CHAPTER 4

PETROGRAPHY

4.1 Introduction

The first step in any research is to identify the lithology in the area, which can be achieved through detailed petrographic studies of the rocks under a microscope. They thus form the basic tool to carry out geological investigations in any geology field, which refers to the systematic description of rocks in hand specimens and thin sections. A proper study of rocks in thin sections yields valuable information about the formation of minerals and their recrystallization. Based on mineral assemblage, the environment in which the rock has been formed can also be interpreted. It is evident that regional metamorphism is the result of temperature, pressure, and shearing stress occurring all at once. Microscopic textures and structures reveal the imprints of metamorphism and deformation overprinted by younger and successive events. Additionally, the petrographic information combined with mineralogical and geothermobarometry will suggest the evolution of the rocks, which in turn suggests the rocks' origin and mode of formation. Mineral paragenesis, textures, and their interpretations are most important in deducing the metamorphic reaction history. Photomicrograph and reaction texture play a crucial role in metamorphic petrology. Pressure and temperature conditions affect the pre-existing mineral assemblages; accordingly, they are known as prograde and retrograde metamorphic conditions.

4.2 Petrography

A detailed petrographic investigation has been carried out under the present study of the Mauranipur-Babinagreenstone belt, in which various rock types are present. The rocks are classified based on dominant minerals and textural characteristics. Based on the mineral assemblage, the study area was found to possess an increasing grade of metamorphism. The region is mainly composed of pelitic granulites, different gneisses found interbedded with

TTGs, and basic rocks such as amphibolites and mafic-ultramafic rocks occurring as patches in between. In the following sections, the petrographic features of the various rock types have been described. The rocks of the study area show excellent textural evidence of metamorphic reactions involved in the formation of diverse mineral assemblages.

4.3 Preparation of thin polished section

Besides a good microscope and its standard set of accessories, the first and foremost requisite for successful mineralogical investigation is a well-prepared and highly polished rock sample. This is a challenging and specialized job, particularly for minerals like garnet, biotite, cordierite, plagioclase, clinopyroxene, orthopyroxene, K-feldspar, quartz, etc.

Firstly, fresh rock samples were chosen to prepare rock-thin sections for documenting the petrographic features of genetic significance. Rock-thin sections were indeed prepared using the conventional method of cutting the samples from the bigger size of the collected rock sample, which commonly bears structures and other features of genetic relevance. Rectangular chips are prepared for each sample (dimension: L*B*T; 2 inches * 1 inch * 0.25 inch) for preparing slides using a diamond saw blade. These rock chips are then grinded manually on a rotating lap (850 rpm) using silicon carbide (SiC) powder of 120 mesh size for 20 minutes with a few droplets of water. The above step is repeated with 220 mesh size powders, and then the good quality of the mineral grain boundary is observed. Afterwards, 600 and 800 mesh size powders are used to polish the glass plate and bring it to a suitable thickness. A rock-thin section is then pasted on a glass slide with the help of Araldite (resin & hardener); oblique angle pressure is applied to the chips against the glass slide to eliminate air bubbles. A petro-thin machine is further used to minimize the chips' thickness, and final polishing is carried out on a smooth glass plate using silicon carbide powder (600, 800, and 1000 mesh sizes) till a thickness of 0.03 mm is achieved. The thin sections are again polished by using alumina gel on the cloth. Then the glass slide is washed and cleaned, free from used grinding powder. The section is dried and covered with a cover slip using Canada Balsam as the binding agent for petrographic and modal mineral studies under the polarized microscope.

4.4 Petrography of thin sections

The petrographic study was done by the microscope (LEICA DM 2500 P). It is a combination of incident light and transmitted light; the segments can be controlled individually or jointly. Three magnification lenses (2.5X, 5X, and 20X) have been used for petrographic studies. However, we have considered 5X magnification with a 500 µm scale for standard photomicrograph images.

The megascopic and microscopic characteristics of different rock samples found under field investigation are discussed below under the following headings:

1. Pelitic granulites
2. Garnet-biotite gneisses
3. Amphibolites
4. Granitoids
5. Quartz reefs
6. Dolerite dykes
7. Mylonitised rocks

4.4.1 Pelitic granulites

4.4.1.a Megascopic characters

The pelitic granulites are present in the vicinity of TTG rocks and show a mixture of leucocratic and melanocratic domains in the outcrop (Figs.4.1a&b). The leucocratic domains are composed of plagioclase, quartz, and little k-feldspar, whereas biotite, orthopyroxene, and garnet dominate the mineralogy of the melanocratic domains. The leucosomes are generally considered to have originated fromthe partial melting of rock during prograde evolution. The rock displays a gneissose texture, having medium to coarse grains, whereas the colour appears grey to pink and greasy (Fig.4.1c). In the field, melanocratic layers and leucocratic layers can be easily seen in pelitic granulites in some places (Fig. 4.1d). In the field, pelitic granulites are commonly associated with tonalite- tronjhemite gneisses (Fig.4.1e). Pelitic granulites are dark in colour in comparison to TTGs. Pelitic granulites are massive and medium to coarse-grained with a grey to pinkish colour due to the abundance of garnet with a greasy appearance and granulitic texture (Fig.4.1f). The collected samples are generally fresh. The collected samples are fresh and unweathered. Garnet is abundant with other minerals, including orthopyroxene, biotite, sillimanite, feldspar, and quartz. Garnets are sporadically present with various small to medium round grains and light pinkish tinges. Light pink to white plagioclase crystals can be easily seen in the hand specimen.

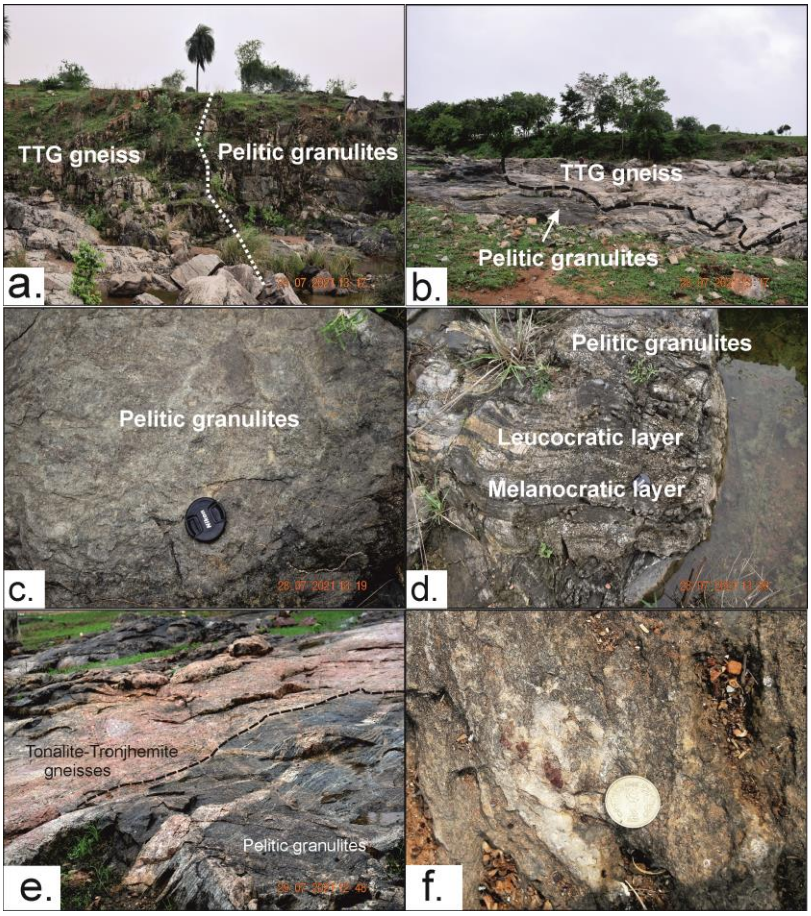

Figure 4.1 Field photographs of the pelitic granulites from the study area. (a,b) Pelitic granulites showing discordant relationship with host rock TTG gneisses. (c) Grt-Opx pelitic granulites having granulose texture.(d) Grt-Opx pelitic granulites showing melano and leucocratic layering. (e) Field image of pelitic granulite associated with Tonalite-Tronjhemite Gneisses. (f) Megascopic field image of garnet bearing pelitic granlites.

4.4.1.b Microscopic characters

Microscopic investigations of the peiticgranulites show the three distinct types of mineral assemblages:

(i) Garnet- orthopyroxene- cordierite- biotite- sillimanite-plagioclase-illmenite-quartz.

(ii) Garnet- orthopyroxene- biotite- sillimanite-plagioclase-illmenite-quartz.

(iii) Garnet- biotite- sillimanite-plaioclase-illmenite-quartz.

(iv) Garnet- cordierite- biotite- sillimanite-plagioclase-illmenite-quartz.

Ilmenite, magnetite, apatite and zircon are minor constituents in the assemblage.

(i) Grt-Opx-Crd pelitic granulites

Microscopically, the Opx–Crd–Grt pelitic granulite consists of garnet porphyroblasts of subrounded to subhedral grains in a matrix of orthopyroxene, cordierite, biotite, plagioclase, K-feldspar and quartz (Fig. 4.2a–e). Minute biotite and plagioclase inclusions are present in the garnet cores (Fig. 4.2a). In localized domains, the garnets are surrounded by coarse-grained biotite (Fig. 4.2a). The garnet porphyroblasts contain inclusions of sillimanite and biotite, and at some places, garnets are embedded in the matrix, which consists of feldspars, quartz, sillimanite, cordierite, and biotite. Textural relations suggest that the garnets include high-grade metamorphic minerals and that, on the other hand, the surrounding matrix minerals are well recrystallized and in chemical equilibrium. One may conclude that the deformation phases that affected the garnets of the metapelites took place under high-grade metamorphic conditions. Cordierite (35%) exists as a dominant mineral in pelitic granulites with garnet (25%), biotite (15%), quartz (10%), and plagioclase (7%), and sillimanite (5%). In contrast, accessory mineral phases are in minor amounts: ilmenite, magnetite, zircon, apatite, monazite, etc. The microstructures and reaction relationships observed between different minerals and mineral assemblages in the Opx–Crd–Grt pelitic granulite indicate the following multistage metamorphic evolution:

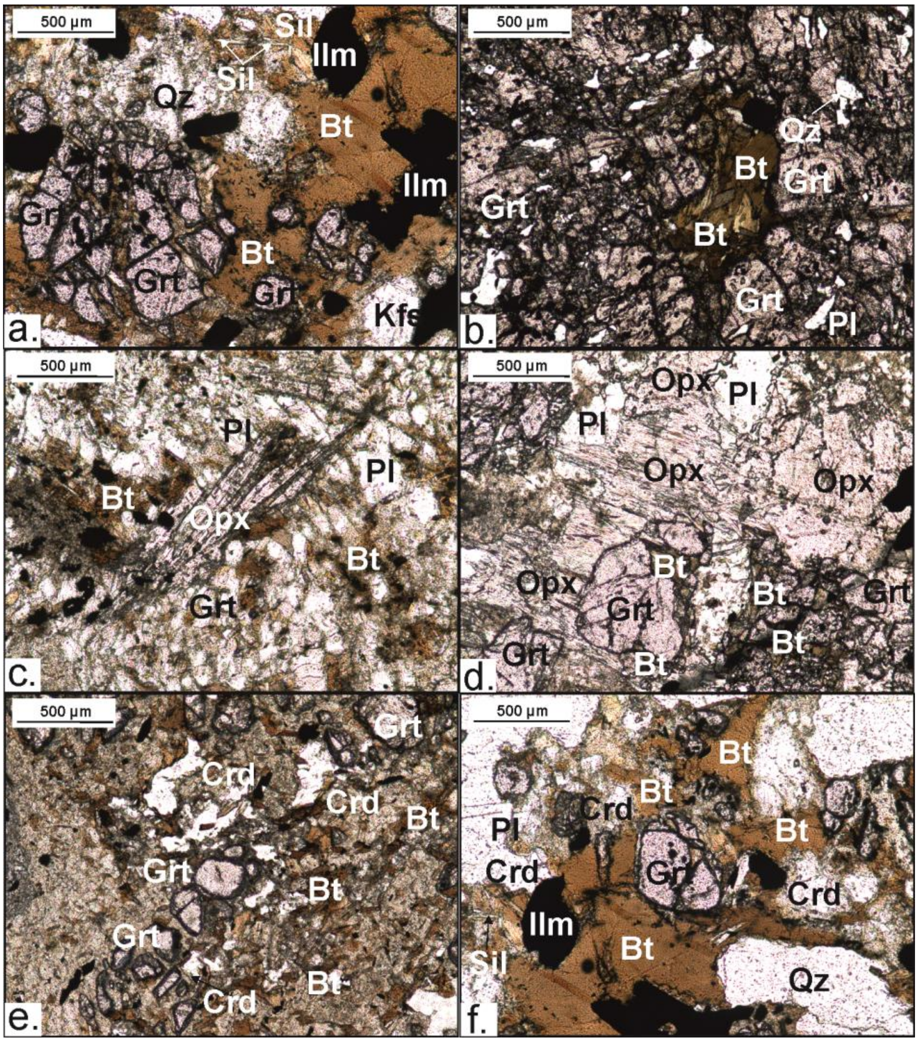

Figure 4.2 Photomicrographs (plane-polarized light, PPL) images of representative mineral assemblages andmicrostructures of the opx–crd–grt pelitic granulite (a) Garnet porphyroblasts in a matrix of biotite,quartz, and plagioclase. (b) Biotite consuming to form garnet. (c) Orthopyroxenethat occurs in the matrix in association with garnet, biotite, and plagioclase. (d) Orthopyroxene flakes cross-cut by matrix biotite. (e) Garnet relicts rimmed by altered biotite, cordierite and plagioclase. (f) Subduded garnets in a matrixcordierite associated with biotite and quartz.

Pre-Peak stage

Garnet porphyroblasts, associated with matrix biotite, plagioclase, sillimanite, and quartz, are inferred to have equilibrated during the peak granulite-facies metamorphic stage, because minute grains of biotite, sillimanite, and plagioclase are observed within the garnets (Fig.4.2a). During the near-peak stage, the garnet grew continuously with the consumption of biotite and plagioclase according to the following biotite-melting dehydration reaction (Vielzeuf and Montel, 1994) (Fig. 4.2b):

Bt+ Sil+ Qz→ Grt+ Kfs + Melt (1)

Bt+ Pl + Qz→ Grt+ Melt (2)

Peak stage

As the pressure rises, coarse-grained orthopyroxene is introduced, and small garnet relicts are found in places adjacent to altered orthopyroxene (Fig.4.2c&d), indicating the following reactions (Vielzeuf and Montel, 1994; Wei et al., 2004):

Grt+ Qz→ Opx+ Pl (3)

Bt+ Pl + Qz→ Opx+ Grt+ Melt (4)

Post-Peak stage

As the pressure continuously descends, matrix cordierite is formed in association with matrix biotite, quartz, and plagioclase (Fig. 4.2e). The appearance of the cordierite phase is a consequence of isothermal decompression (ITD), which is represented as the post-peak assemblage of pelitic granulites. The probable reaction texture has been identified as cordierite grains in the vicinity of garnet grains (Fig. 4.2f).

Grt+ Bt+ Qz→ Crd+ Melt (5)

Grt + Sil + Kfs+ Qz→ Crd+ Bt + Melt (6)

(ii) Grt-Opx pelitic granulites

Pelitic granulites display a gneissose texture in which well-defined foliation caused by parallel alignment of biotite and sillimanite flakes alternates with a matrix of garnet, orthopyroxene, plagioclase, and quartz. The mineralogy of the majority of the samples includes orthopyroxene, garnet, biotite, sillimanite, quartz, and plagioclase. The pelitic granulites contain small to medium-sized garnet grains of rounded to subhedral shape in a matrix oforthopyroxene, biotite, plagioclase, ilmenite, and quartz. Magnetite, apatite, and zircon are present as minor phases. Foliation is defined in some places by biotite flakes that have a specific orientation due to deformational stress (Fig. 4.3a). Sillimanite appears to be deformed in micro-folds surrounding the garnets in strongly deformed zones (Fig. 4.3b) and contains randomly distributed ilmenites (Fig. 4.3c). Inclusions of plagioclase, biotite, and quartz are widely distributed in garnet porphyroblasts (Fig. 4.3d). Orthopyroxene crystals are mostly anhedral to subhedral and are found with garnet, plagioclase, and quartz (Fig. 4.3e), whereas large orthopyroxene grains contain small garnet grains as inclusions at various locations (Figs. 4.3 f&g). Biotites are mostly present either as insertions in garnet or as flakes in the matrix with asymmetrical and cuspate boundaries. Most samples lack K-feldspar, but when it does appear, it is perthitic and intergrown with plagioclase. Plagioclase crystals occur in the matrix as tabular laths associated with quartz grains. The garnet has a deformed texture, with numerous fractures that dissect in various parts of the garnet porphyroblast,along with folded sillimanite laths around the garnets (Fig. 4h). Opaque minerals such as ilmenite and magnetite are scattered throughout the matrix and sometimes as inclusions within garnet and sillimanite. The size of the ilmenite grains ranges from 50 to 600 m and have idiomorphic or at least angular outlines (Fig. 4.3i).

The peak metamorphism consists of orthopyroxene, garnet, plagioclase, sillimanite, K-feldspar, ilmenite, and quartz-based on petrography and reaction texture. The presence of fine-grained biotite, plagioclase, and quartz as inclusions within garnet porphyroblasts indicates that they equilibrated during prograde metamorphism. The lack of the preferred orientation of the included minerals indicates static conditions during heating. Garnet and plagioclase are continuously grown by consuming biotite and quartz in accordance with the following fluid absent dehydration-melting reaction:

$$\text{Bt} + \text{Qz} \rightarrow \text{Grt} + \text{Sill} + \text{Pl} + \text{Melt} \quad (1)$$

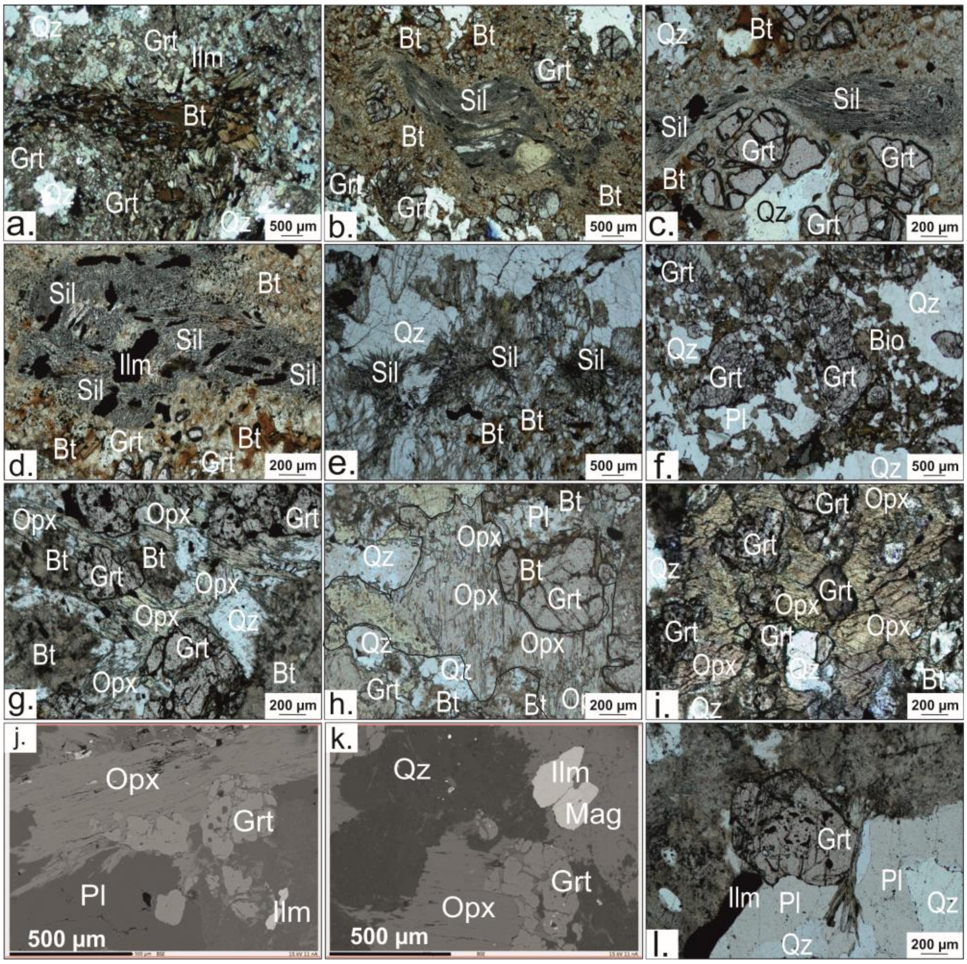

Figure 4.3 Photomicrographs (plane-polarized light, PPL) and back-scattered electron (BSE) images of representative mineral assemblages andmicrostructures of the Grt-Opx pelitic granulites.(a) Biotite crystals showing specific orientation n in a matrix of garnet, quartz and ilmenite. (b) Microfolding in sillimanite crystal in a matrix of garnet, biotite and quartz. (c) Microfolding in sillimanite crystal with broken garnet crystals. (d) Rotation of inclusion ilmenite crystals within biotite. (e) Fibrous sillimanite crystals along with patchy biotite. (f) Garnet porphyroblasts in a matrix of biotite, quartz and plagioclase. (g) Coarse-grained orthopyroxene cross-cut by garnet crystals alongwith matrix biotite and quartz. (h) Orthopyroxene that occurs in the matrix in association with garnet, biotite, and plagioclase. (i) Garnet relicts sourrounded by orthopyroxene alongwith biotite and quartz. (j) & (k) BSE image of orthopyroxene and garnet crystals alongwith plagioclase and ilmenite. (l) Garnet porphyroblast associated with fibrous sillimanite and plagioclase.

