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Petrology of Charnockites from Madurai Block of Southern Granulite Terrain, South India

G. Indu[1]*, E. Shaji[2*], R.B. Binojkumar[3], M. Santosh[4,5,6], T. Tsunogae[7,8]

Author's Affiliations:
[1,2,3]Department of Geology, University of Kerala, Kariavattom campus, Thiruvananthapuram, Kerala695581, India.
[4]School of Earth Sciences and Resources, China University of Geosciences Beijing, 29 Xueyuan Road, Beijing 100083, China
[5]Centre for Tectonics, Exploration and Research, University of Adelaide, Adelaide, SA 5005, Australia
[6]Department of Geology, Northwest University, Northern Taibai Str. 229, Xi'an 710069, China
[7]Graduate School of Life and Environmental Sciences, University of Tsukuba, Ibaraki 305-8572, Japan
[8]Department of Geology, University of Johannesburg, Auckland Park 2006, South Africa

***Corresponding Author: Indu G**, Research Scholar, Department of Geology, University of Kerala, Thiruvananthapuram, Kerala695581, India.

E-mail: indoos209@gmail.com, shajigeology@gmail.com

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ABSTRACT

Charnockites are the most extensively studied rocks in the Southern Granulite Terrain (SGT). Charnockites are popularly known as hypersthene-bearing granite. Charnockite occurs as massive, foliated and incipient varieties in different crustal blocks of SGT. This paper presents the petrology and geochemistry of charnockite from Madurai Block. The charnockite (enderbite) studied from the Madurai Block is a medium grained rock with a mineralogy of 30-40% of quartz, 25-35% of feldspar, 15%-20% of ferromagnesian minerals (2-5% orthopyroxene, 2%-3% hornblende and 2%-3% biotite). Accessory minerals include Fe-Ti oxides (dominantly ilmenite), apatite, and zircon. The charnockites are dioritic to granitic in composition with high Al_2O_3 content and display both ferroan and magnesian characters. The REE plots of charnockites show high concentration of light rare earth elements (LREEs) and relatively low contents of heavy rare earth elements (HREEs), with significant LREE/HREE fractionation. They also show positive Eu anomalies or lack of Eu anomalies. Ba enrichment is the important characteristic of these charnockites with distinct Nb, Ta, and Ti depletion in mantle-normalized primitive mantle multi-elements diagrams, which has been considered to be one of the potential geochemical imprints of continental margin magmatism in a subduction-related environment.

KEYWORDS: *Charnockite, SGT, Madurai Block, Geochemistry, Enderbite*

INTRODUCTION

Charnockites and its variants occur in all the major crustal blocks of the SGT (Coorg, Salem, BR Hills, Nilgiri, Madras, Madurai, Trivandrum, and Nagercoil) (Clark[4] et al., 2009; Rajesh and Santosh[12], 2012; Samuel[13] et al., 2014; Li[9] et al., 2018; Santosh[18]., 2020 and references therein). The name charnockite was first proposed by Sir Thomas Holland[8] in 1893 for a dark hypersthene-bearing rock from the Pallavaram area of Madras, India, in honour of Job Charnock and, thus, Pallavaram area became the type area of charnockite. Holland[8] (1900) redefined the charnockite as a quartz-feldspar-hypersthene-iron ore rock in the charnockite series. The term 'charnockite suite' was suggested by Subramaniam[20] (1960) for group of genetically related metamorphic rocks such as adakites, charnockites, enderbites and orthopyroxene-quartz syenites. Now charnockite has been extensively studied across the globe. The present study focuses on the charnockites of Madurai Block.

STUDY AREA

The Southern Granulite Terrain (SGT), the southern tip of Indian Shield, is made up of different crustal Blocks namely the Coorg, Nilgiri, Salem, Madras, Madurai, Trivandrum and Nagercoil Blocks and the SGT has been extensively studied by various workers (Santosh[14,15,16] et al., 2009, 2015, 2016; Clark et al., 2009[4]; Collins et al., 2014[5]; Plavsa[10] et al., 2014; Praveen[11] et al., 2014; Shaji[19] et al., 2014; Samuel[13] et al., 2014; Yang[22] et al., 2015; Amaldev[1] et al., 2016, Yellappa[23] et al., 2018; Das and Rai[6]., 2019; Chowdhury, P[3]. and Chakraborty, S., 2019). The blocks of SGT are dissected by crustal scale shear / suture zones, ranging in age from Mesoarchean to latest Neoproterozoic-Cambrian (figure 1). Among the various crustal blocks in the Granulite Terrain, the Madurai Block is the largest and is bound by the Palghat-Cauvery Shear Zone to the north and the Achankovil Shear Zone to the south. The study area is located in Madurai Block and the sampling locations are shown in figure 2 and table 1. The table 1 describes location details, with GPS readings, rock name and mineral assemblages.

