Chapter -3

PETROGRAPHY
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3.1 INTRODUCTION

Chapter - 3 embodies petrographic mineralogical descriptions and modal analysis of rocks of the study area represented by gneisses of the Peninsular Gneissic Complex (PGC) and Clopet granite equivalent granites of the basement

3.2 PETROGRAPHY- PENINSULAR GNEISSES

The biotite-hornblende bearing quartzo-feldspathic gneiss is the oldest rock type in the study area. These rocks constitute the country rocks into which other rock types have been invaded. These gneissic rocks are distributed throughout the area, specially in the eastern part of Lakkireddipalle and the western part of Chakrayapeta. Amphibolites are the commonest enclaves within the granite gneiss, particularly in the eastern part of the study area. These dark coloured rocks, made up of prismatic crystals of green hornblende, oligoclase-andesine and quartz, show a xenoblastic granular texture. These Peninsular gneisses in places are migmatitic, as in the present study area, with leucosomes (granitic), melanosomes (biotite rich), abundant quartz veins and amphibolitic enclaves.

The gneissic rocks are medium-grained, grey to pink coloured, consisting essentially of quartz, feldspar, biotite and hornblende. They are well foliated; foliation is produced by the parallel arrangement of the flakes of biotite and gneissosity is shown by the alternate layers of quartz feldspar and biotite and hornblende. Veins of pegmatite with variable thickness ranging from a few inches to a few feet are injected into gneisses. These veins are contorted. The pegmatite veins show both conformable and cross-cutting relationship with the foliation of the gneissic rocks.
The granite gneisses are medium grained and somewhat inequigranular and shows granitic texture (Fig.3.2.1). Petrographically, gneisses are composed mainly of quartz, in addition to feldspars, hornblende, epidote and chlorite with minor zircon, sphene and apatite. Quartz and feldspar grains are interlocked showing granoblastic texture. Feldspars are represented mainly by plagioclase and microcline (Fig.3.2.2). Plagioclase crystals are occasionally sericitised (Fig.3.2.3). Microline forms subidioblastic to xenoblastic short tabular prismatic and poikiloblastic grains and shows cross-hatched twinning. Epidote and chlorite are secondary phases found mostly filling veins, replacing plagioclase and mafic minerals (Fig.3.2.3 & 3.2.4). Sphene (Fig.3.2.5) occurs as idioblastic, elongated grains and is feebly pleochroic. It shows high refractive index and occurs as inclusion within feldspar. Zircon (Fig.3.2.6) is found as pale yellow to pale brown euhedral prismatic crystals. Metamict zircon grains are common and zoned varieties are occasionally present reflecting an overgrowth during metasomatism. Apatite grains are idioblastic to subidioblastic prismatic elliptical and show high refractive index. It occurs as inclusion within feldspar (Fig.3.2.7). Fractures in plagioclase are filled with quartz in granites (Fig.3.2.8). The xenoliths of amphibolites present in the gneisses are essentially composed of plagioclase and hornblende along with the quartz (Fig.3.2.8, 3.2.9 and 3.2.10). Both plagioclase and hornblende show alterations to epidote and chlorite (Fig.3.2.7a, 3.2.10).
Fig. 3.2.1. Photomicrograph of Granitic texture, Q-quartz, P-plagioclase, E-epidote, C-chlorite Gr1, 2x, TL, XN.

Fig. 3.2.2. Photomicrograph of Granitic texture, Q-quartz, P-plagioclase, M-microcline, E-epidote, Gr2, 2x, TL, XN.
Fig. 3.2.3. Photomicrograph of Plagioclase altering to sericite in granite, Q-quartz, P-plagioclase, S-sericite, E-epidote Gr1, 5x, TL, XN.

Fig. 3.2.4. Photomicrograph of Epidote grains at the contact of quartz and plagioclase in granite P-plagioclase, Q-quartz, E-epidote, 10x, TL, XN.
Fig. 3.2.5. Photomicrograph of Sphene in granite, S- sphene, P- plagioclase, 20x, TL, XN.

