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Rare earth element abundance patterns in alkaline basaltic lavas of Kuantan, Peninsular Malaysia.

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Abstract: Rare earth element (REE) concentrations in twelve representative samples of Late Cenozoic Kuantan lavas are presented and compared with those of other regions. The samples include five alkali olivine basalts, two limburgites (basanite) and five olivine nephelinites of known chemical and mineralogical compositions. All the samples show light REE enriched fractionated abundance patterns. Chondrite-normalized Ce and Yb values range from about 34 to 160 and 6 to 9 respectively. The maximum intragroup variations in REE abundances are shown by alkali olivine basalts and their relative abundance patterns are also irregular suggesting a complicated evolutionary history. The total REE contents as well as the degree of light REE enrichment increase in the order alkali olivine basalt, limburgite and olivine nephelinite. The REE abundances in the Kuantan lavas, both absolute and relative, match closely with those in similar rocks of other regions including oceanic islands.

INTRODUCTION

The rare earth elements (REE) as a group are very useful in petrologic studies because of their geochemcial coherence. In recent years, considerable amount of work has been done on REE geochemistry of basaltic rocks. It has become apparent that the REE abundances, both relative and absolute, are correlative with the types and tectonic settings of the basaltic rocks. Although unconstrained interpretations of REE data are not, as yet, plausible, they are nevertheless being increasingly applied in formulating and evaluating models of basalt petrogenesis and mantle source rock chemistry.

The REE abundances of alkaline basaltic rocks (alkali olivine basalt to nephelinite) have been discussed by several workers from different regions (Schilling and Winchester, 1969; Kay and Gast, 1973; Shimizu and Arculus, 1975; Sun and Hanson, 1975; Kyle and Rankin, 1976; Frey et al., 1978). An interesting feature that has emerged from these works is the similarity of REE abundance patterns displayed by compositionally similar basaltic rocks irrespective of their geographic locations. The occurrence of alkali basaltic rocks in the Kuantan area is known since the work of Fitch (1951). The petrography and major element geochemistry of these Late Cenozoic lavas have later been studied by Hanif (1975) and Chakraborty (1977, 1980); but their REE characteristics have so far remained unexplored. We have recently determined the REE abundances in these lavas and in this short article we present our data. Our main objective here is to point out and compare the REE characteristics of the different lava types. The REE-based petrogenetic models will be presented later.

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DESCRIPTION OF THE LAVAS

Three distinct lava groups are recognized in Kuantan, namely, alkali olivine basalt, limburgite and olivine nephelinite (Chakraborty, 1977). The alkali olivine basalt is the most dominant lava group followed by olivine nephelinite. Limburgite is negligible in volume in the present level of exposure. The distribution of the two main lava groups and the overall geology of the Kuantan area are shown in Fig. 1.

The rocks of the alkali olivine basalt group are holocrystalline consisting mainly of olivine, augite and plagioclase with intergranular to subophitic texture. They are nepheline to hypersthene normative and straddle the critical plane of silica undersaturation. The hypersthene normative rocks, having higher $FeO^*/(FeO^* + MgO)$ (FeO^* = total iron as FeO) and lower normative An/(An + Ab), appear to have evolved from the nepheline normative alkali olivine basalts (Chakraborty, 1980).

The limburgites are hypocrystalline and consist mainly of olivine, augite and brownish glass. They are similar to typical basanites in major element chemistry and normative composition (about 10% Ne and 20% Ol). The limburgites contain rare inclusions of spinel lherzolite (Chakraborty, 1979) indicating that their compositions have not been significantly modified by crystal fractionation subsequent to the entrainment of the lherzolite inclusions.

