# Petrographic study around southeastern Madurai Block, part of Thoothukudi District, Tamil Nadu, India

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***Abstract***- *The Southeastern Madurai Block belt belongs to the high grade metamorphic terrain which is very well exposed all along NE of Thoothukudi district but least studied. The study area is mainly composed of Precambrian crystalline rocks of upper amphibolite to granulite facies metamorphism.Petrographicalstudies of various litho units in the south-eastern part of Madurai block of the SGT are carried out and identified the individual litho units understanding their mineral assemblages and textural characteristics.So southeastern Madurai Block area, part of Thoothukudi district, is comprised of lithotypes such ascharnockite, hornblende-biotite gneiss, pyroxene granulite, pink granite wheregranite exists as a single units seen intermixed with banded and migmatised hornblende-biotite gneiss. Within the granite, pyroxene granulite occurs as boudins or small enclaves. As well as charnockite occur as both massive and foliated rocks in outcrops. However fresh out crops of khondalite is seen in the study area. Garnet bearing pink granite is observed in the area with sharp contact with charnockite and gneiss. The exposures are mainly confined towards quarries, small hillocks, road cuttings as well as mine depths. The field due to high grade granulite facies metamorphism also weathering. Evidence of shearing and folding has been observed in the rocks of the area.*

***Keywords***- Petrography, textures, mineral assemblages,Metamorphism, Southeastern Madurai Block,

## I. INTRODUCTION

The Madurai Block lies to the north of Trivandrum and Nagercoil Block bounded by the Palghat Cauvery Shear Zone to its north. The Madurai Block is characterized by the presence of charnockites and metasedimentary rocks (Santosh *et al.*,1992; Bartlett *et al.*,1995; Jayananda*et al.*,1995a). Earlier geological, petrological, geochemical, geochronological and geophysical studies have offered important information on the evolution of the crustal blocks and their amalgamation to the Southern Granulite Terrane (SGT) of Peninsular India (Sato *et al.*,2010; Plavsa*et al.*, 2012; Collins *et al.*, 2014; Koizumi *et al.*, 2014). The Palghat-Cauvery Shear Zone (PCSZ) marks the general boundary between Archean blocks in the north and the Proterozoic blocks to the south in the SGT (Chetty and Bhaskar Rao, 2006; Collins et al., 2007a;Saitoh *et al.*, 2011; Santosh *et al.*, 2012). The crustal evolution of the region remains significant to understand the formation of SGT (Sajeev*et al*., 2005). The Madurai block has recorded extreme crustal metamorphism at ultrahigh-temperature (UHT) conditions (Brown and Raith 1996; Raith*et al.* 1997; Satish-Kumar 2000, Sajeev*et al.*, 2006, Shazia*et al., 2012*, George *et al., 2015*). Extremely high-temperature heat input with related granulite facies metamorphism of the lower crust at temperature above 900°C is considered as Ultrahigh-Temperature (UHT) metamorphism (Harley 1998*a*, 2004). The evidence for UHT metamorphism is preserved as textures and typical mineral assemblages. The tectonic correlation of India-Sri Lanka-Madagascar-Antarctic-Africa has been evaluated in several studies (Janardhan.,1999;Santosh *et al.*,2009b;Collins *et al.*, 2014). The Southern Granulite Terrane in India (SGT) Retrograde amphibolite facies rocks appear at the boundaries of the shear zones (Santosh *et al.*, 2006) (Fig. 1), south of the ArcheanDharwarCraton, exists an assemblage of crustal blocks and intervening suture as well as shear zones ranging in age from Mesoarchean to late Neoproterozoic Cambrian (Jayananda*et al.*, 2000; Clark *et al.*, 2009; Santosh *et al.*,2009b, 2015, 2016; Collins *et al*., 2014). On the direction of the south part of Palghat-Cauvery Suture Zone (PCSZ, considered as the trace of the Mozambique ocean suture; Collins *et al.*, 2007a,b; Santosh *et al*.,2009b) exists the Madurai Block, which in recent studies exists identified such as a collection of three crustal segments, northern, central also southern provinces (Plavsa*et al.*, 2014). Madurai Block be located the largest crustal block in southern India and revelation of hornblende biotite gneiss, charnockites, garnet-biotite gneiss, garnet-biotite-sillimanitegneiss, pinkish and greyish granites also pegmatites, quartzite, diorite (Santosh *et al.*, 2009b; Plavsa*et al*., 2012).

