

# Mineralogical and Geochemical Characterization of Rocks Belonging to Madurai Block and Associated Industrial Minerals Situated in Usilampatti Taluk, South India.

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## ABSTRACT

Mineral investigations and knowledge of their chemical composition are the fundamental facts in determining the deposit's economic potential. In the study field, different rock and mineral samples were collected including limestone (LS6, LS7, and LS8) and granitoids samples (S1, S2, S3, and S4). The detailed investigations reveal that the limestone samples are dominated by calcite associated with accessory minerals, the granitoid samples show high levels of silica minerals and some ultra-high metamorphism minerals of granulite facies. Based on [20] classifications of granitoid, the samples fall in the ferroan granitoid [Fe<sub>2</sub>O<sub>3</sub> (t)/ (Fe<sub>2</sub>O<sub>3</sub> (t) +MgO)]. Modified Alkali-Lime Index (MALI) plotting [Na<sub>2</sub>O+K<sub>2</sub>O-CaO] against SiO<sub>2</sub>. The classification of the granite samples disseminate into alkalic, alkalic-calcic, calc-alkalic and calcic fields and the charnockite (S1), charnockite (S2), charnockite (S3), granite (S4), falls under calcic group. To determine the aluminous nature of granitic samples of the study area, A/CNK vs. A/NK graph was plotted where all the granitoid samples fall under the peralkaline group except the charnockite (S3) of Pommanampatti Village that falls under metaluminous. The AFM (total alkalis, Fe<sub>2</sub>O<sub>3</sub> and MgO), TAS (f Na<sub>2</sub>O +K<sub>2</sub>O against SiO<sub>2</sub>), Discrimination Y+Nb Vs Rb [27] and Discrimination [28] diagrams, the granitoid samples fall under ferroan granitoids, calcic group, metaluminous, tholeiitic series. Charnockite (S2) falls on the boundary of foidite and silexite, Charnockite (S3) falls foidite and granite (S4) falls under the silexite, S1 and S2 fall in the sub alkaline basalt, S3 in rhyodacite dacite and S4 in basanite Nephelinite.

**Keywords:** Mineralogy, chemical composition, industrial minerals, Usilampatti Taluk, XRD, XRF, ICPMS.

## INTRODUCTION

The knowledge of the chemical and mineralogical composition of geological material has been often fundamental in many branches of geosciences [1]. The investigation and the knowledge of mineral composition are highly important for rock classification and determination of its genesis, also provides essential knowledge to assess the economic potential of mineral deposit [2].

A handful number of analytical techniques have been developed for the analyses of geological materials; depending on the elements of interest, their concentration ranges, and definite mineralogical phases

[3]. The development of rapid and accurate instrumental analytical methods with good element coverage and detection capabilities has been of great benefit for research in geological and geochemical sciences, not only regarding the elements and concentration level, but also concerning different type of geological materials [4].

XRF is used for identification and determination of the chemical composition of the geological samples, to examine the quality and grade of the materials [5]. A powerful analytical method, ICP-MS (inductively coupled plasma-mass spectrometer) is used to study the trace element geochemistry. The mass spectrometer (ICP-MS) now recognized as a very powerful technique for multi-elemental analysis of huge samples, particularly in geology and biology. ICP-MS can analyse over

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90% of the elements of the Periodic Table [6]. The X-ray diffraction analysis is a method for the mineralogical identification permitting partly to full quantitative assessment of minerals presence in a sample and their relative occurrence proportions. XRD is, thus, a standard and very important technique in many investigations of the industrial mineral formation and products [7].

The aim of this study is to decipher the mineralogical and geochemical properties of rocks occurred in the area.

## STUDY AREA

The study area, Usilampatti Taluk is located in the northern part of Madurai District in Tamil Nadu State, South India. The Taluk lies between 9°51' 35" and 10°4' 15" North latitude and from 77°40' 30" to 77°52' 15" East longitudes and it covers a total area of 495.11 sq.km. The Usilampatti Taluk is a part of the main spur of hills running parallel to the Western Ghats from north to south direction. The spur is divided into two broad ranges, one being the Palani Hills on the north and the High Wavy Mountains of Varushanadu and the other being the Andipatti Hills in the south and it is the continuing track along the Usilampatti area.

## GEOLOGICAL SETTING

The Usilampatti Taluk rocks belong to the Archaean age and falls under Madurai block, a part of the SGT (southern granulite terrain). The geology the study area may be divided into three major groups of rocks, namely migmatite complex, charnockite group and khondalite group. Apart from the major groups cited above, there are a few minor rock groups and felsic intrusions mainly represented by the granites. These felsic intrusions are of Proterozoic age. A small area is occupied by a sedimentary rock of the Cenozoic age. Charnockites are coarse-grained with almost the same composition of granite and granoblastic texture consists of orthopyroxene-bearing rocks of acid to intermediate compositions having the greasy appearance [8]. Charnockite or hypersthene bearing granite, banded quartz-magnetite granulite or banded magnetite quartzite, pyroxene granulite and thin sized pink quartzo-feldspathic granulite are well developed and exposed from mid to the southernmost parts and counting about 40% of the total areal extent of the study vicinity. Khondalite group, particular to the Eastern Ghats of India (schist or gneiss with an assemblage of garnet-sillimanite-quartz with or without graphite) is closely related to the charnockite group, and consists of rocks of sedimentary parentage such as quartzites, calc granulites, calc gneiss, crystalline limestone, garnetiferous quartzofeldspathic gneisses and meta-pelitics. The khondalites are usually well foliated and in hand specimen show various shades of greyish, brownish, red and pinkish red colours. The colour depends considerably on the level of weathering undergone of khondalites. The dominant minerals of the khondalite are garnet, sillimanite, feldspar, quartz and graphite. The khondalite group, after the migmatite and charnockite groups, is the third in order. The khondalite group consists of calc-granulite, garnetiferous sillimanite gneiss and garnet-sillimanite-graphite gneiss. Migmatite complex is formed by the rocks resulting from a retrogression and transformation of the

