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Petrography and Major Geochemical Studies of Anorthosite, Kadavur and Adjoining Area, Tamilnadu, India

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Abstract

The study area occupies a small part of the Madurai Block (MB) of the Southern Granulite Terrain (SGT) in India. It is chiefly represented by anorthosite and gneissic rocks. The economic importance of rocks (massive nature) brought name and fame of this locality all over the world. The term massive is use here for textural sense with reference of homogeneous composition, without preferred crystal orientation or stratification. This is a common feature among anorthosite in massif type complexes. The study area is chiefly composed of metamorphic and igneous formations. They are older and younger gneissic formation, Granitic intrusions and pegmatitic intrusions beside the anorthosite and related rocks. The anorthosite complex is a large anorthosite – gabbro mass emplaced in the core of a regional antiform which occupies the Kadavur basin. This is surrounded in all sides by thick supracrustal hills of quartzites interbanded with quartzo – feldspathic gneisses. The contact between the metasedimentary quartzites and the anorthosites and related rocks exhibits intrusive nature of emplacement. The Geochemical studies of samples are represented in a unique pattern in major oxide concentrations. The Average SiO_2 content in the Fe-Ti samples we found 4.06wt%, TiO_2- 19.88 wt%, Fe_2O_3- 68.44 wt%. On the basis of TAS Diagram analysis we are classified these rocks in to Picro-basalts and basalt while on the basis of AFM Diagram these falls on sub-alkaline to tholeiitic nature. The geochemical plot study shown that the sample no K12 and K30 rock units are igneous protolith in nature.

Keywords: Petrography, major geochemistry, CIPW Norm, TAS diagram, anorthosite complex.

Introduction

The Madurai block is located in between Palaghat-Cauvery shear zone in the north and Achankoil shear zone in the south. Madurai block is the largest granulite block of South India and dominantly composed of high grade meta-sedimentary rocks, mafic granulites, high land charnockite and massif anorthosite and related rocks. A.P. Subramaniam provided the first Petrological account of the complex and inferred it to be a funnel shaped anorthosite intrusion of ‘Adirondack type’[1]. B.F. Windley and T.A. Selvan commented that the intrusion of is not comparable to Adirondack type massifs and observed that the occurrence represents a typical early Archaean layered gabbro-anorthosite complex[2]. M. Arumugam and R. Senthil kumar described that the anorthosite in and around Kadavur as a diaperic intrusion, on the basis of the presence of sharp contacts and roofing partially by the quartzites near Δ612 anorthosite hill[3]. The anorthosite mass in the area is screened by meta-sedimentary quartzite, which constitutes the circular to elliptical structural basins and domes. A large anorthosite-gabbro mass emplaced in the core of a regional antiform occupies the Kadavur basin. This is surrounded in all sides by thick supracrustal hill of quartzites inter banded with quartzo-feldspathic gneisses. The contact between meta-sedimentary quartzite, anorthosite and related rocks exhibit intrusive nature of emplacements. The study area roughly occupies 508 sq.km and lies between the Latitudes 10°30’ and 10°40’ and Longitudes 78°5’ and 78°20’. It forms the part of the Survey of India toposheet No 58 J/2 and J/6. The location map of the study area is shown in figure 1.

General Geology

The Kadavur meta-igneous complex is exposed amidst a catazonal environment of high grade supracrustal sequence belonging to the Eastern Ghats precambrain belt. The anorthosite is intrusive into the gneisses and the contact wherever exposed shows some degree of silicification marked by appearance of quartz inclusion K-feldspar and formation of myrmekite. The anorthosite is medium to coarse grained light to dark grey brownish to purple in colour showing well developed granoblastic texture in general and a poor mafic content. Based on the field petrographical studies the rocks exposed in the Kadavur area are as follows quartzite, amphibolite, anorthosite and related rocks, granite, pegmatite and they form a circular elliptical structure. The quartzites occur as the distinct circular hill ridges and form the oldest rock type of the area[4]. The Geological map of the study area is given in figure 2.

