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Radioelement geochemistry of alkali granites of the Kerala region, south-west India

M SANTOSH and K VIJAYA KUMAR
Centre for Earth Science Studies, P. B. 2235, Sasthamangalam, Trivandrum 695010, India

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Abstract. Th, U and K abundances in four alkali granites of the Kerala region, south-west India, are presented. The plutons show high radioelement levels, correlatable with those of alkali granites in other regions. The nature of variation is consistent with the correlation of Th and U with accessory phases like sphene, zircon, allanite, apatite and monazite. A geochronologic correlation is also observed between the alkali granites and the Th-bearing beach placers of the region. The petrogenetic features of the alkali plutons, their taphrogenic association, Pan-African affiliation and high Th/U levels suggest that the alkali plutons are favourable locales for radioelement exploration.

Keywords. Radioelement geochemistry; alkali granites; geochronologic correlation; radioelement exploration.

1. Introduction

The Kerala region forms a significant portion of the Indian shield and the south-western part of the continental margin. The region comprises largely Precambrian crystallines including charnockites, khondalites and migmatitic gneisses. Recent studies reveal the occurrences of a number of granite and syenite intrusives representing a Late Precambrian-Early Paleozoic magmatic regime (Santosh and Nair 1983a; Santosh and Thara 1985; Nair and Santosh 1984). The spatial relationship of the intrusives with regional fault-lineaments suggests a taphrogenic association (Santosh and Nair 1983b; Nair *et al* 1983). Among the intrusives are a group of granites which show alkaline character and unique petrochemical features (see for example, Nair and Santosh 1984). Even though general geochemical studies of these alkali granites have been attempted, their radioelement abundance has not been reported.

The present paper documents the abundances of Th, U and K in the alkali granites.

2. The alkali granites

The alkali granites of the region are represented by E-W elongated plutons near Chengannoor in Alleppey, Ambalavayal in Wynad, Munnar in Kottayam and Peralimala in Cannanore districts. These intrusives are spatially related to major fault-lineaments of the region (figure 1). All of them are emplaced within Precambrian basement rocks (figure 2), with which they maintain sharp contacts. Each pluton is exposed over an area of 25–50 km^2. Their general geologic characters, including age, are summarised in table 1.