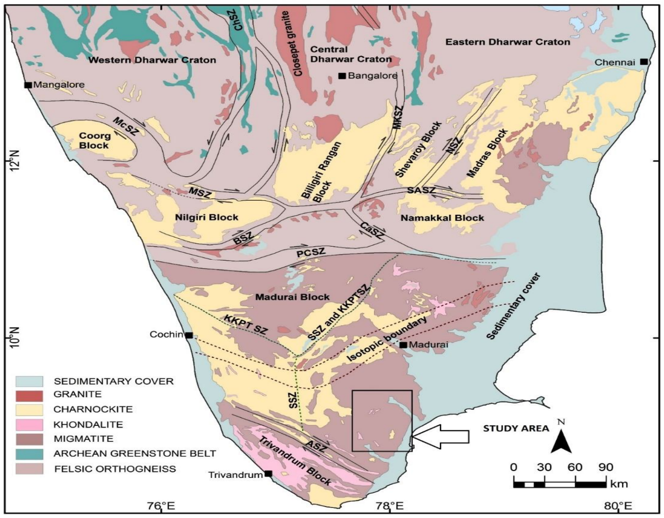


**Figure. 1**. Regional geology and tectonic framework of southern India (geology from Geological Survey of India, 2005). The shear zones are modified after Ishwar-Kumar *et al*. (2013).TTG — tonalite–trondhjemite–granodiorite, KSZ — Kumta Shear Zone, CHSZ — Chitradurga Shear Zone, MeSZ — Mettur Shear Zone, KolSZ — Kolar Shear Zone; NSZ — Nallamalai Shear Zone, MSZ — Moyar Shear Zone, McSZ — Mercara Shear Zone, BSZ —Bhavani Shear Zone, SASZ — Salem Attur Shear Zone, CaSZ — Cauvery Shear Zone, PCSZ — Palghat–Cauvery Shear Zone, ASZ — Achankovil Shear Zone.

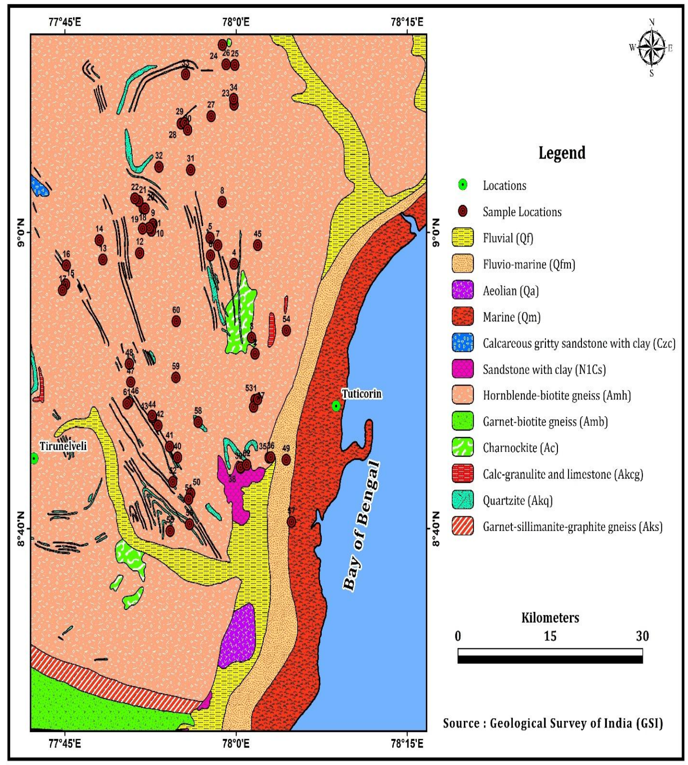


Figure2:Detailed geological map of study area inSouth-eastern Madurai Block.

## Geology of the study area

The Madurai Block (MB) occupies the largest portion of the Southern Granulite Terrain (SGT) and represents a composite middle to lower crustal domain. It has a fundamental part in characterizing the Proterozoic geodynamic evolution of the SGT and its position within eastern Gondwana. Different to the previous studies, Cenki and Kriegsman (2005) highlights a poor structural mechanism for southeastern Madurai block in the SGT as well as for the rocks within it. The PCSZ as well as the ACS, which are defined as the northern and southern boundaries of the MB, has been reconstructed in their study. A previously defined lineament of Karur-Kambam-Painavu-Trissur (KKPT) proposed by Ghosh *et al*.,(1998) runs within the MB.

