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Geochemical Signatures of Gneisses and Granulites of Marthandam, Tamil Nadu, India

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ABSTRACT

The Southern Granulite Terrain of South India is a collage of high grade granulite blocks and major transcrustal shear zones. The study area falls in the southern part of the Kerala Khondalite Belt. The area exposes a series of rocks which comprises of Garnet Biotite Gneiss (GBG), charnockite and pyroxene granulite along with intrusive syenite. Geochemically the gneisses are peraluminous showing an alkali-calcic affinity; while massive charnockites are peralkaline. The gneisses are having numerous patches of incipient charnockite that are peraluminous in nature. Generally it is inferred that strongly peraluminous magmas derived from mature pelitic sediments may produce S-type igneous rocks. The gneisses of the area are not so intensely peraluminous, discounting their being categorized as metapelitic. The source rocks are intermediate to felsic igneous rocks as well as products of partial melting of metaluminous mafic minerals. The gneisses of the Nagercoil massif falls in the within plate granite field (WPG) of Nb vs. Y and Rb vs. (Y + Nb) plot. The present work is an attempt at constraining the geochemistry and tectonic environment of the gneisses and associated rocks of the Marthandam area.

KEYWORDS: *Southern Granulite Terrain, Trivandrum Granulite Block, Incipient charnockite*

INTRODUCTION

The gneisses and charnockites of Trivandrum Granulite Block (TGB) (Chetty[1], 2006) have been studied by various geologists. The discussions about their protolith and genesis became a topic of debate over the years. Although a number of postulates were available for these rocks, stating a purely igneous or metamorphic origin, they are not at all satisfactory. In modern literature 'charnockite' is a general term applied to orthopyroxene-bearing granitic rock of purely igneous origin or an orthopyroxene - bearing granitic orthogneiss observed in a granulitic terrain (Frost[4] et al., 2001). They are seen in almost all tectonic and rheological conditions of our planet. The texture, mineralogy and geochemistry of these granulites vary from time to time. In Precambrian terrains they occur as dark green coloured, massive rocks associated with gneisses of acidic nature. The younger charnockite are light grey colored similar to alkali granites. Moreover they are subjected to intense metamorphism transforming them texturally and mineralogically modified lithological units. As a result some charnockites may retrograde into gneisses and vice-versa. Lensoidal patches of charnockites are developed in gneisses similar to charnockites and are named as incipient charnockites or hydration patches. They form a major lithological entity in parts of the Southern Granulite Terrain (SGT) especially in TGB associated with gneisses and charnockites. Here we present a geochemical characterization of gneisses, charnockites and associated incipient charnockites of the less studied southwestern part of the Southern Granulite Terrain.

GEOLOGIC SETTING

Southern Granulite Terrain (SGT) is a collage of various high grade granulite blocks and major transcrustal shear zones (Drury and Holt[3], 1980). The granulite rocks are well exposed throughout the terrain, except the linear stretches along the coasts where they are overlain by Mesozoic and Tertiary sediments. High grade gneisses interlayered with charnockites and two-pyroxene granulites form the main rock types of the Trivandrum Granulite Block (Figure 1).

The study area, Marthandam, is located in the Kanyakumari district of Tamil Nadu forming the southern tip of Indian Peninsula. Here a series of metamorphic rocks, mainly gneisses and charnockite, are exposed. It falls between north latitudes $8^0$10'& $8^0$25' and east longitudes $77^0$10' and $77^0$20'. The major outcrops have a series of rocks namely garnet biotite gneiss, charnockite and pyroxene granulite. A well-known syenite body, Putteti syenite, is also seen intruding these rocks in parts (Figure 2). The gneisses are mostly foliated and they follow the predominant NW-SE structural trend, similar to the rocks in other parts of the granulite block. The foliations are well preserved in charnockite by the linear arrangement of garnet grains and are formed even in the hydration patches (Figure 3). These incipient charnockite patches are developed in the various part of an area and are hosted by garnet biotite gneiss (Figure 4). They are exposed in working quarries of Parakani, Thandumani, Andur, Mattur, Cherukol etc. The gneisses are invariably migmatised with bands and lenses of quarzo-felspathic gneiss or pegmatites of varying dimensions giving an indication about presence of recrystallised melt pockets of acidic magma in the terrain.

Charnockite forms the typical mafic suite in many Precambrian continental crusts. Both gneissic and massive charnockites are associated with their incipient variety in the gneisses. Gradational contact is alsonoticedbetween garnet biotite gneiss and foliated charnockite (Figure 5). In Parakani ($8^0$15'24'', 77^0 09'98'') the dehydration zones (incipient charnockite) have developed in the migmatizedgneisses. This could be due to fluid induced melting or dehydration melting. Rajesh[10] et al. (2011) has suggested the possibility of both the process working in tandem.Here a melt accompanied the fluid-induced dehydration and the melt was clearly late with respect to fluid movement. Incipient charnockite in some localities contain graphite flakes. An increase in the abundance of graphite while passing from GBG into incipient charnockite has been reported (Santosh[11, 13] et. al., 1990, 1991). It is believed that the CO_2 rich fluids, which were instrumental in dehydration and charnockite formation, precipitated the carbon in the form of graphite in the charnockite. Multiple episodes of dehydration, followed by hydration are evident in the outcrops of the area. Orthopyroxenes occur in association with coarse garnet grains in incipient charnockite (Figure 6).