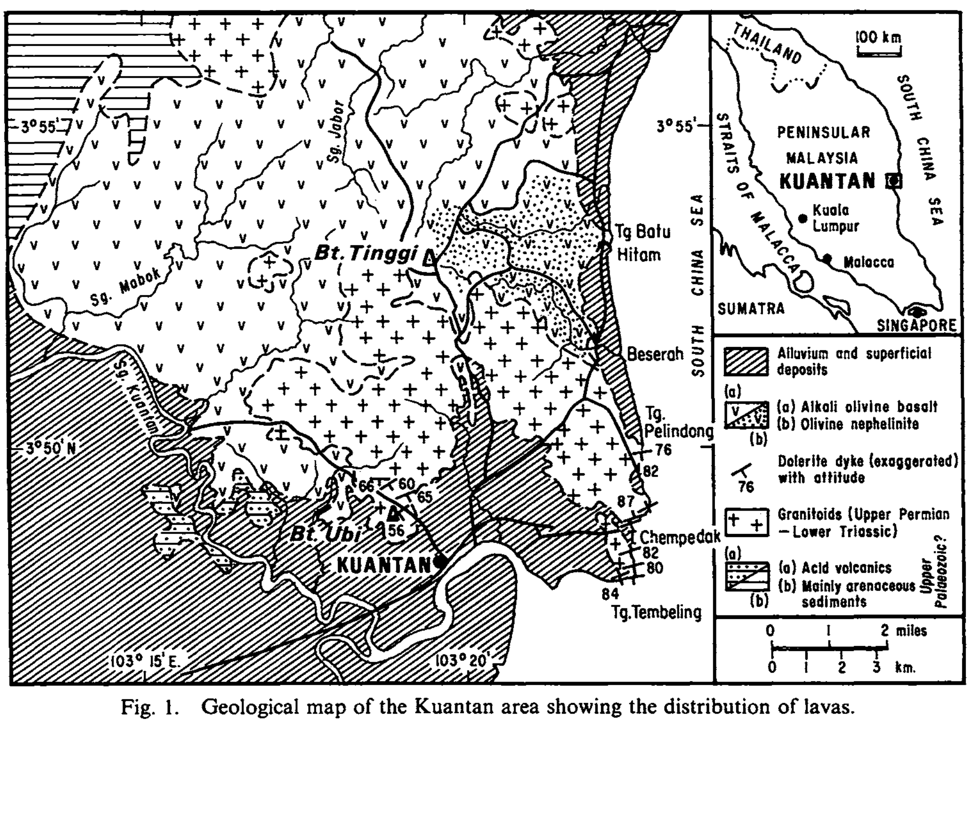

Fig. 1. Geological map of the Kuantan area showing the distribution of lavas.

The olivine nephelinites are very fine grained holocrystalline rocks made up mainly of olivine, augite and nepheline. Feldspar is conspicuously absent. The lack of normative albite is characteristic. Chemical variation within this group is very limited and some lavas possibly represent near primary liquid compositions.

SAMPLE SELECTION AND ANALYTICAL PROCEDURES

A total of twelve lava samples are analyzed for REE. They include five alkali olivine basalts, two limburgites and five olivine nephelinites. The samples cover the compositional range of each lava group and are selected from rocks previously examined microscopically and analyzed for major elements.

The REE were determined by instrumental (non-destructive) neutron activation analysis (INAA). The samples along with USGS rock standards (about 100 mg each) were irradiated at a thermal flux of 1.2×10^{12} neutrons $cm^{-2}\ s^{-1}$ for 12 hours in the APSARA reactor of Bhabha Atomic Research Centre, Bombay. The irradiated samples were later analyzed in the Nuclear Science Laboratory of Universiti Kebangsaan Malaysia using a high-resolution gamma-ray spectrometer (major components being a 84.5 cm^3 Ge(Li)-detector and a 4096 channel analyzer). The details of the analytical procedures followed are given elsewhere (Sita Ram, Chakraborty and Sharifah, Bull. Geol. Soc. Malaysia, this issue p. 87–92).

REE CHARACTERISTICS OF THE KUANTAN LAVAS

The REE concentrations of the twelve analyzed samples are presented in Table 1. The relative REE distribution patterns, normalized to chondrite values (Haskin et al., 1971), in each lava group are shown in Figs. 2, 3 and 4. All the lavas have considerably higher REE concentrations than chondrites, and they show fractionated REE patterns with significant LREE (light rare earth elements) enrichment.

