Geochemistry of mafic dykes from Perhentian and Redang islands: an example of petrogenesis of the younger (dolerite) dykes from the Eastern Belt of Peninsular Malaysia

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Abstract: Mesozoic mafic dykes in the Perhentian islands and their surrounding area can be divided into two types, based on their field occurrence, i.e. the older and younger dykes. The older dykes are synplutonic to their felsic host and the younger dykes post date their felsic host. The younger dykes, which are more abundant, are mainly doleritic in composition and are similar to those found throughout the Eastern Belt of Peninsular Malaysia. They are made up of plagioclase, clinopyroxene, amphibole, iron ore and chlorite. The silica content of the dykes is between 47.17 to 53.7% and can be classify as basalt, trachybasalt and basaltic trachyandesite. Geochemical study shows that the younger dykes formed in a continental within plate tectonic setting.

INTRODUCTION

One of the Mesozoic igneous events in the Eastern Belt of Peninsular Malaysia is the intrusion of mafic magmatism as dykes. These dykes are without doubt the most neglected aspect of the igneous province in Peninsular Malaysia. The dykes, intruding both intermediate to felsic igneous rocks and older layered rocks, are found widespread, not only in the mainland but also in several islands off the East Coast Peninsular Malaysia (Haile *et al.*, 1983; Azman, 1992; 2000a, b; Azman *et al.*, 1998). Despite being abundant in many parts of the area, they have to date received little consideration in regional models. A complete field and geochemical based study, which comprises data for the dykes in this region, does not, as yet, exist. Such a study is an important step to fully constrain the wholly mantle derived magma composition which were available throughout the second half of the Mesozoic time.

This paper presents the geochemical data of the mafic dykes from the Perhentian and Redang islands, Terengganu (Fig. 1). In this area, two groups of dykes have been identified, that is the younger and the older dykes. The subdivision is based on the relative age of the dykes with their host rocks (Azman, 2000a, b, 2002 in press). The dykes extensively intruded both the metasediments and igneous rocks of the islands (Fig. 1). Studies show that the younger ones are more abundant and are found intruding the Eastern Belt igneous and sedimentary rocks (e.g. Haile *et al.*, 1983; Azman *et al.*, 1998).

GENERAL GEOLOGY

The Perhentian and Redang islands are situated at the northern part of the Eastern Belt of Peninsular Malaysia and west of the Tertiary Malay Basin. The Perhentian islands consist of several islands, the biggest of which are Perhentian Kecil and Perhentian Besar (Fig. 1). The area is underlain by metasedimentary rocks and intruded by a series of igneous rocks ranging from granitic to syenitic compositions. They are considered as part of the Eastern belt magmatism of Peninsular Malaysia (Cobbing & Mallick, 1987). The metasedimentary rocks are represented by slate, quartzite, pelitic hornfels and calc-silicate hornfels (Azman, 1992; Azman & Khoo, 1998)

Two igneous plutons were identified in the Perhentian island namely the Perhentian Kecil syenite and the Perhentian granite, which intruded the metasediments (Azman, 2001). The Perhentian Kecil syenite forms a circular outcrop at the central part of Perhentian Kecil Island. Although from the map, it appears to intrude the surrounding granite body, field evidence shows that the Perhentian granite is relatively younger than the Perhentian Kecil syenite (Azman & Khoo, 1998). The pluton consists of a variety of igneous rocks ranging in composition from syenitic to monzonitic and even gabbroic. In terms of percentage, the syenitic rock totals almost 90% of the pluton. Epidote nodules and veins (thickness from 2 to 5 cm) can be seen throughout the pluton. The Perhentian granite has been divided into 2 varieties by Cobbing and

Mallick (1987) namely hornblende-bearing and hornblende-free granite. The main body of Perhentian granite consists of medium to coarse grained biotite granite (hornblende-free granite) exposed along the coast of Perhentian Besar Island, north and south part of Perhentian Kecil Island and the whole of Rawa Island (Fig. 1). Microgranite and granite porphyry are found at the contact with Perhentian Kecil syenite. Occasionally the microgranite contains pegmatite patches characterized by large plates of muscovite, biotite and K-feldspar. Field, petrography and chemical evidence suggest that the Perhentian Kecil syenite and Perhentian granite are not co-magmatic (Azman & Khoo, 1998; Azman, 2001).

