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Rare Earth Element patterns in some granitic rocks of Peninsular Malaysia

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Abstract: Seventy one samples of granitic rocks have been collected from Peninsular Malaysia, covering Langkawi, Ipoh, Kuala Lumpur, parts of Johor, Pahang, Kelantan and Terengganu to represent the granite provinces of the Peninsula. Included in the samples are the Cretaceous granites from Gunung Ledang, Batang Melaka and Gunung Pulai. The samples were crushed and anlaysed by Instrumental Neutron Activation Analysis (INAA), and values obtained were normalised against chondrite.

The results indicate that the total rare earth elements (ΣREE) are generally low with a range of 85–414 ppm. The Langkawi granite especially have low ΣREE values, usually less than 200 ppm while those of the Main Range, Central and East Coast Provinces granites have contents higher than 200 ppm. The East Coast samples have a wide range, from 85 to 327 ppm. Out of the nine samples of the Cretaceous granites, six samples have values of less than 200 ppm while the highest value recorded for the group is 231 ppm.

The shapes of REE patterns for the granitic rocks obtained varies from typical "bird-wing" pattern, with a distinct negative Eu anomaly, to a simple upward-concave pattern with a hardly visible Eu anomaly. The negative Eu-anomalies have degrees of magnitudes, but most are small to moderate, clearly seen on their REE curve. Exceptions are from Jemaluang and Kledang granites, that have moderate to large negative Eu anomalies (Eu/Sm 0.0009–0.074). The Central Province and the East Coast granites have dominantly small to moderate anomalies, together with patches of granites with small or no negative Eu-anomalies.

Based on the REE patterns, the Peninsular Malaysian granites can be divided into two groups, a) with anomalous Eu values and "bird-wing" REE pattern from the West Coast Triassic, parts of Central and East Coast Provinces, and b) without or with small Eu anomaly from the Cretaceous granites of the West Coast, granites of Gua Musang area and granite patches from the East Coast Province.

The non-anomalous Gua Musang granites seems similar to the Noring granite and may be related to the Cretaceous granites of the southern Peninsular. The non-anomalous East Coast granite is related to the I-type granite, whereas anomalous ones in the Province is from S-type, like those of the Main Range.

The anomalies are due to partial melting or fractional crystallization or both, of parental materials from a sialic basement originally rich in plagioclase feldspars. The dominant shapes of REE patterns in the Peninsular granites could be explained as such. But the small to non-anomalous patterns in the Cretaceous granites are probably due to a poor plagioclase source. The Cretaceous southern Peninsular granite is derived from a primitive mantle source. The non-anomalous I-type granite in the East Coast is derived from an oceanic or primitive mantle source.

INTRODUCTION

The geology of Peninsular Malaysia granites is well covered in Gobbet and Hutchison (1973). Bignell and Snelling (1977) in their work on the age determinations of the Malayan granites divided the Peninsular into three tectonic provinces; the West Coast Province, the Central Province and the East Coast Province. On the west coast is the Main Range granite, with smaller batholiths, namely Taiping, Kledang, Bukit Mertajam, Penang and Langkawi on its western flanks. On the east lies the East Coast Province that includes pluton such as the Boundary Range, Maras-Jerong, Jemaluang, Muntahak, etc. (Rajah *et al.*, 1977). In between the West Coast and the East Coast Provinces lies the Central Province, containing a narrow line of plutons extending from Stong Igneous Complex that contains the Noring granite near to the Thailand border through, Senting, Gua Musang and its neighbourhood, Damar, Bukit Kajang and Gunung Benom.

The granites of the Main Range belt are commonly coarse to very coarse grained and contain large phenocrysts up to 5 cm long. Chemically the Main Range is strictly confined to the granite field, exclusively of S-type and of the Ilmenite-series. Based on rock geochemistry and strontium isotope ratios, Hutchison (1977) believed that the Main Range is underlain by a well established continental sialic basement. Liew and Page (1985) showed that the West Coast Province is of S-type granites and are derived from sedimentary sources recycled, at least in part, from mid-Proterozoic crystalline basement sources. The granite of Langkawi contains intermediate microcline and have pronounced contact metamorphic aureole. The granites of the Eastern Province are characterised by an equigranular to weakly porphyritic texture, implying that they were emplaced epizonally. The Eastern Province has been stable since the Triassic. The dominant lithologies are biotite granite and biotite-hornblende granite containing euhedral hornblende. In terms of granite series, the East Coast granite is of mixed affinities. The northeast subprovince from Kuantan to Kelantan, including the Boundary range is of mixed I and S types, while the subprovince of eastern Johor and Singapore has I-type characteristics (Hutchison, 1989). In the Central Province granites are few, represented by Gunung Benom and Gunung Stong. Late Cretaceous granite have high-level characteristics and are devoid of tin mineralization.

Age determinations by Bignell and Snelling (1977) indicates episodes of granite intrusions occurring during late Carboniferous, late Permian /early Triassic and late Triassic. Granite batholiths in the East Coast Province show a westward younging. The Kapal, Jengai and Maras Jerong granites in Terengganu are mainly of 270–255 Ma. To the west, the Boundary Range and Lawit granites are younger with ages of 240–220 Ma. Finally the Central Province granites are 220–200 Ma. Small granite bodies of late Cretaceous age occur in southern Peninsular in Johor and Melaka. Late Cretaceous granite has also been confirmed in the northern part of the Central Province (Hutchison, 1989).

The subdivision into provinces is pertinent as they are tectonically different. The East Coast granite show features of high-level emplacement and is regarded as epizonal whereas the Main Range and the West Coast granites show characteristics of deep seated mesozonal emplacement. The Main Range has since being uplifted by several kilometers since Triassic. In the Central Province, the Benom batholith has high-level characteristics (Hutchison, 1977). Similarly the late Cretaceous intrusions in the southern part of Peninsular Malaysia are high-level epizonal granites.

Studies of REE in granite is useful as it complement other trace element studies in petrogenesis. Unfortunately REE data of Malaysian granites is rather lacking. A study of the REE in Kuantan basalt was made by Chakraborty *et al.* (1980). Some unpublished data on REE of Malaysian granites are available in Wan Fuad and Mohd Suhaimi (1990), Sukiman *et al.* (1988) and Liew (1983). This work looks at the REE patterns in some Malaysian granitoid and its general relationships to the petrogenesis

ANALYTICAL METHODS

Seventy one granite samples were collected from road cuts, quarries and occasionally river and coastal exposures. Sample localities are indicated in Figure 1. Samples were made into powder by grinding in a TEMA mill. The REE were analysed by instrumental neutron activation analyses (INAA). Sample was activated in the Malaysian Institute of Nuclear Technology (MINT) Triga MKII reactor using Pneumatic Transfer System (for short irradiation) and Lazy Susan or rotary rack (for 6–12 hours irradiation) irradiation facilities. Irradiated sample was counted on PC based gamma spectrometer. The spectrometer consists of Hyper Pure Germanium detector, pre-amplifier, amplifier, analog to digital converter and multichannel analyser. Gamma spectrum was analysed using Canberra spectrum analysis software, Sampo 90. Mixed rare earth standard solution and USGS reference materials were used as standards. The REE obtained were normalised against chondrite using the standard data of Wakita *et al.* as given in Henderson (1984).

REE PATTERNS

i) West Coast Province

West Coast Province includes the granite batholiths from Langkawi Islands in the north to that of Batu Pahat in the south. The main batholiths of the West Coast Province have been dated by U-Pb zircon to yield a precise and ambiguous ages of 198 to 220 Ma, late Triassic to early Jurassic (Liew and Page, 1985). The rocks are mainly coarse to very coarse grained and contain large phenocrysts of up to 5 cm long in the Gap pluton. The batholiths is biotite granite and hornblende is conspicuously absent except for a few isolated cases. Chemically the Main Range is confined to the granite field, exclusively of S-type and the Ilmenite-series of Ishihara (Hutchison, 1986). The central and eastern part of the Main range have been interpreted as mesozonal in contrast to the east coast granite which is epizonal.