All are massive, pink, medium to coarse grained rocks composed of interlocking

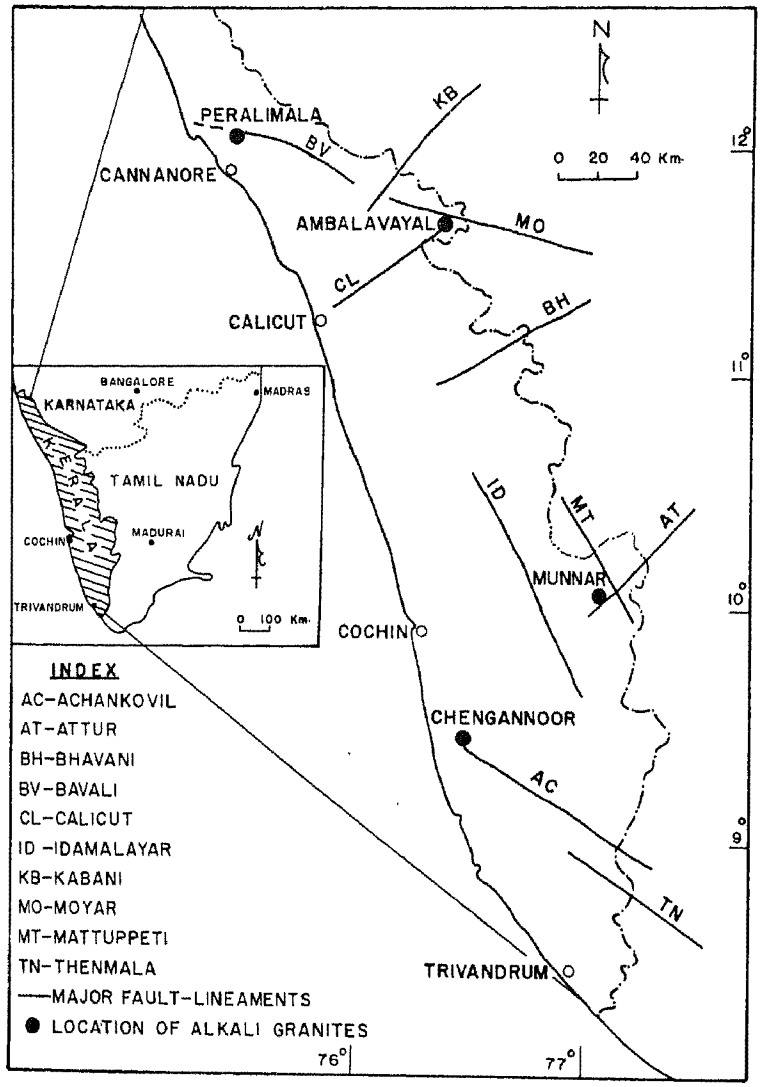

Figure 1. Lineament map of the Kerala region showing the location of the alkali granites.

quartz and feldspar. In thin sections, they show a general hypidiomorphic granular texture with alkali feldspar as the dominant constituent. The perthitic phase in the K-feldspar grains range from micro and string perthite in Ambalavayal, Munnar and Peralimala to coarse mesoperthite in Chengannoor. Plagioclase is subordinate and shows a range in composition of $Ab_{95}An_5$ in Ambalavayal to $Ab_{85}An_{15}$ in Chengannoor. It generally occurs as minor laths showing lamellar twinning. Two-feldspar geothermometry based on the Ab-component in coexisting alkali feldspar-plagioclase pairs give an estimate of 704–740°C for the Ambalavayal granite (Santosh 1985a). The modal *Q-A-P* proportions of the granite correspond to a range between quartz alkali feldspar granite and normal granite as per Streckeisen's scheme (1976).

The major mafic mineral in all the granites, except Munnar, is greenish pleochroic

Table 1. General geologic and petrologic data for the alkali granites of Kerala.

Granite	Radiometric age (10^6 yr)	Country rock	Associated fault-lineament	Average modal composition: Quartz	Alkaline feldspar	Plag.	Hb/ Biot.	Others
Chengannoor	550[a]	Charnockite	Achankovil	24·31	61·30	7·00	2·52	4·87
Ambalavayal	595[b]	Biotite gneiss	Moyar and Calicut	31·67	27·10	30·74	4·89	5·60
Munnar	740[c]	Migmatitic gneiss	Attur	21·53	60·32	12·06	3·29	2·80
Peralimala	n.d.	Migmatitic gneiss	Bavali	25·95	57·90	7·29	6·88	1·98

[a]after Soman *et al* (1983); [b]after Santosh *et al* (1985); [c]after Odom (1982); n.d.— not determined; Plag.— plagioclase; Hb.— hornblende; Biot.— biotite.

