CHAPTER - 4

PETROGRAPHY

4.1 Introduction

Petrography is the most effective primary tool and direct method to characterize the nature of magma's final product, which is reflected in a specific mineral assemblage of igneous rocks as a result of crystallization. Textural features differentiate the major rock-types into igneous, metamorphic and sedimentary ones but play a crucial role while determining the geochemical behaviour and physico-chemical environments of rocks. Photomicrograph and reaction texture play a crucial role in metamorphic petrology. Pressure and temperature conditions affect the pre-existing mineral assemblages, and accordingly, it is known as prograde and retrograde metamorphic conditions. Protolith represents the parent rock, which existed before metamorphism. Metamorphic rocks preserve the original texture in low-grade facies and determine potential protoliths. As the metamorphic grade increases, the original texture is replaced with the metamorphic textures. Igneous rocks are formed by the differentiation processes (crystallization, fractionation, mixing, and assimilation) during a liquid or magma cooling. Petrography includes megascopic and microscopic observations which can reveal the involved magmatic processes and nature of melt composition based on the mineral assemblages, mineral size, shape and their cumulus and intercumulus proportions etc. A crystal or mineral developed through the first nucleation at liquidus, followed by diffusion of elements and growth rates that depend upon compositions, prevailing physical conditions of magma such as fugacity, pressure, temperature, nature of emplacement (intrusive or extrusive) and type of protolith for generating these melts.

The petrographic observations of mafic granulites and pelitic granulites collected from Betul Belt of Central Indian Tectpnic Zone (CITZ) have been documented in order to establish P-T conditions and metamorphic evolutionary history. Further electron probe microanalyses (EPMA) of silicate minerals constituting these granulites have been carried out from the representative samples of studied lithotypes, which usually help deciphering mineral-chemical evolution, classification, elemental substitution relationships, P-T estimation for exchange reaction on equilibrium condition, multistage of metamorphism condition recognized by zoning minerals, and oxygen fugacity determined by the ilmenite-magnetite association.

4.2 Petrography

The detailed petrographic characters of different rock types are described, emphasizing their mineral associations' textural characteristics and reaction relationship from the study area. The textural characteristics have been made to decipher the time relationships between crystallization and the different deformation phases. The structural characters indicates that the supracrustal rocks have undergone deformation as a result of three distinct periods.

(1) The initial generation structures (D1) are characterised by folds that range from isoclinal to reclined in nature.

(2) The subsequent generation folds (D2) exhibit a tight to isoclinal configuration, with an orientation that varies from upright to inclined. These folds define the regional tectonic trend of the belt, which runs in an ENE–WSW direction.

(3) The D2 structures have undergone additional folding (D3) that has resulted in the development of broad, open folds oriented in a north-south direction.

Most deformed metamorphic rocks are characterized by preferred orientation. The relationship between S_i and S_e is not well documented in granulite facies of rocks due to crystallization during post kinematics phase after deformation compared to those from the lower grade greenschist and amphibolite facies. However, the study area's granulites have undergone multiple deformation and poly-metamorphism. The rocks of the studied areas exhibit tremendous metamorphic reaction textures that participate in the formation of various mineral assemblages and are documented by various reaction corona and symplectites intergrowth. Here, it is defined that high-grade granulites hold strong refractory mineral phases such as garnet, orthopyroxene, clinopyroxene, amphibole, plagioclase, sillimanite, and cordierite. That is competent to retain evolutionary history signatures through "arrested" and "frozen-in" textures. It is strongly felt that disequilibrium textures in rocks are more promising contestants for detailed petrological examinations. The metamorphic textures retained in high-grade rocks exert fine control in deducing orogenic P-T path. Therefore, critical investigation of such textural features preserving P-T path segments' signatures can be highly advantageous.

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 such minerals like garnet, biotite, cordierite, plagioclase, clinopyroxene, orthopyroxene, K-feldspar, quartz etc. A thin section of rock chips is prepared for petrographic investigation with a microscope; a standard thickness of the slide is approximate 0.035 mm. For thin section preparation, thin rock chips are pasted with a glass slide and grinding with the carborundum powder until a thin layer of rock.