Langkawi Islands is intruded by a number of granite batholiths forming Gunung Raya, Pulau Tuba, Pulau Bumbon and part of Pulau Dayang Bunting during late Triassic. They are predominantly medium to coarse-grained highly porphyritic biotite granite. Late phase hydrothermal activity is shown by numerous tourmalinization and greisenization of the granites. Limited geochemical analyses (Amirul Naim, 1997; Syafrina Ismail, 1998) indicated that the Langkawi granites are high silica type, with SiO_2 percentage ranging from 70.67 to 76.98.

Content of REE in seven granite samples from Langkawi Islands is given in Table 1 and their REE patterns is given in Figure 2A. The shape of their REE curves shows a general enrichment of the LREE components followed by low HREE components with $(La/Yb)_{cn}$ values from 2.59 to 10.79. Their ΣREE content is generally low (110–232 ppm). Negative Eu anomalies are clearly observed, shown by a mixture of small to moderately strong negative peaks.

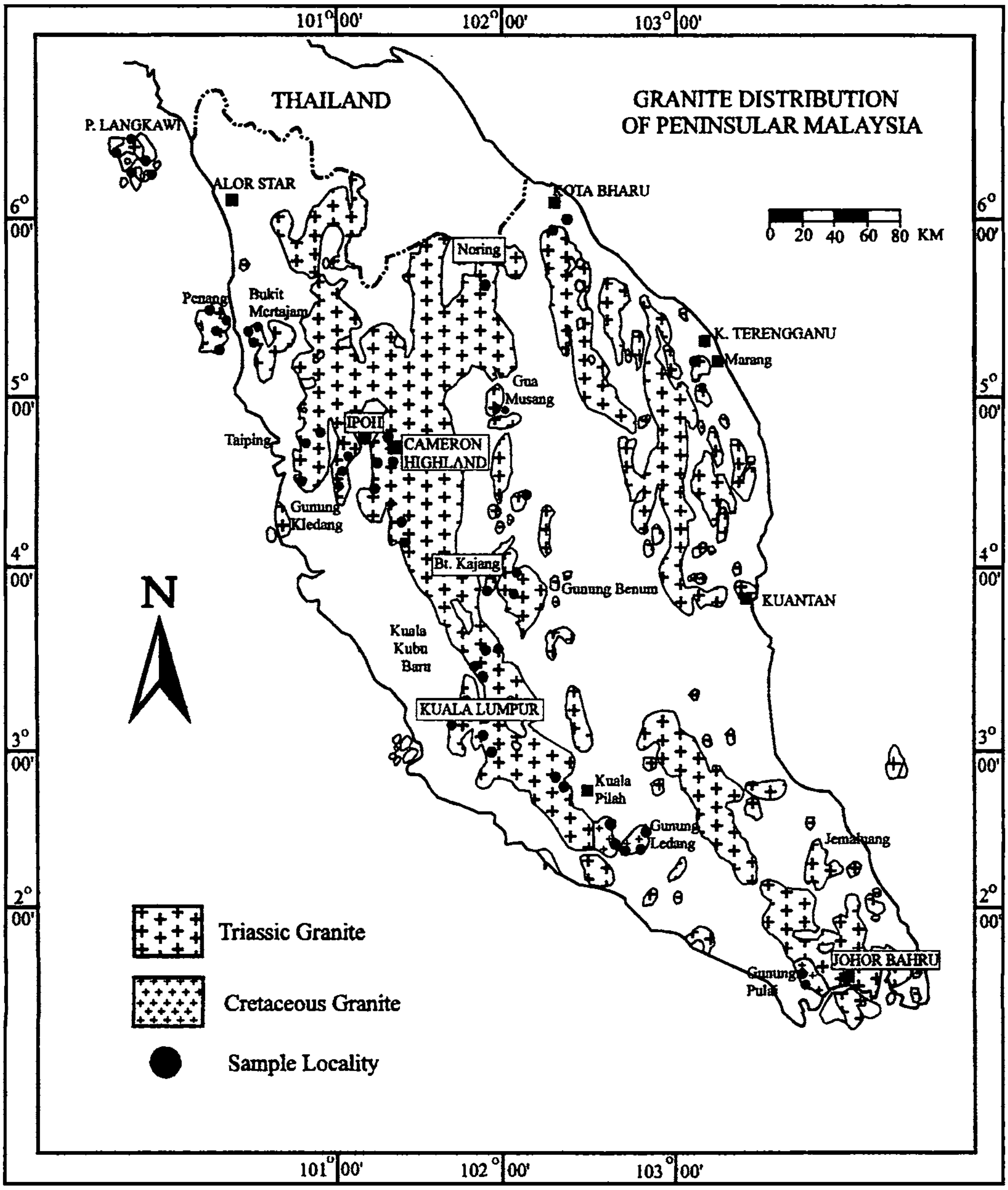

Figure 1. Distribution of granite bodies of Peninsular Malaysia. Sample locations are marked as black dots.

Table 1. REE content in samples from Langkawi Islands.

	F1 Pasir Hitam	F2 Penerak	F3 Ulu Melaka	F4 G. Raya	F5 P. Tuba	F8 P. Bumbon	F9 Telaga Tujuh	F11 P. Dayang Bunting
La	38.9	16.4	31.1	51.6	29.8	26.1	32.9	40.3
Ce	94	53	85	117	69	66	75	94
Nd	35	24.5	19.4	41.3	30.2	27.7	26.2	35.5
Sm	7.54	6.14	6.3	9.65	6.47	6.78	6.87	8.14
Eu	1.2	0.3	1.1	1.3	0.6	0.8	1.0	1.1
Tb	1.02	0.67	0.93	1.09	0.83	1.4	0.94	1.07
Dy	6.3	4.6	4.7	5.9	5.6	8.4	6.0	7.1
Yb	5.0	4.1	4.1	3.8	3.9	8.0	4.5	5.2
Lu	0.56	0.97	0.51	0.50	0.66	0.91	0.55	0.67
ΣREE	190	110	153	232	147	146	154	193
$(La/Yb)_{cn}$	6.9	2.59	6.10	10.79	4.51	2.86	5.97	5.99
Sm/Nd	0.21	0.25	0.32	0.23	0.21	0.24	0.26	0.22
Eu/Sm	0.16	0.05	0.17	0.13	0.09	0.11	0.14	0.14

Table 2. REE content in samples from Penang and Bukit Mertajam.

	PENANG				BUKIT MERTAJAM		
	85/23 Teluk Tempoyak	85/24 Sg. Pinang	85/25 Miami Beach	85/25 Air Hitam	85/18 Kuari QSK	85/19 Kuari Kubang Semang	85/20 Kuari Kubang Semang
La	53	53	44	41	39	41	82
Ce	90	102	88	99	65	83	168
Nd	55	48	51	47	41	44	89
Sm	9.3	9.2	8.2	8.9	6.5	6.7	12.2
Eu	1.10	0.89	0.86	0.71	1.13	0.79	1.09
Tb	1.3	1.5	1.5	2.0	1.0	0.93	1.50
Dy	12.9	10.7	9.9	13.2	7.9	9.8	12.0
Yb	3.7	4.2	5.2	7.3	3.1	4.0	3.3
Lu	0.56	0.65	0.79	0.94	0.41	0.49	0.38
ΣREE	227	230	209	220	165	190	369
$(La/Yb)_{cn}$	10.05	8.55	5.92	4.55	9.69	8.80	22.33
Sm/Nd	0.17	0.19	0.16	0.19	0.16	0.15	0.14
Eu/Sm	0.12	0.10	0.10	0.08	0.17	0.12	0.09

To the south, Penang granite, ranging from adamellite to leucogranite, has been divided into two suites; Bukit Bendera and Sungai Ara suites (Liew, 1983). These suites, dated as late Triassic, show mineralogical similarities to the suites of southern Main Range batholith. Their chemical compositions show they are of high silica type, with SiO_2 varying from 72.46 to 73.92% (Yeap, 1980).

