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Field Relation and Lithology of South-Eastern Madurai Block, Tamil Nadu, India

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ABSTRACT

Madurai Block belt is the largest high among the crustal fragments of the Southern Granulite Terrane. Our study focuses on the southeastern part of the Madurai Block which falls in the Thoothukudi District of Tamil Nadu. The geomorphology of the area is represented by high and mid-land regions with prominent hillocks and associated valleys. This region chiefly comprises of crystalline basement rocks that experienced granulite facies metamorphism. The southeastern region has been mapped, and the major rock types observed were identified as charnockite, hornblende-biotite gneiss, pyroxene granulite, quartzite, granite, pink granite and pegmatite. Massive garnet bearing charnockite exists as hills and which are intermixed with banded and migmatised hornblende-biotite gneiss. Diorite occurs as boudins and small enclaves within the charnockite. The charnockite occurs as both massive and foliated rocks in outcrops. A 5 km long intrusive body of pyroxene granulite is identified during the field study which trends NW-SE. Due to intense weathering they are found as boulders of varying size and shape.

Introduction

The Southern Granulite Terrain (SGT) of India is one of the largest Precambrian deep continental crustal sections exposed in the world consisting of several deformed, high grade metamorphic as well as igneous rocks. The SGT covering approximately 2,00,000 square kilometer area covering parts of Tamil Nadu, Kerala some parts of Karnataka and Andhra Pradesh. The SGT has a geological history from Mesoarchaean to Neoproterozoic (3000 – 550 Ma). Previous studies have reported the region has diversity in tectonic process, lithology, structural pattern and, metamorphism. The crustal evolution of the region remains important to understand the formation of SGT (Sajeev *et al*., 2005). Southern Granulite Terrain is bisected by several crustal scale shear zones. Drury *et al*. (1984) divided the southern Indian shield into two distinct blocks namely the Palghat-Cauvery shear zone that divides the Archean Craton in the north from the Proterozoic terranes in the south (Harris *et al*. 1994), the Northern Block and Southern Block, separated by the major E-W trending PCSZ (Bhaskar Rao *et al*., 2003). The Northern Block includes southern part of Dharwar Craton parts of Salem, Madras, Nilgiri hills and Biligiri Rangan hills characterized by the presence of granulite rocks. However, Ramakrishnan (2003), Ghosh (2004), Tomson *et al*. (2006) and Tomson *et al*. (2013) emphasizes that it is an extension of Karur-Kambum-Painav-Trichur (KKPT) shear zone of local significance and organizes not constitute a major terrain boundary. The Madurai Block is the largest amongst the crustal fragment of the SGT, which comprises of the Anamalai-Kodaikanal ranges of the Western Ghats on the west and made up largely by the massive to gneissic charnockite rocks with minor bands of Khondalites (Rajesh, 2007)

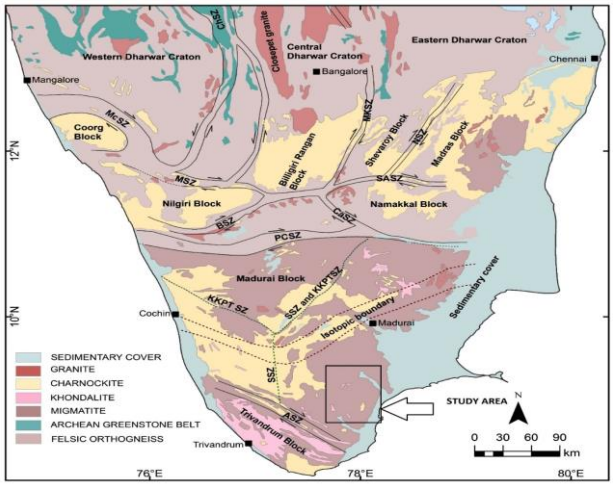

Fig. 1. Regional geology and tectonic framework of southern India (geology from Geological Survey of India, 2005). The shear zones are modified after Ishwar-Kumar *et al*. (2013). TTG — tonalite–trondhjemite–granodiorite, KSZ — Kumta Shear Zone, CHSZ — Chitradurga Shear Zone, MeSZ — Mettur Shear Zone, 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.

