. Phyllite shows cataclastic texture with the
development of stretched, elongated distorted quartz grains and they are masked by graphites (Fig. 5.27). Phyllite consists of quartz, K-feldspar, sericite, muscovite, biotite and plagioclase.

5.10.1 Chlorite
It shows plechorism form yellowish green (Z) to green (X or Y) and blue or dark grey interference colour. On the basis of size of the flakes chlorite are classified into chlorite I and II. Chlorite I flakes occur as tiny flakes in quartz rich layers and define schistosity, where as chlorite II are elongated flakes and define crenulation foliations.

5.10.2 Sericite/Muscovite
White micas are commonly oriented along the $S_1$ schistosity. At times muscovite contains inclusions of epidote. Occasionally, the large flakes of muscovite oblique to the schistosity ($S_1$) plane.

5.10.3 Biotite
It occurs in small quantity. Biotite are aligned along the foliation plane. Biotite-I defines the schistosity and is pleochoric (X-light yellowish brown, Y=Z=brown). The second variety of biotite (II) occur as tiny flakes and is superimposed over the schistosity.
5.10.4 **Quartz**

Quartz is a major constituent of psammitic layers and occurs as inequid grains. They are of two generations. Quartz-I is medium to coarse grained and second generations quartz are fine grained. Both quartz-I and II show undulose extinction.

5.10.5 **K-Feldspar**

In some thin section microcline are seen exhibiting cross hatched twinning. K-feldspar are intimately associated with biotite.

5.10.6 **Plagioclase**

Small laths of plagioclase (An-10) occur in association with quartz. At places they are altered to sericite. Some time deformed twin lamallae are also seen.

Tourmaline and Iron Oxides minerals like hematite, magnetite and limonite occur as accessory minerals.

5.11 **SLATE**

Greyish green slate band occurs in Ghuttu window. The rock is fine grained and shows development of slaty cleavage.

Under microscope, slates are very fine grained and show the development of foliation plane. The rock is traversed by the quartz veins which run parallel to or cut
across the primary schistosity plane. The foliation plane is defined by the chlorite, sericite, and muscovite. The slate contains quartz, K-feldspar, sericite, muscovite, chlorite and some biotite flakes.

5.11.1 Quartz
Quartz is one of the major constituents in the rock. Their grains are mainly subhedral to anhedral in shape. The quartz are of two generations, first generations, quartz are subrounded to rounded in shape. The second generations quartz grains are placed along the foliation plane.

5.11.2 Feldspar
Both the K-feldspar and plagioclase are seen in the rock in small quantity. K-feldspars are mainly microcline and exhibit cross hatched twinning. Small laths of plagioclase occurs in association with quartz grains.

5.11.3 Chlorite
Chlorite are yellowish green (Z) to green (X or Y) colour in pleochoric scheme. They are of two generations: First generation chlorite (I) define the foliation plane, whereas the chlorite (II) are placed oblique to the S1 plane.
5.11.4 **Sericite/Muscovite**

Sericite and muscovite are aligned along the \( S_1 \) plane. Often sericite is also seen in K-feldspar.

5.11.5 **Biotite**

Biotites are aligned along the schistosity plane \( (S_1) \) but the amount is very less. Some time they exhibit pleochoric halos.

5.12 **QUARTZITES**

A thick sequence of quartzite occur below the Chail Thrust (Main Central Thrust-I) associated with bands of chlorite schists and metabasics.

The quartzites are mainly dirty white to greyish green in colour and thickly bedded. The grain size ranges from medium to fine grained. The quartzites show pronounced orientation of mica flakes, which not only defined the bedding plane but also well developed mineral lineation. Often the quartzites are grity in nature.

Petrographically quartzites have been classified into two types.

5.12.1 **Massive quartzite**

5.12.2 **Schistose quartzite**

5.12.1 **Massive quartzite**

The quartzites exhibit granoblastic texture and consist of sub-rounded to elongated grains of quartz.
quartz grains are of two generations. Generally the quartz grains show straight extinction. Most of grains exhibit relics of sedimentary structures. Inclusions of muscovite and biotite in quartz are quite common. Occasionaly magnetite inclusions are also observed. Flaky minerals like muscovite and biotite define poorly developed foliation plane. The laths of muscovites are mainly parallel to schistosity plane.

5.12.2 Schistose quartzite

Schistose quartzites are mainly observed around the Ghuttu window. They are mainly intercalated with schists. The quartzites are varigated in colour ranging from white to green. Muscovite, biotite and chlorite define the schistosity plane. Near the thrust plane mortar texture in quartzite is observed (Fig.5.28). The essential mineral assemblages in the rock are quartz, biotite and chlorite with apatite, zircon and magnetite occuring as accessory minerals.

5.13 Metabasics

The metabasic rocks are penecontemporaneously deposited with quartzites of Garhwal Group rocks. They contain thin lenses of secondary quartz along the foliation plane.
The schistosity is weekly developed and defined by the chlorite. Amygdoloidal structure is also seen, whereas the vesicles are filled by the secondary quartz.

