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Petrography And Rare Earth Element Geochemistry Of Pan-African Granites Of A Part Of Mikir Hills, NE India

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Abstract:
Petrography and rare earth element (REE) geochemistry of representative anorogenic granite samples of Pan-African origin from the Kathalguri-Lungsung-Lalpahar area in western Mikir Hills of NE India were analyzed in an attempt to determine their origin, evolutionary status and tectonic setting. Petrographic study indicates appearance of REE enriched accessory minerals like zircon, monazite, apatite, sphene, allanite, xenotime etc., thereby, forcing reasonably high absolute REE concentrations. Chondrite normalized REE patterns suggest richness in LREE (194-2138 ppm; av. 688.05 ppm) and low HREE content (27-65 ppm; av. 44 ppm). The LREE and HREE distribution patterns maintain consistent parallelism in the studied samples suggesting comagmatic origin, although, two samples, however, show minor deviation in cases of La and Eu values only. The ratios of Ce_N/Yb_N (7.66-35.35); La_N/Yb_N (3.18-16.67); La_N/Sm_N (2.72-5.27) and Tb_N/Yb_N (0.91-1.87) suggest differentiation and REE fractionation during magma production and derivation from mantle sources under variable degree of contamination with crustal material. Evaluated Eu/Eu* (0.26-0.91 av. =0.47) ratios over a consistent level indicate moderate but less fluctuating f_{O2} level of magma at the source.

Key words: Pan-African, Mikir Hills, LREE, HREE, differentiation, fractionation.

Introduction:

The extended Dizo Valley magmatic suite in the NW Mikir Hills Craton (MHC) of Assam (NE India) is a granite-greenstone terrain of Pan-African origin. The MHC forms a small protocontinental block of NE India, appears as a horst like body at the western edge of Upper Assam alluvium. It is yet to establish the tectono-magmatic evolution of the craton, however, suggestions are that the evolutionary trend of the craton is similar in many aspects with the rest of Indian Pan-African protocontinents viz., Dharwar, Singhbhum, Bhandara, Bundelkhand and Aravalli (Hussain and Ahmad, 2009). It is viewed that the protocontinents formed between 3.5-2.5 Ga, were welded and accreted together to generate the Mesoproterozoic (2.0-1.6 Ga) terrain of Indian Peninsula; paving the way of subsequently formed supercontinental assembly of Gondwana and Rodinia (Naqvi, 1985). The episodic (polyphase) magmatic activities were part of the protocontinental setup, producing both intrusive and extrusive rocks. Unlike certain reported Pan-African granites of India, the contemporary granites of MHC bear characteristic physical and chemical features; however, data on established chronology of scores of lithostratigraphic units of the craton are unavailable. The presently studied Kathalguri granites (Longitude $92^{o}52^{/}24^{//}$ E; Latitude $24^{o}22^{/}10^{//}$ N) are significant in few aspects: firstly, the granitoids are enriched in REE, more particularly rich in LREE but relatively low in HREE, although HREE content is characteristically higher than normal leucogranite and secondly, there is a greater concentration of REE bearing accessory minerals.

The granites of MHC at large have received poor research attention because of the poor accessibility, thick soil vis-à-vis vegetal cover and rough terrain condition. Earlier workers, viz, Mazumdar (1986), Ghosh et al., (1991) and Nandy (2001) studied the Neoproterozoic intrusive granites of adjacent Meghalaya Plateau. However, a few recent workers confirm I-type character of the Kathalguri and certain other granites of northern and western MHC (Rajaraman et al., 2008; Hussain and Ahmad, op cit.). The present paper highlights the petrography and rare earth element (REE) geochemistry to provide new data and discuss the evolutionary trend of magmatic rocks concerning their origin as a member of the breakaway segment of Pan-Africa.