The lithology of this block comprises dominantly of charnockite massifs intercalated with tonalitic and granodioritic gneisses. Thin belts and slivers of metasedimentary rocks including quartzites, metamorphosed

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carbonates and pelites, completely suggest an accretionary land (Santosh *et al.*, 2009).

The ages of the late Neoproterozoic metamorphic overprint in this block are older than the uniform cluster of Cambrian metamorphic ages within the PCSZ. Metamorphic rocks exposed in different parts of Madurai Block include hornblende-gneiss, granites, khondalite, metapelitic, hornblende-biotite-gneiss, garnetiferous-biotite-gneiss, charnockite, pyroxenegranulite, quartzite, pegmatite and migmatite. The southern part of Madurai block (south of KKPT) covers most part of Madurai Block, although very little studies are done in this area. This 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 is considered as (UHT) metamorphic process (*T* above 900_C; Harley 1998*a*, 2004), Mg-Al-rich pelitic granulites e.g., Harley *et al.* 1990; Brown and Raith 1996; Raith *et al.* 1997; Harley 1998*b*; Sajeev and Osanai 2004*a*, 2004*b*; Sajeev *et al.*2004, 2006), rarely preserved in mafic and ultramafic granulites (Harley 1989). Harley (2004) proposes that UHTs from mafic granulites are reliable only if the surrounding pelitic granulites preserve reaction textures of UHT metamorphism. The rare occurrences of sapphirine-bearing granulites in the central part of Madurai block are thus important because they preserve a wide range of reaction textures, which to trace their multi-stage metamorphic evolution. Sapphirine-bearing granulites have been reported only from a few localities in southern India: at Ganguvarpatti (Grew 1982; Mohan *et al.* 1986; Hensen1988: Sajeev *et al.*2006), Panrimalai (Grew1984) and Perumalmalai in the Palani hills (Sivasubramanian *et al.* 1991; Brown and Raith1996; Raith *et al.* 1997). The present study examines some critical exposures in south-eastern Madurai block, where several igneous intrusives were also identified during the field survey but, emphasis is devoted to metamorphic rock.

Geology of Study area

The southern part of SGT is made up of Precambrian crystalline rocks that covers over 80% of the terrane. The Phanerozoic sedimentary rocks cover the eastern costal terrain and the river valleys account for the rest. In the deeply eroded Precambrian terrain the south-eastern Madurai block consists of granite, khondalite, charnockite and migmatites.

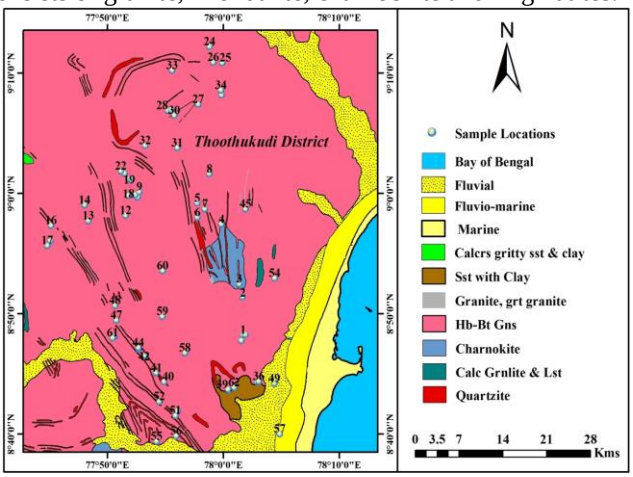

Fig. 2. Detailed geological map of study area in South-eastern Madurai Block.