Fig. 3.2.6. Photomicrograph of Zoned zircon in granite, Z-zoned zircon, Q-quartz, H-hornblende, 20x, TL, XN.
3.2.7a. Photomicrograph of Alteration of plagioclase to epidote in Granite, P-plagioclase, E-epidote, 20x, TL, XN.

Fig. 3.2.7. Photomicrograph of Apatite in granite, A-apatite, Q-quartz, P-plagioclase, E-epidote, C-chlorite, 20x, TL, 1N.
3.2.8. Photomicrograph of Fractures filled with quartz in plagioclase in granite, P-plagioclase, Q-quartz, C-chlorite, 10x, TL, XN.

Fig.3.2.8a. Photomicrograph showing partial alignment of hornblende and plagioclase in amphibolite. H-hornblende, P-plagioclase, AMP, 2x, TL, XN.
Fig. 3.2.9. Photomicrograph of Sphene grains in association with quartz and hornblende. S-sphene, H-hornblende, Q-quartz, AMP, 10x, TL, XN.

Fig. 3.2.10. Photomicrograph of Biotite, bleached biotite and hornblende in amphibolite B-biotite, Bl-bleached biotite, H-hornblende, AMP, 10x, TL, XN.
3.3. PETROGRAPHY- UNALTERED BASEMENT GRANITES

The granitoids forming the southwestern environs of Cuddapah basin occur as peniplanar, near circular and elongated mounds, hillocks and plutons and considered to be equivalents of Palaeo-Proterozoic Closepet granites. They are emplaced as steep-sided bodies and many of them record relatively high background radioactivity. Megascopically, the rocks are leucocratic, crystalline, medium to coarse-grained and generally gray in colour with restricted occurrence of pink variety. Local development of coarser laths of (phenocrysts) pink feldspar imparts porphyritic texture, at places. Felsic minerals account about 90% of the rock volume and the rest is accounted by accessory to minor abundance of mafic and ore minerals. Petromineralogical studies of these granitoids were carried out to establish textural, mineralogical, deformational and alteration parameters to establish phase difference amongst them.