khondalitic and charnockitic. They are comprised of different types of gneisses. Even though the migmatite complex consists of components of different ages, generally they have been assigned Mid-Archaean age [9]. The geology of Usilampatti Taluk is exhibited in Fig.1.

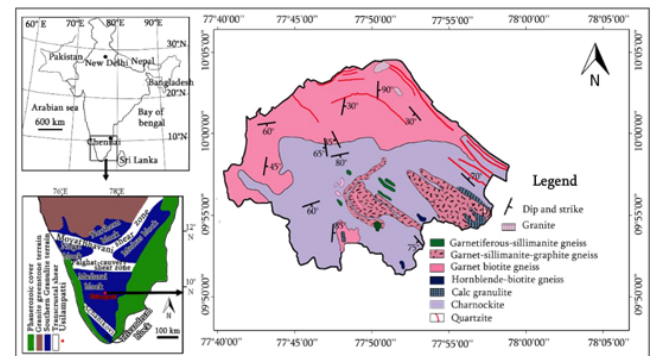


Figure 1: Geological map of the study area

## MATERIALS AND METHOD

Representative samples of different rocks and minerals were collected including limestone with associated rocks (LS6, LS7, and LS8) and granitoid (S1, S2, S3 and S4).

Table 1: The details of rock and mineral specimens collected for geochemical and mineralogical studies

S.No	ID	Name of the rocks and minerals	Habitation	Coordinates
1	LS6	White limestone	Uttappanayakkanur	N 10°01'44" E 77°47'43" N 10°01'49.05" E 77°48'00.98"
2	LS7	Dolomitic limestone	Uttappanayakkanur	
3	LS8	Grey limestone	Vellaimallai patti	N10° 1' 13.26" E 77° 47' 15.4" N 9° 57' 52.85"
4	S1	Charnockite	Khunuttipatti	
5	S2	Charnockite	Kannanur	E 77° 42' 46.37" N 9° 57' 23.48" E 77° 57' 23.12" N 09° 56' 13.00" E 77° 47' 24.00" N

				10°	1'
				30.79"	
6	S3	Charnockite	Pommanam patti		
7	S4	Granite	Krishnapura m	E 77°	52'
				54.26"	

Rock samples collected from the study area were chipped into pieces, washed with deionized water and dried in hot air till complete drying. Then chips using an iron mortar were crushed into 2 mm size. The crushed samples were homogenized well and about 100gm of homogenized samples were taken and pulverized to less than 75µm using pre-cleaned agate mortar and the pestle. The mineralogical properties of the specimens were analyzed using P-XRD Bruker D8 Focus Powder XRD from the Dept. of Earth Science, IIT Madras, Chennai, Tamil Nadu. Two types of analytical technique were used to obtain geochemical data. The major oxides composition were obtained where the rock powder of approximately 150 meshes were analyzed by X-ray fluorescence spectrometry (XRF) make of Malvern PANalytical model Epsilon-1, from the Central Analytical Laboratory at BITS (Birla Institute of Science and Technology) Pilani, Hyderabad campus. For the trace element samples were prepared by measurement approximately 25 mg of fine powder sample was dissolved using a combination of HCl and HNO<sub>3</sub> acids at the ratio of 1:3 (aqua regia) using double-distilled acids. Heating the mixture at the temperatures of 125° Celsius, it was evaporated to remove the acids. The residue was diluted with 100 ml of 2% nitric acid and stored in HDPE/LDPE bottles of 125 ml each and analyses have been carried out with Inductively Coupled Plasma Mass Spectrometry (ICP-MS), a model of Agilent-7700x at Centralized Instrumentation and Service Laboratory (CISL), Annamalai University. For the carbonates samples (limestone), the loss on ignition (LOI) was determined by heating in a temperature controlled furnace at 800°C and measuring the difference of the weight of the sample before and after heating [10].

## RESULTS AND DISCUSSION

In this study, economically significant different rock and mineral samples were collected including limestone and associated rocks (LS6, LS7, and LS8) and granitoid (S1, S2, S3 and S4).

### Mineralogy

Through powder XRD, the qualitative analysis of samples collected such as white limestone (LS6), dolomitic limestone (LS7) and grey limestone (LS8), of Uttappanayakkanur Village and charnockite of Khunuttipatti Village (S1), charnockite of Kannanur Village (S2), charnockite of Pommanampatti Village (S3), granite of Krishnapuram Village (S4), were studied and the results are discussed below.

