Bulletin of Pure and Applied Sciences.
Vol.38 F (Geology), No.1, 2019: P.16-24

Print version ISSN 0970 4639
Online version ISSN 2320 3234
DOI 10.5958/2320-3234.2019.00002.7

Available online at www.bpasjournals.com

Original Article

Mineral Chemistry of Mafic Clots in Putteti Alkaline Suite, Kanyakumari District, Tamil Nadu, India

Anjana A.V. Panicker[1], S.N. Kumar[2], Manu Raj R.[3]

Author's Affiliations:
[1,2,3]Department of Geology, University of Kerala, Kariavattom Campus, Thiruvananthapuram Kerala 695581, India

***Corresponding Author: Anjana A.V. Panicker**, Assistant Professor, Department of Geology, University College, Thiruvananthapuram, Kerala 695034, India.

E-mail: anjanasajayan@gmail.com

(Received on 08.01.2019, Accepted on 16.03.2019)

ABSTRACT

Putteti is a well-known alkaline suite south of Achankovil Shear Zone in Southern Granulite Terrain (SGT). This intrusive is quite famous for the ubiquitous zircon megacrysts, and various sulphides and oxides. Syenite and pyroxenite, with textural and compositional diversity, form the major intrusive phases of this suite. They occur as alternate magmatic layers where pyroxenes form cumulates. Clots or segregates of pyroxenes are also noticed in the syenite. The amount of pyroxene in syenite varies considerably. Earlier workers explained this phenomenon as due to liquid immiscibility of a single magma. The temperature, composition and rheology of the original melt play a major role in deciphering the texture and mineralogy of the resultant rocks. Mineral chemistry helps to infer the thermal history of the members of the suite and the sequence of crystallization. Here we present the chemical data of pyroxenes in syenite and hybrid rock that help to establish the interrelationships of the members of the suite and their evolution.

KEYWORDS:Achankovil Shear Zone, Southern Granulite Terrain, Liquid immiscibility, Thermal

Introduction

The existing thermal and compositional contrasts between the host rock and the intrusive igneous body have been a dilemma for petrologists over the years. In most of the intrusive phases, there exists a compositional diversity among rock types such as mafic magma intruding into felsic country rock and vice versa. But this cannot be generalized for all alkaline magmatic terrains. Putteti alkaline suite is one such case located south of Achankovil Shear Zone in the Southern Granulite Terrain (SGT). It is seen intruded into the surrounding gneisses and granulites of the region that are compositionally similar to that of the dominant felsic member of the suite, the syenite. Although major textural and structural variance occurs between these rocks, the only compositional difference is observed in the mafic counterpart of the suite, the pyroxenite. The clinopyroxenes form the main mafic mineral in pyroxenite and syenite along with their cumulus variant, a hybrid rock. It is nearly absent in the country rocks that enclose these intrusive rocks. Hence an attempt is made in this paper to understand the temperature and origin of syenite, pyroxenite and hybrid rocks, the prominent constituents of the suite, with the help of Electron Probe Microanalysis (EPMA) of clinopyroxenes in the said rocks and thereby establishing the temperature conditions of crystallization of the suite.

Background Geology

Putteti alkaline suite (8^0 14' N and77^0 12'E), located near Karungal in Kanyakumari district of Tamil Nadu, has a unique position in South India (Fig. 1). It is a NNW- SSE trending intrusive body seen intruded into the surrounding granulites and gneisses. It encompasses two compositionally diverse members, namely syenite and pyroxenite, which are suggested to have been derived from a single parental magma (Rajesh[16]). These rocks along with their cumulus variant, a hybrid rock, reveal the entire sequence of the process of magmatic crystallization. Although they are believed to be from the same magmatic source, there exists wide variation in the texture and composition of these rocks even in the same exposure.The syenite has been known to the geologic community for the presence of zircon megacrysts that have been widely used for radiometric age determination in the terrain over the past several decades (Parthasarathy and Sankar Das[12]; Odom[11]and Miyasaki and Santosh[7]; Santosh et.al.,[17])

