Journal of Geointerface, Vol. 4, No. 1, July 2025, pp. 56–67 e-ISSN: 2583-6900

Madhavaram metavolcanic belt, Southern India: spatial continuity of Neoarchean Raichur–Gadwal schist belt, Eastern Dharwar Craton

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ABSTRACT

Through detailed field and laboratory studies involving geological mapping, petrographic, geochemical and mineral chemistry studies, a metavolcanic belt comprising of basalt–basaltic andesite–andesite is reported from the Precambrian granitic terrain at Madhavaram area in southern India. The WNW-ESE trending Madhavaram metavolcanic belt is located along the southern extension of Raichur schist belt of Eastern Dharwar Craton. Field studies reveal that the major foliation recorded in the area is WNW-ESE to NW-SE trending with moderate to steep NE dips. Petrographically the andesite is essentially composed of hornblende, plagioclase, clinopyroxene and Fe Ti oxides, while the dacite is composed of plagioclase, amphibole, quartz and opaques. In the IUGS TAS diagram the studied rocks essentially fall in the field of basalt–basaltic andesite–andesite field. Major oxide analyses of the metavolcanic rocks indicate that the SiO_2 ranges from to 49.68 wt.%, in basalt and 59.01 wt.% in andesite. The MgO ranges from 3.46 in andesite to 5.22 wt.% in basalt. Geochemically the basaltic rocks exhibit tholeiitic trend, while the andesitic rock exhibit calc alkaline nature. Chondrite normalised REE plot reveal a general enrichment of LREE relative to HREE and a low magnitude Eu anomaly. In primitive mantle trace element spider diagram the metavolcanic rocks of Madhavaram area exhibit negative Nb and Ti anomaly indicating their eruption in subduction zone tectonic setting. The basalt–basaltic andesite–andesite metavolcanic rocks of Madhavaram area indicates the possible spatial continuity of the Neoarchean Raichur–Gadwal greenstone belts in Southern India.

ARTICLE HISTORY

Received: 08 April 2025
Revised: 15 May 2025
Accepted: 16 May 2025

https://doi.org/10.5281/zenodo.15442984

KEYWORDS

Basalt
andesite
metavolcanic
Madhavaram
Eastern Dharwar Craton

1. Introduction

Though greenstone belts evolved during the Precambrian and Phanerozoic times (Condie, 1989). It is well established that the Archean period witnessed distinct and dynamic events of crustal evolution (Hawkesworth et al., 1975; Archibald et al., 1978; Armstrong et al., 1990; Shackleton, 1995; Anhaeusser, 2014). Further, studies on the Archean greenstone belts contributed in understanding the records of the Earth's initial phases of lithospheric evolution (Dewit and Ashwal, 1995). Studies on the evolution the Japanese arcs paved way to understand the Archean greenstone belts (Taira et al., 1992). The metavolcanic rocks in the Precambrian

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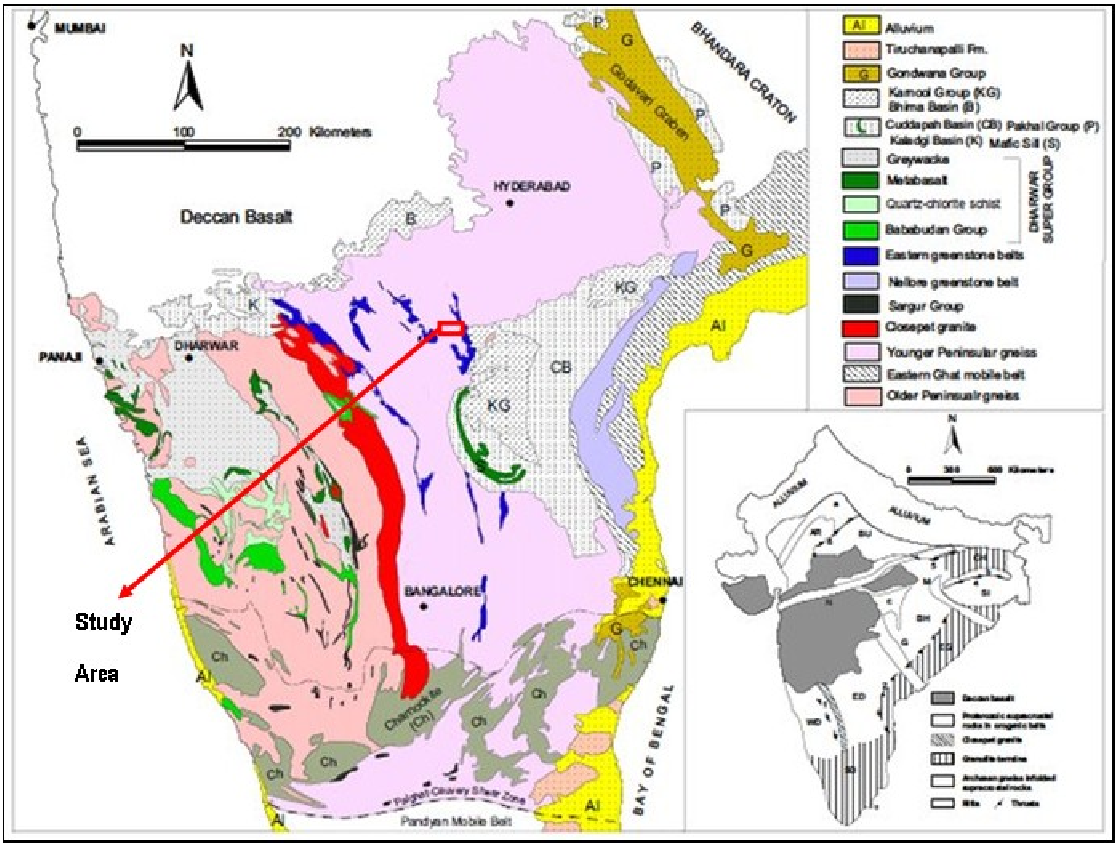

Fig. 1. General geological map of the Dharwar craton showing the distribution of the greenstone belts (Geological Survey of India, 1994).

granite - greenstone terrains that are exposed in the present day stabilised cratonic areas were originally erupted as lavas in the linear subduction domains during Mesoarchean–Neoarchean, a period that witnessed distinct and dynamic events of crustal evolution (e.g., Hawkesworth et al., 1975; Archibald et al., 1978). The term 'greenstone belt' is used specifically to describe deformed and metamorphosed volcano-sedimentary successions in the stabilised Archean cratons. The greenstone belts are granitic and gneissic rocks. Geochronological studies in the Dharwar Craton of southern India indicated the ages of important events of the Archean crustal evolution (Anand et al., 2014; Jayananda et al., 2018; Jayananda et al., 2020). The petrogenetic and tectonic aspects of the metavolcanic rocks of the Archean schist belts in Dharwar Craton were studies by earlier workers (Rajamani, 1990; Chadwick et al., 2000).