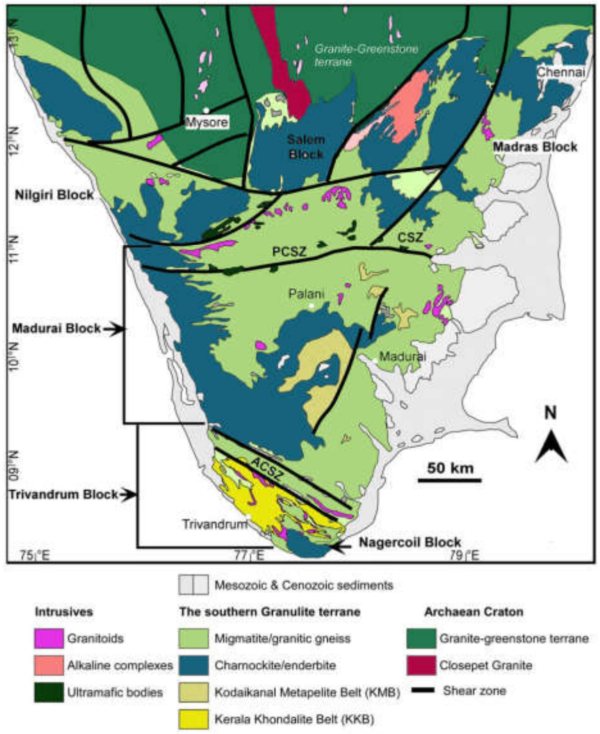

Figure 1: Geological map of SGT (modified after Geological Survey of India[5] (1994), Santosh[12] et al., (2009a).

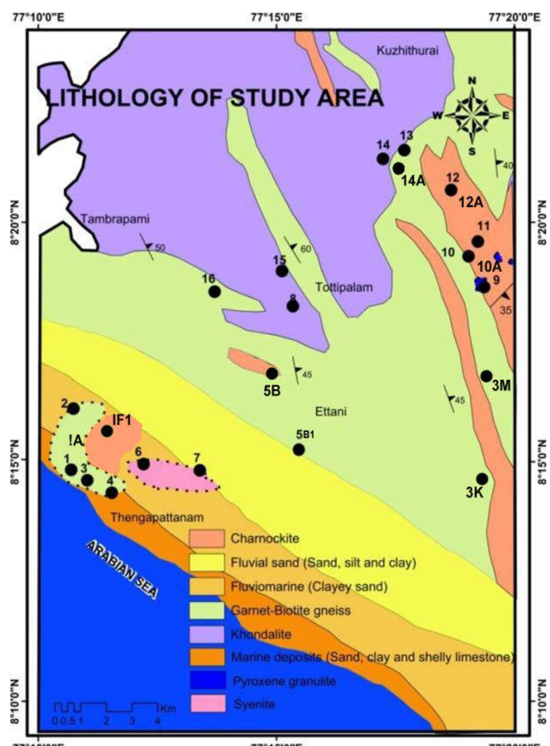

Figure 2: Geological map of the study area with sample locations

Figure 3: Aggregated melt pockets formed parallel to the foliations in GBG.

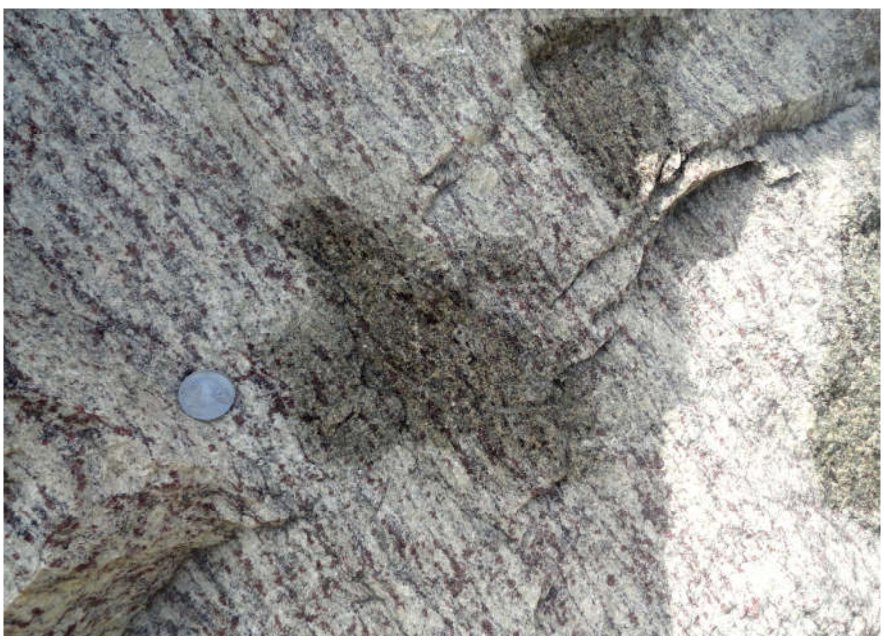

Figure 4: Patches of incipient charnockite in GBG.