Microscopically, the granitoids show inequigranular hypidiomorphic texture (Fig.3.3.1 (a) & (b)) with local myrmekitic and perthitic textures. Modal abundance (volume) of quartz varies from 22.2% to 41.80%, alkali feldspar from 16.60%-55.7% and plagioclase from 16.7%-47.30% as major minerals. Biotite is present in accessory to major (<1-3.% by volume) abundance and other minerals, which are present in accessory to minor abundance, include, chlorite (0.2 - 8.9%), muscovite (0.2 -5.8%), epidote 0.1 - 6.6%), opaque ore minerals 0.1-0.5%). When the volume percentages of quartz, alkali feldspar and plagioclase based on the 22 samples spreading from Sundupalle in the east to Chakrayapeta in the west are plotted in QAP diagram (Fig. 3.3.2) of Lemaitre (1989). All the samples fall in the fields of monzogranite, granite and granodiorite. The details of modal analysis (volumetric abundance) of individual minerals are given in the Table-1. Both biotite and muscovite are equally important accessory to major minerals and hence, the rock can be called two-mica granite.
Opaque ore minerals are generally represented by hematite, magnetite (titanomagnetite, at places) and ilmenite. The K-feldspar is represented by microcline, microcline perthite and orthoclase perthite in variable proportions. Most perthite grains are subhedral and elongated and rang up to 15 mm long. Cross hatched twinning of microcline and Carlsbad twinning in orthoclase are well documented. Plagioclase is mostly oligoclase in composition and occurs as medium- to coarse-grained and subhedral to euhedral grains and shows polysynthetic twinning and strong to normal oscillatory zoning. Brittle deformation is recorded by fracturing of some quartz and feldspar grains, at places. Ductile deformation is reflected by occasional distortion and bending in plagioclase twin lamellae (Fig.3.3.3 (a) & (b)). Fractures developed due to later deformations are generally, filled with secondary quartz and chlorite and occasionally by calcite, epidote, sericite and ferruginous material. Some of the feldspar grains are pigmented with dusty coating of hydrous iron oxide. Alteration of constituent minerals is generally mild to moderate but locally intense. Moderate to intense alteration of alkali feldspar to sericite and muscovite is common in majority samples. Saussuritization is well exhibited by some of the plagioclase grains. Mild to intense alteration of plagioclase to epidote and chlorite is significant in some of the plagioclase grains and chloritisation of feldspar is generally reported in alkaline environment. Biotite and muscovite occur, mainly, as interstitial minerals between major rock forming minerals and as irregular bands swirling around quartz and feldspar grain margins (Fig.-3.3.4 (a) & (b)). Though the bulk of biotite is primary, significant amount of muscovite is an alteration product of feldspar and biotite. Allanite is observed as important source of radioactivity and it occurs, along with zircon, as fine- to medium-grained, euhedral inclusions in feldspar with radiation cracks (Fig.3.3.5 (a), (b) & (c)) and in biotite with pleochroic haloes. The pleochroic
haloes are generally formed around the radioactive minerals when they occur in coloured minerals like biotite, chlorite, hornblende etc. due to atomic bombardment. Zircon occurs as euhedral crystals with and without pyramidal terminals, along with apatite, and some of the grains show moderate zoning. Subhedral to euhedral inclusions of sphene, apatite and magnetite can be observed in some of the biotite grains (Fig.3.3.6). Epidote also occurs as primary, in addition to its occurrence as alteration product of feldspar and biotite, and the primary, euhedral and elongated crystals cut primary muscovite, indicating its later formation in the system (Fig.3.3.7). The sequence of crystallization is most probably plagioclase-perthite-quartz. Occurrence of biotite as independent mineral and as inclusions in perthite and quartz suggests that it belongs to two generations, both in early and late phase of magmatic crystallisation. Based on the colour, cleavage and inclusions, the biotite can, broadly, be described to belong to two generations. The biotite with dark green colour, prominent one set of cleavages and inclusions of zircon, allanite and apatite can be ascribed to older generation and the one with relatively paler colour and without cleavages and inclusions can be considered as belonging to younger generation. The chlorite also represents different generations as it occurs as criss-cross bands and fracture fillings (Fig.3.3.8 a & b, 3.3.9a & b and 3.3.10).

Chlorite at places also occurs as major mineral (>1%). It is green in colour, pleochroic with anomalous blue and grey interference colours. Feldspar is altered to chlorite (Fig.3.3.11) and the iron released during the process is present as fracture filling in feldspar along the cleavage planes. Released iron also forms a coating on the grains and due to this the feldspars are orange to pink in colour in hand specimen. Two types of chlorite are present. One with blue to mauve coloured interference colour and the other with yellowish brown interference colour. Blue variety is iron
rich whereas the other is magnesium rich chlorite. Chlorite with titanate occupy interstitial spaces along with fracture filling in biotite, muscovite and feldspars (Fig. 3.3.12 a & b)).

Apatite is a widespread accessory mineral in the granites of the study area. They are euhedral to subhedral and typically small (50–150 µm), transparent, mostly colorless but some grains show light yellowish to greenish colors. Apatite is associated with microcline, plagioclase and chlorite (Fig. 3.3.13 a,b & c). Zircon is the dominant accessory mineral, occurs mostly as euhedral crystals less than 1mm in diameter. It is associated as inclusions in feldspar (Fig. 3.3.14 & 3.3.15), perthite, chlorite (Fig. 3.3.16) and biotite Euhedral to subhedral opaques and sphene are the other accessories. Magnetite is found associated with biotite and also along the cleavage planes, probably due to release of iron during bleaching. Some minor amount of titanomagnetite is also noted. Apatite is eu-subhedral; an early-crystallizing phase often associated with biotite.
Fig- 3.3.1(a). Photomicrograph of inequigranular hypidiomorphic texture in Granite of Mulapalle area. Q-quartz, F- feldspar. 20x, TL, XN.