Geological features:

The Kathalguri granite pluton has been identified as A- type, within plate granite of calc-alkaline nature, intruded into the mid Proterozoic 'Shillong Group' of metasediments and amphibolite hosts (Rajaraman et al., op cit.). It apparently bears the age of emplacement around 500±50 Ma (Hussain and Ahmad, op cit.), akin to those that occur in other proven Pan-African segments of India like the granite plutons of Kerala (740-550 Ma; Santosh and Drury, 1988); Tamil Nadu (637-395 Ma; Santosh et al., 2005); certain acid volcanics activity of Rajasthan (780-680 Ma, Rathore et al., 1999). The present opinion is that the contemporary granitoids of MHC including the studied one were originated due to tensional stress and thermal upwell related to the collision and extensional episodes of the "Gondwana Supercontinent" prior to the arrival of mantle pluming event of 'Kerguelen' (Ghosh et al, 2005). Incidentally, diapirism of magma through colder crust is documented here in this pluton by the common occurrence of partly or unassimilated larger volcanic bombs of host amphibolites with chilled margin within mass of granites. Although, the pluton covers only a tiny part of the terrain (MHC), but its conspicuous association with metasediments and other coarse grained non-porphyritic granitoids, amphibolites, dolerites and traps bear special significance (Fig. 1)

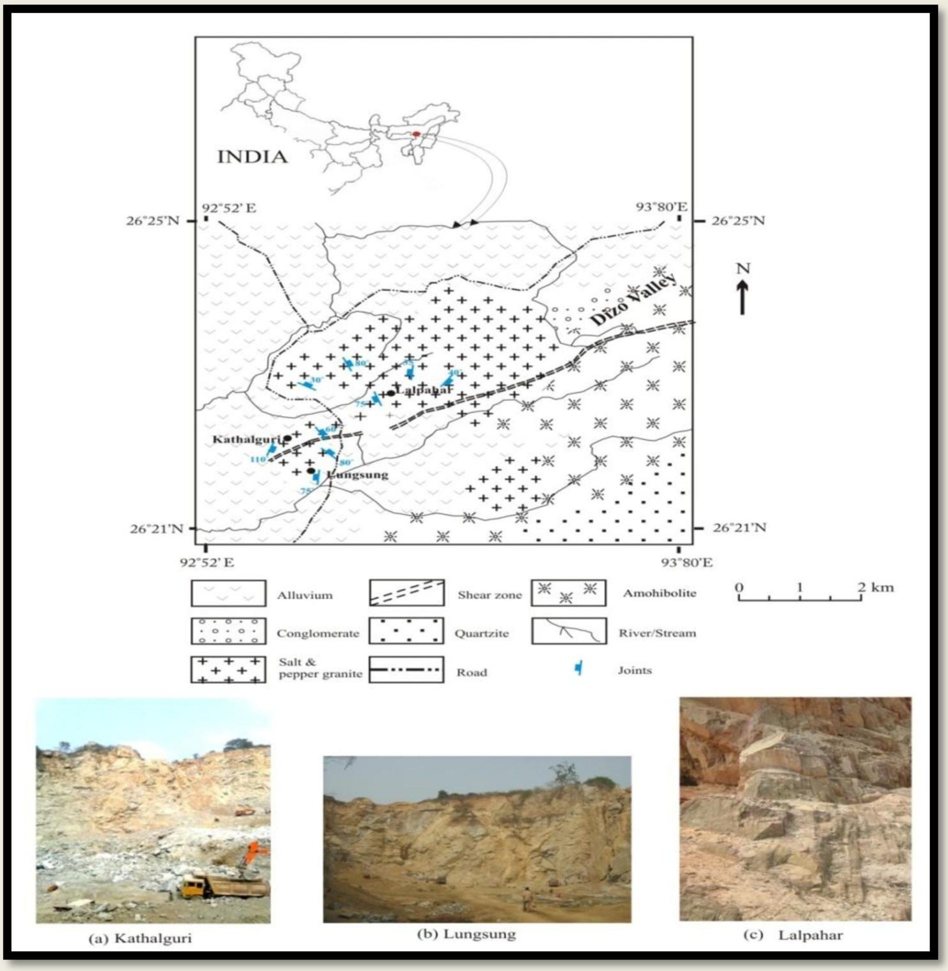

Fig.1. Geological map of the study area with field photographs of (a) Kathalguri, (b) Lungsung and (c) Lalpahar area.

