Basaltic dykes of the Eastern Belt of Peninsular Malaysia: The effects of the difference in crustal thickness of Sibumasu and Indochina

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ABSTRACT

Basaltic dykes of Peninsular Malaysia are confined to the Eastern Belt (Indochina/East Malaya block) as compared with the Western Belt (Sibumasu Block). The dyke intruded through a crustal fracture formed by stress developed from the evolution of two offshore basins (Malay and Penyu basins) east of Peninsular Malaysia. The Ar–Ar dating from the present study combined with the previous geochronological data indicate that the ages of dykes range from 79 ± 2 Ma to 179 ± 2 Ma. Thus it is difficult to correlate the dykes with the closure of Tethys during Permo-Triassic time because of the younger age of the dykes. The majority of the dykes exposed in the Eastern Belt may have been attributed to the difference of crustal thickness between the Eastern and Western belt of Peninsular Malaysia. A thicker Western Belt crust (13 km more than both Eastern and Central belts) is difficult to rupture with normal plate tectonic stress and therefore serves to contain the rise of a mantle derived melt. The chemistry indicates the basalts are olivine to quartz normative and are of the continental within-plate category.

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1. Introduction

Indochina, Thailand and Peninsular Malaysia and its offshore region of South East Asia located at the relatively stable Sundaland (Metcalfe, 2011). Sundaland is made up of several tectonic blocks such as South China block, Indochina–East Malaya block, Sibumasu block and SW Borneo block. These blocks originate from the India–Australian margin of eastern Gondwana and assembled by the closure of multiple Tethyan and back-arc ocean basins now represented by suture zones. Among the sutures are Song Ma, Nan Uttaradit, Bentong Raub and Sra Kaeo (Metcalfe, 2000, 2001, 2002, 2011). One of the common expressions of mantle magma generation related to crustal fracturing during extensional tectonics is the presence of basaltic dykes. Despite being abundant in many parts of the Southeast Asia, these dykes have been neglected to-date in regional models.

In Peninsular Malaysia, mafic dykes, intruding into both intermediate to felsic igneous rocks and older layered rocks, are found widely not only on the mainland, but also on several islands off the east coast of the peninsula (Fig. 1) (Lee, 1977; Haile et al., 1983; Ghani, 2000a,b, 2001a). Previous geochemical studies on basaltic dykes of the Peninsula are found in Haile et al. (1983) on the Kuantan dolerite as well as Ghani (2000a,b) and Ghani et al. (2002) on the dykes from Perhentian, Redang Islands and mainland Terengganu. Ghani (2000a,b) divided the dykes in into two main groups based on their relative age. These are: (1) the older dykes which are syn-plutonic, and (2) the younger dykes, which are post-plutonic to the host rock. The younger dykes constitute about 98% of the total dykes found in the Eastern Belt.

This paper will focus on the geochemistry of the younger dykes and its implication to regional tectonics. A comprehensive geochemical based study that includes all data for the younger dykes in this region and their correlation does not, as yet, exist. This paper reports an ongoing research of the basaltic to intermediate dyke magma that was emplaced throughout the latter half of the Mesozoic in Peninsular Malaysia. The dykes were not only restricted to the Cretaceous age but were also emplaced during the middle Jurassic. The study helps in understanding the characteristics of mafic magma emplaced during that time.

2. Tectonic setting and general geology

Peninsular Malaysia is traditionally subdivided into two north–south trending zones based on differences in magmatism, stratigraphy, mineralization and structure (Cobbing et al., 1992). The Peninsula is made up of two blocks, Sibumasu (Continental block derived from Gondwana) and Indochina (Arc terranes derived from Southchina or Indochina) blocks (Metcalfe, 2011). Sibumasu terrane of Peninsular Malaysia is part of the Sibumasu continental lithospheric terrane which also includes western
Yunnan (Baoshan and Tenchong Blocks), the Shan States of Burma, northwest Thailand Peninsular Burma and Thailand (Metcalf, 1986, 1988). The Indochina terrane of Peninsular Malaysia was interpreted as an arc terrane derived from South China or Indo-China in the Carboniferous. These two terranes started to collide in lower Permian to middle Triassic which marked the closure of the Tethys Ocean (Metcalf, 2000). These two terranes are separated by the Bentong-Raub suture that represents the main Devonian to Middle Triassic Paleo-Tethys Ocean (Metcalf, 2000). The suture zone is a result of subduction of the Palaeo-Tethys ocean beneath Indochina during the early Permian and Triassic collision of the Sibumasu terrane with the Indochina block (Metcalf, 2000).