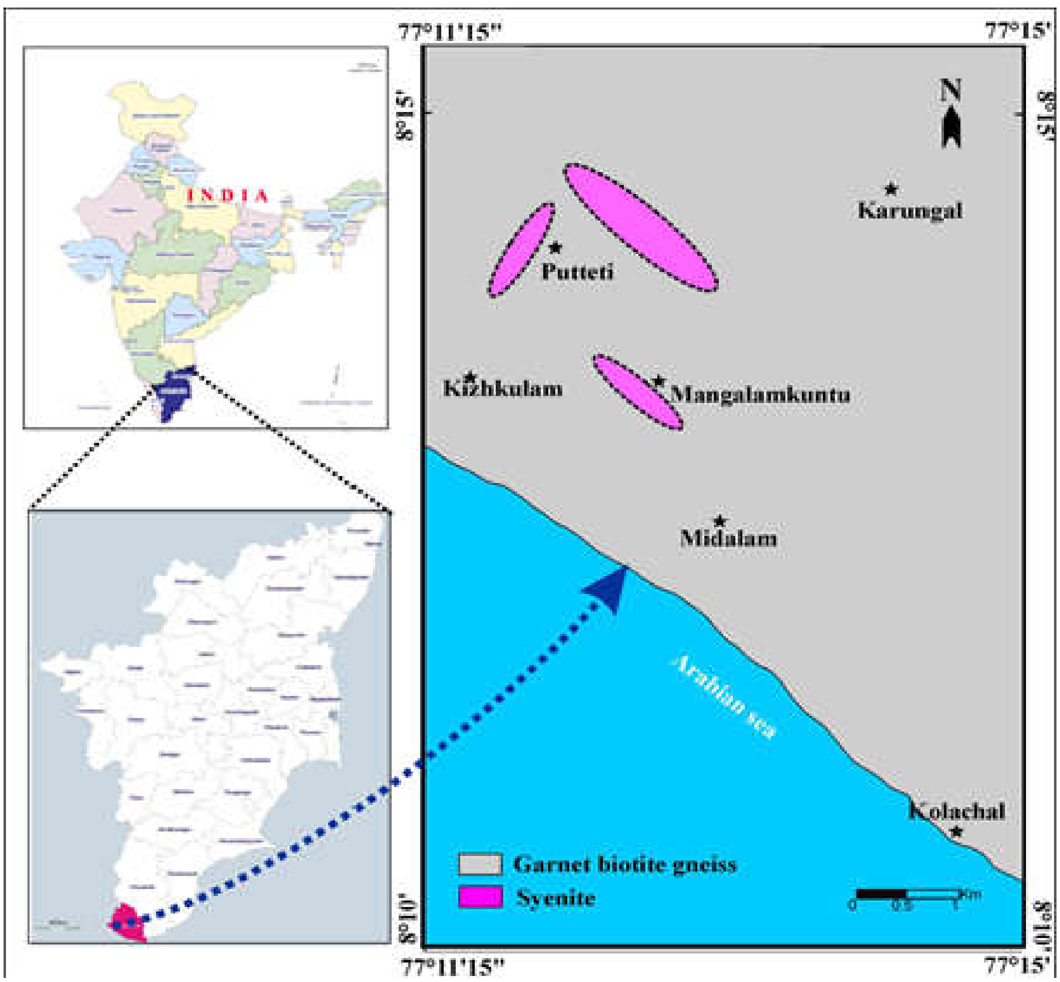

Figure 1: Location Map and Geologic Map of the area around Putteti

Field Relations

The members of this alkaline suite are exposed as small exhumed hillocks in the village of Putteti and adjoining areas. The emplacements in SGT including Putteti are suggested to be through existing deep fractures or lineaments in the area (Grady[2]). The rocks of the suite, syenite, pyroxenite and hybrid rock, shows wide variation in texture and mineral composition even in the same exposure (Fig. 2). Syenite is the major intrusive phase in most of the exposures, with intervening layers or bands of pyroxenite. Two coloured varieties of syenite are identified- grey and white; in addition pegmatitic varieties of both these syenites are also noticed. The concentration of pyroxenes and other mafic minerals vary in these variants. The common accessory minerals include zircon, apatite, sphene with various sulphides (pyrite, chalcopyrite, molybdenite, bornite etc.) and oxides (magnetite, ilmenite, rutile etc.). Pyroxenite is dark coloured, medium to coarse grained with the characteristic pyroxenes and phlogopite. They occur either as continuous bands within the magmatic layers or as dykes that cut across the intrusive syenite.