4.3.1 Introduction

In addition to possessing a high-quality microscope and its accompanying accessories, a well-prepared and meticulously polished rock sample stands as the primary necessity for conducting fruitful mineralogical investigations. This occupation has significant complexity and specialization, particularly when dealing with minerals such as garnet, biotite, cordierite, plagioclase, clinopyroxene, orthopyroxene, K-feldspar, quartz, and others. In order to conduct petrographic analysis using a microscope, a slender portion of rock fragments is meticulously produced. The slide utilized for this purpose adheres to a conventional thickness of approximately 0.03548 mm. In the process of thin section preparation, thin rock chips are affixed onto a glass slide and subsequently ground using carborundum powder until a thin layer of rock is achieved.

4.3.2 Method

Firstly, colour, grain size and texture are seen in natural light for rock samples. After that, 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. The practical experience of the present author and the literature dealing with the preparation of polished rock samples show that the attitude of individual minerals and their associates in the course of polishing is not uniform. For different minerals and their associates, different techniques are taken into consideration. The classical polishing on a billiard table cloth may be superior for specimens containing minerals with many cracks, but they should be near the same hardness. The final polishing is done manually on a grinder pitch; it gives excellent results but is time-consuming.

In recent years, the quality of polished sections has improved since the material used for impregnation has been replaced more and more by plastics. One of the most efficient methods to have an excellent finish in the last stage of polishing rock samples, particularly for such opaques having more hardness are to use diamond power plates of different grain sizes. Synthetic diamond is made of fine round octahedral crystal of the same size, different from the powdered natural material. Likewise, synthetic alumina was also found useful for obtaining better results.

After cutting the appropriate pieces of rock samples, now these rock chips are grinded on a rotating lap (850 rpm) using silicon carbide (SiC) powder of 120 mesh size for 20 minutes with the addition of few droplets of water. The above step is repeated with 220 mesh size powders, and then good quality of mineral grain boundary is observed. Afterwards, 600 and 800 mesh size powders are used to polish on glass plate. The sample is then mounted on glass slide with the help of Araldite (resin & hardener); oblique angle pressure is applied to the chips against glass slide to eliminate air bubbles. A petro-thin machine is further used to minimize the chips' thickness and reduce the grinding time, and the rock slide is again grinded on a glass plate using silicon carbide powder (600, 800 & 1000 mesh sizes) until the thickness is attained to 0.035 mm.

The samples are then prepared for polishing by alumina gel or synthetic diamond on the cloth. Two precautions are taken into consideration at the time of polishing. Firstly while changing the section form one plate to the other, the thin section is thoroughly washed to avoid contaminations and secondary the sample is put on the lap and rotated in a circular mode opposite to the rotation of the lap and uniform light pressure is applied while doing the final diamond polishing. The time for the individual polishing section varies from 10 to 30 minutes, depending upon the hardness of minerals.

4.4 Petrography of the thin section

The petrographic study has 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 used to petrographic studies. These are some rocks find out under field investigation. Now, the megascopic and microscopic characteristics of the collected rock samples are described under the following heading:-

1. Granite Gneiss
2. Mafic and ultramafic intrusive
3. Mafic Granulite
4. Pelitic Granulite
5. Intrusive granite

4.4.1 Granite Gneiss

Granite gneisses are medium to fine grained in nature. The individual grains are interlocked in each other such that the grain boundaries of each grain are fused together. Quartz and plagioclase feldspar are subhedral to anhedral in appearance. Quartz grains also exhibit dynamic recrystallization patterns and grain boundary migration patterns. In general, the rock does not show signs of foliation in thin sections (Fig 4.1).

Granitic gneiss is dominantly composed of felsic minerals such as quartz and feldspar but, the proportion of the plagioclase feldspar is more than alkali feldspar. Other mineral phases include muscovite mica, biotite mica and chlorite. Occasionally, the rocks also contain iron rich chlorite which appears as blue colour in cross polars.