The Sibumasu terrane, west of the Bentong-Raub suture, is characterized by tin bearing, continental collision S-type granites, emplaced at around 200–220 Ma (Searle et al., 2012; Ghani et al., 2013a; Cottam et al., 2013). They have been interpreted as granites formed by crustal thickening and melting of the Sibumasu terrane following collision with Indochina and closing of the Bentong-Raub suture zone (Mitchell, 1977; Hutchison, 1978; Metcalfe, 2000; Searle et al., 2012). The main granite type is coarse megacrystic biotite granite and two-mica granite with SiO$_2$ content more than 67%. To the east of the suture in Indochina block, granites are older compared to those from the Western Belt, emplaced approximately at about 220–290 Ma and are mainly I-type granitic comprise of extended compositional spectrum from gabbro (±syenites) through granodiorite to monzogranite, usually forming small batholiths and plutons (Cobbing et al., 1992; Ghani, 2001b, 2009; Ghani et al., 2013b). The Eastern granite batholiths intrude into deformed, metamorphosed Carboniferous to Triassic sediments and volcanics. Mafic rocks associated with the Permian to Triassic granite constitute less than 5% of the total surface exposures. Rare occurrences of alkali series rock (syenite, monzonite and alkali gabbro) occur in Perhentian Island and Benom Complex (Ghani, 2001b; Mustafa and Ghani, 2003).

The granites, as well as sedimentary and metamorphic rocks of the Eastern Belt, have been intruded by a series of basaltic dykes with average thicknesses ranging from 10 cm to 20 m. The dykes do not occur only at the northeastern part of the Eastern Belt but are also found abundantly in the southeastern part of the Eastern Belt.

![Fig. 1. Map of Peninsular Malaysia showing the study area where most of the dyke samples were collected. Also shown is the distribution of the granitic rocks from Peninsular Malaysia where most of the dykes intruded granites. The main trends of the dykes are shown in the Rose diagrams. Note the two different trends of northern and southern part of the study area.](image-url)
Belt. In this paper most of the dykes were sampled from the central part of the Eastern Belt including Kuantan, Perhentian Island and central Terengganu (Fig. 1).

3. Field occurrence and petrography

The dykes are not uniformly distributed in the Eastern Belt. In some areas, dykes are very common, for instance in the Kuantan area, a total of 65 basaltic dykes, both fresh and weathered, have been recorded. The length of the dykes exposed is usually less than 5 m and the thickness vary from 2 cm to 2 m. The thickest dyke recorded in the Eastern Belt is about 20 m wide, found near Kenyir Lake, Terengganu (Ghani et al., 2001). The general trend of the dykes from the study area is shown in Fig. 1. Dykes from the northern part of the study area (e.g. Perhentian Islands) show N–S trend compared to the dykes from south of the study area (e.g. Kuantan area) which strike E–W. The N–S and E–W trends coincide with the major trends of Malay and Penyu Basins basement east coast off Peninsular Malaysia (Fig. 2). Generally, the dykes are straight, indicating that they have been apparently emplaced along sharply defined fractures. Macroscopically, these dyke rocks are mainly massive and the color varies from dark green to greyish green. The dykes are usually weathered and are totally changed to soil when hosted by sedimentary rocks (Fig. 3a). They are aphanitic and characterized by ophitic to sub-ophitic textures but in places they also show porphyritic texture (Fig. 3b and c). The predominant host rocks of these dykes are the Eastern Belt granitoids. The dykes have not been metamorphosed, but sometimes show evidence of having been locally affected by brittle shearing. The dykes often exhibit chilled margin 0.5–5 cm thick and show a darker color compared to the center of the dyke (Fig. 3b). Occasionally dykes enclosed granitic enclaves of various sizes; the largest enclave has length of about 0.5 m.