The Redang group comprises the islands of Redang and Pinang and several islets. The Redang island is underlain by Redang and Pinang beds which have been thermally metamorphosed by the Redang granite. The granite is bordered by more basic tonalitic rocks (Yaw, 1977). Fossils plants (*Taenopteris, Pecopteris* and others) discovered in chiastolite bearing black slate of the Redang beds resemble Permain species (Khoo *et al.*, 1988)

FIELD OCCURRENCE OF THE MAFIC DYKES

The best dykes' exposure can be found along the coastal area. As mentioned earlier, the dykes can be divided into two groups based on their relative age to the host rock i.e. the older and younger dykes. The older dykes are coeval to their felsic host and younger dykes post-date their felsic host. The older dykes are rarely found and they are more likely to intrude the syenitic rocks (Azman, 1998) compared to the younger dykes which is more abundant.

The younger dykes are green to dark green in colour with average thickness ranging from 10 cm to 3 meters. A total of 23 younger dykes were found to intrude all the three main rock types in the study area. The thicker dykes commonly show chilled margin and a regular inward increase of grain size. Angular to sub-angular inclusions of granitic host up to 0.5 m across are occasionally found in the dykes. In the Perhentian Besar Island, at Pasir Tiga Ruang, three dykes converge to form a dyke. The dykes are sometimes intruded by yellowish green epidote veins with average thickness of 15 cm. Amygdales filled with calcite, zeolite, quartz and analcite are sometimes found in the dykes.

PETROLOGY

The dyke rocks are made up of plagioclase, clinopyroxene, amphibole, iron ore and chlorite. In general the texture is either intergranular or subophitic. The rocks are often chloritised to varying degrees and in the most extreme case contain up to about 60% modal chlorite. Pale green fibrous uralite may be present within chlorite. MacDonald (1967) suggested that both chlorite and uralite are late magmatic phases. Plagioclase crystals occur as small subhedral to euhedral laths, which do not show any preferred orientation. The crystals sometimes show twinning but rarely zoning. Clinopyroxene, mainly augite, generally subhedral to anhedral, occurs as interstitial grains between plagioclase laths forming a typical doleritic texture. Lamprobolite (basaltic hornblende), if present, is usually less than 5% of total rock. This mineral is characterised by its brown colour. Common pleochroism is X = light yellow; Y = brown and Z = dark red brown. In some samples,

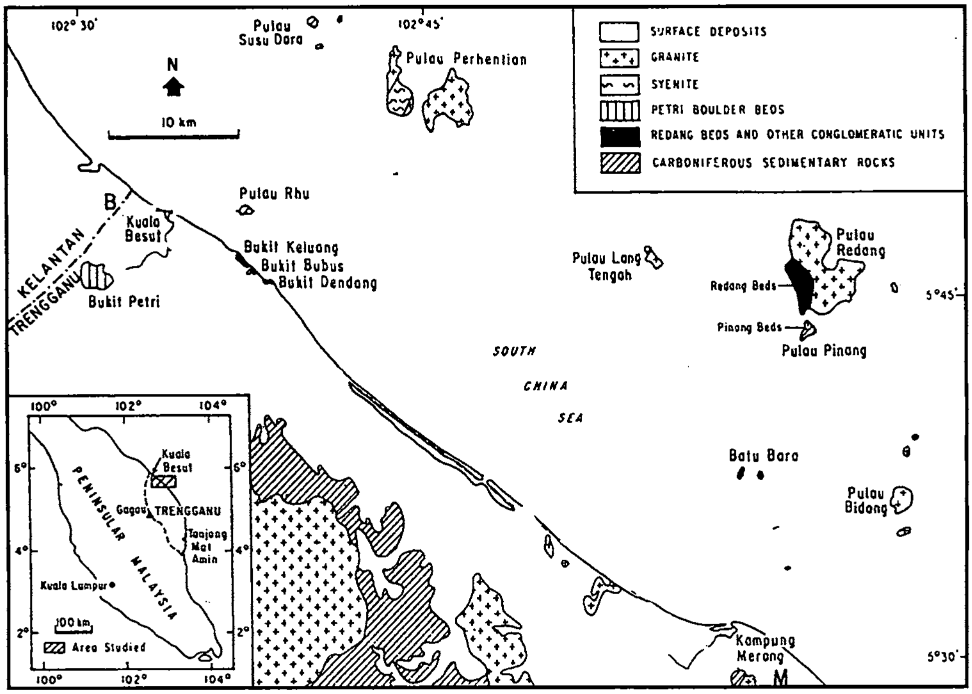

Figure 1. Geological map of the Perhentian Island and their surrounding area.

euhedral to anhedral iron ore can constitute up to 10% of total rock. MacDonald (1967) showed that ilmenite is the main iron ore type in the quartz dolerite from the Eastern Belt. In rare cases, some interstitial calcite may occur.

