

PETROGENETIC STUDY ON ULTRAMAFIC–MAFIC SUITE OF SATHYAMANGALAM SCHIST COMPLEX (SOUTH INDIA)

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Abstract

The ultramafic–mafic suite exposed in the Gobichettipalayam region of Tamil Nadu, forming part of the Sathyamangalam Schist Complex (SSC), displays a well-layered stratiform structure aligned along the Bhavani Lineament Zone. Field evidence such as rhythmic layering, chromitite lenses, and preserved cumulate textures indicates an intrusive origin with co-magmatic relationships. The sequence comprises pyroxenite at the base, overlain by metagabbro and capped by meta-anorthosite, all emplaced into high-grade metamorphic terrain and later deformed under upper amphibolite to granulite facies. Petrographic analysis reveals adcumulate textures in anorthosites with calcic plagioclase, garnet-bearing metagabbros with relict pyroxenes, and clinopyroxene-rich pyroxenites, pointing to fractional crystallization and metamorphic overprinting. Major, trace, and REE geochemistry show a tholeiitic trend, with meta-anorthosites enriched in Al_2O_3 and CaO and depleted in TiO_2 , K_2O , and P_2O_5 . Tectonic discrimination diagrams and REE patterns suggest an arc-related, supra-subduction zone setting, marked by negative Eu anomalies and HREE enrichment, indicating plagioclase and pyroxene fractionation.

Keywords: Bhavani Lineament Zone, Layered mafic-ultramafic suite, Fractional crystallization, Tholeiitic differentiation, High-grade metamorphism

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Introduction

The meta-anorthosite-metagabbro-pyroxenite suite in Gobichettipalayam, Tamil Nadu, is a significant feature in understanding the petrogenesis of Archaean granulite gneiss terrains (Ashwal *et al.*, 1993). Anorthosite-bearing layered complexes are commonly found in such terrains, and Tamil Nadu hosts three major anorthosite suites: the Sittampudi-Bhavani layered anorthosite suite (SAS-BAS), the Kadavur anorthosite suite (KAS), and the Oddanchatram anorthosite suite (OAS), each exhibiting considerable diversity (Subramaniam, 1956; Janardhan & Leake, 1975). Previous investigations of the Sittampudi and Bhavani complexes (Bhaskar Rao *et al.*, 1996) have revealed a strong association between stratiform chromitites and calcic meta-anorthosites, resembling Archaean layered intrusions such as the Fiskenaesset Complex in West Greenland (Windley *et al.*, 1973). The SAS-BAS complexes are intensely deformed and metamorphosed, situated within the Cauvery shear zone (CSZ) of South India. These complexes are considered to represent a rare tectonic setting akin to that of the Messina Complex in the Limpopo Mobile Belt, South Africa (Barton *et al.*, 1979). The magmatic stratigraphy of these layered intrusions shows similarities to those found in other regions of southern India, though they have been altered by high-grade regional metamorphism and deformation (Satyanarayanan *et al.*, 2011). Globally, anorthosite-gabbro-pyroxenite complexes are crucial for understanding early Earth crustal evolution and magmatic processes. Examples such as the Fiskenaesset, Stillwater, and Bushveld complexes have been pivotal in studies of mineralogical and geochemical characteristics, including chromitites and cumulate layering. Research on these suites in Tamil Nadu has focused on their tectonometamorphic evolution, revealing complex interactions between magmatism and deformation, particularly within the Cauvery Shear Zone. The study of the Gobichettipalayam suite, in particular, offers valuable insights into the magmatic and tectonic history of the region, highlighting the role of high-grade metamorphism and deformation in modifying the original magmatic features. Furthermore, the similarities to globally known Archaean layered intrusions emphasize the importance of these complexes in reconstructing ancient tectonic environments and understanding the interplay of magmatism and deformation in mid-crustal shear zones, which played a significant role in early continental formation and cratonization.

Geologic Setting

The meta-anorthosite suite in the Gobichettipalayam region (longitude: 77°15'-77°25', latitude: 11°20'-11°30') is characterized by highly deformed, metamorphosed, and dismembered tectonic lenses situated within the Precambrian granulite gneiss terrain of South India. This layered suite is emplaced into metasedimentary rocks, including fissile biotite gneisses, garnet-hornblende-biotite gneisses, garnet-sillimanite gneisses, and garnetiferous quartzofeldspathic gneisses. The oldest rocks in the area are the meta-sedimentary supracrustals, which host the layered meta-anorthosite, meta-gabbro, and pyroxenite suite. The geological map of the region (Figure 1) highlights the key lithologies within the suite, which forms about one-tenth of the mapped area. Notable outcrops occur near Karappadi, Tittamalai, Nagamalai, and Karattupalayam. The main body of the layered complex consists of differentiated lithologies, which are present as pinch-and-swell dismembered units with sharp, sheared contacts with the surrounding metasediments. These rocks are emplaced along the axial zone of ENE-WSW trending isoclinal overturned folds and display a penetrative fabric with a largely planar arrangement of felsic and mafic layers. Anorthosites near Karappadi contain chromitite lenses and pods, while gabbros exhibit distinct foliated fabrics with alternating felsic layers (plagioclase) and mafic layers (chiefly clinopyroxenes, orthopyroxenes, and garnets). The outcrops follow an ENE-WSW trend, indicating their emplacement parallel to the Bhavani Suture Zone (BSZ). High-grade metamorphic rocks in the area include gneisses and granites, derived from tonalite and granodiorite metamorphism. Intrusive igneous rocks include gabbro, anorthosite, dolerite dykes, charnockite, and layered ultramafic-gabbroic-anorthositic complexes, with granulite-facies pyroxenite forming under high-temperature conditions. Meta-igneous rocks include metamorphosed anorthosite, gabbro, pyroxenite, and dunite, while amphibolite and basic-ultrabasic rocks represent metamorphosed mafic and ultramafic formations. Metasedimentary rocks such as schists, marble, and quartzite are derived from sedimentary and volcanic precursors, and the basement gneiss serves as the region's ancient foundational rock. The Bhavani layered complex and its associated units span from the Archaean to the Proterozoic, with the basement gneiss and Sathyamangalam Group, formed between 3.2 and 2.5 Ga, representing some of the oldest crustal

components. The Mettupalayam Complex, comprising meta-anorthosite, meta-gabbro, and dunite, dates back to 3.0-3.1 Ga and has undergone subsequent deformation. Late Archaean units such as pyroxenite granulite and charnockite formed around 2.6 Ga, marking significant tectonothermal events, while Meso-Proterozoic intrusives, including gabbro and dolerite dykes, indicate continued magmatic activity between 1.6 and 2.1 Ga. During the Proterozoic to Palaeozoic, tonalite-granodiorite metamorphism and granite formation occurred around 530-570 Ma, associated with the Bhavani Shear Zone. The Bhavani layered complex has been extensively deformed by the Cauvery Shear Zone, exhibiting ENE-WSW trending isoclinal folds and intense shearing, with well-developed foliation and mineral alignment indicative of tectonic stress. The region has also experienced high-grade granulite-facies metamorphism during major tectonothermal events in both the Archaean and Proterozoic, resulting in significant transformation of the rock units.

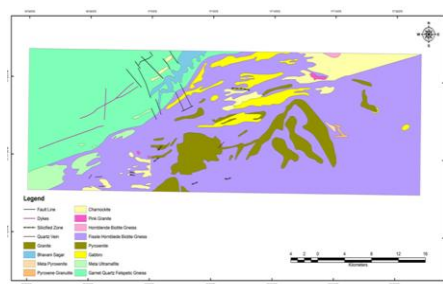


Figure 1. The geological map of the study area showing the main geological units of the Bhavani layered complex

Table 1 represents the generalized stratigraphic succession of rocks along with radiometric ages of the Bhavani Shear Zone, compiled from the works of Bhaskar Rao *et al.* (1996), Satyanarayanan *et al.* (2011), and Ali Mohammed Dar *et al.* (2014).