Figure 5: Gradational contact between gneiss and foliated charnockite.

Figure 6: Orthopyroxenes associated with garnet porphyroblasts in incipient charnockite.

PETROGRAPHY

Garnetiferous biotite gneiss (GBG) is a coarse to medium grained, well foliated and well jointed rock composed mainly of quartz, feldspar, garnet and biotite. Quartz and feldspars form the light coloured layers whereas the dark bands consist of fine flakes of biotite and small euhedral grains of garnet. The alternate arrangement of quartzo-feldspathic and garnet-biotite bands gives a characteristic gneissosity to the rock.

Quartz, orthoclase, plagioclase, garnet, biotite, zircon, apatite and opaques are the important minerals present in the rock (Figure 7). Quartz forms the major mineral along with orthoclase and plagioclase feldspars. The twin lamellae of plagioclase have different width; some pinch out or tapers along the length of the grain. The intergrowth textures are common; myrmekite is seen at the quartz-garnet boundary (Figure 8). Garnet has inclusions of apatite, zircon, biotite and quartz. The gneissosity is governed by the parallel arrangement of biotite grains that are arranged perpendicular to the direction of maximum stress. Zircon is the common accessory mineral in the gneiss and is seen as independent grains and as inclusions in garnet, biotite and cordierite. Apatite is also present in very small amounts, mainly as inclusions in garnet.

Varieties of gneisses are characterized by the gradual increase and decrease of the major minerals; in parts they get altered. The quartzo-feldspathic gneisses are almost devoid of garnets, as it has been consumed in the process of charnockitisation. The distinct reaction textures for this transformation have not been observed in any of the samples collected. The inclusions of quartz and biotite in garnets indicate the commencement of the break down reactions in garnet.

Charnockite is the major granulite found in the area with medium grained granoblastic texture. Charnockite consists of quartz, potash feldspar, plagioclase, hypersthene, accessory opaques and zircons. They may contain garnet, either as small grains or as porphyroblasts. The dominant feldspar seems to be microcline. Perthite, quartz, plagioclase and hypersthenes form the major minerals with some biotite and opaques.Different varieties of perthites (line, string, flame, spindle, bead and rod) are also noticed (Figure 9). Smaller inclusions of quartz, garnet and biotite are seen in perthite. Hypersthene is the dominant mafic component in the rock that has strong pleochroism (Figure 10). Biotite is seen closely associated with hyperthene and are mostly altered and crudely aligned. Biotite may be the product of alteration of hypersthene. Opaques with different outlines are scattered in the rock.

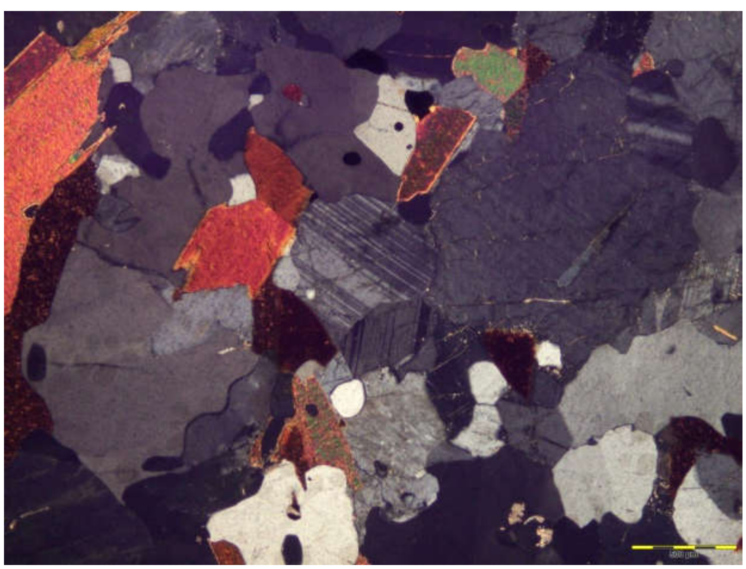

Figure 7: Mineral assemblage in garnet biotite gneiss (XPL)