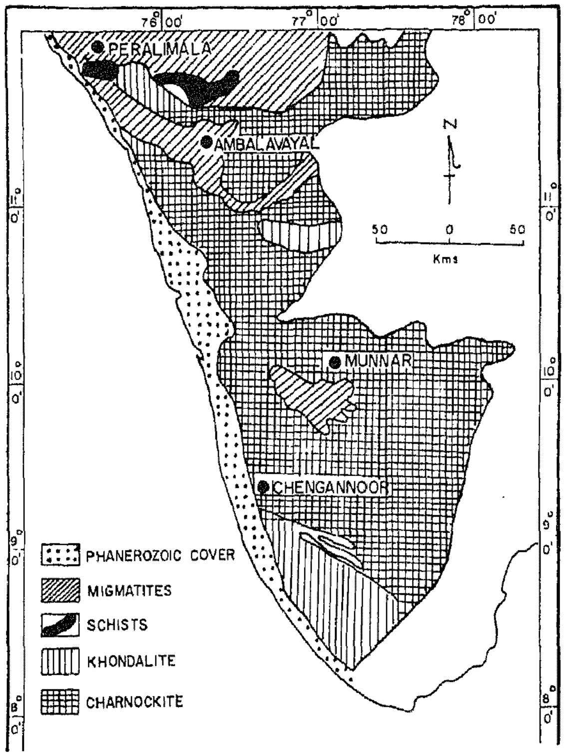

Figure 2. Generalised geological map of the Kerala region showing the location of the alkali granites.

hornblende. In Munnar, biotite forms the dominant mafic constituent, whereas biotite is found in subordinate amounts in the others. Sphene and apatite are ubiquitous accessories in all the granites. Other accessories include zircon, epidote, allanite, calcite and Fe-Ti oxides, Euhedral grains of monazite occur as minor inclusions in biotite and

Table 2. Average major element contents of the alkali granites.

Oxide	Chengannoor	Ambalavayal	Munnar	Peralimala
SiO_2	69·39	74·51	71·74	64·53
Al_2O_3	15·65	13·67	13·84	18·0
TiO_2	0·38	0·16	0·24	0·08
Fe_2O_3	2·68	0·94	1·68	0·93
FeO	1·05	1·87	0·84	0·65
MnO	0·03	0·02	0·02	0·05
MgO	1·62	0·42	0·66	0·62
CaO	0·53	1·44	1·70	1·48
Na_2O	3·48	3·01	2·56	3·11
K_2O	4·19	3·64	5·66	9·68
P_2O_5	0·08	0·01	0·02	0·05

Data sources: Chengannoor, after Santosh and Nair (1983a); Ambalavayal, after Nair *et al* (1982); Munnar, after Nair *et al* (1983) and Peralimala, after Nair and Santosh (1984).

hornblende. Such inclusions are especially common in Chengannoor and Ambalavayal granites. Zircon, monazite and allanite grains frequently exhibit metamict texture.

The average major element compositions of the alkali granites are given in table 2. Moderate variation in SiO_2 and Al_2O_3 levels, sympathetic variation of alkalies and alumina, higher alkali content and pronounced depletion of FeO^t, MgO, TiO_2 and P_2O_5 with increasing differentiation are typical geochemical characters of these alkali granites. In the $\log_{10}K_2O/MgO$ vs. SiO_2 diagram (Rogers and Greenberg 1981), the plots of the granites fall mainly in the field delineated for alkali granites. Petrochemical features suggest that the alkali granites were derived from partial melts generated at mantle depths as a probable response to crustal distension and mantle degassing prior to the rifting of the continent (Santosh and Nair 1983b; Nair and Santosh 1984).

3. Abundance of Th, U and K

Fresh representative samples of the alkali granites were collected, mainly from working quarries. Seven samples from Chengannoor, ten from Ambalavayal, five from Munnar and twelve from Peralimala were selected for the present study. The samples were crushed and pulverized to -200 ASTM mesh and were analysed for equivalent U and Th using a ECIL single channel analyser (SC 604 B) coupled to a NaI (Tl) detector and calibrated using natural standards. K was analysed by flame photometry.

The analytical results are given in table 3, along with Th/U ratios, $Mg/Mg+Fe^t$ levels, SiO_2 values and mean and standard deviation for each pluton. Th, U and Th/U levels of the alkali granites are compared with those of similar granites from other regions in table 4.