Fig- 3.3.1(b). Photomicrograph of inequigranular hypidiomorphic texture in Granite, Mulapalle area. Q-quartz, P-Plagioclase feldspar. M=Microcline, S=sericite, 20x, TL, XN.
Fig- 3.3.2. QAP diagram (after Lemaitre 1989) for the basement granite of the study area. Note that samples fall within Monzogranite (3a), granite (3b) and granodiorite (4) field.
Fig-3.3.3(a). Photomicrograph of Deformed plagioclase lamellae in granite from Chakrayapeta, 20x, TL, XN.

Fig.-3.3.3(b). Photomicrograph of Deformed lamellae of plagioclase in granite from Burjupalle. 20x, TL, XN.
Fig.-3.3.4(a). Photomicrograph of muscovite (M) as interstitial to feldspar (F) 10X, TL, XN Chakrayapeta area.

Fig.-3.3.4(b). Photomicrograph of muscovite (M) swirling around Quartz (Q) and feldspar (F), 10X, TL, XN.
Fig.-3.3.5(a). Photomicrograph of yellowish brown coloured allanite (A) in granite of Chakrayapeta, 20X, TL, 1N.

Fig.- 3.3.5(b). Photomicrograph of allanite (A) with radiation cracks in granite, Timmareddigarpalle area 10x, TL, 1N.

Fig.3.3.5(c). Photomicrograph of sphene(S), zircon(Z) with pleochroic halo and chlorite(C) in granite, Mulapalle area, magnified view, 20x. TL. XN.
Fig. 3.3.6. Photomicrograph of sphene (S), apatite (A) and magnetite (M) inclusions in biotite of granite, Mulapalle area, 20x, TL, XN.

Fig. 3.3.7. Photomicrograph of epidote cutting across muscovite in granite, Mulapalle area 20x, TL, XN.
Fig- 3.3.8a. Photomicrograph of two generations of chlorite in granite of Burjupalle area, 20X, TL, 1N.

Fig-3.3.8b. Photomicrograph of two generations of chlorite in granite of Burjupalle area 20X, TL, XN.
Fig- 3.3.9a. Photomicrograph of Chlorite (C) in between quartz grains in granite of Burjupalle area 10X, TL, 1N.

Fig- 3.3.9b. Photomicrograph of Chlorite in between quartz grains in granite Burjupalle, 10X, TL, XN.
3.3.10. Photomicrograph showing chloritization (C) of biotite (B) in granites of Chakrayapeta area, 5x, TL, 1N.

Fig-3.3.11. Photomicrograph Fe and Mg varieties of chlorite & development of muscovite at the grain margin of feldspar in granite, 20x, TL, XN.
Fig-3.3.12a. Photomicrograph of Chlorite(C), titanate (t) and muscovite (m) formed from biotite in Granite Chenchalapalle 50x, TL, 1N.

Fig-3.3.12b. Photomicrograph chlorite (C), titanate (t) and muscovite (m) formed from biotite granite Chenchalapalle 50x, TL, XN.
Fig.3.3.13a. Photomicrograph of apatite (A) associated with chlorite (C), feldspar (F), and sericite (S) in granites of Chakrayapeta area 10x, TL, 1N.

Fig.3.3.13b. Photomicrograph of apatite associated with chlorite and feldspar in granites of Chakrayapeta area 10x, TL, XN.
Fig. 3.3.13c. Photomicrograph of Allanite (Al) and apatite (Ap) inclusion in plagioclase in granites of Chakrayapeta area, 5X, TL, XN.

Fig. 3.3.14. Photomicrograph of radioactive zircon (Z) inclusion in feldspar in granite cataclasite Varikuntapalle area, 10X, TL, 1N.
3.3.15. Photomicrograph Radioactive zircon (Z) as inclusion in altered plagioclase feldspar  Granite cataclasite, T.R.Palle area, 20X, TL, 1N XN.