### White limestone (LS6)

The mineral composition of the white limestone shows that it is composed of calcite, dolomite and chalcocopyrite. Among the reported 49 XRD peaks, three phases were observed, 26 peaks (53.66 w %) composed calcite (CaCO<sub>3</sub>) minerals, 14 peaks (34.87 w %) report dolomite [CaMg(CO<sub>3</sub>)<sub>2</sub>] mineral, and the remaining 9 peaks reported chalcocopyrite mineral (Fig. 2). The white limestone is dolomitic limestone. The chalcocopyrite (CuFeS<sub>2</sub>) with 11.47%, amorphous colloidal chalcocopyrite is found always in contact with pyrite and pyrrhotite. This mineral formed in late-stage replacement products of the pyrite and / or pyrrhotite.

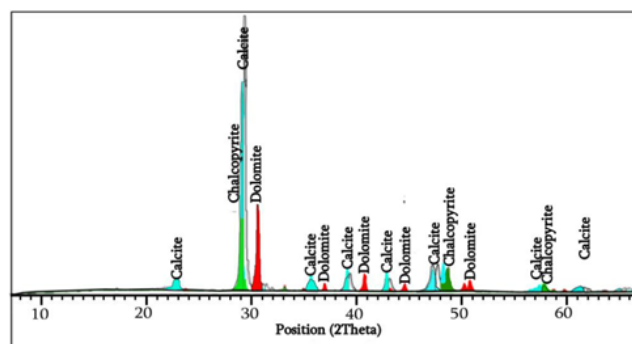


Figure 2: X-ray diffractograms of white limestone (LS6).

### Dolomitic limestone (LS7)

The XRD pattern for dolomitic limestone (LS7) is given in Fig. 3. The LS7 sample consists of 15 peaks, among the peaks 10 peaks reported for calcite. The remaining 5 peaks were shared wollastonite (2 peaks), quartz (1 peak), magnetite (1 peak) and zeolite (1peak). The mineral wollastonite is a calcium metasilicate with a chemical formula of CaSiO<sub>3</sub>. The presence of wollastonite in limestone is explained by the possible reaction during the metamorphism by which calcite reacts with silica to give wollastonite, calcite + SiO<sub>2</sub> → wollastonite + CO<sub>2</sub>, this relation of the combination of phase displays that silica metasomatism of the host limestone by infiltration of aqueous nature fluids plays to form wollastonite [11].

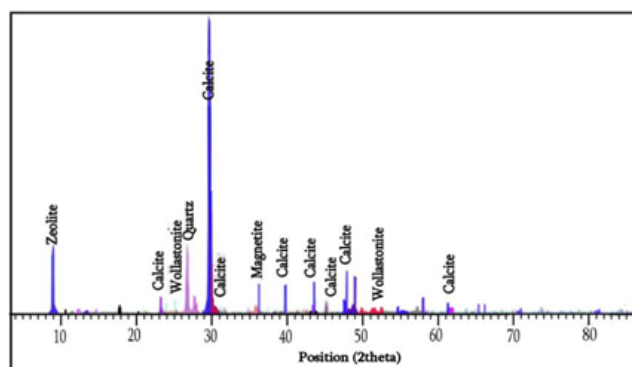


Figure 3: X-ray diffractograms of dolomitic limestone (LS7)

### Grey limestone (LS8)

The mineral composition of the grey limestone of Uttappanayakkanur Village shows that the limestone consists of

calcite, quartz, chalcopryrite, illite and sodian. X-ray diffraction spectra performed on the grey limestone exhibits of 13 peaks with 5 mineral phases, namely calcite, chalcopryrite, quartz sodian and illite were. A total of 9 peaks reported for calcite mineral, the leftover peaks are shared by 2 peaks for chalcopryrite mineral, 1 peak of quartz and 1 peak is shared between sodian and illite (Fig. 4). The grey limestone have the order of calcite (CaCO<sub>3</sub>), quartz (SiO<sub>2</sub>) and chalcopryrite (CuFeS<sub>2</sub>) by 80.26, 8.65 and 4.13 percent respectively. However, extant 6.96% is shared between illite and sodian minerals. Illite in association with copper (chalcopryrite) is considered as indicator of depositional environments of shallow continental shelf marine depositional with slow rates of deposition process [12].

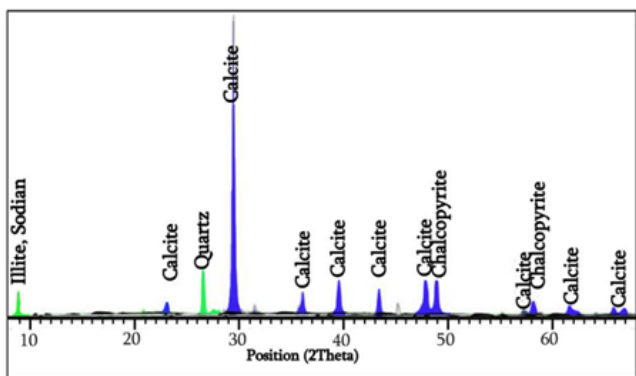


Figure 4: X-ray diffractograms of grey limestone (LS8).