To the west of the south-eastern Madurai Block are the charnockite a massif of Western Ghats and the Eastern part is composed of gneisses, charnockite, khondalite and granite. This region differs from the Northern and Central regions by the prominence of meta-sedimentary rocks such as quartzites, calc-granulites, garnet and cordierite bearing metapelites. This region is totally devoid of banded magnetite quartzites (BMQ). In the northern part of this region, calc-silicates and crystalline limestone occur as thick sequences for a few tens of meters thickness. Extensive limestone deposits are found from Palayam to Kiranur, Rajapalayam-Alangulam belt east of Varshanad hills and Talaiyuthu near Tirunelveli. At the southern extremity of peninsular India, to south of the Achankoil Shear Zone consists of garnet-biotite-graphite gneisses and garnetiferous charnockite and khondalites (garnet-sillimanite-biotite-spinel), cordierite gneiss. The south eastern Madurai Block consists of medium to high pressure charnockite and gneiss that are squeezed into a long thin band presumably resulting from shearing in the PCSZ. Madukkarai Supracrustals also fall in this area that display broad doming, complex folding and extreme hinge line variation caused by Neoproterozoic-Ordovician suturing along the PCSZ extending beyond the Madras Block (Chetty and Rao, 2006). Retrograde amphibolite facies rocks appear at the boundaries of the shear zones (Santosh *et al*., 2006). South-eastern Madurai block forms one of the important granulite grade metamorphic shield areas in India and comprises of charnockite and khondalite groups of rocks. The block comprises of argillaceous, arenaceous and calcareous facies of meta-sediments is a repository of crystalline lime-stone. Garnet sillimanite gneiss - pyroxene granulite, magnetite, quartzite, crystalline limestone, calc-gneiss, calc granulite, quartzite and cordierite gneiss form important litho units of the Meta sedimentary group. Migmatite gneiss, granite, ultramafic rocks, basic dykes are the other formations present in the region.

Migmatite gneiss

The litho variants of magmatic gneiss in south-eastern Madurai Block are biotite gneiss as well as migmatite that shows gneissosity and also banding due to the injection of granitic magma.

Migmatite gneiss Ottudanpatti (location9 N09.00965E077.87864) is well banded or layered in nature and is formed as a result of granitisation of the pre-existing metamorphic litho assemblage of south-eastern Madurai Block (SEMB). It is distinctly evidenced by the presence of various migmatic structures such as stromatic, strictolithic, agmatic, dyktyonic, raft, schlieren, and ptygmatic. The contact of migmatite gneiss with other granitoids of the area is gradational; it is sharp to diffusing at places.

The rocks of the khondalite and charnockite groups have experienced regional migmatisation as well as retrogression with inflow of quartzo-feldspathic gneissic minerals resulting in the formation of different types of gneisses such as hornblende gneiss, biotite gneiss, garnetiferous biotite gneiss, quartzofeldspathic gneiss, augen gneiss, garnetiferous gneiss depending upon the parent rock composition. These rocks are grouped under migmatite complex. The migmatites are generally grey colored but at many places they are affected by late stage permeation of pink feldspar veins caused by potash metasomatism and are converted to pink migmatite. The complex gneisses are made up of hornblende-biotite gneiss,