Four samples, three from Bukit Bendera and one from Sungai Ara suites have been analysed for their REE and their results presented in Table 2 and Figure 2B. They have higher ΣREE contents from 209 to 230 ppm compared to those of Langkawi, show similar enrichment of LREE component with $(La/Yb)_{cn}$ values from 4.55 to 10.05 and have moderately strong negative Eu anomalies with Eu/Sm ratios from 0.08 to 0.12.

Bukit Mertajam batholith, on the mainland across the coast from Penang, is also known as Kulim batholith. This batholith is recognized as belonging to two suites; Penanti and Bongsu suite (Courtier, 1974). Penanti suite consist of low Al biotite, sphene bearing pluton while Bongsu suite is of high Al biotite, tourmaline-muscovite-garnet bearing pluton. Radiometric age dating determined gave a late Triassic age (Bignell and Snelling, 1977). Penanti suite, with SiO_2 value of 73.92% is also of silica rich granite (Liew, 1983).

Three samples from the Penanti suite have been analysed for their REE (Table 2 and Fig. 2C).

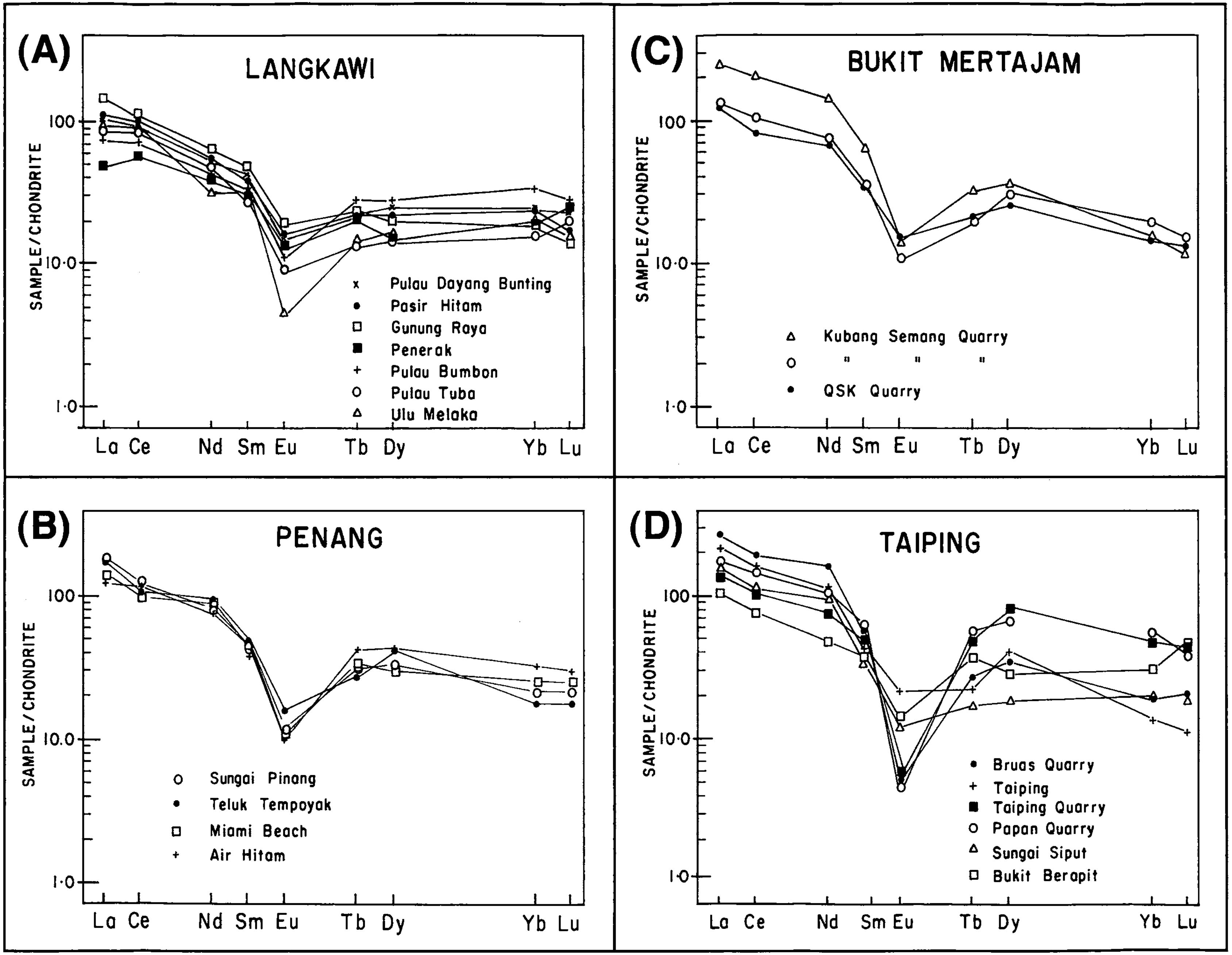

Figure 2A to 2D. REE patterns of granite batholiths of the West Coast Province of Peninsular Malaysia.