Structurally, the granite gneisses are deformed and fractured. The fracture types observed are intergranular, intragranular and transgranular fractures which can be observed truncating the fabric of the rock. In many thin sections, it is observed that the fractures are filled with secondary minerals such as quartz or chlorite (Fig 4.1). Apart from this, shearing in the fabric of the rock is also common deformation signature observed. Another feature associated with rock deformation is the presence of distortion in the twin planes of plagioclase. By the textural relation, it is evident that, the deformation features are of post dynamic or post kinematic type i.e. they have been formed after the formation of the rock. This rock suffered metamorphism and tectonism which is reflected in its obliterated mineralogy and texture in the form of deformation signatures.

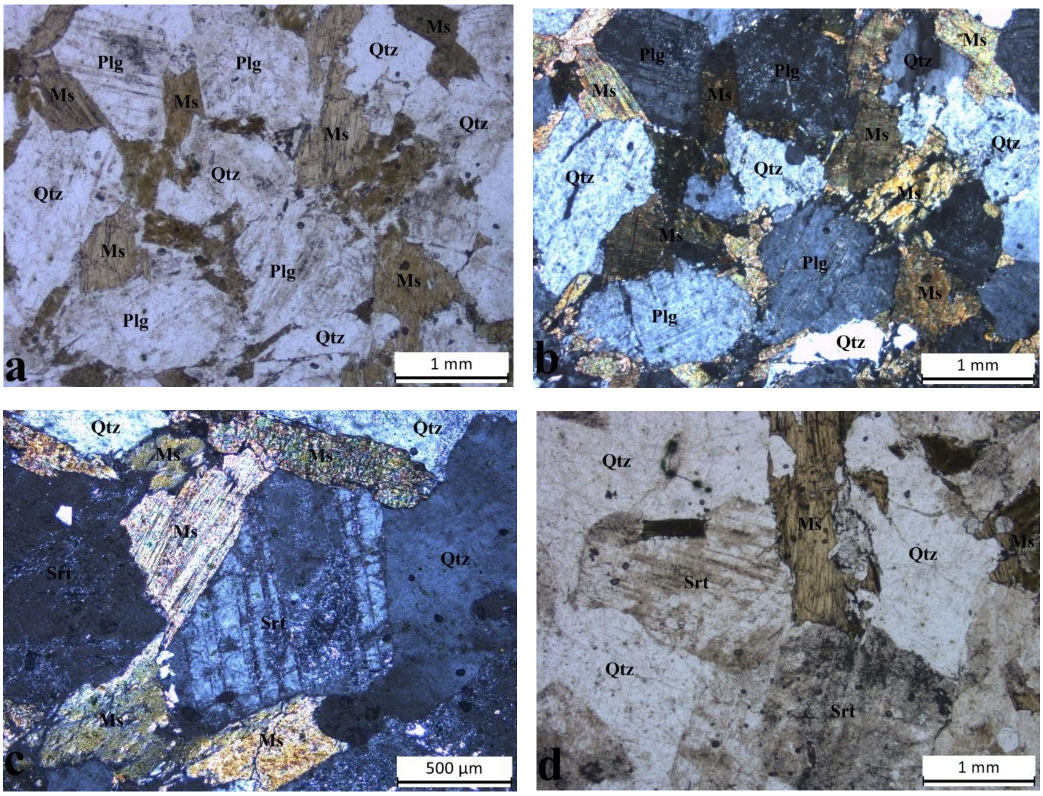

Figure 4.1 (a) Photomicrograph of the granite gneisses from Betul Belt showing coexisting mineral phase quartz, plagioclase muscovite in PPL. (b) Photomicrograph of coexisting mineral phases in XP. (c) Photomicrograph showing coexistence of altered mineral plagioclase within granite gneiss in XP. (d) Photomicrograph showing coexistence of altered mineral plagioclase within granite gneiss in PPL.

