CHAPTER V

PETROGRAPHY AND MINERALOGY
PETROGRAPHY AND MINERALOGY

5.1 METHOD OF STUDY

The petrographic study indicates the study of mineralogy, texture and modal variation of the different minerals present in the rocks.

The optic angle (2Vx of hornblende, and 2Vz of diopside) determination has been carried out with the help of Leitz 5-axis universal stage following the method described by Wahlstrom (1955, p. 57–62). The anorthite contents of the plagioclase and twin laws have been determined with the 5-axis U-stage method suggested by Turner (1947) and latter modified by Slemmons (1962). The extinction angle of hornblende and diopside was determined with the help of 5-axis universal stage.

5.2 QUARTZO-FELDSPATHIC ROCKS

Amongst the quartzo-feldspathic rocks, the granite gneiss is the most dominant one. The grey porphyritic granite is next to this in abundance. The fine-grained granite, the pegmatitic and the quartzo-feldspathic veins are though of common occurrence yet these are small in dimensions.

5.2.1 Granite gneiss

The granite gneiss is mainly composed of feldspars, quartz and biotite. Feldspars include microcline and plagioclase. Hornblende,
magnetite, sericite, kaolin, chlorite, epidote, zircon, apatite, sphene are accessories. The modal values of microcline, quartz, plagioclase and biotite range from 10.7 to 52.8, 12.0 to 31.0, 12.4 to 39.6 and 3 to 20.9 per cent, respectively (Table 1; Figs. 53, 54).

The rock unit shows the following mineral assemblages:

The microcline grains are subidioblastic to xenoblastic in shape. The percentage varies between 10.7 to 52.8. The grain boundaries are very often serrated and corroded. Characteristic cross hatch twinning is common (Photo 72) and the twinning is sometimes distorted (Photo 73). Myrmekitic (Photo 74, 75) and perthitic (Photo 76) textures are common. Sericitization and Kaolinization are common alterations. Sodic rims around plagioclase inclusions in microcline are observed (Fig. 55). Tiny spots and patches of microcline in plagioclase (Photo 77) and microcline with plagioclase remnants are observed (Fig. 55).

Plagioclase (An$_{35-40}$) grains are generally subidioblastic rarely xenoblastic and also tabular in form. Their abundance varies from 12.4 to 39.6 per cent. The grain boundaries are smooth but often serrated (Fig. 56). Two sets of cleavages are present. Twinned and untwinned
grains are observed. The twin lamellae are generally broad, but often very thin (Fig. 57) and distorted (Photo 78). Most grains exhibit the characteristic albite twinning (Fig. 57). Occasionally a combination of carlsbad and albite twinning (Photo 79,80), and pericline twinning are observed. Rarely the twin lamellae are at right angles to the elongation direction (Photo 80,81,82). Perthitic (Photo 75,76) and myrmekitic (Photo 74,75) textures are common. Bending of twin lamellae (Photo 78), kinking of twin lamellae (Photo 83) and slight displacement of twin lamellae (Fig. 58) are rarely observed. The plagioclase grains are sometimes intensely sericitised. Undulose extinction (Fig. 59) is rarely observed. Observations such as patch of microcline in plagioclase (Photo 77), plagioclase filled by impregnation of microcline, and microcline impregnations combine to form large irregular grains with remnants of plagioclase (Fig. 55), are made. Thus there are three modes of occurrence of plagioclase namely: (1) medium to coarse, subidioblastic to xenoblastic plagioclase (Fig. 57); (2) rims of albite (Fig. 55) and (3) perthitic intergrowths (fine lamellae of included perthite in microcline) (Photo 75,76).

The amount of quartz in the rock ranges from 12.0 to 31.0 percent. Three generations of quartz are seen. Quartz—I occurs as inclusions and is rounded with smooth outline (Fig. 60,61); Quartz—II is xenoblastic with embayed and serrated margins. It is coarse and shows undulose extinction. Inclusions of minute flakes of biotite, apatite and quartz—I are present. Flattened and elongated grains of quartz—II are parallelly placed within feldspar and biotite grains. Quartz—III occurs
as very fine-grained blebs or vermicules within plagioclase giving myrmekitic intergrowths (Photo 74,75).

Biotite constitutes 3 to 20.9 per cent of the rock. The grains are subidioblastic to xenoblastic with corroded, irregular and rarely smooth margin. The grains are pleochroic: $X = \text{greenish yellow}, y = z = \text{dark brown}$. Two generations of biotite are observed (Fig. 62,63). The grains of the second generation shows cross cut relationship with the grains of the first generation defining the schistosity. Association of zircon with biotite is common (Fig. 64, 65). Pleochroic haloes and mottled appearance are common. Crenulations of cleavages, fracturing and bending of grains (Fig. 62) and undulose extinction are seen. Corrosion and replacement of biotite by microcline (Fig. 66) are observed.