The MB is a high-grade granulite facies terrain and the major rock types in the block include charnockites and mafic granulites (Fig.1). The MB can be lithologically divided into Western Block and Eastern Block (Cenki and Kriegsman, 2005). The southeastern Madurai Block (SMB) part of thoothukudi district is characterized by two different groups of hornblende-biotite and orthopyroxene-biotite (charnockite) gneisses, one being quartz rich and the other feldspar rich. The SEMB is also composed of massive charnockites with heterogeneously distributed quartzites and calc silicate series of rocks (Cenki and Kriegsman, 2005). Garnetiferous rocks are relatively less in the MB when compared to the adjacent blocks, but hornblende, biotite and orthopyroxenes are present all over the SMB. A sharp boundary between hornblende occurs in the southern boundary of the SMB, which exposes as the difference in composition of protolith rather than alteration in the metamorphic grade.

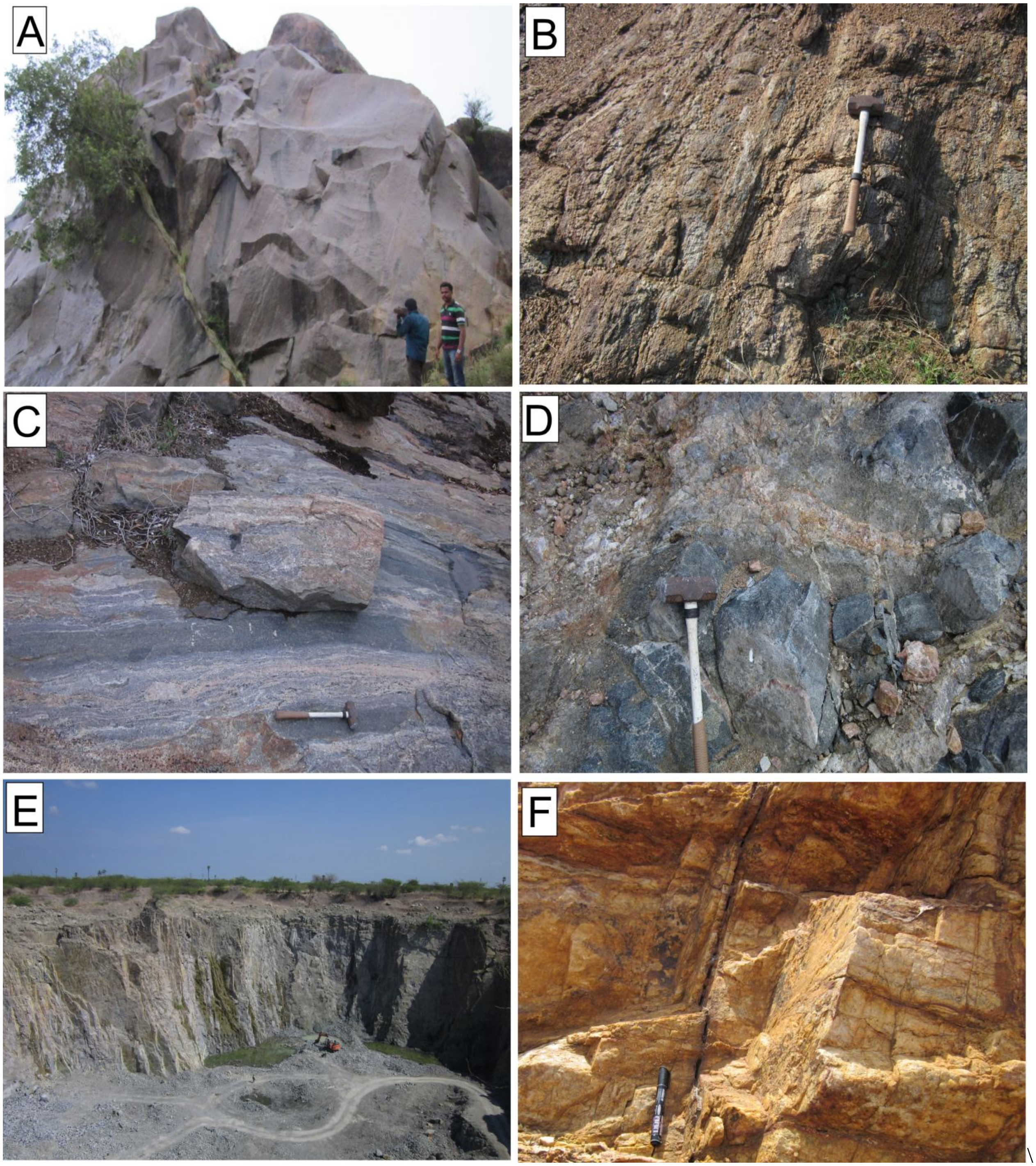


Figure 3. A)Field photographs of granite Domin in Marukalthallai B) Field photographs of Calc Granulite in Ettaiyapuram C) Field photographs of hornblende biotite gneiss D) Field photographs showing pyroxene granulite E) Field photographs showing massive charnockite quarry F) Field photographs of Quartzite rock in Karunkulam village

**Petrography discussion**

Generalized petrographic descriptions of South Indian granulites have been published in many classical works by many prominent geologists (Rama Rao, 1945;Pichamuthu.,1979; Howie, 1955;Subramanian.,1967),more detailed petrography, and mineral chemistry in recent works. (Raith*et al.*, 1983;Chacko *etal.*,1987;Brown*etal.,1992;*RavindraKumarandChacko.,1994; Srikantappa.,1993,1996;Santosh,1996;Mohan.,1996;Satish-Kumar.,2000;Ravindra Kumar.,2005).But very less studies are there concentrating on the rocks of the MGB (Mohan *et al.