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Petrogenetic Significance in the Relationship between Nepheline Syenite and Shonkinite of Elchuru Alkaline Complex, Cuddapah Intrusive Province, Andhra Pradesh, India

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Abstract: *The highly deformed eastern side of the Cuddapah basin led to the formation of numerous rifts, faults and major lineaments which in turn facilitated the Meso Proterozoic miaskitic alkaline magmatism. Co spatial association of mafic and felsic alkaline rocks within this zone is found in a row trending in NE-SW direction, all the plutons, constitute the Prakasam alkaline province later renamed as Cuddapah intrusive province. The above mentioned association appears pronouncedly at Elchuru, designated as Elchuru alkaline complex, where mafic and felsic (feldspathoidal) alkaline syenites i.e. shonkinite, malignite, nepheline syenite, lamprophyre are present in adequate representation to correlate the genesis of these rocks. Petrographically shonkinite shows the predominance of clinopyroxene, biotite and amphibole as mafics and on the other hand, nepheline and perthitic feldspar constitutes the felsics. This phenomenon is reverse in the case of nepheline syenites, which predominantly consists of subhedral nepheline along with the K-feldspar (perthitic) with subordinate aegirine augite, ferrohastingsite and discrete biotite. Predominance of mafics in the former and dearth of those in the later denote the fractionation of nepheline syenites from the shonkinitic magma. Geochemically, the percentages of FeO, MgO, and CaO are higher in shonkinite and low in nepheline syenite indicating the fractionational crystalisation process that was involved in the genesis of nepheline syenites. Subsequent increment of SiO_2, Na_2O and K_2O with the magmatic differentiation from the early formed shonkinites to later formed nepheline syenites is also noticed. Geochemical discrimination diagrams and the plots in the Petrogeny's residua system at 1Kb PH_2O clearly illustrates the evolution of nepheline syenites from the K- rich hydrous mafic magma. Enrichment of transition metals such as Cr, V, Ni, Zn and LFSE in the shonkinites and lack of them in the nepheline syenites further substantiate that the genesis of nepheline syenites is undoubtedly from an undersaturated shonkinitic magma at Elchuru alkaline complex.*

Keywords*: Cuddapah Intrusive Province, Elchuru alkaline complex, Fractional crystallization, Shonkinite, Nepheline syenite.*

1. Introduction

The oblong, concordant and Meso-proterozoic (1321±17 Ma, U-Pb method on zircon Upadhyay et al., 2006), Elchuru alkaline pluton lying in-between 79°55′42″ E, 16°04′48″ N, is spread in an area of 16 sq. km. oriented in a NE-SW direction, which is the regional trend of the Prakasam alkaline province. The exposed rocks of this pluton show crescent shape, marked by four distinct physiographic units: Karumanchikonda, Peddakonda, Malakonda and the hill 637. This pluton is emplaced in between the charnokites cordierite gneiss (khondalite) in the east, gabbroic rock in the south and the quartzo- feldspathic gneisses and schist's (Dharwars) in the north and west. The contact between the surrounding country rocks and the alkaline pluton is very sharp. The complex is predominantly composed of nepheline syenite with subordinate foidolite, shonkinite, malignite, and lamprophyres (Madhavan et al., 1988).

2. Petrology and Petrography

Petrologically this pluton consists, predominantly of subsolvous and hypersolvous nepheline syenites along with the shonkinite and malignite in subordinate amounts, which were intruded by the later stage lamprophyres (Camptonite), microshonkinites, manifested as dykes and the nepheline syenite as veins and veinlets. Lamprophyres of the complex are believed to have originated from the regeneration of shonkinitic magma, which have profusely intruded the massif to constitute a dyke swarm (Madhavan, 1992). The mesocratic malignite is considered as the cogenetic and intermediate member to the last evolved nepheline syenites and early formed shonkinites. All the above said rocks consist of feldspathoidal minerals but exhibit the variations in their proportions.

Shonkinite is a melanocratic rock and it shows the predominance of clinopyroxenes as mega crysts, the felsics are mainly represented by nepheline, K-feldspar and plagioclase, and the other mafic is represented by biotite, both the felsics appear in the ground mass. Biotite flakes are aligned parallel to foliation planes. Titanite, apatite, zircon are the accessory phases in this rock.