GEOCHEMISTRY

Seven (six samples from Perhentian and a sample from Redang) dyke samples were analysed for major and trace elements composition. Five of these samples were also analysed for the rare earth elements (REE). All analyses were done at Department of Geology University of Liverpool. Major and trace elements were analysed on rock powders using Siemens sequential X-Ray spectrometer at Liverpool University. Calibration curves were based on international standards. Major and trace elements were measured using fused glass disc and pressed powder pellets respectively. The REE concentration was determined by using Inductively-Coupled Plasma (ICP) also located in the Department of Earth Sciences, Liverpool University.

Results of the major, trace and rare earth elements analysis is given in Table 1. The silica content of the dykes is between 47.17 to 53.7%. The dykes from the Perhentian area have relatively high MgO content (5.6 to 10.04%) compared to the dyke from Redang Island (3.24%). The former also has high Co and V and low TiO_2, K_2O and P_2O_5, Ba, Ce, La, Y and Zr. However it should be noted, that the sample from Redang island has very high Ba content (1,509 ppm) compared to those of Perhentian area (127–424 ppm). Selected major and minor elements plots against Zr and are given in Figure 2. Good positive correlation can be seen in the TiO_2, FeO (total) and P_2O_5 vs Zr plots. Some plots in Harker diagrams also produce a good correlation between the Perhentian and Redang rocks. This is evident from MgO, CaO and K_2O vs SiO_2 diagrams (Fig. 3).

On a total alkali silica (TAS) diagram (Fig. 4) five samples from the Perhentian plot in the basalt and one sample plot in the trachybasalt fields. The sample from Redang plots in the basaltic trachyandesite field. The dykes plot in the same field to those from the Terengganu Mainland (Azman *et al.*, 1998) (Fig. 4). On a TiO_2 vs K_2O vs P_2O_5 plot, all the samples plot in the continental fields (Fig. 5). Normative mineralogy of the dykes show that three of the analysed samples are quartz normative. In the basalt tetrahedron (Fig. 6), plots of the Perhentian and Redang rocks indicate that they have evolved from saturated (Ol-Di-Hy) to oversaturated (Di-Hy-Q) basaltic magmas ranging in composition from olivine tholeiite to quartz tholeiite. This is supported by the Zr/Y ratios, both elements being immobile during post magmatic alteration processes (van Gerven & Pichler, 1995). The Zr/Y ratios for the Perhentian and Redang rocks are between 3 to 5.5 which is characteristic of tholeiitic magma from elsewhere (Lesher *et al.*, 1986; MacLean & Barrett, 1993). This is evident from Zr vs Y diagram (Fig. 7) (MacLean & Barrett, 1993) where all the samples plot in the tholeiite or transitional field.

Rare earth elements

4 dolerite samples from the Perhentian were analysed for the rare earth elements (Table 1) and the chondrite normalised profile is shown in Figure 8. REE concentration show enrichment in the light REE (LREE) relative to the heavy REE (HREE) for all samples. In general all the samples from Perhentian show a similar profile except sample PH4 which has a significant negative Eu anomaly. This may be related to plagioclase fractionation. This is supported by the fact that the sample has the lowest Sr content among those analysed samples (Hergt *et al.*, 1989).

Table 1. Major, trace and rare earth elements analyses of the mafic dykes from the Perhentian and Redang islands.