*,1985; Mohan, 1996; Mohan *et al.*,1996b; Satish-Kumar 2000) and none of it give a complete picture as the block is moreover massive as well as complex. So the present study aims to bring out some of the important petrographic features chance upon in the charnockites and associated gneisses of the SEMB.

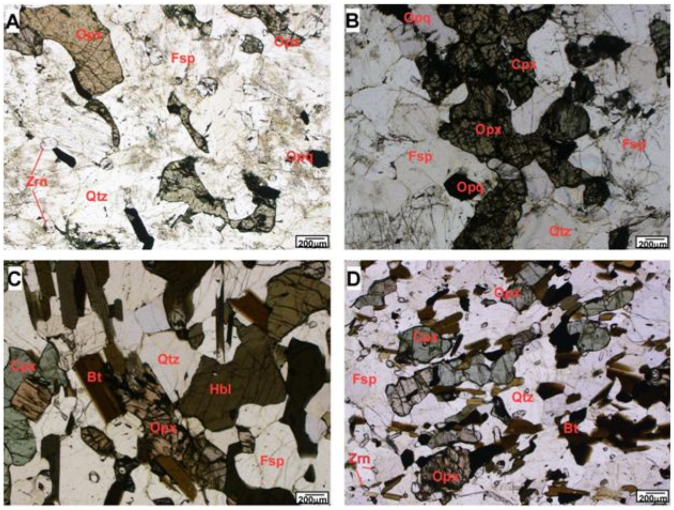


Figure 4. A) Photograph showing Largeorthopyroxene crystals in felsic matrix in gneiss charnockite Quartz-plagioclase myrmekite textureB)Photo graph showing 2 pyroxenegranuliteC)Photo graph showing Hornblende-orthopyroxene assemblage indicating retrogression hornblende biotite gneiss. D) Photo graph showing Granitic gneissic rock hornblende -orthopyroxene assemblage indicating retrogression

In SEMB in part of thoothukudi district at many outcrops the appearance of the charnockite in contact with the hornblende ± biotite gneiss is noticed. The petrography also confirms these retrogressive assemblages with the co-existence of orthopyroxene and hornblende. Presence of cordierite also gives evidence for retrogression reactions. Development of quartz-cordierite symplectites at the magnetite rims in the presence of hornblende is also an evidence of retrograde metamorphism. Quartz-plagioclase myrmekites are noticed in the hornblende ± biotite gneiss from Melathattaparai(Figure 4.A).

Garnets occur very rarely in these rocks. Garnet bearing charnockites are seen in the Perumalpuram area. Figure_ shows such an occurrence of garnet in a charnockite body, Some charnockites show typical granoblastic texture with significant amount of orthopyroxene (fig4.D). Figure 4 A shows a typical assemblage of Orthopyroxene, biotite and plagioclase in a charnockite.