Table 1: Details of sample locations with rock type and mineralogy

Sl. No	Sample Name	Location	Coordinates	Rock Type	Mineralogy
1	IM-2-1	Chenkottai	08º59´27.56´´ 77º14´15.10´´	Enderbite	Plg+Kfs+Qtz+Opx+Bt+Ap+Zr
2	IM-2-3	Chenkottai	08º59´27.56´´ 77º14´15.10´´	Enderbite	Plg+Kfs+Qtz+Opx+Bt+Ap+Zr
3	IM-3-1	Sivagiri	09º21´04.06´´ 77º26´25.55´´	Enderbite	Plg+Kfs+Qtz+Opx+Bt+Ap+Zr
4	IM-3-2	Sivagiri	09º21´04.06´´ 77º26´25.55´´	Enderbite	Plg+Kfs+Qtz+Opx+Bt+Ap+Zr
5	IM-5-1	Kuttalam	08º55´52.65´´ 77º14´19.41´´	Charnockite	Kfs+Qtz+Plg+Opx+Bt+Ap+Zr
6	IM-5-2	Kuttalam	08º55´52.65´´ 77º14´19.41´´	Charnockite	Kfs+Qtz+Plg+Opx+Bt+Ap+Zr
7	IM-7-4	Alangulam	08º52´19.70´´ 77º27´58.46´´	Charnockite	Kfs+Qtz+Plg+Opx+Hbl+Bt+Ap+Zr
8	IM-8-2	Karumpuliyuthu	08º50´07.71´´ 77º31´53.74´´	Enderbite	Plg+Kfs+Qtz+Hbl+Il+Ap+Bt
9	IM-10-1	Sitaparappanallur	08º46´53.81´´ 77º36´57.67´´	Enderbite	Plg+Kfs+Qtz+Hbl+Bt+Ap+Il+Zr
10	IM-10-2	Sitaparappanallur	08º46´53.81´´ 77º36´57.67´´	Enderbite	Plg+Kfs+Qtz+Hbl+Bt+Ap+Il+Zr
11	IM-13-1	Thalayuth	08º48´09.52´´ 77º43´20.57´´	Enderbite	Plg+Kfs+Qtz+Opx+Cpx+Hbl+Il+Ap+Zr
12	IM-13-2	Thalayuth	08º48´09.52´´ 77º43´20.57´´	Enderbite	Plg+Kfs+Qtz+Opx+Cpx+Hbl+Il+Ap+Zr
13	IM-14-1	Kaanarpetti	08º53´18.48´´ 77º38´28.15´´	Enderbite	Plg+Kfs+Qtz+Opx+Hbl+Mt+Ap+Zr
14	IM-14-3	Kaanarpetti	08º53´18.48´´ 77º38´28.15´´	Enderbite	Plg+Opx+Hbl+Bt+Il+Ap+Zr
15	IM-15-1	Veerakeralaputhur	08º58´48.96´´ 77º26´15.99´´	Charnockite	Kfs+Qtz+Plg+Opx+Hbl+Bt+Ap+Zr

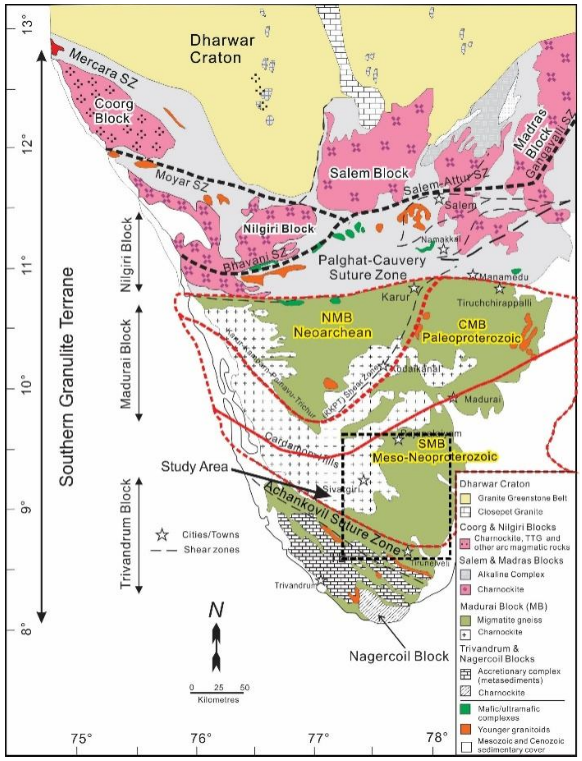

Figure 1: Geological and tectonic framework of the Southern Granulite Terrane of India showing the major crustal blocks and intervening suture zones (after Collins[5] et al., 2014; Santosh[15,16,17] et al., 2015, 2016, 2017)