Sample	PH4	PSD	PTRC	TBP	PTRE	TBND	REDOL
Location	PER	PER	PER	PER	PER	PER	RED
wt%							
SiO2	47.17	46.70	49.24	48.18	47.76	50.57	53.70
TiO2	1.13	0.98	1.54	1.46	1.49	1.10	2.01
Al2O3	16.78	15.24	16.95	16.79	16.69	17.54	15.26
Fe2O3*	8.89	8.99	10.22	10.29	10.12	9.58	10.39
MnO	0.11	0.11	0.11	0.14	0.11	0.12	0.18
MgO	8.07	10.04	6.99	6.80	7.77	5.60	3.24
CaO	11.08	9.55	8.19	8.25	8.05	8.01	6.52
Na2O	2.20	1.38	3.10	3.10	3.07	3.62	3.10
K2O	1.26	0.28	1.37	1.52	1.74	2.01	2.66
P2O5	0.10	0.22	0.41	0.28	0.36	0.20	0.69
LOI**	1.40	7.37	2.96	4.60	3.19	1.29	1.54
Total	98.19	100.86	101.08	101.41	100.33	99.66	99.28
ppm							
Ba	127	178	337	352	328	424	1509
Ce	28	20	36	42	53	41	62
Co	32	41	200	49	37	36	29
La	8	14	32	31	26	31	50
Nd	14	16	23	42	45	29	48
Ni	7	86	10	0	63	0	0
Pb	14	11	8	11	8	11	14
Rb	90	14	109	138	154	155	89
Sc	34	24	19	26	18	30	27
Sr	639	467	470	650	442	744	577
Th	3	7	3	6	2	4	0
V	212	194	152	199	175	207	109
Y	27	19	34	34	32	23	42
Zn	88	69	95	104	96	92	120
Zr	80	87	173	148	160	126	216
REE (ppm)							
La	9.8	39.01	41.86	21.05	41.86	21.05	31.73
Ce	20.4	83.14	84.67	48.59	84.67	48.59	73.55
Pr	2.48	8.65	9.5	5.47	9.5	5.47	8.48
Nd	10.9	38.4	42.8	24.5	42.8	24.5	40
Sm	2.8	7.92	10.2	5.21	10.2	5.21	8.9
Eu	0.87	1.73	2.9	1.43	2.9	1.43	3.7
Gd	2.89	6.5	8.7	4.2	8.7	4.2	6.95
Ho	0.49	1.21	1.7	0.78	1.7	0.78	1.21
Er	1.29	3.12	4.3	1.92	4.3	1.92	3.07
Dy	2.31	5.83	7.9	3.65	7.9	3.65	5.92
Yb	1	2.55	3.3	1.65	3.3	1.65	2.55
Lu	0.15	0.35	0.45	0.23	0.45	0.23	0.3

Location : PER : Perhentian island ; RED : Redang island
* Total iron as Fe2O3 , ** LOI : Loss of ignition , n.d : not determined