4.4.2 Mafic and ultramafic intrusive

The predominant composition of the intrusive rocks consists primarily of mafic and ultramafic varieties, including pyroxenite, olivine websterite, and various forms of gabbro exhibiting equigranular, poikilitic, and cumulate textures. These rocks contain a variety of minerals, including olivine, clinopyroxene, orthopyroxene, plagioclase, phlogopite, magnetite, ilmenite, and chromite, which are present in different amounts. Hornblende gabbro is mostly composed of hornblende (30-40%), pyroxene (20-30%), plagioclase (25-35%), with modest amounts of biotite (~5%) and quartz (1-2%). In this context, the substitution of pyroxenes and plagioclase by hornblende, as well as the presence of magnetite as an inclusion phase, can be observed. Diorite is composed of plagioclase, hornblende, and clinopyroxene minerals, and exhibits intergranular intergrowth of plagioclase and clinopyroxene.

The pyroxenites have suffered uralitisation and chloritisation due to which the grain boundaries seem to be corroded. Quartz in these rocks forms a minor phase and also occurs as inclusions within the pyroxene grains.

4.4.3 Mafic granulites

4.4.3.1 Two pyroxene granulites

The granulites found in the Chicholi area consist of two types of pyroxene minerals. These granulites exhibit a colour range from dark grey to greyish black and possess a medium to coarse-grained texture. The rock displays a granoblastic/granulitic texture characterised by a granular mosaic composed of orthopyroxene, clinopyroxene, hornblende, and plagioclase minerals. Biotite is observed in a limited number of thin sections, displaying a subtle foliation. The two pyroxene granulites exhibit the following mineral assemblage: The mineral assemblage consists of orthopyroxene, clinopyroxene, hornblende, plagioclase, biotite, and quartz (Fig 4.2).

Hornblende

Hornblende exhibits significant pleochroism, displaying a range of colours including green, yellowish-green, bluish-green, dark green, and greenish-brown. The pleochroic coloration observed in hornblende exhibits variation in response to alterations in its chemical composition. Hornblende can be classified into two distinct generations, namely hornblende1 and hornblende2. The first generation, hornblende1, exhibits signs of corrosion and is found as an inclusion within orthopyroxene. This occurrence provides evidence for the decomposition of hornblende1 in the presence of quartz, resulting in the formation of two pyroxenes. Hornblende2 is typically generated during the latter phase of pyroxene retrogression. (Fig 4.2 b and c).

Orthopyroxene

Orthopyroxene is hypersthene which exhibits a colourless to pale green hue, displays minimal pleochroism, and possesses sub-idioblastic to idioblastic grain morphology. Hypersthene has a modest degree of birefringence when observed under polarised light, resulting in first-order interference colour. It also demonstrates parallel extinction when viewed under crossed nicols using a petrological microscope (see Figure 4.2 b and c).

The orthopyroxene mineral exhibits the presence of corroded hornblende (Hbl1) and quartz inclusions, indicating a prograde reaction.

hornblende1 +quartz =orthopyroxene + clinopyroxene+ plagioclase +H_2O (1)

At some places, orthopyroxene is also partially encircled by hornblende2 (figure 2c), which shows a retrograde reaction as:

Orthopyroxene+ clinopyroxene +plagioclase +H_2O =hornblende2 +quartz (2)

Orthopyroxene also rims flakes of biotite along with quartz inclusions (figure 2d), which indicates a prograde reaction as:

Biotite+ quartz =orthopyroxene + alkali feldspar+ vapour (3)

Clinopyroxene

Clinopyroxene is diopside. It is colourless to pale yellow, slightly pleochroic and shows inclined extinction. Reaction (1) can also be evidenced by the occurrence of inclusions of hornblende and plagioclase in clinopyroxene.

Plagioclase

It occurs as a medium to coarse-grained, idioblastic to sub-idioblastic aggregate. The myrmekitic and symplectitic intergrowth are common. The plagioclase shows undulose extinction and deformed twinned lamellae, which provide the signature of postcrystalline deformation (Fig 4.2 d). Plagioclase contains inclusions of orthopyroxene and clinopyroxene. Some porphyroblast of plagioclase contains hornblende, pyroxene, quartz, and ilmenite inclusions in a single grain, thus showing the poikiloblastic texture.