The present project was carried out as part of Geological Survey of India annual field season program to locate possible zones of gold and associated mineralisation in the study area. With the limited data of X-ray Fluorescence (XRF) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) on the petrochemical samples collected it is observed that the metavolcanic rocks show variation i.e. basalt–basaltic andesite–andesite in the study area. Owing to the petrogenetic significance of the metavolcanic association in the study area that falls along the southern extension of the Neoarchean Raichur greenstone belt, through the present paper we report the basic information on the geological, petrological and geochemical aspects of the Madhavaram metavolcanic belt, Southern India.

2. Geology of Madhavaram area

Geologically the study area is located in between the Raichur and Gadwal schist belts in southern India (Fig. 1). The granite–greenstone terrain area comprising of the Raichur–Gadwal schist belts and granitoids form part of the eastern Dharwar Craton (Naqvi and Rogers, 1987; Srinivasan and Nagaraja Rao, 1992; Manikyamba et al., 2005, 2007). The metavolcanic rocks of the study area are exposed as a linear belt to the east of Madhavaram area in EDC. Lithologically the area is made of meta-volcanic rocks

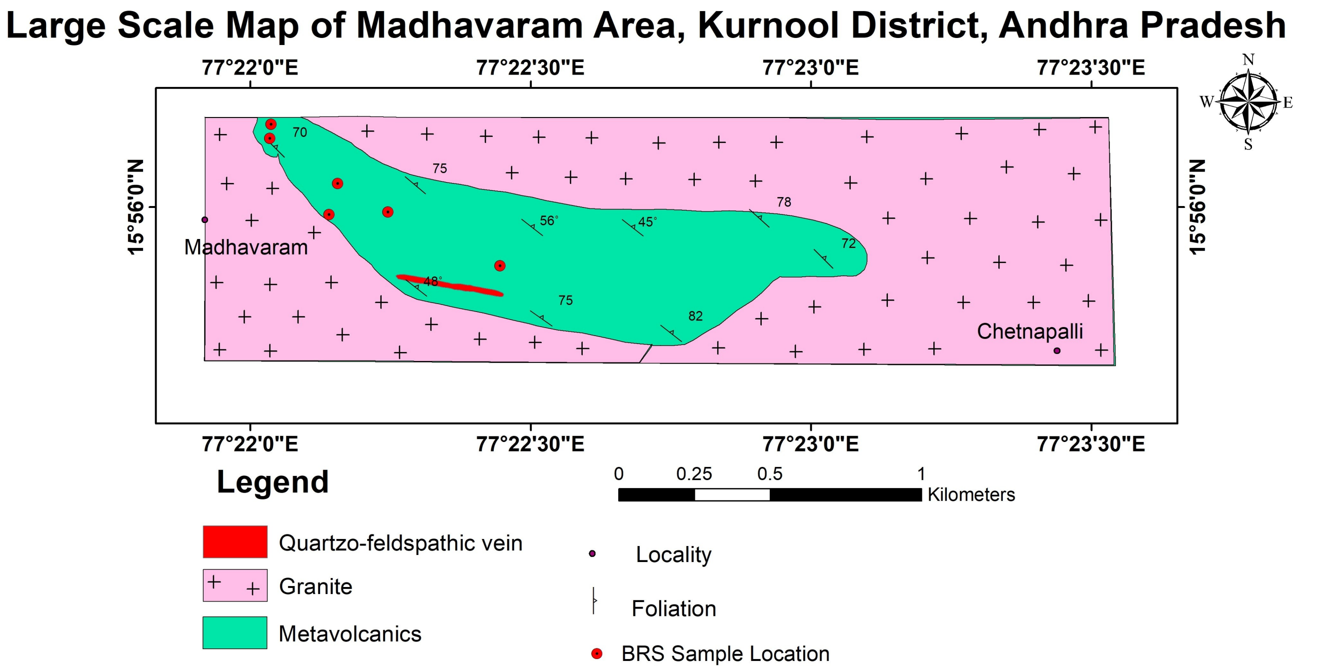

Fig. 2. Large-scale geological map of Madhavaram area, Kurnool district, Andhra Pradesh, Eastern Dharwar Craton (Khond and Mahanta, 2018).

that are intruded by granitoids, dolerite dykes, pegmatite and quartz veins. The metavolcanics of Madhavaram area are emplaced as intermittently exposed outcrops along WNW-ESE to NW-SE direction. Geological mapping was carried out in the study area (Khond and Mahanta, 2018) and the field relationship of the metavolcanics along with the granite and later quartzo-feldpathic veins have been established (Fig. 2). The fine-grained, greyish metavolcanics are exposed as low-lying outcrops in the granitic terrain (Fig. 3A). At places due to the presence of amphibole the metavolcanics are grey to greenish in colour. Field studies indicate that pegmatite veins traverse the metavolcanics along the schistosity (Fig. 3B) as well as the development of foliation in the metavolcanic rocks (Fig. 3C). The schistosity strikes in NW-SE direction with north-easterly dip ranging from 55-65 $^{\circ}$.

Two varieties of granitoids are noticed in the adjoining area (i) Medium-grained biotite granite (Fig. 3D) and (ii) Porphyritic granite. The porphyritic granite is characterised by the presence of tabular phenocrysts of alkali feldspar (Fig. 3E).