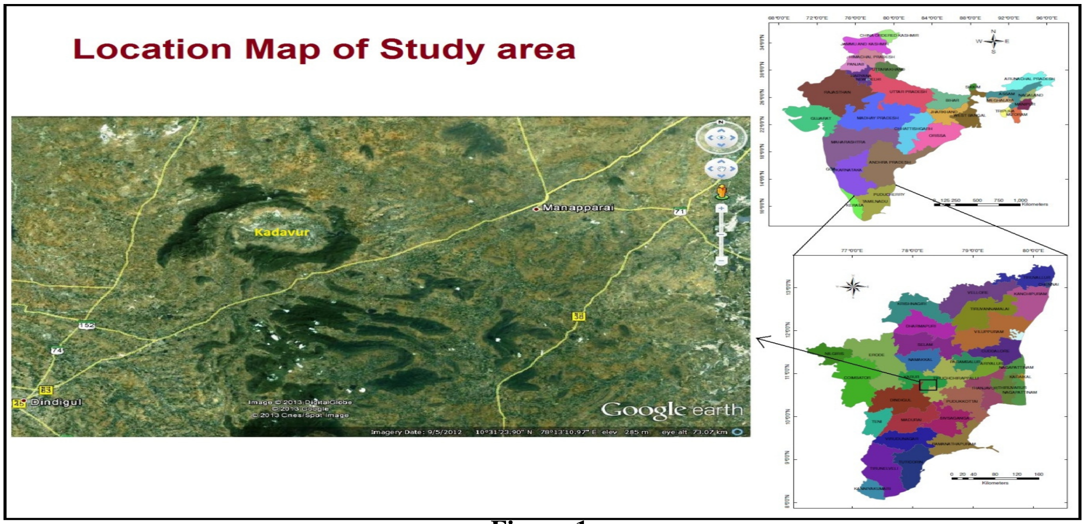

Figure-1
Location Map of study area

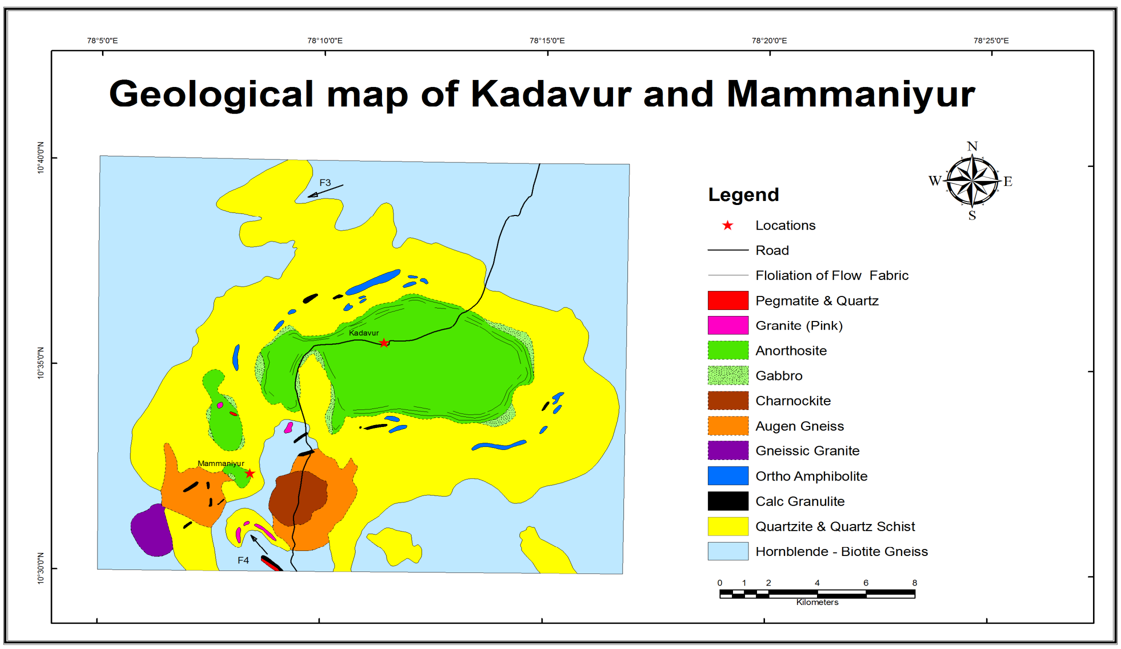

Figure-2
Geological Map of study area

Field Relationship

In this present study, we observed the following petrographic units in Kadavur and its adjoining area: i. Anorthosite, ii. Noritic Anorthosite, iii. Gabbroic Anorthosite, iv. Anorthositic Gabbro, v. Gabbro, vi. Norite.