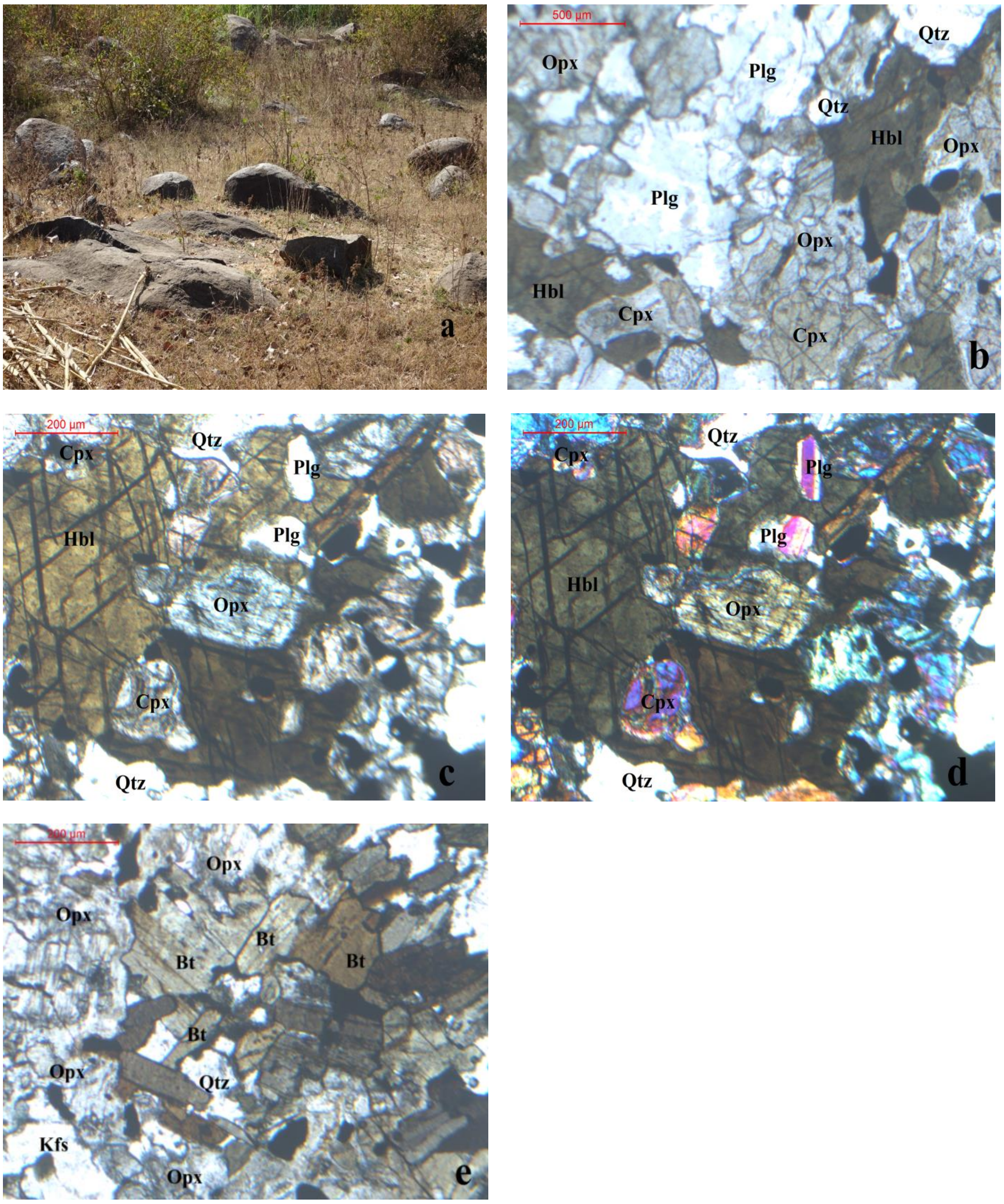

Figure 4.2 (a) Photograph of the two-pyroxene granulites in field which occur in the form of patches. (b) Photomicrograph of coexisting mineral phases in orthopyroxene coexisting with clinopyroxene and plagioclase contain inclusions of corroded hornblende and quartz under plane-polarised light. (c) Photomicrograph shows the inclusions of orthopyroxene, clinopyroxene and plagioclase in hornblende coexisting with quartz (plane-polarised light). (d) Photomicrograph of coexisting mineral phases shows inclusions of biotite and quartz in orthopyroxene under plane-polarised light. Where, Opx = orthopyroxene; Cpx = clinopyroxene, Hbl = hornblende, Plag = plagioclase, Bt = biotite, Kfs = alkali-feldspar and Qz = quartz [67].

Quartz

It commonly occurs as equant xenoblasts showing wavy extinctions, indicatingpost-crystalline deformation. Coarse-grained quartz which does not show wavy extinction indicates its crystallization when all the deformation ceased. It occurs in lesser amounts. The fine-grained granular aggregate of quartz occurs along grain border.

Minor Constituents

These include quartz, K-feldspar, magnetite, ilmenite, apatite, zircon, etc. Magnetite sometimes occurs as coarse-grained crystals of irregular shape along the interstices of quartz-plagioclase mosaic. Inclusions of quartz, plagioclase, diopside, biotite, hypersthene etc. have been identified within coarse magnetite. Some of them coarse magnetite grain overprint the matrix's foliated fabric and contain linear trails of biotite (S1) merging with the matrix's foliation (Se).

4.4.3.2 Garnet pyroxene mafic granulites

The garnet-bearing mafic granulite reveals that it contains mafic minerals; garnet, clinopyroxene, orthopyroxene, plagioclase, ilmenite, and quartz. The amphibole is absent (Fig.4.3a and b).

Mineral assemblage