3. Sampling and analytical technique

Systematic sampling was carried out around Madhavaram area, in EDC. Efforts have been made to collect fresh samples that free from any secondary minerals or affected by post magmatic alteration. A total of ten samples were collected for chemical analysis and petrographic studies. Based on petrographic studies the areas of interest were selected for mineral chemistry studies. Major oxide, trace element and Rare Earth Element analyses were carried out by XRF and ICP-MS methods at the Geological Survey of India, Chemical Laboratory, Southern Region, Hyderabad. The results of XRF and ICPMS analyses of metavolcanics are furnished in Table 1 & Table 2 respectively.

Electron Probe Micro Analyses (EPMA) was carried out at Geological Survey of India, Southern Region, Hyderabad, by CAMECASX100. Analytical conditions: Accelerating voltage: 15kV, current: 12nA. Beam size: 1µ. All the natural standards have been used except for Mn and Ti for which synthetic standards have been used. The Electron Microprobe is equipped with five wavelength dispersive spectrometers (WDS), e.g., WDS 1 (TAP crystal), 2 (PET crystal) and 4 (LIF crystal) fitted with low-pressure detectors and WDS 3 (LPET crystal) and WDS 5 (LIF) fitted with high pressure detectors (all detectors use P-10 gas). Poly-propylene separation windows were used with WDS 1, 2 and 4 and Mylar windows are used with WDS 3 and 5.

(A) Low-lying outcrops of the metavolcanics, Madhavaram area, EDC, southern India.

(B) Pegmatite along the foliation of the metavolcanic rocks, Madhavaram area, EDC, southern India.

(C) Development of foliation in the metavolcanic rocks, Madhavaram area, EDC, southern India.

(D) Medium-grained biotite granite.

(E) Porphyritic granite.

Fig. 3. Field relations of the various rock types in the study area.

4. Petrography

Petrographic studies reveal that the basalt from Madhavaram area is essentially composed of plagioclase and clinopyroxene with accessory opaques. The Madhavaram metavolcanics are characterised by the presence of phenocrysts of hornblende and clinopyroxene at places within the fine-grained groundmass

Table 1. Major oxide analysis of metavolcanics, Madhavaram area, EDC, South India.

Oxide	MAD/BRS-104	MAD/BRS-110	MAD/BRS-114	MAD/BRS-118	MAD/BRS-101	MAD/BRS-120
SiO_2	50.36	50.86	49.68	49.87	53.68	59.01
Al_2O_3	15.68	14.68	14.87	14.45	13.98	14.12
Fe_2O_3	11.68	12.68	12.68	12.36	12.68	7.22
MnO	0.16	0.16	0.16	0.19	0.59	0.16
MgO	4.41	4.58	5.22	5.01	3.84	3.46
CaO	11.98	12.68	11.67	12.21	9.04	8.78
Na_2O	2.98	2.53	1.90	2.96	1.79	3.48
K_2O	0.72	0.69	1.87	0.62	0.65	1.29
TiO_2	0.61	0.58	0.65	0.70	0.45	0.50
P_2O_5	0.22	0.23	0.20	0.25	0.18	0.25
LOI	1.14	1.00	1.12	1.63	1.36	1.28
Total	99.94	100.67	100.02	100.25	98.24	99.55
Rock	Basalt	Basalt	Basalt	Basalt	Basaltic andesite	Andesite

Table 2. Trace element analysis (ppm) of metavolcanics, Madhavaram area, EDC, South India.

Element	MAD/BRS-101	MAD/BRS-104	MAD/BRS-110	MAD/BRS-114	MAD/BRS-118	MAD/BRS-120
Ba	475	388	501	746	400	683
Ga	16	16	15	14	16	16
Sc	25	30	28	29	33	15
V	149	163	161	187	186	95
Th	<4	<4	<4	<4	<4	6
Pb	16	19	18	19	16	17
Ni	167	137	226	226	243	140
Co	50	47	54	58	65	41
Rb	25	25	26	56	16	46
Sr	265	291	352	418	274	395
Y	11	16	17	15	19	14
Zr	82	80	75	81	84	134
Nb	<5	5	<5	5	<5	6
Cr	401	397	456	527	447	214
Cu	131	85	76	88	143	92
Zn	87	88	99	116	145	80
Be	0.92	0.88	0.69	0.91	0.69	1.25
Ge	1.75	1.37	1.41	1.39	1.24	0.76
Mo	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Sn	<5	<5	<5	<5	<5	<5
La	56.70	94.29	42.45	26.01	28.82	26.68
Ce	116.34	200.09	86.21	58.84	60.73	57.52
Pr	14.69	22.49	10.77	7.51	8.45	7.32
Nd	55.87	82.38	44.38	29.78	33.71	30.57
Eu	2.19	1.90	1.88	1.63	1.72	1.47
Sm	9.81	13.71	7.44	5.50	6.38	5.51
Tb	1.06	1.21	0.90	0.69	0.78	0.64
Gd	7.67	9.47	6.12	4.79	5.25	4.25
Dy	5.16	5.62	4.57	4.46	4.58	3.36
Ho	0.97	1.00	0.82	0.86	0.76	0.60
Er	2.80	2.47	2.28	2.60	2.61	1.87
Tm	0.41	0.36	0.32	0.40	0.41	0.25
Yb	2.56	2.55	2.30	2.80	2.31	1.69
Lu	0.36	0.47	0.35	0.45	0.36	0.25
Hf	10.84	20.21	13.14	37.38	5.05	5.61
Ta	0.32	0.38	0.41	0.27	<0.2	<0.2
W	<5	<5	<5	<5	<5	<5
U	5.97	6.95	4.62	5.45	4.59	5.77
Rock	Basalt	Basalt	Basalt	Basalt	Basaltic andesite	Andesite

(Fig. 4A & B). Andesite is mainly composed of hornblende and plagioclase, while titanite, apatite and opaques are noticed as accessory phases. Hornblende occurs as subhedral grains. Hornblende is characterised by the presence of rhombohedral cleavage and exhibits pleochroism in shades of green in plane polarised light (Fig. 4C). Under crossed nicols hornblende is anisotropic and show bluish and greenish interference colours of second order (Fig. 4D). Plagioclase is alerted and sericitised at places. At places twin lamellae are noticed in partially altered plagioclase grains. The opaques are represented by Fe-Ti oxides that are more or less uniformly distributed in the rock. At places the Fe-Ti oxides are also no-

Table 3. EPMA analyses of plagioclase, clinopyroxene and amphibole in the andesite, Madhavaram area, EDC, South India.