A number of mafic and felsic dykes cutting across one another are observed that probably represent intrusions through existing fractures at different times within a short period (Fig. 3). They points to continued igneous activity in the area throughout the formation of the suite. Some parts of the suite show well developed rhythmic layering of alternating syenite and pyroxenite that resemble cumulate texture. These layers often get segregated into a hybrid rock with equal proportion of syenite and pyroxenite (Fig. 4). The pyroxenes form as cumulates within the syenite matrix and are occasionally show preferred orientation. Irregular clots or blebs (with diameter 0.1cm - 2cm) of pyroxenes are noticed in syenite at many places (Fig. 5). Some of the smaller pyroxene clots have coalesced to form larger ones.A few pyroxenite layers are exceptionally thick (Fig. 6) which exhibit crude folding. The syenite also encloses parts of undigested country rock, the charnockite, as enclaves (Fig. 7). These enclaves and the prominent magmatic layering conformable withthe foliations, indicate the post-deformational nature of the intrusive body.

Figure2: Syenite-pyroxenite association at Putteti. Note the hybrid rock with magmatic layering at the bottom

Figure 3: Crosscutting bands of syenite and pyroxenite

Figure 4: Preferentially oriented pyroxene grains in syenite that form the hybrid rock

Figure 5: Irregular clots of pyroxene in syenite

Figure 6: Broad pyroxenite bands in syenite

Figure 7: Enclaves of charnockite in medium grained grey syenite

Petrography

Syenite of Putteti exhibits phaneritic texture; it is mainly composed of alkali feldspars and pyroxenes. The dark coloured pyroxenes are unevenly sprinkled throughout the rock giving it an overall 'salt and pepper' look (Fig. 8). The accessory phases present include zircon, sulphides and iron oxides along with chevkinite occasionally. Two colour variants of syenite are characterized by the presence of distinct minerals. The dominant white syenite is having high specific gravity with colourless feldspar, dark irregular clots of pyroxenes with interstitial quartz and calcite with accessory minerals, sulphides and oxides. Pyroxenes occur as clots or blebs of varying dimensions from rounded to ovoid in outline. The grey variety is having low specific gravity with subhedral to euhedral feldspar and with less pyroxene and more accessories.

Under the microscope, syenite is a holocrystalline, medium to coarse grained rock with characteristic hypidiomorphic texture. The grey and white varieties of syenite are characterized by distinct texture and mineralogy. In the grey variety orthoclase is the major constituent; minor amounts of pyroxene, plagioclase and amphiboles are also seen. In the white syenite perthite is the dominant phase with minor amounts of calcite and quartz. Clinopyroxenes are the major mafic components of the rock and they occur as irregular clots or blebs with uneven boundary (Figs. 10 & 12). Augite, diopside and a few hedenbergite grains form the major pyroxenes along with accessory zircon, apatite, biotite, sphene and opaques. The intimate association of accessory minerals like zircon, apatite and opaques with that of pyroxene in syenite indicates magmatic origin for the rock. The concentration of pyroxenes and orthoclase in the rock is maintained as 30 and 70%.A few clots of pyroxenes, especially diopside and hedenbergite, are cracked and preserve the traces of cleavage typical to that of pyroxenes.