### Charnockite (S1)

The Khunuttipatti Village charnockite rock mineral composition identified through XRD consists of anorthite, cristobalite, kyanite, quartz and gehlenite. The XRD detected 16 peaks, among that, 6 belongs to anorthite, 4 for kyanite, 2 for quartz, 2 for cristobalite and 2 for gehlenite (Fig. 5). In this sample, two polymorphs of silica are available; quartz and cristobalite. According to [13], cristobalite is a low-density SiO<sub>2</sub> polymorph.

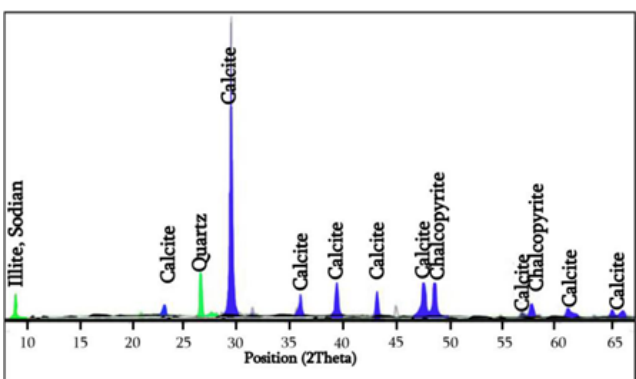


Figure 5: X-ray diffractograms of charnockite (S1).

### Charnockite (S2)

The Kannanur Village charnockite mineral composition shows that the rock charnockite is composed of anorthite, quartz, hematite and coesite. From the overall 14 identified peaks, 6 peaks exhibit anorthite, 3 for coesite, 3 for hematite, and 2 for

quartz (Fig. 6). The presence of coesite, an ultra-high metamorphism mineral known to be formed at very high pressure varying between two and three gigapascals and moderate temperatures (700°C) during the metamorphic reactions [14].

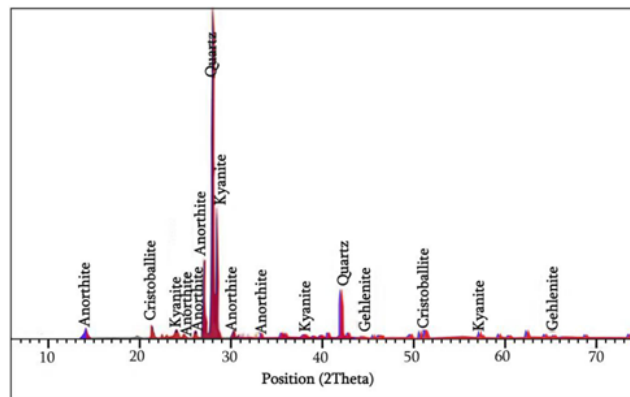


Figure 6: X-ray diffractograms of charnockite (S2).

### Charnockite (S3)

Under XRD identification, the charnockite rock of Pommanampatti Village is chiefly composed of quartz, anorthite and clinopyroxene minerals. Among 14 identified peaks, 6 peaks belong to quartz, 5 belong to clinopyroxene and 3 belong to anorthite (Fig.7). The association of minerals like quartz, clinopyroxene and feldspar demonstrates the mineral assemblage of granulite facies of metamorphism.

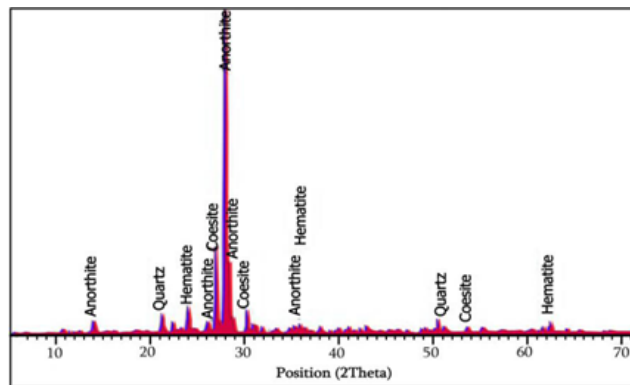


Figure 7: X-ray diffractograms of charnockite (S3).

### Granite (S4)

The XRD analysis indicates that the granite rock of Krishnapuram Village consists of anorthite, nepheline, quartz and hematite. In this specimen, XRD exhibits 15 peaks; among the exhibited peaks, 6 peaks belong to anorthite, 3 to hematite, 3 to nepheline and the remaining three belong to quartz (Fig. 8). Nepheline, commonly occurring feldspathoid, also present in this specimen. It is usually by the characteristic of alkalic rocks and product of sodium metasomatism [15]. Nepheline occupies the space between the alkali feldspars but it is seen to penetrate through the plagioclase. Thus, the substitution of nepheline by plagioclase can be ruled out [16].

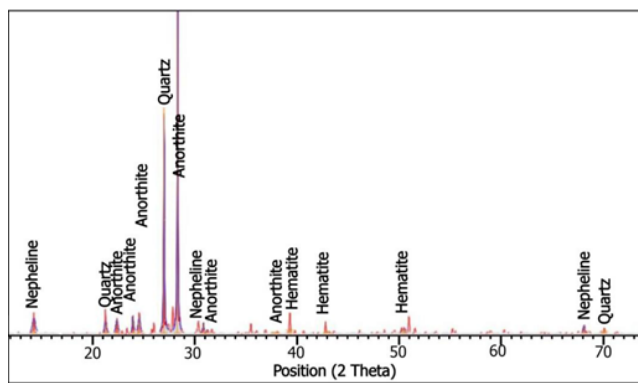


Figure 8: X-ray diffractograms of granite (S4).