The study area comprises of few groups of rocks, namely the Hornblend-Biotite Gneiss, Charnockite, Granite, Garnet-Biotite gneiss, Khondalite, Quartzite. So detailed petrographic analysis of these major rock types were carried out. More than 122 thin sections covering all the rock types were prepared by conventional methods. The petrography of each thin section was studied under a petrological microscope. The textural relationships of various minerals present in the rocks were studied in order to unearth the metamorphic reaction processes involved in the evolution of different rocks. Micrographs and photomicrographs were prepared using Olympus BX51 microscope attached with a camera.

**Charnockites**

Origin and formation of Charnockites are still in debate and so it approves that the charnockites present in the study area are either formed of igneous or metamorphic. Hence fine to medium grained massive to banded charnockites exposures occur in an open quarries in the Southeastern Madurai block.

The mineral assemblages of Charnockite are:

Qtz + Pl+ Kfs + Opx ± Bt +Mag ± Cpx± Grt

Quartz is colourless, cleavage-absent, non pleochroic, low relief and refractive index is 1.55, Anisotropic, wavy extinction, low interference colour. Orthopyroxene in charnockitic rocks occurs as anhedral to subhedralporphyroblasts in the interspaces of quartz, plagioclase, clinopyroxene and alkali feldspar. Orthopyroxene shows simple twinning. Orthopyroxene along with biotite is often concentrated in layers to define the gneissosity. Closely associated ilmeniteare also noted. Clinopyroxene is colourless to green in colour and occurs as euhedral to subhedral grains with poorly developed cleavages. Alkali feldspar grains are large, anhedral and perthitic. Flame shaped perthite are common in the rock present in the study area. Deformed grains show undulose extinction. Extensive myrmekite intergrowths are present along the boundaries between feldspars. Plagioclase grains are small and deformed verities have bent lamellae. Deformed biotite show undulose extinction as well as bent lamellae. The retrograded and nonretrograded original hypersthene of charnockite is visible.
The prismatic orthopyroxene or biotite defines prominent foliation in this charnockite. The retrograde alteration seems to have produced biotite and chlorite.

**Granite**

Granite consists of major minerals like feldspars (mostly plagioclase), quartz and biotite along with opaques and zircon, muscovite, chlorite and garnet. Microscopic study indicates that granite is fine to medium grained, having hypidiomorphic texture and relict intergranular texture (fig4.D).The feldspar grains are euhedral to subhedral with two different sizes of grains. In feldspar grains size ranges from 0.02mm to 0.1mm. Plagioclase and quartz grains resemble porphyritic texture (fig4.D). Few feldspar grains also show cracks, which have been filled by quartz,Both K-feldspars and plagioclase grains are present. The grains are highly altered, development of carbonates and epidote is observed. Perthite texture is observed. Few grains show deformation of twin lamellae. The quartz grains show wavy extinction and development of triple point. The development of myrmikitic (intergrowth of quartz and feldspar) and perthite (flame perthite), which is an intergrowth of K-feldspar and Na-feldspar have been observed. The magmatic state deformation can be observed in the feldspar, where the parallel cracks have been filled by quartz.

And in Southeastern Madurai block, two different varieties of gray / pink granite are identified in the study area which show no significant variation in their mineralogy.

**Grey granite:** Textures of gray granites in Southeastern Madurai block are inequigranular, granoblastic grains with embayed grain boundaries. The grey granite band of Vallanadu shows the modal contents – quartz +Orthoclase+, plagioclase + Biotite +, Magnetite +, Apatite+ chlorite+perthite+ zircon

Quartz are anhedral, platy-fractured and shows undulose extinction, strain free bigger in size. But rarely in some particular grains of bigger quartz some grains are surrounded by endoblasts of smaller grains of quartz, which are fresh bluish coloured recrystallized quartz are also noticed. Microcline feldspar is of two generation in which one is larger, tabular to irregular in shape, cross hatched twining. Inclusions mainly quartz, biotite and plagioclase are noticed. Most of them prominently show perthitic texture, the plagioclase grains are vermicular type, strings to rod shaped grains. But overall the microcline feldspars have undergone kaolinisation as well as sericitization. Myrmikitic texture is commonly observed. Fractures are filled by opaques. The second generation of microcline feldspars is subhedral, comparatively small, no alteration and also inclusions are noticed, fresh and cross hatched twining is prominently observed. Plagioclase feldspars are large, tabular and polysynthetic twining is prominently observed. Mineral inclusions like biotite, quartz and orthoclase are noticed. The alterations of plagioclase grain to sericite and rarely to epidote specks are noticed.