Sampling and analytical methods:

Ten representative outcrop samples collected at random from two vertical sections each of about 100 mts heights were taken for thin section preparation and six samples for REE analysis. Petrographic studies were done under Leica DM 750P transmitted light microscope. Mineral identifications were based on optical characters. The trace elements were analyzed in a Perkin Elmer Sciex DRC II inductively coupled Plasma-Mass Spectrometer (ICP-MS) at National facilities of the National Geophysical Research Institute (NGRI), Hyderabad (India). For the analysis, 100 mg of powdered samples of each were dissolved in acid mixture ($HF+HNO_3+HClO_4$) in an open vessel and heating on a hot plate at atmospheric pressure. Results of REE determined were having an accuracy of 20- 30 % Relative Standard Deviation (RSD) in an unknown sample.

Results:

Petrography

The granitoids of Kathalguri area are leucocratic, inequigranular, hypidiomorphic, medium to coarse grained, salt pepper coloured, non-porphyritic, mostly hypersolvus; essentially composed of quartz (av. 51.17%), K-feldspar (av. 30.40%), biotite and muscovite (av. 11.6%), plagioclase (av. 8.5%) and common accessories are zircon, allanite, sphene, xenotime, apatite etc. (Table 1; Fig. 2). The Streckeisen (1973; Fig. 3) plot as per IUGS classification suggest true granitic nature for the rock type.

Preservation of primary magmatic textures viz., perthitic intergrowth and myrmekitic textures are common; sericitization is often noticed within feldspars; abundant mineral inclusions of volatile phases e.g., needle-shaped apatites in biotite and/or feldspar are common with random orientation. Biotites often show pleochroic halos; good occurrences of allanite with common metamict character are some of the important features characteristic of the Kathalguri granites. Evidences of magmatic differentiation with induced potash and silica metasomatism are evident, although, potash metasomatism is a late stage differentiation phenomenon during which plagioclases are replaced by potash feldspar.

	5KA2	5KA3	DKA 1	KG1	KG2	KG3	KG 7	KG 8	KG 9	KG 10
Quartz	43.95	51.66	48.10	37.5	48.02	43.20	37.60	40.59	39.86	41.25
Alkali feldspar	19.78	22.42	27.96	34.38	14.12	22.22	38.98	29.52	20.20	19.25
Plagioclase	15.38	15.60	10.07	12.5	19.77	17.28	16.71	9.22	15.55	21.50
Muscovite-Biotite	7.69	6.82	11.19	9.38	14.12	13.58	5.57	16.60	18.90	12.15
Accessories	2.82	3.5	2.68	4.13	3.95	3.36	1.14	4.03	4.75	5.34
Total	89.62	100	100	98.28	99.98	99.64	100	99.96	99.26	99.49

Table 1. Modal composition (vol%) of Kathalguri granite with accessories.

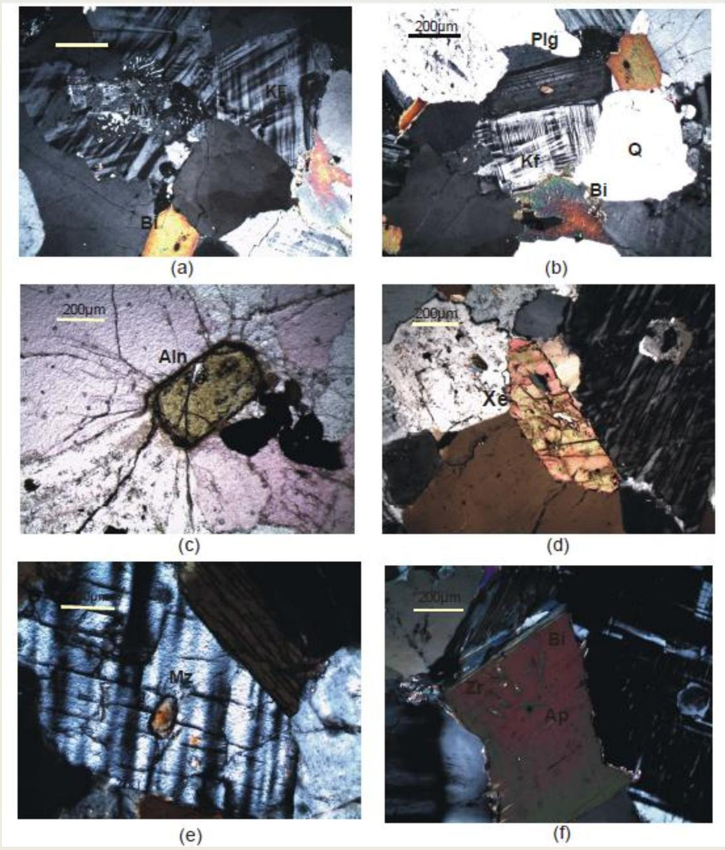

Fig. 2. (a) Biotite(Bi) showing halo with myrmekite(Myr) texture (b) Hypidiomorphic texture (c) Allanite showing metamict texture (d) Xenotime (Xe)shows interlocking texture, (e) Monazite (Mz), (f) Biotites are enriched in volatile phases like zircon (Zr) and apatite (Ap) crystals.