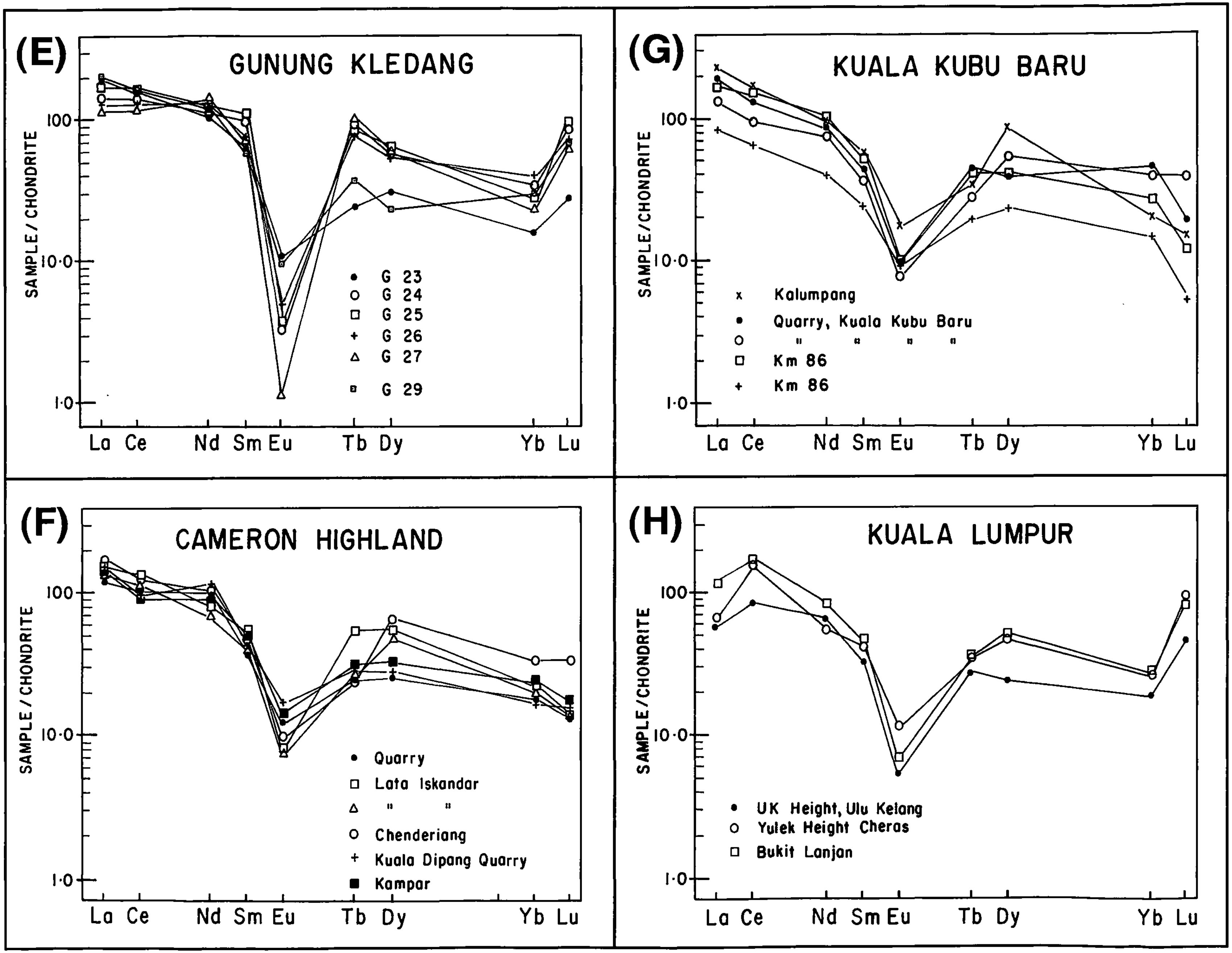

Figure 2E to 2H. REE patterns of granite batholiths of the West Coast Province of Peninsular Malaysia.

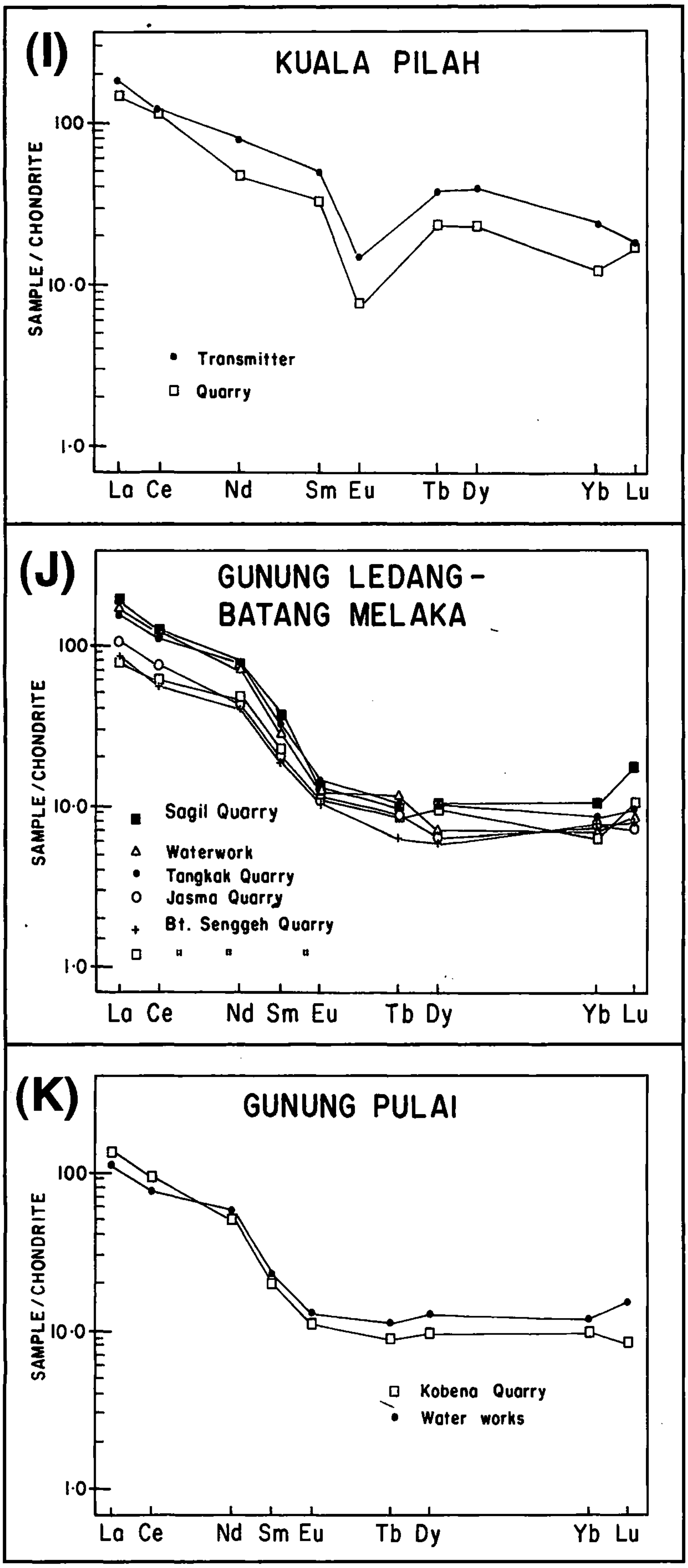

Figure 2I to 2K. REE patterns of granite batholiths of the West Coast Province of Peninsular Malaysia.

Similar LREE enrichment is observed, with $(La/Yb)_{cn}$ values from 8.80 to 22.33. Their ΣREE content have a wider range of values, from 165 to 369 ppm. Similarly they have sharp negative Eu anomalies with Eu/Sm ratios from 0.09 to 0.17.

Taiping samples represent the Bintang batholith or the Bubu suite of Liew (1983). The rock is predominantly coarse-grained porphyritic adamellite granite. Age dating by Bignell and Snelling (1977) indicate late Triassic age. Taiping granite is associated with tin mineralization. Silica content in Taiping granites range from 65.95 to 73.08% (Liew, 1983).

Six granite samples were analysed for their REE (Table 3, Fig. 2D). A general picture indicates enrichment of the LREE components with $(La/Yb)_{cn}$ values from 4.60 to 17.82. Their ΣREE content is comparable to those of Penang and Kulim with values from 143 to 362 ppm. Negative Eu anomalies are clearly seen. Based on the prominence of the anomalies, they can be divided into two types. Samples from Papan Quarry, Bruas Quarry and Taiping have strong anomalies (Eu/Sm from 0.03 to 0.4) while samples from Sungai Siput, Bukit Berapit and Taiping Lake Garden have small anomalies (Eu/Sm 0.14 to 0.18).

Kledang Range granite is grey, medium-grained, fairly porphyritic biotite granite. Evidence of pneumatolysis and mineralization in the granite is found over wide areas. They are silica rich granite with SiO_2 contents ranging from 73.29% to 74.38% (Ingham and Bradford, 1960). Radiometric age determination indicate late Triassic age. Kledang Range granite is associated with tin minerlization in the famous Kinta Valley.

Results of REE analysed in 6 samples (Table 4) strong negative Eu anomalies, with Eu/Sm 0.01 to 0.07 clearly shown in Figure 2E. Their ΣREE content is relatively high, ranging from 278 to 328 ppm. Their LREE enrichment is not pronounced and have $(La/Yb)_{cn}$ relatively lower with values mainly about 2.

Cameron Highland granites in this work is the Main Range granites exposed along the road from Kampar to Cameron Highland. Bignell and Snelling (1977) recognized two intrusive events in the Cameron segment of the Main range batholith, at 280 Ma and between 210 and 230 Ma. Bujang Melaka intrusive gave an age of 211 Ma. The rocks here is described as grey, medium-grained, moderately porhyritic biotite granite.