Inclusion-free garnet is associated with coarse-grained orthopyroxene, implying that both phases grew almost simultaneously. Orthopyroxene contains biotite, plagioclase and quartz as inclusions, which indicate the following reaction, suggesting that the Bt-Pl-Qz assemblage was replaced by the Grt-Opx assemblages, where garnet and opx bearing leucosomes record evidence of melt production (Vielzeuf and Montel, 1994):

Bt + Pl + Qz → Grt + Opx + K-fs + Melt (2)

The association of orthopyroxene and garnet mineral phases is considered to be a peak metamorphic assemblage, which further records orthopyroxene dissociation. Later stages have consumed orthopyroxene to form the biotite and plagioclase matrix masses; the formation of the biotite matrix and loss of melt represents retrograde metamorphism.

Grt + Opx + K-fs + Melt → Bt + Pl + Sill + Qz (3)

(iii) Grt-Bt-Sill pelitic granulites

The pelitic granulites contain garnet, sillimanite, biotite, K-feldspar, and plagioclase as major constituents and ilmenite, apatite, zircon, and monazite as minor constituents. These pelitic granulites contain medium to large garnet grains having a rounded to subhedral shape. Medium-sized biotite grains wrap around the garnet, and fine-sized biotite, sillimanite, and plagioclase occur as garnet inclusions.Garnet grains occur as porphyroblasts containing biotite, sillimanite, k-feldspar, plagioclase, and quartz as inclusions. Inclusions of biotite, quartz, and plagioclase are found in garnet, which shows the formation of garnet, suggesting the reaction:

Bt + Pl + Qz → Grt + K-fs + Melt (1)

Sillimanite appears as fibres closely associated with biotite and quartz and also occurs inprismatic form as inclusions within the plagioclase and garnet porphyroblasts (Fig.4.4a), which suggests the reaction (2).

Bt + Qz → Grt + Sil + Pl + Melt (2)

K-feldspar is colourless in thin sections and perthitic, intergrown with plagioclase. Biotite is light brown with moderate relief showing zero degrees of extinction. The biotite and quartz inclusions occurring within the garnet and k-feldspar suggest the reaction (Fig.4.4b):

Bt + Qz → Grt + Kfs + Melt (3)

Garnet is also surrounded by biotite, k-feldspar, and quartz, suggesting that the above reaction occurs in a retrograde direction (Fig.4.4c). Fig.4.4d shows a BSE image showing garnet surrounded by biotite in a plagioclase matrix. Tiny ilmenite crystals are present as inclusions within the garnet.

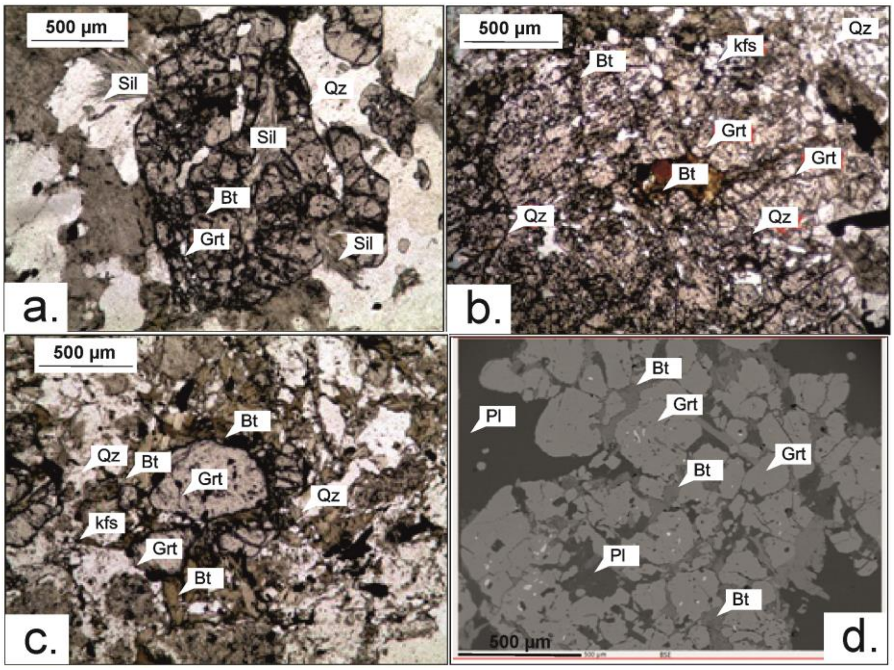

Figure 4.4 (a) Photomicrograph of retrograde metamorphism in which corroded garnet is sourrounded by a rim of biotite under plane polarized light. (b) Photomicrograp shows the inclusions of biotite and quartz coexisting with sillimanite within garnet (plane-polarised light). (c) Photomicrograph showing that garnet contains inclusion of biotite and quartz reacting to form garnet and k-feldspar. (d) BSE image showing garnet rimming by biotite in a matrix of plagioclase.

4.4.2 Garnet-biotite gneisses

4.4.2.a Megascopic character

The garnet-biotite gneisses typically show dark and light-coloured minerals bands and are medium to coarse-grained. Various structural features have been observed in garnet-biotite gneisses, such as folding (Fig. 4.5a), faulting (Fig. 4.5b), and augen-tail structure (Fig. 4.5c). Grt–Bt gneisses are leucocratic in color. Garnet-biotite-rich layers and quartzo-feldspathic layers define foliations in the rock (Fig. 4.5d). Irregular patches of Grt-Bt gneisses are exposed within the TTG gneisses (Fig. 4.5e) throughout the studied area. The patches range in size from 40 cm to 2.8 m. The patches are randomly distributed throughout the study area. Small-scale folding is observed in Grt-Bt gneiss (Fig. 4.5f).

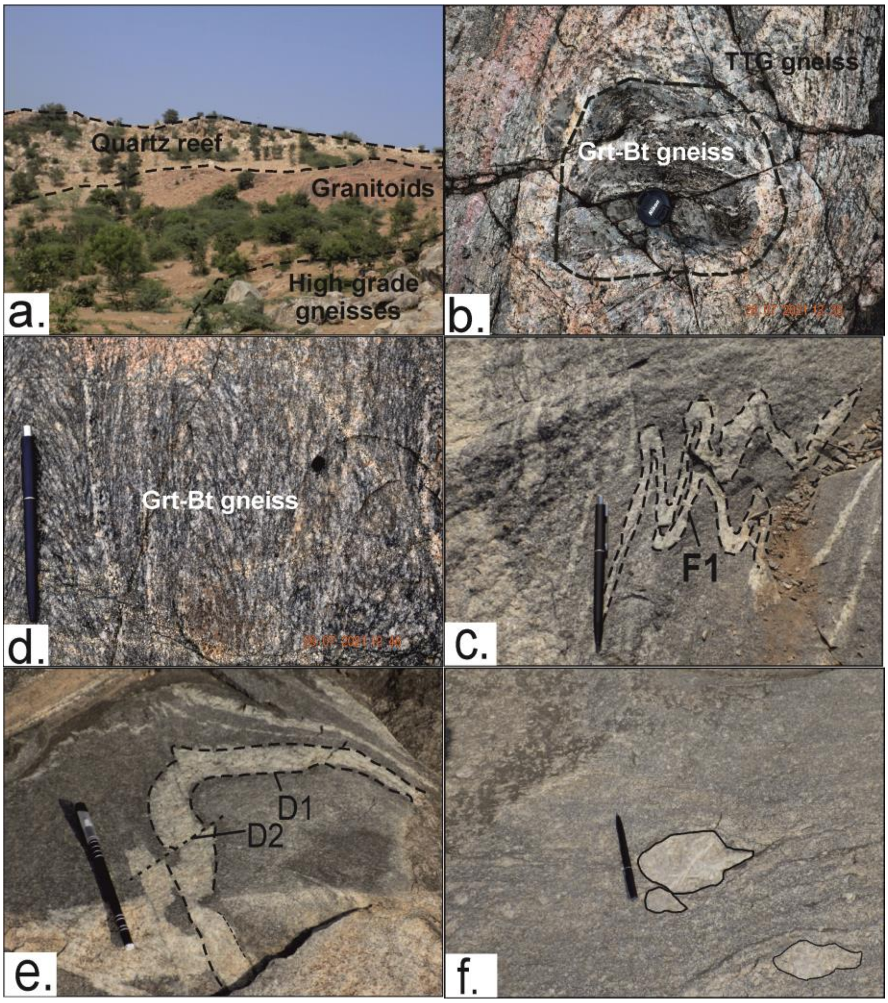

Figure 4.5 Field photographs of garnet-biotite gneisses of Bundelkhand craton showing (a) folding, (b) faulting and, (c) augen and tail structure. (d) Grt-Bt gneiss interlayered with TTG gneisses. (e) Grt-Bt gneiss as an enclave within the TTG gneisses. (f) Grt-Bt gneiss showing small scale folding.