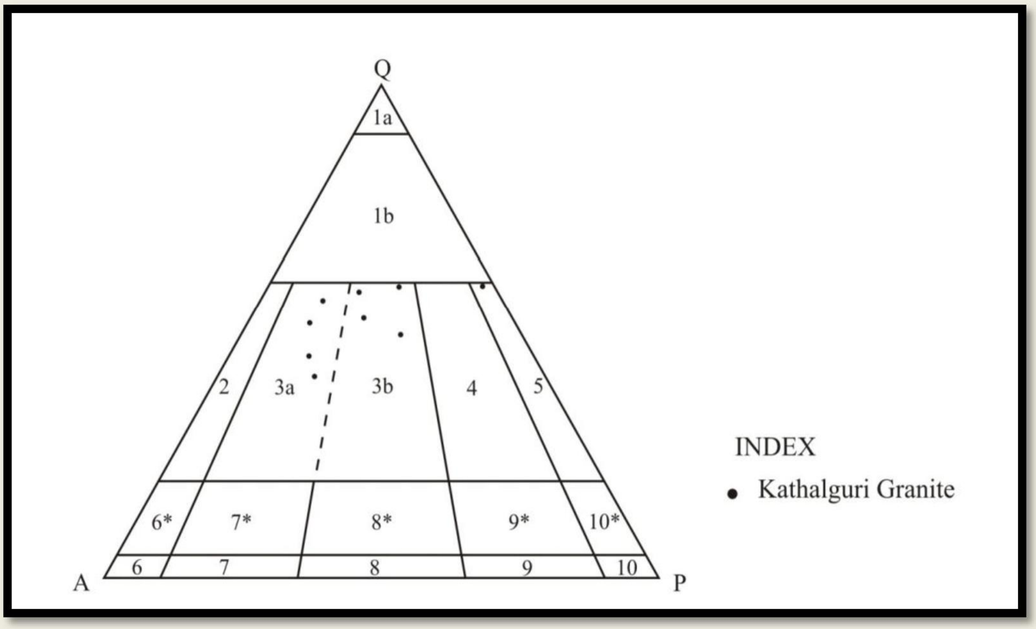

Fig. 3. QAP plot of Kathalguri granitoids (after Streckeinsen, 1973). Effective fields are Granite (3a and 3b); hybridized sample falling in field 5 (tonalite) (Index: Q= Quartz; A= Alkali feldspar and P= Plagioclase).

Rare Earth elements

The Rare Earth Elements (REE) geochemistry of studied granites is presented in Table 2. There is an overall REE enrichment (240.8-2202.5 ppm; av. 731.64 ppm) compared to the average of about 250 ppm recordable in normal granites (Emmermann et al., 1975). Abundance or depletion of REE is stated to be sensitive to the fractionation pattern among igneous rocks so that a wide variety of patterns are observed (Fairbridge, 1972). The chondrite normalized REE data as per the Nakamura (1974) scheme for the present study maintains higher slope in LREE distribution; possessing customary enrichment in La (42.70-140.7 ppm) and Ce (91.94-1848.5 ppm); Pr ranges in between 10.03-32.5 ppm; Nd (39.74- 128.1 ppm) while Sm varies from 9.67- 22.4 ppm; Tm content is low (0.29-1.2 ppm); the Yb content (2.98–13.3 ppm) does not support depletion in HREE, Ce, Pr, Nd and Sm but maintain slopes downward toward a lower wavy HREE pattern with moderate to strong negative Eu anomalies (Fig. 4.) as can be found in many calc-alkaline Pan-African granites (Ukaegbu and Beka, 2008). A general abundance of LREE but depletion of HREE with higher values of La, Ce, Pr, Nd and other rare earth elements indicate partial melting of mantle peridotite producing basaltic fluid with enriched value of these rare earth elements. Contrary to this, Eu, Yb and Tm have similar geochemical characteristics hence, exhibit similar distribution pattern. Strong negative Eu anomaly is indicative of early removal of plagioclase during fractionation, thereby, tend towards lower Europium (Eu) concentrations (Allégre et al., 1978). The concentration of Eu in the present study with an average concentration of 1.79 ppm, however, is compatible with the average leucogranites commonly found of elsewhere. The Eu/Eu* ratio is a measure of depletion in Eu content of crystallizing magma and in turn an indicator fo_2 of crystallizing magma (Davis and Hawkesworth, 1994); the value extracted in this work (0.26-0.91; av.= 0.45), indicate moderate to higher ratio, documenting fo_2 enriched environment of crystallizing magma.