Biotite is long, elongated by yellowish brown in colour and cleavage are very distinct and small quartz inclusions are prominently noticed in few grains. Although biotite commonly alters to chlorite. Biotites shows twist band/curved lamellae feature. The pleochroic haloes are commonly seen in the bigger grains of biotite. Occasionally accessory minerals like apatite also zircon located noticed rarely.

**Pink granite:** Petrographic studies of pink granites exhibit inequigranular, granoblastic and interlobate grains with embayed grain boundaries.

The mineral assemblages in the pink granite are:

quartz +orthoclase +plagioclase +perthite +zircon +apatite+magnetite +Ilmenite + biotite

Quartz are anhedral, platy fractured and shows undulose extinction, strain free bigger in size. But rarely in some of bigger quartz grains show recovery and recrystallization to give rise to smaller grains of quartz. Microcline feldspar are tabular to irregular in shape, exhibit cross hatched twinning. Inclusions mainly quartz, biotite and plagioclase are noticed. Most of them prominently show perthitic texture, the plagioclase grains are vermicular type, strings to rod shaped grains. But overall the microcline feldspars have undergone kaolinisation and sericitization. Myrmikitic texture commonly observed. Fractures are filled by opaques. Plagioclase feldspars are large, tabular, polysynthetic twinning is prominently observed. Mineral inclusions like biotite, quartz and orthoclase are noticed. The alterations of plagioclase grain to sericite and rarely to epidote specks are noticed. Biotites are long, elongated with yellowish brown in colour. Cleavages are very distinct and small quartz inclusions are prominently noticed in few grains. The biotite commonly alters to chlorite. Biotites shows kink band/bent lamellae features. The pleochroic haloes are commonly seen in the bigger grains of biotite. Sometimes accessory minerals like apatite and zircon are noticed rarely.

**Mafic granulites**

The mafic granulite samples are mainly composed ofclinopyroxene, garnet,plagioclase, minor amount of rutile, amphibole and opaque minerals. Garnet and clinopyroxeneporphyroblasts exist as the major equilibrium mineral assemblage (Fig5.B). Fine grained rounded inclusions of orthopyroxene and plagioclase is identified within the core of garnet and clinopyroxeneporphyroblasts. The core of resorbed garnet porphyroblasts contains needles or lamellae of rutile. Ilmenite is present as an exsolved phase inside clinopyroxene. The garnet-clinopyroxene assemblage has been overprinted by the later amphibole–plagioclase symplectite.

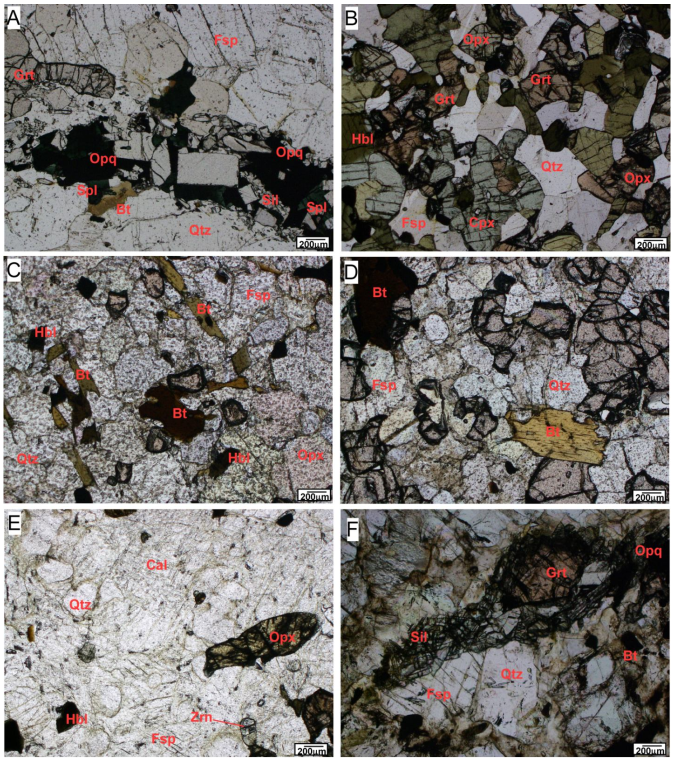


Fig 5.A)`Photograph showing Garnet sillimanite biotite gneiss B) Photograph showing granoblastic texture mafic granulite C)Hornblende biotite showing gneissic texture D)Granite rock showing porphyroblastic texture E) Photograph showing calc granulite rock F)Photograph showing corona structure microphotograph Khondalite rock.