Anorthosite: The anorthosite is leucocratic and medium to coarse rocks. The mafic content of the rock is variable though in smaller proportions. In some specimens, two distinct type of plagioclase can be noted in anorthosite as coarse blue grey plagioclase crystals are set in a matrix of dull white fine grained plagioclase. This imparts the rocks to a porphyritic appearance. The coarse crystals range from a quarter centimeter to two centimeter in size. The medium grained anorthosite is dull whitish to creamy in colour. Generally the mafic occurs as medium size grains[5]. In some places, however there is coarse development of hornblende crystals which measure up to 2 to 8 cm in size. In the outcrops, there are occasional mafic clots in the rocks can be observed.

Noritic Anorthosite: These are medium grained rocks with cumulate fabric which occur transitional to pure anorthosite. They are largely composed of white and grey plagioclase feldspar plates ranging from 0.5 mm to 4 mm in length. In thin sections it shows typical igneous equilibrium texture. It is composed of plagioclase 'An' 55-58, orthopyroxene with enstatite molecules 40 to 45: few grains of clinopyroxene, hornblende and scapolite as alteration product from pyroxenes and plagioclases[6].

Gabbroic Anorthosite: These are medium to coarse grained rocks with less leucocratic nature than the anorthosite due to their higher ferromagnesian content. They show in the field gradational changes into pure anorthosite and are genetically related to the latter. They show blotchy appearance due to clustering of granular aggregates of hornblende in a matrix of plagioclases in some sections. In thin sections these rocks preserve cumulate texture to a greater extent.

Anorthositic Gabbro: These are medium to coarse grained rock and display the typical gabbroidal texture. The plagioclase constituents 65 to 75% of the rock mass. The most abundant rock type observed in the study area shows an intermediate phase between the gabbro and anorthosite. These rocks are characterized by dark coloured minerals of pyroxene, Amphibole and plagioclase feldspar. The anorthositic gabbro rock also contains enough magnetite and ilmenite and these minerals can be easily detected in hand specimen samples by the help of magnifying glass.

Gabbro: The gabbro is interpreted to be part of the anorthositic intrusive suite. Plagioclase feldspar is the dominant light coloured mineral in these rocks, Magnetite and ilmenite can also readily identified in hand sample. Some of these rocks are quite dense and heavy[7]. These are melanocratic equigranular medium grained rocks. These are gradational to leucogabbros and crude foliation in outcrops. These are essentially composed of plagioclases, clinopyroxenes and orthopyroxenes with fair amount of ores. The relative proportions of these essential minerals show wide variation from plagioclase dominated varieties to mafic dominated varieties and either as clinopyroxene dominated or orthopyroxene dominated varieties.

Norite: Norite is a coarse-grained basic igneous rock dominated by essential calcic plagioclase and orthopyroxene. Norites also can contain up to 50% clinopyroxene and can be considered orthopyroxene dominated gabbro. Minor components can include biotite and hornblende. Norite is generally found in layered igneous intrusions formed by progressive crystal fractionation. The crystallization of large amounts of orthopyroxene can occur by the reaction of olivine with the magma. Norite is sometimes associated with anorthosite and troctolite.

Petrography

Petrographic studies carried out of 50 thin sections in the petrology Laboratory, Department of Earth Sciences, Annamalai University, Tamil Nadu by using Euromex Petrological microscope. The ultramafic rock is plutonic in nature and composed chiefly or entirely by plagioclase. They are dominated by coarse grained massive laminated anorthosite, leuconorite and leucotracolite, including minor mafic and Fe-Ti oxide rich rock. Plagioclase is the predominating constituent constituting 90 to 95% of the rock. It occurs as equant, subhedral or anhedral grains. The anorthite content of the plagioclase is ranging from 50 to 60%. Pyroxenes are observable in most sections of anorthosites. They show partial alteration to hornblende. The clinopyroxene is colourless to pale green in colour. They occur as interstitial phase between the mosaics of plagioclases as also granular aggregate. They show higher degree of alteration to hornblende. The above properties indicate that the mineral is diopsidic augite. The orthopyroxene occurs both as prismatic and anhedral grains. The presence of intergrowth texture between pyroxenes, plagioclases and iron oxides indicate isothermal mode of emplacement of anorthosite mass. The clino and orthopyroxene volumetrically constitute 5 to 7%. Clinopyroxene occurs as inclusions within plagioclases and also discrete grains.