3.1 *Thorium*

The mean thorium values of Chengannoor (41·4 ppm), Ambalavayal (21·6 ppm) and Munnar (23·8 ppm) are considerably higher than the average for granites (18 ppm; Rogers and Adams 1969). However, they are closely comparable with the generally high Th values exhibited by alkali granites of other regions as compiled in table 4. Rogers *et al* (1978) observe that Pan-African granites are Th-rich. In this regard, it is significant to mention that the beach placers in the western coastal tract of Kerala are rich in Th-bearing minerals, the probable provenances of which are the granite and syenite bodies as well as the rare metal and rare earth bearing pegmatites of the region (Santosh 1984; Soman *et al* 1983). This observation is substantiated by the accessory mineral assemblages in the plutons. Also, the ages reported for monazite (600×10^6 yr; Holmes 1955) and zircon (700×10^6 yr; Parthasarathy and Sankardas 1976) from the beach sands are correlatable with the ages of the plutons. Th shows inhomogeneous distribution in each pluton, with large standard deviation (SD) values. Thus, Th levels in Chengannoor show a range of 7–130 ppm (SD = 42·4), in Ambalavayal from 10 to 41 ppm (SD = 10·96), in Munnar from 6 to 42 ppm (SD = 17·01) and in Peralimala from 3 to 25 ppm (SD = 6·9).

3.2 *Uranium*

The mean uranium contents of Chengannoor (10·29 ppm), Ambalavayal (9·7 ppm), Munnar (8 ppm) and Peralimala (8·08 ppm) are higher than for usual granite (4 ppm,

Table 3. Radioelement abundance and other salient geochemical characters of the alkali granites of Kerala.

	Chengannoor								
	CR-1	CR-2	CR-4	CR-5	CR-6	CR-7	CR-8	Mean	SD
Th	7	11	26	20	130	53	41	42·40	41·14
U	2	3	4	3	31	18	11	10·29	10·83
Th/U	3·5	3·7	6·5	6·7	4·2	2·9	3·6	4·44	1·52
K	3·65	2·64	3·41	2·71	2·71	5·02	3·58	3·39	0·84
SiO_2	66·13	71·21	70·89	68·42	69·80	68·17	73·20	69·69	2·33
Mg/Mg + Fe^t	0·31	0·28	0·35	0·25	0·27	0·22	0·23	0·27	0·05

	Ambalavayal											
	AL-1	AL-2	AL-3	AL-6	AL-10	AL-14	AL-15	AL-23	AL-25	AL-35	Mean	SD
Th	15	11	16	10	19	33	41	36	16	19	21·6	10·96
U	8	8	8	4	4	24	6	15	6	14	9·7	6·25
Th/U	1·9	1·4	2	3·5	4·8	1·4	6·8	2·4	2·7	1·4	2·73	1·75
K	3·79	3·17	3·48	4·63	3·76	3·89	3·27	3·77	3·11	3·02	3·59	0·49
SiO_2	72·46	73·88	73·17	74·03	73·58	72·87	74·67	74·52	71·30	73·86	73·43	1·02
Mg/Mg + Fe^t	0·14	0·09	0·08	0·18	0·14	0·10	0·07	0·08	0·13	0·13	0·11	0·15

	Peralimala													
	PM-1	PM-2	PM-3	PM-4	PM-5	PM-6	PM-7	PM-8	PM-9	PM-10	PM-11	PM-13	Mean	SD
Th	6	9	13	25	9	7	21	5	5	4	7	3	9·5	6·9
U	5	15	3	8	13	7	2	7	10	10	7	10	8·8	3·8
Th/U	1·2	0·6	4·3	3·1	0·69	1·0	10·5	0·7	0·5	0·4	1·0	0·3	2·02	2·93
K	8·57	8·69	8·92	7·48	8·98	8·12	8·87	7·75	8·58	8·98	6·0	9·10	8·34	0·90
SiO_2	63·71	64·55	64·29	63·96	66·10	63·48	65·32	63·09	63·30	66·24	63·46	66·86	64·53	1·29
Mg/Mg + Fe'	0·24	0·23	0·22	0·28	0·15	0·25	0·11	0·27	0·26	0·17	0·31	0·13	0·22	0·06