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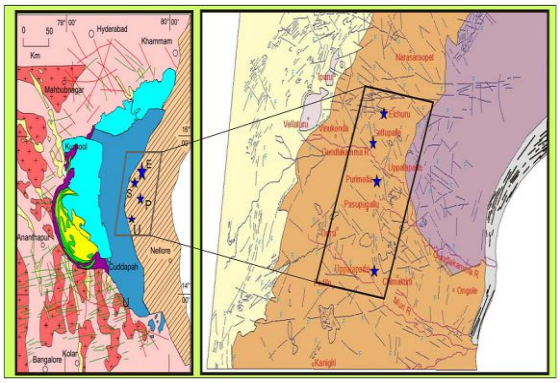
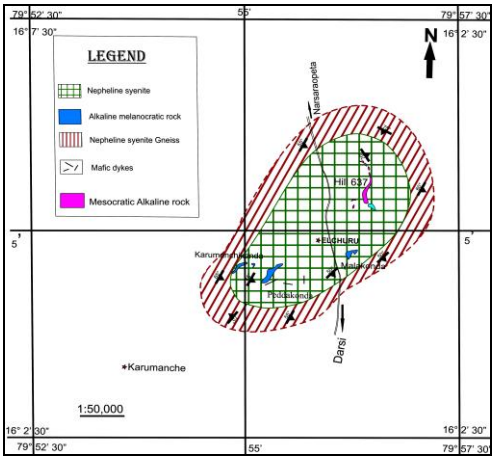


***Fig: 1**. A) Eastern margin of the Cuddapah Basin showing the locations of major alkaline plutons of the cuddapah intrusive province E-Elchuru, S-Settupalle, P-Purimetla, U-Uppalapadu*



B) Geological map of Elchuru showing the spatial association of various rock types of the pluton

Both hypersolvus and subsolvus nepheline syenites have been identified in the field of which the hypersolvus, leucocratic and coarse grained rock often shows foliation defined by oriented ferromagnesian minerals and altered feldspar and deformed nepheline. Biotite, aegirine augite and ferrohastingsite are the main ferromagnesian minerals present in this rock. Titanite, apatite and zircon are the accessory minerals. The subsolvus nepheline syenite is characterized by inequigranular porphyroblastic texture and they not only show the gneissic foliation but also the granulation around the feldspar grains. Whereas the mafic content varies minutely from sample to sample, the predominant mineral is K-feldspar perthite which is microcline or microcline perthite in some samples, the K-feldspar is subhedral with the perthitic intergrowth closely arranged and exhibit variation in the degree of unmixing of plagioclase and K-feldspar. Nepheline is anhedral and found as porphyroblasts and it often occurs as small rounded crystals. In general, nepheline in this rock is more frequently found as large grains unlike feldspar, which is found as smaller and as well as bigger grains. In this rock the mafics are represented mainly by biotite and ferrohastingsite, biotite shows dark brown to pale yellow colour and found as broad flakes often showing a tendency to come closer to each other, on the other hand, large grains of amphibole show dark green tint and occur together with biotite in some samples. Calcite is noticed in minor quantities and scattered all through the rock, some samples show the conspicuous absence of calcite. A bimodal crystallization sequence for the genesis of this pluton was proposed by earlier workers (Upadhyay et.al. 2006).