5.13.1 Hornblende

In metabasic, hornblende is the most abundant mineral and appears as elongated prisms. They appear as porphyryblasts in schistose variety, showing irregular outline embedded in a granoblastic groundmass of anorthite and quartz. Greenish and bluish hornblende show strong pleochrism (X=yellow or greenish yellow, Y=green or bottle green, Z=greenish blue and the absorption being X>Y>Z). Positive elongation is exhibited by prismatic crystals and extinction angle ranges from 18 to 23°. Often prismatic sections of hornblende show fine lines of basal parting and simple twining parallel to the cleavage lines.

5.13.2 Plagioclase

Plagioclase in metabasics range in varying amount. Normally the size of the plagioclase ranges between 1 mm. to 2 mm. Plagioclase composition varies from (An 40-70). Due to later phase of regional retrogression, most of the plagioclases are highly Kaolinized and sericitized. At places plagioclase show undulose extinction. Sometime plagioclase exhibits corroded margins. Also laths of plagioclase show blasto-subophitic texture with hornblende. Plagioclase shows
lobe relation with hornblende. Inclusions of clinozoisite, sericite, calcite and apatite are common in plagioclase.

5.13.3 Pyroxene

The pyroxene in the metabasics appears as big crystals. Some of the big crystals show relict pyroxene with schiller structure in the core. It appears that the original pyroxene has given rise to amphiboles by uralitzation. Some of the hornblende has given rise to biotite with the release of titanium.

5.13.4 Epidote

Epidotes occur as rounded as well as well developed crystals with faint yellowish are green pleochorism. Clinozoisite occurs as elongated colourless crystals with anomolus blue interference colour. The epidotes are mainly concentrated in plagioclase. Some of the clinozoisite occurs within the hornblende. The epidotes are the retrograded product of hornblende and plagioclase.

5.14 CHLORITE SCHIST

The chlorite schist is made up of pelitic and psammitic layers. The pelitic layers exhibit dark green colour, and the psammitic layers give greyish white appearance. Quartz grains are embedded along the foliation plane. At places quartz grains appear to form porphroblasts
which are wrapped by chlorite and biotite. At some places chlorite schists are rich in quartz and is interbedded with sericite-chlorite schists.

Primary schistosity (S₁) is well preserved. The foliaceous minerals occur as idioblastic in pelitic layers and as minute porphyroblasts in the psammitic layers. Quartz exhibits granoblastic to xenoblastic texture. The mylonitization is well observed due to crushing of quartz into small granoblastic aggregates.

5.14.1 Quartz and feldspar

Quartz and feldspar of the groundmass vary greatly in grain size. They are mainly colourless and at times dusty due to inclusions of tiny dots of iron-oxides. Two varieties of quartz are recognised. Quartz I is coarse grained, anhedral with sutured periphery. This quartz has acquired ellipsoidal form and occurs as porphyroblasts. Chlorite and micaceous flakes are mainly associated with second type quartz (II). Occasionally quartz shows undulose extinction. Big porphyroblasts of quartz and feldspar are aligned along the foliation plane, wrapped by the chlorite and micas. Both the orthoclase and microcline are observed, and microcline dominated rock exhibit perthitic intergrowth. K-feldspars are highly sericitized, and sericites are mainly developed along the fracture planes of K-feldspars. Associated
plagioclase ranges between albite and oligoclase, showing albite and symmetrical twinning.

5.14.2 Chlorite

Chlorite is faintly pleochroic from light green to green. It forms fibrous to idioblastic form and occurs as tiny specks. Chlorite are of two types. Chlorite-I is in form of minute flakes and shows distinct cleavage. It shows faint pleochroism from light green to green and shows 1st order interference colours and parallel extinction. Chlorite-II is yellowish green to green in colour, and is the altered product of biotite and garnet. At times, it is observed to be pseudomorph. Chlorite-II shows berlin blue interference colours and parallel extinction. In northern part of the area chlorite (X=pale yellowish green, Y=yellowish green, Z=green) show gradual change from irregular disseminated to well defined elongated flakes. They are very intimately intergrown with muscovite and sericite. Chlorite exhibits two patterns of orientation, one being parallel to the main schistosity (S₁) and the other at an angle to the S₁. Some sections show the development of crenulation foliation in chlorite.

5.14.3 Muscovite

It occurs next in abundance to chlorite. Colourless muscovite is associated with Chlorite-I. Idioblastic grains
occur as porphyroblasts arranged parallel to the foliation and at times also occur oblique to the S-plane. It also occurs as inclusion in quartz and as alteration product of feldspar. Muscovite shows high order interference colours and parallel extinction.

5.14.4 Sericite

Small colourless flakes of sericite occur as minute porphyroblasts in psammitic layers and exhibits high order interference colour with parallel extinction.

Among the accessory minerals zircon and apatite are quite common. Tourmaline, epidote, clinozoisite, calcite and varieties of iron oxides are observed in some sections. Zircons are colourless or brown and occur as small rounded or irregular grains enclosed in biotite, chlorite and quartz. Some tourmaline grains show inclusions of apatite. Calcite appear in the form of veins.