Field Relations

The layered meta-igneous suite of Gobichettipalayam is emplaced within the Sathyamangalam supracrustals and forms a part of the Sathyamangalam Schist Complex (SSC). This suite primarily comprises gabbroic facies, with subordinate anorthosite and minor pyroxenite components. The presence of chromitite in the form of pods and lenses within the anorthositic rocks, though volumetrically insignificant, serves as a key indicator of the magmatic origin of the Gobichettipalayam complex. The sharp and sheared contacts between the layered suite and the surrounding metasedimentary rocks further reinforce its intrusive nature. The suite occurs as an echelon outcrops, exhibiting a pinch-and-swell structure, which suggests structural control during emplacement.

Primary igneous features, such as rhythmic layering observed in the sequence from pyroxenites through gabbros, gabbroic anorthosites, and culminating in anorthosites, are particularly well-preserved near Karappadi, providing strong evidence of the original layered structure. The development of foliation, characterized by alternating plagioclase-rich and mafic-rich layers along with the presence of garnet, signifies the

Table1. A stratigraphic sequence for Bhavani layered complex represents the generalized stratigraphic succession of rocks along with a diometric ages of Bhavani Shear Zone complied from works of Bhaskar Rao *et al.* (1996), Satyanarayanan *et al.* (2011), Ali Mohammed Dar *et al.* (2014)

Eon/Era	Major rock type	Group	Age (Ma)
Proterozoic to Palaeozoic	Deformation and metamorphism of tonalite-granodiorite to give rise to high-grade gneiss and Granite	Younger granite	530-570
	Gabbro, Anorthosite	Ultrabasics/ basics younger	700-900
Meso Proterozoic	Gabbro/Dolerite dyke Charnockite	Basic Intrusives	1600-2100
Late Archaean	Pyroxenite granulite	Charnockite group	2600
Archaean	Meta-anorthosite	Mettupalayam complex	3000-3100
	Meta-gabbro		
	Meta-pyroxenite		
	Dunite		
	Amphibolite, basic/ultrabasic rocks	Sathyamangalam Group	3200.7-2.5 Ga
	Sillimanite-kyanite-corundum-mica schist (basic volcanic, pelitic schists and gneisses		
	Fuchsite-kyanite, marble, ferruginous quartzite		
	The intrusion of layered ultramafic-gabbroic-anorthositic complexes	Supracrustals	
	Intrusions of tonalite-granodiorite		
	Basement gneiss		

metamorphic overprint on this suite. The geological setting, lithological composition, and structural features of the Gobichettypalayam meta-igneous suite closely resemble those of the central zone of the Limpopo Belt in South Africa, particularly the Messina Complex.

During field investigations, a total of 100 samples were collected across different lithologies, including meta-anorthosite, metagabbro, and pyroxenite. A detailed sample location map will be generated using GIS tools, plotting key outcrops at Karappadi, Tittamalai, Nagamalai, and Karattupalayam, with rock types and sample counts labeled accordingly.

The foliation patterns within the layered suite exhibit directional variations from ENE-WSW through NE-SW to NW-SE, with a steep southward dip, suggesting multiple deformation phases. At least three folding events are inferred, with axial planes trending E-W, NNE-SSW, and NW-SE. The mineral assemblages, particularly the ubiquitous presence of garnet in all lithological units except pyroxenite, indicate that these rocks have undergone

metamorphism within the upper amphibolite to lower granulite facies (Bhaskar Rao *et al.*, 1996).

The surrounding Sathyamangalam supracrustal rocks predominantly consist of biotite-hornblende gneisses, garnet-biotite gneisses, garnetiferous quartzofeldspathic gneisses, garnet-sillimanite gneisses, para-amphibolites, and amphibolites, which have been intruded by later-stage granites and dykes. At Karappadi, the stratigraphic sequence of meta-anorthosite transitioning into metagabbro and pyroxenite is exposed within an overturned isoclinal fold structure. While pyroxenite exhibits massive textures, the other rock types display well-developed foliation, as shown in Figure 2.

Gabbros at Tittamalai are distinguished by localized mafic segregations, with garnet porphyroblasts ranging from a few millimeters to 2 cm in diameter, often encased by rims of pyroxene or hornblende. Notably, garnet concentrations are higher at fold noses compared to other sections of the outcrop. Gabbroic rocks are volumetrically dominant over anorthosites, while pyroxenites occur

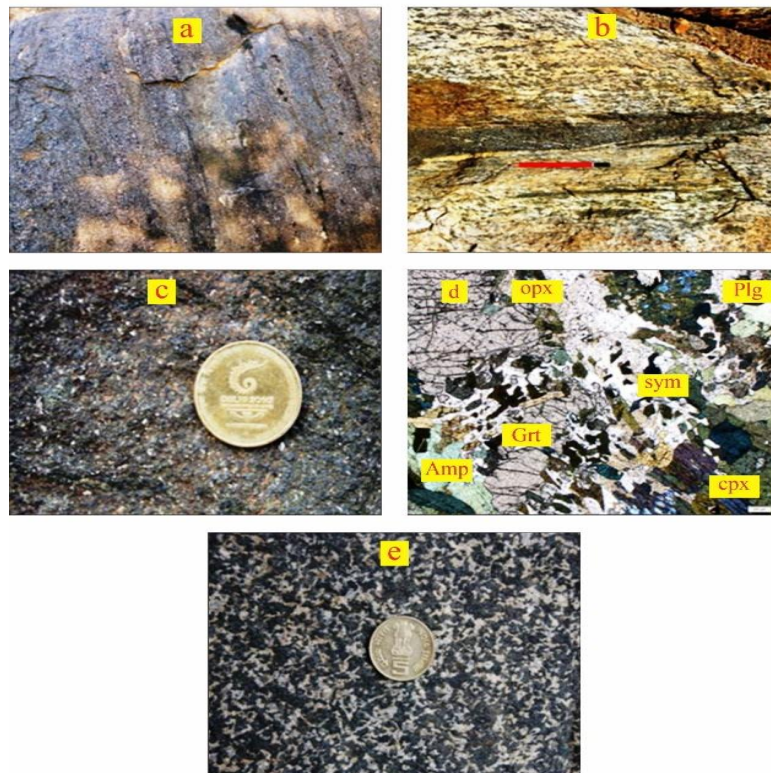


Figure 2. (a) Fine-grained layered gabbro showing parallel foliation. (b) Foliated gabbroic anorthosite interlayered with hypersthene-rich gabbro. (c) Photograph showing anhedral chromitite grains aligned parallel to the foliation. (d) Photomicrograph of garnetiferous gabbro showing a retrograded mineral assemblage. Amp: amphibole; Sym: symplectitic intergrowth around garnet; Grt: garnet; Cpx: clinopyroxene; Opx: orthopyroxene. (e) Coarse-grained plagioclase indicating a massive anorthosite rock body

as relatively minor masses beneath the gabbros. In Nagamalai, metagabbros lack distinct lithological differentiation, although variations in the proportion of felsic and mafic minerals are observed.