Six samples analysed (Table 5, Fig. 2F) show relatively high ΣREE content ranging from 203 to 249 ppm, have pronounced LREE enrichment with $(La/Yb)_{cn}$ from 4.90 to 11.07 and small to moderately strong negative Eu anomalies (Eu/Sm 0.15 to 0.06).

The Kuala Lumpur and Kuala Kubu Baru part of the Main Range is mapped into a number of rock suites. Those around Kuala Lumpur is recognized as part of the Beranang Suite and those around Kuala Kubu Baru as that of Ulu Kali suite. Both suites vary from biotite granodiorite to muscovite leucogranite. Porphyritic phase with large K-feldspar phenocrysts are common. U-Pb zircon ages for this portion of the Main Range range from 198 to 215 Ma (Liew, 1983). These are silica-rich granites with SiO_2 values from 73.27 to 75.58% (Yeap, 1980).

Both suites give similar shaped REE patterns (Fig. 2G, 2H). They have similar ΣREE content (Table 6), similar LREE enrichment and similar small to moderate negative Eu anomalies.

Kuala Pilah represent the southern portion of the Main Range granite. The samples collected is part of the Tampin batholith with radiometric age of 217 Ma (Bignell and Snelling, 1977). This granite has a familiar ΣREE pattern (Fig. 2I) showing the typical West Coast REE pattern with LREE

Table 3. REE content in samples from Taiping.

	85/11 K Bruas	85/12 K Papan	85/14 Sg. Siput	85/15 Bt. Berapit	85/16 Taiping	85/17 Taiping
La	83	54	48	33	45	65
Ce	153	113	90	62	90	130
Nd	98	60	58	28	44	62
Sm	10.9	12.0	6.6	6.8	9.2	8.5
Eu	0.39	0.37	0.91	1.02	0.4	1.6
Tb	1.3	2.7	0.8	1.7	2.3	1.0
Dy	11.1	22.1	5.8	8.8	25.7	13.0
Yb	3.5	11.5	2.0	2.0	9.6	2.8
Lu	0.63	1.20	0.28	0.30	1.21	0.34
ΣREE	362	277	212	143	227	284
$(La/Yb)_{cn}$	13.40	4.70	17.82	11.78	3.82	19.09
Sm/Nd	0.11	0.20	0.11	0.24	0.21	0.14
Eu/Sm	0.04	0.03	0.14	0.15	0.04	0.18

Table 4. REE content in samples from Gunung Kledang.

	G23	G24	G25	G26	G27	G29
La	60.52	45.83	56.87	45.59	37.82	58.54
Ce	126.6	117.3	144.7	117.4	98.3	135.8
Nd	63.95	70.91	72.45	79.01	83.68	76.64
Sm	12.14	19.61	21.81	15.05	13.32	11.30
Eu	0.82	0.23	0.23	0.34	0.09	0.71
Tb	1.14	4.51	4.36	4.07	4.36	1.73
Dy	9.62	18.30	19.40	16.90	18.51	7.19
Yb	3.14	6.70	5.64	7.79	4.91	5.81
Lu	0.83	2.84	2.88	2.19	2.19	2.15
ΣREE	278	286	328	288	263	299
$(La/Yb)_{cn}$	7.5	1.67	1.85	2.16	1.79	2.83
Sm/Nd	0.19	0.27	0.30	0.19	0.16	0.15
Eu/Sm	0.07	0.01	0.01	0.02	0.01	0.06

Table 5. REE content in samples from Cameron Highland.

	85/2 Quarry	85/3 Lata Iskandar	85/4 Km 2	85/5 Chende-riang	85/6 Chende-riang	85/7 Temoh-Kampar	85/8 Kampar	85/9 Kampar	85/10 Kuala Dipang
La	38	48	45	45	47	51	47	44	50
Ce	86	111	87	91	103	124	83	98	96
Nd	56	53	40	44	60	66	53	76	61
Sm	7.2	10.3	7.7	4.0	8.7	9.7	9.1	7.5	8.5
Eu	0.9	0.65	0.6	0.6	0.7	1.2	1.08	1.18	1.25
Tb	1.2	2.6	1.3	1.5	1.2	1.5	1.3	1.0	1.3
Dy	8.0	18.1	15.9	12.7	21.7	10.4	10.2	9.0	9.0
Yb	3.8	4.7	4.7	4.9	6.3	4.4	4.5	3.5	3.5
Lu	0.43	0.46	0.45	0.61	1.01	0.55	0.49	0.47	0.47
ΣREE	210	249	203	204	248	268	210	241	231
$(La/Yb)_{cn}$	9.36	11.07	10.36	7.63	4.90	9.71	10.13	9.47	10.73
Sm/Nd	0.113	0.19	0.19	0.09	0.15	0.15	0.17	0.10	0.14
Eu/Sm	0.12	0.06	0.08	0.15	0.08	0.12	0.12	0.15	0.15

Table 6. REE content in samples from Kuala Kubu Baru and Kuala Lumpur.

	KUALA KUBU BARU					KUALA LUMPUR		
	85/1 Kalum-pang	86/1 KK Baru	86/2 KK Baru	86/6 Sg. Sangka Dua	86/4 Sangka Dua	G3 UK Heights	G5 Yulek Heights	G7 Bt. Lanjan
La	73	59	40	25	58	18.03	19.35	12.64
Ce	135	109	76	53	123	65.42	124.52	49.10
Nd	57	50	45	24	60	37.55	28.26	55.56
Sm	10.8	8.2	7.1	4.7	9.8	6.09	7.89	4.76
Eu	1.25	0.68	0.55	0.70	0.83	0.43	0.82	0.40
Tb	1.5	2.1	1.3	0.9	1.9	1.28	1.51	1.22
Dy	10.3	122.1	16.6	7.4	12.9	7.80	14.38	7.41
Yb	4.0	9.5	8.1	2.9	5.6	3.84	4.95	7.39
Lu	0.46	0.56	1.25	0.15	0.38	1.50	3.06	2.14
ΣREE	293	361	195	119	272	142	205	258
$(La/Yb)_{cn}$	16.79	11.18	3.31	16.20	15.58	19.53	0.65	1.54
Sm/Nd	0.19	0.16	0.16	0.19	0.16	0.16	0.27	0.09
Eu/Sm	0.11	0.08	0.07	0.15	0.08	0.07	0.10	0.06

enrichment $(La/Yb)_{cn}$ 7.82–10.52, small to moderate negative Eu (Eu/Sm 0.08–0.12).

Towards the southern part of West Coast Province, two batholiths, Gunung Ledang and Batang Melaka and another one in Gunung Pulai, over a hundred kilometers to its south, show many differences with those of the Main range. Age determinations (Bignell and Snelling, 1977) gave late Cretaceous age, and Liew (1983) marked them as anorogenic granites. These are epizonal pinkish, medium to coarse grained and usually equigranular adamellite granite. Gunung Ledang granites with SiO_2 ranging from 74.48 to 74.58% are also of high silica type.

Their REE patterns are remarkably different (Table 7, Fig. 2J). Gunung Ledang samples have higher ΣREE (205–231 ppm) compared to those of Batang Melaka (106–132 ppm). They are strongly enriched in LREE components and low HREE, with $(La/Yb)_{cn}$ values ranging from 7.40 to 20.06. But the most outstanding difference is the absence of negative Eu anomaly (Eu/Sm 0.14–0.21) in their REE pattern. The absence of the negative Eu anomaly reflects the chemical composition of their parental source. Gunung Pulai batholith has similar petrographic and tectonic characteristics to that of Ledang and Melaka. Its similarity is supported by REE evidence by having similar REE characteristics (Fig. 2K), although its ΣREE is somewhat lower ranging from 140 to 165 ppm (Table 7).

ii) Central Province

Central province contain a narrow line of granitoids through Gunung Benom to Stong Complex in the northern-most end.