Sample No.	**MAD OM11**	**MAD OM11**	**MAD OM11**	**MAD OM11**	**MAD OM11**	**MAD OM11**	**MAD OM11**	**MAD OM11**	**MAD PS-2**	**MAD PS-2**	**MAD 104**	**MAD PS-2**
Point	25	27	29	36	26	28	41	37	47	56	80	50
SiO_2	52.483	52.96	49.269	48.975	65.522	65.959	59.3	65.603	50.803	51.636	50.503	52.129
Al_2O_3	1.604	1.936	4.119	4.672	20.767	21.014	25.487	21.232	0.488	0.398	1.083	0.264
TiO_2	0	0.071	0.089	0.099	0	0	0.01	0.036	0.009	0.009	0.027	0.058
FeO	15.945	14.619	18.746	17.299	0.327	0.403	0.02	0.174	14.554	12.701	13.457	9.29
MnO	0.288	0.282	0.296	0.357	0.069	0	0	0	0.64	0.441	0.391	0.346
MgO	13.205	13.05	11.153	10.235	0.045	0	0.02	0.015	8.292	9.61	9.306	12.013
Cr_2O_3	0	0.081	0.057	0.057	0	0.001	0.001	0	0.016	0.028	0.016	0
NiO	0.052	0.1	0.03	0.113	0.001	0.001	0	0	0	0.056	0.172	0.092
Na_2O	0.179	0.271	0.696	0.972	11.017	11.111	7.808	11.224	0.325	0.234	0.667	0.222
K_2O	0.076	0.117	0.254	0.333	0.094	0.065	0.124	0.2	0	0	0.027	0.013
CaO	12.778	14.273	12.503	12.837	1.583	1.42	6.756	1.468	23.797	24.377	23.348	25.012
P_2O_5	0.099	0.185	0.12	0.042	0	0.033	0.11	0	0.218	0.229	0.324	0.221
ZnO	0	0.679	0.269	0.067	0	0.07	0.00	0	0.841	0.237	0.47	0.205
Total	96.708	98.623	97.603	96.059	99.515	100.253	99.598	100.024	99.983	99.956	99.791	99.865
Mg #	0.45	0.47	0.37	0.37	0.1	0	0.05	0.05	0.36	0.43	0.4	0.56
Mineral	Hornblende				Plagioclase				Clinopyroxene			

ticed as clusters. Basaltic andesite is fine grained and is essentially composed of hornblende, clinopyroxene and plagioclase. Randomly oriented lath shaped plagioclase is noticed in the basaltic andesite of Madhavaram area (Fig. 4E & F). The rocks of study area are subjected to low grade metamorphism. Presence of euhedral to subhedral clinopyroxene, plagioclase and the twinned nature of the lath shaped randomly oriented plagioclase indicate preservation of primary igneous textures in the metavolcanic rocks of Madhavaram area.

5. Mineral Chemistry

EPMA studies of the mineral phases of the andesite from Madhavaram area were carried out to determine the chemical compositions of feldspar, amphibole and pyroxene. The results of EPMA analyses of the mineral phases from andesite are furnished in Table 3.

5.1. Feldspar

EPMA analyses of the feldspar of the andesite metavolcanic rock of Madhavaram area indicate that the SiO_2 content range from 59.3 to 65.95 wt%, Al_2O_3 20.76 to 25.48 wt%, K_2O 0.06 to 0.2 wt%, Na_2O 7.8 to 11.22 wt%, MgO 0 to 0.045 wt% and CaO 1.42 to 6.75 wt% indicating composition of the plagioclase ranging from albite to oligoclase. The P_2O_5 content range from 0.03 wt% to 0.1 wt% in the feldspar. BSE image (Fig. 5A & B) shows the embayed contact between the plagioclase and clinopyroxene indicating the preservation of the primary magmatic texture. Studies also indicate that the hornblende and plagioclase exhibit interlocking nature giving rise to the development of consertal texture (Fig. 5C). It is also observed that minute subhedral grains of apatite occurs within the plagioclase in the andesite. The mineral chemistry analysis data of the plagioclase feldspar is furnished in Table 3.

5.2. Amphibole

EPMA analyses of the amphibole from the andesite of the Madhavaram area indicate that the SiO_2 content range from 48.97 to 52.96 wt%, Al_2O_3 1.60 to 4.67 wt%, K_2O 0.07 to 0.33 wt%, Na_2O 0.17 to 0.97 wt%, MgO 10.23 to 13.20 wt%, MnO 0.28 to 0.35 wt%, FeO 14.61 to 18.746 wt% and CaO 12.50 to 14.27 wt%. The chemical composition of the Ca–Mg–Fe amphibole from the study area indicates the presence of magnesio hornblende, a member of calcium hornblende subgroup (Leake, 1968; Hawthorne et al., 2012). Hornblende is a characteristic hydrous Fe-Mg mineral phases that occurs in the andesites of calc alkaline affinity emplaced in subduction zone tectonic setting (eg. Anderson, 1980; Kelemen et al., 2003).

BSE image show that subhedral grains of partially prismatic hornblende is noticed as a conspicuous mineral phase in the Madhavaram andesite (Fig. 5D). Fe oxides are noticed as clusters at places in the andesite. The mineral chemistry analysis data of the amphibole is furnished in Table 3.