Hornblende grains are very rare. The grains are mostly subidioblastic and pleochroic, $X = \text{greenish yellow}, Y = \text{green}, Z = \text{blue green}$.

Zircons are subidioblastic to xenoblastic in shape and occur as inclusion in other minerals mainly biotite (Figs. 64,65). Overgrowths and outgrowths of zircons are common (Figs. 67, 68). Apatites are colourless, subidioblastic to xenoblastic with moderate relief. Most of the grains are small and rounded. Sphene often shows xenoblastic shape with irregular fractures. Magnetite is idioblastic to xenoblastic in shape, and is opaque showing metallic lustre under reflected light.

Intergrowths such as myrmekitic and perthitic are very common in granite gneiss. Myrmekites are worm-like bodies of quartz with plagioclase host (Fig. 69). These symplektic textures are often shown
by plagioclases associated with microcline (Fig. 56).

String perthites (Photo 76), vein perthites and replacement perthites are present. Irregular fine veinlets of perthite transversing the cleavage of the microcline (Fig. 70) are common. Sometimes the perthite formation in certain portion is restricted to the cleavage, in others it diffuses (Fig. 71, 72). Sometimes perthite is observed along cracks in microcline (Fig. 73) and sometimes occupies the block displacement patterns in microcline (Fig. 73).

Textures and Microstructures

In thin-sections the rocks appear as foliated to non-foliated with mostly subidioblastic to xenoblastic grains forming an inequigranular granoblastic texture. The alternating layers are exposed by varying modal proportions of the felsic and mafic minerals. The rock ranges from well banded to homogeneous and is fine to medium grained (Fig. 74). Sometimes the layerings are quite subtle or even absent and a faint schistosity is expressed by preferred orientation. Another textural variation observed in some is the type where biotite occurs in lenses or streaks so that the rock grades into a streaky gneiss. Usually the rock shows alteration of schistose and granulose bands. The schistose layers consist of mafic minerals. The granulose bands are essentially composed of quartzo-feldspathic minerals and do not show a preferred orientation. Thus based on the textural aspect the gneissic rock of the area can be named as streaky gneiss, and composite gneiss, but based on the mineral composition the rock can be named as granite.
gneiss. Micro-faulting (Fig. 58), kinking (Photo 83), micro folding of twin lamellae (Photo 78), and bending and wrinkling of biotite (Fig. 75, 76) are some common features.

5.2.2 Grey porphyritic granite

The rock is essentially composed of potassic feldspar, plagioclase, quartz and biotite. Sphene, magnetite, apatite, zircon, hornblende, sericite, kaolin, chlorite, epidote are the accessory minerals. Microcline is abundant. The volume percentages of microcline, plagioclase, quartz, and biotite are 36%, 25%, 19% and 16%, respectively (Table 2*, Fig. 53).

Microcline occurs as large subhedral to anhedral phenocrysts, and also as small grains in the groundmass. Microclines possess the characteristic cross-hatch twinning. Some grains also show combined carlsbad and cross-hatch twinning. Smaller grains of plagioclase, quartz and biotite occur as inclusions in the microcline.

Plagioclase (An$_{21-25}$) occurs as subhedral to anhedral grains in the groundmass. Albite, carlsbad and combination of albite-carlsbad (Photo 84, 85) twinnings are common. Development of albite rim around plagioclase grains occurring as inclusions in microcline (Photo 85, 86) is observed. The rimmed plagioclase inclusions differ from actual zoning in plagioclase, the former does not show any gradation to anorthite content from the outer rim to the core of the inclusion. The albite components occur as perthite lamellae in microcline (Photo 85, 86, 87), and also along contact planes of plagioclase and microcline. The development of albite rims are
much well developed in plagioclase present in perthitic grains. Most of the plagioclase inclusions show albite twinning (Photo 85, 87) but the rims are untwinned. The refractive index of the rims is slightly lower than the core of the inclusions.

Quartz grains are mostly anhedral with serrated margin and undulose extinction. Some smaller rounded grains occur as inclusions inside microcline and plagioclase, whereas others occupy the interstitial spaces between the different minerals. Again worm like bodies of quartz as intergrowth with plagioclase host are observed showing myrmekitic texture (Photo 88).

Biotite mostly occurs as prismatic subhedral grains. The biotite grains occur as clusters in the groundmass. Association of biotite with sphene, magnetite, zircon and apatite is common. Biotite is abundant in the groundmass. The grains are strongly pleochroic: $X =$ yellow, $Y = Z =$ dark brown. The characteristic mottled appearance is observed.