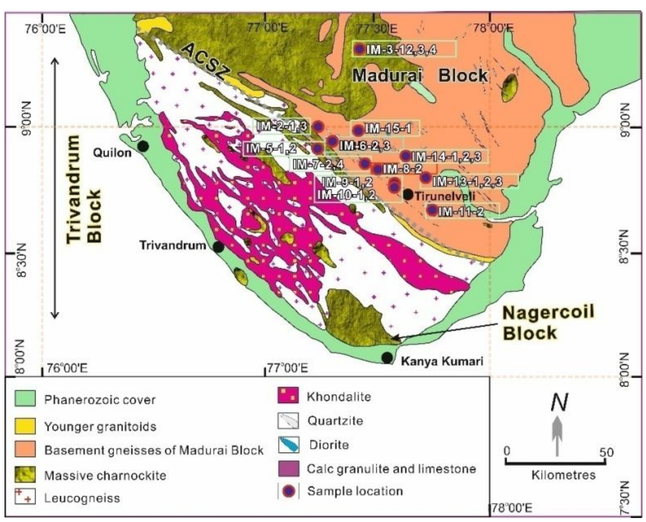

Figure 2: Geological map of the study area with sample locations

METHODOLOGY

Detailed geological and structural mapping in and around Shenkottai, Tirunelveli and Thenkasi area was carried out to discover new locations and to collect field data as well as representative rock samples.The laboratory studies include preparation of polished thin sections and their detailed petrological studies to identify the assemblages, textures and mineral reactions. The polished thin sections were prepared from Continental Instruments, Lucknow and petrography was done from the Department of Geology, University of Kerala. Mineralogical studies based on Electron Probe Micro Analysis was done from Indian Institute of Science, Bangalore, India. Determination of major element, trace element and REE geochemistry of representative samples were carried out in the National Research Center for Geoanalysis, Beijing, China.

Methods of collection of rock samples and detailed instrumentation is described below.

(i) Collection of rock samples

Representative rock samples were collected from each location for petrographic studies as well as geochemical studies. Unaltered chip samples are collected for the preparation of thin sections and fresh exposures of charnockites are chosen for the geochemistry.

(ii)Petrography

Representative chip samples of charnockites were collected and thin sections were prepared using the facilities of the petrology lab of the Department of Geology, University of Kerala and Continental Instruments, Lucknow. The petrography of each rock type was studied and mineral assemblages, textural relationships were documented along with photomicrographs.

(iii)Electron Probe Micro Analysis (EPMA)

Polished sections of representative rock samples were prepared from charnockite for petrographic study at the University of Tsukuba, Japan and continental Instruments, Lucknow. Mineral chemistry (EPMA) was determined using an electron microprobe analyser (JEOL JXA8530F) at the Chemical Analysis Division of the Indian Institute of Science, Bangalore. The analyses were performed under conditions of 15 kV accelerating voltage and 10 nA sample current, and the data were regressed using an oxide-ZAF correction program supplied by JEOL.

(iv) X-ray Fluorescence (XRF)

The least altered and homogeneous portions of whole rock samples were selected from charnockite and pulverized for geochemical analyses using Philips MagiXPRO model PW 2440 at National Centre for Earth Science Studies (NCESS), Trivandrum. Geochemical data of these samples were generated by using the X-Ray Fluorescence (Bruker, formerly Siemens, model S4 Pioneer sequential wavelength-dispersive x-ray spectrometer and sample preparation units). Geochemical diagrams were prepared using geochemical software Geochemical Data Toolkit Version 3.00 which is a program for recalculation of geochemical data from igneous and metamorphic rocks.

(v) Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

Trace and REE geochemical data of twenty four samples were generated using the Inductively Coupled Plasma Mass Spectrometry (ICP-MS) at National Geophysical Research Institute, Hyderabad.

Petrological and geochemical characteristics of charnockite

This study concentrates on the geochemical characteristics of charnockitic rocks in the southern Madurai Block. The major litho units of the Madurai block are charnockites, enderbites (Intermediate charnockite), Hornblende Biotite Gneiss, diorites, gabbros, pink and grey granites and pegmatites. Besides these units, some metasedimentary sequences have been found intercalated with the magmatic lithologies. It includes garnet-biotite gneiss, garnet-biotite sillimanite gneiss, quartzites and metacarbonates. Mineral paragenesis of these metapelites give the key information of ultra-high temperature metamorphism in the Madurai Granulite Block.