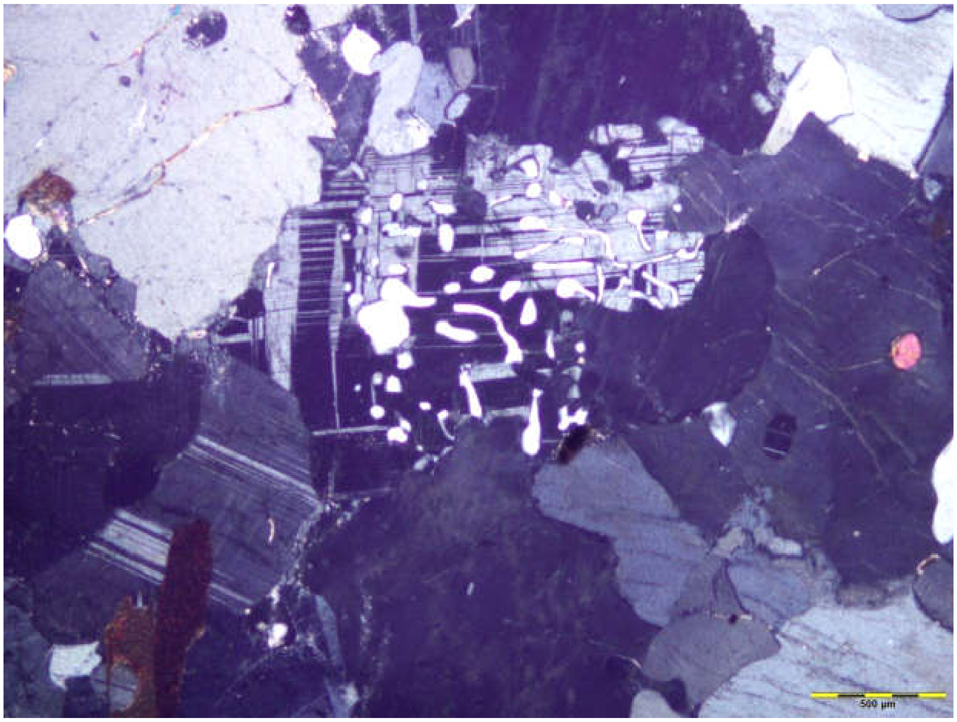

Fig 8: Myrmekites in garnet biotite gneiss (XPL)

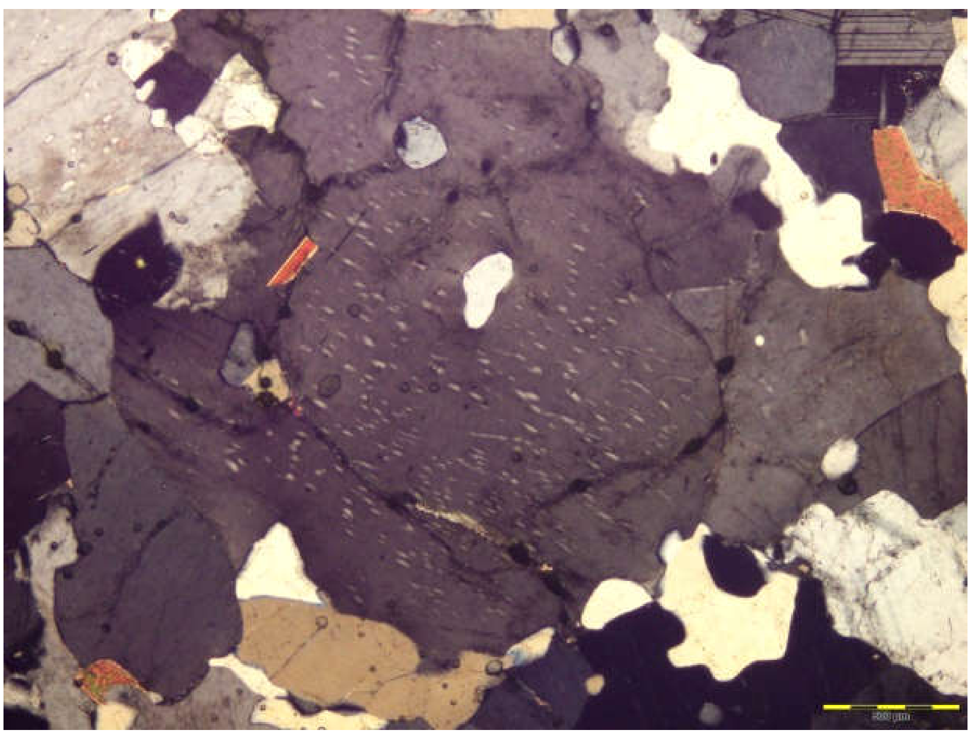

Figure 9: Perthites (bead) in incipient charnockite (XPL)