4.4.3.b Microscopic character

The Grt-Bt gneiss is composed mainly of garnet, biotite, plagioclase, quartz, and K-feldspar, with accessory minerals ilmenite, magnetite, apatite, and zircon. Plagioclase occurs as lath-shaped, showing lamellar twinning along the margins of biotite and garnet. Quartz occurs as irregularly shaped crystals that exhibit undulose extinction in alliance with plagioclase, biotite, and garnet. Accessory minerals include ilmenite, monazite, and apatite. Garnet and biotite established two different reaction textures; they must have developed at various stages of metamorphic conditions. In some samples of Grt-Bt gneisses, garnet porphyroblasts are scattered throughout the sample (Fig.4.6a). The first reaction texture shows that biotite occurs within garnet porphyroblast along with plagioclase and quartz. Here, biotite is reddish-brown and pleochroic. K-feldspar is identified by cross-hatched twinning. This reaction texture has been observed in some samples in which biotite reacts with quartz to form garnet during prograde metamorphism. It contains an inclusion of biotite along with plagioclase and quartz at various places (Figs.4.6a&b), suggesting the following reaction:

Bt + Pl + Qz → Grt + Kfs+ Melt (1)

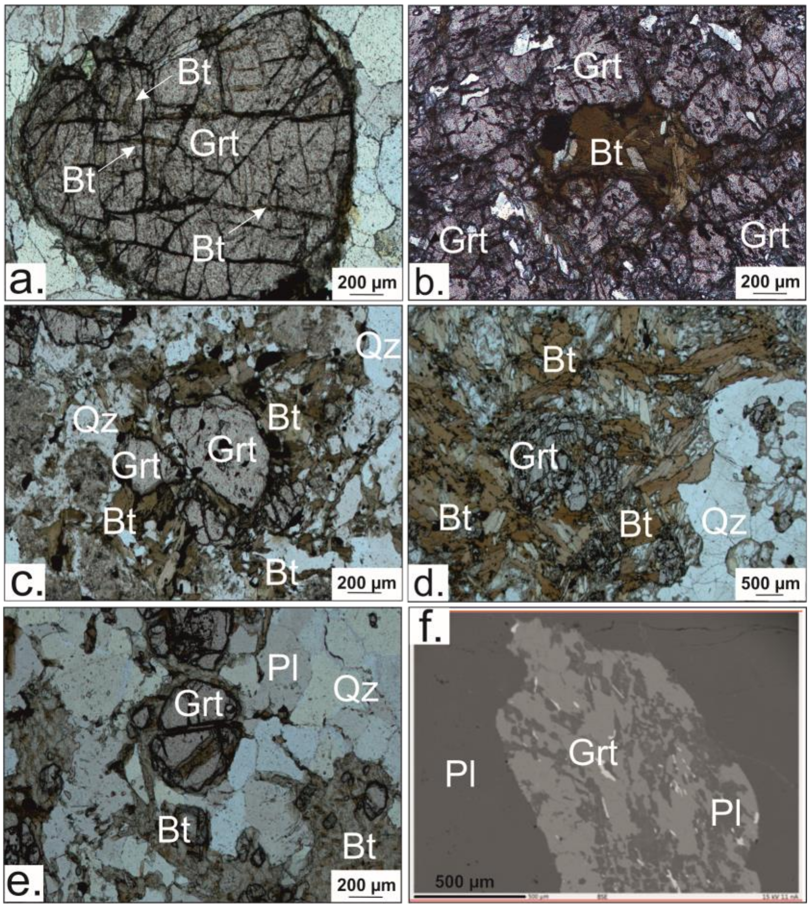

Figure 4.6 Photomicrographs (plane-polarized light, PPL) and back-scattered electron (BSE) images of representative mineral assemblages and microstructures of the Grt-Bt gneisses.(a) Garnet porphyroblast containg inclusion of biotite along its fractures. (b) Biotite crystal completely sourrounded by garnet crystals and quartz. (c) Garnet porphyroblast sourrounded by biotite and quartz. (d) Garnet crystal associated with biotite and quartz in matrix (e) Garnet crystal having fractures which are transverse to the length of the cystal.(f) BSE image showing inclusion of plagioclase in garnet crystal.

Plagioclase is dominated in this sample and is present as a medium-grained zone in the vicinity of garnet and biotite. Quartz and K-feldspar are generally scattered in the matrix as small to medium-sized grains. Biotite laths are wrapped around the garnet porphyroblast and are also present in the matrix. Ilmenite is present in small amounts and as a fibrolitic variety with a patchy variety. In some of the thin sections, biotite and quartz border the porphyroblasts of garnet, which provides evidence for late hydration during cooling (Fig.4.6c&d) as the pressure continuously decreases, indicating the following reaction:

Grt + Pl + Melt → Bt + Qz (2)

In many places, garnet crystals show fractures due to brittle deformation. These fractures are primarily transverse to the length, which might be due to the response to the compressional force acting on these rocks (Fig.4.6e). Fig.4.6f shows the BSE image of a garnet crystal containing plagioclase as an inclusion.

4.4.3 Amphibolites

4.4.3.a Megascopic character

The amphibolite samples were collected from various locations in the Babina and Mauranipur regions of the Babina-Mauranipur Greenstone Belt. Here, amphibolites are present as enclaves within the TTG gneisses and felsic granitoids (Fig.4.7a); however, they have also been reported from both the Mauranipur and Babina regions as intrusive dykes in the TTG gneisses (Fig.4.7b). Various rocks such as BIF, calc-silicate rocks, white schists, quartzites, and metapelites have also been exposed with amphibolites. Amphibolites of Mauranipur are found with garnetiferrous gneisses, whereas amphibolites of the Babina are associated with meta-ultramafic rocks. Amphibolites from both sites exhibit a nematogranoblastic texture, in which all the previous textures and structures are wiped out (Singh and Slabnouv 2015b). The amphibolites are predominantly dark in colour and fractured in some areas of the study area (Fig.4.7b). A large emplacement of felsic magmatism can be easily seen in amphibolites of the Mauranipur region (Fig.4.7c). Amphibolites also show folded and deformed structures in various places (Fig.4.7d). The amphibolites of the Babina region (near Sukwa-Dukwa dam) are similar to the Mauranipuramphibolites and are also intruded by felsic magma (Figs.4.7e&f). Garnet-bearing amphibolites were collected from the Babina area near the Sukwan dam site, while garnet-absent amphibolites were collected in the Mauranipur area near the Saprar river section. The amphibolites are found as enclaves in the TTGs' basement and as trapped intrusive bodies, and they are further influenced by various metamorphic events (Figs.4.8a,b,c&d). At the rimmed portion of enclaves, garnet-bearing amphiboles contain leucocratic and melanocratic layers (Fig.4.8b).

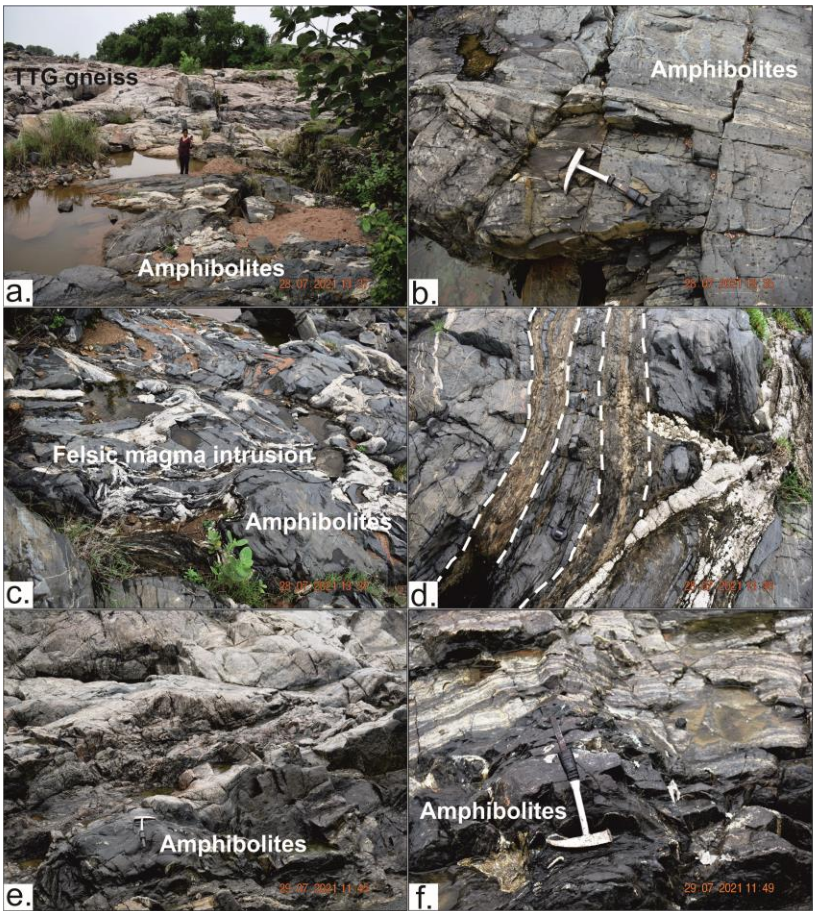

Figure 4.7 Field photographs of the amphibolites from the study area (a) Amphibolites exposed along with TTG gneisses in Mauranipur (b) Small scale field photograph of amphibolites along with deformational features in Mauranipur (c) Felsic magma intrusion in amphibolites of Mauranipur (d) Folding in the layers of amphibolites of Mauranipur (e,f) Amphibolites of Babina (near Sukwa-dukwa dam) intruded by felsic magma.

The leucocratic layers are made up of garnet, plagioclase, and quartz, which were formed as a result of partial melting during prograde metamorphism. However, the melanocratic layer is defined by the presence of amphibole, clinopyroxene, chlorite, ilmenite, and biotite. Garnet-absent amphibolites are exposed in medium to small scattered outcrops, but they are also surrounded by a massive mass of TTGs, which may also represent a signature of intrusive, felsic magma (Fig.4.8c), and deformed amphibolites can be found in some places (Fig.4.8d). Fig.4.8e&f shows close photographs of amphibolites.