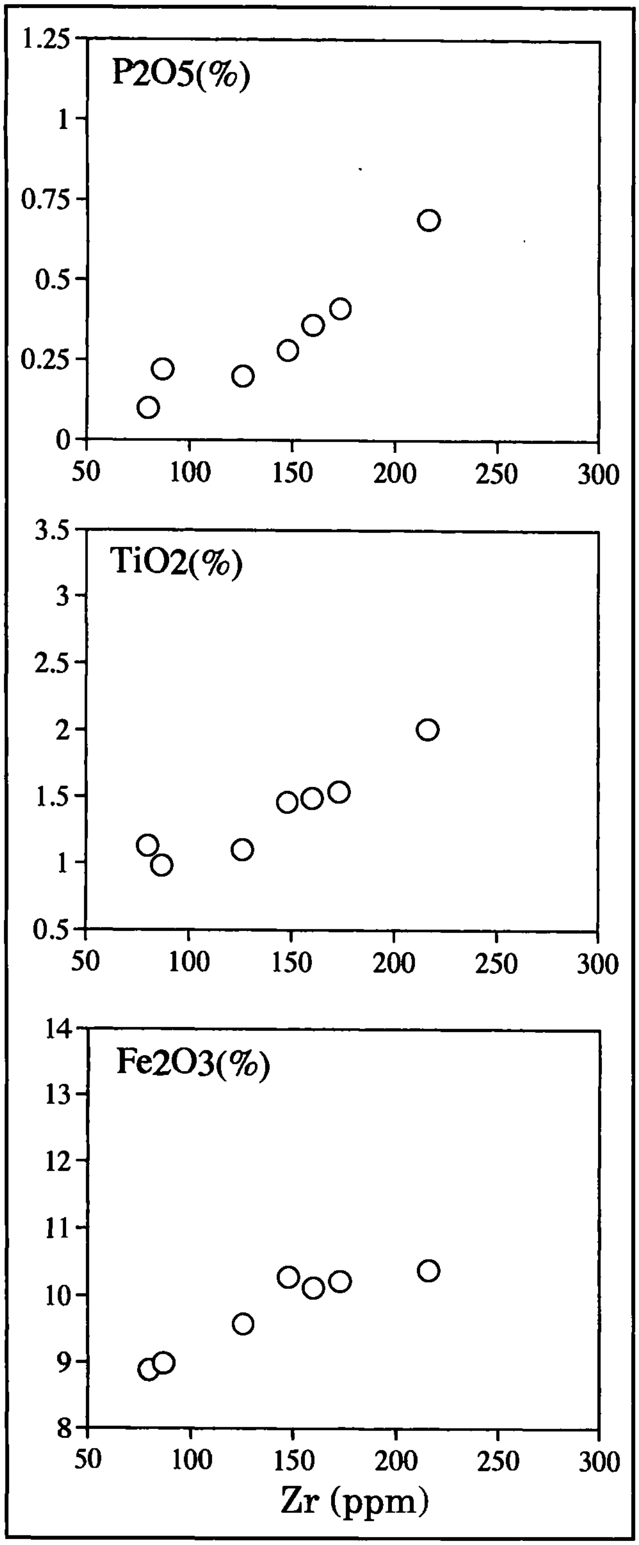

Figure 2. Zr vs Fe_2O_3, TiO_2 and P_2O_5 of the younger dykes from the Perhentian Island

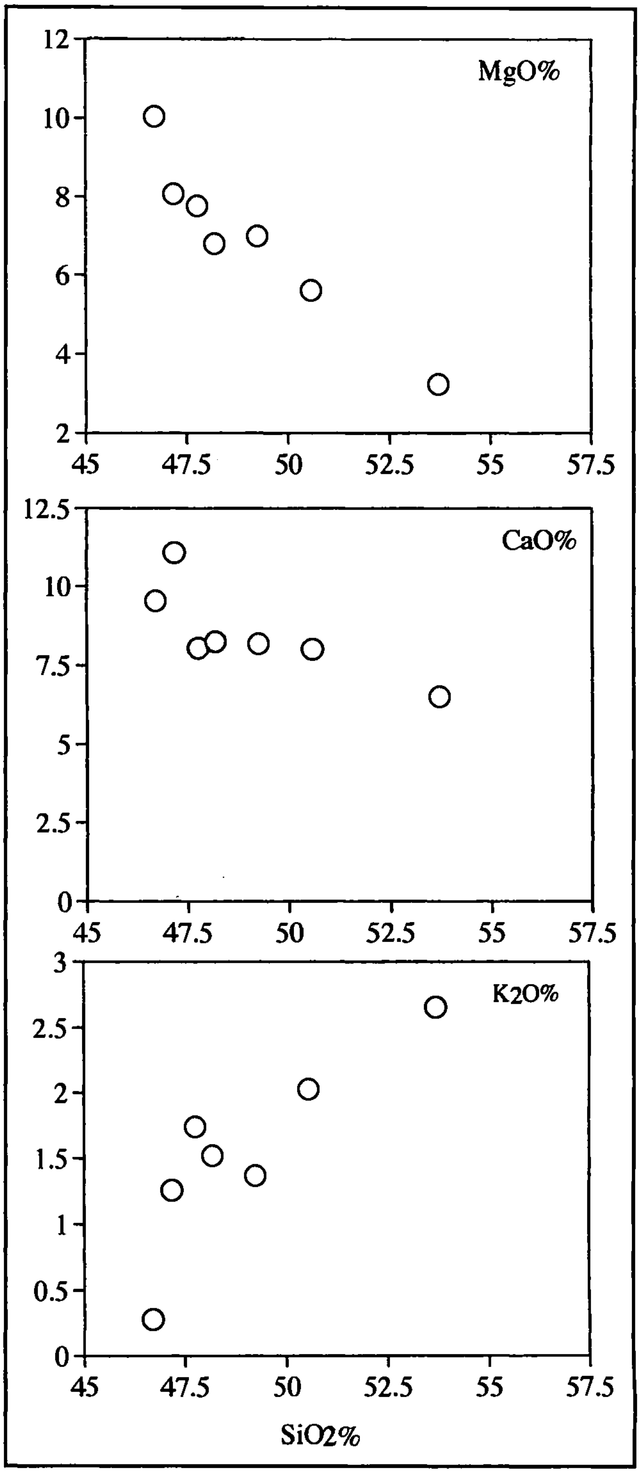

Figure 3. Selected Harker diagram of the younger dykes from the Perhentian Island.