Outcrops of gabbroic anorthosites and anorthosites, along with chromitite occurrences, are observed near Karappadi, where they exhibit gradational contacts with the surrounding gabbros. Chromitite is present within the anorthositic rocks in the form of lenses and pods. The meta-anorthosite-metagabbro-pyroxenite suite is interpreted as tectonic slices embedded within the gneisses, having undergone at least three deformation events. These meta-igneous rocks are crosscut in certain locations by dolerite dykes, pegmatites, and quartz veins, indicative of subsequent igneous activity in the region. Field observations suggest that the meta-igneous and metasedimentary rocks of the area have experienced three phases of deformation and two metamorphic episodes. The contact between the meta-igneous layered suite and the surrounding metasediments is consistently sharp and marked by shear zones, indicating a tectonic juxtaposition of these units.

Petrography

The layered mafic rocks of the Gobichettipalayam region are petrographically classified into meta-anorthosites, meta-gabbroic anorthosites, metagabbros, and pyroxenites. Anorthositic rocks are primarily composed of plagioclase and hornblende, with minor phases of garnet, zoisite, epidote, scapolite, and opaque minerals as accessories. In gabbroic rocks, pyroxenes and garnets are predominant. The rocks exhibit a medium-grained, granular texture, with fresh mineral phases and minimal alteration. In anorthositic rocks, hornblende is observed replacing pyroxene in a paramorphic transformation, although relict pyroxenes are rare. Gneissose textures, planar fabric, and triple-junction grain boundaries indicative of equilibrium conditions are characteristic of these layered rock types (Subramaniam, 1956; Bhaskar Rao *et al.*, 1996).

Thin section preparation involves cutting rock samples into small blocks, mounting them on glass slides, and grinding them to a standard thickness of approximately 30 micrometers, followed by polishing to enhance optical clarity. Petrographic examination under a polarizing microscope, equipped with polarizing filters and a rotating stage, enables the study of mineral optical properties such as birefringence, pleochroism, and extinction angles.

Anorthosites predominantly consist of plagioclase (>90%) with minor hornblende (<10%) and occasional garnet. Scapolite and zoisite are present as minor constituents. Anorthositic rocks near Karappadi display an adcumulate texture and contain chromitite lenses and pods. Plagioclase in these rocks commonly exhibits twinning, although some grains show indistinct twin lamellae near margins, suggesting recrystallization (Janardhan & Leake, 1975). Deformation features such as kinked and bent twin lamellae, as well as ladder twinning, are frequently observed. The anorthite content of plagioclase ranges from 75-85%, while xenomorphic granular anorthosites with garnet inclusions show a lower anorthite content (65-70%), often accompanied by alteration to zoisite and scapolite. These rocks exhibit adcumulate textures, with euhedral calcic plagioclase making up approximately 99 vol%, with grain sizes ranging between 2 and 6 mm. Clinopyroxene, comprising about 1 vol%, is interstitial to the cumulus plagioclase acting as a post-cumulus phase (Salavati *et al.*, 2013).

Gabbroic anorthosites are massive to foliated rocks characterized by a planar alignment of mafic minerals. The plagioclase composition exhibits a narrow anorthite (An) range of 73-80%. Clinopyroxene (CPX) and orthopyroxene (OPX) are present as relict phases and discrete crystals. Pyroxenes display paramorphic transformation into hornblende, while garnet occurs as anhedral to subhedral grains, occasionally enclosing relict plagioclase and pyroxene. Garnet also shows cataclastic deformation and alteration to chlorite or aggregates of hornblende and plagioclase as symplectites. Scapolite and zoisite represent secondary phases resulting from plagioclase alteration. Cumulate textures are partially preserved in thin sections, although equilibrium granoblastic textures with triple junctions are predominant.

Metagabbros are medium-grained, exhibiting a granular texture and composed primarily of plagioclase, clinopyroxene, orthopyroxene, and garnet, with minor hornblende derived from pyroxene alteration. The presence of garnet is a defining feature of these rocks, often occurring with sieve textures. The texture of the mafic suite varies from fine-grained microgabbros to pegmatitic gabbros, with hornblende reaching several centimeters in length and interstitial plagioclase forming anhedral grains (Mathias *et al.*, 2012). Based on the felsic-to-mafic ratio, metagabbros are classified into meta-anorthositic gabbros, metagabbros, and meta-mafic gabbros. Near Karappadi, meta-mafic gabbros exhibit transitional contacts with anorthositic rocks, whereas

metagabbros range from gradational to sharply bounded contacts with anorthosites. In thin section, metagabbros reveal granoblastic textures with plagioclase and pyroxene aligned parallel to subparallel orientations. Triple junctions and polygonized plagioclase grains are notable features. Symplectites composed of hornblende and plagioclase occur along garnet grain boundaries and also form through garnet breakdown. Structurally, garnetiferous mafic granulites are conformable with the surrounding gneisses and are closely associated with websterites, calcic meta-anorthosites, and serpentinized dunites (Selvan & Janardhan, 1990; Janardhan & Leake, 1975; Pearce, 1982). Plagioclase modal abundances vary, ranging from 14–32% in meta-mafic gabbros, 53–58% in meta-anorthositic gabbros, and 38–53% in metagabbros. The relatively low plagioclase content in gabbroic rocks may be attributed to garnet formation at the expense of plagioclase. The anorthite content of plagioclase in these rocks ranges between 50–65% and decreases with declining plagioclase modal abundance in garnet-bearing samples.

Pyroxenites are medium- to coarse-grained, dense, and compact, with a high proportion of melanocratic minerals. They are predominantly composed of clinopyroxene with subordinate orthopyroxene, and radial growth textures are common. Near Tittamalai, pyroxenites occur structurally below gabbros along the limbs of a folded basic mass with a NW-trending axial plane. In Karappadi, pyroxenites exhibit sharp contacts with mafic gabbros and vary from gradational to sharp contacts with gabbroic anorthosites near Ayyampalayam. Megacrystic pyroxenites contain dominant clinopyroxene and orthopyroxene, with minor olivine, garnet, and spinel. Mineral modal compositions in pyroxenites vary significantly, with spinel (0–1%), garnet (1–25%), olivine (0–10%), clinopyroxene (0–65%), and orthopyroxene (30–65%). Pyroxenites found in ophiolites and orogenic peridotite massifs may preserve records of mantle processes occurring in supra-subduction environments (Tilhac *et al.*, 2017). These rocks may represent either the recycling of crustal material within mantle domains or primary mantle-derived lithologies formed via olivine-consuming melt-rock reactions or crystal fractionation (France *et al.*, 2015). The presence of primary magmatic amphiboles in meta-pyroxenites suggests their crystallization from a hydrous parental magma within the Archaean mantle (Keeditse *et al.*, 2016).

Chromitites occur as pods and lenses, exhibiting syntectonic textures and primarily composed of chromite, chlorite, plagioclase, and amphibole, with relict pyroxene and plagioclase also present. The textures and structures of

chromitites closely correspond to those of the associated silicate rocks, though they manifest differently. Layering of chromite, olivine, and their intergrowths is a prominent feature in many chromite-bearing deposits. Structural features such as remarkable lineation and boudinage are evident in some occurrences (Guild, 1942; Wells *et al.*, 1949). Chromitite cores are encased in poikilitic aureoles, where euhedral to subhedral chromite grains act as chadacrysts. Chromite grains exhibit no preferred crystallographic orientation, whereas orthopyroxene grains commonly cluster and share the same crystallographic orientation, indicating synkinematic deformation and mineral growth (Kaufmann *et al.*, 2018).