The ratio of $(La/Sm)_N$, $(La/Yb)_N$, $(Ce/Yb)_N$ produces variable but higher levels of REE fractionation and differentiation of derived magmatic fluid. Inter-element relationships of the granites with positive correlations in La-Ce, La-Pr, Ce-Pr and Ce-Nd (Fig. 5A, C, D, E), refer to a plagioclase guided fractionation scheme. The other inter-element relationships viz., La-Sm, Nd-Gd and Pr-Sm (Fig.5B, F, G) show scattering of data points, indicating magma contamination during ascent.

REE	5KA2	KG1	5K3	KG2	DKA1	KG3	Average n=6	Leucogranite#
La	140.7	42.70	127.5	74.29	125.0	72.01	97.03	84.0
Ce	298.5	91.94	1848.5	160.78	258.9	153.02	468.52	85.0
Pr	32.5	10.03	29.6	18.07	26.2	16.46	22.14	9.8
Nd	128.1	39.74	112.1	72.02	95	64.43	85.23	55.0
Sm	22.4	9.67	20.0	11.63	14.6	11.90	15.03	8.5
Eu	1.9	1.29	1.9	3.0	1.1	1.60	1.79	1.7
Gd	18	8.88	15.5	8.77	12	9.70	12.14	6.7
Tb	2.6	1.89	2.6	1.19	1.6	1.54	1.90	1.6
Dy	15.3	15.32	18.2	6.80	9.78	9.85	12.54	6.0
Ho	1.6	1.80	2.1	0.73	1.0	1.11	1.39	2.2
Er	5.5	6.33	7.9	2.44	3.6	3.77	4.92	3.8
Tm	0.7	0.89	1.2	0.29	0.5	0.49	0.68	0.66
Yb	7.2	8.95	13.3	2.98	5.0	5.08	7.08	5.4
Lu	1.2	1.37	2.1	0.48	0.8	0.83	1.13	0.45
∑REE	676.2	240.8	2202.5	363.47	555.08	351.79	731.64	105.0
Y	55.0	95.95	119.80	37.00	86.90	59.55	75.70	46.0
∑REE+Y	731.2	336.7	2322.3	400.47	641.98	411.35	807.33	151.0
La/Ce	0.48	0.46	0.069	0.46	0.48	0.47	0.403	0.54
Eu/Gd	0.10	0.14	0.12	0.34	0.09	0.16	0.16	0.03
∑LREE	622.2	194.1	2137.7	336.8	519.7	317.8	688.05	81.9
∑HREE	54.0	46.72	64.8	26.68	35.38	33.97	43.60	23.38
(Eu/Eu*)	0.29	0.33	0.26	0.43	0.91	0.46	0.45	0.69
(La/Yb)N	13.03	6.39	16.67	3.18	16.61	9.45	10.89	10.37
(La/Sm)N	3.86	3.92	5.27	2.72	3.93	3.72	3.90	6.08
(Ce/Yb)N	10.54	35.35	13.17	2.61	13.72	7.66	13.84	4.00
(Tb/Yb)N	1.69	0.91	1.49	0.99	1.87	1.42	1.40	1.386

Table 2: Rare-earth element compositions and ratios in the studied granites (in ppm)

#Rare earth abundances of leucogranite (in ppm; after Fairbridge op. cit.)

