CHAPTER 2

MADURAI GRANULITE BLOCK-AN OUTLINE
2.1 INTRODUCTION

Precambrian crust of the Earth constitutes nine cratons, namely regions in Asia and Indian subcontinent, Europe, Greenland, North America, South America, Africa, Australia and Antarctica. The Indian craton including Sri Lanka forms about 3% of the total area of Precambrian crust. The Indian Precambrian terrain include the Dravidian shield (the Western Dharwar craton, the Eastern Dharwar craton and the Southern Granulite Terrain) in the south, the Eastern Ghats in the east, the Chotanagpur-Singhbhum in the northeast and the Aravallis in the northwest (Goodwin, 1996) (Fig 1.1). The oldest rocks of Indian craton lie in the Aravallis, the Singhbhum and the Dharwar regions (~3.4 Ga). Major events of orogeny occurred during 3.0 Ga and 2.5 Ga, in which the later marks a boundary for Archaean-Proterozoic ages. It is further characterized by high-grade metamorphism, which in turn has resulted in consolidation of South Indian Shield (Goodwin, 1996, Jayananda and Peucat, 1996).

2.2 THE SOUTHERN GRANULITE TERRAIN (SGT)

The SGT is one of the best-exposed granulite terrains suited to address some fundamental problems concerning the origin and development of granulites. The contact between Dharwar craton and the SGT is marked by a series of crustal zone shear zones like the Moyar-Bhavani-Attur shear zone to the south of the regional orthopyroxene isograd. Geochronological studies reveal that the PCSZ forms a major divide between older Archaean granulite crust in the north and the younger supracrustal dominated crust in the south (Harris et al., 1994, 1996;
Brandon and Meen, 1995; Loyd et al., 2004). But the Noyil-Cauvery shear zone marks the tectonic boundary as well as the Archaean-Neoproterozoic boundary resulting from collision with a craton in Africa or Antarctica (Ramakrishnan, 2003), later through which some Pan-African granitic emplacement has taken place. Thus the major Proterozoic domains in India fall in the SGT and comprise of the Nilgiri Block (NB), the Madras Block (MB), the Madurai Granulite Block (MGB) and the Trivandrum Block (TB) (Hariss et al., 1994; Jayananda and Peucat, 1996; Braun and Kriegsman, 2003). The major shear zones demarcating these blocks are, the Moyar shear zone (between the transition zone and the Nilgiri block), the Moyar-Bhavani and the Palghat-Cauvery shear zone (between Madras/Nilgiri Blocks and the Madurai Granulite Block) and the Achankovil shear zone (between the Madurai Block and the Trivandrum Block) (see Fig 1.2).

The NB and the MB are characterised by the occurrence of enderbites and charnockites where as the MGB and the TB are dominated by metasedimentary rocks with abundant tectonothermal activity in the Pan-African time (Choudhari et al., 1992; Santosh et al., 1992; Bartlett et al., 1995; Jayananda et al., 1995a). The main granulite facies metamorphism of most of the tectonic blocks of the SGT is found to be occurring around 750 ± 50°C temperatures and 5-9kb pressure at 2.5Ga ago (Harris et al., 1982; Peucat et al., 1989; Choudhari et al., 1992; Santosh et al., 1992; Srikantappa et al., 1992; Bartlett et al., 1995; Jayananda et al., 1995a; Jayananda and Peucat, 1996). But some models proposed in the recent studies display that granulite-facies metamorphism in the SGT has occurred as part of the east Gondwana (Eastern Africa,
Arabian–Nubian shield, Seychelles, India, Madagascar, Sri Lanka, East Antarctica and Australia) assemblage during 750-530 Ma (Meert, 2003) or by the collision between East and West Gondwana at a time span of 590-520 Ma (Meert et al., 1995). Appropriate geochronological results infer protracted heating of the deep continental crust during this time, which is also referred as the poly phase Proterozoic evolution of the SGT. Abundant evidences put forth this Pan-African activity, which include amphibolite-facies gneiss formation at 550 Ma (Hansen et al., 1985), the peak metamorphic age of the Kodaikanal granulites, just south of the Palghat-Cauvery lineament at ~550 Ma (from garnet-whole-rock Sm-Nd ages) (Jayananda et al., 1995a). The Nd isotopic patterns also indicate considerable formation of juvenile crust and/or reworking of Archaean crust throughout the Proterozoic (Harris et al., 1994; Brandon and Meen, 1995).