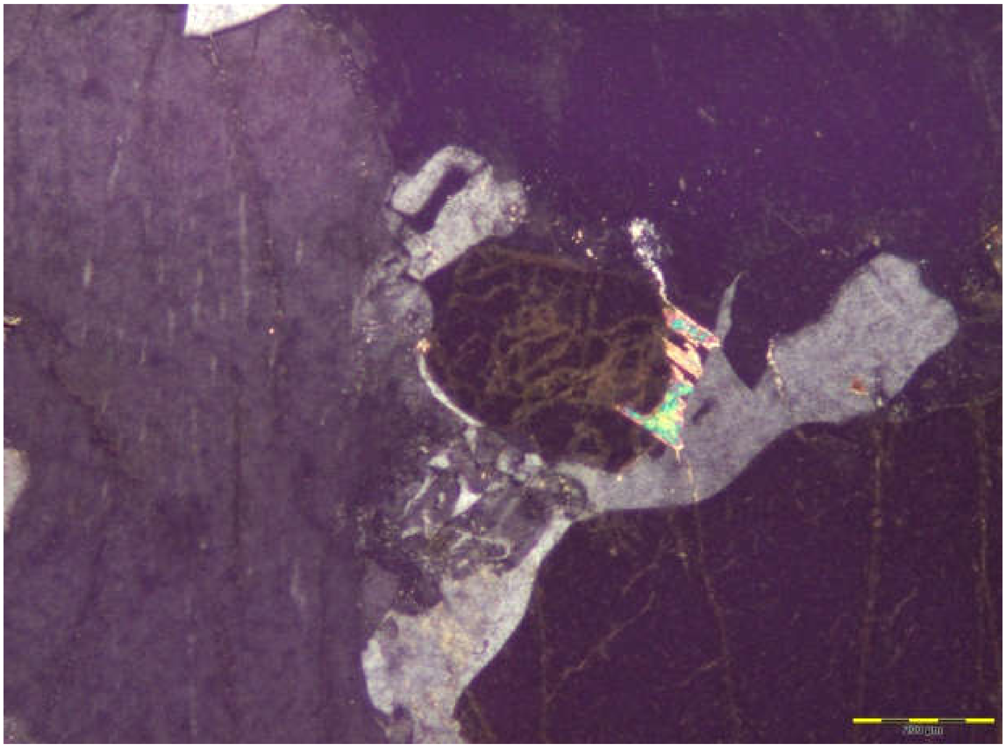

Figure 10: Altered hypersthene in incipient charnockite (XPL)

GEOCHEMISTRY

The selected rock samples of gneisses (5), charnockite and incipient charnockite (2 each) were analyzed with the help of X-Ray Fluorescence technique at NCESS Akkulam, and the results obtained were used for the present study.

Major elements

Majority of the gneisses have SiO_2 > 64% (Table.1). The range of SiO_2 in gneisses is narrow (64.88 to 69.15 wt %). The Al_2O_3 content is moderate to high (14.26 and 17.09 wt %) and this has given rise to normative corundum in all the samples. Corundum suggests the presence of excess alumina over $CaO+Na_2O+K_2O$. The Na_2O and K_2O content ranges from 2.2 to 3.6% and 4.1 to 5.52% respectively. The content CaO, MgO, FeO, TiO_2 and MnO gradually decrease with increase in SiO_2. The mean values of CaO are low and ranges between 1.72% and 3.02%; MgO and TiO_2 content is 0.63% and 0.68%. The amount of P_2O_5 is very low (range 0.07 to 0.35%) and is mainly concentrated in the accessory apatite. Major normative minerals include quartz, orthoclase, albite and anorthite. The alumina content of magmas decreases with progressive magmatic differentiation due to the crystallization of feldspars.

Geochemical data of charnockite shows distinctive geochemical pattern for major oxides. The mean SiO_2 content of charnockite ranges from 58 to 66%. The total iron content ranges from 4.199 to 8.006%. The K_2O and Na_2O content range from 3.572 to 6.494% and 2.09 to 4.479%. The CaO content of charnockite ranges from 2.15 to 6.76%. MgO content in the charnockite is varies from 0.232 to 1.528 wt%. The P_2O_5 values are very negligible.The mean values of quartz in norm calculations ofthe rocks ranges from 6.02 to 28.36. Orthoclase and plagioclase are the dominant feldspar.