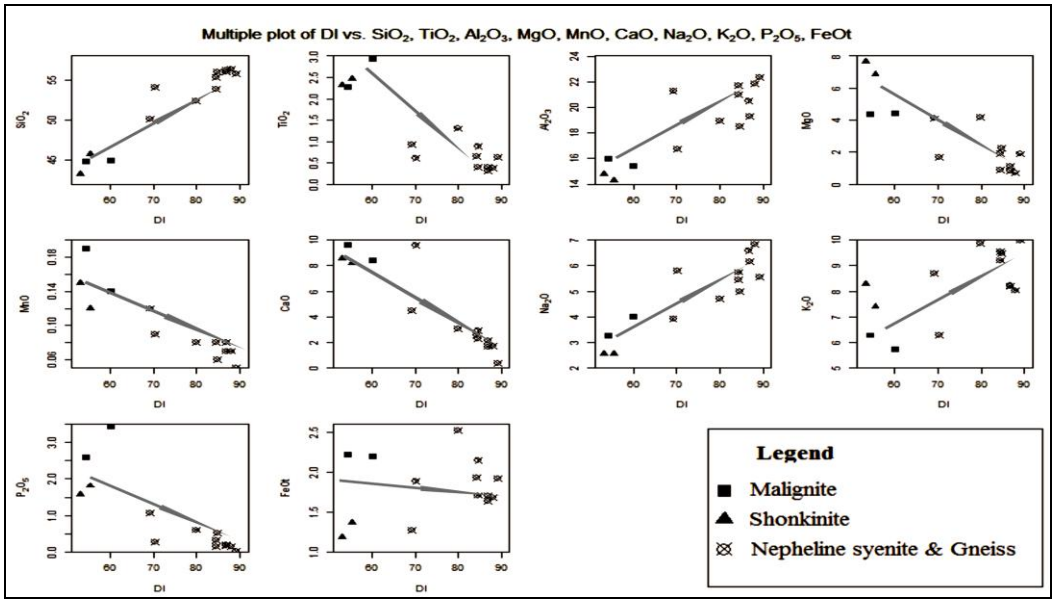


***Fig.2**. Plots of major oxides against DI (Thornton and Tuttle, 1969) for the Elchuru alkaline rocks*

3. Geochemistry

All samples of the Elchuru alkaline complex fall in their respective fields when plotted in SiO_2 Vs total alkalies diagram (Cox, et al., 1979) Fig.3A. Shoshonitic rocks are characterized by high contents of K_2O with respect to Na_2O in this respect the mafic

rich rocks of the Elchuru alkaline complex come under the shoshonitic category. The geochemical behavior of the mafic and felsic rocks in several variation diagrams demonstrates that the felsic rocks are the fractionated products of a mafic rich magma as demonstrated by the presence of mafic rocks of the pluton. Fractional crystallization is clearly represented in the bivariant diagram (Fig.2) by exhibiting the clear magmatic crystallization sequence/trend. Increment of felsic components such as SiO_2, K_2O, and Na_2O in the later evolved felsic alkaline rocks and less prominence of them in the former mafic rich lithounits of the pluton clearly indicates the fractionation of later from the former.

On the other hand the enrichment of ferromagnesian constituents like CaO, MgO, FeOt, MnO in the earlier mafic rocks and lack of them in the evolved felsic rich ones with the increasing differentiation of the magma suggest that the fractionation was dominated in the initial stage by the mafic rich components and the reverse in the case of the later formed rocks. All the litho units of the pluton are feldspathoidal and therefore are nepheline normative. The agpaitic index (Mol.Prop. Al_2O_3/K_2O+Na_2O) of the rocks is <1 and therefore they represent their miaskitic alkaline character. The range in different major oxides of the Elchuru alkaline complex has been shown as follows: Total alkalies (10.49-15 Wt %) and their K_2O/Na_2O ratios (1.7-2.9), variations in the alumina saturation (14.26-21 Wt %) and TiO_2 (1.3-2.2) will bring out the shoshonitic affinity of these rocks. Further these rocks when plotted in the SiO_2 Vs K_2O and Co Vs Th trace diagrams cluster within the shoshonitic series regions (Fig.3B,C).