The alkali olivine basalts show significant and appreciable intragroup variations in both absolute and relative REE abundances (Fig. 2) as expected from their major element chemistry. The total REE contents in this group vary by a factor of more than 2. The samples with higher ΣREE (QB-12 and QB-2) show slight positive Eu anomaly. Although the samples of this group all display LREE-enriched fractionated patterns with CE_N/YB_N ratios ranging from about 5 to 12 (Ce_N = chondrite-normalized value of Ce), the trends are not generally parallel (Fig. 2). An important characteristic of this group is the decrease of both ΣREE and the degree of LREE-enrichment from nepheline-normative to hypersthene-normative types. QB-12 and QB-2 are nepheline normative (also have lower $FeO^*/(FeO^* + MgO)$) and both have higher ΣREE and Ce/Yb ratios. If the hypersthene-normative types have evolved from the nepheline-normative types by fractional crystallization as pointed out earlier (see also Presnall et.al., 1978, for experimental results indicative of such differentiation trend), then the observed decrease of ΣREE with differentiation suggests participation of a phase or phases that preferentially incorporate REE relative to the liquid. The crossing REE patterns (Fig. 2) also point to a rather complicated fractionation history for their evolution.

TABLE 1

CONCENTRATIONS (in ppm) OF RARE EARTH ELEMENTS IN KUANTAN LAVAS OBTAINED BY INAA

Sample	La	Ce	Nd	Sm	Eu	Gd	Tb	Yb	Lu	∑REE
Alkali olivine basalts										
QB-12	42.7 ± 0.9	74.6 ± 1.1	37.2 ± 2.0	8.03 ± 0.06	3.06 ± 0.35	7.6 ± 2.6	1.07 ± 0.15	1.59 ± 0.22	0.208 ± 0.024	176
QB-2	30.0 ± 0.6	53.6 ± 1.2	30.2 ± 2.2	5.72 ± 0.48	2.40 ± 0.18	N.D.	0.70 ± 0.09	1.34 ± 0.14	N.D.	124
QB-46B	27.1 ± 0.6	50.1 ± 1.6	28.4 ± 2.0	5.72 ± 0.29	1.93 ± 0.02	5.7 ± 0.5	0.77 ± 0.01	1.27 ± 0.10	0.197 ± 0.013	121
QB-36	19.4 ± 0.9	33.3 ± 0.9	24.6 ± 1.1	5.31 ± 0.03	1.59 ± 0.15	N.D.	0.44 ± 0.07	1.75 ± 0.04	0.268 ± 0.030	87
QB-13	16.8 ± 1.4	29.1 ± 1.3	17.7 ± 0.3	4.74 ± 0.03	1.40 ± 0.01	3.1 ± 0.4	0.39 ± 0.12	1.29 ± 0.12	0.186 ± 0.013	75
Limburgites										
QB-7A	48.5 ± 0.4	83.6 ± 3.5	48.0 ± 1.1	14.8 ± 0.7	2.92 ± 0.06	8.2 ± 1.4	1.32 ± 0.08	1.82 ± 0.14	0.266 ± 0.004	209
QB-7B	45.4 ± 1.1	80.8 ± 1.1	43.9 ± 1.2	8.5 ± 0.1	2.49 ± 0.28	7.5 ± 1.8	1.16 ± 0.20	1.44 ± 0.17	0.252 ± 0.021	191
Olivine nephelinites										
QB-38	67.8 ± 1.6	124 ± 1	68.8 ± 0.3	12.0 ± 0.1	4.47 ± 0.30	N.D.	1.79 ± 0.06	1.66 ± 0.08	0.263 ± 0.032	281
QB-22	70.0 ± 0.2	137 ± 3	78.2 ± 3.5	12.2 ± 0.2	4.67 ± 0.60	N.D.	1.59 ± 0.28	1.65 ± 0.09	N.D.	305
QB-8	65.9 ± 2.0	127 ± 6	72.7 ± 2.1	11.6 ± 0.2	4.18 ± 0.20	11.2 ± 2.7	1.67 ± 0.30	1.70 ± 0.26	0.197 ± 0.015	296
QB-15	59.7 ± 1.0	111 ± 2	60.6 ± 0.8	10.5 ± 0.7	3.96 ± 0.39	N.D.	1.57 ± 0.10	1.67 ± 0.24	0.267 ± 0.004	249
QB-49C	65.2 ± 1.9	118 ± 2	68.1 ± 4.0	11.3 ± 0.3	3.71 ± 0.16	11.2 ± 2.3	1.39 ± 0.05	1.67 ± 0.20	0.179 ± 0.003	281