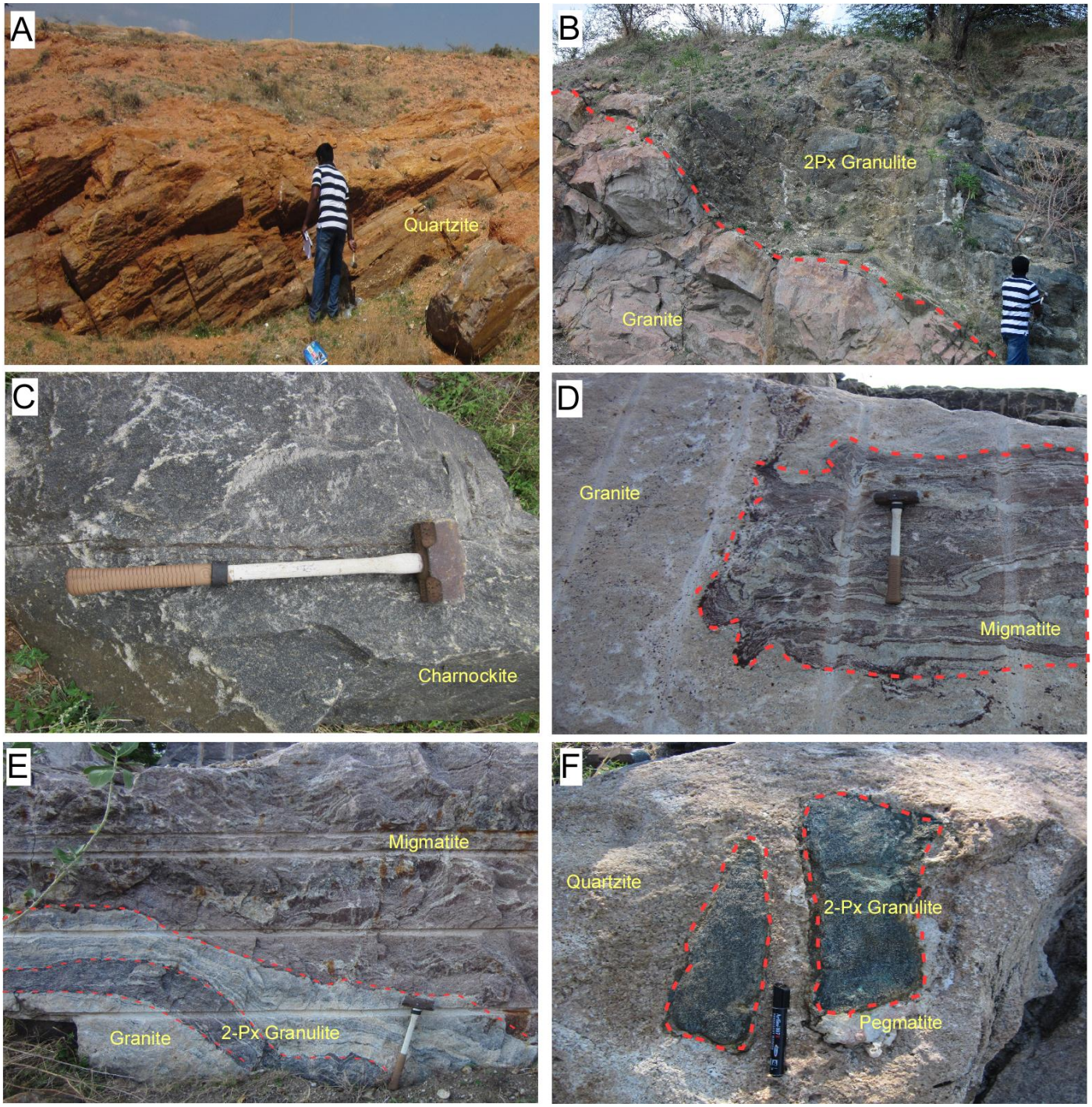

Fig. 3. Various locations of the study area in South-eastern Madurai Block a) Quartzite exposure in Puthiyamputhur b) Exposure of pyroxene granulite and granite bodies massive pluton c) Massive Charnockite d) Granite exposure Migmatite inclusion Ottudanpatti e) Migmatite gneissic granite inclusion d) Quartzite exposure enclaves of pyroxene granulite edges in pegmatite.

biotite gneiss and granitoid gneiss. Where different stages of their formation from meta-texites to diatexites (homophanous pink granite gneiss) are observed, similar migmatites occurring extensively in Kappikulam, Pasuthanai around Ottudanpatti is another example of regional migmatisation of granulite facies of rocks at different stages culminating in homophanous granite. The different granitoids belonging to the migmatite complex have also been identified in south-eastern Madurai Block.

Charnockite

Charnockites samples were collected from the Melathattaparai and Keelathattaparai region (location 1 N08.81165, E078.02778). This area is dominated by massive charnockite consisting of different minerals like orthopyroxene, clinopyroxene, biotite and feldspar in hand specimen (Fig. 3 C). Charnockite present in this area occupies the major part of the study area and almost all of the quarries are studied. Some formation shows foliations striking generally NW - SE with dip amount varying around 50° towards SW. Two sets of joints are seen horizontal and the others are vertically trending in different directions. Charnockite present in this area are meso-type, and occurs in green colour and are mostly medium grain in nature. Occasionally fine grained and coarser grained rocks are also noted. This rock consists of quartz identified by its colouress nature, vitreous luster and conchoidal fracture. It also consists of hypersthene that is green in colour. Cleavage, is present

uneven fracture is noted. Hornblende present is identified by its elongated form and its green colour.

The major rock type of the region is garnetiferous - hornblende - biotite gneiss. The gneisses occupy almost 70% of the study area. In the northern and southern parts of the block, some exposures and quarries show rocks with weak foliation while it does not exhibit any metamorphosed features.