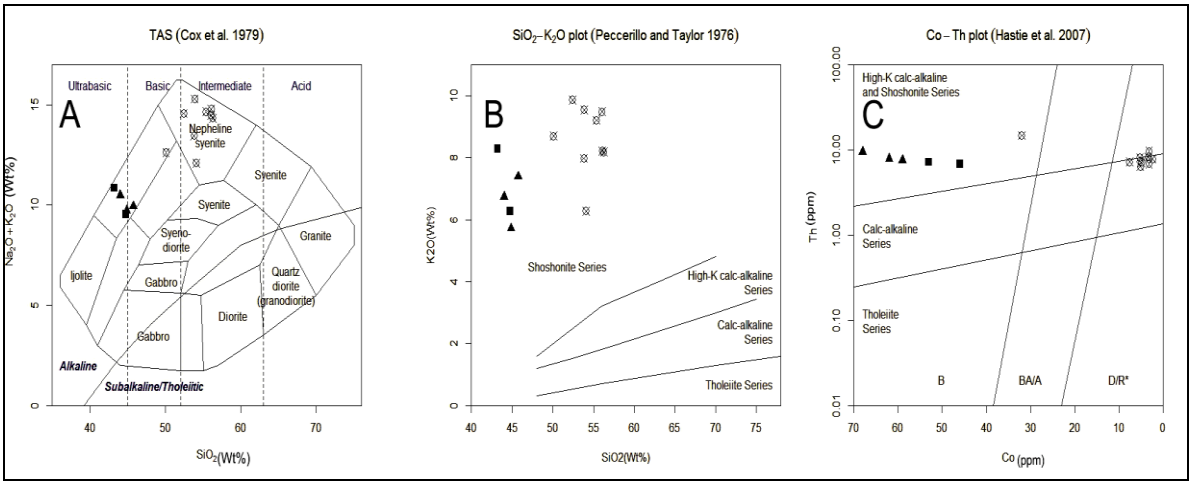


Fig.3. *A) Total alkalies silicate diagram illustrate the plots of mafic and felsic rocks of the Elchuru alkaline pluton. B) SiO_2 against K_2O diagram showing the shoshonitic affinity of the Elchuru alkaline rock. C) Co Vs Th (ppm) trace element diagram showing the shoshonitic affinity of the same pluton*

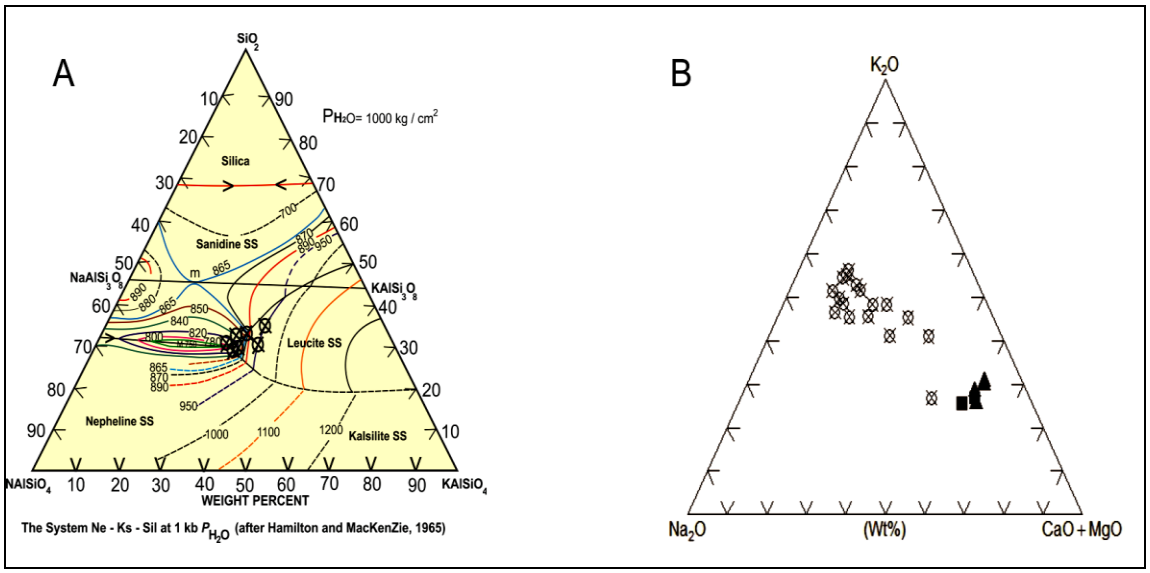


Fig: 4*. A) Petrogeny's residua system (Hamilton and Mackenzie, 1965) clearly representing the plots of nepheline syenites towards the K-rich side. B) Triangular diagram of Na_2O, K_2O, $CaO+MgO$ display the tendency of nepheline syenites heading towards the alkalies particularly towards the K_2O*