N.D. means that the value is not determined. The errors indicated are counting errors only (one standard deviation).

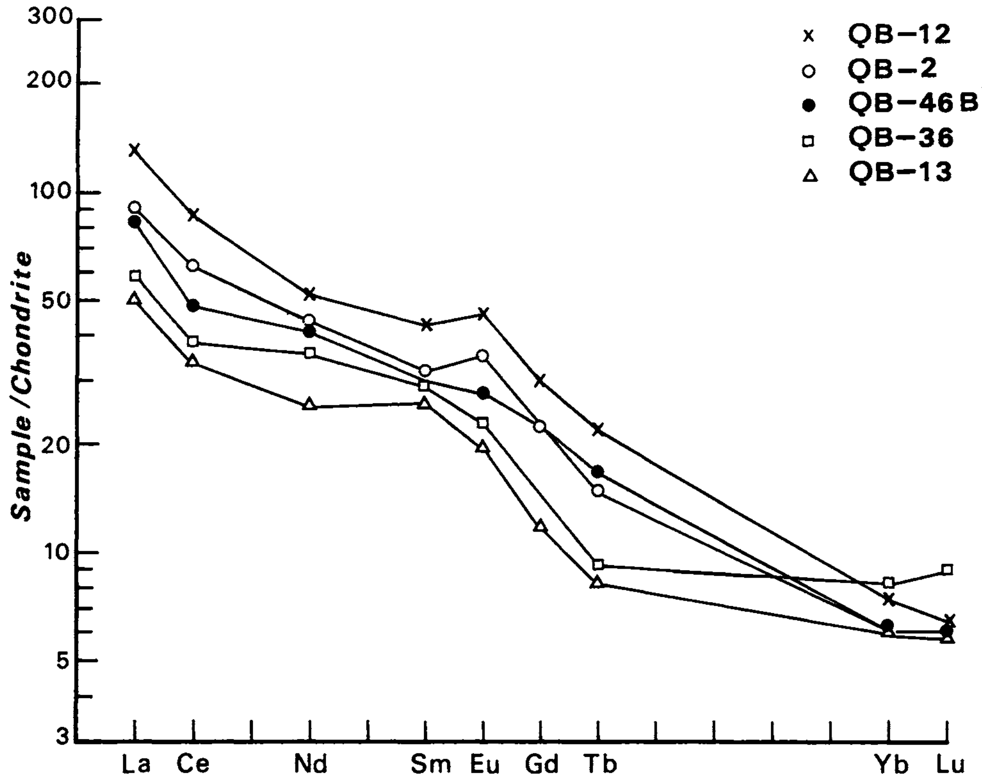

Fig. 2. Chondrite-normalized REE abundances in five alkali olivine basalts from Kuantan.