Fig-3.3.16. Photomicrograph of Radioactive zircon (Z) with Chlorite (c) In 50x, TL, 1N, oil, Varikuntapalle area.
3.4. PETROGRAPHY- MYLONITE

Mylonite/phyllonites in the shear zones hosted by the granites in the study area are typically dark green, grey to black coloured, largely aphanitic and massive. A foliation is macroscopically visible, but the rock does not cleave easily. In contrast, phyllonite breaks easily along foliation planes (much like a slate), is generally grey-brown grey and though the rock is dominantly aphanitic, a micaceous sheen is evident along foliation planes. Mylonites and phyllonites are compositionally, mineralogically and texturally similar.

Both in hand specimen and under the microscope, the mylonites are characterized by well developed S–C fabrics (Fig.3.4.1 & 3.4.2), which are defined by variation in colour, preferred orientations of fragments. Dark green to dark coloured mineral laminations wrapped around the oriented fragments or aggregates of fragments are mainly composed of biotite altering to chlorites. These biotite/chlorite grains are aligned parallel to subparallel to the oriented fragments or aggregates of fragments.

All the quartz and feldspar grains contain abundant intergranular fractures. S- and C-surfaces were present at all stages of the deformation, developing simultaneously. S surfaces (Fig.3.4.1 & 3.4.2) are defined by the dimensional preferred orientation of quartz grains within quartz domains and by the long dimensions of biotite porphyroclasts. C-surfaces (Fig.3.4.1) are parallel to the boundaries of mineralogical domains. As deformation progressed, the spacing between mineralogical domains became smaller, the number and size of porphyroclasts decreased, and C-surfaces became increasingly dominant over S-surfaces. The S-surfaces rotated towards the C-surfaces with increasing deformation.
Petrographic observations indicate that reduction in grain size occurs in two very different ways within the mylonite zone. The first involves an initial abrupt decrease in grain size through cataclasis, followed by ductile deformation. The second way involves a progressive, rather than abrupt, reduction in grain size outside micro-shear zones by mechanisms that vary from mineral to mineral. As the grain size is reduced, the rock passes through the stages of protomylonite (10-50% matrix) and mylonite (50-90% matrix), therefore can only be produced through this progressive reduction in grain size.

Mylonite has higher matrix content which ranges from 40 to 60%, and the overall grain size is lower. There are large clasts, mainly of quartz and a fine-grained matrix (Fig.3.4.3). In addition, compositional segregation begins to develop, leading to a layered foliation (Fig.3.4.3b). Mylonite, consists of quartz and feldspar grains occurring as porphyroclasts in the matrix. Quartz exhibits microstructures diagnostic of crystal-plastic deformation, including subgrains, deformation bands, and dynamically recrystallized new grains. Many high-strain samples contain completely recrystallized quartz ribbons with large quartz neoblasts that exhibit both interlobate and polygonal grain boundaries. Their shape is commonly rounded, but some porphyroclasts in mica-rich samples show an irregular outline. Quartz commonly shows elongation, fragmentation and recrystallization to polygonal grains along small narrow bands. Quartz aggregates commonly form lenses or asymmetric boudins (Fig.3.4.3a, b &c). Phyllonite samples (3.4.3d) are most strongly deformed with the largest percentage of matrix and the smallest grain size. Phyllonite samples are identified with visible planor fabric similar to pyllites.

Two types of quartz are identified namely relict quartz and fine grained recrystallised quart. Relic quartz occur as big porphyroclasts (Fig.3.4.4), Quartz
porphyroclasts exhibit undulatory extinction and usually contain deformation lamellae. Quartz shows core and mantle structure with subgrains and dynamically recrystallized grains 10 to 30 µm diameter, mantling cores of quartz with undulatory extinction (Fig.3.4.4). Relict quartz are highly strained and traversed by numerous fractures (Fig.3.4.5). The second type of quartz is fine grained, recrystallised, polygonised sparsely distributed with in the matrix (Fig.3.4.6). Grain size of recrystallized quartz varies between several microns and tens of microns. The presence of these fine-grained (≈30 µm) recrystallized quartz grains is common in ultramylonites. Fine grained quartz is typically elongated or smeared out into millimetre scale ribbons (Fig.3.4.7a & b), defining a strong foliation.