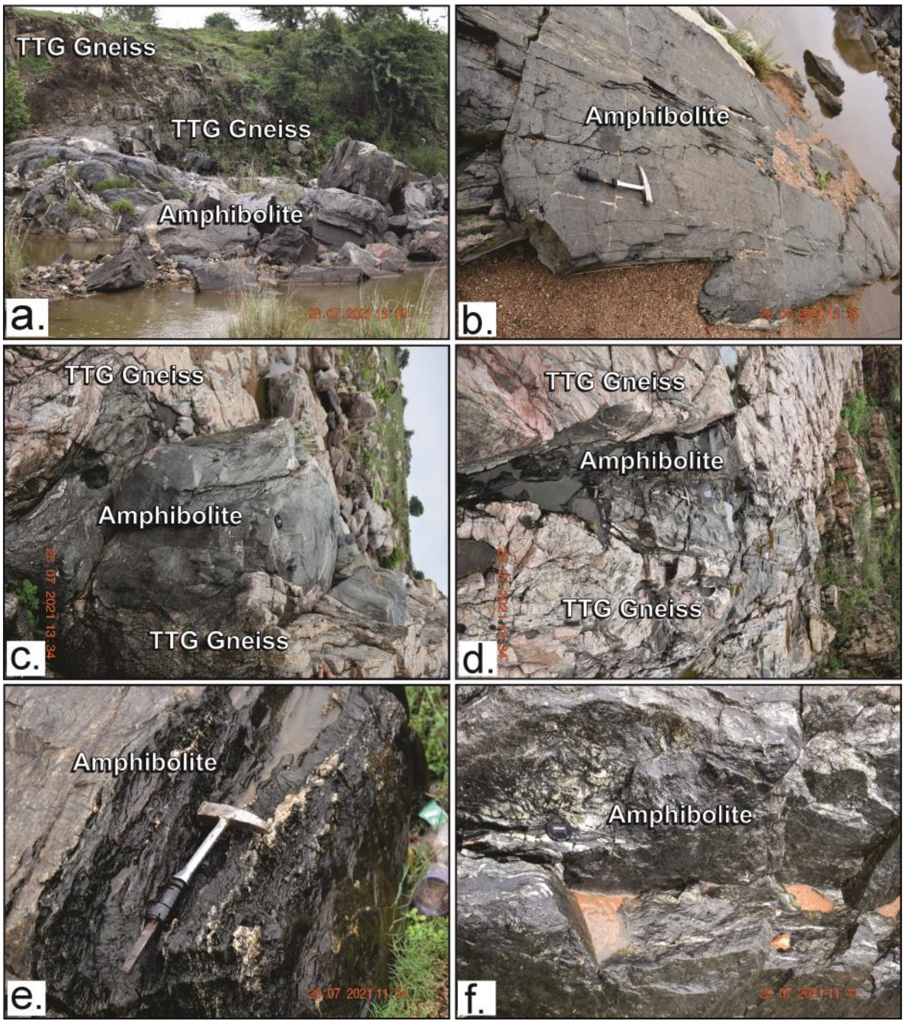

Figure 4.8 Field photographs of the amphibolites from the Babina and Mauranipur regions, (a) Amphibolites exposed as enclaves within the basement rock of TTG gneisses. (b) Amphibolites also present as enclaves form but at the marginal portions it is characterized by leucocratic and melanocratic layers. (c) Here, massive mass of amphibolites occur as broken boulder and also showing intrusive signature of felsic magma. (d) At some places, small scale deformation and fractures in present in the amphibolites.

4.4.3.b Microscopic character

Garnet, amphiboles, clinopyroxene, biotite, plagioclase, orthoclase, quartz are the common minerals that occur in different proportions in the amphibolites. On the basis of mineral paragenesis, the amphibolites have been classified into two types:

(i) Garnet-bearing amphibolites have mineral assemblage garnet-amphibole-plagioclase-biotite-quartz-ilmenite.

(ii) Garnets-absent amphibolites have mineral assemblage clinopyroxene-amphibole-plagioclase-epidote-rutile-ilmenite-quartz.

(i) Garnet-bearing amphibolites

Petrographic observation of garnet-bearing amphibolites shows a porphyroblastic texture with a fine-grained matrix. These garnet-bearing amphibolites are mainly composed of garnet (40–35%), amphibole (25–20%), plagioclase (20–15%), quartz (10%–8%), chlorite (8–6%), biotite (6–4%), clinopyroxene (7–5%), and ilmenite (~5%). A few of the yellowish amphiboles are associated with dark green chlorites and biotites (Fig.4.9a). Amphiboles are green to yellow and have a fine-grain size that is prominently developed as an anhedral shape, with no visible cleavages. Garnets are rounded and euhedral porphyroblasts with 1.0–1.5 mm grain sizes, numerous fractures and corroded boundaries, and inclusions of Amp, Bt, Chl, Ilm, Qz, and Pl mineral grains (Figs.4.9b&c). The textural association revealed three types of amphiboles in the studied samples; according to interpretation, amphiboles show characteristic features with different metamorphic stages. The first generation of amphibole appears as a fine-grained texture within the garnet as inclusions and is thought to be a product of the studied amphibolites' pre-peak metamorphic stage (Figs.4.9b&c). The second generation of amphibole is associated with garnet and clinopyroxene; however, clinopyroxene is very rare in these amphibolites, so clinopyroxene is comparatively small-grain size (Fig.4.9d). This mineralogical association has been recognized as the peak metamorphic stage. The third generation of amphibole is anhedral, with small flakes surrounding the garnet, indicating post-peak metamorphism (Fig.4.9e). The enormous mass of amphiboles composed of fragmented or fractured garnet crystals has been demonstrated to be a dominant feature of amphiboles (Fig.4.9f). Plagioclase is a major matrix component, though its crystals exhibit sericitization in a few places. Photomicrographs indicate that three stages of metamorphism were recorded by garnet-bearing amphibolites from the Mauranipur and Babina regions of the BuC. Instead, before the pre-peak stage, a meta-stable stage also coexists, which is characterized by low-grade metamorphic minerals, including chlorite and biotite, coupled with meta-stable amphibole. The following are the three significant stages with peculiar reaction textures:

Pre-peak metamorphic assemblage

The pre-peak metamorphic assemblage has been recognized as Grt-Amp-Chl-Bt-Pl-Ilm-Qz, which contains amphibole, chlorite, biotite, plagioclase, and ilmenite as inclusions inside garnet porphyroblast. This phase has preserved mineral inclusions that were consumed during prograde metamorphism (Figs.4.9b&c). These textural features suggest a pre-peak prograde metamorphic condition, with the following reaction:

Chl + Bt + Qz → Grt + Amp + Melt (1)

Amp + Pl → Grt + Qz + Melt (2)

Peak metamorphic assemblage

The formation of medium-grained clinopyroxene is observed in association with porphyroblastic garnet and amphibole (Fig.4.9d). The Grt-Amp-Cpx-Bt-Pl-Ilm-Qz assemblages in the garnet-bearing amphibolite characterize the peak metamorphic assemblage. It infers that the peak metamorphic assemblage is formed by the following reactions:

Amp + Qz → Cpx + Grt + Melt (3)

Amp + Pl + Qz → Grt + Cpx + Amp + Pl (4)

However, trails of biotite are present within amphibole and clinopyroxene, which is represented by reaction (5) (Fig.4.9e).

Bt + Qz → Cpx + Amp + Melt (5)

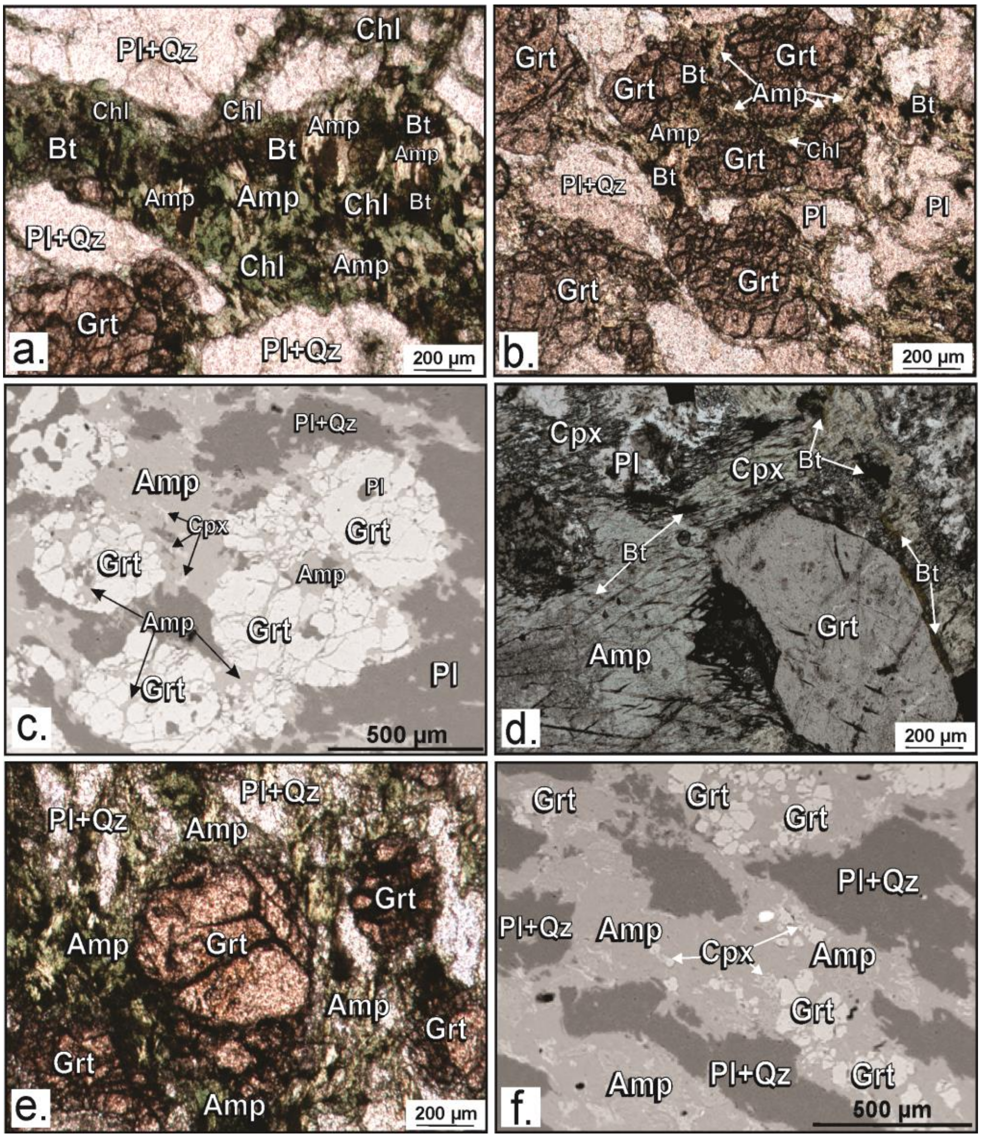

Figure 4.9 Photomicrographs (plane-polarized light, PPL) show representative mineral assemblages and textural relationships of the garnet-bearing amphibolites, (a) yellowish amphiboles are associated with dark green chlorites and biotites. (b) Numerous fractures and corroded boundaries, and inclusions of Amp, Bt, Chl, Ilm, Qz, and Pl mineral grains. (c) Inclusions of Amp, Bt, Chl, Ilm, Qz, and Pl in garnet, clearly shown by back-scattered electron (BSE) images. (d) Porphyroblast of amphibole is associated with garnet and clinopyroxene. (e) Anhedral amphiboles presnt as small flakes around the garnet. (f) Enormous mass of amphiboles composed of fragmented/fractured garnet crystals.