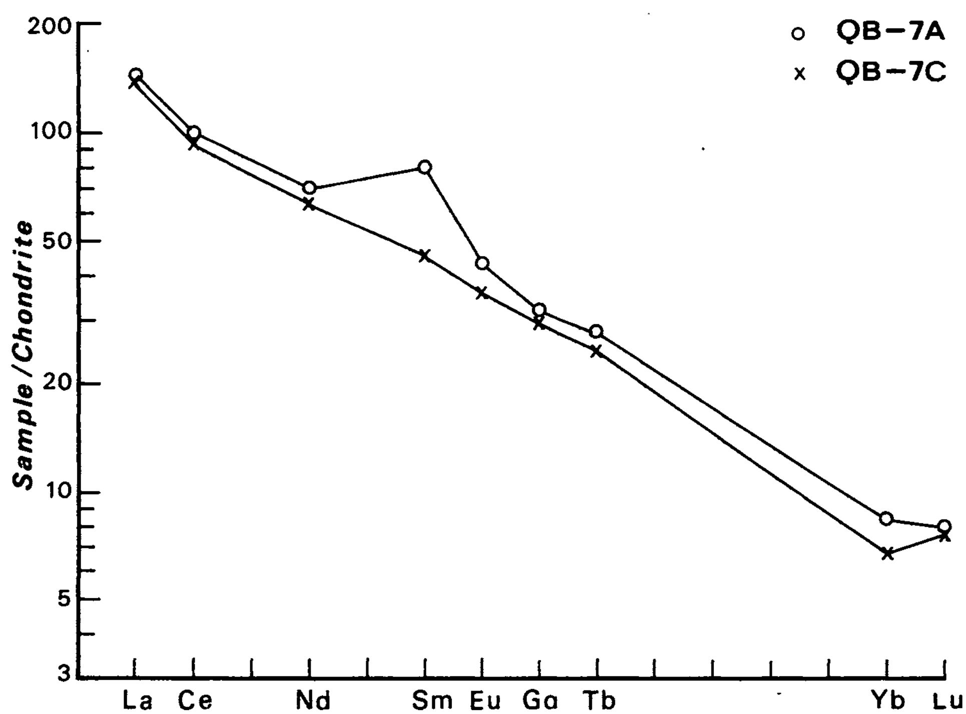

Fig. 3. Chondrite-normalized REE abundances in two limburgites from Kuantan.

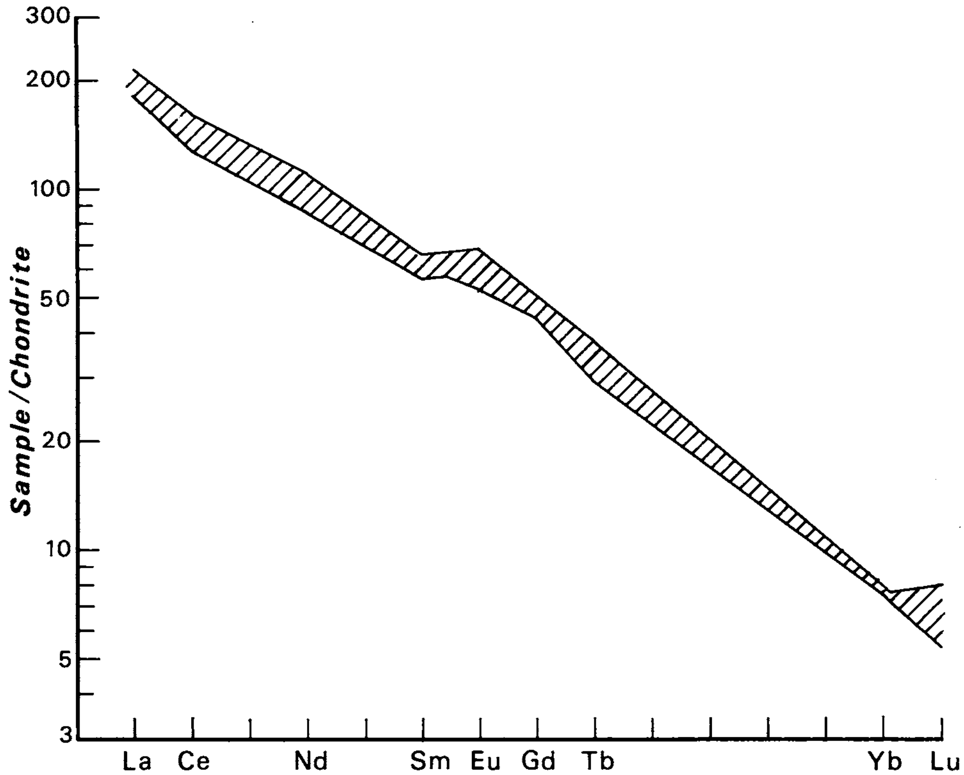

Fig. 4. Chondrite-normalized REE abundances in five olivine nephelinites of Kuantan. All the five samples lie within the shaded band.