Hornblende grains are rarely observed, and these are subhedral to anhedral in form. The pleochroism is: $X =$ yellow green, $Y =$ olive green, and $Z =$ blue green. $2Vx = 72\degree$, $Z \wedge C = 18\degree - 22\degree$. Sphene, magnetite, epidote and biotite are found in close association with hornblende.

Perthitic intergrowth of potassic and sodic feldspar are common. The potash feldspar is commonly microcline. Rare occurrences of antiperthitic intergrowths are also observed. The different types of perthites are string, vein (Photo 85), patch (Photo 87) and flame (Photo 86). The albitic components generally follow the cleavage traces, the cracks and the fissures in potassic feldspars. The areas adjacent to the
albite rims are devoid of perthitic albite, and wherever present, appears as thin stringers draining into the rims (Photo 85).

Texture and Microstructure

The rock shows porphyritic texture. The phenocrysts are microcline, and the groundmass consists of microcline, plagioclase, quartz and biotite.

5.2.3 Fine-grained granite

The fine-grained granite is essentially composed of feldspar, quartz and biotite. Feldspar is represented dominantly by microcline, plagioclase, and perthite. Sericite, chlorite, magnetite, zircon, sphene, apatite, hornblende, epidote, allanite are the accessory minerals.

Volumetrically the percentages of microcline, plagioclase, quartz and hornblende are 39 to 61, 2 to 12, 20 to 37 and 1 to 9, respectively (Table 3; Fig. 53).

Microcline is the most abundant mineral among the feldspars. The grains are mostly anhedral in shape. Characteristic cross-hatch twinning and inclusions of rounded quartz are observed (Photo 89).

Plagioclase (An$_{22-28}$) is mainly subhedral and sometimes anhedral. Characteristic albite twinning is observed. Rounded quartz occurs as inclusions in plagioclase.
The quartz grains are either small, rounded with smooth margin, and bigger, anhedral with irregular margin. Undulose extinction is common. Inclusions of plagioclase and microcline are sometimes observed.

Perthitic intergrowth is common in microcline. These are string, vein, and flame-perthite.

Euhedral and subhedral grains of zircon, apatite, and sphene occur as inclusions. Sericite is rare.

**Texture and Microstructures**

The felsic minerals which form the major portion of the rock are placed at random and are interlocking. Microcline and plagioclase give rise to the perthitic intergrowth. Again microcline and quartz give rise to the myrmekitic texture (Photo 90). The rock possesses fine aplitic texture to medium-grained hypidiomorphic texture (Photo 91).

5.2.4 **Pegmatite**

The pegmatites are essentially composed of feldspars and quartz, with streaks of biotite. Other minerals are zircon, apatite, magnetite and hypersthene. Feldspar is represented by microcline, plagioclase and perthite.

The microcline, plagioclase and perthite are mainly coarse-grained. The perthitic intergrowths are mainly string, vein and patch types (Photo 92). Quartz vermicules in plagioclase (Photo 93), and albite rims around plagioclase inclusions in microcline are common.
The pegmatites are medium-to coarse-grained in texture. The medium-grained rocks show a hypidiomorphic texture (Photo 94).

5.3 BASIC ROCKS

The basic rock is mainly amphibolite. This occurs as compositional layerings, patches and lenses in granite gneiss and grey porphyritic granite.

5.3.1 Amphibolite

The amphibolites are essentially composed of hornblende and plagioclase, with or without biotite, with or without diopside, with or without quartz. Sphene, magnetite, zircon, apatite, epidote, sericite, vermiculite occur in minor quantity. Based upon their mineralogy and texture three varieties of amphibolites are recognised: hornblende amphibolite, biotite amphibolite and diopside amphibolite. The modal values of the amphibolites are given in Table 4.

The assemblages of the different amphibolites are:

**Hornblende Amphibolite**

**Biotite Amphibolite**

1. Hornblende - plagioclase - biotite - quartz - sphene - magnetite - apatite
2. Hornblende - plagioclase - biotite - sphene - magnetite - apatite

**Diopside Amphibolite**

1. Hornblende - plagioclase - diopside - sphene - magnetite
2. Hornblende - plagioclase - diopside - magnetite - zircon - apatite