2.3 GEOLOGICAL FRAMEWORK OF THE MADURAI GRANULITE BLOCK

The MGB occupies the largest portion of the SGT and it represents a composite mid to lower crustal domain. It has played a fundamental role in characterising the Proterozoic geodynamic evolution of the SGT and its position within East Gondwana. The location of the MGB defined by many early workers is as directly south of the PCSZ and north of the ACS. On contrary to the earlier studies, Cenki and Kriegsman (2005) highlights a poor structural control for different granulite blocks in the SGT as well as the rocks within it. The PCSZ and the ACS, which are defined as the northern and southern boundaries of the MGB, has been reconstructed in their new study. A recently defined lineament of Karur–Kambam–Painavu–
Trissur (KKPT) proposed by Ghosh et al. (1998) runs within the MGB. An Achankovil Nd unit (AU) is defined by the workers as a relatively young unit (of Nd modal ages 1.3-1.6 Ga) approximately overlaps the ACS in the western half where as it is diverged in the east.

The MGB is a high-grade granulite facies terrain and the major rock types in the block include charnockites, mafic granulites and different gneisses (Fig 2.1). The MGB can be lithologically divided into a western region and an eastern region; MBK in Kerala and MBTN in Tamil Nadu (Cenki and Kriegsman, 2005). The MBK is characterised by two different groups of hornblende—biotite and orthopyroxene—biotite (charnockite) gneisses, one being quartz rich and the other feldspar rich. While the eastern part, MBTN is composed of massive charnockites and enderbites with heterogeneously distributed quartzites and calc silicate series of rocks (Cenki and Kriegsman, 2005). Garnetiferous rocks are relatively less in the MGB when compared with the adjacent blocks, but hornblende, biotite and orthopyroxenes are present all over the area. A sharp boundary between hornblende and garnet occur in the southern boundary of the MGB, which is elucidated as the difference in composition of protolith rather than a difference in the metamorphic grade. Cenki and Kriegsman (2005) propose a volcano-sedimentary sequence in the MGB.

2.3.1 Lithology

The important rock types found in the MGB, their physico-chemical properties and the characteristic mineral assemblages are given below.
Fig 2.1. Geological map of MGB (compiled after GSI, 1995)
2.3.1a Charnockites

Charnockites present in the block are typically coarse to medium grained with overall grey colour. Presence of smoky/blue quartz as well as plagioclase feldspars is the causative factor for this appearance. The mafic minerals constitute less than 25% in these rocks. Other than the massive varieties, there are charnockites showing gneissic appearances due to the quartzo-feldspathic bandings together with the arrangement of pyroxenes in the foliation. At several places the ferromagnesian bands are seen mobilised with the charnockites (Mohan, 1996). In general the major mineral assemblage of the rock is orthopyroxene (hypersthene), plagioclase, alkali feldspars and quartz. Garnet is some times present in the rock.

2.3.1b Mafic granulites

Mafic granulites, differently refered as basic granulites or pyroxene granulites are high-grade rocks having high Fe and Mg. The major constituents are orthopyroxene, clinopyroxene, plagioclase, hornblende and quartz. Mafic granulites sometimes show foliated nature. In the MGB the occurrence of this peculiar rock is not concentrated in some particular zones, but seems to scattered through out the area.

The outstanding variety of granulites is one, which have sapphirine. The appearance of this mineral is inferred to its high temperature genesis. The occurrence of sapphirine bearing granulites is reported from Perumalmalai, Ganguvarappatti and Panrimalai in Tamil Nadu, the northeastern part of the MGB (Mohan et al., 1996b; Brown et al., 1992;
Sivasubramanian et al., 1991; Grew, 1982). The major mineral assemblage in this rock is sapphirine, orthopyroxene, sillimanite, spinel, and phlogopite. Garnet is rarely present.

2.3.1c Gneisses

**Hornblende-biotite gneiss:** Hornblende-biotite gneiss forms a major rock type in the MGB. Usually this rock is found associated with charnockite bodies as a product of retrogressive metamorphism occurred in the block. A vast extend of this rock is found almost around the Munnar granitic body on the eastern side of MBK and many other places adjacent to charnockites. It is inferred that the high temperature effects during the Munnar granitic intrusion may have influenced in the formation of this gneissic body. Dehydration mechanism occurred by high thermal influx has led to the development of hornblende from orthopyroxenes. As the name indicates the major minerals present in this gneiss are hornblende and biotite with intermittent quartzo-feldspathic bands.