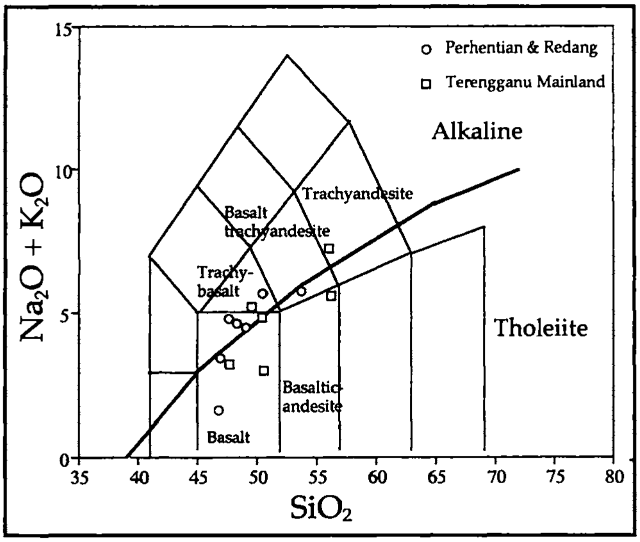

Figure 4. Total alkali ($Na_2O + K_2O$) vs SiO_2 for the dykes from the Perhentian Island.

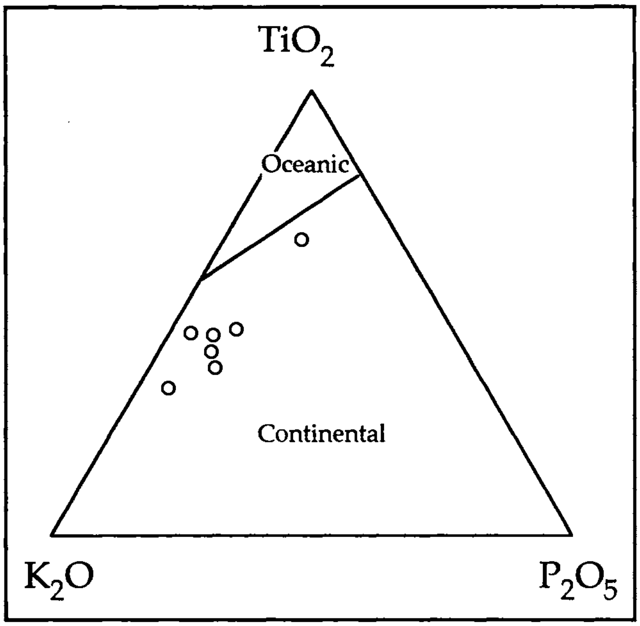

Figure 5. Ternary plot of TiO_2 vs K_2O vs P_2O_5 for the dykes from the Perhentian Island.

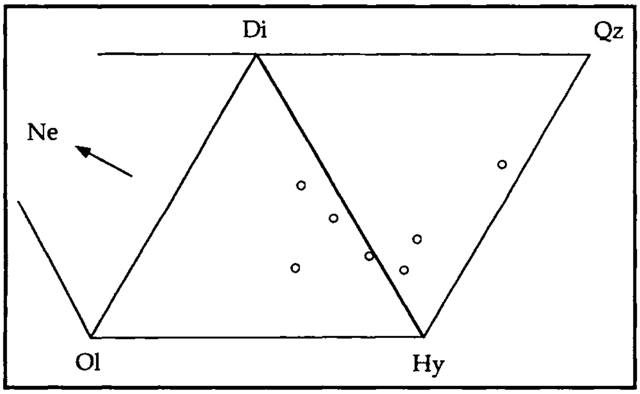

Figure 6. Normative mineralogy of the analysed dykes from the Perhetian island projected into the basalt tetrahedron.

Total REE decrease from 218 ppm in PTRC to as low as 55 ppm in PH4. The sample from Redang (REDOL) show a slightly different profile from those from Perhentian. It has a significant positive Eu anomaly which may be due to accumulation of plagioclase.

DISCUSSION

The overall geochemical similarities of the Perhentian and Redang dyke magmas indicate a common model of origin. This is evidence from most of the multi-elements bivariate plots (e.g. Fe_2O_3 vs Zr, TiO_2 vs Zr and MgO vs SiO_2). The relatively low MgO and CaO contents of the Redang sample may suggest that the dyke magma had undergone extensive fractionation before emplacement.