The amount of hornblende present is 25.1 to 67.2 per cent in hornblende amphibolite and diopside amphibolite, and 30.8 to 53.8 per cent in biotite amphibolite. Most of the hornblende grains are subidioblastic and columnar in habit and some are prismatic. Xenoblastic grains with corroded margin occur. Interleaving of hornblende and biotite is commonly observed (Fig. 77). Twinning of hornblende is rare. Mostly the hornblende is oriented parallel to the S1 foliation of the rock. Prismatic sections are characterised by a set of (110) cleavages (Photo 95) and sometimes by parting parallel to (001) and basal sections by two sets of cleavages at 124° and 56° (Photo 95). The pleochroic scheme of hornblende differs in the various amphibolites. In hornblende amphibolite the pleochroism of hornblende is, X = greenish yellow, Y = green, Z = blue green. In biotite amphibolite X = yellow green, Y = olive green, Z = dark green, and in diopside amphibolite hornblende shows two different pleochroic schemes, X = yellow green, Y = olive green, Z = dark green and X = straw yellow, Y = yellow green, Z = blue green. The absorption in all the cases is Z < Y < X. 2Vx varies between 74° to 78° and Z _ A C varies between 15° to 18°.
Two generations of hornblende namely syntectonic and post-tectonic hornblende (Photo 96) are found. The syntectonic hornblende is subidioblastic, elongate grains defining $S_1$ foliation (Photo 96). The post-tectonic hornblende is larger in size and xenoblastic with inclusions of the groundmass fabric (Photo 96).

The plagioclase grains are subidioblastic to xenoblastic and characterised by polysynthetic twinning. The composition of plagioclase in the biotite amphibolite and hornblende amphibolite is oligoclase-andesine ($An_{25-40}$) and in the diopside amphibolite is labradorite ($An_{50-60}$). They are usually twinned according to albite and pericline and combinations of albite - carlsbad laws (Fig 78). Untwinned plagioclases are also common. Tapering and distortion of twin lamellae are sometimes observed. Sericitization of plagioclase are common along borders and cleavages of plagioclases. Both syntectonic and post-tectonic plagioclases (Fig. 78) are seen. The syntectonic plagioclases are developed parallel to $S_1$ foliation and post tectonic plagioclases are poikiloblastic. Very often plagioclase grains show twin lamellae perpendicular to the elongation direction.

Epidote occurs as granular aggregates, small prism and irregular grains around hornblende. The grains are colourless to pale yellow and are weakly pleochroic, $X$ = colourless $Y$ = yellowish grey, $Z$ = pale yellow; $ZAC = 0°-5°$.

In diopside amphibolite, the diopside grains are xenoblastic with corroded and irregular margin (Photo 97). Replacement relationship of diopside and hornblende are very often noticed (Photo 98).
mineral is colourless or pale green. The pale green variety is weakly pleochroic, \( X = \) pale green, \( Y = \) pale greenish yellow, \( Z = \) pale yellow. 

\[ 2V_z = 58° \pm 3°, \quad Z\wedge C = 37°-40°. \]

Occurrence of quartz is subordinate. It occurs as xenoblastic grains. Undulose extinction is common.

Biotite mostly occurs as interlaminated grains with hornblende, in the biotite amphibolite. Biotite occurs as elongated plates defining the \( S_1 \) foliation (Photo 99). Orientation of biotite in three different directions is observed (Photo 99). The mineral is strongly pleochroic: \( X = \) yellow, \( Y = Z = \) brown. Alternation of biotite to vermiculite and chlorite is observed. Biotite sometimes occurs at the expense of hornblende where it replaces hornblende with corroded margin.

Magnetite is black and opaque giving metallic lustre under reflected light. Replacement of sphene by magnetite is common (Photo 100).

Rounded apatite, oval to rounded sphene (Photo 98) and oval-shaped zircons are common.

**Texture and microstructure**

Texturally the rock is medium- to coarse-grained. Schistose fabric due to orientation of ferromagnesian minerals is noticed. Equal proportions of hornblende and plagioclase in hornblende amphibolite sometimes show a banded texture consisting of almost monomineralic layers of elongate hornblende and of plagioclase (Photo 96) and also sometimes a diablastic intergrowth of hornblende prisms and xenoblastic
plagioclase. In biotite amphibolite the diablastic intergrowth of hornblende and biotite prisms define the $S_1$ foliation (Photo 99). Whereas in diopside amphibolite, the orientation of hornblende and plagioclase give the schistose fabric. The mineral lineation is defined by prismatic hornblende in hornblende amphibolite, by hornblende and biotite in biotite amphibolite and only by hornblende in diopside amphibolite (Photo 97). Replacement relationship of hornblende and biotite (Photo 95), and diopside and hornblende (Photo 96) are very common. Orientation of hornblende-I and biotite-I, hornblende-II and biotite-II, hornblende-III and biotite-III define $S_1$, $S_2$ and $S_3$ respectively (Figs. 79, 80, 81). Microfolding is rare (Fig. 82).