## GEOCHEMISTRY

### Major Oxides Geochemistry

In whole rock elemental chemistry each group of elements plays vital role in understanding the rocks' nature, the mode of origin and the processes involved during the formation. Major elements, measured in oxide weight percentage, include the commonly found ten elements such as Si, Ti, Al, Fe, K, Mn, Na, Mg, Ca and P. The XRF analysis measured different oxides, CaO, SiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, Na<sub>2</sub>O, Al<sub>2</sub>O<sub>3</sub>, MnO, TiO<sub>2</sub>, P<sub>2</sub>O<sub>5</sub> and MgO; the contents were used for the discussion of the geochemistry. Using the data from XRF different inferences was made with the help of different classification schemes. Oxide and elements concentrations were determined through XRF analysis, in the rock specimens collected from the Usilampatti Taluk. The white limestone (LS6), dolomitic limestone (LS7) from Uttapanayakkanur and grey limestone (LS8) of Vellaimallaipatti, charnockite (S1) of Khunuttipatti Village, charnockite (S2) of Kannanur Village, charnockite (S3) of Pommanampatti Village, granite (S4) of Krishnapuram Village, feldspar (S5), quartz (S6) and mica (S7) of Vadakkampatti Village were discussed. The geochemical results of the samples are shown in Table 2.

Table 2. Geochemical results of the samples

S. No.	ID	Si O <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	K <sub>2</sub> O	MnO	TiO <sub>2</sub>	CaO	P <sub>2</sub> O <sub>5</sub>	MgO	Na <sub>2</sub> O	LOI	T O
1	LS6	1.88	0.21	0.31	0.11	0.04	0.11	49.26	0.03	7.28	0.88	39.90	10.0
2	LS7	3.87	0.65	2.35	0.57	0.18	0.14	52.61	0	1.68	3.08	34.87	10.0
3	LS8	3.01	0.54	0.65	0.09	0.04	0.04	54.97	0.12	2.06	2.44	36.03	10.0
4	S1	44.50	10.73	13.45	15.48	0.15	1.72	9.69	1.41	0.39	2.48	0	10.0
5	S2	40.50	10.59	20.75	9.57	0.31	3.08	12.59	1.85	0.39	0.37	0	10.0

6	S3	39.56	5.04	9.32	0.23	0.02	22.8	19.37	1.09	0.14	2.34	0	10.0
7	S4	66.56	10.9	3.16	10.7	0.29	0.26	3.76	1.61	0.15	2.62	0	10.0

For the interpretation, the study area samples were grouped into limestones and ranitoids. The limestone specimens namely white limestone (LS6), dolomitic limestone (LS7), and grey limestone (LS8) of Uttapanayakkanur studied in this section are discussed for geochemical characteristics below. The content in the major oxides (CaO, MgO, Na<sub>2</sub>O, Mn<sub>2</sub>O<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub>) in carbonate rocks gives critical information to understand the original mineralogy and chemical properties of depositional and diagenetic solutions.

In the study area limestone deposits, manganese oxide (Mn<sub>2</sub>O<sub>3</sub>) is 0.04% in white limestone (LS6), 0.18% in dolomitic limestone (LS7) and 0.04% in grey limestone (LS8). The low concentration of Mn<sub>2</sub>O<sub>3</sub> represents a deposition in a protected climate.[17], reported that carbonates with content below 0.07% of Mn<sub>2</sub>O<sub>3</sub>, is deposited under protected environment and those above 0.07% of Mn<sub>2</sub>O<sub>3</sub> are formed under a warm and humid environment. The white (LS6) and grey limestone (LS8) presents very low Mn<sub>2</sub>O<sub>3</sub> concentration; this indicates that they are formed under a protected environment while the dolomitic limestone is formed under warm and humid environment. The P<sub>2</sub>O<sub>5</sub> concentration in white limestone is 0.03% and could not be detected in dolomitic and grey limestone specimens which indicate that these rocks were formed under no-reducing environment with a low amount of organic matter. [18] discussed that the P<sub>2</sub>O<sub>5</sub> in carbonate rock is an index of reducing environment containing organic matter or the phosphate minerals, the low content in P<sub>2</sub>O<sub>5</sub> depict inorganic non reducing environment of deposition. The concentrations of Ca, Mg and their ratios (Ca/Mg and Mg/Ca) are used to classify the carbonates rocks geochemically. Where LS6 is classified under magnesium rich limestone, LS7 and LS8 falls under pure limestone (Table 3)

Table 3. Chemical classification limestone samples

Sample ID	Ca%	Mg%	Ca/Mg	Mg/Ca	Nomenclature(after Todd, 1966)
LS6	35.1857	4.368	8.05534	0.1241412	magnesium rich limestone
LS7	37.5786	1.008	37.2803	0.026823	Pure limestone
LS8	39.2643	1.236	31.7672	0.0314789	Pure limestone

The Ca/Mg ratios are calculated. Ca/Mg ratio was used to determine the salinity and evaporation condition. The rising in Ca/Mg ratio in the limestones means the lower salinity in the deposition area around the shore line. The Ca/Mg ratio in

white, dolomitic and grey limestone are 6.77, 31.32 and 26.68 respectively; the lower Ca/Mg ratio in the carbonate rocks (limestones) shows higher salinity in the deposition environment around the shoreline [19]. White limestone present the least Ca/Mg ratio thus it was formed under the condition of highest salinity, dolomitic limestone and grey limestone present very high Ca/Mg ratio which shows the low salinity environment.