	Munnar						
Th	MR-4	MR-28	MR-34	MR-35	MR-36	Mean	SD
Th	42	42	13	16	6	23·8	17·01
U	3	7	4	14	12	8·0	4·85
Th/U	14	6	3·3	1·1	0·5	4·98	5·49
K	4·79	3·83	5·19	5·27	4·05	4·61	0·64
SiO_2	71·47	71·18	72·72	71·35	71·43	71·68	0·70
Mg/Mg + Fe'	0·22	0·22	0·17	0·43	0·24	0·26	0·10

Major element data of Ambalavayal granite from Santosh (1983, unpublished data) and other granites from references listed under table 2. SD-standard deviation.

Table 4. Th, U and Th/U values of the alkali granites of Kerala region compared with those from other regions.

	CR	AL	MR	PM	P-2	P-7	S-6013	S-6015
Th	42·40	21·60	23·80	6·90	10·0	32·0	21·20	50·0
U	10·29	9·70	8·0	3·80	5·0	6·30	3·90	5·50
Th/U	4·44	2·73	4·98	2·93	2·0	5·08	5·44	9·09

	SA	HR	116A	34R/B	28B	NANTB
Th	13·0	14·0	12·0	23·0	9·0	27·0
U	4·0	4·0	3·0	3·0	2·0	4·0
Th/U	3·25	3·50	4·0	7·67	4·5	6·75

CR—Chengannoor; AL—Ambalavayal; MR—Munnar; PM—Peralimala; P-2 and P-7—Chamundi granite (Reddy *et al* 1983); S-6013 and S-6015—Arsikere granite (Reddy *et al* 1983); SA— average of alkali granites of Arabian Shield (Drysdall *et al* 1984); HR—alkali granites of central Hijaz region, Arabia (Jackson *et al* 1984); 116A, 34 R/B and 28 B—alkali granites of Labrador (Collerson 1982); NANTB— alkali granites of Lleyn Peninsula, North Wales (Croudace 1982).

Rogers and Adams 1969). Wilson and Akerblom (1982) observe that high U contents are characteristic of alkali granites. This is substantiated by the general correlation between U values of the alkali granites with similar granites from other regions (table 4). Uranium also shows inhomogeneous distribution like Th, yielding high SD values like 10·83 for Chengannoor and 6·25 for Ambalavayal. In Munnar and Peralimala, the inhomogeneity is less pronounced (SD = 4·85 and 3·80 respectively).

3.3 *Th/U ratio*

Even though Th and U show wide variation in their distribution (figure 3), the average Th/U ratios lie in a limited range of 1·52 to 5·49, comparable with similar values for alkali granites elsewhere (table 4). The highest variation is exhibited by Munnar with Th/U ranging from 0·5 to 14, whereas Chengannoor shows the least variation (SD = 1·52). In general, alkali granites show higher Th/U ratios as compared to normal granites, where the average is only 4 (Rogers and Adams 1969).

3.4 *Potassium*

The average K contents of Ambalavayal (3·59 %), Munnar (4·6 %) and Peralimala (8·34 %) are higher than the clarke of 3·6 % for normal granites (Rogers and Adams 1969), but comparable with the high K-content of alkali granites in other regions (Rogers and Greenberg 1981). The K-rich nature is a common characteristic of the alkaline plutons in the Kerala region, which, together with the trace element characters suggest magma derivation by partial melting of a K-enriched, Rb-depleted deep crustal