Hornblende is the common mafic in marginal gabbros. In anorthosite it occurs mostly as paramorphic alteration product of pyroxenes by the action of late stage mineralization. In some sections the hornblende aggregate carry a core of clinopyroxenes. Generally hornblende occurs as spongy aggregates, retaining the crystal outline of primary pyroxene. Brown biotite occurs as secondary mineral after pyroxenes and amphiboles. Magnetite and ilmenite occur as accessories. Magnetite occurs as droplets as also as rod likes oriented inclusions in plagioclases and rarely in pyroxene plates. Study of medium grained anorthosite also show similar mineralogical characters expect the grain size variation. Pyroxenes particularly clinopyroxene found to from major mafic with higher degree of alteration to hornblende. Few discrete grains of apatite, zircon, droplets of iron ores and scapolite as alteration product of plagioclase are also often observed. The ultramafic rock is plutonic in nature and composed chiefly or entirely by plagioclase[8]. The presence of intergrowth texture between pyroxenes, plagioclases and iron oxides indicate isothermal mode of emplacement of anorthosite mass.

Magnetite and ilmenite occur as accessories. Magnetite occurs as droplets as also as rod likes oriented inclusions in plagioclases and rarely in pyroxene plates. Rare occurrences of clinopyroxene, biotite, hornblende, quartz, apatite, and zircon are seen. They commonly exhibit a xenomorphic, roughly equigranular texture. Plagioclase in the Kadavur massif occurs in two modes large megacrystals and recrystallised fine grains, in varaible proposition from the margin towards the centre of the pluton. Orthopyroxene is generally intertitial and occurs as subhedral to anhedral grains in variable proportion in all the rock types of the pluton. They often form clusters and contain inclusions of plagioclase and opaque minerals. Petrographically, the megacrysts show dust-like Fe-Ti oxide inclusions. In general, exsolution lamellae are less abundant in recrystallized grains, a typical feature of most massif-type anorthosites [9].

Figure-3

A. Field photograph showing in pegmadoital anorthosite. B. Fine gained gabbroic outcrop Nearby Valayapatti drainage area. C. Medium to fine grained gabbro. D. Field photograph showing this medium grained Anorthositic foliation fabric. E. Outcrop of a coarse grained anorthosite three dimensional plagioclase feldspar with the dimension. F. Anorthosite outcrop exposure showing very coarse grained grey anorthosite note the preferred orientation of plagioclase and mafics