The dykes always show a sharp contact (Fig. 3b) with the host rock and are almost planar and near vertical, but some display dips as low as 45°. They are either porphyritic (with plagioclase phenocrysts) (Fig. 3b and c) or very fine grained. Sometimes they show symmetrical textural zoning with a chilled margin and a regular inward increase of grain size (Fig. 3c). Angular to sub-angular inclinations of granitic host rock up to 0.5 m across (Fig. 3d) as well as amygdalae filled with calcite, zeolite, quartz and analcote are occasionally found in the dykes. From the field studies it is likely that the intrusion of the dyke magma occurred in several episodes. This is based on the cross-cutting relationship between two dykes with the younger having developed a chilled margin against the other. The dykes sometimes occur in closely parallel sets forming straight swarms, indicating that they were emplaced along sharply defined fractures. In the coastal area of Kuantan, a 2.5 cm thick mafic dyke forms a zig-zag pattern which is clearly an early joint pattern (Fig. 3e). The dyke also intruded the volcanic rocks of Permian age (Fig. 3f).

The minerals present in the dykes, in decreasing order, are olivine, plagioclase, clinopyroxene, amphibole, iron oxide and chlorite (Fig. 4). General texture of the dyke is shown in Fig. 4. Olivine, clinopyroxene and plagioclase are the main phenocrystic phase. They are mainly basaltic andesite in composition, although some lamprophyre has been reported (Mac Donald, 1967). The texture is either intergranular, porphyritic or sub-ophitic (Fig. 4a–c), and the rock are often chloritised to varying degrees (Fig. 4e), in the most extreme case with up to about 10% modal chlorite. Amygdalae occurs in various shapes and sizes and are commonly filled with fine crystalline silica, epidote and calcite (Fig. 4d). Pale green fibrous uraltite may be present within the chlorite. Plagioclase (An32–An35) crystals usually occur as small subhedral to euhedral laths which do not show any preferred orientation. The crystals sometimes show twinning but rarely zoning. In porphyritic samples plagioclase crystals can occur up to 1.5 cm in length (Fig. 4f). The crystals display oscillatory, normal zonation and albite twinning. Clinopyroxene, mainly augite, is subhedral to anhedral and occurs as interstitial grains between plagioclase laths, forming a typical doleritic texture (Fig. 4b). In some samples, euhedral to anhedral iron oxide can constitute up to 10% of the rock. In rare cases, some interstitial calcite may occur. Quartz can occur as an interstitial mineral with minute fluid inclusions.

4. Geochronology

4.1. Previous work on the age of the basaltic dykes

Haile et al. (1983) reported K–Ar ages for 10 basalt samples from the Kuantan area showing that the majority of the dykes
were emplaced in the range of 79 ± 2 Ma to 129 ± 2 Ma. Ghani et al. (2002) dated an older dyke sample from Perhentian Island, Terengganu, by using the K–Ar technique and found an age of 219 ± 11 Ma. The sample is a synplutonic dyke which intruded the Perhentian Kecil Syenite. In this paper a total of 4 younger dyke samples were dated using the 40Ar/39Ar step-heating technique.

4.2. Sample descriptions

The four dyke samples that were analyzed include a sample on the Central Belt of Peninsular Malaysia. A summary of the field occurrences of these samples are given below:

- The BADAK dyke sample intruded a small granitic body of the Kijal pluton in the central part of the study area. The pluton is zoned from leucogranite and biotite granite to hornblende granite and gabbroic in composition.
- The DAMAR dyke sample intruded a leucogranite body (2 km width) of the Bukit Damar pluton located in the southern part of the Central Belt of Peninsular Malaysia. This pluton has been intruded by a swarm of intermediate to mafic dykes with widths ranging from 0.4 m to 2 m.
- The PTIAN dyke sample is taken from a dyke intruded into the Perhentian Kecil Syenite (Ghani, 2001b). Field occurrence led Ghani (2001b) to classify this dyke as an older dyke which may be coeval with its syenitic host. The features such as necking, pinch and swell, back veining and lobate to crenulate contact of the dykes and the host rock suggest that the dyke magma intrude while the host rock was ductile.
- The PLANG dyke sample is taken from an intrusion in a small island (Lang Island) off east coast of Peninsular Malaysia. The island is less than 1 km² underlain by coarse grained biotite granite.