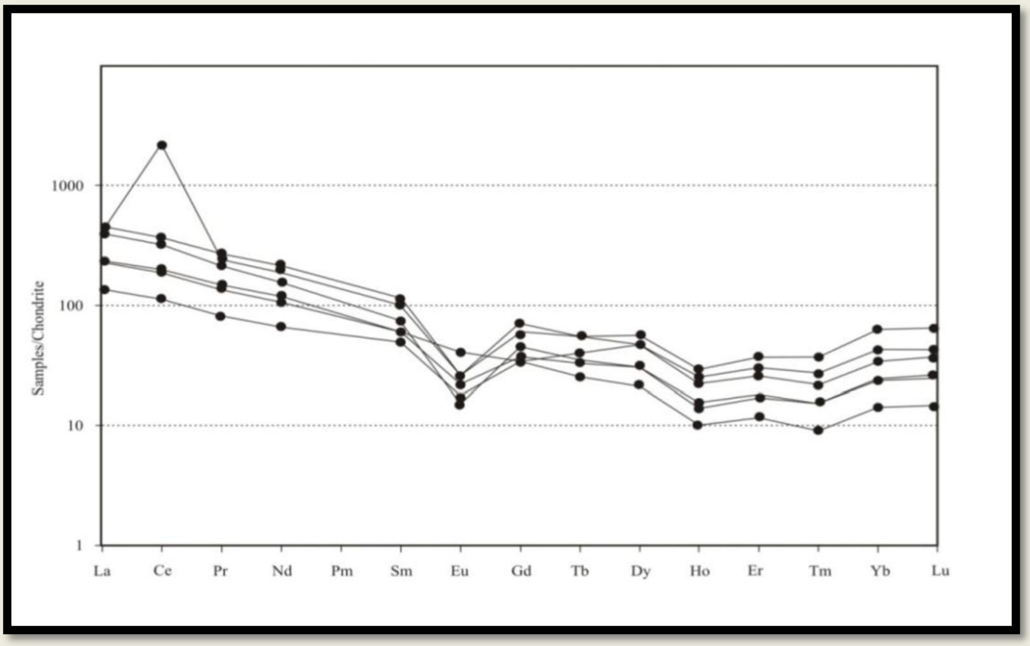

Fig. 4. Chondrite normalized REE pattern of the studied granites

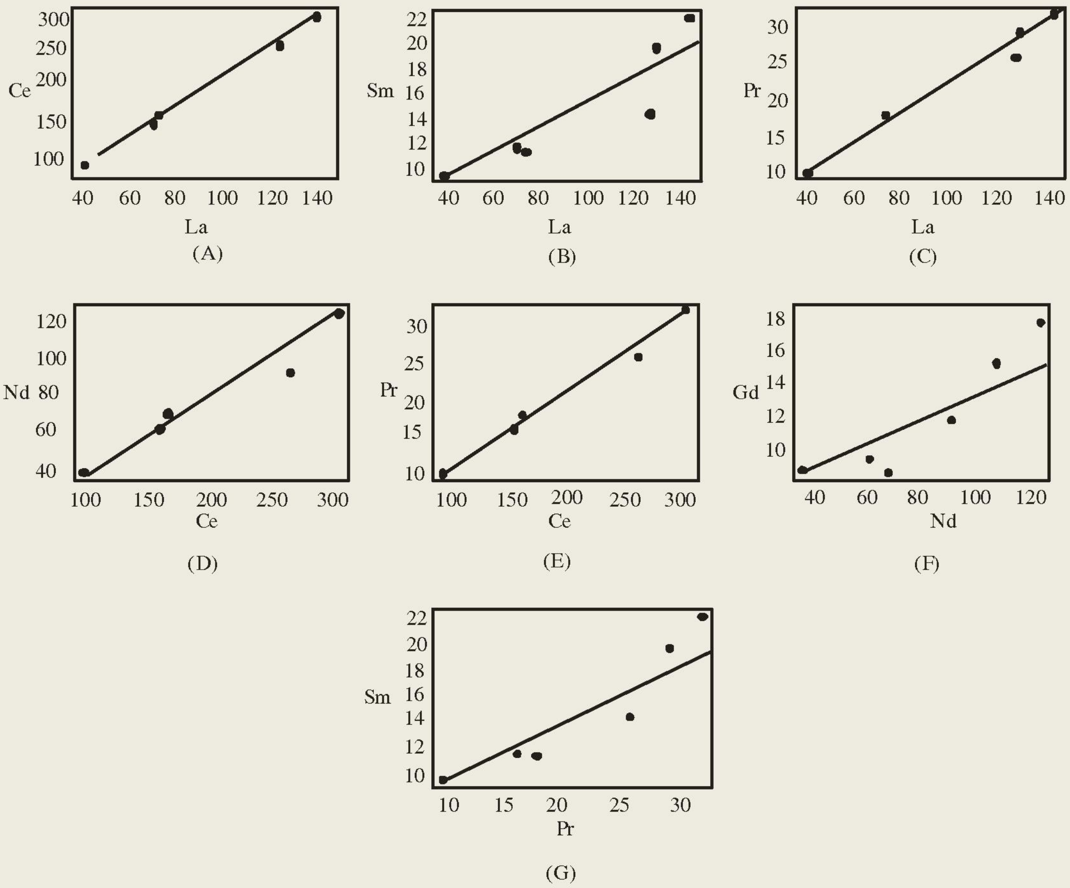

Fig. 5. Inter-element variation diagrams of (A) La-Ce, (B) La-Sm, (C) La-Pr, (D) Ce-Nd, (E) Ce-Pr, (F) Nd-Gd and (G) Pr-Sm of the Kathalguri granites. Some amount of scattering is noticeable in (B, F, G) probably due to crutal contamination during magmatic evolution.

Discussion:

The granites of Kathalguri pluton bear enough textural evidences of magmatic origin. Acicular or needle-shaped apatite inclusions in quartz and feldspar indicate higher degree of magmatic differentiation with occasional introduction of potassium and silica metasomatism. Potash metasomatism is characterized by the replacement of plagioclase by K-feldspar during the late stages of magmatic differentiation. The K-metasomatism, therefore, can reach deeper into the crystal structure, thereby, increasing its effect. Complete to near complete replacement of plagioclase takes place, leading to the formation of wartlike myrmekite (Fig. 2a) in places where the replacement remains incomplete. Occurrences of abundant mineral inclusions in primary minerals with random orientation are common. Biotites showing pleochoric halos are also common (Fig. 2b). Geochemical signature of the pluton is such that the presence of accessory mineral phases like apatite, allanite, xenotime, monazite, apatite etc. (Fig. 2c-f) contributes to the enriched value of REE (max. 2205 ppm) in these rocks. Several different types of granites in the present study have been distinguished viz., apatite type-enriching La-Nd; monazite type- La-Sm enriched and allanite type- La-Nd enriched. The presence of apatite enhances the La+Ce contents; high $(La/Yb)_N$ ratios are equated with the presence of LREE rich phases such as monazite and apatite or due to the low abundances of HREE rich mineral