***Table 1**. Major oxide and norm calculations of Elchuru mafic and felsic rocks*

S.No	1	2	3	4	5	6	7	8	9	10	11
Sample .No	EL16	EL(M)54	EL(M)80	EL(M)77	EL(M)76	EL22	EL(M)65	EL12	EL(M)84	EL(K)40	EL8
Rock	Shonkinite	Shonkinite	Shonkinite	Malignite	Malignite	M..N.Sy	N.Sy	N.Sy	N.Sy	N.S.G.	N.Sy.
SiO_2	44.02	44.87	45.75	44.75	43.22	50.09	52.43	53.81	53.86	54.08	54.96
TiO_2	2.23	2.93	2.46	2.26	2.32	0.92	1.3	0.36	0.65	0.6	0.43
Al_2O_3	14.46	15.42	14.26	15.95	14.8	21.26	18.96	20.78	21.01	16.73	21.25
Fe_2O_3	3.07	2.43	1.52	2.46	1.32	1.42	2.8	1.66	2.15	2.1	2.23
FeO	8.19	6.62	8.36	6.49	8.39	2.93	2.63	2.48	1.72	2.95	2.38
MnO	0.14	0.14	0.12	0.19	0.15	0.12	0.08	0.12	0.08	0.09	0.17
MgO	6.48	4.4	6.86	4.36	7.64	4.09	4.16	2.38	1.89	1.68	1.69
CaO	9.46	8.37	8.2	9.58	8.54	4.51	3.07	3.56	2.59	9.61	2.52
Na_2O	3.75	4	2.55	3.26	2.57	3.93	4.71	5.49	5.75	5.81	5.78
K_2O	6.74	5.72	7.39	6.27	8.28	8.7	9.87	7.98	9.55	6.28	8.36
P_2O_5	1.21	3.42	1.81	2.59	1.58	1.07	0.61	0.62	0.33	0.28	0.17
Na_2O+K_2O	10.49	9.72	9.94	9.53	10.85	12.63	14.58	13.47	15.3	12.09	14.14
CaO+MgO	15.94	12.77	15.06	13.94	16.18	8.6	7.23	5.94	4.48	11.29	4.21
Fe_2O_3+Feo	11.26	9.05	9.88	8.95	9.71	4.35	5.43	4.14	3.87	5.05	4.61
Total	99.75	98.32	99.28	98.16	98.81	99.04	100.62	99.24	99.58	100.21	99.94
DI	52.547	60.216	55.438	54.455	53.138	69.216	79.909	78.103	84.359	70.274	82.183
Norm											
Or	19.11	33.80	43.67	37.05	13.84	50.43	58.28	47.16	56.44	37.11	49.41
Ab	0.00	17.63	0.17	5.36	0.00	0.00	0.00	12.61	3.41	14.25	13.71
An	2.72	7.23	5.64	10.37	4.39	14.67	1.44	8.49	3.31	1.02	7.35
Lc	16.25	0.00	0.00	0.00	27.52	0.78	0.04	0.00	0.00	0.00	0.00
Ne	17.19	8.79	11.60	12.04	11.78	18.02	21.59	18.34	24.51	18.92	19.07
Di	22.65	1.79	11.77	10.21	15.69	0.00	4.35	3.38	4.23	9.03	2.50
Ol	3.95	7.10	8.15	4.30	8.24	7.14	5.85	3.06	1.93	0.00	2.14
Il	0.30	0.30	0.26	0.41	0.32	0.26	0.17	0.26	0.17	0.19	0.36
Hm	3.07	2.43	1.52	2.46	1.32	1.42	2.80	1.66	2.15	2.10	2.23
Pf	3.53	4.72	3.96	3.48	3.66	0.35	2.06	0.38	0.95	0.85	0.41
Ap	2.87	8.10	4.29	6.14	3.74	2.53	1.45	1.47	0.78	0.66	0.40
Total	91.63	91.88	91.02	91.81	90.51	96.17	98.02	96.79	97.88	97.28	97.57

4. Petrogenesis

The high LILE and LREE of the Elchuru alkaline rocks indicate that the source magma for these rocks is of fertile nature. Devoid of significant depletion in the Nb and Ta anomalies (Fig.5A&B) in the Chondrite normalized multi trace elements and the absence of –Eu anomaly (Fig.5C&D) in the Chondrite normalised REE patterns indicate that crustal contamination did not play any considerable role in the genesis of these rocks. In diagram (Fig.5D) where all the nepheline syenites are plotted for their normalized REE variation, it can be seen that the nepheline syenite gneisses tend to be richer in REE when compared to undeformed nepheline syenite of the complex.

High Rb/Cs, low Th/Ce (Table 2) along with absence/noticeable negative Eu, Nb and Ta anomalies in the REE and trace elemental patterns further strengthen the fact of insignificant crustal contamination. According to Zhang et al., (2008), the crustal contaminated magmas have high Th/Ce ratios, While the mantle derived magmas have low Th/Ce ratios (Sun and McDonough, 1989). Low Th/Ce ratio i.e. 0.02-0.07 of the syenites from the study area implies that their mantle source did not experience any crustal interference. When the nepheline syenites are plotted in the Petrogeny's residua system Hamilton and Mackenzie.1965 (Fig.4) they cluster towards the orthoclase region thereby denoting that these syenites have evolved from the alkaline magma, which is compositionally K-rich i.e. shoshonitic magma. The nepheline syenites are confined to the undersaturated, K-rich portion of the residua system, which indicates that their source magma is of K-rich and undersaturated nature.