Geochemistry

Twenty rock samples were analyzed using X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) at ACT Laboratories in Canada (Tables 2 and 3). The meta-anorthositic rocks are characterized by high Al_2O_3 (17.12–18.62 wt.%) and CaO (14.23 wt.%), while exhibiting relatively low concentrations of TiO_2 (0.28–1.06 wt.%), K_2O (0.27–0.30 wt.%), and P_2O_5 (0.02–0.28 wt.%). Trace element contents include Rb (4–7 ppm), Nb (2–6 ppm), Zr (12–96 ppm), and Y (0.33–55 ppm). Na_2O shows a slightly elevated range (2.43–2.91 wt.%), and Ni concentrations vary widely (47–1291 ppm), likely influenced by the albite content in plagioclase. The average chemical composition of these anorthosites is comparable to similar occurrences in other regions, showing close similarity to the Messina anorthosite and Daly's average anorthosite. However, these rocks contain slightly higher SiO_2 and Na_2O than the Sittampundi anorthosite.

Gabbroic rocks in the study area exhibit higher MgO and Fe_2O_3 contents compared to the anorthosites, with slightly increased CaO concentrations. Pyroxenites are distinguished by their relatively high MgO and Fe_2O_3 but lower Al_2O_3 and CaO contents. The geochemical classification of the meta-anorthosite suite reflects its high Al_2O_3 and CaO composition, with low TiO_2 , K_2O , and P_2O_5 , while variations in Ni concentrations appear to correlate with plagioclase composition. Gabbro samples show enrichment in MgO and Fe_2O_3 , whereas pyroxenites follow a similar trend with elevated MgO and Fe_2O_3 but lower proportions of Al_2O_3 and CaO.

The A ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) - F ($\text{FeO} + \text{Fe}_2\text{O}_3$) - M (MgO) ternary diagram for the Gobichettipalayam rock suite (Figure 3) demonstrates a significant spread of data points, reflecting an igneous

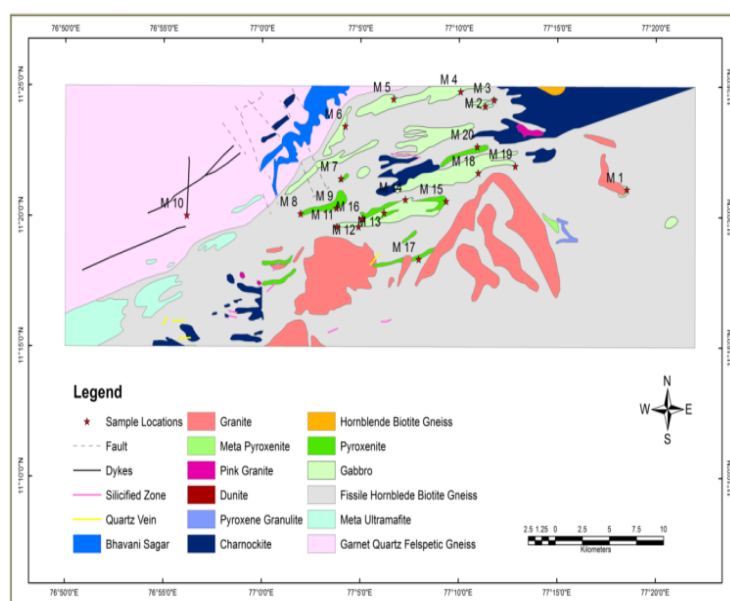


Figure 3. Sample location map of study area

differentiation trend. The meta-anorthosites exhibit mild iron enrichment and align with a calc-alkaline differentiation trend. Some gabbros display pronounced iron enrichment, positioning them above the typical calc-alkaline trend. The ultramafic pyroxenites plot near the F-M base and fall within the calc-alkaline field, while gabbros occupy a central position in the diagram. The majority of the analyzed samples fall within the tholeiitic series (Figure 3), exhibiting an iron-enrichment trend consistent with fractional crystallization processes.

Detection limits for major elements typically fall within the range of 0.01 to 0.1 wt.%, while trace elements are generally detected at concentrations between 0.1 and 1 ppm, depending on the analytical technique employed, such as X-ray fluorescence (XRF) or inductively coupled plasma mass spectrometry (ICP-MS). The analytical precision for major elements is typically within 1-2% relative for concentrations above detection limits, whereas trace elements exhibit a precision of approximately 5% at higher concentrations, with reduced accuracy at lower levels. Comparisons with certified reference materials indicate that the accuracy of major element analysis is generally within 1-3%, while trace element determinations fall within 5-10%, validated using standards and reference samples.

The primary lithologies identified in the study area include meta-anorthosite, gabbroic anorthosite, metagabbro, pyroxenite, and chromitite. Meta-anorthosite is composed predominantly of plagioclase (>90%), with subordinate hornblende, garnet, and accessory phases such as scapolite and zoisite. Gabbroic anorthosite contains 53-58%

plagioclase, with relict clinopyroxene and orthopyroxene, while garnet occurs as anhedral crystals, and hornblende forms through the alteration of pyroxenes. Metagabbro is characterized by 38-53% plagioclase, 20-30% clinopyroxene, and garnet displaying sieve textures, along with symplectite assemblages. Pyroxenite is composed primarily of clinopyroxene and orthopyroxene (30-65% each), with minor garnet and occasional occurrences of spinel and olivine. Chromitite consists predominantly of chromite, along with chlorite, plagioclase, and amphibole, while relict pyroxenes and well-developed layering textures are also observed.

Geochemical analyses of the suite of rocks, as represented in the A-F-M ternary diagram, indicate an iron-enrichment trend, with compositions aligning with subalkaline and tholeiitic series. The Nb/Th vs. Y and Ce/Yb ratios suggest a magmatic origin associated with an island arc tectonic setting. Additionally, magma evolution patterns exhibit geochemical signatures indicative of crustal interaction and assimilation, further supporting a complex petrogenetic history.

To minimize the effects of alteration, fresh rock samples were preferentially collected; however, gabbroic and ultramafic samples exhibited loss on ignition (LOI) values of less than 3 wt% (Tables 2 and 3). The moderate alteration observed, inferred from major element mobilization, suggests some degree of chemical modification. However, high-field strength elements (HFSE) such as Ti, Zr, Y, and Nb are considered relatively immobile during alteration processes (Farahat *et al.*, 2004;

Manikyamba *et al.*, 2004; Parlak *et al.*, 2004; Saccani & Photiades, 2004; Krienitz *et al.*, 2006). Consequently, the interpretation of geochemical data primarily relies on these relatively stable elements, together with rare earth elements (REE) and Th, to avoid complications arising from element mobility.