Gunung Benom batholith has been studied by Jaafar (1976). This granite is a coarse-grained non-porphyritic biotite granite of Triassic age. The non-porphyritic nature of this granite is distinctly different from those of the Main range and its high level intrusion led Hutchison (1977) to it as an epizonal granite. It has been dated by Bignell and Snelling (1977) and revised by Darbyshire (1988) as 207 Ma. Benom granite has a lower SiO_2 content varying from 68.18 to 72.66% (Yeap, 1980).

REE pattern of Benom samples show high enrichment of LREE components $(La/Yb)_{cn}$ 9.49–22.73 with a moderately strong negative Eu anomaly (Eu/Sm 0.09–0.23) and a rather high ΣREE (181–354 ppm) (Table 9, Fig. 3A).

Bukit Kajang granite body, a small batholith to the north of Gunung Benom, is associated with the gold mineralization of Raub. This granite is of low silica with SiO_2 of 67.89% (Ahmad Sabri, 1991). Three samples Bukit Kajang granite have been analysed for their REE and they show a relatively high ΣREE contents (241–414 ppm), enrichment of the LREE components $(La/Yb)_{cn}$ 9.04 to 15.53 and have moderately strong negative Eu anomaly (Eu/Sm ratios 0.03–0.01) (Table 9). The REE pattern shows similarity of Bukit Kajang granite to that of Gunung Benom (Fig. 3B).

Further to the north of Bukit Kajang, a number of granite plutons are found ending in the Stong Complex. For this work they are grouped as granites of Gua Musang and its neighbourhood. The five samples analysed were taken from four different batholiths, ranging from Noring in the Stong complex, through Senting to the west of Gua Musang, Gua Musang itself, Damar east and finally

Table 7. REE content in samples from Kuala Pilah-Gunung Ledang-Batang Melaka-Gunung Pulai.

	Kuala Pilah		Gunung Ledang			Batang Melaka			Gunung Pulai	
	86/9 Transmitter station	86/10 Quarry	89/3 Sagil	89/4 G. Ledang	89/5 Kuari Tangkak	89/6 Kuari Jasma	89/7 Bt. Senggeh	89/8 Bt. Senggeh	89/1 Kobena Quarry	89/2 Water works
La	58	44	57	56	49	34	27	25	33	46
Ce	113	96	113	100	98	61	47	48	60	77
Nd	47	27	47	46	46	29	24	28	34	32
Sm	9.4	6.5	7.03	5.51	6.22	3.90	3.85	4.57	4.73	4.02
Eu	1.09	0.53	1.02	0.90	1.05	0.82	0.84	0.79	0.90	0.85
Tb	1.7	1.1	0.5	0.6	0.5	0.4	0.3	0.4.	0.5	0.4
Dy	11.9	7.1	3	2	3	2	n.d.	3	4	3
Yb	4.8	2.5	2.2	1.3	1.8	1.6	1.3	1.3	2.3	1.9
Lu	0.58	0.57	0.57	0.29	0.31	0.26	0.28	0.35	0.46	0.25
ΣREE	247	185	213	212	205	132	106	111	140	165
$(La/Yb)_{cn}$	7.82	10.52	10.33	20.06	14.46	13.59	16.46	7.40	7.44	19.02
Sm/Nd	0.20	0.24	0.15	0.12	0.14	0.14	0.16	0.16	0.13	0.13
Eu/Sm	0.12	0.08	0.14	0.16	0.17	0.21	0.17	0.17	0.19	0.21

n.d. = not determined

a quarry to the south of Kuala Lipis. No age datings available for these granite bodies except for that in the Stong Complex that has been identified as late Cretaceous (Hutchison, 1989).

Despite their diverse occurrence, they amazingly show similar REE characteristics (Fig. 3C). They all have rather high ΣREE contents (205 to 282 ppm), enrichment of the LREE components with $(La/Yb)_{cn}$ values 11.82 to 68.66 (Table 8), and small hardly noticeable negative Eu anomalies. On this point they are different from those described from the West Coast Province. Their HREE component show depletion towards the heavy elements and are different from those of Ledang-Melaka-Pulai. These Gua Musang granites, on account of their similar REE patterns, may represent another collection of Cretaceous granites that may or may not be related to the Cretaceous granites of the southern Peninsular.

iii) East Coast

The East Coast granite is in many ways different from the West Coast granite. Tectonically they are epizonal (Hutchison, 1977). Because they are of high level, pegmatite occurrence is seldom decscribed from the east coast although they are widespread in the West coast. Mineralogically, in certain batholiths hornblende is common in the granites. Liew (1983) showed that the East Coast province granite consist of S-type and I-type granite of Chappel and White (1974) or the Ilmenite-magnetite series granite of Ishihara (1977). The

Table 8. REE content in samples from Gua Musang and adjacent.

	Rb 25 Senting	Rb 29 G. Musang	BM 4/85 Noring	Rb 39 Usha Tenaga	Rb 38 Damar East
La	51.8	59.8	64	47.4	68.2
Ce	106.3	125.6	130	105.6	148.4
Nd	n.d	n.d.	75	41.8	n.d
Sm	8.3	8.3	7.0	7.7	12.7
Eu	1.7	1.3	1.30	1.4	1.9
Tb	0.8	0.7	0.6	0.5	0.7
Dy	8.5	7.8	3.1	4.1	6.5
Yb	2.0	1.0	1.2	0.3	1.0
Lu	0.04	0.03	0.1	0.1	0.6
ΣREE	252	205	282	209	240
$(Lu/Yb)_{cn}$	13.6	20.74	68.66	47.30	11.82
Sm/Nd	n.d	n.d	0.09	0.18	n.d.
Eu/Sm	0.20	0.16	0.19	0.18	0.15

n.d. = not determined

Table 9. REE content in samples from Gunung Benom and Bukit Kajang.

	GUNUNG BENOM				BUKIT KAJANG		
	86/7 Sg. Ruan	Rb 48 Lata Jarum	G 48 Sg. Chalit	86/8 Ulu Dong	Ra 7 Bt. Kajang North	Rb 46 Bt. Kajang North	Rb 50 Sg. Sempan
La	47	63.3	111	68	122.5	67.8	75.9
Ce	85	136.3	218	138	249.1	150.3	166.0
Nd	29	n.d	n.d.	53	n.d	n.d	n.d.
Sm	6.0	10.0	12.93	9.6	17.6	10.9	13.3
Eu	0.93	0.9	3.05	0.91	0.6	0.3	0.2
Tb	0.7	0.9	0.67	1.3	1.7	0.9	1.2
Dy	9.7	9.0	7.27	11.9	17.4	8.9	12.8
Yb	3.2	3.1	3.16	3.4	5.1	2.3	3.7
Lu	0.33	0.3	0.35	0.43	0.5	0.2	0.1
ΣREE	181	224	354	286	414	241	273
$(Lu/Yb)_{cn}$	14.20	21.90	34.30	15.90	15.53	'9.04	13.25
Sm/Nd	0.20	n.d.	n.d.	0.18	n.d.	n.d.	n.d.
Eu/Sm	0.16	0.09	0.02	0.09	0.03	0.02	0.01