Table 1: Major, trace element and CIPW norm of the rock types of Marthandam area

	Incipient charnockite		**Massive charnockite**		**Garnet Biotite gneiss**				
Samples	**IF1**	**5B**	**10A**	**12A**	**1A**	**3M**	**3K**	**5B-1**	**14A**
SiO_2	65.357	65.886	61.667	57.777	68.564	64.888	69.151	65.543	68.322
TiO_2	0.937	0.925	0.381	0.899	0.719	0.662	0.675	0.947	0.4
Al_2O_3	14.63	14.996	18.699	15.58	14.68	17.098	14.265	15.742	16.546
MnO	0.085	0.081	0.058	0.126	0.045	0.045	0.05	0.065	0.029
Fe_2O_3	4.024	3.533	2.399	4.574	4.702	4.543	4.721	5.583	3.1
CaO	2.158	2.937	2.508	6.76	2.151	2.477	1.721	3.026	2.253
MgO	0.754	1.056	0.232	1.528	0.609	0.685	0.588	0.695	0.599
Na_2O	2.09	2.38	4.41	4.479	2.723	2.79	2.232	2.557	3.658
K_2O	5.267	4.281	6.494	3.572	4.665	5.469	5.527	4.759	4.156
P_2O_5	0.298	0.307	0.095	0.468	0.31	0.276	0.236	0.358	0.074
TOTAL	**98.618**	**99.032**	**98.753**	**99.195**	**99.168**	**98.933**	**99.166**	**99.275**	**99.137**
Trace elements in ppm									
V	64	61	36	99	35	37	32	55	31
Cr	57	53	24	53	29	43	28	48	24
Co	14	12	7	16	9	9	9	11	6
Ni	15	19	8	4	10	20	10	12	9
Cu	15	13	28	ND	11	13	4	10	7
Zn	68	59	49	148	68	124	61	129	53
Ga	14	17	17	21	17	17	15	16	18
Rb	256	214	103	100	282	268	296	214	181
Sr	141	148	2900	1100	111	156	99	193	577
Y	73	56	ND	19	46	33	53	54	4
Zr	397	330	ND	19	333	247	368	361	ND
Nb	19	17	7	13	18	14	15	22	ND
Ba	2500	1300	3900	913	834	0.12	707	949	0.12
Pb	58	45	45	26	66	75	78	64	56
Ce	191	167	175	265	172	165	214	152	130
Sm	13	9	10	18	11	9	14	10	7
Th	37	ND	42	ND	29	17	58	ND	15
CIPW Norm									
Qtz	27.72	28.36	5.36	6.02	29.95	21.95	30.81	25.67	25.36
Or	31.12	25.3	38.38	21.11	27.57	32.32	32.66	28.12	24.56
Ab	17.68	20.14	37.32	37.9	23.04	23.61	18.89	21.64	30.95
An	8.81	12.61	11.82	11.86	8.85	10.54	7.17	12.93	10.88
Cor	2.26	1.82	0.08	0	1.89	2.13	1.93	2.04	1.9
Mag	5.83	5.12	3.48	6.63	0.73	0.65	0.56	0.85	0.18
Di	0	0	0	0	0.01	0.01	0.01	0.01	0.01
Hyp	2.7	3.2	1.38	2.1	0.07	0.05	0.07	0.07	0
Ap	0.71	0.73	0.23	1.11	1.37	1.26	1.28	1.8	0.76
Ilm	1.78	1.76	0.72	1.71	1.91	2.73	1.98	1.65	2.04
Zir	0.08	0.07	0	0	3.9	3.76	3.91	4.63	2.5
Ratios and indices									
K_2O/Na_2O	2.52	1.798	1.472	0.797	1.71	1.96	2.48	1.86	1.14
A/CNK	1.537	1.562	1.394	1.051	0.2	0.26	0.21	0.23	0.22
Mali	5.199	3.724	8.396	1.291	5.24	5.78	6.04	4.29	5.56

Trace Elements

Trace elements play a major role in magmatic and metamorphic processes. They are useful in understanding the origin of gneisses and charnockites in the area and concentrations are presented in Table 1. Rb concentration is comparatively high and it ranges from 100-296 ppm. The Sr and Ba content vary from 99-2900 ppm and 0.12-3900 ppm. The gneisses have high content of Rb, Sr and Ba and low concentration of Th and Ga. The Ga content is more or less uniform in almost all rocks. Gneisses and incipient charnockite are having exceptionally high concentration of zirconium.

Geochemical Diagrams

A number of geochemical diagrams were drawn to characterize the parentage of gneisses and granulites of the study area. In Total Alkali vs Silica (TAS) diagram, the gneisses and incipient charnockites fall in the field of granitoids (granite and quartz-diorite) and the massive charnockite in the syenite field (Figure 11). The gneisses of belongs to the alkali-calcic variety of Frost[4] et al., 2001 (Figure 12). All charnockite, including incipient and massive varieties, are peraluminous, with alumina saturation index values (molar values) greater than 1 (A/CNK >1). In Shand's diagram of Maniar and Piccoli[8] (1989), gneisses and incipient charnockites fall in the peraluminous field and massive charnockite in the metaluminous field (Figure 13).

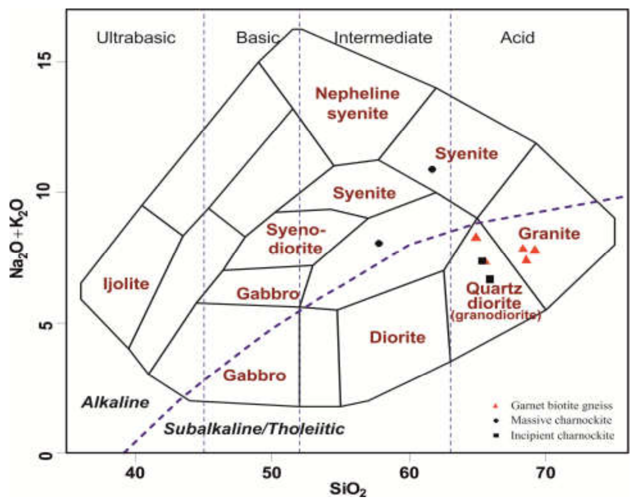

Figure 11: Total alkali vs Silica (TAS) diagram (Le Maitre[7] et al., 1989)

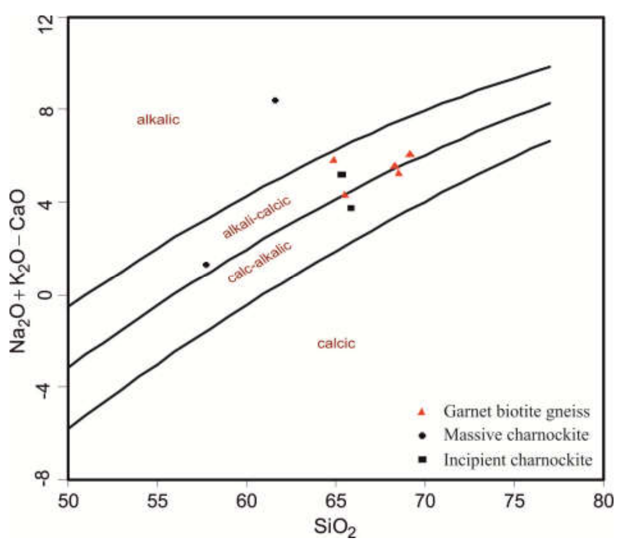

Figure 12: Modified alkali lime index (MALI) vs. SiO_2 diagram (Frost[4] et al 2001)