**Hornblende-biotite gneiss:**

Hornblende-biotite gneiss forms a major rock type in the SMB. Usually this rock is found associated with charnockite bodies as a product of retrograde metamorphism. This area mainly consists of two types of gneisses. The hornblende-biotite gneiss represents metamorphosed Madurai Block (MB), with an assemblage of quartz + plagioclase +hornblende+ biotite. In some rocks biotite and hornblende define the general foliation. Samples from the southeastern Madurai Block (fig 5.A) show minor presence of garnet and secondary actinolite. Pyroxene observed in few sections has alteration haloes. Following are the mineral assemblages in homblende-biotite gneiss:

Qtz + Pl + Hbl + Bt + Mag
Qtz +P1 + Kfs + Hbl + Bt +Mag + ± Opx + Chi

**Garnetiferous hornblende - biotite gneiss**

The mineral assemblages present in SEMB gneiss are Qtz + PI + Kfs + perthites +biotite + opaque, but the biotite gneiss show gradation to biotite + sillimanite/kyanite bearing gneiss, suggesting that the SEMB gneiss represent metamorphosed rock. The mineral textures in the SEMB gneisses are metamorphic with equidimensional grains. It is an equigranular polygonal texture with straight to moderately curved grain boundaries. Most of the plagioclase grains show perthitic textures. The mineral assemblages of SEMB Gneiss are

Qtz + PI + Kfs + Bt + Opq
Qtz + PI + Kfs + Bt + Sil- Opq.

The SEMB Gneiss exhibits well developed quartzgrains, which constitute about more than 60% of the rock. Quartz-plagioclase grains do not show any stretching thus indicating that high grade metamorphism outlasted deformation. Plagioclase is seen as laths, it shows polysynthetic twinning and often shows zoning. Plagioclase exhibits the myrmikitic texture and antiperthitic texture. Potash feldspar are euhedral to subhedral, medium relief, cross hatch twinning is prominently observed. Potash feldspar exhibits micro-kink bands. Biotites are long, elongated, yellowish brown in colour.

**Granitic gneiss**

Granitic gneiss displays moderately to strongly deformed, foliated as well as gneissose structure with preferential orientation of biotite flakes. Some of the primary magmatic feature such as phenocrysts of plagioclase and K-feldspar are still preserved (Fig 5.D). Granitic gneiss bearing qtz-hlb-bt-K-fl-pl-mag-ap-zrn assemblage modally corresponds to quartz granodiorite. Plagioclase shows lamellar twining whereas K-feldspar exhibits series of perthite with simple twinning. Few plagioclase grains have undergone sericitization. Quartz intergrowth can be observed between K-feldspar grains boundaries. Euhedral to subhedralunzoned hornblende is found in close association with plagioclase and biotite phases. Biotites are subhedral to euhedral, flaky and tabular in habit showing parallel extinction and second order of interference colour. They are randomly associated with amphibole, K-feldspar, (microcline), plagioclase and quartz. Bending of cleavages and ductile deformation feature of biotites can be observed.

**Calc granulite**

The minerals present in the calc-granulite are calcite + hornblende + quartz + epidote. (Fig 5.E)Quartz occur as interstitial grains. It is anhedral in nature and exhibits andulouse extinction. Calcite is colorless with anhedral grains exhibiting perfect rhombohedral cleavage. It twinkles during rotation with the relief being moderate. Epidote is present as an accessory phase which is pale green in colour which is pleochroic and has pseudo hexagonal outline.