Table 2. *Trace and REE (ppm) values of mafic and felsic rocks of Elchuru alkaline pluton*

S.No	1	2	3	4	5	6	7	8	9	10	11
Sample .No	EL16	EL (M)54	EL(M) 80	EL(M) 77	EL (M)76	EL22	EL(M) 65	EL12	EL (M)84	EL (K)40	EL8
Rock	Shnk	Shnk	Shnk	Malig	Malig	M.NSy	N.Sy	N.Sy	N.Sy	N.S.G	N.Sy
Co	59	68	62	53	46	3.2	2.4	32	3.2	4.9	NA
Cr	538	622	586	122	102	49	40	318	72	42	NA
Cu	32	42	37	36	28	3.6	4.2	28	22	18	NA
Mo	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	NA
Ni	148	189	162	52	47	4.3	3.1	92	5.3	7.5	NA
Pb	18	17.3	16.4	11	10	9.88	14.1	13	10.6	10	NA
V	178	192	180	186	128	7.6	2.8	176	8.3	6.9	NA
Zn	264	243	258	312	327	98	94	184	106	178	NA
Ba	1746	1942	1684	2846	2692	291	1389	2032	1729	1619	NA
Sr	1286	1146	1248	1863	1764	1879	1643	3769	1233	2386	NA
Ga	12	12	20	16	23	18	16	13	14	15	NA
Hf	6	6.7	5.38	8.4	7.9	4.67	4.42	5	8	6	NA
Rb	104	98	112	73	62	128	126	167	113	148	NA
Li	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	NA
Cs	1.7	0.86	1.4	0.69	0.72	0.59	0.8	3.4	1.3	0.67	NA
Y	28	23	27	49	37	24	20	30	15	12	NA
Sc	20	23	17	19	16	3.9	2.8	17	0.87	2	NA
Nb	73	92.7	70	133	138	92	80	126	96.2	112	NA
Ta	4.6	5.9	4.2	8.9	8.7	7.8	5.87	6	6.52	9.76	NA
Zr	234	226	264	332	370	187	166	282	106	112	NA
Th	7.6	9.5	7.9	7.2	6.87	9.7	7.9	14.8	6.86	7.15	NA
U	2.8	2.67	2	2.3	2.8	2.4	1.9	3	0.8	2	NA
La	101	92	74	249	178	148	95	153	68	58	44
Ce	198	182	139	435	325	296	172	279	135	98	96
Pr	20	18	14	39	31	29	17	27	13	9	9
Nd	74	67	52	136	114	107	58	92	45	28	31
Sm	15	13	11	22	20	20	12	16	8	5	5
Eu	4.2	3	3	6	6	6	4.5	4.6	2.2	1.2	1.5
Gd	11	8	8	17	13	15	7	11	6	4	4
Tb	1.6	1.1	1	2.4	1.9	1.5	1	1.5	0.7	0.5	0.5
Dy	6	5	5	9	8	7	4	6	3	2	3
Ho	1	0.9	0.8	1.6	1.2	1	0.7	1	0.5	0.2	0.5
Er	2.5	2.3	2	4	3.2	2.6	1.8	2.7	1.3	1.1	1.1
Tm	0.3	0.4	0.2	0.4	0.2	0.2	0.3	0.4	0.2	0.1	0.3
Yb	2.5	2	2	3.6	3	2.2	1.8	2.4	1.5	0.8	1.1
Lu	0.3	0.5	0.3	0.6	0.4	0.5	0.6	0.2	0.5	0.3	0.4
Rb/Cs	61.2	114	80	105.8	86.1	216.9	157.5	49.1	86.9	220.9	-
Th/Ce	0.04	0.05	0.06	0.02	0.02	0.03	0.05	0.05	0.05	0.07	-

Shnk*-Shonkinite,* ***Malig****-Malignite,* ***N.S.G*** *- Nepheline syenite gneiss,* ***M. Nsy*** *- Meso Nepheline syenite* ***N.Sy*** *- Nepheline syenite*