n.d. = not determined

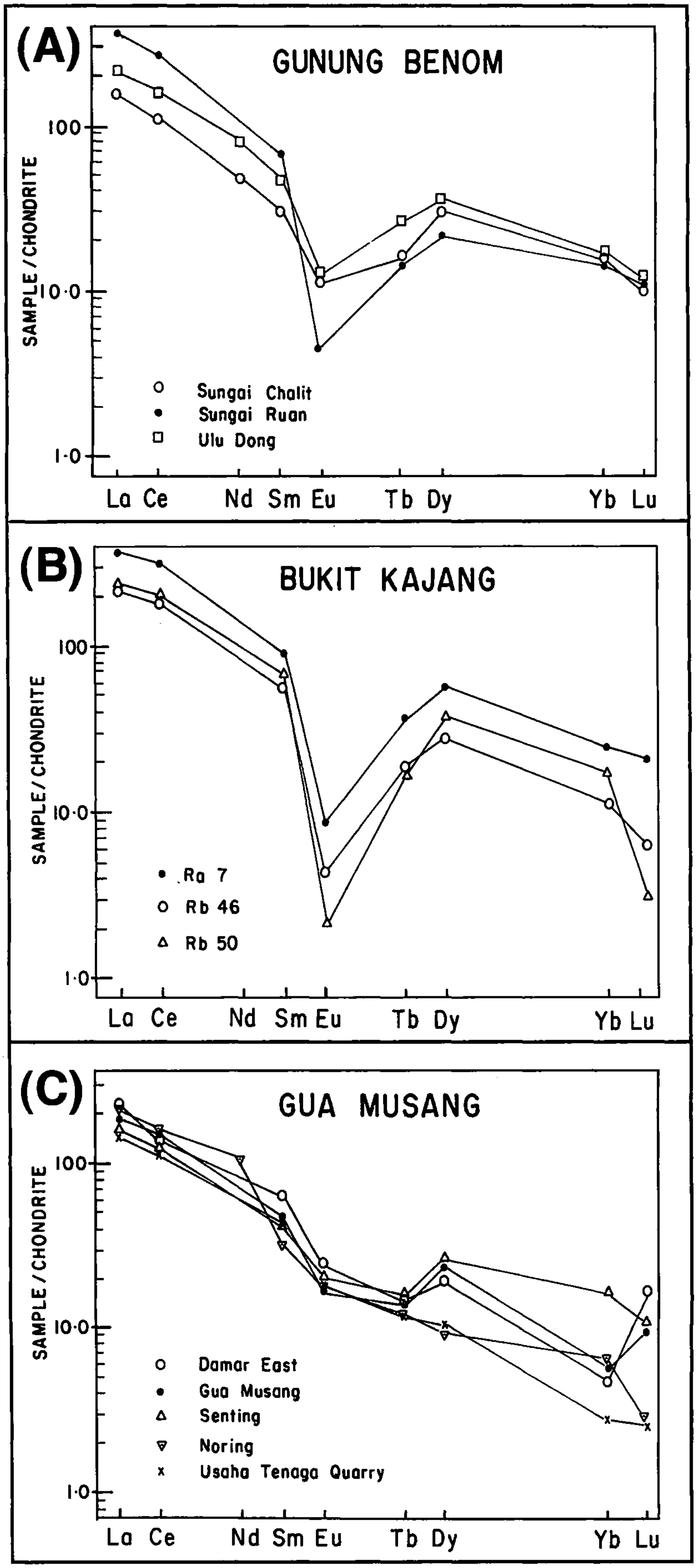

Figure 3A to 3C. REE patterns of granite batholiths of the Central Province of Peninsular Malaysia.

East Coast Province has been subdivided into two subprovinces. Subprovince A consists of batholiths from Kuantan to Kelantan, has a mixed S and I affinity and a Nd-Sr, U-Pb zirconium age of 265 to 230 Ma, while that of subprovince B, those in south east Johor and Singapore, has I-type characteristics and has Nd-Sr isotopic age of 230 Ma.

Limited samples have been taken for the present work. Five samples were analysed, four samples from the northern and middle part of subprovince A and one sample representing subprovince B.

Two samples from the northern subprovince were taken from the Boundary Range granites. They have wider range of silica values ranging from 67.02 to 75.13% (Yeap, 1980). Each of them have different REE characteristics. The Bukit Buluh sample has low ΣREE content (140 ppm), small LREE/HREE (0.62) and moderately strong negative Eu anomaly (Eu/Sm = 0.08) while the Bukit Marak sample has high ΣREE content (278 ppm), stronger LREE enrichment (La/Yb)cn 1.49 and small negative Eu anomaly (Eu/Sm 0.17) (Table 10, Fig. 4A). Liew (1983) pointed out that the I-type granite on the East Coast province consistently has small negative anomaly. Hence the two samples analysed is likely to represent granites of different types; S- and I-type.

Maras-Jerong granite near Marang is said to be related to the gold mineralization in the area. Liew (1983) identified them as I-type granite. Two samples from Marang, taken from Maras Jerong granite reveal that they have wide range of ΣREE content (85–327 ppm), are strongly enriched in LREE and depleted in HREE, with $(La/Yb)_{cn}$ 21.50–21.73 (Table 10) and small negative Eu anomalies (Eu/Sm 0.22–0.23) hardly noticeable by eye (Fig. 4B). These two samples certainly is different from the Main Range granite of the West Coast.

One sample was taken from Jemaluang quarry representing the subprovince B. This granite has low ΣREE (169 ppm), slight LREE enrichment with $(La/Yb)_{cn}$ 1.86 and has strong negative Eu anomaly (Eu/Sm 0.001) (Table 10, Fig. 4C). This granite is certainly different from these of Marang or Bukit Marak and may well represent type-S granite. Jemaluang granite is associated with tin mineralization. Its strong negative Eu anomaly is similar to that of Gunung Kledang, which is similarly associated with tin mineralization.

DISCUSSIONS

It is observed from this work the that ΣREE in the Peninsular Malaysian granites range from 85 to 414 ppm. This range is small compared to the values quoted by Cullers *et al.* (1984). The Peninsular granite however are comparatively similar to the Triassic-Cretaceous Southern Thailand granites (Chengyu *et al.*, 1994). Both are associated with tin mineralizations.

Among the various batholiths of the Peninsular, the Langkawi batholith with ΣREE ranging from 110–232 ppm contains the lowest amount. Others are relatively high with values generally exceeding 200 ppm. Bukit Kajang granite apparently has the highest ΣREE with values from 241 to 414 ppm.

Among the Cretaceous granites of the southern peninsular, the Melaka and Pulai batholiths have generally low ΣREE with values being below 200

Table 10. REE content in samples from Northern Kelantan-Marang-Jemaluang.

	NORTHERN KELANTAN		MARANG		JEMALUANG
	G13 Bt. Buluh	G 14 Bt. Marak	23/5A Bt. Jerong	24/5E Bt. Temiang	Rb 68.1
La	12.6	44.97	90.0	23.5	30.5
Ce	49.1	142	170	51.	84.8
Nd	55.6	56.08	46.1	n.d.	n.d.
Sm	4.8	7.17	8.53	3.6	13.0
Eu	0.4	1.23	2.0	0.8	0.02
Tb	1.2	1.22	0.65	0.4	2.1
Dy	7.4	18.04	3.7	4.5	25.3
Yb	7.3	4.29	2.7	0.7	12.3
Lu	2.1	3.12	0.33	0.2	1.7
ΣREE	140	278	327	85	169
$(La/Yb)_{cn}$	0.62	1.49	21.50	21.73	1.86
Sm/Nd	0.08	0.12	0.18	n.d.	n.d.
Eu/Sm	0.08	0.17	0.23	0.22	0.001