5.4 PELITIC ROCKS

Biotite schist is the only pelitic rock seen in the area. The schist occurs as compositional layerings, patches and lenses in granite gneiss and grey porphyritic granite.

5.4.1 Biotite schist

The rock is mainly composed of biotite, plagioclase, and quartz. The accessory minerals are magnetite, sphene, apatite, chlorite, epidote, zircon, sericite. The volume percentage of biotite ranges between 33.2 to 56.0, quartz 17.5 to 30.2 and plagioclase 20.5 to 37 (Table 5, Fig. 54). The assemblages are as follows:

1. Biotite—plagioclase—quartz—magnetite—apatite
2. Biotite—plagioclase—quartz—magnetite—chlorite—epidote
3. Biotite - plagioclase - quartz - magnetite - sericite
4. Biotite - plagioclase - quartz - zircon - sericite - magnetite

Biotite mostly occurs as elongated prisms. Three generations of biotite viz \( S_1, S_2, S_3 \) are noticed (Photo 101). The latter two forms are short, sharply crystallised stubby prisms. The biotite-I is larger, elongated and shows preferred orientation, and parallel to \( S_1 \) (Photo 102). Microfolding (Photo 103) kinking and twisting of biotite flakes are present. Characteristic birds-eye maple structure is common. The pleochroic scheme of biotite is as follows: \( X \) = pale yellow, \( Y \) = brown, \( Z \) = dark brown. Thus \( X < Y = Z \). The biotite-II is also characterised by its preferred orientation and parallel to the foliation \( (S_2) \). The biotite-III lies at an angle of 20°-30° to \( S_2 \) and parallel to \( S_3 \) (Photo 101).

Two generations of quartz are present. Quartz-I occurs as inclusions in biotite and plagioclase. The grains are mostly rounded in shape with smooth margin. The quartz-II occurs as xenoblastic, elongated interstitial big grains, with corroded margin. Wavy extinction is common.

Plagioclase (An\textsubscript{18-26}) grains are subidioblastic to xenoblastic in shape. They mostly occur as interstitial grains with irregular margins. Porphyroblastic plagioclases often occur where Si of the mineral is parallel to Se of the rock. Sericitisation is very common. Twinned and untwinned grains are present. Twinning on albite and/or pericline laws are mostly observed.
Magnetite is subidioblastic to xenoblastic in form giving metallic lustre under reflected light. Apatite grains are subidioblastic to xenoblastic in form, very often rounded to subrounded. The sizer grains are small and rounded to subrounded in form. Chlorite is formed after biotite. Sericite is formed after plagioclase. Sericite occurs as fine scaly aggregates.

Textures and microstructures

The rock possesses a medium-grained schistose texture. The preferred orientation of the biotite flakes gives the rock a schistose texture (Photo 102). The plagioclase with some of the elongated quartz are also an add to the schistosity (Fig. 83). The biotite-I, biotite-II and biotite-III are aligned parallel to $S_1$, $S_2$ and $S_3$, respectively (Fig. 84,85). Microfolding is shown by the biotite flakes (Photo 103) along with plagioclase and quartz. Sometimes beading and faulting of twin lamella, twisting, fracturing and bending of biotite flakes (Photo 103) and granulation of quartz and biotite give the rock the cataclastic texture.

5.5 CALCAREOUS ROCK

It includes only one rock unit namely calc-silicate rock. This rock unit occurs as banded rock exhibiting a conformable relationship with the host rock unit, granite gneiss.
5.5.1 Calc-silicate rock

The calc-silicate rock is essentially composed of diopside, garnet, quartz, epidote, plagioclase and calcite. Sphene, zircon, apatite and actinolite are the accessory minerals. The rock shows the following assemblages:

1. Diopside—garnet—quartz—epidote—calcite—actinolite—zircon—apatite—sphene
2. Diopside—garnet—quartz—plagioclase—epidote—apatite—sphene—magnetite
3. Diopside—garnet—hornblende—plagioclase—quartz—sphene
4. Diopside—garnet—hornblende—plagioclase—quartz—biotite—microcline

Diopside occurs mostly as xenoblastic grains with characteristic 110 cleavages. Some grains show parting parallel to 100. The grains are pale bluish green in colour and weakly pleochroic. Replacement relationships between diopside and epidote (Fig. 86), and garnet and diopside (Fig. 87) are observed. Anomalous interference colour is distinct. $2V_z = 58° \pm 2°$, $ZAC = 37°-40°$.