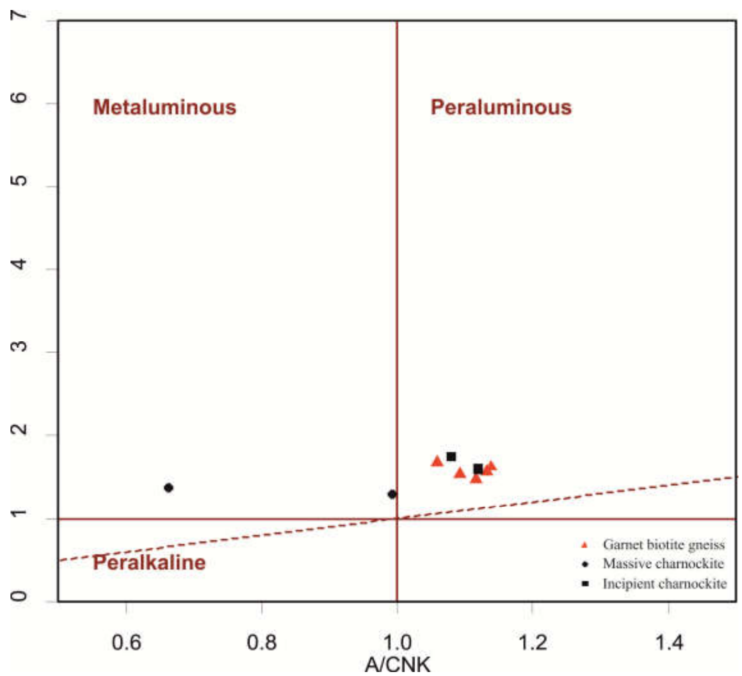

Figure 13: A/CNK versus A/NK Shand index diagram (Maniar and Piccolli[8], 1989).

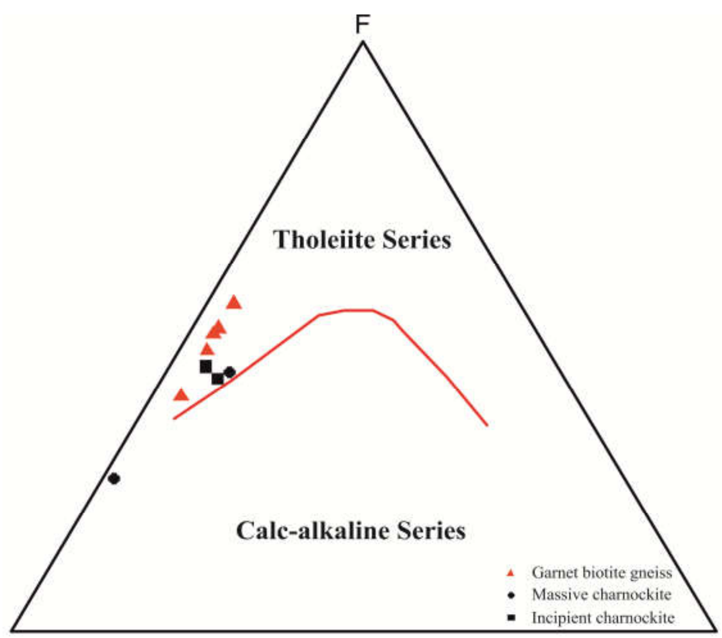

Figure 14: AFM diagram (Irvine and Baragar[6], 1971).