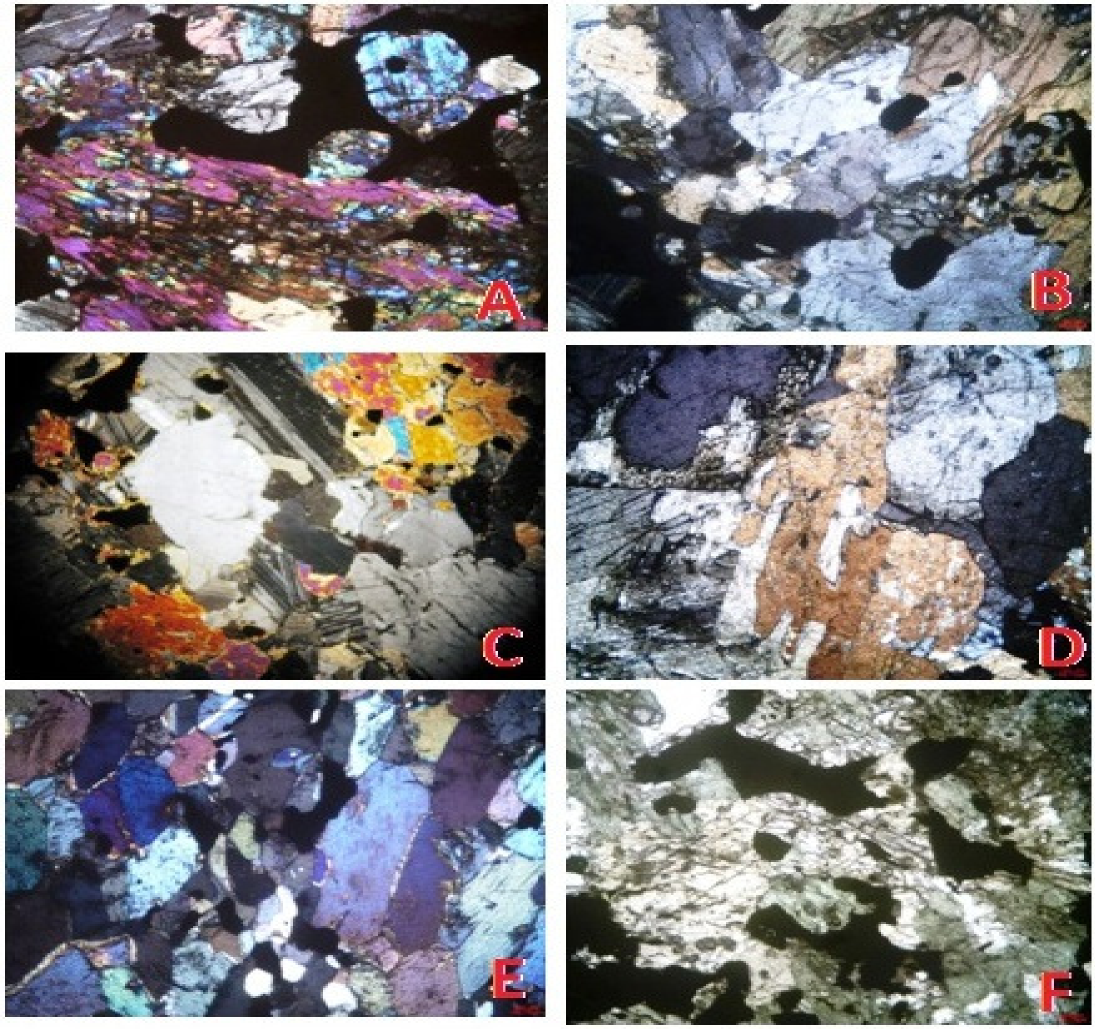

Figure-4

A. Microphotograph showing medium grained inequigranular character of basic anorthosite. Sub ophitic texture and alteration of plagioclase and clinopyroxene (Cpx) in the rock. B. Microphotograph showing medium grained holocrystalline ground mass anorthosite rock. Note the presence feldspar and alterated mafic phenocrysts in the rock. C. The Microphotograph of Gabbroic anorthosite showing inequigranular, interlocking texture. The plagioclase exhibits simple twinning. Note the bimodal nature of plagioclase can be seen in the left top (Under cross nicol condition 5x10) showing holocrystalline subophitic texture in the rock. D. Microphotographic showing the presence of mica lying parallel to the elongated Quartz vein. E. Microphotographic showing hypersthenes pyroxene showing equigranular indicates hypidiomorphic texture. F. Mafic minerals associated with alteration of clino pyroxene (Cpx)

Geochemistry

Five representative samples were analyzed for major and minor elements. The major oxides and minor elements analyzed are SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, CaO, MgO, Na_2O, K_2O and P_2O_5. The rock samples were analyzed at the XRF (Bruker, formerly Siemens, model S4 Pioneer sequential wavelength-dispersive x-ray spectrometer and sample preparation units) facility available at the Centre of Earth Science Studies (CESS), Thiruvanthapuram. Geochemical data of ultrabasic rock samples are presented the data show unique geochemical pattern. The SiO_2 content ranges between 42 and 44%. Al_2O_3 percentage found maximum in Mamarathupatti sample (16.59) and minimum in Pusaripatti sample (0.81). The TiO_2, MnO, K_2O value is ranges from 0.62 to 31.66, 0.2 to 0.28, 0.01 to 0.09 wt% respectively. Total Fe_2O_3 value is minimum (7.04 wt %) in Idiyapatti sample and maximum in Vedikkaranattam (77.97 wt %). The CaO value ranges from 0.42 to 25.19 wt% minimum value is recorded from Vedikkaranattam and maximum from Idiyapatti. The wt% MgO value recorded minimum in Idiyapatti sample (1.48%) and maximum in Pusaripatti (15.15%). The value of Na_2O range from 0.01 to 1.35% in Pusaripatti and Valaiyapatti samples respectively.