Charnockites

In the study area greasy green coloured massive charnockites are found with obvious foliation and migmatization. This type of charnockites are the typical feature of high grade metamorphic terrains. It contains 30-40% of quartz, 20-30% antiperthitic plagioclase, 20-30% alkali feldspar and 2-5% orthopyroxene as major minerals. Calcic amphibole is with dark greenish subhedral to anhedral grains found as accessory along with biotite, apatite and zircon. The localities are mainly subsurface quarry exposures and well cuttings which indicates that the basement rocks are mainly charnockites. In many places within the southern Madurai Block, the charnockites are slightly more intermediate in composition and are therefore designed as enderbites. Enderbites are coarse grained, xenoblastic with 20-30% quartz, 40-50% plagioclase and 5-10% orthopyroxene and potash feldspar. These are having inclusion free orthopyroxene surrounded by plagioclase and quartz. Adjacent to orthopyroxene grains, flakes of brown biotite is seen in 2-5%. This biotite is formed by the following reaction

$Opx+Kfs+H_2O \rightarrow Bt+Qtz$

Mineral chemistry

The major minerals and its chemistry of the charnockite are displayed in Table 2 and 3 and the detailed mineral chemistry is described below:

Pyroxene

Orthopyroxene show consistent enstatite composition of X_{Mg} = Mg/ (Fe + Mg) = 0.52-0.61 except in two samples, it displays slightly Fe-rich compositions of X_{Mg}=0.45-0.47. There is a significant variation in the Al_2O_3content of orthopyroxene in enderbite. The highest Al_2O_3 content 6.66-7.01 wt. % found in the orthopyroxene in one enderbite sample and it is plotted near the array of orthopyroxene in metamorphic charnockite. Clinopyroxene in the examined samples are all classified as augite (figure 3a) (Rajesh et al., 2012). Clinopyroxene in enderbite samples is slightly rich in Fe than in charnockite whereas Na_2O and Al_2O_3 contents in the mineral are low (Na_2O = 0.31-0.68 wt. % and Al_2O_3=1.2–2.6 wt. %.)

Amphibole

The amphiboles are calcic amphiboles and are enriched in Ca (1.75-1.92 pfu) and Na + K (0.65-0.93 pfu), depleted in Ti (0.18-0.35 pfu). So these are classified mostly as edenite, pargasite, or ferro-pargasite. Calcic amphibole is enriched in X_{Mg}(0.59-0.65) and Si (6.56-6.80 pfu) as edenite, whereas in one sample which is slightly depleted in X_{Mg} (0.48) and Si (6.35-6.42 pfu) and classified as ferropargasite (figure 3b).

Feldspars

Plagioclase shows consistent anorthite content of $An_{24–34}$. Charnockite of coarse-grained K-feldspar with plagioclase lamellae in sample shows intermediate compositions of $Or_{79–81}$(figure 3c).

Biotite

The biotite shows intermediate TiO_2 (4.5–5.0 wt. %) content and higher Mg (0.64–0.70), and some is depleted in TiO_2 and XMg as 3.0–3.1 wt. % and 0.48– 0.49, respectively (figure 3d).

Table 2: Representative electron microprobe analyses on calcic amphibole (Hbl), biotite (Bt), orthopyroxenes (Opx), clinopyroxenes (Cpx) and feldspars (Pl, Kfs) of charnockites from Madurai Block.

Sample No.	IM-5-1	IM-5-1	IM-15-1	IM-5-1	IM 5-2	IM-15-1
Mineral Name	Pl	Kfs	Kfs	Opx	Bt	Hbl
SiO_2	60.49	63.85	64.9	49.63	37.22	40.82
Al_2O_3	24.81	18.69	18.77	3.22	14.84	10.4
TiO_2	0.04	0.01	0	0.14	5.01	2.39
Cr_2O_3	0	0	0	0.04	0.03	0.01
FeO*	0.09	0.03	0.01	27.02	13.84	18.45
MnO	0.02	0	0.02	1.21	0.13	0.27
MgO	0	0	0	17.64	14.68	9.53
CaO	6.47	0.12	0.24	0.15	0.02	10.88
Na_2O	7.56	1.01	1.91	0.01	0.02	1.78
K_2O	0.43	14.88	13.4	0	9.8	1.72
Total	99.9	98.59	99.24	99.07	95.57	96.24
Si	2.696	2.981	2.99	1.918	5.531	6.346
Al	1.303	1.028	1.019	0.147	2.599	1.905
Ti	0.001	0	0	0.004	0.56	0.28
Cr	0	0	0	0.001	0.003	0.001
Fe2+	0.003	0.001	0.001	0.873	1.719	2.398
Mn	0.001	0	0.001	0.04	0.016	0.035
Mg	0	0	0	1.015	3.248	2.207
Ca	0.309	0.006	0.012	0.006	0.003	1.812
Na	0.652	0.091	0.17	0.001	0.004	0.535
K	0.024	0.886	0.787	0	1.857	0.342
Total	4.99	4.993	4.979	4.004	15.539	15.86

Table 3: Representative electron microprobe analyses on calcic amphibole (Hbl), biotite (Bt), orthopyroxenes (Opx), clinopyroxenes (Cpx) and feldspars (Pl, Kfs) of enderbites from Madurai Block.