4.3. Method

All samples were analyzed at the Department of Geosciences, National Taiwan University. Whole-rock chips were crushed and sieved to size 20–40 mesh (850–425 μm), ultrasonically cleaned.
in distilled water and dried, and handpicked under a stereoscope to remove visible impurities. The samples were then irradiated at THOR Reactor at Tsing-Hua University (Taiwan) for 8 h. After irradiation and closing-off the samples were loaded into an automated extraction and purification line, and heated using double vacuum Mo resistance furnace, incrementally from 500 to 1600 °C following a 30 min/step schedule. The released gas was purified with a Ti sponge and Zr–Al getters and measured with a Varian-MAT GD150 mass spectrometer run in a static mode at the National Taiwan University. Plateaus was defined by at least four successive steps with dates that fall within 2σ of the average and the gas fraction of these plateau steps must comprise >50% of total 39Ar released. Result of the analyses is shown as age spectrum plots in Fig. 5.

4.4. Result

The apparent age spectrum for all samples are relatively flat for 63–85% of the 39Ar release with plateau ages of 124.07 ± 0.34 Ma for BADAK, 127.05 ± 0.33 Ma for DAMAR, 178.46 ± 1.05 Ma for PTIAN and 179.14 ± 0.75 Ma for PLANG samples (Fig. 5). The gas composition of the plateau steps suggest intercept ages which are consistent with the respective plateau ages and reasonable 40Ar/39Ar initial values close to atmospheric composition (295.5) in isotope correlation plots. Thus the obtained plateau ages are adopted to represent the intrusion ages of the dyke samples.

5. Geochemistry

5.1. Analytical method

34 dyke samples were analyzed for major and trace elements. 8 samples were taken from Perhentian, Lang and Redang islands, off the East Coast of Peninsular Malaysia and 26 samples from the East Coast Mainland. All analyses were carried out at the Department of Geology, University of Liverpool. Major oxide elements and trace elements were analyzed by using Siemens sequential X-ray spectrometer. The major oxides were determined using Cr primary beam radiation generated at 50 kV and 40 mA and trace elements using W beam radiation generated at 45 kV and 60 mA.

Accuracy in major, trace and REE elements analysis was checked by routine analysis of the USGS standard G2 with error of less than 0.5% to 1.0%. REE composition of the dyke samples were taken from Ghani et al. (2002) and Sita Ram et al. (1980).

5.2. Results

Representative major and trace element compositions of the dykes are given in Table 1. The SiO2 contents range from 44.26% to 56.38%. It is well established that geochemical mobility of elements is commonly associated with alteration and metamorphism of the rocks (Pearce and Cann, 1973; Sun and Nesbitt, 1977; Pearce,
Alteration effects can be observed in the outcrop and can further be verified by petrographic studies under microscope. Growth of secondary minerals like uralite, chlorite, epidote, and sericite occur in various dyke samples from the study area and can be used as parameters to determine the degree of alteration (Kumar and Ahmad, 2007). The mobility of elements in the Eastern Belt dykes were assessed using Harker Zr and CIW (CIW = Chemical Index weathering Al₂O₃/(Al₂O₃ + CaO + Na₂O)) plots (Figs. 6-8), since it is considered that Zr is immobile under most metamorphic conditions (Pearce and Cann, 1973; Floyd and Lees, 1973; Winchester and Floyd, 1977; Sheraton, 1984; Macdonald et al., 1988; Harnois, 1988; Wang et al., 2010). In Figs. 6 and 7, most of the major and trace elements plot are scattered except TiO₂, Na₂O, Ce, Y and Zn increase and CaO decreases with increasing Zr. The effect of alteration on the whole rock major elements compositions are also determined by CIW molecular ratio diagram (Harnois, 1988; Wang et al., 2010)(Fig. 8). The studied dykes have low CIW values compared to the basic rocks elsewhere (e.g. Wil-louran Basic Province, South Australia and Guibei Large Igneous Province, South China (Wang et al., 2010). Negative correlation of CaO–CIW indicates that the alteration resulted in CaO depletion. The increasing of K₂O with increasing CIW reflects possible K-metasomatism (Crawford and Hilyard, 1990; Wang et al., 2010). TiO₂, MgO and Na₂O show no correlation with CIW implying they are essentially immobile. The good correlations in some of the elements above suggest that they retained original magmatic relationships which the element behaves incompatibly under mantle melting and basalt crystallization. Furthermore the effect of alteration on the whole rock composition may be insignificant because of the low LOI values (Table 1) in most studied samples.