The CIPW Norm is calculated by using the major element chemistry given in table 2. The content of quartz ranges from 0 to 15.4%. Olivine is present in the sample collected from Kadavur. The diopside value ranges from 3.3 to 43.22%. The low content of diopside is reported from the Singampatti sample and the higher content in Idiyapatti. Orthoclase is present in all the samples except Mamarathupatti and Pusaripatti. Plagioclase is commonly occurred in all samples. The Albite values ranges from 0.51 to 11.42%. The Anorthite ranges between 1.73 to 40.54%. Opaques are also presented in all samples. Hypershene is minimum in Vedikkaranattum and maximum in Sigampatti sample. Hematite values ranges from 7.04 to 77.97% in Idiyapatti and Vedikkaranattam respectively. Titanite value is range 2.29 to 14.44%. Ilmenite value ranges from 0.3 to 0.77% at Valaiyapatti and Sigampatti respectively. CIPW norm was calculated and are in conformable with the XRF data[10].

Based on the major element chemistry various diagrams were prepared using Igpet software. Harker variation diagrams prepared for the Meta-igneous area are show in (figure 5). In the diagram Al_2O_3, Na_2O, K_2O, CaO, P_2O_5, MnO, FeO, TiO_2 and MgO are plotted against SiO_2. The Al_2O_3 Content of the rocks shows a positive correlation with SiO_2 whereas Na_2O, K_2O, Fe_2O_3, TiO_2, MgO and MnO show a negative correlation. The CaO and P_2O_5 content did not show any specific trend with SiO_2 and the plots are characteristics of an igneous rock.

The total alkalis – silica diagram (TAS) is one of the most useful classification schemes available for plutonic rocks Na_2O and K_2O content (total alkalis TA) and the SiO_2 content (S) are taken directly from a rock analysis as weight percentage oxides and plotted on the classification diagram. The usefulness of the TAS diagram was demonstrated by K. G. Cox *et al* (1979)[11], who showed that there are sound theoretical reasons for choosing SiO_2 and Na_2O+K_2O as a basis for the classification of volcanic rocks and prepared TAS diagram. The TAS diagram divides rocks into ultrabasic, basic, intermediate and acid on the basis of their silica content[12]. The protolith of the rock can be determinate by using this diagram. Volcanic rocks may be sub divided into two major magma series- the alkaline and sub alkaline (originally termed Theolitic series on a total alkalis silica system)[13,14]. The present data were plotted in the TAS diagram and shown in figure 6, Plots of the Meta Igneous of the study area are falling in basaltic fields[15]. This figure shows that this rock unit had an igneous protolith. The Meta igneous study area occurs as boulders (sample no K-12, K-19, and K-41) show typical picrobasaltic nature. This two K-30, K-42 A sample in ultramafic samples (0-10%) range in plotted. The geochemical plots show that this rock unit had an igneous Protolith. Studied rocks are classified a basalts or basaltic andesine, sub-alkaline tholeiitic nature of these samples is also observed on the plot. In the AFM plot of the samples (figure 7) almost all the samples fall on the theoleitic series[16].