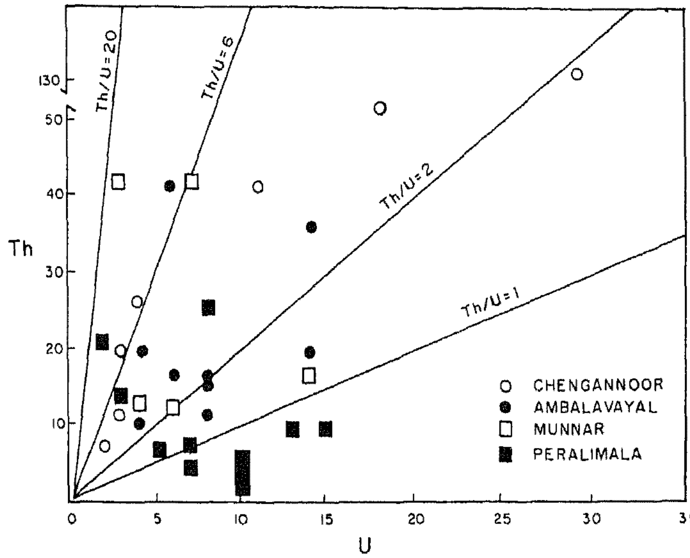

Figure 3. Th vs U plots.

or upper mantle source (*cf.* Nair and Santosh 1984; Santosh and Thara 1985). There is a consistent homogeneity in the distribution of K in individual plutons yielding low standard deviation values (0·49–0·90).

4. Discussion

Plots of Th, U and Th/U with respect to SiO_2 (figure 4) and K (figure 5) indicate a poor correlation. Studies by other workers (e.g., O'Conner *et al* 1982) have also shown weak correlation between U and Th with these major elements. However, plots against $Mg/Mg + Fe^t$ indices (figure 6) exhibit definable trends of variation. Th and U tend to concentrate (except the Th depletion in Munnar) towards lower $Mg/Mg + Fe^t$ values, consistent with an enrichment in the radioelement abundance with increasing fractionation. The trends are similar to those obtained by O'Conner *et al* (1981) for Carrigmore complex. O'Conner *et al* (1982) observe strong correlation of U and Th with FeO and MgO. The dependence in the distribution of radioelements with $Mg/Mg + Fe^t$ relates to the higher modal content of hornblende, biotite and other accessories in these alkali granites and testifies to the significant role played by ferromagnesium minerals in the fractionation processes (*cf.* Nair *et al* 1983). Inter-element correlation and fission-track results presented by various workers (O'Conner *et al* 1981, 1982) indicate that the radioactive elements are mainly bound in restite accessory phases like zircon, sphene, apatite, allanite and monazite. The ubiquitous occurrence of these accessories in the alkali granites possibly account for the higher levels of Th and U. This is further established by the correlation between the averaged total of accessories and the average abundances of U and Th, signifying that the U and Th in these granites are mainly locked up in the accessory minerals. Higher Th-content as compared to U is noted to be a common feature of these granites, yielding high Th/U ratios. Rogers *et al*

(1978) suggest that there is a preferential release of U relative to Th from the mantle into the derived melt during partial melting. U is released from the mantle not only into the magma but also directly into the volatile phases. Petrochemical and tectonic studies of the alkaline plutons suggest their derivation from partial melts generated in the mantle (Santosh and Thara 1985). An intrinsic association of volatiles with the petrogenesis of these plutons is also suggested (Nair and Santosh 1984). Fluid inclusion studies on the alkaline plutons (Santosh 1985b) and related ore mineralization (Santosh 1984) also indicate that volatiles played a significant role. A taphrogenic control over the generation and emplacement of the alkali granites with the fault-lineaments acting as conduits for volatile transfer from the upper mantle is also deduced (Santosh and Nair 1983b; Santosh 1985b) This together with the common occurrence of Th-bearing