Post-peak metamorphic assemblage

The post-peak metamorphic assemblage is defined by Amp-Bt-Pl-Ilm-Qz. The post-peak condition in this rock is indicated by a few reaction textures, where amphibole is formed by the breakdown of garnet and clinopyroxene. Amphibole is present in a majority of the matrix phases (Fig.4.9f). The following reactions are inferred:

Cpx + Melt → Amp + Bt + Qz (6)

Cpx + Pl + Melt → Amp + Qz (7)

Grt + Bt + Melt → Amp + Qz + Melt (8)

(ii) Garnet absent amphibolites

The amphibolites from both Mauranipur and Babina regions are mainly composed of amphibole, clinopyroxene, and plagioclase as major minerals. In contrast, K-feldspar, epidote, quartz, and opaque (rutile, ilmenite, magnetite) are present as accessory mineral phases, the mineral assemblages are showing as follows:

a. Amphibole–clinopyroxene–plagioclase–rutile–epidote–ilmenite–quartz

b. Amphibole–clinopyroxene–plagioclase–albite–epidote–ilmenite–quartz

c. Amphibole–clinopyroxene–plagioclase–rutile–ilmenite–quartz

d. Amphibole–clinopyroxene–plagioclase–ilmenite–quartz

e. Amphibole–plagioclase–rutile–ilmenite–quartz

f. Amphibole–plagioclase–ilmenite–quartz

The petrographical investigations of garnet-absent amphibolites reveal porphyroblastic to granoblastic textures of amphibole and clinopyroxene minerals. The main constituents of garnet-absent amphibolites are amphibole (50–45%), clinopyroxene (25–20%), plagioclase (20–15%), K-feldspar (10–8%), ilmenite (~4%), epidote (~2%), and quartz (~10%). Amphiboles have porphyroblastic grains that range from euhedral to subhendral and have an octahedral to rhombohedral shape (Fig.4.10a). Clinopyroxene is found in prismatic and lath-shaped textures, and it is frequently associated with amphiboles (Fig.4.10b). Amphibole, clinopyroxene, and plagioclase are important in defining the foliation of the studied rock (Fig.4.10c). Amphiboles can be classified into three generations based on mineral crystal morphology and distribution. The first-generation amphiboles are pale yellow in colour and appear to be included within a massive mass of clinopyroxene; plagioclase is present nearby (Fig.4.10d). This textural feature indicates that amphibole is involved in the pre-peak metamorphism process.The epidote is only visible as inclusions within clinopyroxene and amphibole, indicating that epidote availability is very low in this sample. Ilmenite can be found in both the inclusions and the matrix. The second generation of amphibole exhibits porphyroblastic features with two sets of rhombohedral cleavage and is associated with the clinopyroxene porphyroblast, which is thought to be a product of the peak metamorphic stage (Fig.4.10e). Clinopyroxene is found here as long subidioblastic crystals with high relief and euhedral shape, with no corrosion on the boundary, implying that it is closely associated with amphibole. It has an ophitic texture in some places, with plagioclase laths occurring within clinopyroxene crystals. This amphibole has a yellow to dark brown colour and a medium to coarse grain size with a euhedral to subhedral shape. During the third generation of amphibole, a massive mass of amphiboles exists near clinopyroxene crystals (Fig.4.10f). Their textural relationship indicates that amphiboles are constantly replacing clinopyroxene, which could signify retrograde metamorphism.

The petrographical investigation of other slides of amphibolites (samples MM-1 and BB-1) has revealed three different modes of occurrence of amphiboles. All three amphiboles have characteristic features and textural associations, which are depicted in the following way: the inclusion-type amphibole (Amp1) enclosed in clinopyroxene, the porphyroblastic amphibole (Amp2) associated with clinopyroxene crystals, and the retrograde amphibole (Amp3) replacing clinopyroxene crystals.

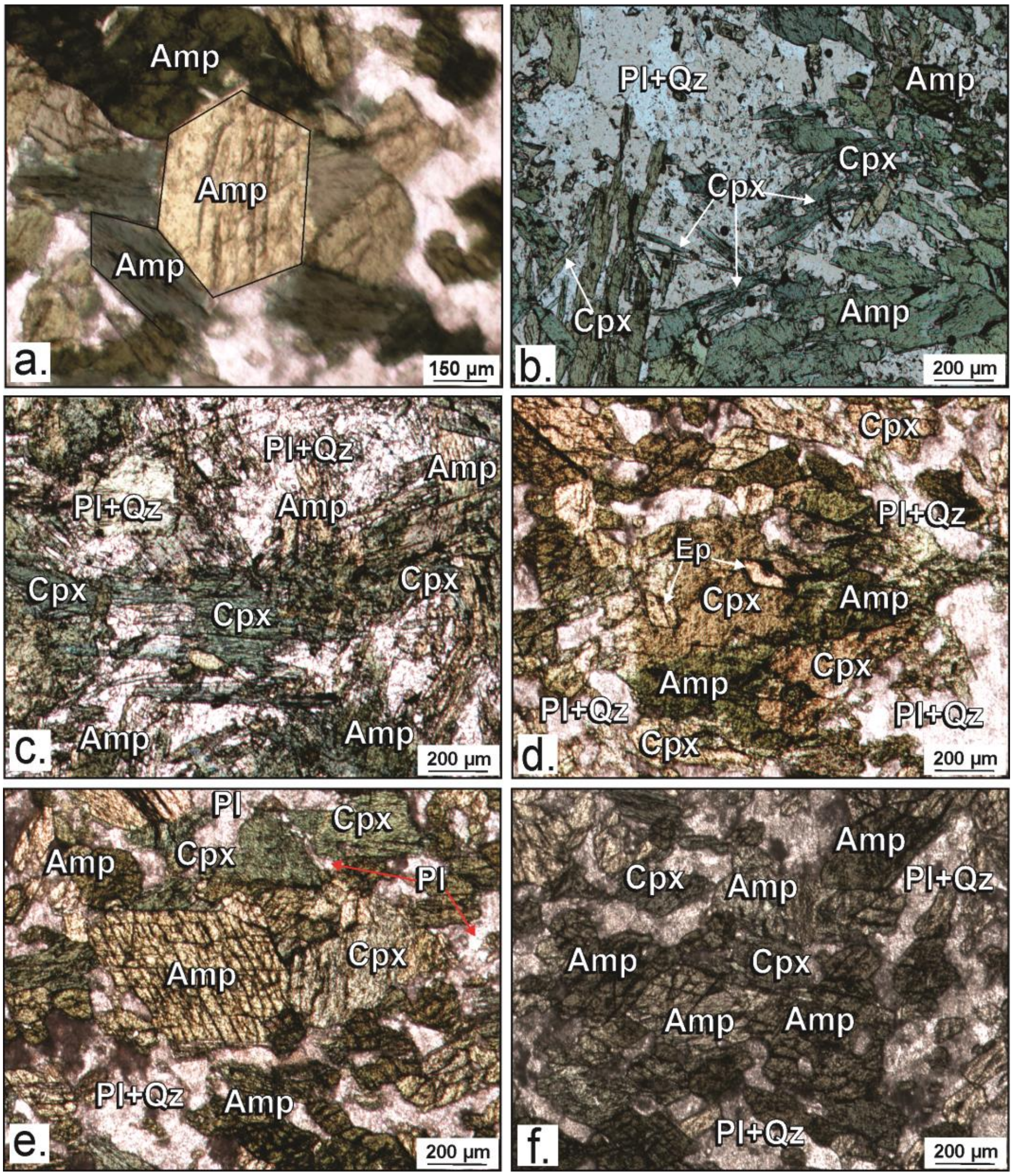

Figure 4.10 Photomicrographs (PPL) show representative mineral assemblages and textural relationships of the garnet-absent amphibolites, (a) Porphyroblast amphiboles show an octahedral to rhombohedral shape grains. (b) Clinopyroxene is found in prismatic and lath-shaped textures, and associated with amphiboles. (c) Amphibole, clinopyroxene, and plagioclase are defining the foliation. (d) Amphiboles are present as inclusion within a massive mass of clinopyroxene. (e) Amphibole associated with the clinopyroxene porphyroblast. (f) Massive mass of amphiboles exists around clinopyroxene crystals.

The first-generation amphibole (Amp1) is light brown to green in colour and occurs as inclusions within porphyroblast clinopyroxene, which is also associated with plagioclase, a textural feature indicating that Amp1 is involved in the process of prograde metamorphism (Figs.4.11a&b). Numerous tiny crystals of epidote are included in the clinopyroxene along with amphibole (Figs.4.11a&b). Porphyroblastic and subhedral grains of amphiboles are considered as the second generation of amphiboles (Amp2) and are closely associated with clinopyroxene porphyroblast. Textural features suggest that it would be a product of peak metamorphism (Figs.4.11c&d). The Amp2 is green and contains inclusions of discrete plagioclase, quartz, and ilmenite, representing sieve texture. Amphibole crystals are mainly medium to coarse-grained and subhedral to anhedral in shape. Prismatic crystals of amphibole depict two sets of cleavage, which are present with porphyroblasts of clinopyroxene (Fig.4.11c). Clinopyroxene occurs as 0.5–1 mm long subidioblastic crystals with high relief. It shows pleochroism from green to grey, and it also displays an ophitic texture showing the occurrence of plagioclase laths within clinopyroxene crystals (Fig.4.11d). A massive mass of amphiboles is present in the vicinity of a small clinopyroxene crystal. Their textural relationships suggest that amphiboles continuously replace clinopyroxene as a sign of retrograde metamorphism (Figs.4.11e&f). This petrographical evidence indicates that the third generation of amphibole (Amp3) is preserved in the studied amphibolite rocks. The plagioclase is fine to medium-grained, 0.1–0.2 mm in size and of anhedral shape, and is characterized by colourless prismatic crystals and first-order grey colour. Despite the presence of plagioclase as inclusions within clinopyroxene and amphibole, it also occurs as the dominant phase of the matrix (Fig.4.11g). Epidotes occur as <50μm rounded subhedral crystals and are associated with amphibole and plagioclase but mostly appear as inclusions within amphibole and clinopyroxene crystals. In some places, plagioclase contains inclusions of amphibole (Fig.4.11g). Apart from this, plagioclase is also present as an inclusion within the matrix of amphibole and clinopyroxene (Fig.4.11h). Fig. 4.11i shows a long lath of ilmenite at the junction of amphibole and plagioclase.