**Garnet-cordierite-sillimanite gneiss:**

The Grt–Opx–Crd is a coarse-grained granulite-facies rock in peliticprotolith. The mineralogy is plagioclase +orthopyroxene +garnet +K-feldspar +quartz+ cordierite with accessory biotite, spinel, sillimanite, as well as Fe–Ti oxide (Ilm) (Fig.5.A). Garnet is very coarse-grained as well as subidioblastic, and contains numerous fine-grained inclusions of sillimanite, biotite, spinel, and quartz .The inclusion sillimanites are aligned along the foliation defined by matrix biotite (Fig.5.A). The Biotite is also present as an inclusion phase. Brownish orthopyroxene is subidioblastic and very coarse-grained. It contains inclusions of quartz, K-feldspar, as well as Fe–Ti oxide. Orthopyroxene does not coexist with sillimanite as sillimanite occurs only as inclusions in garnet. Cordierite is present as a matrix phase coexisting with quartz- as well as sillimanite-bearing garnet.Biotite also sillimanite define the foliations in the rock. Garnet is usually found as porphyroblasts. Patches of cordierite sillimanite gneisses are seen in the southern part of the MGB in close association with Achankoil shear zone (ASZ). The cordierite bearing gneisses are generally coarse grained with quartz, plagioclase, perthite, cordierite, garnet and biotite as the major minerals. The dark bands are mostly biotite rich. The quartzo-feldsopathic bands are rich in K-feldspar, perthite with minor quartz and garnet.

**Result and discussion**

A detailed petrographic study of southeastern Madurai Block part of thoothukudi district was carried out for the rocks present in the study area. About sixty two locations were covered. 128 thin sections were made and observed. It is seen that in this terrane gneisses predominate charnockite. Also, along the transition zone which shows typical sedimentary texture, few samples are taken and studied petrographically, the different minerals occurring in each of the rock type are described. In the description, the shape and size of the mineral grains, the other properties are given. Charnockite present in this area occupies the major part of the study area which is towards southeast of Melathattaparai, Keelathattaparai, Sillanatham, Akhiladapuram, Patemanagaram, Paneerkulam, Therikuathikulam, Therikuelathakulam, Lingapatti, Seetharkulam. Charnockite present in this area are meso-type, occurs green in colour, Hornblende is also present which is identified by its elongated form and its green colour. Garnetiferous - hornblende - biotite gneiss, granitic gneiss, garnetiferous - hornblende - biotite gneiss are the major rock types of the region. The gneisses occupy almost 70% of the mapped area. Almost 60% of the detached outcrops are gneisses. At few locations granite, mafic granulite, migmatites, calc silicate, as well as quartzite were exposed.

## II. CONCLUSION

An extensive petrographical studies of various litho units in the south-eastern part of Madurai block part of thoothukudidistrictthe SGT has been attempted for identifying their mineral assemblages and textural characteristics. Based on the detailed petrographical studies various litho units such as charnockites, granite (grey granite and pink granite), mafic granulite, Hornblende-Biotite-gneiss, Garnetiferous Hornblende biotite gneiss, granitic gneiss, calc granulite and garnet cordierite sillimanite gneiss or Khondalite have been identified. Fine to medium grained massive to banded charnockites exposures were microscopically studied and the retrograded and nonretrograded original hypersthene of charnockite was identified. And two different varieties of gray and pink granite are identified in the study area which show no significant variation in their mineralogy. And myrmikitic texture commonly observed in both types of granite where Fractures are filled by opaques. Mafic granulite is essentially composed of Ortho-pyroxene, clinopyroxene and hornblende. Hornblende-biotite gneiss forms a major rock type in the SMB and found associated with charnockite bodies as a product of retrograde metamorphism. The Hornblende biotite Gneiss exhibits well developed granoblastic texture quartz, which constitutes about more than 60% of the rock which occurs as anhedral grains and shows undulose extinction. In granitic gneiss, perthites are noticed in the granitic gneiss, these perthites are formed by replacement of microcline by plagioclase. Plagioclase occurs as twinned crystals exhibiting well developed polysynthetic twinning. In calc granulite epidote is present as an accessory phase which is pale green in colour which is pleochroic and has pseudo hexagonal outline.The garnets is surrounded by quartzofeldspathic melt and are rich in cordierite, feldspar and quartz. In the petrographic study khondalite is also defined as garnet-cordierite-sillimanite gneiss. When going from outer rim to inner core, the garnet grains decrease in size and the equigranular grains are uniformly distributed throughout the rock. It is therefore important to establish the textural charectistic properties and mineral assemblages of various litho-units as studied.

## III. ACKNOWLEDGMENT

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