Table-1
XRF Major Oxide Data

Sample No.	**K42A**	**K41**	**K30**	**K19**	**K12**
ROCK TYPES	**Anorthosite**	**Gabbro**	**Fe rich rock**	**Noritic gabbro**	**Fe rich rock**
SiO_2	42.8	47.01	3.44	42.99	4.68
TiO_2	6.29	1.37	31.66	1.25	8.1
Al_2O_3	2.06	10.52	0.81	16.59	5.15
MnO	0.36	0.2	0.14	0.28	0.15
Fe_2O_3	29.06	12.49	59.31	16.57	77.97
CaO	5.92	12.53	2.61	12.35	0.42
MgO	12.63	15.15	1.64	6.64	1.48
Na_2O	0.2	1.35	0.1	1	0.06
K_2O	0.03	0.1	0.01	0.08	0.01
P_2O_5	0.15	0.18	0	0.22	0.73
Total	99.49	100.9	99.72	97.98	98.75

Table-2
CIPW Norm Values of study area

Sample No	**Quartz**	**Orthoclase**	**Albite**	**Anorthite**	**Diopside**	**Hypersthene**	**Olivine**	**Ilmenite**	**Hematite**	**Titanite**
K42A	15.4	0.18	1.69	4.63	3.3	29.93	0	0.77	29.26	14.44
K41	0	0.59	11.42	22.35	27.89	17.42	4.82	0.43	12.49	2.81
K30	0	0.06	0.85	1.73	0	0	0	0.3	59.31	2.77
K19	4.98	0.47	8.46	40.54	13.6	10.23	0	0.6	19.57	2.29
K12	1.19	0.06	0.51	2.08	0	3.69	0	0.32	77.97	0