The bulk composition and the major element variation patterns of the dolerite from Perhentian-Redang area points to their evolution through crystallisation being controlled

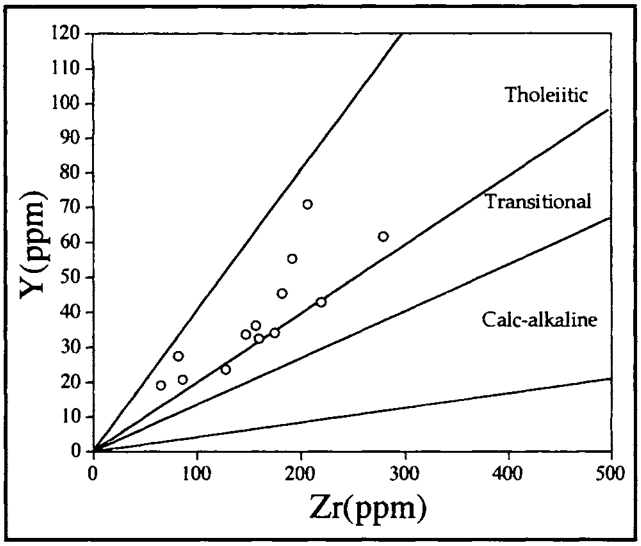

Figure 7. Y vs Zr plot of the mafic dykes from the Perhentian Island.

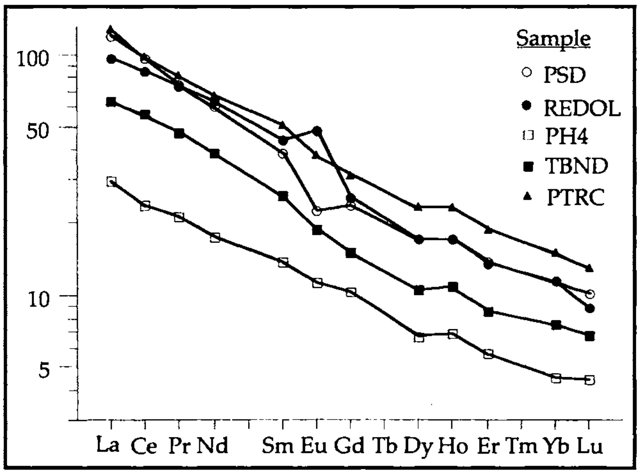

Figure 8. Chondrite normalised REE profile for Perhantian mafic dykes

by fractionation of clinopyroxene and plagioclase in the early stage. Furthermore, good positive correlation of some of the major and minor elements (TiO_2, FeO and P_2O_5) against Zr suggests the importance of fractionation of early phase mineral such as ilmenite and clinopyroxene in the magma.

Comparison of the dykes from Perhentian-Redang area to those of Terengganu mainland showed that they (Perhentian and Redang dykes) have more restricted TiO_2, Al_2O_3, Fe_2O_3 (total iron), low MnO and high Pb and Sr contents. The mainland dykes however plot in the continental basalt field in the TiO_2-K_2O-P_2O_5 diagram suggesting a common petrotectonic origin for the dyke magmas in the Eastern Belt area. The mainland dykes also evolved from saturated (Ol-Di-Hy) to oversaturated (Di-Hy-Q) composition similar to those from the study area.

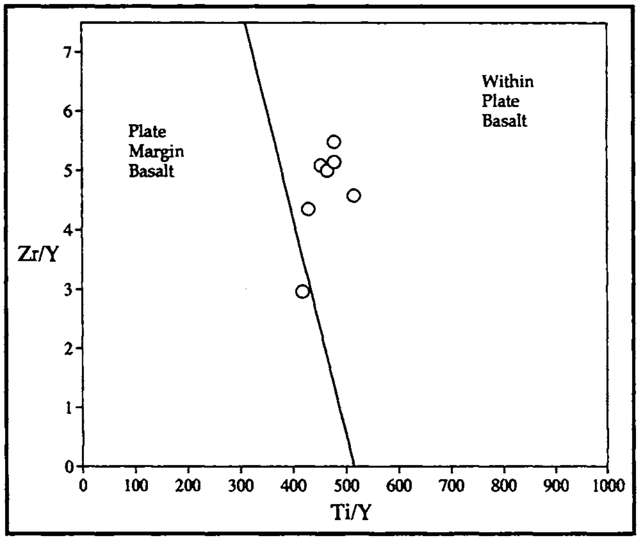

Figure 9. Zr/Y vs Ti/Y plot of the mafic dykes from the Perhentian Island.