**Table 4.** Correlation coefficient matrix limestone samples of the study area.

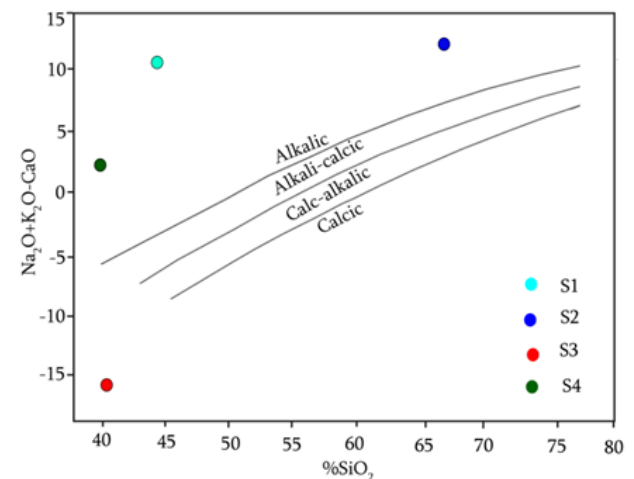
	SiO2	Al2O3	Fe2O3	K2O	Mn2O3	TiO2	CaO	P2O5	MgO
SiO2	1								
Al2O3	0.98	1							
Fe2O3	0.9	0.8	1						
K2O	0.8	0.66	0.98	1					
Mn2O3	0.82	0.69	0.99	1	1				
TiO2	0.22	0.01	0.61	0.76	0.73	1			
CaO	0.65	0.79	0.26	0.06	0.1	-0.61	1		
P2O5	-0.16	0.04	-0.57	-0.72	-0.69	-1	0.65	1	
MgO	-0.93	-0.98	-0.68	-0.52	-0.55	0.17	-0.88	-0.22	1
Na2O	0.99	1	0.83	0.7	0.72	0.06	0.76	-0.01	-0.97

The correlation coefficient matrix of the limestone samples of the study area is shown in Table 4. It shows very high (>80%) positive correlations between SiO2 and Al2O3; SiO2 and Fe2O3, SiO2 and K2O, SiO2 and Na2O, Al2O3 and Fe2O3, Fe2O3 and Mn2O3, Fe2O3 and K2O and K2O and Mn2O3. Moderate correlations (60-80%) is found between SiO2 and CaO, Al2O3 and K2O, Al2O3 and Mn2O3, Al2O3 and CaO, Fe2O3 and TiO2 and K2O and TiO2 in the data set. In all the correlation tables CaO and MgO show strong negative correlations.

The granitoids (granitic rocks) samples collected from the study area (Charnockite (S1) of Khunuttipatti Village, Charnockite (S2) of Vadikovil Village, Charnockite (S3) of Pommanampatti Village; Granite (S4) of Krishnapuram) were plotted using WinRock software on the basis of different geochemical indices and are discussed below.

Modified Alkali-Lime Index (MALI) plotting [Na2O+K2O-CaO] against SiO2. According to [20], classification the granites samples disseminate into alkalic, alkalic-calcic, calc-alkalic and

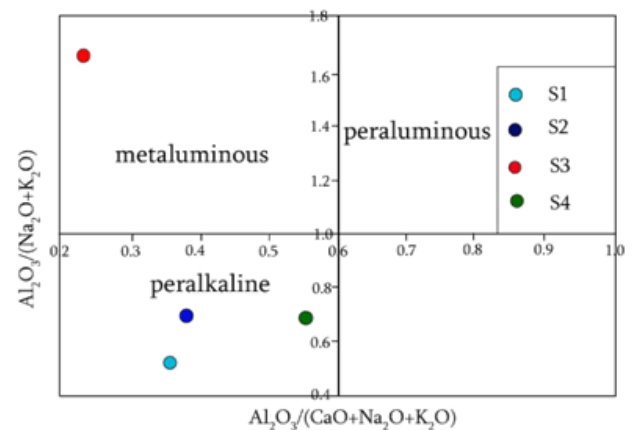
calcic fields and the charnockite (S1), charnockite (S2), charnockite (S3), granite (S4) falls under calcic group (Fig. 9).



**Figure 9:** MALI vs. SiO2 plot for the granitoids samples of the study area

To determine aluminous nature of granitic samples of the study area, A/CNK vs. A/NK graph was plotted where all the granitoids samples fall under peralkaline group except charnockite (S3) of Pommanampatti Village which falls under metaluminous (Fig. 10).