Hybrid rock is a phaneritic, medium to very coarse grained with very high specific gravity. It is essentially composed of orthoclase and pyroxenes and minor amount of amphiboles. The pyroxenes occur as segregates and/or as cumulates in the hybrid rock. Pyroxene grains, in a matrix of syenite, are more or less euhedral (Fig. 9) without other accessory minerals and opaques. A few pyroxene cumulates assemble together forming continuous rhythmic mafic layers with preferred orientation. They sometimes indicate the syn- plutonic controls of tectonic activity in the region.

In thin section hybrid rock is holocrystalline with alternate layers of syenite and pyroxene with a cumulate texture (Fig. 11 & 13). Major clinopyroxenes identified include augite, diopside and hedenbergite along with some plagioclase, hornblende and biotite. The amount of mafic minerals in the hybrid rock, however, does not exceed 50%. The content of zircon and other accessory phases are less when compared to that in syenite.

Figure 8: Hand specimen of syenite with pyroxene clots

Figure 9: Hybrid rock with pyroxene cumulates

Figure 10: Syenite with pyroxene and opaques. Note inclusions of zircon and apatite in pyroxenes (PPL)

Figure 11: Pyroxene cumulates in hybrid rock (PPL). Note the regular borders of grains (PPL)

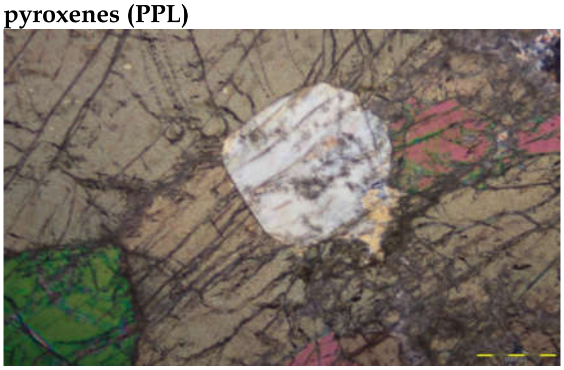

Figure 12: Euhedral inclusions of orthoclase and diopside in augite of syenite (XPL)

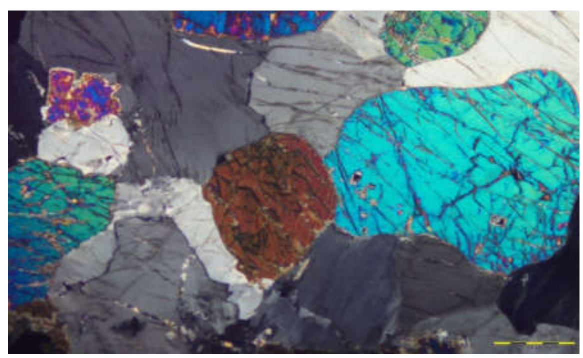

Figure 13: Euhedral diopside grains formed as cumulates in hybrid rock (XPL)

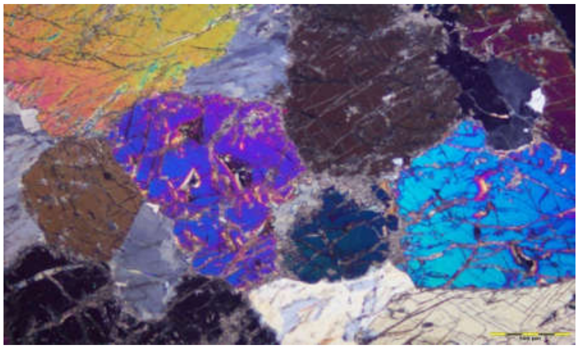

Figure 14: Clinopyroxenes in pyroxenite(XPL)

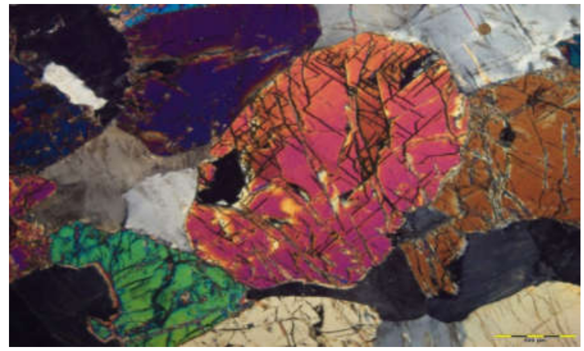

Figure 15: Highly cracked grains of pyroxenes in hybrid rock (XPL)

The average mineral composition data of syenite, hybrid rock and pyroxenite of Putteti alkaline suite selected for chemical analysis is given below (Table. 1). The modal and chemical analysis data of pyroxenite is given for the comparison of mineralogy.