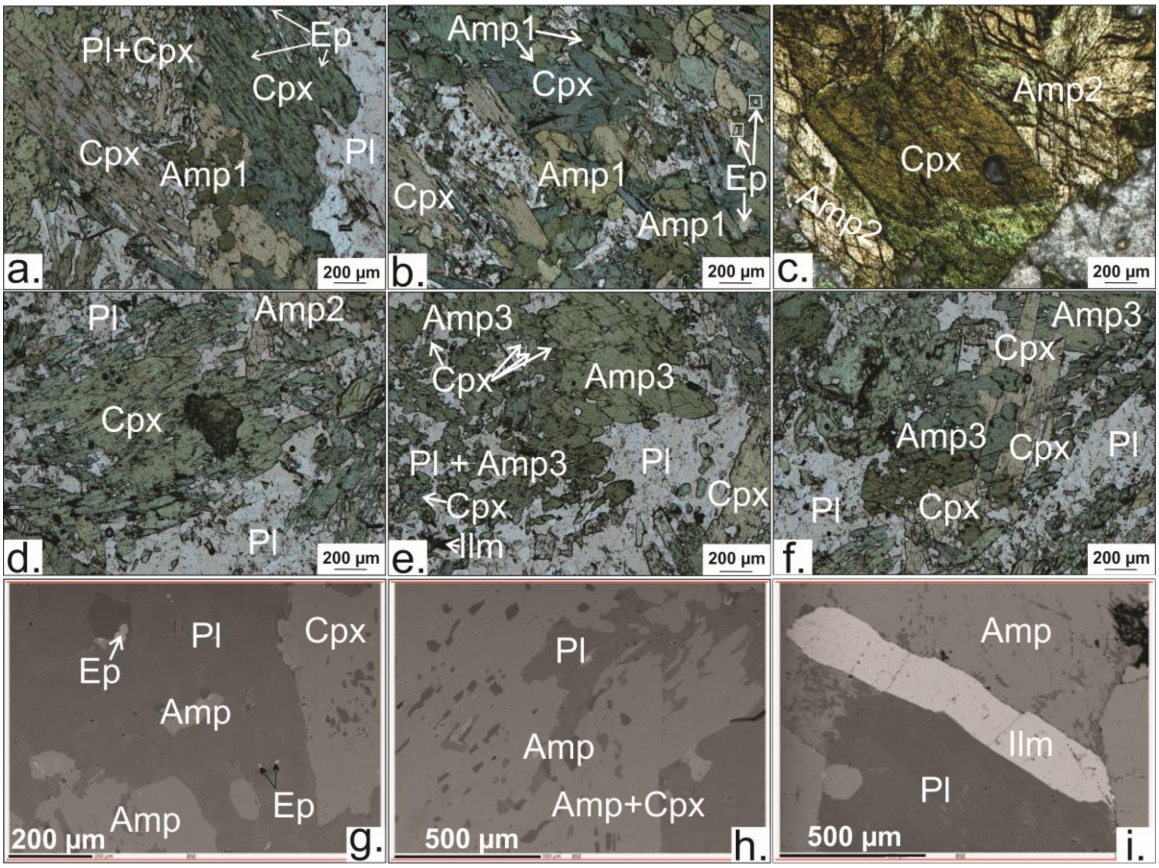

Figure 4.11 Photomicrographs (plane-polarized light, PPL) and back-scattered electron (BSE) images of representative mineral assemblages and microstructures of the amphibolites (MM-1 and BB-1): (a & b) Amp1 and epidote present as inclusions in clinopyroxene with plagioclase, (c) Prismatic crystals of Amp2 depicting two sets of cleavage with porphyroblastic clinopyroxene, (d) Laths of plagioclase embedded within clinopyroxene crystals depicting ophitic texture, (e) Amp3 contains inclusions of clinopyroxene (f) Clinopyroxene crystals partially replaced by Amp3, (g) Epidote crystals occuring as inclusions within amphibole and plagioclase (h) Plagioclase present as inclusion within the matrix of amphibole and clinopyroxene (i) Long lath shaped grain of ilmenite at a junction of amphibole and plagioclase.

4.4.4 Granitoids

On the basis of field relationships, mineral compositions, and textural and structural studies, the following types of granitoids have been obtained in the study area viz., (1) biotite granite (2) hornblende granite (3) grey granite (4) leuco granite (5) fine grain granite.

4.4.4.a Megascopic character

Megascopically, the granite of the investigated area varies in grain size from coarse to fine-grained. The porphyries of feldspar are very frequent in fine-grained leucogranite rock. The leucogranite contains feldspar, quartz, biotite, and a rare amount of hornblende. Some types of granite rock contain two perfect sets of joints and fractures. The deformed granite bands contain quartz feldspathic masses and alternate ferromagnesium mineral bands in a biotite-rich variety. Leucogranite rocks are coarse to fine-grained. They are holocrystalline, equigranular, and hypidomorphic in texture. In many thin sections, leuco granite shows porphyritic texture. The large porphyroblasts of feldspar are often found in fine-grained leucogranite rock. The leucogranite contains feldspar, quartz, biotite, and a tiny amount of hornblende. Two sets of joints and fractures are also observed in granite rock. Bands of quartz feldspar show alternation with biotite-rich ferromagnetic bands.

4.4.4.b Microscopic character

The mineral constituents of granitoids are as follows:

(1) Predominant: quartz, feldspar minerals

(2) Accessory minerals: biotite (rare), hornblende, zircon, allanite and sphence, magnetite

(3) Secondary minerals: epidotes, chlorites, sericite.

(i) Biotite Granite

Orthoclase

It is one of the predominant minerals of biotite-granite rock. Orthoclase minerals are medium to coarse-grained in thin sections. They are euhedral to anhedral in shape. It shows the intergrowth of microcline (hair-like) crystals. The core of orthoclase forms a perthite texture that is followed by plagioclase crystals. Orthoclase is commonly found to change in sericite minerals.Thephenocrysts of fresh and unaltered characters of feldspar (Orthoclase) are also observed in a few sections. They show Carlsbad twinning and low relief.

Microcline

Microcline is fine, euhedral to anhedral in shape. Cross-hatched twinning is well developed in microcline crystals. In some places, microcline-perthite is also recorded. In plane-polarized light, cross-hatched twinning is a common feature of microcline minerals.

Quartz

Quartz is also one of the predominant mineral constituents of granite. It occurs as coarse-to-fine-grained anhedral crystals. Quartz is characterized by low relief, undulose extinction but less altered minerals.

Biotite

Biotite crystals are coarse to medium-grained, tabular crystals with a perfect one-set of cleavage. Two types of biotite crystals are present in the thin section. The biotite is brown, but in some places, it is green in colour. Pleochroic haloes were absent in the biotite of this granite.

Hornblende

In thin sections, hornblende crystals are rare or nearly absent. Hornblendes are medium to fine-grained and composed of euhedral prismatic crystals. They are light green in thin sections. They show light green to dark green pleochroism and second order interference colour. Two perfectly set cleavages are present in hornblende crystals in many thin sections.

Zircon

Zircon crystals are present in the form of inclusions in biotite granite. It is usually small prismatic crystals. They distinguished each other based on high relief, parallel extinction, and absence of cleavages.

(ii) Leuco granite

Megascopically, the granites of the investigated area are fine-to-coarse-grained. The leucogranite is greyish to greyish pink rock. These rocks are hard and compact. A large amount of phenocryst of feldspars is very frequent in the coarse-grained leuco granite. The feldspar, quartz, biotite, and magnetite are assecceory minerals visible in the handspecimen. The hornblende crystals are rarely observed in leucogranite. Microscopically, all these rocks are characterized by coarse to medium-grained textures. They are holocrystalline, equigranular, hypidiomorphic, or allotriomorphic in texture.

Biotite

Biotite is medium to fine-grained, light brown, but the few biotite crystals show the pleochroic haloes. Some biotite also contains magnetite zircon.

Plagioclase

Plagioclase crystals are medium to coarse-grained, subhedral andhave lamellar twinning. Plagioclase feldspars are rare. In many places, antiperthite textures are developed by the contact of orthoclase crystals. In some areas, orthoclase feldspars altered to formthe albite. The twin lamellae of albite are observed.

Quartz

Medium to coarse-grained grains is euhedral in shape and colourless in thin sections. Quartz is characterized by low relief, sharp extinction, and less alteration. Due to the strain effect, quartz exhibits excessive extinction in some places and also observed as inclusion in feldspar, biotite, and magnetite.

Hornblende

The hornblende shows a light green colour and a medium to fine-grained texture. The hornblende shows the characteristic pleochroism of greenish-brown to light green colour.

Zircon

It is occasionally found as an inclusion in biotite and hornblende crystals and also as pleochroic haloes in biotite and hornblende. They have low relief and gives parallel extinction. No cleavages are present in the biotite crystals.

Magnetite

Magnetite is euhedral to anhedral in shape. They are low relief, non-pleochroic, and dark black. No cleavage is present in the magnetite crystals. In many thin sections of leucogranites, magnetite is present as inclusion in the biotite, hornblendes, and quartz crystals.

(iii) Grey granite

Grey granite is a dark grey-coloured rock with massive fabrics. The pegmatite veins are present in grey granite rock. The weathered surface of granites forms thick alternate bands of light and dark-coloured minerals. Chlorite is also present at the margin of biotite at its contact with plagioclase in the deformed granite.The granite is characterized by K feldspar, quartz, biotite, hornblende, and magnetite with a small amount of apatite and retrograded chlorite. The granites are dominated by minerals like hornblende, zircon, chlorites, biotite, quartz, and plagioclase. Rutile, magnetite, actinolite, and epidote are all present in trace amounts.