**Garnet-biotite gneiss:** The occurrence of garnet-biotite gneiss (Leptinite) is mostly traced in the southern margin of the MGB, and in some parts of central Kerala and Tamil Nadu. These rocks are characterised by a massive fabric due to the predominance of K-feldspar and quartz. These rocks associated with charnockites are some times host rock for graphite mineralization.

**Garnet-cordierite-sillimanite gneiss:** Garnet-cordierite sillimanite gneisses are found as bands along the Kodaikannal and Madurai region (Prakash, 1999). Biotite and 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 ACS (Sinha-Roy et al., 1984; Santosh, 1987) and another occurrence is reported from Kottayam district, central Kerala. The cordierite bearing gneisses are generally coarse grained with quartz, plagioclase, perthite, cordierite, garnet and biotite as the major minerals. Varghese (1990) has reported the presence of hypersthene or sillimanite also in this gneiss.

Migmatitic gneisses: Migmatite, a megascopically composite rock consists of two or more petrographically different components, one of them may be the country rock generally in a more or less metamorphic stage termed as "mesosome", the other is of pegmatitic, aplitic, granitic or generally plutonic appearing phase termed as "leucosome". The presence of relict orthopyroxenes in quartzo-feldspathic gneisses gives evidences of the magmatic activity that had affected in the MGB. These quartzo-feldspathic gneisses that are showing a mixed texture are termed as migmatitic gneisses. Such rocks in the MGB are sometimes refered to as migmatitic charnockites (Mohan1996). These rocks are noted in the contact zones of sapphirine bearing granulites in the MBTN, in the eastern side of the MBK, in and around the Munnar granites etc. Gneissic layerings of dark and white bands are seen in the rock. The dark bands are mostly biotite rich. The quartzo-feldspathic bands are rich in K-feldspar, perthite with minor quartz and garnet.

2.3.1d Intrusives

Alkali granites and syenites occur widely in the East Gondwana continents such as India, Sri Lanka, Madagascar, East Antarctica and Australia. Most of these alkaline magmatic activities are associated with the
Proterozoic lineaments and contemporaneous with the Pan-African activities widely reported in different parts of the Gondwana fragments (Rajesh and Santosh, 1996 and Rajesh et al., 1996). The major alkaline plutons in the MGB are the granite bodies of Chengannoor, Pathanamthitta, Athiringal, Munnar, Pariyaram, Kizhakkanchery, Vadakkanchery and syenite bodies of Sholayar, Mannappra and a carbonatite body at Kambammettu. These intrusives are metaluminous to peralkaline in nature with high SiO₂ and low CaO and Sr resembling the characteristics of A-type granites (Santosh and Nair, 1983a; Santosh et al., 1983; Santosh and Thara, 1985; Santosh 1989; Thampi et al., 1993; Rajesh and Santosh, 1996; Rajesh, 2004 etc).

Mafic dykes, which have intruded in almost all parts of the Peninsular India, plays a significant role in the geologic history of the Precambrian terrain, but no much studies are available on this. The MGB is also characterised with abundant mafic dyke swarms. They show a general trend of NNW-NW. Minor sets of dykes are also noticed with ENE-WSW trend (along the Bhavani valley). NW-SE trending dyke swarm in the MGB, which in turn extends up to ACS, is truncating a major dyke swarm in the northern Kerala region. This basic magmatism is also considered as representing Proterozoic as well as Cretaceous magmatic events (Radhakrishna et al., 1986, 1990; Murthy, 1995).