Garnet is mostly xenoblastic and highly fractured. The crystal outline is shown by very few grains. Association of garnet with diopside and epidote is very common. Porphyroblasts of garnet often show poikiloblastic texture with the inclusions of quartz (Photo 104). The colour of the mineral is pinkish brown.

Plagioclase (An$_{30-40}$) grains are mostly xenoblastic. The grains are colourless and twinned. Twinning on albite and pericline laws are
well-developed, although albite-carlsbad combination twins are also noted.

Hornblende usually occurs in the form of tabular to prismatic plates. The mineral is pale green in colour and pleochroic:

\[ X = \text{pale yellow}, \quad Y = \text{pale green}, \quad Z = \text{bluish green}. \quad 2V_x = 73^\circ - 74^\circ, \quad ZAC = 16^\circ - 19^\circ. \]

Quartz grains are mostly xenoblastic in the quartz band, but rounded quartz is present as inclusions inside diopside and garnet. Diopside grains on the other hand are surrounded by xenoblastic quartz grains. Very often association of diopside, garnet, epidote and also some rounded quartz are surrounded by quartz xenoblasts. Quartz shows first order grey interference colour and undulose extinction. Thus two generations of quartz may be differentiated, the rounded grains which occur as inclusions in plagioclase, hornblende and garnet are designated as quartz-I and the xenoblastic larger grains as quartz-II.

The calcite is xenoblastic and cloudy. It occurs in association with garnet, plagioclase, epidote and diopside. The grains show twinkling and higher order interference colours.

Epidote is characterised by the pistacio-green colour and straight extinction. Anomalous bluish grey interference colour is seen.

Microcline with irregular outlines characterised by cross-hatch twinning is confined to quartz-plagioclase bands.

Actinolite is fibrous and colourless, and occurs in association with diopside and epidote and is secondary after hornblende. Lozen-
shaped sphene, oval shaped zircon with euhedral outgrowth and rounded apatite are observed.

Textures and Microstructures

The rock shows coarse-grained textures. Strongly defined (but irregular and lenticular) segregation banding is observed. The segregations are generally composed of one or two minerals, with some amount of other minerals. Although the section as a whole shows banded appearance, each band itself is granoblastic. Porphyroblastic garnet, porphyroblastic diopside and diablastic intergrowth of garnet and diopside (Photo 105) occur in a groundmass of xenoblastic quartz. Thus the calc-silicate rock is coarse-grained and banded and may commonly be called calc-silicate gneisses even though they are granoblastic and not particularly well foliated.

5.6 MIGMATITES

The migmatites constitute of leucosomes and mesosomes. The leucosomes are mainly pegmatitic and quartzo-feldspathic and the mesosomes are granite gneiss, amphibolites and biotite schist. The leucosomes are constituted of feldspars and quartz, and the mesosomes of biotite and hornblende.

Leucosomes are constituted of microcline, plagioclase and quartz with minor amounts of biotite, hornblende, zircon, apatite, magnetite. Potassic feldspars are xenomorphic and mostly occupy the interstices of other minerals. They are coarse-grained and inclusions of other minerals
are present, mostly quartz and plagioclase. Perthitic intergrowth is very common. Sericitization and sometimes development of muscovite are seen. Myrmekite is sometimes observed at the margins of plagioclase and potassic feldspars.

The plagioclase grains are hypidiomorphic, partially idiomorphic and partially xenomorphic with respect to quartz and the shape is isometric. The composition of the plagioclase is An$_{30-40}$. Sodic rim is commonly observed at the contact of plagioclase and perthite or microcline. Quartz occurs as xenomorphic grains and as aggregates.

The mafic minerals are very rarely present or almost absent. Biotite and/or hornblende occur as irregularly shaped aggregates. They are arranged as schlieren, and connected with parts of the neighbouring mesosome.

The leucosomes are coarse-grained and the texture is aplitic to pegmatitic. The mineral grains do not show any preferred orientation. About 50 per cent to 75 per cent of the leucosome are composed of microcline and quartz, and 25 per cent to 50 per cent are quartz.