Sample No.	IM-2-3	IM-3-1	IM-13-1	IM-2-3	IM-3-1	IM-14-1	IM-14-1	IM-2-3	IM-3-1	IM-13-1	IM-14-1	IM-2-3	IM-3-1	IM-14-1
Mineral Name	**Pl**	**Pl**	**Pl**	**Kfs**	**Kfs**	**Kfs**	**Cpx**	**Opx**	**Opx**	**Opx**	**Opx**	**Bt**	**Bt**	**Hbl**
SiO_2	61.14	60.1	62.78	64.21	64.47	63.81	52.38	47.77	50.1	51.46	52.09	37.09	36.12	43.46
Al_2O_3	24.05	24.62	23.37	18.6	18.64	18.61	1.89	6.97	0.79	0.6	1	15.13	13.22	9.93
TiO_2	0	0	0.02	0.05	0.02	0.02	0.25	0.21	0.12	0.14	0.1	5.01	3.1	1.63
Cr_2O_3	0	0.02	0	0.01	0	0	0	0.01	0.07	0	0.01	0.01	0.06	0.03
FeO*	0.04	0.09	0.2	0.01	0	0.07	10.05	24.66	30.91	26.11	24.48	12.36	20.85	14.65
MnO	0.02	0.03	0	0	0	0	0.24	0.53	0.7	0.93	0.84	0.12	0.06	0.18
MgO	0	0.02	0.02	0	0	0	13.18	18.98	15.25	19.3	20.43	15.42	10.88	12.04
CaO	6.01	6.53	4.85	0.17	0.06	0.04	21.37	0.09	1.51	0.75	0.63	0	0.07	11.75
Na2O	7.71	7.27	8.16	0.66	0.51	0.4	0.58	0.04	0.04	0.03	0	0.03	0.03	1.28
K2O	0.71	0.68	0.75	15.17	15.6	15.41	0	0	0	0.01	0	9.77	8.96	1.56
Total	99.69	99.36	100.15	98.87	99.3	98.36	99.94	99.26	99.48	99.33	99.58	94.94	93.35	96.49
Si	2.729	2.696	2.78	2.989	2.991	2.988	1.962	1.818	1.969	1.974	1.973	5.509	5.682	6.572
Al	1.265	1.301	1.219	1.02	1.019	1.027	0.083	0.313	0.036	0.027	0.044	2.648	2.451	1.769
Ti	0	0	0.001	0.002	0.001	0.001	0.007	0.006	0.004	0.004	0.003	0.559	0.366	0.185
Cr	0	0.001	0	0	0	0	0	0	0.002	0	0	0.002	0.007	0.003
Fe^{2+}	0.001	0.003	0.007	0	0	0.003	0.315	0.784	1.016	0.837	0.775	1.534	2.742	1.852
Mn	0.001	0.001	0	0	0	0	0.008	0.017	0.023	0.03	0.027	0.015	0.008	0.023
Mg	0	0.002	0.001	0	0	0	0.736	1.076	0.893	1.103	1.153	3.411	2.55	2.711
Ca	0.287	0.314	0.23	0.008	0.003	0.002	0.857	0.004	0.063	0.031	0.025	0	0.012	1.904

Na	0.667	0.632	0.7	0.059	0.046	0.036	0.042	0.003	0.003	0.002	0	0.008	0.01	0.374
K	0.04	0.039	0.043	0.9	0.923	0.92	0	0	0	0	0	1.851	1.797	0.301
Total	4.992	4.988	4.981	4.979	4.983	4.976	4.01	4.021	4.009	4.009	4.001	15.536	15.626	15.694