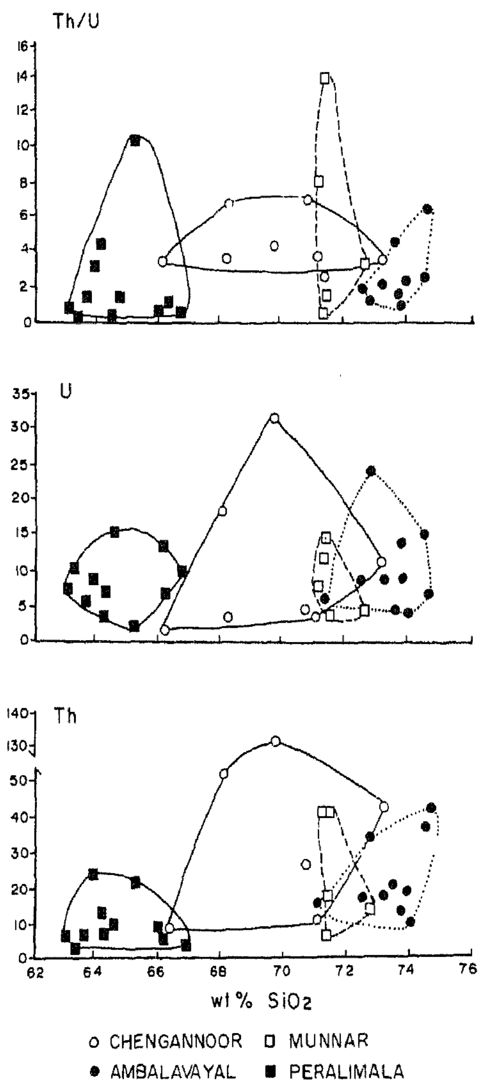

Figure 4. Th, U and Th/U vs SiO_2 plots of the alkali granites.

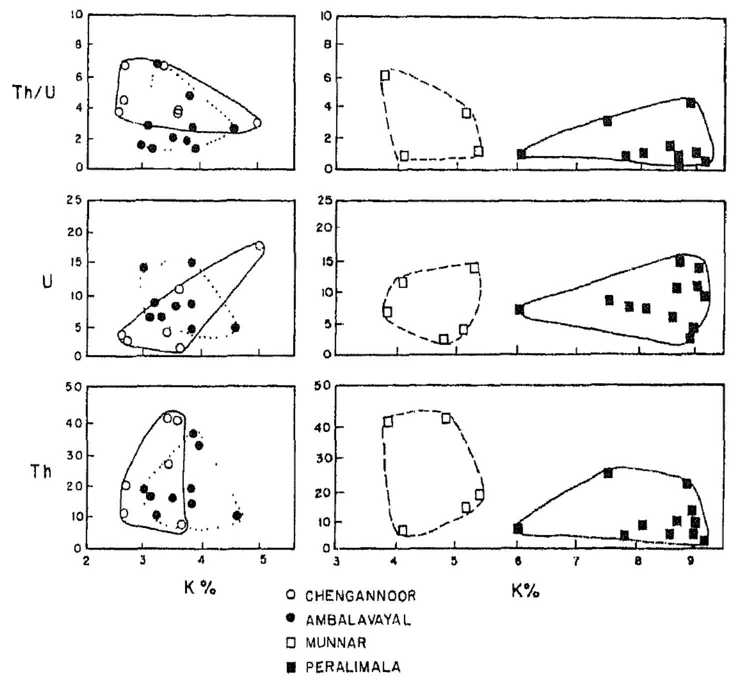

Figure 5. Th, U and Th/U vs K plots of the alkali granites.

minerals in the beach placers promise scope for detailed radioelement exploration in the alkali granites. Above all, their similarity to Pan-African alkali granites elsewhere is also significant as investigations have shown that Pan-African provinces are favourable tectonic belts for radioelement mineralization (Ragland and Rogers 1980).

5. Conclusion

The alkali granites of the Kerala region show higher Th, U and Th/U contents as compared to normal granites, but are closely comparable with similar alkaline plutons from adjacent terranes and elsewhere. The nature of distribution of radioelements testifies to their correlation with the ferromagnesium minerals and accessory phases. There is a general trend of concentration of Th and U and decrease in Th/U ratio with progressive fractionation. Their Pan-African tectonic setting, alkaline nature and higher Th/U levels, together with the findings of related rare metal pegmatites and the occurrence of Th-rich beach placers in the region are encouraging factors for detailed radioelement exploration in these alkali granites.