The two analyzed limburgites have identical REE abundances except for Sm. QB-7A has appreciably higher Sm content than QB-7C, and no proper explanation for this anomaly is yet apparent. The limburgites show LREE-enriched fractionated patterns (Fig. 3) with average Ce_N/Yb_N of about 13.

The REE abundances, both absolute and relative, in the five olivine nephelinite samples are very close. The maximum deviation for individual elements is mostly less than 10 per cent. The chondrite-normalized abundance patterns of the five samples lie within the shaded band shown in Fig. 4. The Ce_N/Yb_N ranges from about 16 to 20.

The REE abundances of the three lava groups are compared in Fig. 5 where the average REE contents of the olivine nephelinites and limburgites relative to the average of the alkali olivine basalts and the average of the olivine nephelinites relative to the average of the limburgites are plotted. It is apparent that the REE abundances in the Kuantan lavas are correlative with their types. The REE contents, both individually and collectively, increase in the sequence alkali olivine basalt, limburgite and olivine nephelinite. On the average, the total REE contents of the olivine nephelinites and limburgites are about 2.5 and 1.7 times, respectively, that of the alkali

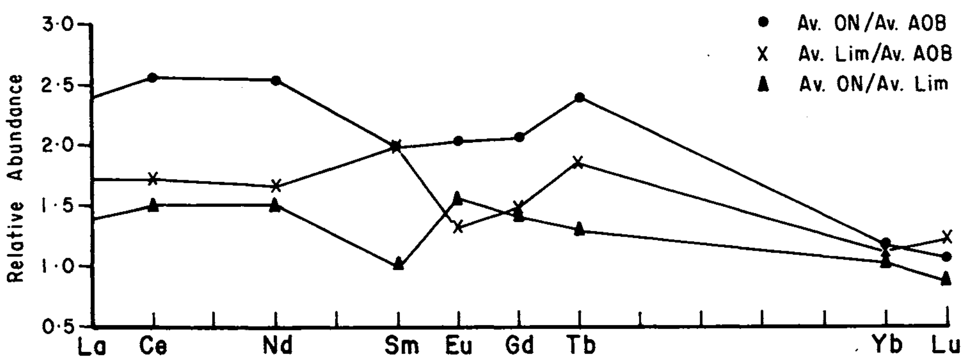

Fig. 5. Comparison of the REE abundance averages of the three lava groups of Kuantan. ON = olivine nephelinite, Lim = limburgite, AOB = alkali olivine basalt. (Av. = Average).