The gneissic mesosomes are mainly constituted of microcline, plagioclase, biotite and quartz. The amphibolitic mesosomes are constituted of hornblende, plagioclase, ± biotite, ± diopside and quartz and the schistose mesosomes are constituted of biotite, plagioclase and quartz. The mesosomes show well-developed foliation, sometimes having very thin laminae of quartz and feldspar along the foliation. Very often in gneissic mesosomes the concentration of biotite is observed.
The main textural dissimilarity between the leucosome and mesosome is in the grain sizes. The average grains of leucosomes are larger than those of the mesosomes. The amount of biotite is higher in the mesosomes, and the orientation of the biotite is parallel to the foliation of the rock, is more pronounced, in the mesosomes. The proportions of quartz and feldspars are different in leucosomes and mesosomes.
Table 1. Modal analysis of granite gneiss

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Microcline</th>
<th>Plagioclase</th>
<th>Quartz</th>
<th>Biotite</th>
<th>Perthite</th>
<th>Accessories</th>
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<td>4.8</td>
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<td>100</td>
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<td>Sau Q₂-3</td>
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<td>11.3</td>
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<td>100</td>
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<td>Mag Q₂-₄B</td>
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<td>12.6</td>
<td>3.6</td>
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Table 2. Modal Analysis of grey porphyritic granite

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<tr>
<th>Minerals</th>
<th>Average mode of groundmass minerals excluding K-feldspar crystals &gt;20 sq mm. From thin section</th>
<th>Phenocrysts mode analysis only K-feldspar phenocrysts &gt;20 sq mm.</th>
<th>Average intra-phenocryst mode determined from thin sections</th>
<th>Intra-phenocryst mode recalculated to 25,19,33,31</th>
<th>Final mode</th>
<th>Average mode</th>
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Table 3. Modal analysis of fine-grained granite

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Accessories: Hornblende, Biotite, Plagioclase, Quartz, K-Feldspar.
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Table 4. Modal analysis of amphibolite
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Table 5. Modal analysis of biotite schist
Photo

72. Microcline with characteristic cross-hatch twinning occupying the interstitial spaces between quartz and plagioclase grains in granite gneiss. X 10.

73. Distorted cross-hatch twinning in microcline with xenoblastic round quartz grains as inclusion in granite gneiss. X 10.
74. Intergranular myrmekite occurring in microcline in granite gneiss. Note that a biotite flake occurs as inclusion. X 25.

75. Myrmekitic and perthitic intergrowth in granite gneiss. Biotite is observed at the contact of perthite and microcline. X 10.
Photo

76. String perthite along one set of cleavage in microcline in granite gneiss. Note that flakes of biotite occur at the contact of microcline and perthite. X 10.

77. Plagioclase grain with characteristic albite twinning and with a patch of microcline in granite gneiss. X 25.
78. Distortion of twin lamellae in plagioclase in granite gneiss. X 25.

79. Combination of albite and carlsbad twinning in plagioclase in granite gneiss. X 10.

80. Xenoblastic small quartz grains in plagioclase in granite gneiss. The plagioclase grain shows combination of both carlsbad and albite twinning. The albite twin lamellae are very thin and at right angles to the elongation direction. X 10.
81. A strained plagioclase grain with serrated margin in granite gneiss. The twin lamellae are at right angles to the elongation direction. Note the replacement relationship of plagioclase with microcline. X 10.

82. Very fine twin lamellae at right angles to the elongation direction of the plagioclase grain in granite gneiss. X 10.

83. Kinking of the twin lamellae of the plagioclase grain in granite gneiss. X 10.
Combination of albite and carlsbad twinning in plagioclase in grey porphyritic granite. X 4.

Inclusion of plagioclase in a perthitic microcline grain in grey porphyritic granite. The perthites are string and vein type. Note that the plagioclase inclusion shows a combination of carlsbad and albite twinning. Albite rim is also observed. X 4.
86. Inclusion of plagioclase with albite rim in a perthite grain in grey porphyritic granite. The perthites are flame type. X 4.

87. Inclusion of plagioclase in a perthite grain in grey porphyritic granite. The perthites are vein and patch type. X 4.

89. Inclusions of round quartz grains in microcline showing cross-hatch twinning in fine-grained granite. X 10.

90. Myrmekitic intergrowth in the intergranular spaces of microcline and quartz in fine-grained granite. X 10.

91. Medium-grained hypidiomorphic texture in fine-grained granite. X 10.


94. Hypidiomorphic texture in pegmatite. X 4-
95. Replacement relationship of hornblende and biotite in biotite amphibolite. Note that prismatic section of hornblende is characterised by one set of cleavage parallel to (110) and parting parallel to (001). The basal-section is characterised by two sets of cleavages at 124° and 56°. X 10.

96. Strongly foliated hornblende amphibolite. Note that both syntectonic and post-tectonic hornblende occur parallel to $S_1$ foliation. The syntectonic hornblende is subidioblastic, elongate prismatic grains and the post-tectonic hornblende in xenoblastic with irregular margin and inclusions of the groundmass fabric (mainly quartz). X 10.

97. Weakly foliated diopside amphibolite. Note that the diopside grains are xenoblastic with corroded and irregular margin and the foliation is marked by parallel alignment of hornblende. X 10.