Table1: Average modal analysis data of minerals of rock types from Putteti alkaline suite

Rock Type/ Minerals	Syenite (PU-6)	Hybrid Rock (MK-6)	Pyroxenite (MK-2)
Orthoclase	59.8	45.98	5.38
Augite	13.72	21.89	24.73
Diopside	7.84	17.51	16.13
Hedenbergite	5.88	5.84	32.26
Biotite	3.92	-	3.23
Perthite	2.94	3.65	8.6
Plagioclase	1.96	2.92	9.68
Calcite	1.96	-	-
Zircon	0.98	1.45	-
Chevkinite	0.49	-	-
Apatite	0.29	1.09	-
Opaques	0.29	-	-

Mineral Chemistry

The clinopyroxenes from the syenite, hybrid rock and pyroxenitewere analyzed using automated Electron Probe Micro Analyzer (EPMA) facility in the Advanced Facility for Microscopy and Microanalysis (AFMM) of Indian Institute of Science, Bangalore. An analysis was performed with acceleration voltage of 15 keV and beam current of 12nA. The compositions and arrived temperatures of crystallization of clinopyroxenes from these two rocks are presented in Table 2, along with the clinopyroxene composition in the pyroxenites of the area.

Table 2: Chemical composition and calculated temperature for clinopyroxenes from the rocks of Putteti alkaline suite