2.3.2 Structure

The Precambrian crystalline rocks of the SGT are multiply deformed at different periods in the geologic past. The major shear zones can be considered as one of the products of those complex deformational
histories. These are but comparatively of younger age. Deformations in the MGB, reflects the partial reorientation and transposition of earlier foliation into later trends, with altering low strain and high strain domains. The Western Ghats is a major geomorphic feature, which divides the MGB into the Kerala part and the Tamil Nadu part. It forms the western limb of a NNW plunging synclinorium. The axis of the synclinorium extends from Belgaum in the north to Tuticorin in the south (Soman, 2002). The overall geometry reflects the superposition of at least two regional fold generations reworking the main gneissic layering. Structural evolution around three groups of structures are noticed in the MGB; D1, D2, and D3 (Cenki and Kriegsman, 2005). D1 is the main foliation-forming event, which is synchronous to the main ultra high temperature metamorphic event. It has affected in a regional scale and produced a well-developed gneissic layering. The regional strikes of the D1 is NW-SE TO WNW-ESE, with a steep dip towards SW. D2 are less pervasive deformation and are less affected to the internal fabric of the rocks. This actually represent the regional scale refolding of the earlier structure during 700-800 Ma (Ghosh et al., 2004) with a NNE-SSW trend in the highlands and a NE-SW trend at the northern most part of the lowlands of the MGB. D3 is characterised by strain partitioning into localized high strain zones with WNW-ESE and W-E trend (the ACS and the Palghat lineament respectively). This is believed to be of early Paleozoic age (530-550 Ma), which is normally found coexisting with the Pan-African orogeny, major charnockitization, granitic intrusions etc in the MGB (Ghosh et al., 2004).
Based on these conclusions a biphase structural model has been put forward by Cenki and Kriegsman (2005). It says that in the first phase the region has underwent the D1 deformation which is dominated by regional top-to-the-N displacement, but locally close to the PCSZ, top-to-the S displacement. The second phase comprises of a more complicated refolding episodes, but giving a general movement, which ended in sub horizontal shortening.

2.3.3 Metamorphism

2.3.3a Previous P-T estimates

P-T estimates of Indian Peninsular Shield from mineral equilibria and fluid inclusion studies fall in the range of 5-10kb and 650°C to 950°C, where as the peak metamorphic grade is in a higher range as revised by Mahadevan (1996). In general, the P-T estimates for the different tectonic blocks of the SGT is as follows: an intermediate pressure of 6kb and 750° ± 50°C has been reported from Madurai Granulite block and a high P-T range of 8kb and 800°± 50°C is reported from Nilgiri block. The KKB and the rocks in Kodaikanal gave an intermediate pressure of 6kb and a temperature near to the Madurai Granulite block assemblage (Mahabaleshwar, 1993). A combination of mineral equilibria studies and studies on fluid phases in the rocks of KKB by Santosh (1986b, 1987) define a similar P-T range.

In the northern Madurai block peak metamorphic conditions of 800°C and 8kb have been observed from the sapphire-bearing granulites of Ganguvarpatti (Mohan and Windley, 1993; Mohan et al., 1996). Similarly
Ravindrakumar and Chacko (1994) report a high-grade metamorphism (9-10 kb pressure and 900°C) in and around the Palghat gap region. Near peak metamorphic conditions of 10.2 kb and 900°C are reported from the Nilgiri block (Raith et al., 1990; Srikantappa et al., 1992). However the peak metamorphic temperatures recorded by the charnockites, calc silicate rocks, and sapphirine bearing granulites from the SGT are more than 900°C, but the pressure falls in a wide range (Chacko, et al., 1996; Brown and Raith, 1996; Raith et al., 1997; Satish-Kumar et al., 2001).

2.3.4 Geochronology

Isotopic dating during the last two decades has played a relevant role in understanding the geochronological framework of the SGT. Based on these techniques different age provinces with distinct pre-crustal histories have been recognized in the SGT. Earlier workers believed that the whole south Indian shield was evolved in a common granulite facies event at the end of Archaean. But the recent studies put forth different age history ranging from 3000 Ma to 550 Ma for the terrain (Yoshida et al., 1996). New results on U/Pb/Th single zircon and monazite dates from six structural transects across regional shears signifies seven tectono-thermal events in the SGT during 2.5 Ga, 2.0 Ga, 1.6 Ga, 1.0 Ga, 0.8 Ga, 0.6 Ga, 0.55 Ga and two episodes of charnockitization at 2.5 Ga and 0.55 Ga (Ghosh et al. 2004). The oldest rock reported from the terrain is of 3358 ± 66 Ma age (Beckinsale et al., 1980). In the Dharwar Craton U-Pb SHRIMP of detritel zircon is reported by Nutman et al., 1992, is of about 3580 – 3130 Ma. Comparatively younger ages (2.6 – 2.5 Ma) are reported from the southern margin of Dharwar Craton–around Kolar–Bangalore, Krishnagiri,
Southern Closepet batholith and Gundepet areas (Krogstad et al., 1991; Peucat et al., 1989, 1993; Jayananda et al., 1995b), which are resulted from the juvenile accretion associated with reworking of older continental crust.