Granitic Gneiss

The gneisses are leucocratic in nature. Granitic Gneiss samples were collected from the Kappikulam region (location 6 N08.97454, E077.96268). They are grey, pinkish grey, greenish pink in color. These gneisses show heterogeneous textures, and are mostly medium grained. Occasionally fine-grained textures are exhibited by the gneisses, while coarse grained rocks are noted rarely. Gneissic banding is exhibited by these rocks and the bands are parallel to subparallel. The widths of the bands very much from half a centimeter to two to three centimeter. At places, they are homogenous and devoid of gneissosity. Wherever gneissosity is exhibited, the dark colored bands are composed of hornblende and biotite. Also, garnet is present in some of the rocks and it may be called as garnetiferous - hornblende gneiss.

Granite

Hornblende and biotite bearing granites are exposed in the northern part of the study area as hillocks (Fig. 3 B). The association with charnockites is in some parts of the exposure. A number of granites or alkaline rocks of late – Proterozoic age is found emplaced within the older gneisses and granulites. Their distribution in linear arrays and proximal to known lineaments alludes to their genetic association.

The spatial distribution indicated that the granites are exposed very little above the ground in the northern part around Pasuthanai and their proportion decreases towards the central part Kappikulam (Location 6,N 08.97454, E 077.96268) and southern part Ottudanpatti (Location N 08.98603, E 077.97312), where they occur as criss-cross veins within the host, hornblende-biotite gneiss and the pelite-carbonate sequence.

The contact between the granite and the country rock is quite distinctive and no contact metamorphic or metasomatic effect could be seen in the latter. However, in the case of the contact between crystalline limestone and the granite, coarsening of calcite and mafic minerals and development of sphene are noticed within the former granite. Granite is generally massive and no planar fabric is developed even at the contact. Granites in the south-eastern Madurai Block might have been emplaced sync to post tectonic process with the last deformational event. The south-eastern Madurai Block granite comprises of two distinct phases of which one is the leucocratic phase and the other is the one pink phase both showing grain size variation from medium grained to pegmatititic.

Garnet Sillimanite Gneiss

Garnet Sillimanite gneiss with minor cordierite association are exposed in certain locations in the south-eastern part of the study area. The foliation of garnet – sillimanite gneiss is always seen parallel to the associated garnet-biotite gneiss. In certain locations in Melaparapatti (Location 22, N 09.03856, E 077.85246) and Keelaparapatti (Location 21, N 09.03553, E 077.85791) large amount of sillimanite with minor cordierite forms partial rims around garnet porphyroblasts are seen. The felsic portion is dominated by quartz, plagioclase and K-feldspar. Garnet-biotite-sillimanite gneiss (khondalite) are seen in considerable amount. The rock always have highly sheared and often exhibits augen structures. Garnets occur as phyroblasts of irregular, rounded or semi-rounded grains. The khondalite shows a general mineralogy of K-feldspars, quartz, garnet, biotite, sillimanite, cordierite, spinel, and plagioclase, with apatite and zircon as major accessories. Garnet, biotite, cordierite and spinel minerals define the compositional bands. In few places garnets show recrystallization into large porphyroblasts. A peculiar feature observed in some of the garnet grains is its flattened nature because of shearing. Pegmatitic veins are found common in most of the exposures, sometimes containing coarser crystals of graphite and often cordierite. The veins are always discordant to the gneissosity and are highly distorted or folded.

Quartzo-Feldspathic gneiss

These formations are found to occur towards NW of Mummalaipatti Domain (Location 19, N 09.02749, E 077.86454). It has a dull white color. It contains quartz and feldspar with gneissic texture. It also contain small amount of garnet and biotite, which were found to form along the bands of the mafic as well as felsic rocks.

Quartzite

In general, quartzites are metamorphic rocks, which are mostly non-foliated and have quartz as essential mineral. Quartzites are the metasedimentary formation of the region which may be derived from siliceous sediments. Hence quartzite occurs as patches with high relief as they are resistant to the weathering. They are generally dull white in colour and show mineral lineation. The linear minerals found are biotite and muscovite micas. Quartzite occur in Pudukottai (Location 34, N 08.74654, E 078.04827), Vallinagakapuram (Location 2, N 08.86413, E 078.02776), Vagaikulam (location 38, N 08.73500, E 078.00681), Puthiyamputhur (location 3, N 08.88217, E 078.02271), Keelamudiman (location 4, N 08.96493, E 077.99702), and Sirupadu (Location 49 N 08.74427, E 078.07323). The quartzites are normally pure and always ridges due to high resistance to weathering.