	Clinopyroxenes as clots in Syenite PU-6					opyroxenes as cummulates in Hybrid Rock N					Clinopyroxenes from Pyroxenite MK-2				
Major Oxides (wt%)															
Sample	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
SiO2	51.259	51.153	51.022	51.495	51.325	52.607	52.215	52.078	52.329	52.522	63.971	63.917	60.046	67.331	67.970
TiO2	0.195	0.127	0.173	0.198	0.219	0.19	0.126	0.174	0.194	0.155	0.026	0.084	0	0	0.025
Al2O3	1.392	1.413	1.491	1.453	1.405	1.253	1.226	1.136	1.158	1.124	19.314	18.278	23.818	19.687	19.741
Cr2O3	0	0	0	0	0	0	0.004	0.028	0	0	0.002	0.01	0	0	0
FeO	10.113	9.804	10.005	10.263	10.134	6.724	6.494	6.7	6.597	6.305	0.039	0.039	0.039	0.039	0.039
MnO	0.181	0.162	0.185	0.199	0.186	0.287	0.352	0.247	0.293	0.341	0.011	0.022	0.018	0.002	0
MgO	11.53	11.564	11.363	11.478	11.415	13.115	13.169	13.007	13.179	13.126	0	0.011	0.007	0	0.014
CaO	22.06	22.254	22.418	21.947	22.014	22.463	22.381	22.631	22.22	22.444	0.95	0.215	5.531	4.595	4.593
Na2O	0.339	0.312	0.25	0.327	0.288	0.393	0.346	0.355	0.332	0.347	4.1	2.266	6.748	5.886	5.857
K2O	0	0.011	0.024	0.002	0.006	0	0	0.009	0	0.008	9.461	13.089	0.191	0.139	0.135
Total	97.069	96.8	96.931	97.362	96.992	97.032	96.313	96.365	96.302	96.372	97.874	97.892	96.359	97.645	98.404
Number of cations on the basis of 6 oxygen															
Si	1.982	1.988	1.983	1.992	1.994	2.014	2.013	2.008	2.018	2.024	1.910	1.908	1.905	1.927	1.909
Ti	0.006	0.004	0.005	0.006	0.006	0.005	0.004	0.005	0.006	0.004	0.014	0.018	0.015	0.018	0.015
Al	0.064	0.065	0.068	0.066	0.064	0.057	0.056	0.052	0.053	0.051	0.240	0.251	0.247	0.240	0.233
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.001	0.000
Fe	0.328	0.319	0.325	0.332	0.329	0.215	0.209	0.216	0.213	0.203	0.193	0.214	0.216	0.217	0.215
Mn	0.006	0.005	0.006	0.007	0.006	0.009	0.011	0.008	0.010	0.011	0.004	0.005	0.003	0.001	0.003
Mg	0.666	0.670	0.658	0.662	0.661	0.748	0.757	0.748	0.758	0.754	0.666	0.652	0.654	0.663	0.664
Ca	0.917	0.926	0.934	0.910	0.917	0.922	0.924	0.935	0.918	0.927	0.889	0.872	0.881	0.889	0.882
Na	0.025	0.024	0.019	0.025	0.022	0.029	0.026	0.027	0.025	0.026	0.083	0.080	0.078	0.045	0.080
K	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001
Total cation	4	4	4	4	4	4	4	4	4	4	4.000	4.000	4.000	4.000	4.000
XMg*	0.653	0.662	0.653	0.641	0.639	0.726	0.735	0.735	0.724	0.726	0.770	0.733	0.744	0.686	0.756
Mole proportion of end member															
Q	1.910	1.915	1.917	1.904	1.907	1.890	1.890	1.900	1.890	1.880	1.747	1.734	1.750	1.756	1.759
J	0.051	0.047	0.038	0.049	0.043	0.058	0.052	0.053	0.05	0.052	0.166	0.159	0.155	0.088	0.159
Fs	0.169	0.164	0.168	0.172	0.171	0.112	0.109	0.112	0.111	0.106	0.105	0.118	0.118	0.120	0.117
En	0.344	0.345	0.340	0.343	0.343	0.391	0.395	0.388	0.396	0.395	0.364	0.359	0.358	0.365	0.361
Wo	0.473	0.478	0.482	0.472	0.475	0.481	0.482	0.486	0.480	0.485	0.486	0.480	0.482	0.490	0.479
Calculated temperature for clinopyroxenes															
T1 °C	1125.83	1129.43	1125.42	1123.78	1124.54	1179.00	1182.48	1178.58	1181.15	1184.79	1178.29	1166.60	1166.21	1166.92	1168.24
T2 °C	1232.89	1243.26	1231.72	1227.03	1229.21	1395.46	1406.84	1394.08	1402.47	1414.47	1393.14	1355.61	1354.36	1356.62	1360.80

Discussion and Conclusion

A few workers have attempted on the genesis and mineral chemistry of Putteti alkaline suite (Nair and Santosh[10]; Rajesh[16]). Although detailed mineral chemistry pertaining to the mafic minerals in syenite has been done the thermometry of the same has not been attempted so far. In this paper a sincere effort is made to compare the compositions of pyroxenes in the intrusive rocks of the area in order to understand the origin and sequence of crystallization of the igneous suite.

Clinopyroxenes are the major mafic mineral components of the suite both in syenite, hybrid rock and pyroxenite. The oxide concentrations of the clinopyroxenes (Table. 1) give a more or less similar systematics and origin for these minerals. They are rich in SiO_2 (51.02-52.61 wt%), MgO (11.36-13.18 wt%) , CaO (21.95-22.63 wt%) and FeO (6.30-10.26 wt%) and poor in Al_2O_3 (1.12-1.49 wt%), Na_2O (0.25-0.39 wt%) and K_2O (0-0.02 wt%). The elemental concentration per oxygen also varies accordingly. These indicate that they are predominantly Ca-Mg clinopyroxenes with an average XMg* values of about 0.650 for syenite, 0.738 for pyroxenite and 0.729 for hybrid rock. The data reveals the presence of more or less same clinopyroxenes in the syenite, pyroxenite and hybrid rocks. The concentration of these minerals varies considerably in part of the rocks probably due to variation in the magmatic processes and tectonic controls prevailed in the terrain. These are comparable with the whole rock geochemical data already obtained.