The MGB, which is the largest tectonic part in the SGT, is characterised by some of the highland granulite massifs in South India like, the Palani, the Anamalai and the Cardamom hills. Ages of these granulite massifs range from Mid- to late Proterozoic (i.e. from 2.5 Ga. to 0.5 Ga) (Jayananda et al., 1995a; Miller et al., 1996; Mohan and Jayananda, 1999). The MGB is an ancient crust with preserved protolith ages, which has been reworked in the Pan-African tectonothermal event, with considerable additions from the mantle. U-Pb data on zircon has gained 1.85 Ga whereas the whole rock isochron age from a charnockite body from Kodaikanal show 553±15 Ma (Jayananda et al., 1995a). The major Protolith in this block has been reported to be of ages around 2.5 Ga. (Bartlett et al., 1998) and Pan-African tectonothermal events evidenced as incipient charnockite are of 550-560 Ma age. (Jayananda et al., 1995a; Bartlett et al., 1995). These ages corresponds with the Rb-Sr whole rock isochron ages by Hansen et al. (1985). The Nd model ages (3.0-2.0 Ga) and zircon ages (2.43-2.1 Ga) from the MGB, which is a marked discrepancy reflect that the Proterozoic crust as a remobilised basement. Due to the lack of sufficient age data for different components and due to the difficulties in delineating such components of the terrain it is not clear how much of the crust represents the original basement and how much is added later.
2.3.5 Economic mineral deposits

The Proterozoic era is considered to be the greatest and varied period of mineralization all over the world. The world's leading deposits of gold, gemstones, graphite, molybdenite, iron, chromium, copper and manganese, other rare metals, mica, cordierite etc were formed during this period.

One of the major economic minerals reported from the MGB is graphite. The geological and structural features of the graphite occurrences of Kerala indicate their similarity to some world famous graphite deposits in Sri Lanka and Madagascar (Rajesh-Chandran et al. 1996). In the MGB, graphite is concentrated in Kottayam, Ernakulam, and Idukki districts of Kerala state (Radhika et al., 1995; Soman, 2002) and some isolated pockets in Tamil Nadu. Based on the mode of occurrence the graphite deposits of the MGB can be classified into four major categories.

1) Disseminated flakes and segregations in high grade rocks
2) Graphites in pegmatites
3) Shear / fracture zone hosted graphites
4) Graphites concentrated in weathered rocks and laterites

Molybdenite is another economic mineral reported from the MGB. It is usually associated with the Pan-African alkaline magmatism. So the mineral is found in the granite and syenite plutons in the terrain. Chengannur granite is a major molybdenite bearing pluton in the southern boundary of the MGB. Spatial relationship of individual molybdenite occurrences and their parent rocks with seismically active deep folds and shear margins suggest a metallogenic episode related to taphrogenesis of
the continental margin (Santosh and Nair, 1983b). Molybdenite is also seen as disseminations in quartz, K-feldspar and hornblende in the pegmatites.

Many other salient mineralizations were also reported from the MGB. Odara pegmatite near Thiruvalla, Kerala is having columbite and tantalite together with aquamarine variety of beryl (Santosh, 1984). Books of mica are reported from Alleppey and Punalur. Sillimanite has been reported from Alleppey, Ernakulam, Kottayam, and Palghat districts in Kerala and from many places in Tamil Nadu. Minor deposits of magnetite are found in Kottayam, Plaghat and Trichur in Kerala and magnetite-quartzite bands from places like Selam in Tamil Nadu (Rajesh-Chandran et al., 1996). Rich placer concentrations of monazite, ilmenite, rutile, zircon, cheralite, sillimanite and garnet are common in the coasts of Kerala and Tamil Nadu, and the MGB is among the presence for these deposits.
They were first found in full variety at St. Thomas' Mount and Plallavaram, 10 miles south of Madras city; from quarries in these localities large quantities of rocks have been obtained for building and ornamental purposes in Madras. Subsequently the same rocks were found to make up the mountain masses of the Shevaroys, Nilgiris, the Palnis and the great ridge of high ground forming part of the Western Ghats, stretching southwards as far as Cape Comorin and reappearing above the sea level in Cylone.

- Thomas Holland

CHAPTER 3

FIELD RELATIONSHIPS AND PETROGRAPHY