99. Orientation of biotite in three different directions in biotite amphibolite. Note that the diablastic intergrowth of hornblende and biotite prisms define the S1 foliation. X 10.

100. Replacement of sphene by magnetite in diopside amphibolite. X 25.
101. Three generations of biotite defining $S_1$, $S_2$ and $S_3$ in biotite schist. X 10.

102. Well defined schistosity in biotite schist. $S_1$ and $S_2$ are defined by biotite. X 10.

103. Slight folding and fracturing of biotite flakes in biotite schist. Note two different directions of orientation of the biotite, $S_1$ and $S_2$. X 10.

Figures

53. QAP diagram showing the modal values of quartz, plagioclase and alkali feldspars of granite gneiss (squares), grey porphyritic granite (dots) and fine-grained granite (triangles). The fields (after Streckeinsen, 1976) are: 2- Alkali feldspar granite, 3- granite, 4- granodiorite, 7*- quartz-syenite.

54. QPM diagram representing the modal values of quartz, total feldspar, and mica in granite gneiss (squares) and biotite schist (dots). The fields in the diagram show the composition of metamorphic rocks (after Winkler, 1976, p. 329).
55. Inclusions of plagioclase in microcline with albite rim (Ab) in granite gneiss.

56. Myrmekite in contact with plagioclase, microcline and quartz in granite gneiss. The grain boundaries of quartz and plagioclase are serrated.

57. Plagioclase exhibiting albite twinning in granite gneiss, the twin lamellae are very thin.

58. Displacement of twin lamellae due to minor faulting in granite gneiss.

59. A strained plagioclase with undulose extinction in granite gneiss. The twin lamellae are at right angles to the elongation direction.

60. Inclusions of quartz-I grains in a strained microcline grain in granite gneiss.

61. A strained microcline grain with perthitic lines (Pe-l) and perthitic veinlets (Pe-v) in granite gneiss. Quartz-I grains occur as inclusions in microcline.
Figures

62. Cross-cut relationship shown by two generations of biotite in granite gneiss. Bending of a biotite grain is noticed.

63. Cross-cut relationship by two generations of biotite in granite gneiss.

64. Inclusion of zircon in biotite in granite gneiss.

65. Inclusion of zircon in biotite in granite gneiss.

66. Replacement relationship of biotite and microcline in granite gneiss. The grain margin in biotite is corroded.

67. Overgrowth of zircon in granite gneiss.

68. Outgrowth of zircon in granite gneiss.

69. Quartz-III occurring as worm-like rods within plagioclase giving a symplektitic texture in granite gneiss.

70. A grain where perthitic veinlets transverse strings of perthite which occur along cleavage lines in granite gneiss.
Figures

71. Microcline, where perthitic veinlets (Pe-v) transverse direction of the perthitic lines in granite gneiss.

72. Strings of perthite along cleavage directions in microcline. The perthite formation in certain portions is restricted to the cleavage plane, whereas in others it diffuses in granite gneiss.

73. Microcline affected by a system of cracks (resulting in microcline blocks) infiltrated by perthite in granite gneiss.

74. Gneissic texture is granite gneiss.

75. Bending of biotite grain in granite gneiss.

76. Wrinkling and fracturing of biotite in granite gneiss.
Figures

77. Interleaving of biotite and hornblende in amphibolite.

78. Post-tectonic plagioclase porphyroblast showing combination of twin lamellae in amphibolite.

79. $S_1$ and $S_2$ defined by hornblende in hornblende amphibolite. Inclusions of sphene are observed.

80. $S_1$, $S_2$ and $S_3$ defined by hornblende in hornblende amphibolite.

81. $S_1$ defined by biotite-I, $S_2$ defined by biotite-II, and $S_3$ defined by hornblende-III in biotite amphibolite.

82. Microfolding shown by hornblende prisms in diopside amphibolite.
Figures

83. $S_1$, defined by biotite-I and elongated grains of quartz and plagioclase. $S_2$ defined by biotite-II in biotite schist.

84. $S_1$, $S_2$ and $S_3$ directions defined by biotite-I, biotite-II and biotite-III in biotite schist.

85. Plagioclase showing thin twin lamella at right angles to the elongation direction. Biotite aligned parallel to $S_1$ and $S_2$ foliation directions in biotite schist.
Figures

86. Association of epidote, diopside and garnet in calc silicate rock. The intragranular spaces between epidote and diopside are occupied by garnet. Inclusions of quartz-I is observed in epidote and garnet.

87. Association of garnet and diopside surrounded by xenoblastic quartz-II in calc-silicate rock. Inclusions of quartz-I inside garnet is also noticed.