phases such as garnet as suggested by Gromet and Silver, (1983). The negative Eu anomaly is a yardstick of classical differentiating magma, involving removal of plagioclase feldspar from the parent magma. Igneous differentiation series eventually tend towards lower Europium (Eu) content. The concentration of Eu in the present study with an average concentration of 1.79 ppm is, however, compatible with the average of leucogranites. It is viewed that granites having higher fractionation and differentiation are enriched in LREE and consequently deficient in HREE (Fairbridge, op cit). Positive correlations between inter rare earth elements for the studied Kathalguri suggest similarity with the Pan-African granites of Obudu Plateau of SE Nigeria (Ukaegbu and Beka, op cit.). The present observation of LREE enrichment is characteristics of crust and calc-alkaline rocks as suggested by O'nions and Pankhurst (1974) for similar types of granite.

Conclusions:

The petrographical-geochemical studies carried out on the leucogranites of Kathaluri area display a complex magmatic origin of the granites with their derivation from mantle or near mantle region. The REE profile show general enrichment both in LREE and HREE content. However, relative enrichment of light REE accompanied by depleted flat to inverted bow- shaped HREE patterns with a sharp negative inflection at Eu, which is a characteristic of typical Pan-African granite. The LREE pattern of present study is due to the enrichment in La-Sm content which is in turn an indicator of higher differentiation of melt originally derived due to the partial melting of mantle peridotite producing basaltic melt. Crystallization and differentiation ultimately led to an added volatile percentage through production of REE bearing mineralogy like apatite, zircon, sphene, monazite etc.

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