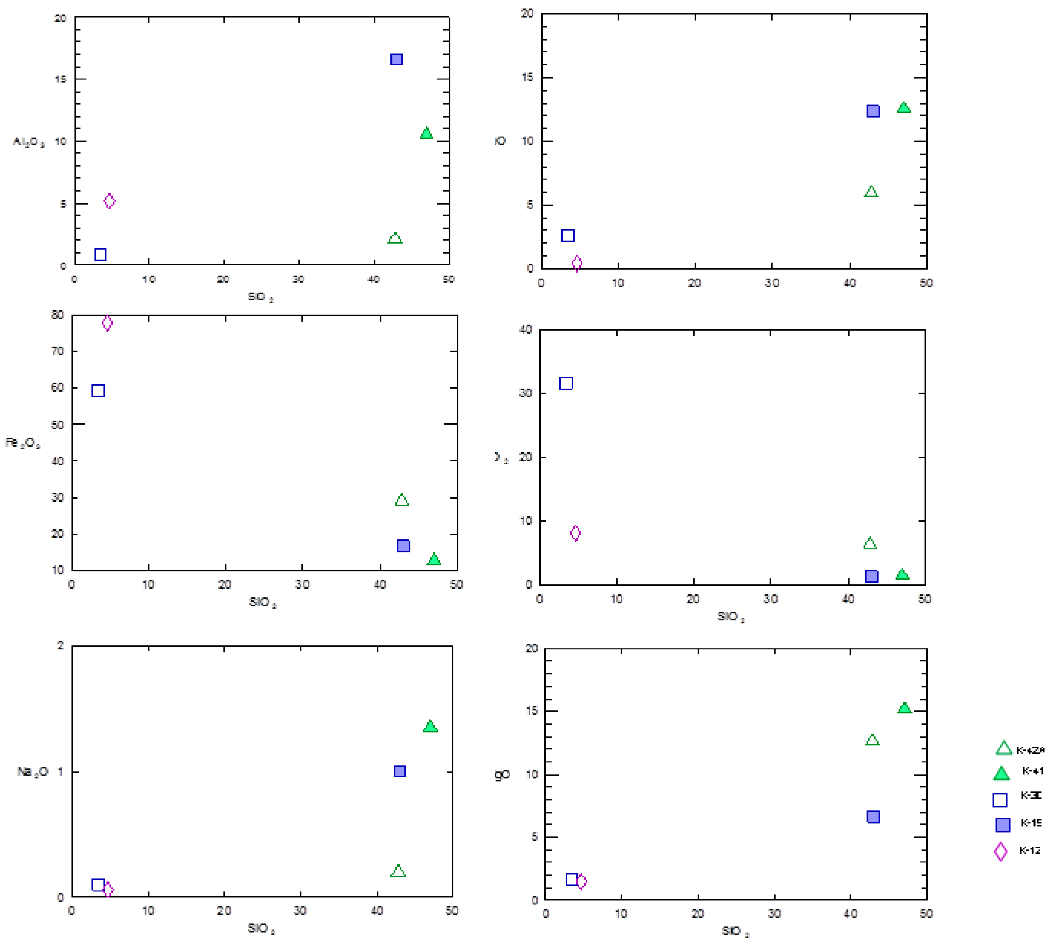

Figure-5
Harker variation diagrams

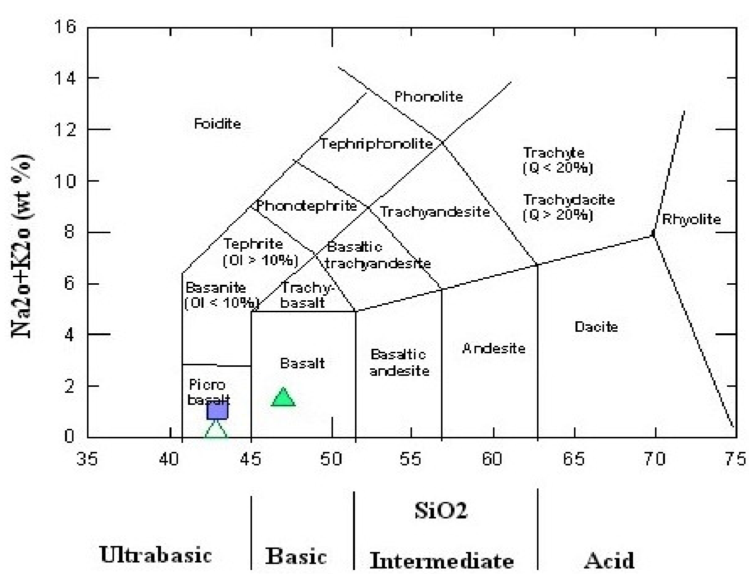

Figure-6
TAS diagaram after Le Bas et.al

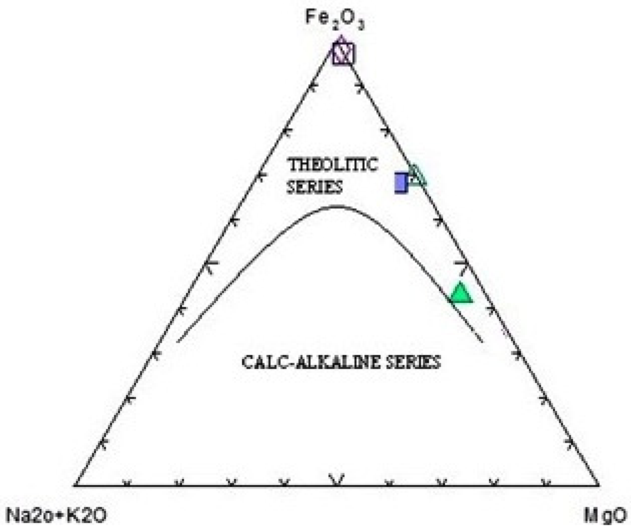

Figure-7
AFM diagram (Irvine and Barakar, 1971)

Conclusion

The field petrographic, major geochemical discussed, a general model of evolution of anorthosite emerges. As these interfering forms one of the latest igneous in the region thus addition the crustal structure activity of the region. The petrographic studies reveal distinct textures and mineralogical characteristics particularly the anorthosites and related rocks exhibit diagnostic equigranular fabric and gradational variation in the relative proportion of plagioclase and pyroboles from fine grained border gabbros to coarse grained core an anorthosites. In the study area TiO_2 content in samples was ranging from 1.25 to 31.66 wt % and Fe_2O_3 ranging from 12.49 to 77.97 wt %. The AFM Diagram showing that samples are belongs to the Theolitic Series and having more concentration of Fe. During the field study we were found that Fe-Ti band length ranging from 4m to 10m and width from 0.5m to 2m. Fe – Ti deposits of study area shown various degree of deformation, most of the deposits were located in border zone, and marginal parts of anorthosite was more deformed due to sync-emplacement and high temperature. This deformation could be play a vital role during separation of Fe – Ti oxides from other minerals and formed a layered structure of transient magma chamber to concentrate them in pods and veins into the enclosing anorthosite.

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