Orthopyroxene-clinopyroxene-garnet-plagioclase

Orthopyroxene-clinopyroxene-plagioclase-garnet-quartz

Clinopyroxene-orthopyroxene-garnet-quartz

Garnet

It occurs as course to fine-grained xenoblastic crystals. Inclusion of quartz, magnetite, clinopyroxene, and plagioclase are present in garnet. It rarely occurs in mafic granulite in the assemblage garnet-clinopyroxene-orthopyroxene plagioclase- quartz. They are always present in sporadic amount and occur characteristically as small to medium xenoblasts with a dodecahedral outline. The aggregates of garnets and clinopyroxene are ubiquitously rimmed by a thick corona of symplectic plagioclase + orthopyroxene showing prograde reaction as:

Clinopyroxene+ garnet + quartz= orthopyroxene+ plagioclase (1)

Orthopyroxene

It is pleochroic; X = yellow, Y = pink, Z = green, X<Y<Z. The mineral is commonly observed in the form of subidioblastic to xenoblastic grains, and in some instances, it is present as idioblastic crystals (Fig.4.3 a-d). Orthopyroxene porphyroblast is poikiloblastic with inclusions of garnet and clinopyroxene (Fig.4.3 c and d). At some places, garnet and clinopyroxene is commonly rimmed by aggregates of orthopyroxene and plagioclase. The textural relations described above provide the evidence of the reaction (1) i.e.

Clinopyroxene+ garnet + quartz= orthopyroxene+ plagioclase

Clinopyroxene

The crystals exhibit a range of colours from colourless to light green, and possess a medium-grained prismatic structure. The crystal structure can be described as sub-idioblastic to idioblastic (Fig.4.3 c and d). Coarse clinopyroxene is poikiloblastic occurring as inclusions within aggregates of orthopyroxene and plagioclase (Fig.4.3 c and d). Clinopyroxene is rimmed entirely or partially by orthopyroxene and garnet aggregates, which suggests retrograde reaction.