Table 4: XRF data of charnockites and enderbites from Madurai block

Sample No.	IM-5-1	IM-5-2	IM-15-1	IM-2-1	IM-2-3	IM-3-1	IM-3-2	IM-8-2	IM-10-1	IM-10-2	IM-13-1	IM-13-2	IM-14-1	IM-14-3
Rock type	Charnockite			Enderbite										
SiO_2	65.39	69.88	71.47	56.6	58.48	59.53	56.59	59.92	58.45	57.42	55.3	55.45	55.59	54.12
TiO_2	0.85	0.33	0.32	1.11	1.15	1.65	2.01	0.71	1.11	1.2	1.56	1.59	0.84	0.98
Al_2O_3	14.9	14.6	13.16	17.91	16.44	15.26	15.6	14.73	16.41	17.4	16.84	16.72	17.91	17.45
FeO	2.77	1.04	0.4	3.27	5.14	5.86	7.47	6.22	5.03	4.42	4.1	4.75	4.62	4.63
Fe_2O_3	2.47	1.63	2.02	6.36	3.51	1.35	1.26	1.56	3.49	4.22	3.69	3.31	2.49	2.67
MnO	0.1	0.06	0.03	0.09	0.16	0.13	0.15	0.18	0.18	0.17	0.13	0.14	0.13	0.12
MgO	1.26	0.64	0.84	2.83	3.64	2.08	2.48	4.83	3.18	2.42	2.34	2.56	3.7	4.04
CaO	2.71	2.16	1.66	2.62	3.63	4.73	5.43	5.31	3.31	2.82	4.94	5.24	5.25	7.01
Na_2O	3.09	2.87	2.58	2.21	3.39	3.54	3.79	3.16	4.09	3.99	4.11	4.49	4.28	4.23
K_2O	4.47	5.25	5.31	3.7	2.09	3.25	2.53	1.01	2.3	3.88	4.29	2.81	2.89	2.06
P_2O_5	0.25	0.12	0.08	0.08	0.06	0.67	0.84	0.24	0.17	0.16	0.54	0.62	0.39	0.45
Total	98.26	98.58	97.87	96.78	97.69	98.05	98.15	97.87	97.72	98.1	97.84	97.68	98.09	97.76
LOI	0.17	0.5	0.98	1.45	0.52	-0.11	-0.35	0.12	0.42	0.14	0.39	0.25	-0.04	0.25
A / CNK	1.48	1.87	1.87	1.51	1.01	0.99	0.89	0.7	1.05	1.3	1	0.92	0.9	0.74
A / NK	1.91	2.19	2.38	2.67	1.71	1.31	1.2	1.21	1.66	1.94	1.34	1.24	1.35	1.08
Mg#	31	31	40	36	44	34	34	53	41	34	36	37	49	51
FeO Total	4.99	2.51	2.22	8.99	8.3	7.07	8.6	7.62	8.17	8.22	7.42	7.73	6.86	7.03

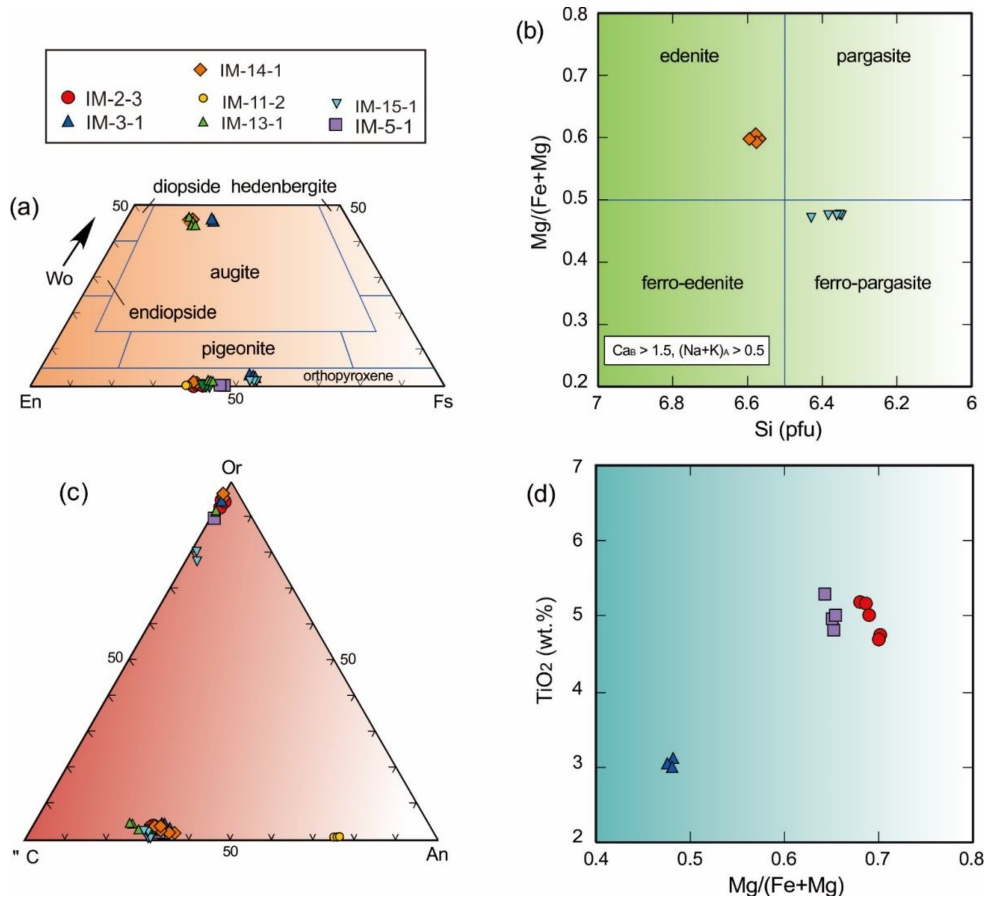

Figure 3: Mineral chemistry diagrams. (a) Triangular diagram showing pyroxene chemistry. (b) Si (pfu) versus XMg diagram showing compositions of calcic amphibole. (a) Triangular diagram showing feldspar chemistry. (a) XMg versus TiO2 (wt. %) diagram showing biotite chemistry