n.d. = not determind

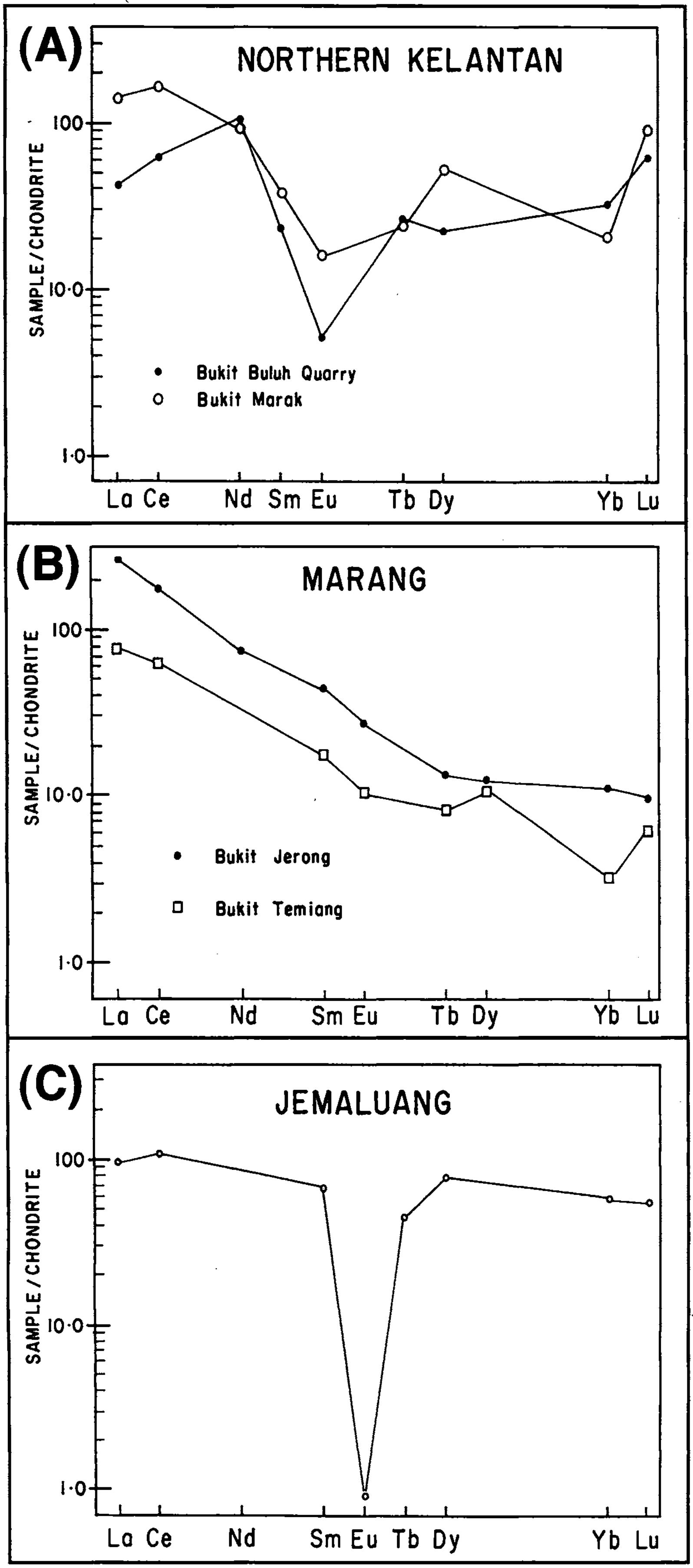

Figure 4A to 4C. REE patterns of granite batholiths in the East Coast Province of Peninsular Malaysia.

ppm while that of Gunung Ledang is similar to that of the Main range, exceeding 200 ppm in value.

Noring granite, also of Cretaceous age, has ΣREE value exceeding 200 ppm and is different from the Cretaceous granites of the southern Peninsular. The Malaysian granites do not show ΣREE enrichment through time unlike those described from the Schwarzwald region of West Germany (Emmermann *et al.,* 1975)

From the shapes of REE patterns obtained, two main types are observed, a) "bird-wing" shape with pronounced negative Eu anomaly, and b) simple concave-upward shape without pronounced Eu anomaly. The shape of the REE patterns as pointed by previous workers is much related to the source material of the granite. Granites with large negative anomalies, high concentrations of REE and high LREE/HREE ratios require a source with abundant plagioclase and small amounts of garnet, amphibole, or pyroxene (Henderson, 1984) Such source include greywackes, metapelites, metaquartz diorites and siliceous granulites (Hanson, 1980). Looking at REE patterns of the Malaysian granites, most of the Triassic West Coast batholiths have patterns associated with the plagioclase-rich source.

REE pattern for Langkawi granites show a mixture of weak to moderately strong negative Eu anomalies. Chengyu *et al.* (1994) have analysed two siltstone samples from the Machinchang formations of Langkawi, and obtained patterns with weak negative Eu anomalies. They suggest that the Thailand granites may originate by partial melting of such material. A similar sedimentary source material may be the parent material for the Langkawi granites.

The high-level Cretaceous granites of Gunung Ledang, Batang Melaka and Gunung Pulai certainly originate from a different source from those of the Main Range. Hutchison (1977) from Rb-Sr and Sr isotope ratios suggested that it originate from a primitive mantle origin through a tectonic dislocation zone.

In the Central Province, granitoids in the Gua Musang area have no apparent negative Eu anomaly. They are different from those of Gunung Benom and Bukit Kajang. Texturally they are different from the Cretaceous granites of southern Peninsular although age wise, the Noring granite has been identified as Cretaceous. Based on their REE patterns, they are more similar to the Noring granite, and may yet be another group of Cretaceous granites that may or may not be related to the Cretaceous granites of southern Peninsular.

In the East Coast province, although samples are limited, patterns obtained indicate there are two types of patterns; one prominent negative Eu anomaly and another with small negative Eu anomaly. In the north Kelantan, the two samples analysed represent two sample types. Liew (1983) identified the Bukit Marak granite as the I-type whereas the Bukit Buluh granite as the S-type.

The Maras-Jerong samples without the negative Eu anomaly is most probably the I-type granite. Down south in Jemaluang, the granite shows a sharp negative Eu peak, and this is more likely to be an S-type granite similar to those of the West Coast. Although Hutchison (1989) noted that the granitoids of this terrain is more akin to I-type, the existence of "bird-wing" pattern in the Jemaluang granite suggest the existence of S-type granite in the B subprovince.

CONCLUSIONS

Based on the REE patterns, the granites of Peninsular Malaysia can be divided into two main types; a) those having distinct negative Eu anomaly, and b) those having small or no Eu anomaly. In the West Coast Province all the Triassic granites have small to moderate negative Eu anomalies. The late Cretaceous high-level granites of Gunung Ledang, Batang Melaka and Gunung Pulai have REE pattern similar to one another and they do dot have visible Eu anomaly. In the Central Province, the group of granites around Gua Musang similarly do not posses Eu anomaly. In the East Coast province, granite with and without Eu anomalies are both present. The Maras-Jerong granite is without Eu anomaly.

Granite without Eu anomalies are of different types. The late Cretaceous, high-level post -orogenic granite in the southern Peninsular, based on their Sr isotope evidence, originates from a primitive mantle source unlike the Main Range granites which are derived from a sialic basement source. Though substantive data is lacking, those non-Eu anomalous granites around Gua Musang have similar REE pattern to the Noring granite of the northern Central Province. The granites in the Stong Complex including the Noring granite has been established as late Cretaceous. On this evidence the Gua Musang group of granites may have a common relationship to the late Cretaceous granites of southern Peninsular.

In the East Coast province the presence or absence of Eu anomaly is related to the granite type. S-type granites, like those in the West Coast, have prominent Eu anomalies whereas the I-type granite show no prominent Eu anomaly. The source material for the I-type granite, based on Sr isotope evidence, is the oceanic or a more primary mantle material.

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