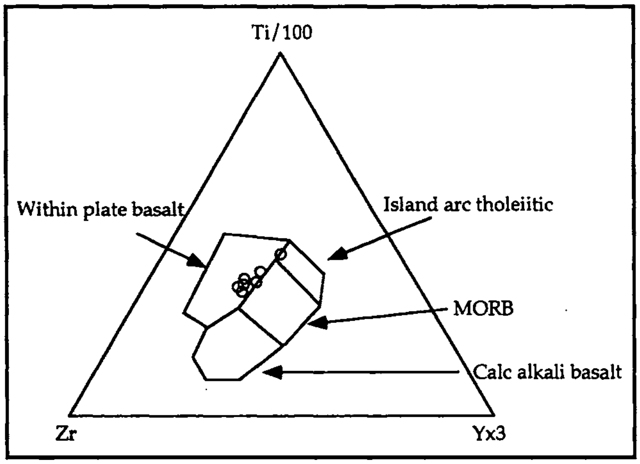

Figure 10. Ternary plot of Ti/100-Zr-Yx3. Fields from Pearce and Cann (1973).

Tectonic setting and magmatic affinities

Numerous studies have shown that immobile element compositions of basaltic rocks can be used to determine chemical affinities and tectonic setting, even after alteration (Pearce & Cann, 1973; Meschede, 1986). Many of the diagrams use high field strength elements such as Ti, Zr, Y and Nb and P which are thought to be relatively immobile in aqueous fluids unless there are high activities of F^-. On a plot of Zr/Y and Ti/Y (Fig. 9), the majority of the samples plot in the within plate basalt field. On a plot Ti-Zr-Y ternary diagram (Fig. 10), most of the samples plot mainly on the within plate basalt-island arc tholeiite line. The tholeiitic nature of the dykes magma is also supported by the petrographic and geochemical studies, for example the normative plot which established that the dykes range in composition from olivine tholeiite to quartz tholeiite. This is also true for the dykes from Terengganu mainland (Azman *et al.*, 1998). Comparison to the continental tholeiites mean composition (Pearce, 1975) show a close similarity in most of the analysed elements.

Hence, the chemical data indicate that the dolerites are tholeiitic, and formed in a continental within plate tectonic setting. The magmatic affinities and tectonic setting of the presently studied dykes is similar to the dolerites in the Kuantan area (central Eastern Belt) which also range in composition from olivine tholeiite to quartz tholeiite and bear affinities to the tholeiites of continental setting (Chakraborty, unpublished work, in Sita Ram *et al.*, 1980). This is supported by REE normalised pattern which are

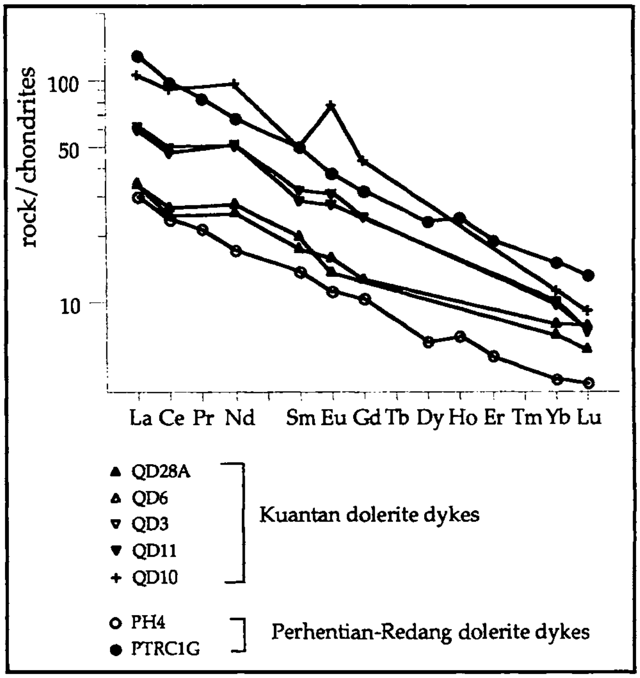

Figure 11. Chondrite normalised REE profile for Perhantian and Kuantan mafic dykes. Data for Kuantan dyke is taken from Sita Ram *et al.*, 1980). Note the similarity of general profiles.

intermediate between those of Perhentian-Redang pattern (Fig. 11). Regionally, the tectonic setting of the dykes are similar to the Upper Paleozoic volcanic rocks from Chiang Mai belt, northern Thailand (Barr *et al.*, 1990) and Upper Cenozoic basaltic rocks of Thailand, Kampuchea and Vietnam (Barr & James, 1990).

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