Feldspars are commonly intergrown with polygonal quartz crystals and show polysynthetic twinning, the K-feldspar loses its microperthitic texture (Fig.3.4.6). Fine-grained aggregates of feldspar surrounding a porphyroclast are sometimes stretched out into the matrix forming tails. Fine-grained matrix is mainly composed of quartz, K-feldspar, plagioclase, biotite, chlorite and epidote. In some samples, however, a larger amount of fine-grained biotite is present. The K-feldspar fragments are angular, their shape being generally controlled by cleavage planes (Fig. 3.4.6). Incipient tails or fine grained K-feldspar can be found in the strain shadows adjacent to some fragments. Most of the feldspar has undergone grain size reduction in local fine-grained layers of mylonite. In many cases the feldspar has undergone alteration to fine grained sericite (Fig.3.4.6). The grain-size of matrix plagioclase and K-feldspar varies from submicrons to several microns. Biotite is generally lower in the ultramylonite than in the surrounding granitic protolith. As is the case in the cataclastic zones, only relics of biotite and chlorite survive in the mylonitized zones.
The accessory minerals identified are zircon, monazite, apatite, and tourmaline. Zircon both unzoned (Fig.3.4.8a) and zoned (Fig.3.4.8b) is the most common accessory mineral present in almost all the rocks. These are disseminated, euhedral slightly brown coloured and metamict. Monazite (Fig.3.4.9) occurs as discrete crystals and form tectonic fish. Apatite (Fig.3.4.10) and tourmaline (Fig.3.4.11) associated in the mylonites are oriented to planor fabric. Opaques identified are limonite (Fig.3.4.12), haematite (Fig.3.4.13), magnetite (Fig.3.4.14) anatase (Fig.3.4.15) and brannerite (Fig.3.4.16). Limonite and anatase are spongy mass type which has formed a coating on the base minerals. Anatase occurs in two modes. One as fracture fillings and clusters of fine, elongated and skeletal anatase which is transparent to translucent. Brannerite occur as an accessory dark brown coloured mineral. It is in the form of anhedral to subhedral, columnar and needle-shaped crystals with brownish grey colour and yellowish to reddish brown internal reflections in reflected light and registering medium dense alpha- tracks. The sulphides identified are galena (Fig.3.4.16), pyrite and chalcopyrite (Fig.3.4.17).

3.5. PHYLLOMITE

Phyllonite is a fine-grained well foliated rock which shows a pronounced stretching lineation. Phyllonite samples are brown gray rocks with visible foliation and lineation. No crystals can be seen with the unaided eye. Phyllonite samples are most strongly deformed with the largest percentage of matrix (95%) and the smallest grain size.

Microscopically, the samples show schistosity (Fig.3.4.18 & 3.4.19)) defined by major minerals of quartz, feldspar, chlorite, sericite, and hematite. Chlorite constitute nearly 30%, sericite 15 to 20%, and most of it is formed by alteration of feldpars. Quartz (about 10%) occurs as fine-grained segregations and vein-fillings.
Zircon, zoisite, tourmaline (Fig 3.4.19 & 3.4.20) and apatite occur as finer inclusions. In some samples, hematite (Fig.3.4.21) is the most dominant and it occurs mainly as fine platy aggregates (specular hematite) and lesser medium grains. Leucoxene and pitchblende are found generally, in association with hematite (specularite).

The most noticeable characteristic feature of the phyllonite microstructure is its low content of quartz and plagioclase. The well-defined quartz layers of the mylonite nearly disappear in the phyllonite bands. Plagioclase is also nearly absent in most bands. In contrast, the white mica content (product of plagioclase breakdown) increases dramatically in the ultramylonites in the form of fine-grained aggregates, K-feldspar occurs as stretched layers of finely crushed microbreccia.

The investigated mylonites and phyllonites were derived from a granitic protolith which was deformed under greenschist facies conditions, and in the presence of fluid. Evidence for fluid activity during shearing includes the production of muscovite via reaction-softening in feldspar (White and Knipe, 1978; Dixon and Williams, 1983), and chloritization - muscovitization of the original biotite. The presence of very fine chlorite aggregates along grain boundaries of the weakly deformed protomylonite indicates that fluid circulation occurred since the earliest stages of deformation.
Fig. 3.4.1. Photomicrograph showing random orientation of clasts defining S-C fabric, TL, 20X.