5.3. Pyroxene

EPMA analyses of clinopyroxene of the of the andesite metavolcanic rock of Madhavaram area indi-

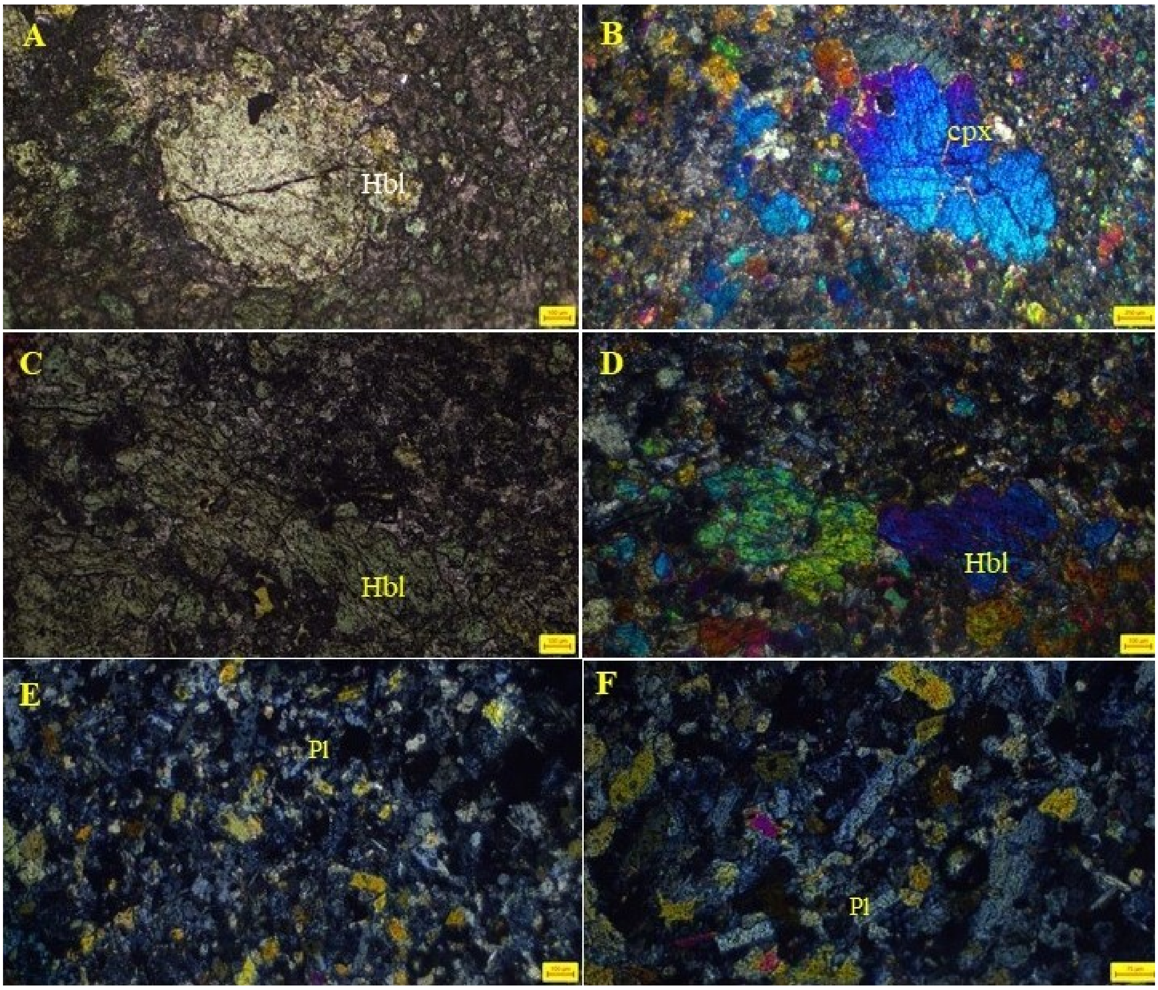

Fig. 4. A. Photomicrograph in plane polarised light (PPL) showing partially altered clinopyroxene. The pale greenish part in PPL is hornblende (Hbl). B. Photomicrograph in crossed niocols (XeD) showing the anisotropic nature of clinopyroxene (cpx) exhibiting 2nd order interference colours. C. Photomicrograph in PPL showing greenish hornblende in andesite. Note the rhombohedral cleavage in hornblende. D. Photomicrograph in crossed niocols (XeD) showing the anisotropic nature of hornblende. E. Photomicrograph in PPL showing the fine-grained nature of basaltic andesite. F. Photomicrograph in XeD showing the lath shaped nature of plagioclase (Pl) in basaltic andesite.

cate that the SiO_2 content range from 50.50 to 52.32 wt%, Al_2O_3 0.26 to 1.08 wt %, Na_2O 0.22 to 0.66 wt%, FeO 9.29 to 14.55 wt%, MgO 8.992 to 12.313 wt%, MnO 0.34 to 0.64 wt% and CaO 23.34 to 25.01 wt%. The P_2O_5 content range from 0.21 to 0.32 wt% in the clinopyroxene. The mineral chemistry analysis data of the pyroxene is furnished in Table 3.

In the Wollastonite–Enstatite–Ferrosalite pyroxene mineral chemistry diagram (Morimoto et al., 1988) the andesite of the Madhavaram metavolcanic rocks show diopside composition and fall in the sub-alkaline field (Fig. 6 after Le Bas, 1962).

6. Geochemistry

In the IUGS TAS diagram (Le Bas et al., 1986) the studied rocks essentially fall in basalt-basaltic andesite–andesite field. Geochemically the andesite–dacite rocks exhibit calc alkaline nature (Irvine and Baragar, 1971) and in the SiO_2--K_2O plot show calc alkaline andesite character. Major oxide analyses indicate variation in the silica, calcium and magnesium contents in the basalt–basaltic andesite–andesite metavolcanic rocks of Madhavaram area.

Basalt: Major oxide analyses (Table 1) of the basaltic rocks indicate that the SiO_2 content in the range from 49.68 to 50.86 %, Al_2O_3 14.45 to 15.68 %, Fe_2O_3 11.68 to 12.69 %, MnO 0.16 to 0.19 %, MgO 4.41 to 5.22 %, CaO 11.67 to 12.68 %, Na_2O 1.90 to 2.98 %, K_2O 0.62 to 1.87 % and TiO_2 0.58 to 0.70 %. In the IUGS TAS diagram (Le Bas et al., 1986) the samples fall in the field of basalt (Fig. 7B).