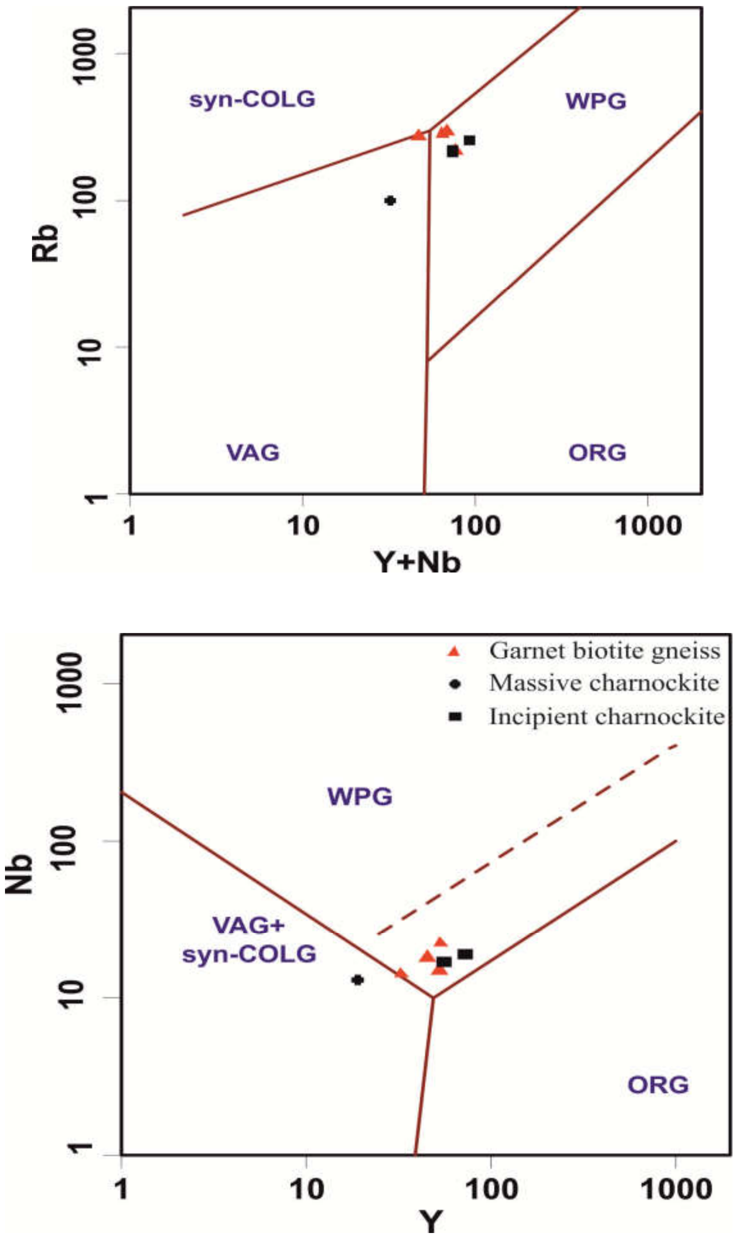

Figure 15: Nb vs. Y and Rb vs. (Y+Nb) diagram of Pearce[9] et al., 1984

In the AFM plot of Irvine and Baragar[7] (1971) all gneisses, charnockites and incipient charnockites are coming under the tholeiitic field, except one massive charnockite in the calc-alkaline field (Fig.14).In the diagram of Pearce[9] et al., 1984, all samples belong to within-plate granite field, except one massive charnockite in the volcanic arc granite field (Figure 15).

DISCUSSION AND CONCLUSIONS

The detailed field, petrographic and geochemical studies of the gneisses and granulites of Marthandam in Trivandrum Granulite Block reveals interesting outcomes about the geologic history of the entire terrain. Gneisses and incipient charnockites are peraluminous to moderately peraluminous; while the massive charnockite aremetaluminous. Generally strongly peraluminous magmas are derived from mature pelitic sediments and may produce S-type igneous rocks. The gneisses in the study area are not so intensely peraluminous, discounting it being categorized as metapelitic. The major elemental data of the rocks of the area indicate that the parent rocks may be intermediate to felsic granitoids or products of partial melting of metaluminous mafic minerals.

There have been several attempts to distinguish between the different granitoid associations and the geotectonic environments inwhich the rocks are formedusing variousdiscrimination diagrams. They may shed light on the palaeotectonic setting of ancient granitoid magmatism in cases where unambiguous field evidencesare difficult to obtain. The most widely used scheme is proposed by Pearce[9] et al. (1984) who used multi-element plots emphasizing HFSE (Y, Nb) as parameters and normalized the samples to hypothetical ocean ridge granite (ORG) in order to discriminate tectonic fields. High field strength elements (HFSE) provide values typically unmodified by moderate grade metamorphism. These elements are used as robust parameters in discrimination of tectonic environment (Pearce[10] et al., 1984).

Cobbins[2] cautions that such diagrams though useful in studying magmatism in geologically complex areas need to be used with caution. Nb and Y are relatively immobile elements, whose primary concentrations in silicate rocks are relatively robust, in the case of moderate degrees of alteration and metamorphism. The same cannot be said of the mobile element Rb; for plots to be reliable, it is vital to ensure that only analyses of fresh unmetamorphosed rocks are used. The compositional differences that emerge from the plots actually have more to do with differing source compositions and crystallization histories than with tectonic setting *per se* (Frost[4] et al., 2001).The gneisses are geochemically similar to within plate or intraplate granitic rocks recognized in India. An extensional tectonic regime with ductile to brittle-ductile shear zones has been identified for the emplacement of these granitoids (Sarvothaman and SeshaSai[14], 2010).

Thus the gneisses, especially Garnet Biotite Gneiss, belong to the group of compositionally alkali-calcic, peraluminous within-plate granites. Close examination of the pair of GBG and incipient charnockites reveal that they are geochemically similar; their trace element contents, especially Nb, Y, and Zr for the rocksare also similar. This indicates that the metamorphism has not mobilized elemental movement, especially of the HFSE in gneisses. The incipient charnockites may be produced by the chemical alteration of the gneisses; while the massive charnockites display a different geochemical signature entirely different from gneisses and associated rocks in the area.

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