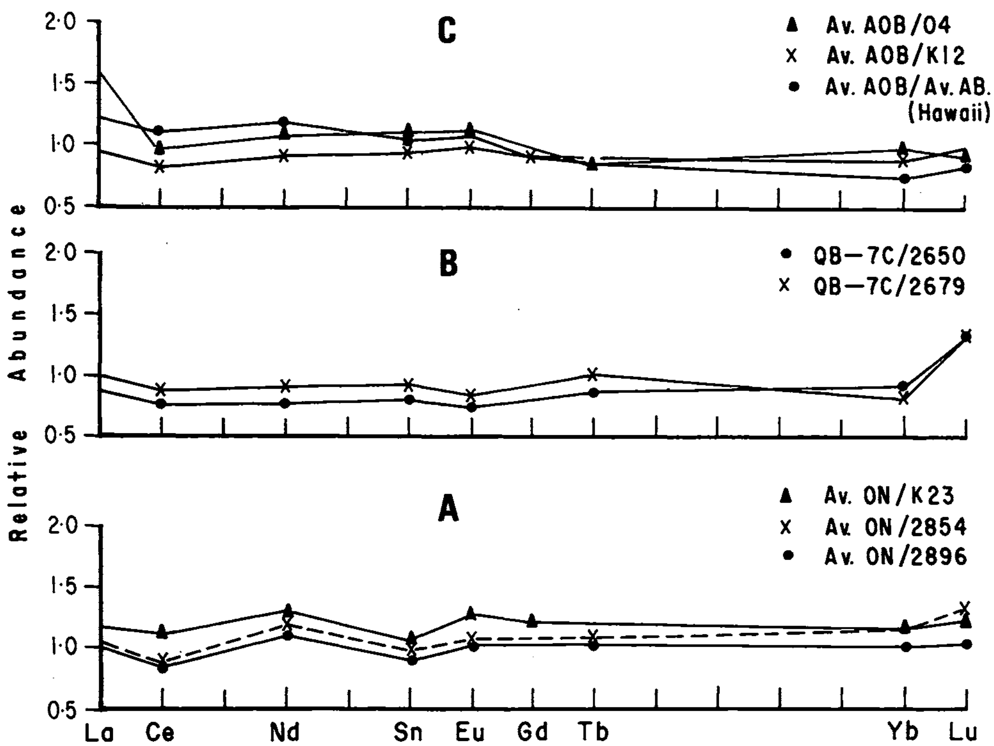

Fig. 6. Comparison of the REE abundances of Kuantan lavas and that of similar lavas of other regions. (A) average of Kuantan olivine nephelinites compared to one Hawaiian (K 23) and two Tasmanian (2854, 2896) olivine nephelinites. (B) Abundance in one Kuantan limburgite (QB-7C) compared to two basanites (2650, 2679) from W. Victoria, Australia. (C) Average of Kuantan alkali olivine basalts compared to two Hawaiian alkali basalts (04, K 12) and to average Hawaiian alkali basalts.

Analyses 2896, 2854, 2679 and 2650 are from Frey et al., 1978. Analyses K 23, K 12, 04 are from Kay and Gast (1973). The average Hawaiian alkali basalts taken from Schilling and Winchester (1969).

AB = alkali basalt. Other abbreviations as in Fig. 5.

olivine basalts. The degree of LREE enrichment also progressively increases from alkali olivine basalt to limburgite to olivine nephelinite, the average Ce_N/Y_N ratios being 8, 13 and 19 respectively. The increase in the degree of LREE enrichment, however, is related to the increasingly higher abundances of the LREE inasmuch as the HREE (heavy rare earth elements) contents of the three groups are about the same.

COMPARISON WITH OTHER REGIONS

The REE abundances of the Kuantan lavas are closely similar to those of the alkali olivine basalt - olivine nephelinites of other oceanic islands and continental regions. When normalized to each other, they display more or less flat REE patterns. A few examples are shown in Fig. 6 where the Kuantan rocks are compared with similar rocks from Australia (Frey et al., 1978) and/or Hawaii (Kay and Gast, 1973; Schilling and Winchester, 1969). Fig. 6A, for example, shows the average REE concentrations of the Kuantan olivine nephelinites relative to one Hawaiian olivine nephelinite (K 23) and two Tasmanian olivine nephelinites (2854 and 2896). It is evident from the flat distribution patterns hovering around unity (Fig. 6) that the REE abundances, both absolute and especially relative, in the compared rocks are remarkably similar.

CONCLUDING REMARKS

The progressive decrease of the total RRE abundances and L/HREE ratios from olivine nephelinite to alkali olivine basalt, as observed in Kuantan, has also been documented in many other well studied basaltic provinces, and appears to be a universal characteristic. Progressively higher degree of melting has been invoked to account for such systematic variation (see, for example, Kay and Gast, 1973; Sun and Hanson, 1975; Frey et al., 1978). However, the suggested extent of melting relies heavily on factors such as initial REE abundances and mineralogy of the mantle source prior to melting, the phase proportions of the residue and liquid/solid partition coefficients of REE. To what extent the REE patterns of the three lava types of Kuantan can be explained by varying degrees of melting of a common source is yet uncertain. Appropriate petrogenetic models and possible mantle source rock chemistry of the Kuantan lavas are currently being worked out.

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