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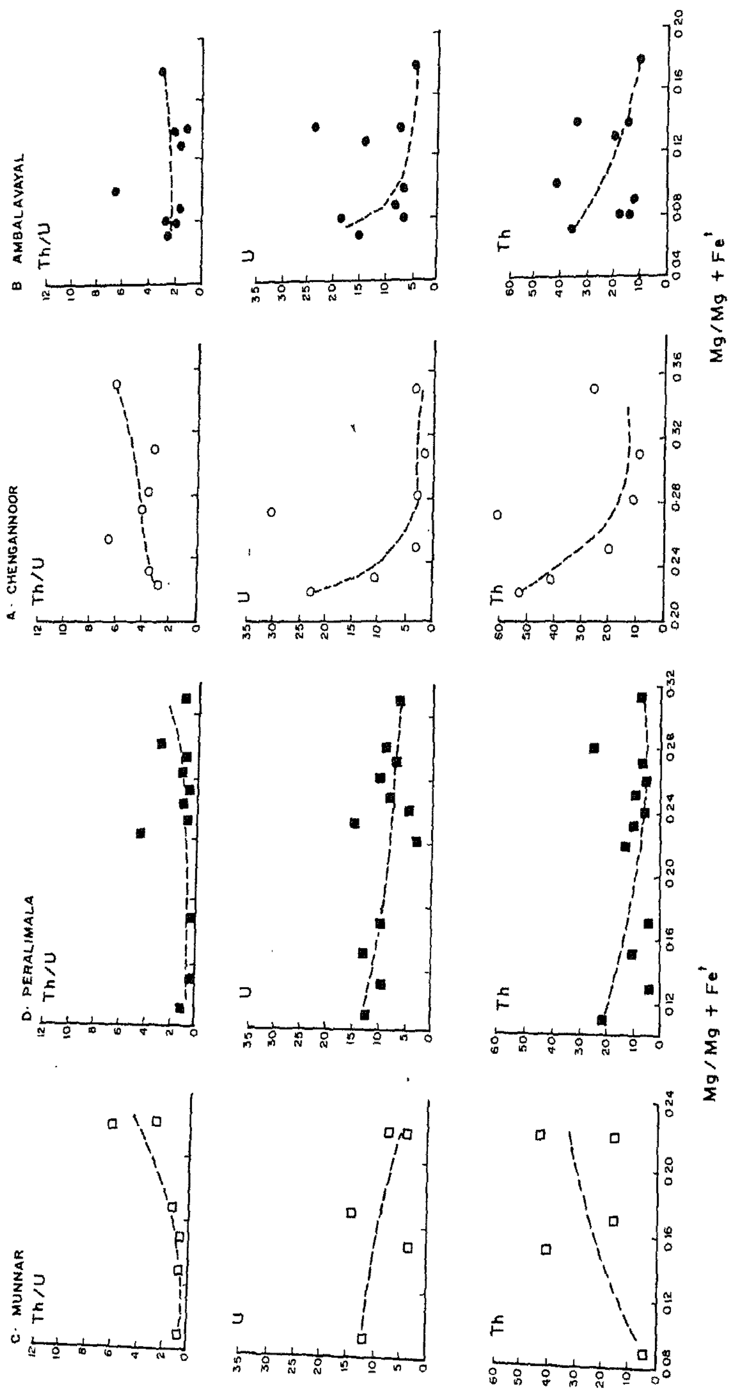

Figure 6. Th, U and Th/U vs Mg/Mg + Fe' plots of the alkali granites. Note that the felsic end is towards the left (decreasing Mg/Mg + Fe' levels).

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