A number of compositional plots were drawn using the available mineral composition data of clinopyroxenes. In Wo-En-Fs compositional plot (Deer et al.[1]) the clinopyroxenes in both the rocks show diopside composition (Fig. 16). In the binary diagram of Morimoto[8,9] (Fig. 17), pyroxenes are predominantly Ca-Mg-Fe end members indicating calcium rich diopside and augite. In both the plots are found adjacent to each other or clustered, indicating the unique composition of these minerals. It is pertinent to note that the composition of pyroxenes in pyroxenites is similar to the one in the two rocks (Fig. 16 & 17)

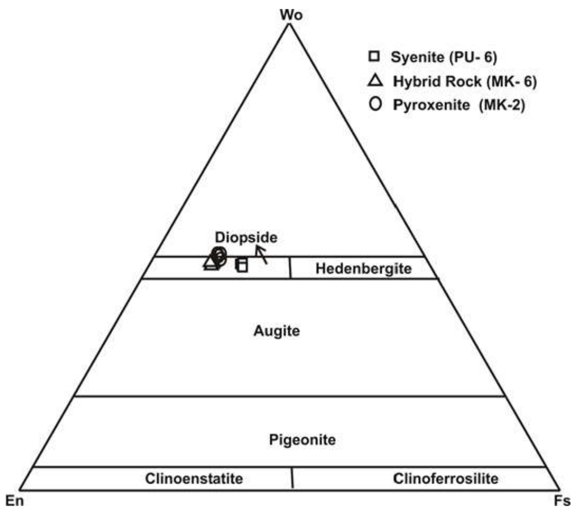

Figure 16: Compositional plot (Wo-En-Fs) for clinopyroxenes of Putteti (Deer et al.,1997)

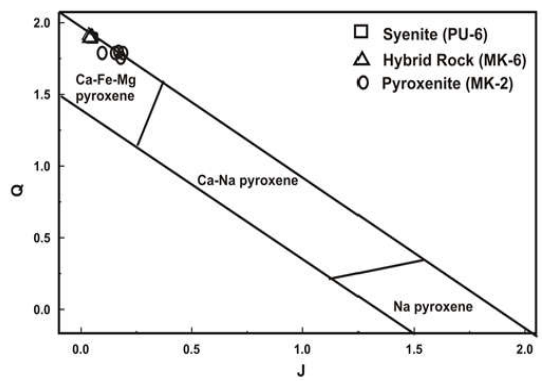

Figure 17: Q (Ca+Mg+Fe) vs. J (2Na) Diagram (Morimoto, 1988) for clinopyroxenes

Geothermometry

The available EPMA data for clinopyroxenes from syenite and hybrid rock are further used for arriving at their geothermometry. Geothermometry calculations based on Putirka[14,15] for these pyroxenes have been carried out. The mean temperature of formation of these pyroxenes was calculated as 1181.20^{o}C. The present study and the calculated temperature values suggest a comparatively high temperature of crystallization for the clinopyroxenes in the rocks of the suite. The temperature of clinopyroxenes were estimated using the plots of Lindsley[5] and Mercier[6] and they give low temperatures for these rocks compared to that of Putirka[14,15] and hence avoided.

Augite is the dominant pyroxene followed by diopside and hedenbergite. The higher Mg number of pyroxenes suggests Mg enrichment at the time formation of these rocks suggests an upper mantle source for the magma. As the crystallization proceeds, the Mg content gradually decline resulted in Ca enrichment in pyroxenes forming Ca-rich clinopyroxenes. This may occur either from the fractionation of Ca- rich parental magma or carbonate metasomatism (supported by the presence of good amount of calcite in syenite) during the course of crystallization of these rocks. Although the syenite and hybrid rocks have been subjected to various crystallization processes during their formation, not much change has influenced the composition of these pyroxenes. Moreover they show high temperature of crystallization (1181.20^{o}C) compared to the orthoclase and perthite that co-exist with them in the rock. This indicates they might have been formed earlier and isolated from the remaining melt or have not participated in chemical reactions at a later time.