Basaltic andesite: Major oxide analyses of the

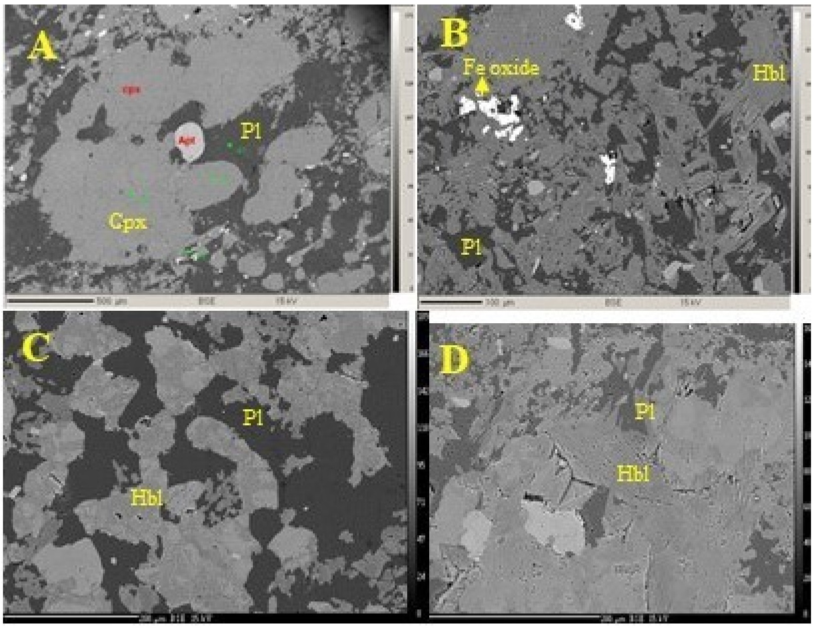

Fig. 5. BSE images of the mineral phases in the metavolcanic rocks at Madhavaram area, EDC, Southern India A. Subhedral apatite B. Clustered Fe Oxides C. Hornblende and plagioclase exhibit interlocking nature D. Subhedral hornblende. Abbreviations. Cpx: Clinopyroxene, Hbl: Hornblende, Epi: Epidote, Pl: Plagioclase, Apt: Apatite.

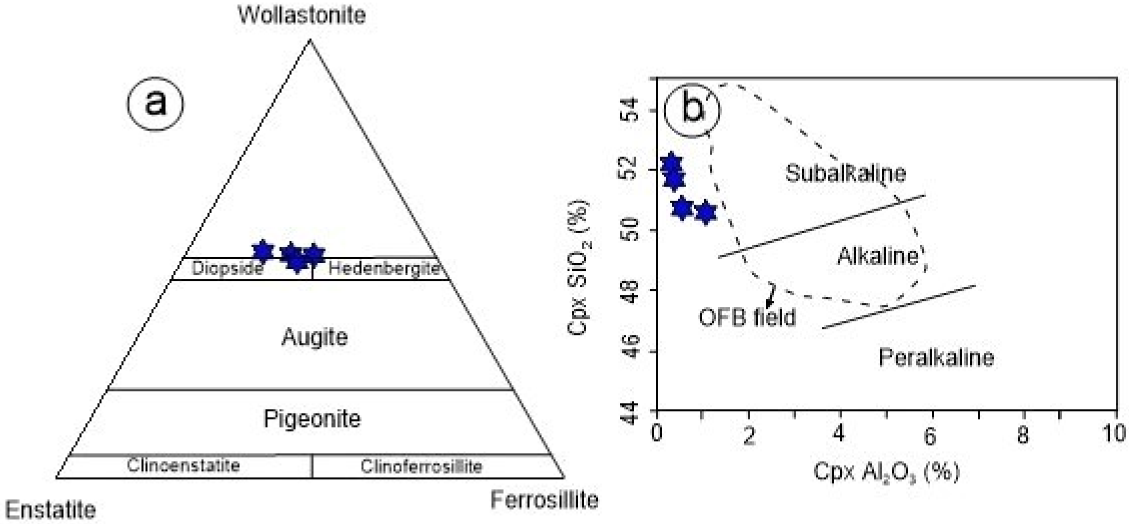

Fig. 6. Pyroxene mineral chemistry diagrams the Madhavaram metavolcanic rocks showing **(a)** diopside composition and **(b)** sub alkaline nature.

basaltic andesite (Table 1) indicate relatively enhanced silica and depleted MgO and CaO contents in comparison with the basaltic rocks of Madhavaram area. Basaltic andesite analysed SiO_2 content 53.68 %, Al_2O_3 13.98 %, Fe_2O_3 12.68 %, MnO 0.59 %, MgO 3.84 %, CaO 9.04 %, Na_2O 1.79 %, K_2O 0.65 % and TiO_2 0.45 %. In the IUGS TAS diagram (Le Bas et al., 1986) the samples fall in the field of basaltic andesite (Fig. 7B).

Andesite: Major oxide analyses of the andesite (Table 1) indicate relatively enhanced silica and depleted MgO and CaO contents in comparison with the basaltic andesite of Madhavaram area. Andesite analysed SiO_2 content 59.01 %, Al_2O_3 14.12 %, Fe_2O_3 7.22 %, MnO 0.16 %, MgO 3.46 %, CaO 8.78 %, Na_2O 3.48 %, K_2O 1.29 % and TiO_2 0.50 %. In the IUGS TAS diagram (Le Bas et al., 1986) the samples fall in the field of andesite (Fig. 7B).