Quartzites are mainly exposed in the central part and are seen associated with biotite gneiss or layered gneisses.

Pyroxene Granulite

The major mineral assemblage of mafic charnockite (two pyroxene granulite) are clinopyroxene, orthopyroxene, hornblende, plagioclase, quartz and biotite along with minor amount of opaque minerals. In the field Pasuthanai area (Location 7, N 08.98603 E 077.97312), the rock has a very dark appearance due to the presence of high amount of mafic minerals.

Pegmatites

Major pegmatites of Neo-Proterozoic to Early-Palaeozoic age occur within the gneisses and also in granulites in the south-eastern Madurai block, from Thoothukudi district of Tamil Nadu. Several zoned pegmatites, with a core of white to smoky quartz as well as margins represented by quartz + feldspar intergrowth are exposed in Vagaikulam and

Ottapidaram areas. The pegmatite intrudes the khondalite supracrustals, typically metapelites, of the south-eastern Madurai Block. As in the case of intrusions in granites and charnockites, there is a marked difference in the mineralogy of pegmatites of different regions. The genesis of the pegmatites has been linked to tectonic and metamorphic evolution of the geological terrains and the timing of granite emplacement.

Pegmatite veins occur to the SE of Ambai (domain) (Location 61, N08.8075 E 077. 84083). It mainly contains quartz, feldspar and magnetite. Pegmatite vein has intruded through the fault plane and bedding and the layers have developed faulted pegmatite vein intrusion in the country rock.

Quartz Veins

Quartz veins occur near Ambai (Location 61, N 08.8075, E 077.84083) and Perumalpuram (Location 62, N 08.73861, E 077.015556). In addition, quartz veins are exposed in Mummalaipatti, Ettayapuram and also Sorakaipatti areas. Mumalaipatti Reef quartz vein, the carriers of these veins which are exposed intermittently occur as hillocks and ridges and that are confined to a well-defined shear zone. Some of them are seen trending in N-S and NE-SW direction. Vertically dipping quartz veins are seen exposed in the plains between Ottudanpatti domain .Mummalaipatti outer hillocks quartz-vein zones extend intermittently up to Mummalaipatti inner. These veins are characterized by milky white quartz displays highly sheared nature.

Discussion

The south-eastern Madurai Block is a high grade granulitic terrain in the peninsular India. Petrologically, the term granulite denotes, medium to coarse grained size recrystallized rocks formed at a temperature range of 700° to 900°C and in a pressure range of 2 to 14 kb. The rock type in the study area generally shows granulitic texture with feldspar and quartz and has deformed structures. Southeastern Madurai Block charnockite and granite both are associate with quartzo-feldspathic rock in the two pyroxene facies, were the charnockite are restricted finally foliated and it transitional zones. Quartzites might have formed from the siliceous sediments. At some places chert is noticed along with quartzite. In the transitional zone of the study area both quartzites and lime stones are present. At some places quartzites are found folded along with calc-granulites. The presence of high grade metamorphic mineral assemblage indicates that the rock of the study area has undergone granulitic facies of metamorphism. Hence, the study area is considered as a metasedimentary origin. Some metasediments are complexly folded. This kind of tectonic disturbance is more prominent in the transitional zone. The folding is more open and is characterized by number of basins and domes. Faults are prominent at some places and are tectonically less disturbed. The South-eastern Madurai Block consists largely of weaker zone. The area has undergone a long period of geologic evolution and prolonged high grade metamorphism.

Conclusions

An extensive field investigation of the south-eastern part of Madurai block of the SGT has been attempted to identify its litho-units. The South-eastern Madurai Block has various litho units such as, charnockites, quartzofeldspathic-gneiss, khondalite, granite, quartzite, pyroxenegranulite, pegmatite, gneissic and granulites. However, the geological relations between these rock types are not well understood. It is therefore important to establish the petrology, age and tectonic settings of various litho-units. Hence, the future studies are required to consider the above aspects so as to build a general view on the evolution of Madurai Block in the SGT assembly.

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