Whole Rock Chemistry

The term charnockite is applied to a suite of compositionally diverse rocks. The major element data of charnockite shows a highest range in SiO_2 content and the enderbite samples have intermediate SiO_2 content in the range of 54-60 Wt % In the TAS diagram, the charnockite samples vary from dioritic to granitic in composition and follow a calc-alkali trend (figure 4a). In terms of alumina saturation index (A/CNK) all the charnockites are metaluminous to peraluminous (Figure 4b) (Santosh et al., 2018). In the normative An-Ab-Or and K-Na-Ca diagrams, the samples define the Monzogranite field for charnockites and granodioritic field for enderbites (figure 4c). QAP classification of charnockite refers all intermediate rocks as enderbites (tonalite/trondhjemite composition) and felsic rocks as charnockites (granitic composition). The rocks display a range of TiO_2 values from 0.1 to 2.83 wt. %, the charnockite samples show the lowest TiO_2 content (0.1-0.85 wt. %) (Table 4). In plots of modified alkali lime index (Na_2O+K_2O-CaO) and SiO_2 versus FeOt/(FeOt+MgO), the charnockites display both ferroan and magnesian features, and straddle the fields from calcic to alkalic (Figure 5a and Figure 5b). Because of the higher Al_2O_3 content of the samples, they are in the field of adakite.