7. Trace element geochemistry

Trace element analysis of the metavolcanics, Madhavaram area in EDC indicate relative depletion of niobium, an important high field strength ele-

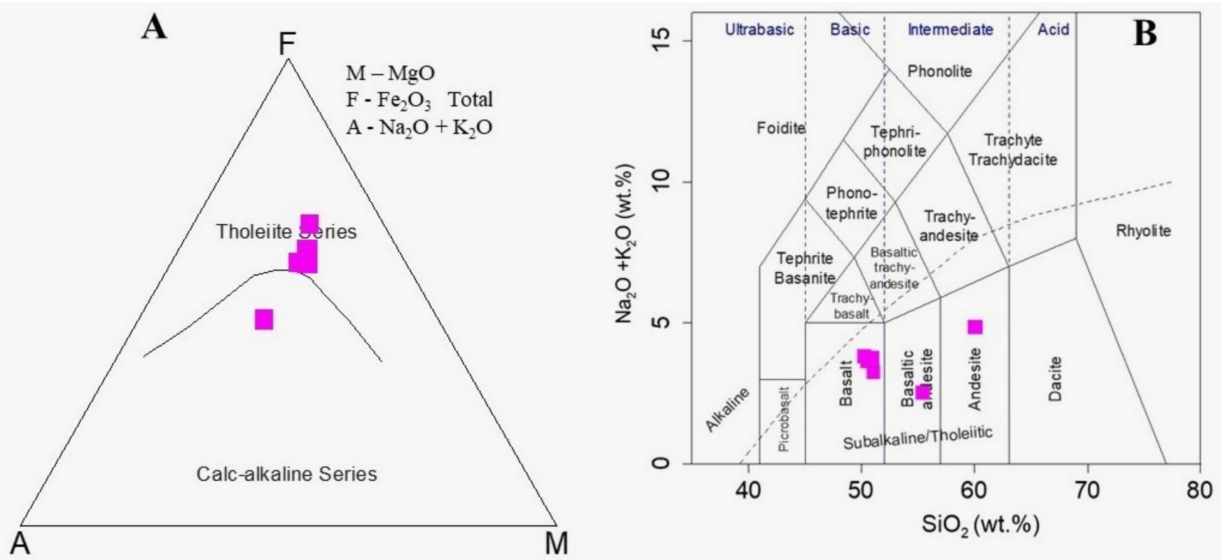

Fig. 7. **(A)** Basaltic rocks exhibiting tholeiitic trend and andesitic rock showing calc alkaline nature in the AFM diagram (Irvine and Baragar, 1971). **(B)** Metavolcanic rock of the Madhavaram area, EDC, southern India falling in the field of basalt–basaltic andesite–andesite in the IUGS TAS diagram (Le Bas et al., 1986).

ment whose geochemical concentration in the volcanic rocks of both tholeiitic and calc-alkaline nature reveals the nature of tectonism and magmatism. The Sr content in the basalt varies from 265 to 418 ppm, while the Sr content in basaltic andesite and andesite is 274 ppm and 395 ppm respectively. The Ba content in the basalt varies from 388 to 746 ppm, while the Ba content in basaltic andesite and andesite is 400 ppm and 683 ppm respectively. Barium is a soluble trace element whose enrichment can be ascribed to the sediment source in subduction zone. Among the high field strength element (HFSE) trace element analyses, the Zr content in the basalt varies from 75 to 82 ppm, while the Zr content in basaltic andesite and andesite is 84 ppm and 134 ppm respectively.

In primitive mantle trace element spider diagram (Sun and Mc Donough, 1989) the basalt–basaltic andesite rocks show negative Nb and Ti anomaly. Depletion of niobium is observed in some of the arc related magmas and the continental crust (Kelemen et al., 1993, 2003). These rocks are further characterized by high $(La/Yb)_N$ coupled with low $(Yb)_N$ ratios that are typically observed in the Na-rich granitoids (Manya et al., 2007) and adakites (Khanna et al., 2014) generated in subduction-related tectonic environment. The trace element character of the metavolcanics shows profound negative niobium (Nb) and titanium (Ti) anomaly, characteristic of arc magmas (Fig. 8A). The Y content in the basalt varies from 11 to 17 ppm, while the Y content in basaltic andesite and andesite is 19 ppm and 14 ppm respectively. Chondrite normalised REE plot (Nakamura, 1974) reveal a general enrichment of LREE relative to HREE (Fig. 8B). Owing to the limited geochemical data, detailed studies on crustal contamination and petrogenesis based on the trace element compositions have not been attempted. However, detailed trace element studies on the metavolcanic rocks of the Neoarchean schist belts in EDC do not indicate crustal contamination (Khanna and Sesha Sai, 2020). Detailed studies by earlier workers indicated Archaean subduction processes during the evolution of the Gadwal greenstone belt (Manikyamba et al., 2005). In the Ti-V discrimination diagram (Shervais, 1982) the metavolcanic rocks from Madhavaram area falls in the field of arc basalts of oceanic setting. In an earlier work, presence of an intraoceanic environment has been indicated during the eruption of the volcanic rocks in Neoarchean Gadwal greenstone belt (Manikyamba et al., 2005).

8. Discussion

Field and laboratory studies on the metavolcanic rocks in the greenstone belts contribute in understanding the Archean lithospheric processes and evolution of the early part of the Earth's crust-mantle tectonics (Dewit and Ashwal, 1995; Condie, 1997; Smithies et al., 2005). The Dharwar Craton of Southern India preserves evidences of wide range of geological events of crustal growth spanning from Meso