Plagioclase

It occurs as a medium to coarse-grained, idioblastic to sub-idioblastic aggregate. The myrmekitic and symplectitic intergrowth are common. The plagioclase shows undulose extinction and deformed twinned lamellae, which provide the signature of postcrystalline deformation. Plagioclase occurs in association with orthopyroxene and clinopyroxene. Some porphyroblast of plagioclase contains hornblende, pyroxene, quartz, and ilmenite inclusions in a single grain, thus showing the poikiloblastic texture.

Quartz

It commonly occurs as equant xenoblasts showing wavy extinctions, indicating post-crystalline deformation. Quartz with a coarse grain size that lacks wavy extinction is indicative of its crystallisation occurring after the cessation of all deformation processes. It occurs in lesser amounts. The fine-grained granular aggregate of quartz occurs along grain border.

Minor Constituents

These include quartz, K-feldspar, magnetite, ilmenite, apatite, zircon, etc. Magnetite sometimes occurs as coarse-grained crystals of irregular shape along the interstices of quartz-plagioclase mosaic. Inclusions of quartz, plagioclase, diopside, biotite, hypersthene etc. have been identified within coarse magnetite. Some of them coarse magnetite grain overprint the matrix's foliated fabric and contain linear trails of biotite (S1) merging with the matrix's foliation (Se).