Biotite

It is observed as coarse to fine, subhedral crystals. Coarse-grained flacks of biotite show pleochroism from dark pale greenish, yellow to brown and dark brownish yellow. The parallel orientation of biotite defines the schistosity of foliation. Biotites are crystallized in two generations. The biotite of the first generation is characterized by xenoblasts. The biotite of the first generation is characterized by brown to dark brown pleochroism. In contrast, the biotite of the second generation is light yellowish green to dark greenish brown and occurs as subidioblastic crystals. Inclusions of hornblende and quartz are present. Pleochroic haloes are present in biotite crystals.

K-feldspar

In many places, orthoclase is altered and forms sericite minerals. Orthoclase is in a hair-like structure and has developed the irregular stringers of sodium-rich feldspar and potassium-rich feldspar. The subhedral to anhedral crystals of orthoclase contain the inclusion of hornblende and magnetite.

Microcline

Medium to fine-grained crystals of microcline is present in grey granite rock. They are the least predominant mineral constituents of this granitic rock. They are differentiated on the basis of cross-hatched twinning. Microcline minerals are euhedral to anhedral in shape crystals, but some alteration from orthoclase through microcliniation is also recorded.

Magnetite

Medium to fine-grained crystals of megnatite is present in aeuhedral shape. Magnetite is included in the hornblende and orthoclase crystals.

Hornblende

Hornblende crystals are coarse-grained and strongly pleochroic (paleogreen to straw yellow or greenish below in colour). Magnetite crystals are present in the form of inclusions. Two sets of cleavage are present in the hornblende crystals. The hornblende minerals are one accessory mineral, usually present in xenoblastic form and associated with biotite and magnetite in the matrix of quartz.

Quartz

Medium-to fine-grained crystals of quartz are present in the grey granite. The coarse-grained crystals of quartz are arranged along the foliation plane. It shows the wave extension. Magnetite crystals are included in quartz crystals.

(iii) Pink granite

Coarse-grained pink granite is one of the most dominant rock types in the study area. Pink granite is usually compact and massive. The pink granite rock contains pink feldspar crystals and grey-coloured plagioclase crystals. NE-SW trending pegmatite veins have been found intrusive in the pink granite, devoid of muscovites but containing biotite coarse-grained (20cm x 15cm size), feldspar crystal, and quartz (10cm x 5.5cm size). The deformed pink granite rock comprises epidote as a vein. The medium to coarse-grained pink granite in places contains porphyroblast of hornblende and feldspar. The pink granite is also characterized by perthite and myrmekite textures. Sphene is a very common mineral and is present in large amounts. Magnetite crystals are found to develop along the cleavages of hornblende crystals. The pink granite consists of potash feldspar, perthite, quartz, hornblende, magnetite, sphere, rutile, hercynite, zircon, allanite, chlorite, epidote, and apatite. The biotite mineral is not common in the pink granite of Mahoba. Hornblende is consistently found to be more abundant than biotite.The microcline is greater than the orthoclase.

Hornblende

The coarse-grained hornblende shows strong pleochroism (pale green to strong yellow or greenish-blue in colour). The medium-grained hornblende contains more magnetite crystals. The core part of the hornblende contains small granules of magnetite. Sometimes, hornblende alteration into chlorite has been noted. Augite crystal is surrounded by hornblende. A xenoblastic type texture of hornblende is also pointed out in a few granites where biotite and hornblende are both found as inclusions in coarse crystals of hornblende.

Chlorite

The chlorite is medium to coarse-grained, light green in colour, and usually intermingled with biotite. Fine-grained magnetite is present along the prismatic cleavage of the chlorite. In thin sections, it usually appears pale green and pleochroic.

Biotite

Biotite is not very common and low in comparison to hornblende. Most of the biotite crystals are oxidized forms. The exsolved texture of biotite is very common. The biotite crystals are altered and form the chlorite mineral. Magnetite crystals can be found at the cleavages of biotite crystals.

Quartz

The quartz is euhedral to anhedral in shape, colourless in thin sections, and characterized by first-order grey interference colour. The crystal shows a straight extension. They are coarse to medium-grained in thin sections.

Orthoclase

Orthoclase minerals are medium to coarse-grained and one of the dominating minerals in this rock. They are colourless, low-relief minerals. Orthoclase minerals are euhedral to anhedral in shape. Orthoclase minerals show how the hair-like structure and perthitic texture are formed.

Microcline

Microcline is one of the essential assecceory minerals of the pink granite rock. These minerals are colourless in thin sections and euhedral to anhedral in pink granite. Low relief minerals and no cleavage in the microcline are visible. The characteristic feature of this mineral is cross-hatched twinning.

Plagioclase

They are colourless in thin sections and euhedral to anhedral in shape. Plagioclase crystal shows the lamellar twinning. Plagioclase minerals contain the inclusion of biotite, magnetite, and hornblende minerals. The plagioclase lamellae are very thin. The interference colour is mostly first-order grey in plagioclase.

Magnetite

Magnetites are present in the form of inclusions as well as parallel to the cleavage. Magnetites are opaque, euhedral to anhedral shape, and medium to fine-grained in a thin section. Magnetite is formed around the reaction rim of biotite crystals.

Zircon

Zircon is only present in biotite minerals in the form of pleochroic haloes. But in many places, large crystals of zircon are also found.

Ilmenite

In the thin section, ilmenite is anhedral with a long rectangular outline and a deep red colour. In some places, ilmenite is altered and forms leucoxene. Leucoxcene is a fine-grained aggregate.

4.4.5 Quartz Reef

The NE-SW trending quartz reef is the most spectacular landmark geological feature massif in the Bundelkhand. In many places, quartz reef cuts across the granitoids and gneiss rock in the study area. In many places, the quartz reef is sinistrally displaced. The two sets of joints and tension joints are present, reflecting the quartz reef's late tectonic activity. Quartz reefs are predominantly greyish white, but pinky white and milky white reefs are also present. They are complex, compact, and massive. A series of milky white secondary quartz veins traverse the quartz reef's greater part. Under the microscope, the quartz reef represents the very coarse grains of quartz and feldspar. The quartz reef shows the varied texture and large rectangular grains of quartz with straight borders and undulose extinction. Feldspar, magnetite, and chlorite are also observed in thin sections of quartz reef. Epidote veins are also observed in the thin section of the quartz reef. The microcline is medium to coarse-grained, colourless to cross-hatched twinning is common, and altered to fresh in thin sections. Quartz crystals and series are common inclusions in microcline minerals. Quartz, sericite, and opaque are present along the fracture plane.

4.4.6 Dolerite Dykes

The ENE-WSW trending Great Mahoba dyke passes through Mahoba town about 11 km in length. A dolerite dyke is also exposed at Thana. Megascopically, dolerite is dark green or melanocratic in colour, hard and compact. In the hand specimen, prismatic crystals of pyroxene and orthopyroxene can be identified, but greyish white leucocratic bands and streaks (patches) of feldspar can also be seen. The sub-ophitic texture is common in most coarse and medium-grained varieties of dolerite dykes. Pyroxene, orthopyroxene (hypersthene), clinopyroxene (augite), and plagioclase feldspar are essential, while magnetite and hornblende are present as secondary. The secondary minerals are mostly epidote quartz and chlorite in the dolerite dyke.

Clinopyroxene (augite)

Augite crystals are euhedral to anhedral to anhedral in shape. It shows light green, colourless and short prismatic crystals. Augite crystal gives high relief, second order interference colour, and a high extension angle mineral. In many places, the plagioclase (labradorite) crystals are embedded in the augite crystal. They form the ophitic texture. According to the thin section of dolerite dyke, the clinopyroxene crystals are less altered than plagioclase crystals.

Plagioclase

Plagioclase is colourless and is observed as long as laths of euhedral to anhedralcrystals. The anhedral crystal is often large as compared with those of other plagioclase. It shows the polysynthetic twinning and low relief and also shows the higher extinction angle. The labradorite crystal is embedded in clinopyroxene crystals. The plagioclase grains are twinned.

Magnetite

Magnetite crystals are dark black in colour and coarse to medium-grained in thin sections. The magnetite crystals are found along the cleavage plane of pyroxene crystals.

Epidote

It is present as the secondary product which is formed by the saussoricitisation of plagioclase feldspar minerals. It is observed as granular aggregates. The epidote mineral is a mineral of high relief, colourless in plane-polarized light, but under cross nicol, the epidote minerals show second order interference colour.

4.4.7 Mylonitised Rocks

Recrystallizedprotomylonites, ultra-mylonites, and myloniterocks have been observed in many places. Nauranga and Chando are near the BijanagarSagar dam. The well-developed S-C mylonite is present in the pink granite rock where basic rock emplaces along the E-W trending dolerite rock. They have been found to be medium to fine-grained, but a coarse-grained variety has also been observed at places. These rocks have diverse physical appearances, textures, and mineral compositions. Four types of deformed mylonites have been observed in the Mahoba area: (1) protomylonites, (2) ultramylonites, (3) mylonite, and (4) phyllonites. Megascopically, they show medium to fine-grained where quartzofeldspathic masses of quartz, feldspar, and flakes have developed and rotated. Mesoscopic shear has also developed in mylonite and ultramylonite. The following mineral assemblages have been identified:

Chlorite

Chlorite is medium to fine-grained, xenoblastic to subhedral in the mylonite. The elongated scalar crystals of chlorite are weakly pleochroic. The chlorite is light green in thin sections due to the alteration of hornblende. Medium-grained garnet has been found in the matrix of chlorite.

Actinolite

Actinolite crystals are fine-grained and light green. Fibrous aggregates of actinolite are generally oriented in the schistosity plane.

Quartz

Quartz is medium to coarse-grained crystals, anhedral but elongated in thin sections. Quartz crystals are colourless, have low relief, no cleavage, and are highly elongated. They are present in thin sections of quartz crystals. The aggregates of quartz crystals are observed around the mylonite planes. They have commonly shown undulose extinction due to the higher strain effects. Coarse-grained crystallized crystals of quartz are observed in thin sections of mylonite rocks, which show ribbon texture.

Orthoclase (K-feldspar)

Mostly euhedral to anhedral elongated and fractured, medium to coarse-grained crystals of orthoclase and microcline are present in thin sections of mylonitic rock. Both orthoclase microcline minerals are colourless and low relief minerals in thin sections. In the thin section of the orthoclase crystals in many places, the phenocrysts of orthoclase are rotated, which indicates the sense of shear.

Plagioclase

It is observed as a medium to fine-grained crystal. In many places, magnetite crystals are embedded in the plagioclase crystals. Plagioclase crystals are present as lamellae that are very thick and thin. The thin lamellae of plagioclase defined the development of albite crystals.