According to Hamilton and Mackenzie1965, the rocks whose composition is salic and fall within the K-rich part of the residua system, might have derived from an already undersaturated (K-rich) magma. Hence, here similar conclusions have been drawn for the Elchuru nepheline syenites that they are the products of fractional crystallization of a K rich hydrous basic alkaline magma, which has the compositional similarity with shonkinite and thereby indicating their potassic lineage. This parental K- rich hydrous basic alkaline magma underwent differentiation process and produced the magmatic residual liquid that crystallized as nepheline syenite at Elchuru. Besides the LREE enrichment in the shonkinites and nepheline syenites of the pluton, there is another mafic lithounit named malignite which also shows the predominance of LREE over shonkinites and nepheline syenites.

The Chondrite normalised REE patterns in the mafic and felsic rocks show a similar behavior, where they show enrichment in LREE and depletion in HREE with no significant negative Eu anomaly. The enrichment of the LREE is the main trait of alkaline rocks in general and the Elchuru alkaline rocks in particular. The enrichment of LILE and LREE and the absence of Nb depletion clearly demonstrate the emplacement history of these rocks conforming to rifting or within plate tectonic environments.

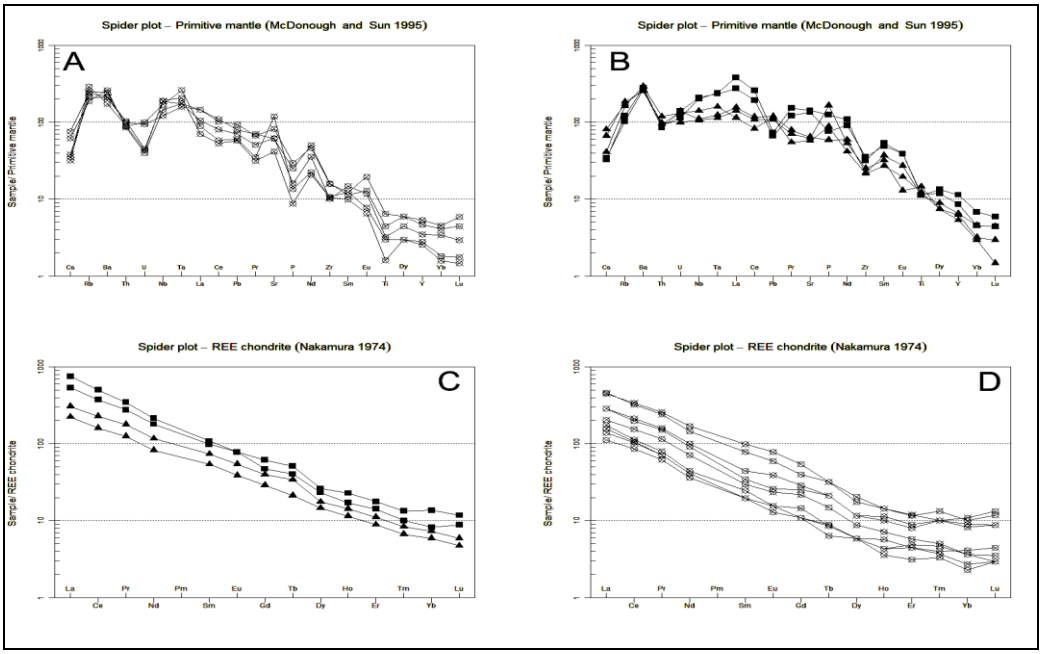


Fig.5*. Primitive mantle normalised trace elemental patterns for Nepheline syenite (A), Shonkinites & Malignites (B), normalised values are taken from (Sun and McDonough,1995). Chondrite normalised REE patterns for shonkinites & Malignites (C), Nepheline Syenites (D) REE normalised values are taken from Nakamura*

Conclusions

Elchuru alkaline pluton is a well known undersaturated alkaline intrusive of the Prakasam alkaline province (PAP), which shows the characteristic shoshonitic affinities. The petrographic and geochemical behavior of both mafic and felsic rocks of the pluton indicate that fractional crystallization is the significant process involved in their genesis. It is to be noted that the enrichment of alkalies, i.e. Na_2O and K_2O during the magmatic differentiation confirms that the feldspathoidal and feldspar fractionation during the evolution of the magma was very significant.

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