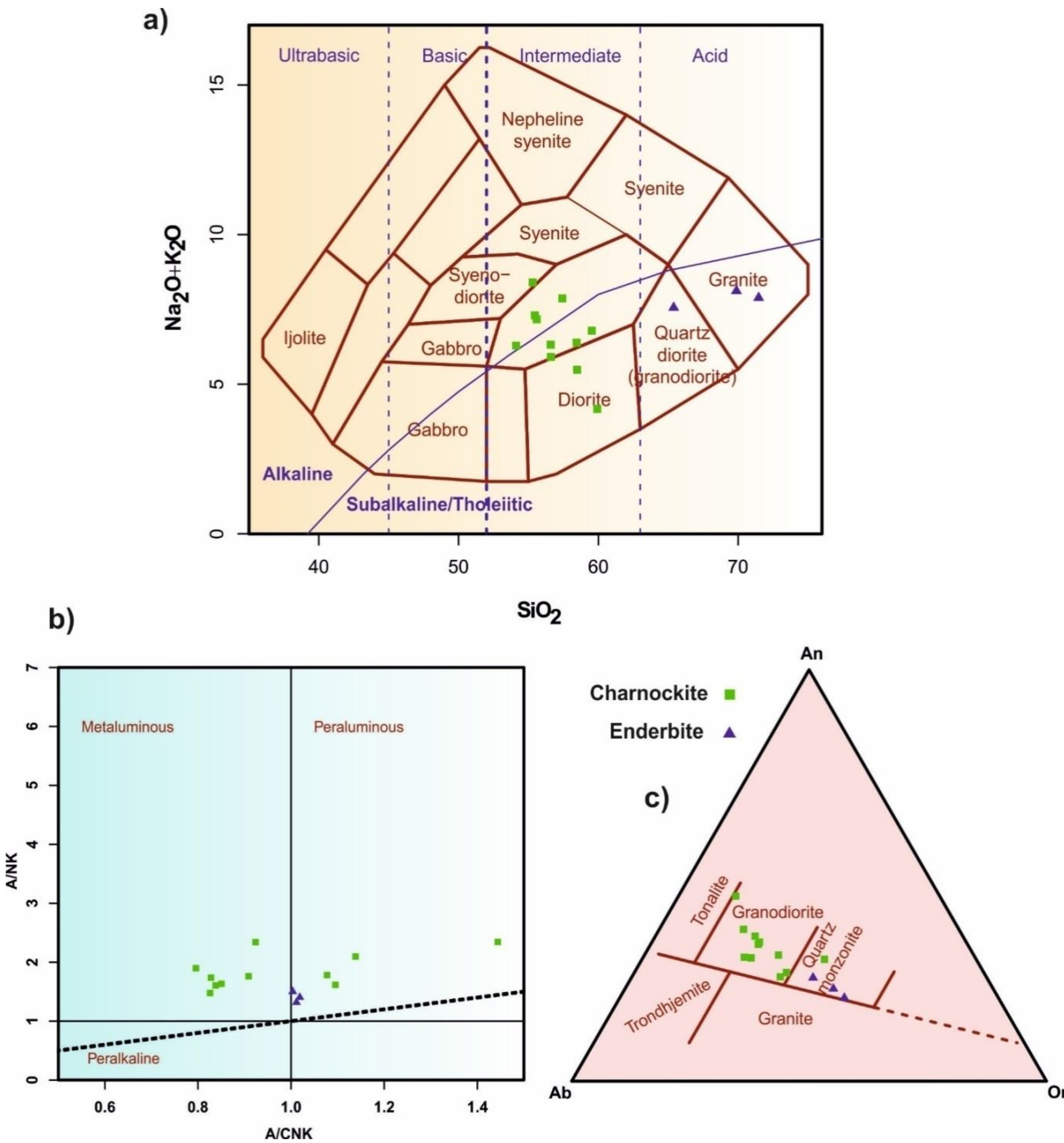

Figure 4: Geochemical plots of enderbites and charnockites. (a) Plots of SiO_2 vs. Na_2O+K_2O after Wilson[20] (1989). (b) Alumina saturation index (ASI) diagram: A/NK [molar ratio $Al_2O_3/(Na_2O+K_2O)$] vs. A/CNK [molar ratio $Al_2O_3/(CaO+Na_2O+K_2O)$]. (c)Normative Ab–An–Or ternary plot and classification of charnockitic rocks after Barker[2] (1979).

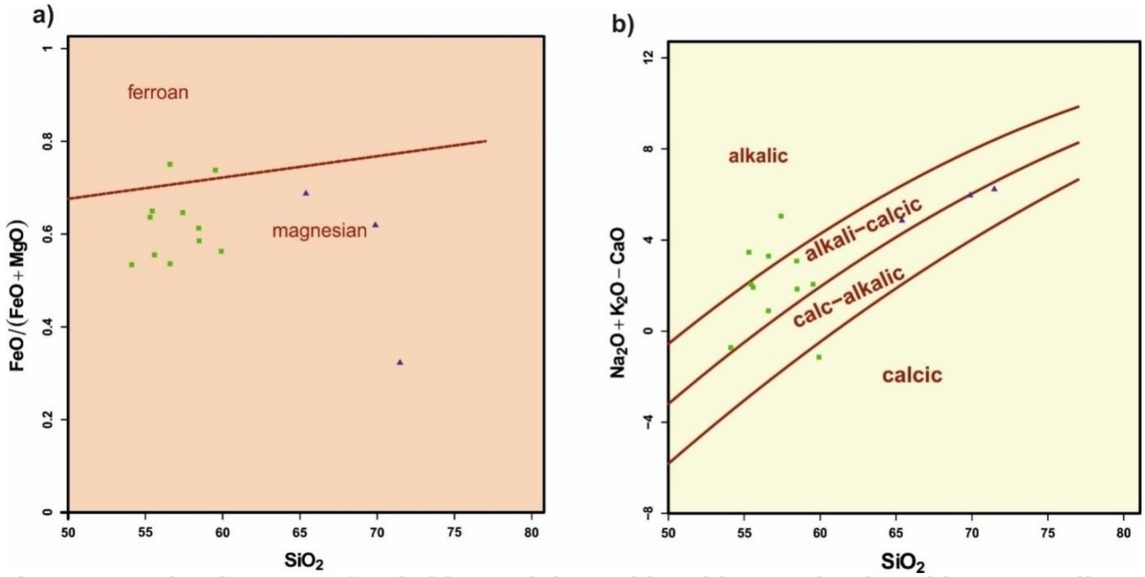

Figure 5: Geochemical plots of enderbites and charnockites. (a)Fe number (FeOt/ (FeOt+MgO)) vs. SiO_2 (b) modified alkali lime index ($Na_2O+K_2O–CaO$) vs. SiO2. Plot boundaries are after Frost[7] et al. (2001).

CONCLUSION

The study presents the following conclusions:

- The charnockites are derived from a dioritic to granitic igneous protolith and they are enderbites.
- The rock contains 30-40% of quartz, 20-30% antiperthitic plagioclase, 20-30% alkali feldspar and 2-5% orthopyroxene as major minerals. Calcic amphibole, biotite, apatite and zircon are the minor minerals.
- Orthopyroxene of the rock shows enstatite composition and the amphiboles are calcic (edenite).
- Charnockites and enderbites possess similar mineralogical constitution except in the content of quartz, K-feldspar, plagioclase and the additional presence of clinopyroxene.
- Tholeiitic-calc-alkaline affinity of charnockite suite of rocks from the study area is similar to that of charnockites reported from a subduction-related setting.

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CONFLICT OF INTEREST

This is an authentic work done by the first author with the supervising teachers. There is no financial interest or any conflict of interest exists in this work.

Abbreviations and Units

1. Hbl-Hornblende/Calcic amphibole
2. Bt- Biotite
3. Opx- Orthopyroxenes
4. Cpx-Clinopyroxenes
5. Pl- Plagioclase feldspar
6. Kfs - K- feldspar

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