Table 2. Representative XRF and ICP- MS analysis of ultramafic rocks from Bhavani layered complex

Sample no. oxides	RKV- 1	RKV- 2	RKV- 3	RKV- 4	RKV- 5	RKV- 6	RKV- 7	RKV- 8	RKV- 9	RKV- 10
SiO ₂	47.99	46.58	45.12	46.36	47.58	46.53	43.35	44.15	45.41	42.05
TiO ₂	0.91	1.06	0.96	0.69	0.59	0.57	0.72	0.7	0.44	0.28
Al ₂ O ₃	12.05	12.03	8.74	15.72	18.62	10.79	14.34	14.45	11.02	17.12
MnO	0.21	0.21	0.19	0.19	0.22	0.3	0.28	0.27	0.2	0.26
Fe ₂ O ₃	12.46	15.69	13.09	12.37	14.5	14.47	15.54	16.27	12.55	16.08
CaO	13.14	12.61	12.56	11.12	8.13	9.11	11.48	9.4	8.31	7.13
MgO	9.83	9.5	17.2	9.45	8.16	15.1	10.42	12.25	16.57	12.43
Na ₂ O	1.96	1.15	1.38	2.43	1.56	0.66	1.12	0.55	0.98	0.85
K ₂ O	0.27	0.13	0.17	0.3	0.18	0.09	0.24	0.08	0.14	0.12
P ₂ O ₅	0.13	0.16	0.15	0.22	0.28	0.06	0.05	0.05	0.03	0.03
Cr ₂ O ₃	0.03	0.06	0.05	0.08	0.03	0.07	0.06	0.02	0.04	0.05
L.O.I	0.98	0.75	0.07	1.05	0.14	2.34	2.34	1.14	4.23	3.21
Total	99.96	99.93	99.68	99.98	99.99	100.09	99.94	99.33	99.92	99.61
La	1.6	1.37	1.35	1.8	0.85	1.13	3.13	1.2	2.68	5.4
Ce	3.84	3.35	2.84	3.38	2.26	2.85	13.01	2.66	8.02	12.9
Pr	0.57	0.48	0.43	0.47	0.29	0.36	1.38	0.39	0.87	1.8
Nd	3.26	2.86	2.9	1.98	1.46	1.81	7.48	2.07	4.77	8.8
Sm	0.85	0.95	0.76	0.63	0.46	0.47	1.67	0.65	1.52	2.7
Eu	0.3	0.28	0.18	0.17	0.15	0.13	0.35	0.16	0.33	1
Gd	1.07	1.22	0.85	0.84	0.63	0.82	1.41	0.66	1.49	3.2
Tb	0.18	0.25	0.19	0.25	0.16	0.25	0.25	0.15	0.27	0.6
Dy	1.22	1.81	1.15	2.2	1.17	1.46	1.91	1.37	1.88	3.6
Ho	0.3	0.38	0.23	0.45	0.35	0.35	0.46	0.26	0.46	0.8
Er	0.77	1.13	0.76	1.28	1.06	1.22	1.31	1.02	1.36	2.2
Tm	0.13	0.16	0.12	0.24	0.14	0.16	0.24	0.13	0.24	0.3
Yb	0.75	0.87	1.31	1.42	1.11	1.28	1.94	0.83	1.82	1.8
Lu	0.14	0.16	0.13	0.28	0.24	0.27	0.6	0.13	0.5	0.3
Sc	24	26	13	32	13	43	48	32	31	31
V	308	3250	392	426	527	69	289	216	149	216
Cr	376	1307	308	520	41	743	368	470	1207	1023
Co	191	132	184	177	132	49	63	100	80	116
Ni	165	236	149	149	47	568	430	793	742	834
Cu	26.9	24	72	32	88	11	507	605	429	369
Zn	50.4	40	72	104	88	27	112	150	108	482
Ga	11	16	12	17	12	3	12	12	13	14
Rb	7	4	5	6	5	4	7	6	5	6
Sr	17	34	60	59	135	152	34	32	42	26
Y	55	0.53	24	24	24	4	18	17	9	12
Zr	42	15	37	67	96	12	31	39	23	27
Nb	4	2	4	3	3	2	5	6	2	5
Ba	81	55	40	58	107	26	154	42	58	31
Pb	4	6	2	4	2	4	3	4	3	4
Th	2	2	2	2	2	2	2	3	2	2
U	1	1	1	1	1	1	1	1	1	1

LOI represents loss on ignition

Table 3. Representative XRF and ICP-MS analysis of ultramafic rocks from Bhavani layered complex

Sample no. oxides	RKV- 11	RKV- 12	RKV- 13	RKV- 14	RKV- 15	RKV- 16	RKV- 17	RKV- 18	RKV- 19	RKV- 20
SiO ₂	49.02	46.99	44.2	46.21	44.03	46.12	45.74	44.86	44.61	44.1
TiO ₂	0.83	0.47	0.29	0.92	1.02	0.48	0.38	0.72	0.58	0.51
Al ₂ O ₃	10.6	10.62	8.63	15.57	12.5	15.78	7.19	13.87	13.77	11.52
MnO	0.22	0.19	0.2	0.25	0.32	0.04	0.23	0.25	0.24	0.17
Fe ₂ O ₃	13.67	12.14	11.19	13.41	17.31	12.4	14.04	14.66	15.21	14.28
CaO	10.33	14.23	7.51	11.67	13.32	12.09	8.05	12.03	9.92	8.56
MgO	11.57	13.69	26.64	10.16	8.35	11.21	18.63	9.72	12.86	14.79
Na ₂ O	2.91	1.26	0.58	0.34	1.9	1.31	0.65	0.84	0.76	0.91
K ₂ O	0.18	0.07	0.08	0.07	0.12	0.15	0.09	0.09	0.1	0.16
P ₂ O ₅	0.05	0.03	0.04	0.05	0.12	0.04	0.02	0.05	0.03	0.02
Cr ₂ O ₃	0.06	0.03	0.04	0.06	0.07	0.05	0.08	0.09	0.04	0.06
L.O.I	0.07	0.06	0.09	1.02	0.05	0.27	4.06	2.43	1.07	4.53
Total	99.51	99.78	99.49	99.73	99.11	99.94	99.16	99.61	99.19	99.61
La	1.55	1.46	2.7	1.51	1.25	1.6	9.68	1.8	3.31	4.6
Ce	4.46	3.75	5.64	3.12	2.23	3.3	24.75	2.94	9.1	10
Pr	0.55	0.51	0.83	0.54	0.36	0.38	1.94	0.55	1.08	1.5
Nd	3.09	2.83	4.98	3.36	1.85	1.95	12.37	2.55	5.37	7.9
Sm	0.95	0.86	1.45	1.07	0.48	0.58	2.2	0.9	2.14	2.4
Eu	0.34	0.27	0.36	0.19	0.14	0.12	0.4	0.18	0.43	0.8
Gd	1.16	1.04	1.73	1.22	0.85	0.83	1.58	0.97	1.68	2.6
Tb	0.29	0.21	0.28	0.23	0.15	0.18	0.37	0.2	0.34	0.5
Dy	1.55	1.41	2.17	1.62	1.44	1.52	2.28	1.54	2.08	3.4
Ho	0.34	0.34	0.37	0.34	0.32	0.35	0.6	0.28	0.52	0.8
Er	0.93	0.93	1.36	1.09	1.24	1.24	1.54	1.35	1.62	1.14
Tm	0.13	0.15	0.18	0.16	0.14	0.22	0.29	0.15	0.25	0.3
Yb	0.73	0.78	1.08	1.35	1.28	1.36	2.37	0.84	2.69	1.09
Lu	0.15	0.12	0.14	0.19	0.22	0.26	0.38	0.14	0.46	0.3
Sc	26	8.5	14	41	27	16	36	47	30	19
V	364	3250	308	297	527	87	221	301	194	296
Cr	322	356	226	281	109	1706	408	669	400	1438
Co	117	176	44	140	140	84	121	78	99	95
Ni	204	126	149	189	71	127	1291	360	666	921
Cu	192	720	72	120	120	35	749	213	235	689
Zn	72	64	80	56	80	99	131	127	122	307
Ga	11	3	14	13	14	14	9	14	12	17
Rb	6	4	5	5	6	5	5	6	7	6
Sr	110	76	152	127	161	64	12	95	30	31
Y	0.33	31	16	0.5	0.4	12	10	20	15	4
Zr	48	30	44	37	81	47	20	25	37	27
Nb	4	2	4	2	5	4	3	3	3	3
Ba	34	26	136	58	31	136	113	111	44	58
Pb	2	4	5	3	4	5	5	7	3	4
Th	2	2	2	2	2	2	2	4	2	2
U	1	1	1	1	1	1	1	1	1	1

LOI represents loss on ignition

The Nb/Y vs. Zr/Ti diagram after Winchester and Floyd (1977) classifies the studied samples within the subalkaline basalt and basaltic andesite fields (Figure 4). The observed geochemical trends suggest a basaltic-to-basaltic andesite evolutionary pathway, likely influenced by the assimilation of pre-existing evolved calc-alkaline material and, in some cases, the mixing of distinct mafic magma types during crustal migration. Many of the analyzed basalts are porphyritic (10-30%), primarily composed of olivine and plagioclase, and exhibit disequilibrium textures, which obscure a precise reconstruction of mantle melting processes, as described by Wanke *et al.* (2019).