Fig. 3.4.2. Photomicrograph of S-C Fabric (S- s planes, C=c planes) Eye shaped quartz porphyroclast (Q) in chlorite matrix (Ch) 20X, TL, XN, Air.
Fig. 3.4.3a. Photomicrograph of Quartz porphyroclast (Q) in chlorite matrix in Mylonites Sundupalle area (C) 10X, TL, 1N, Air.

Fig. 3.4.3b. Photomicrograph of augen shaped porphyroclast (P) of sericite in deformed groundmass in mylonites from Mulapalle area 2X, TL, 1N.
Fig. 3.4.3c. Photomicrograph of Eye shaped quartz porphyroclast (Q) in chlorite matrix in mylonites from Sundupalla area (C) 20X, TL, XN, Air.

Fig. 3.4.3d. Photomicrograph showing deformation in Phyllonites of Mulapalle area, 2X TL, IN.
Fig. 3.4.4. Photomicrograph of porphyroclast of Quartz in the fine grained quartz matrix, 2X, TL XN, Mulapalle area.

Fig. 3.4.5. Photomicrograph of quartz(Q) augen in chlorite (c)2x, TL, 1N. Varikuntapalle area.

Fig. 3.4.6. Photomicrograph showing recrystallised fine grained quartz and microcline (M) in mylonites of 5X, TL, XN, Mulapalle area, Note Feldspars altering to sericite.
Fig. 3.4.7a. Photomicrograph of Recrystallized quartz (Q) in the form of ribbons in chlorite (C) groundmass, 5X, TL, XN Varikuntapalle area.

Fig. 3.4.7b. Photomicrograph of Recrystallised quartz (Q) as folded ribbons in chlorite (C) ground mass 5X TL XN Varikuntapalle area.
Fig.3.4.8a. Photomicrograph of metamict zircon 20 X TL XN, Mulapalle area.

Fig.3.4.8b. Photomicrograph of zoned zircon 20 X TL XN, Mulapalle area.
Fig. 3.4.9. Photomicrograph of monazite (M) in groundmass of chlorite, 20x, TL, XN, Burjupalle area.

Fig. 3.4.10. Photomicrograph of tabular apatite (A) in mylonite, 5x, TL, IN. Burjupalle area.

Fig-3.4.11. Photomicrograph of tourmaline (T) laths in sericitic and chloritic groundmass in mylonite, 20x, TL, IN Mulapalle area.
Fig-3.4.12. Photomicrograph of limonite having adsorbed uranium 50x, TL, 1N.

Fig-3.4.13. Photomicrograph of hematite(H) in phyllonite, 50x, RL, 1N mylonite, Mulapalle area.

Fig-3.4.14. Photomicrograph showing titanomagnetite formed from biotite, peach coloured ilmenite (i) and grey coloured magnetite (m) in mylonites of 50X, TL, XN, Kamaguttapalle area.
Fig.3.4.15 Photomicrograph of anatase 5x, TL, XN Varikuntapalle.

Fig.3.4.16. Photomicrograph of Opaques identified as brannerite and galena 10X, RL, 1N, Mulapalle area.

Fig.3.4.17. Photomicrograph showing galena (G), chalcopyrite (CP) and Pyrite (P)20X, RL, 1N, Varikuntapalle area.
Fig. 3.4.18 Photomicrograph of Argillaceous band in phyllonite 2x, TL, XN.

Fig. 3.4.19. Photomicrograph of Tourmaline and feldspar band in phyllonite 2x, TL, XN.
Fig-3.4.20. Photomicrograph of Tourmaline (T) and feldspar (F) band in phyllonite, 2x, TL, 1N.

Fig-3.4.21. Photomicrograph of Feldspar associated with haematite (H) in phyllonite, 20x, TL, XN.
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