In the AFM (total alkalis, Fe2O3 and MgO) diagram (Fig. 11), one of the widely used plots for classification of mafic rocks, the granitoids of the study area, S1, S2 and S3 fall in calc-alkaline series and granite (S4) falls in tholeiitic series.



**Figure 10:** A/CNK vs. A/NK plot showing aluminous nature of granitic samples of the study area

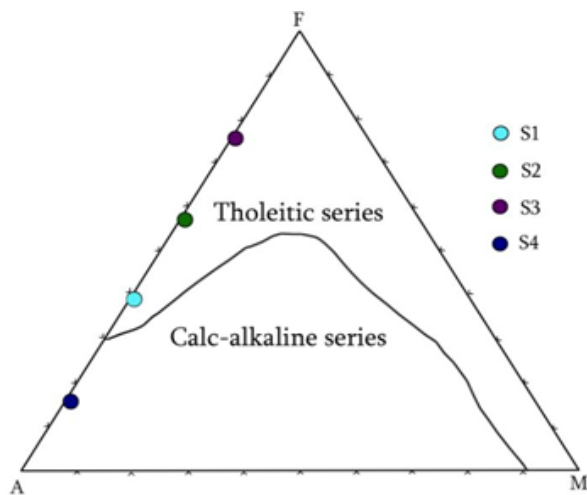


Figure 11: Ternary AFM diagram of granitoids classification

On the plot of Na<sub>2</sub>O +K<sub>2</sub>O against SiO<sub>2</sub> also known as the TAS diagram (Fig.11), S1 Village did not appear on the diagram, charnockite (S2) falls on the boundary of foidite and silexite, Charnockite (S3) falls foidite and granite (S4) falls under the silexite [22] (Middlemost, 1994).

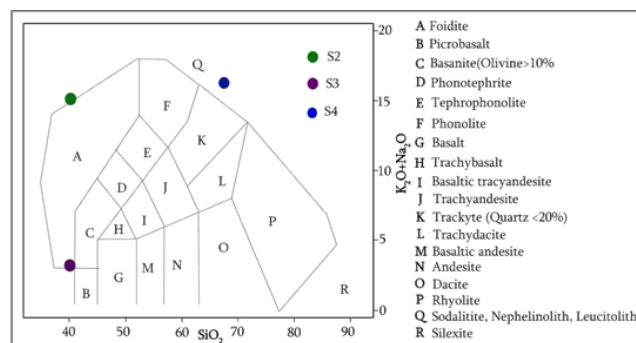


Figure 12: TAS diagram classifying the granitoids of the study area

**Geochemistry of trace elements**

Trace elements are broadly classified as large ion lithophile elements (LILE), high field strength elements (HFSE) and ferromagnesian trace elements (FMTE). During medium to high-grade metamorphism, the large ion lithophile elements (LILE) such as K, Rb, Sr, and Ba as well as Th and U have probably been mobilized. However, the elements with high field-strength elements (HFSE; Ti, Zr, Y, V, Cr, Ni) and REE are interpreted to have been effectively immobile, and are therefore suitable for determining protoliths [23]. The details of the trace elements geochemistry of the study area are given in Table 3.

Table 5. Trace element geochemistry

Table 5. Trace element geochemistry

	LS6	LS7	S1	S2	S3	S4
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	ppm	ppm	ppm	ppm	ppm	ppm
Li	37.91	30.82	36.27	30.21	32.76	33.51
B	153.1	133.5	134.2	119.7	129.4	131.6
Sc	13.34	8.914	12.7	11.03	15.47	11.22
Ti	376.1	574.8	765.2	792.6	1140	323.6
V	794.2	1906	3072	3252	2879	3665
Cr	656.1	307	423.3	400.3	417.4	518.2
Co	5.225	4.472	12.86	8.151	5.126	5.132
Ni	189.4	106.6	143.8	130	148.5	180.1
Cu	47.81	42.02	45.93	45.93	41.67	33.05
Zn	577.5	441.7	430.5	515.9	384	546.5
Ga	2.369	4.882	5.839	8.01	12.59	4.852
Rb	2.674	6.924	7.135	7.34	2.927	11.61
Sr	93.21	90.92	29.69	29.37	79.06	17.79
Y	7.66	9.381	5.367	5.726	17.55	3.785
Zr	0.633	1.036	1.037	1.137	7.72	4.455
Nb	0.5297	0.6964	1.431	1.759	4.78	2.794
Ba	46.41	46.65	68.04	72.78	35.08	51.34
La	4.712	10.2	14.02	14.38	17.42	2.004
Ce	5.368	18.65	33.33	33.41	36.54	5.001
Pr	0.8542	2.092	4.207	4.156	4.33	0.5414
Nd	3.276	7.45	16.61	16.6	16.05	2.131
Sm	0.6031	1.347	2.994	2.998	3.216	0.5966
Eu	0.1457	0.2562	0.2565	0.277	0.554	0.0482
Gd	0.7096	1.271	2.362	2.394	3.009	0.5483
Tb	0.1037	0.1773	0.257	0.2743	0.4305	0.09209
Dy	0.6441	1.246	1.186	1.238	2.61	0.5931
Ho	0.1548	0.2552	0.2089	0.2204	0.5624	0.1258
Er	0.417	0.7363	0.4796	0.5278	1.554	0.3686
Tm	0.0567	0.1138	0.05772	0.06426	0.2307	0.06458
Yb	0.3447	0.7362	0.3424	0.37	1.484	0.4599
Hf	0.0309	0.05407	0.05909	0.06882	0.4128	0.2539