Geochemical discrimination diagrams further support the tholeiitic affinity of the analyzed rock suite. The Ti/Y vs. Nb/Y diagram after Pearce (1982) (Figure 4(c)) and the Nb/Y vs. Zr/P₂O₅ diagram after Winchester and Floyd (1976) (Figure 4(d)) confirm this classification. In the Nb/Th vs. Y diagram after Jenner *et al.* (1991), both ultramafic and mafic samples plot within the arc-related field (Figure 4(e)). Similarly, the Ce/Yb diagram after Hawkesworth *et al.* (1993) also indicates an island arc-related geochemical trend (Figure 4(f)). In addition, the Ti/V vs. Zr and Ti/Cr vs. Ni discrimination diagrams after Hawkesworth *et al.* (1993) display relatively low values, suggesting affinities with island arc-related rocks (Figure 4(g-h)).

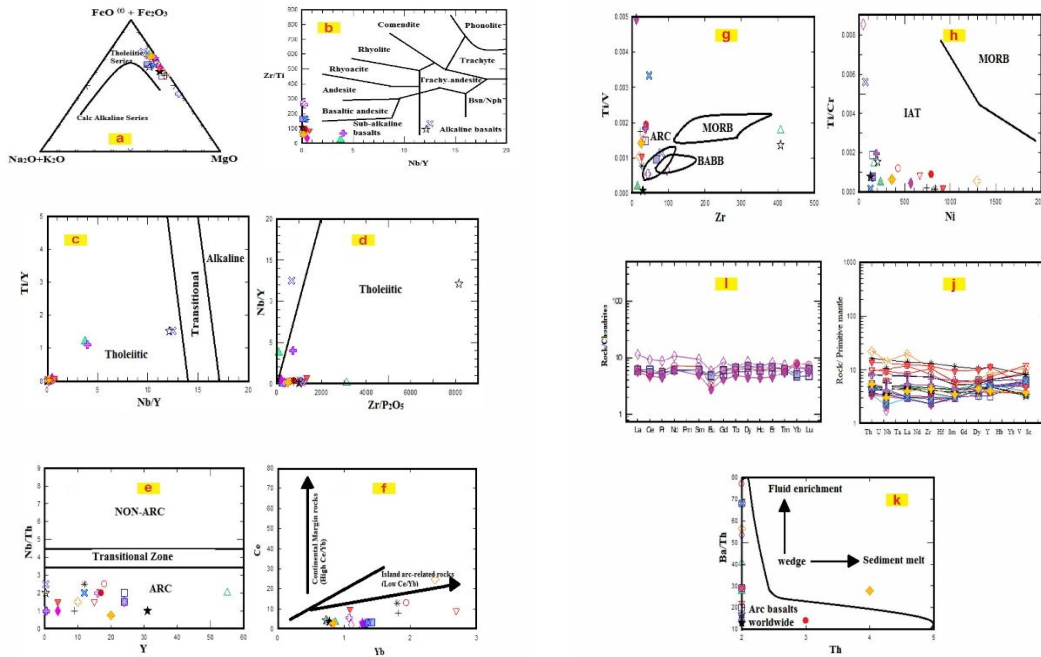


Figure 4. (a) AFM diagram, Irvine and Baragar (1971); (b) Zr/TiO₂–Nb/Y diagram for ultramafic-mafic rocks from BLC, Winchester *et al.* (1977); (c) Ti/Y vs. Nb/Y diagram, Pearce (1982); (d) Nb/Y vs. Zr/P₂O₅ diagram for studied mafic and ultramafic rocks from BLC, Winchester *et al.* (1976); (e) diagram showing the tectonic setting of mafic and ultramafic rocks of BLC, Nb/Th–Y, Jenner *et al.* (1991); (f) Ce/Yb diagram, Hawkesworth *et al.* (1993); (g) Ti/V vs. Zr diagram, Hollings & Kerrich, (2004); (h) Ti/Cr vs. Ni diagram, Beccaluva *et al.* (1983); (i) chondrite-normalized Rare Earth Element diagram for mafic-ultramafic rocks from BLC; (j) primitive mantle-normalized multi-element spider diagram, Sun *et al.* (1989); and (k) Ba/Th vs. Th diagram, Thorkelson and Breitsprecher (2005)

Intrusive relationships indicate that the intrusion resulted from three distinct magma pulses, all likely derived from a common primitive source. The estimated composition of the Lubei primitive magma exhibits similarities to island arc calc-alkaline basalt, except for its lower Na₂O and CaO contents Chen *et al.* (2018). This suggests a complex magmatic evolution involving fractional crystallization, crustal assimilation, and magma mixing.

The chondrite-normalized rare earth element (REE) patterns of the studied rocks exhibit relatively linear and homogeneous profiles, characterized by a moderate positive slope from heavy REEs (HREEs) to light REEs (LREEs) (Figure 4(i)). The metagabbros display a pronounced negative europium (Eu) anomaly, which is indicative of plagioclase fractionation, while maintaining a relatively uniform REE distribution among samples from the study area. The pyroxenites also show a distinct negative Eu anomaly together with slight HREE enrichment, suggesting the involvement of plagioclase ±

hornblende fractionation during magmatic differentiation. The observed depletion in LREEs and minor enrichment in HREEs may be attributed to the presence of clinopyroxene and, to a greater extent, hornblende, which act as key mineral phases controlling REE distribution.

To facilitate geochemical interpretation, REE concentrations are normalized using primitive mantle (PM) or mid-ocean ridge basalt (MORB) reference values, following the methodology of Sun and McDonough (1989). The normalized data are then plotted using software such as Excel, Origin, or Geochemist's Workbench, with trace elements along the x-axis and their corresponding normalized concentrations on the y-axis. The resulting patterns help delineate geochemical affinities, distinguishing among arc-related, MORB-type, and ocean island basalt (OIB) signatures. In MORB- and primitive mantle-normalized multi-element diagrams (Figure 4(j)), the studied samples exhibit significant geochemical features, including a strong negative Nb anomaly coupled with slight negative Zr and Sm anomalies. These characteristics suggest the

influence of subduction-related processes, in which large-ion lithophile elements (LILE) are enriched because of the influx of fluids or melts from the subducting slab. The depletion of high-field strength elements (HFSE), particularly Nb and Ta, is attributed to their retention in the slab rather than their mobilization into the mantle wedge (Pearce, 1982; Arculus & Powell, 1986; Wallin & Metcalf, 1998; Dawoud *et al.*, 2006). The presence of subduction-derived fluids enriched in LILE, such as Ba, leads to elevated Ba/Th ratios in the resultant magmas, reflecting the characteristic geochemical signature of arc-related magmatism.