ACKNOWLEDGEMENTS

The first author is deeply indebted to the University Grants Commission (UGC), New Delhi for granting Teacher Fellowship under UGC-FDP 12th Plan for pursuing Ph.D programme. The authors express their sincere gratitude to Dr. Sajeev Krishnan, Associate Professor, Indian Institute of Science, Bangalore for Electron Probe Microanalysis (EPMA). Heartfelt thanks are also due to Dr. Rajesh V.J., Associate Professor, Indian Institute of Science and Technology, Valiamala, Thiruvananthapuram and Prasanth R.S., Research Scholar, University of Kerala for their help in various stages during the preparation of this paper.

REFERENCES

1. Deer, W.A., Howie, R.A. and Zussman, J., (1997) Single Chain Silicates. Geological Society of London, London. P.671.
2. Grady J.C. (1971) Deep main faults in South India. Jour. Geol. Soc. India, v.12, pp. 56-62.
3. Le Bas, M.J. (1962). The role of aluminum in igneous clinopyroxenes with relation to their parentage. Am. J. Sci., v.260, pp.267-288.
4. Le Bas, M. J., Le Maitre, R.W., Streckeisen, A., Zanettin, B. (1986) A chemical classification of volcanic rocks based on the total alkali-silica diagram. Jour. Petrol. v.27, pp.745-750.
5. Lindsley, D.H., (1983) Pyroxene thermometry. American Mineralogist, v. 68, pp. 477 – 493.
6. Mercier, J.C.C., (1980) Single-Pyroxene Thermobarometry. Tectonophysics, v.70, pp.1-37.
7. Miyasaki, T. and Santosh, M. (2005) Cooling History of the Puttetti Alkali Syenite Pluton, Southern India. Gondwana Research, v. 8, No. 4, pp. 567-574.
8. Morimoto, N., (1988). The Nomenclature of Pyroxenes. Mineralogical Magazine, v.52, pp.425-433.
9. Morimoto, N., Fabries, J., Ferguson, A.K., Ginzburg, I.V., Ross, M., Seifert, F.A., Zussman, J., (1989) Nomenclature of pyroxenes. Canadian Mineralogist v.27, pp.143 – 156.
10. Nair, N.G.K. and Santosh, M. (1985) Geochemistry and petrogenesis of the Putteti syenite, South India. Neus Jahrb Miner Abh, v.151, pp.213-227.
11. Odom, A. L. (1982) Isotope age determination of rock and mineral samples from Kerala, India. Final report UN Case No.81-10084, pp.10.
12. Parthasarathy, R. andSankar Das, M. (1976)Thorium, uranium and lead contents of some Indian zircons and their ages. Jour. Geol. Soc. India, v.17, pp.262-271.
13. Peccerillo, A. and S.R. Taylor. (1976). Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamonu area, Northern Turkey. Contribut. Mineral. Petrol., v.58, pp.63- 81.
14. Putirka, K.D., (2008). Thermometers and barometers for volcanic systems. Reviews in Mineralogy and Geochemistry, v.69, pp.61–120.
15. Putirka, K.D., Mikaelian, H., Ryerson, F., and Shaw, H.F.,(2003). New clinopyroxene-liquid thermobarometers for mafic, evolved, and volatile-bearing lava compositions, with applications to lavas from Tibet and the Snake River Plain, Idaho. American Mineralogist, v.88, pp.1542–1554.
16. Rajesh, H.M. (2003) Outcrop- scale silicate liquid immiscibility from an alkali syenite (A-type granitoid)- pyroxenite association near Puttetti, Trivandrum Block, South India. v. 145, pp. 612-627.
17. Santosh, M., Iyer, S.S., Vasconcellos, M.B.A. and Enzweiler, J. (1989) Late Precambrian alkaline plutons in southwest India: Geochronologic and rare- earth element constrains on Pan-African Magmatism. Lithos, v.24, pp.65-79.