Ta	0.03531	0.4379	0.03047	0.02073	0.02684	0.04154
Pb	26.49	29.68	21.98	30.84	31.85	32.08
Th	0.5837	1.993	0.7328	0.6825	12.59	16.67
U	0.2408	0.2615	0.2893	0.3189	3.736	3.255

Because of their immobile and incompatible behaviour during post-crystallization alteration, the trace element abundances are generally useful in magma identification and to identify the source characteristics of any magma suite [24] and [25]. The rare earth elements (Z=57-71) have very similar chemical properties and are generally considered to be resistant to fractionation in supracrustal environments. This, coupled with their low solubilities and coherent behaviour, has resulted in REE distributions being used as a “fingerprint” to help in identifying the parental materials [26]. The samples of the study area show enrichment of light rare earth elements (LREE: La, Ce, Nd, Sm) i.e. La content range from 2.27 to 47.46 ppm; Nd (0.95-23.36 ppm), Ce (1.59- 38.18 ppm), Sm (0.227-3.216 ppm) are in contrast to the depletion of heavy rare earth elements (HREE  $\leq$  1 ppm).

The Eu anomalies of the granitoids are highly to moderately negative ( $Eu/Eu^*=0.253295787-0.679427376$ ), for the other samples like limestone ( $Eu/Eu^*$  is around 0.5), and feldspar is highly negative ( $Eu/Eu^*=0.26977$ ). For the limestone samples the  $(La/Sm)_N$  is high ( $(La/Sm)_N= 3.409400545-4.76$

6268365) showing the enrichment of the LREE in limestone. Using the plot of discrimination diagrams (Fig.16) of Y+Nb Vs Rb [27], all the granitoids rocs samples falls in the volcanic arc-granites.

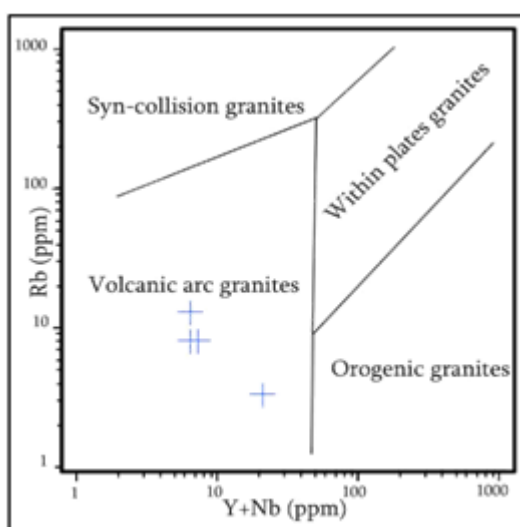


Figure. 13. Discrimination diagrams Y+Nb Vs Rb

Combining the major elements ( $SiO_2$  wt %) and the REE ratio ( $Nb/Y$ ), [28] interpreted the tectonic environment of the magma. The granitoids samples from the study area, S1 and S2 fall in the sub alkaline basalt, S3 in rhyodacite dacite and S4 in basanite Nephelinite (Fig. 17).

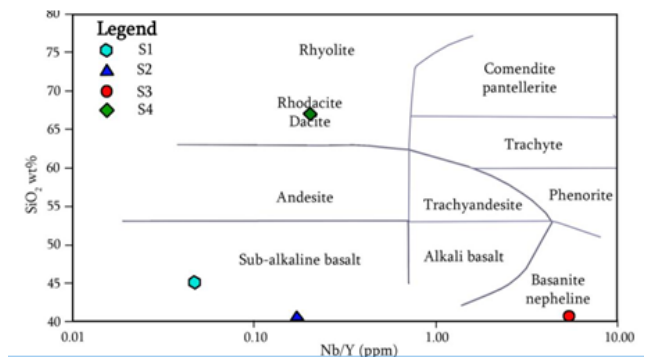


Figure.14: Discrimination diagram showing an alkaline basalt to andesite basalt magmatic nature for the granitoids of the study area.

## SUMMARY AND CONCLUSION

Suite to the studies above the carbonate rocks were classified under magnesium rich limestone and pure limestone. All the granitic rocks probably reflects derivation from reduced basaltic rocks, by either fractional crystallization or partial melting as they are of the A-Type granitoids, Granites could be derived from quartz-feldspathic igneous sources, with a reduced character or, possibly, with a metasedimentary rock contribution, or from differentiated tholeiitic sources. In the study area, different types of economically viable minerals and rocks namely, limestone, granite, charnockite, and charnockite gneiss undergone mineralogical and geochemical studies to assess their quality and their economic viability. Based on the studies, limestone deposits are viable for the utilization of different lime-based industries as they are of pure limestone and magnesium rich groups which are viable for cement, paper, animal feed and many other industries. With recommendation of a sorting and beneficiation system during the mining activities. Charnockite and granite shows a high content in silica which makes them suitable for building and dimensional stone production.

## Compliance with ethical standard

**Conflict of interest:** Authors declare that there is no potential conflict of interest

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