The dehydration of the subducted slab leads to an influx of large-ion lithophile elements (LILE) into the mantle wedge, increasing the LILE/Th ratio within subduction-related magmatic systems (Thorkelson & Breitsprecher, 2005). The studied rock samples exhibit elevated Ba/Th ratios, indicating a significant contribution of slab-derived fluids in their genesis (Figure 4(k)).

Several high-field strength elements (HFSE), including V, Cr, Co, Ni, Cu, Zr, and Sr, were analyzed because these elements are relatively immobile during metamorphism and provide valuable insights into petrogenetic processes, as noted by Sun *et al.* (1978) and Condie *et al.* (1977). Despite moderate alteration, HFSE and rare earth elements (REE) remain reliable geochemical tracers. The identification of three distinct magma pulses suggests multiple episodes of magmatic activity. The geochemical data from the Bhavani Layered Complex (BLC) strongly support a supra-subduction zone (SSZ) origin, as evidenced by trace element systematics (Ti, V, Zr, Nb, Th, and Y), which are characteristic of an arc-basin setting typical of island arc magmatism.

Chondrite-normalized REE patterns display a subtle negative Eu anomaly, indicative of plagioclase fractionation. The enrichment of heavy REEs (HREEs) relative to light REEs (LREEs) suggests retention within clinopyroxene or hornblende, minerals commonly associated with SSZ environments. The presence of a tholeiitic magma signature indicates a mantle source akin to mid-ocean ridge basalt (MORB) or island arc tholeiite. The occurrence of ultramafic lithologies, such as pyroxenites and gabbros, along with cumulate textures, is consistent with SSZ magmatic differentiation processes. These characteristics collectively support a subduction-related magmatic evolution and mineralization.

The fractionation of plagioclase is responsible for the observed Eu anomaly, while clinopyroxene and hornblende influence HREE enrichment. These mineral phases play a crucial role in REE distribution, sequestering HREEs during magma

differentiation. As the magma evolves, the preferential incorporation of HREEs into clinopyroxene and hornblende leads to their relative enrichment in the final rock assemblage. Petrographic investigations further confirm the presence of these minerals and their role in controlling the geochemical evolution of the studied samples.

Conclusion

The Bhavani Layered Complex, comprising anorthosite, metagabbro, and pyroxenite, represents a cumulate sequence crystallized in a magma chamber within a supra-subduction zone island arc setting. Emplaced in high-grade Archean gneiss-granulite terrain, the complex exhibits tholeiitic geochemical signatures indicative of a MORB or island arc magma source. Trace element patterns place the suite within an arc-basin field, with REE systematics suggesting plagioclase fractionation and HREE retention in clinopyroxene. The geochemical data imply potential for reef-type mineralization. Despite uncertainties in post-magmatic alteration and magma mixing, the complex reflects island arc magmatism and subsequent high-grade metamorphism linked to arc-continent interactions.

Conflict of Interest: There is no conflict of interest.

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References

- Ali Mohammed Dar, A., Mir, A. R., Anbarasu, K., Satyanarayanan, M., Balaram, V., Subba Rao, D. V., & Charan, S. N. (2014). Mafic and ultramafic rocks in parts of the Bhavani complex, Tamil Nadu, Southern India: Geochemistry constraints. *Journal of Geology and Mining Research*, 6(2), 18–27. <https://doi.org/10.5897/JGMR14.0197>
- Arculus, R. J., & Powell, R. (1986). Source component mixing in the regions of arc magma generation. *Journal of Geophysical Research: Solid Earth*, 91(B6), 5913–5926. <https://doi.org/10.1029/JB091iB06p05913>
- Ashwal, L. D. (1993). *Anorthosites: Minerals and rocks* 21. Springer-Verlag. <https://doi.org/10.1007/978-3-642-77440-9>
- Barton, J. M., Fripp, R. E. P., Horrocks, P., & McLean, N. (1979). The geology, age, and tectonic setting of the Messina layered intrusion, Limpopo mobile belt, Southern Africa.