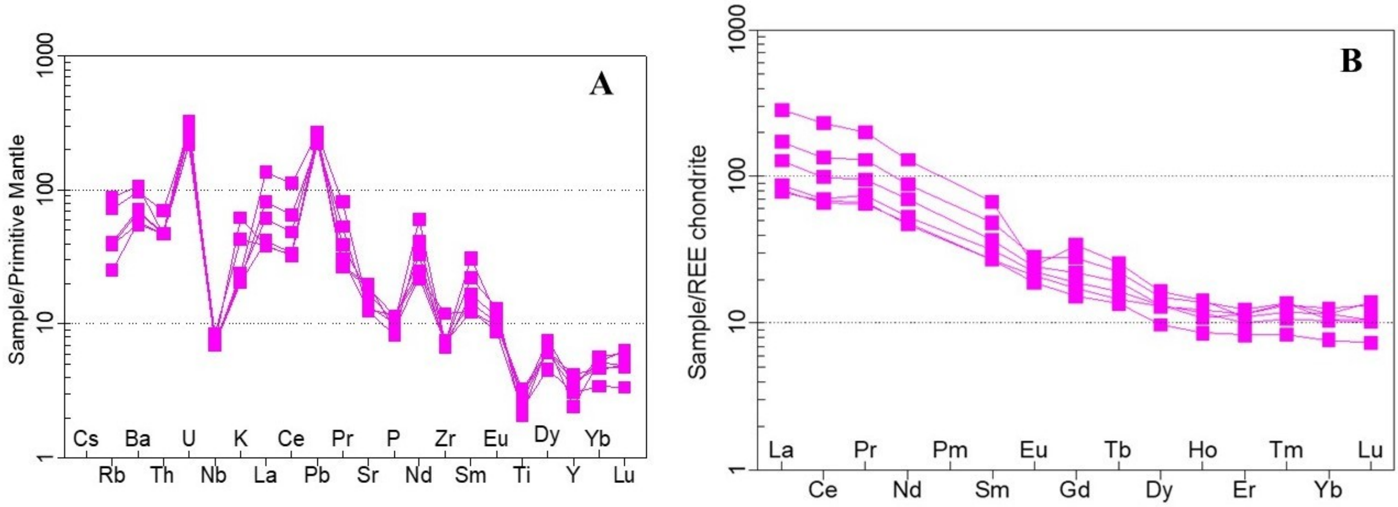

Fig. 8. (A) Metavolcanic rocks of Madhavaram area, EDC exhibiting negative Nb and Ti anomaly in the primitive mantle spider diagram (Sun and Mc Donough, 1989) (B) Metavolcanic rock of the Madhavaram area, EDC, southern India showing LREE fractionation and flat HREE patterns. Note the low magnitude negative Eu anomaly in the chondrite normalised REE plot (Nakamura, 1974).

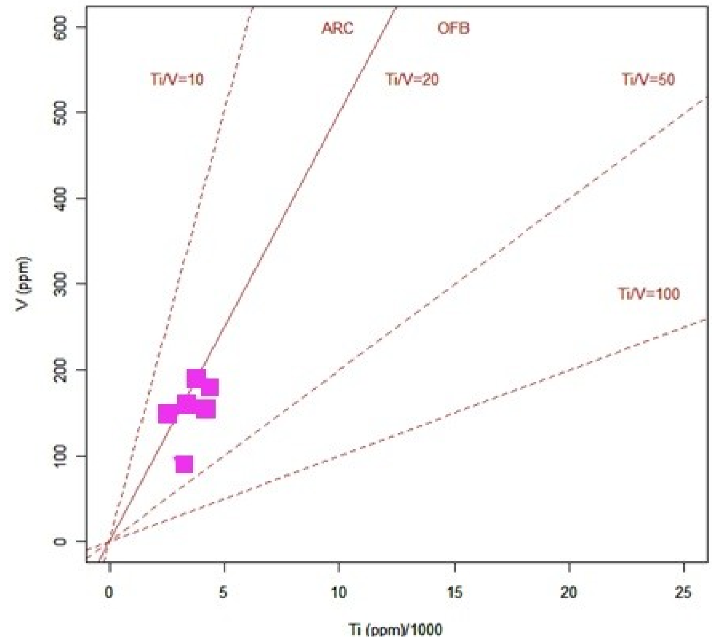

Fig. 9. Ti-V discrimination diagram of **m**etavolcanic rocks from Madhavaram area (Shervais, 1982).

to Neoarchean (Jayananda et al., 2018). Geological mapping of the metavolcanic rocks in the greenstone belts and establishing the field relations is prerequisite to build the evolutionary history. Satellite image studies (Veeriah et al., 2006) indicated that the Gadwal schist belt is discontinuous and narrow, while the areal extent of Raichur schist belt is greater. Geological mapping of the Madhavaram area in EDC was done and the field relationship of the metavolcanics along with the adjoining granites has been established (Khond and Mahanta, 2018). The metavolcanic rocks of Madhavaram area are situated to the south of the existing Raichur schist belt and interestingly fall in the gap area of Raichur–Gadwal Archean schist belts in the EDC. Considering that basalt–basaltic andesite rocks show negative niobium (Nb) and titanium (Ti) anomaly the present work brings to light the possible spatial continuity of the Raichur–Gadwal greenstone belts and its evolution in subduction zone tectonic setting.

9. Conclusion

- Through large-scale geological mapping a linear belt of WNW-ESE to NW-SE metavolcanic rocks has been delineated at Madhavaram area to the south of Raichur schist belt, EDC, southern India.
- Petrographic studies indicate that, though the metavolcanic rocks of Madhavaram area are subjected to low grade metamorphism, primary igneous textures are preserved as indicated by the presence of euhedral to subhedral clinopyroxene and lath shaped twinned plagioclase.
- Major oxide geochemical studies indicate that the metavolcanic rocks are of basalt - basaltic andesite – andesite in composition.
- Trace element studies reveal that the metavolcanic rocks of Madhavaram area show negative Nb and Ti anomaly, indicating geochemical character of arc magmas.
- The present work on the metavolcanic rocks of Madhavaram area indicate possible spatial continuity of the Raichur–Gadwal greenstone belts, EDC, southern India.

Acknowledgements

Director General, Geological Survey of India, HOD and Additional Director General and Dy. Director General, State Unit Andhra Pradesh are thanked by authors for providing an opportunity to work in the study area. Authors thank Chemical Division GSI, SR, Hyderabad for analysing the samples and Petrology Division for preparation of thin-cum-polished sections. Dr. Sonalika Joshi and Mr. S.T. Narahari, EPMA Lab, GSI, Hyderabad, are thanked for mineral chemistry analyses. Dr. Ch. Narsimha of Kumaun University, Nainital is thanked for the help in mineral chemistry studies. Authors express sincere thanks to the reviewers for critical and helpful suggestions. Prof. A.P. Pradeepkumar is thankfully acknowledged for kind suggestions and editorial handling of the manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. No financial, personal, or professional relationships have influenced the content or findings presented in this study.

CRediT statement

VVSS: Conceptualization, Data curation, formal analysis, methodology, supervision, visualization, validation, writing – review & editing. MVK: Conceptualization, Data curation, formal analysis, methodology, software, visualization, writing – original draft, review & editing. NM: Data curation, formal analysis, investigation, validation, writing original draft.

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