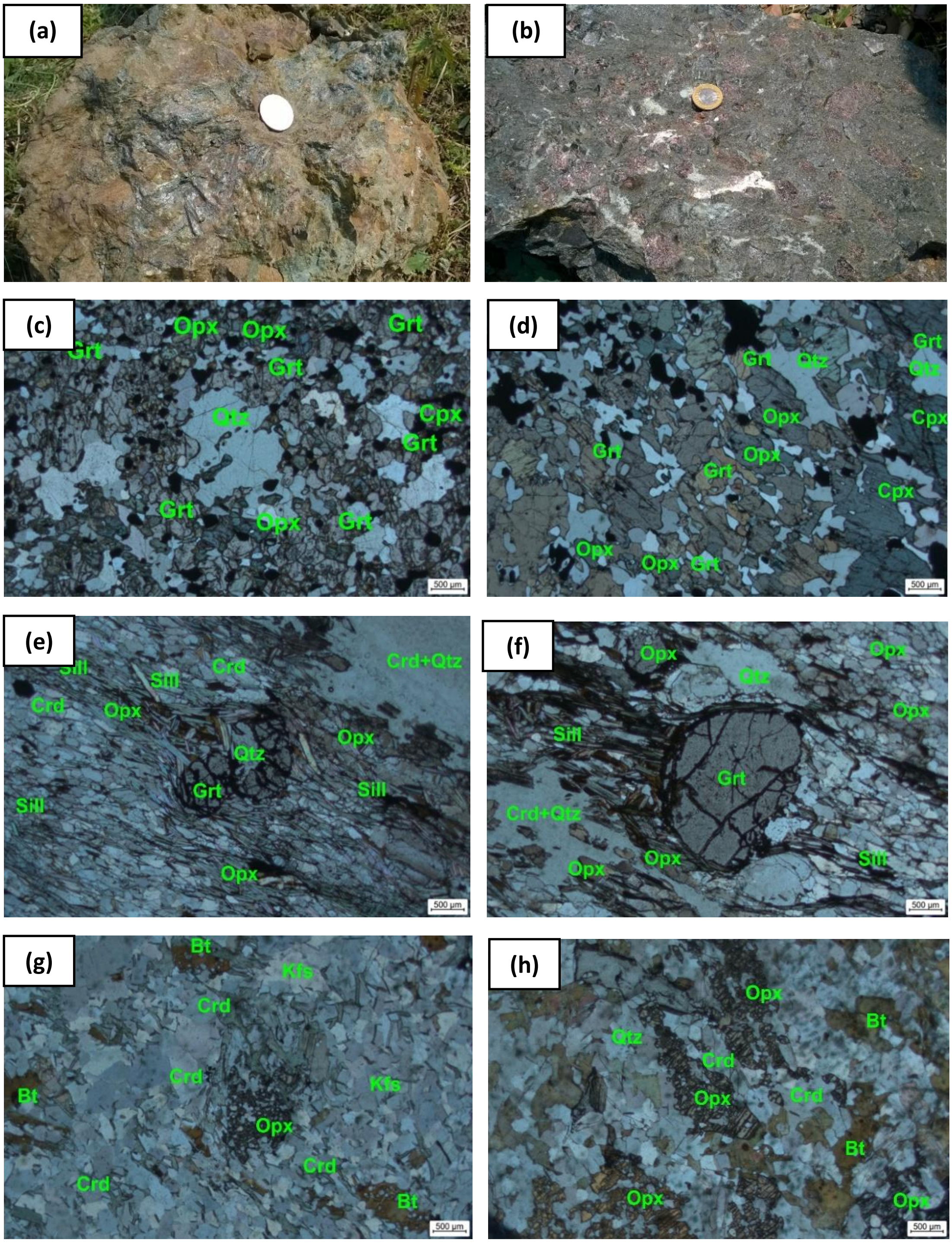

Figure 4.3 (a) Outcrop photograph of pelitic granulite. (b) Outcrop photograph of garnet bearing mafic granulite (c) and (d) Photomicrographs of garnet bearing mafic granulites showing association of garnet opx, cpx, plagioclase. (e) and (f) Photomicrographs showing garnet bearing pelitic granulites showing coexisting mineral phases of garnet, cordierite and opx. (g) and (h) Photomicrographs showing pelitic granulites without garnets showing coexisting mineral phases of opx, cordierite, biotite and quartz.

4.4.4 Pelitic granulite

The pelitic granulites are defined by preferred oriented fabric formed by the structural arrangements of inequidimensional minerals. They are defined by closely spaced foliation defined by alignment of flakes of biotite and orthopyroxene within the mosaic of garnet cordierite and quartz. Pelitic granulites contain medium to large garnet with rounded to subhedral grains (Fig 4.3 c and d).

Mineral assemblages

Garnet-orthopyroxene-cordierite± sillimanite
Garnet- orthopyroxene –biotite –quartz ±sillimanite
Orthopyroxene-cordierite-biotite quartz.

Garnet

Garnet grains are characterized by their unique isotropic optical property in polarized light and range in size from 0.1 to 0.6 mm in diameter. They are always present in sporadic amount and occur characteristically as small to medium xenoblasts with a dodecahedral outline. Garnet is wrapped by the mineral aggregates of Orthopyroxene and cordierite forming porphyroblastic texture. It suggests a prograde reaction as:

Garnet+ quartz+ melt = cordierite + orthopyroxene (1)

The fabric shows the post kinematic deformation where the garnets developed prior to development of foliation planes.

Cordierite

Cordierite occurs as granular aggregate rimming xenoblasts of garnet and needles of sillimanite with overprinting the matrix's fabric. The observed textural relationship indicates that the formation of cordierite is a result of the decomposition of garnet in the presence of quartz, implying a chemical interaction. (1). At some places, cordierite occurs as an aggregate with the orthopyroxene (Fig 4.3 e and f) and it is rimmed by the symplectites of biotite and quartz which suggests following reaction:

Cordierite+ orthopyroxene+ K- feldspar+ water = biotite + quartz (2)

Biotite

It shows pleochroism, varying from yellowish-brown to dark brown, most biotite flakes oriented parallel to S2 foliation, whereas few flakes show S3 foliation (Fig.4.3 e and f). Biotite also occurs between the contacts of K-feldspar and cordierite. The lattice gives biotite the preferred alignment of the dominant S2 fabric and is sometimes weakly wrapped around cordierite grains.

Sillimanite

It occurs in fine needles intergrown with biotite and garnet (Fig.4.2e). The majority of sillimanite needles are found as inclusions within the porphyroblasts of garnet, cordierite, and k-feldspar, or as trails within the matrix (Fig.4.2f). The textural relation suggests its crystallization as broadly coeval with biotite.