- American Journal of Science*, 279, 1108–1134. <https://doi.org/10.2475/ajs.279.10.1108>
- Beccaluva, L., Bigoggero, B., Chiesa, S., & Tunesi, A. (1983). Post-collisional orogenic dyke magmatism in the Alps. *Memorie della Società Geologica Italiana*, 26, 341–359.
- Bhaskar Rao, Y. J., Chetty, T. R. K., Janardhan, A. S., & Gopalan, K. (1996). Sm–Nd and Rb–Sr ages and P–T history of the Archean Sittampundi and Bhavani layered meta-anorthosite complexes in Cauvery shear zone, South India: Evidence for Neoproterozoic reworking of Archean crust. *Contributions to Mineralogy and Petrology*, 125, 237–250. <https://doi.org/10.1007/s004100050219>
- Chen, B., Yu, J., & Liu, S. J. (2018). Source characteristics and tectonic setting of mafic–ultramafic intrusions in North Xinjiang, NW China: Insights from the petrology and geochemistry of the Lubei mafic–ultramafic intrusion. *Lithos*, 308–309, 329–345. <https://doi.org/10.1016/j.lithos.2018.03.016>
- Condie, K. C., Viljoen, M. J., & Kable, E. J. D. (1977). Effects of alteration on element distributions in Archean tholeiites from the Barberton greenstone belt, South Africa. *Contributions to Mineralogy and Petrology*, 64(1), 75–89. <https://doi.org/10.1007/BF00375286>
- Dawoud, M., Eliwa, H. A., Traversa, G., Attia, M. S., & Itaya, T. (2006). Geochemistry, mineral chemistry, and petrogenesis of a Neoproterozoic dyke swarm in the northeastern desert, Egypt. *Geological Magazine*, 143(1), 115–135. <https://doi.org/10.1017/S0016756805001196>
- Farahat, E. S., El Mahalawi, M. M., Hoinkes, G., & Aal, A. A. (2004). Continental back-arc basin origin of some ophiolites from the Eastern Desert of Egypt. *Mineralogy and Petrology*, 82(1–2), 81–104. <https://doi.org/10.1007/s00710-004-0052-6>
- France, L., Chazot, G., Kornprobst, J., Dallai, L., Vannucci, R., & Gregoire, M. (2015). Mantle refertilization and magmatism in old orogenic regions: The role of late-orogenic pyroxenites. *Lithos*, 232, 49–75. <https://doi.org/10.1016/j.lithos.2015.05.017>
- Guild, P. W. (1942). *Chromite deposits of Kenai Peninsula, Alaska* (U.S. Geological Survey Bulletin 931-G, pp. 139–175).
- Hawkesworth, C. J., Gallagher, K., Hergt, J., & McDermott, F. (1993). Mantle and slab contributions in arc magmas. *Annual Review of Earth and Planetary Sciences*, 21, 175–204. <https://doi.org/10.1146/annurev.earth.21.050193.001135>
- Hollings, P., & Kerrich, R. (2004). Geochemical systematics of tholeiites from the 2.86 Ga Pickle Crow assemblages, northwestern Ontario: Arc basalts with positive and negative Nb–Hf anomalies. *Precambrian Research*, 134, 1–20. <https://doi.org/10.1016/j.precamres.2004.05.009>
- Irvine, T. N., & Baragar, W. R. A. (1971). A guide to the chemical classification of the common volcanic rocks. *Canadian Journal of Earth Sciences*, 8(5), 523–548. <https://doi.org/10.1139/e71-055>
- Janardhan, A. S., & Leake, B. E. (1975). The origin of the meta-anorthositic gabbros and garnetiferous granulites of the Sittampundi complex, Madras, India. *Journal of the Geological Society of India*, 16(4), 391–408. <https://doi.org/10.17491/jgsi/1975/160401>
- Jenner, G. A., Dunning, G. R., Malpas, J., Brown, M., & Brace, T. (1991). Bay of Islands and Little Port complexes revisited: Age, geochemical, and isotopic evidence confirm suprasubduction-zone origin. *Canadian Journal of Earth Sciences*, 28(10), 1635–1652. <https://doi.org/10.1139/e91-146>
- Kaufmann, F. E. D., Vukmanovic, Z., Holness, M. B., & Hecht, L. (2018). Orthopyroxene oikocrysts in the MG1 chromitite layer of the Bushveld Complex: Implications for cumulate formation and recrystallisation. *Contributions to Mineralogy and Petrology*, 173(2), 17. <https://doi.org/10.1007/s00410-018-1441-x>
- Keeditse, M., Rajesh, H. M., Belyanin, G. A., Fukuyama, M., & Tsunogae, T. (2016). Primary magmatic amphibole in Archean meta-pyroxenite from the central zone of the Limpopo complex, South Africa. *South African Journal of Geology*, 119(4), 607–622. <https://doi.org/10.2113/gssajg.119.4.607>
- Krienitz, M. S., Haase, K. M., Mezger, K., Eckardt, V., & Shaikh-Mashail, M. A. (2006). Magma genesis and crustal contamination of continental intraplate lavas in northwestern Syria. *Contributions to Mineralogy and Petrology*, 151(6), 698–716. <https://doi.org/10.1007/s00410-006-0088-1>
- Manikyamba, C., Kerrich, R., Naqvi, S. M., & Mohan, M. R. (2004). Geochemical systematics of tholeiitic basalts from the 2.7 Ga Ramagiri–Hungund composite greenstone belt, Dharwar craton. *Precambrian Research*, 134(1), 21–39. <https://doi.org/10.1016/j.precamres.2004.05.010>
- Mathias, J. R., Saxena, M. T., & Mumm, J. S. (2012). Advances in zebrafish chemical screening technologies. *Future Medicinal Chemistry*, 4(14), 1811–1822. <https://doi.org/10.4155/fmc.12.115>
- Parlak, O., Hoeck, V., Kozlu, H., & Delaloye, M. (2004). Oceanic crust generation in an island arc tectonic setting, SE Anatolian orogenic belt (Turkey). *Geological Magazine*, 141(5), 583–603. <https://doi.org/10.1017/S0016756804009458>
- Pearce, J. A. (1982). Trace element characteristics of lavas from destructive plate boundaries. In R. S. Thorpe (Ed.), *Andesites* (pp. 525–548). Wiley.
- Ramadurai, S., Sankaran, M., Selvan, T. A., & Windley, B. F. (1975). The stratigraphy and structure of the Sittampundi complex, Tamil Nadu, India. *Journal of the Geological Society of India*, 16(4), 409–414. <https://doi.org/10.17491/jgsi/1975/160402>
- Saccani, E., & Photiades, A. (2004). Mid-ocean ridge and supra-subduction affinities in the Pindos ophiolites (Greece): Implications for magma genesis in a forearc setting. *Lithos*, 73(3–4), 229–253. <https://doi.org/10.1016/j.lithos.2003.12.002>
- Salavati, M., Kananian, A., & Noghreya, M. (2013). Geochemical characteristics of mafic and ultramafic plutonic rocks in southern Caspian Sea ophiolite (Eastern Guilan). *Arabian Journal of Geosciences*, 6(12), 4851–4858. <https://doi.org/10.1007/s12517-012-0688-1>
- Satyanarayanan, M., Balaran, V., Sylvester, P. J., Rao, D. S., Charan, S. N., Shaffer, M., Dar, A. M., & Anbarasu, K. (2011). Geochemistry of late-Archean Bhavani (Mettupalayam) mafic/ultramafic complex, Southern India: Implications for platinum group element mineralization. *Journal of Applied Geochemistry*, 13(1), 1–14.
- Selvan, T. A., & Janardhan, A. S. (1990). The Moyar–Bhavani–Cauvery tract: A Precambrian suture zone in South India. In *National Seminar on Precambrian Geology of Madras: Abstracts* (pp. 12–13).
- Subramaniam, A. P. (1956). Mineralogy and petrology of the Sittampundi complex, Salem district, Madras State, India. *Geological Society of America Bulletin*, 67(3), 317–390. [https://doi.org/10.1130/0016-7606\(1956\)67\[317:MAPOTS\]2.0.CO;2](https://doi.org/10.1130/0016-7606(1956)67[317:MAPOTS]2.0.CO;2)
- Sun, S. S., & McDonough, W. S. (1989). Chemical and isotopic systematics of oceanic basalts: Implications for mantle composition and processes. In A. D. Saunders & M. J. Norry (Eds.), *Magmatism in the ocean basins* (Geological Society Special Publication No. 42, pp. 313–345). Geological Society of London. <https://doi.org/10.1144/GSL.SP.1989.042.01.19>
- Sun, S. S., & Nesbitt, R. W. (1978). Petrogenesis of ultrabasic and basic volcanic rocks: Evidence from rare-earth elements. *Contributions to Mineralogy and Petrology*, 65, 301–325. <https://doi.org/10.1007/BF00375516>

- Thorkelson, D. J., & Breitsprecher, K. (2005). Partial melting of slab window margins: Genesis of adakitic and non-adakitic magmas. *Lithos*, 79(1–2), 25–41. <https://doi.org/10.1016/j.lithos.2004.04.049>
- Tilhac, R., Grégoire, M., O'Reilly, S. Y., Griffin, W. L., Henry, H., & Ceuleneer, G. (2017). Sources and timing of pyroxenite formation in the sub-arc mantle: Case study of the Cabo Ortegal Complex, Spain. *Earth and Planetary Science Letters*, 474, 490–502. <https://doi.org/10.1016/j.epsl.2017.07.017>
- Wallin, E. T., & Metcalf, R. V. (1998). Supra-subduction zone ophiolite formed in an extensional forearc: Trinity Terrane, Klamath Mountains, California. *The Journal of Geology*, 106(5), 591–608. <https://doi.org/10.1086/516044>
- Wanke, M., Clynne, M. A., von Quadt, A., & Bachmann, O. (2019). Geochemical and petrological diversity of mafic magmas from Mount St. Helens. *Contributions to Mineralogy and Petrology*, 174(1), Article 6. <https://doi.org/10.1007/s00410-018-1544-4>
- Wells, F. G., Smith, C. T., Rynearson, G. H., & Livermore, J. S. (1949). *Chromite deposits near Seiad and McGuffy Creeks, Siskiyou County, California* (U.S. Geological Survey Bulletin 948-B, pp. 19–62).
- Winchester, J. A., & Floyd, P. A. (1976). Geochemical magma-type discrimination: Application to altered and metamorphosed basic igneous rocks. *Earth and Planetary Science Letters*, 28(3), 459–469. [https://doi.org/10.1016/0012-821X\(76\)90207-7](https://doi.org/10.1016/0012-821X(76)90207-7)
- Winchester, J. A., & Floyd, P. A. (1977). Geochemical discrimination of different magma series and their differentiation products using immobile elements. *Chemical Geology*, 20, 325–343. [https://doi.org/10.1016/0009-2541\(77\)90057-2](https://doi.org/10.1016/0009-2541(77)90057-2)
- Windley, B. F., Herd, R. K., & Bowden, A. A. (1973). The Fiskenaesset complex, West Greenland: A preliminary study of stratigraphy, petrology, and whole-rock chemistry. *Geological Survey of Greenland Bulletin*, 106, 1–80. <https://doi.org/10.34194/bullggu.v106.6647>