Utilizing FeO'/MgO as a fractionation index (with FeO' = total iron), Na₂O, P₂O₅, TiO₂, FeO, Ce, Zr, Nd, Zn and Y increase while Al₂O₃, MgO, CaO, Ni and Sr decrease as FeO'/MgO increases (Fig. 9). FeO and TiO₂ trends in Fig. 10 appear to be inconsistent with the case expected for early crystallization of ilmenite. Plots of Na₂O + K₂O vs. SiO₂ (TAS diagram) shows that the majority of the dyke samples lie within basalt, basaltic trachyandesite and trachybasalt fields (Fig. 10) and in the continental basalt field in the FeO₂ vs. MgO vs. Al₂O₃ diagram (Fig. 11). On a plot of Zr/Y and Zr the majorities of the dyke samples plot in the within-plate basalt field (Fig. 12) and also plot in the same field on a Ti–Zr–Y ternary diagram (Pearce and Norry, 1979)(Fig. 13). All these plots suggest that the studied dyke rocks exhibiting the characters of within-plate basalt.

Chondrite normalized profile for REE shows enrichment in LREE relative to HREE for all samples (Fig. 14). In general all the samples from Perhentian show a similar profile, except sample PSD which has a significant negative Eu anomaly. This may attribute to plagioclase fractionation. The sample from Redang Island (REDO) (Fig. 14) has a significant positive Eu anomaly which may be due to accumulation of plagioclase. Multi-element spidergram (Fig. 15) patterns of the dyke also show enriched characteristics for LREE-LILE and depletion of Nb, Sr, P, Ti anomalies.

The dykes are characterized by parallel moderately fractionated patterns ((La/Lu)ₙ = 6.6–11.1) and a relatively weak fractionated HREE segment ((Gd/Lu)ₙ = 2.4–3.03) with absence of significant Eu anomalies. These REE profiles would suggest that the dyke rocks may originated from the same magma chamber as they show a remarkable similarity in chemistry.

6. Discussion

6.1. Age of the dykes

The occurrence of basaltic dykes in the Eastern Belt is one of the main differences between the Eastern and Western Belts of Penin-sular Malaysia. Ar–Ar age data presented in this study show the dyke magmatism peaking at 125 and 178 Ma. The younger dyke from Bukit Badak, in the central part of the study area, gives an age of 124 ± 0.34 Ma which is similar to the uppermost K–Ar age
of the Kuantan dyke (79 ± 2–129 ± 2 Ma; Haile et al., 1983). Compiling the age data from this study and Haile et al. (1983) suggested that the younger dyke magmatism had a long time span, which is ~50 Ma. Haile et al. (1983), however, express some doubt on the age interval on the age of the Kuantan dyke as it is too long to reflect a real range for an intrusion. They favored the mean ages of their K–Ar data which gives 104 ± 10 Ma for the age of the Kuantan dyke intrusion. The present study results also show a same age range for the dyke magmatism in the Central belt, as is evident from the \( ^{40} \text{Ar}/^{39} \text{Ar} \) age of 127 ± 0.33 Ma for DAMAR sample. In the field, the sample intruded the leucogranitic pluton located immediately to the east of the Bentong-Raub line. The other two samples i.e. PTIAN and PLANG gave an even older age that is 178.46 ± 1.05 Ma and 179.14 ± 0.75 Ma respectively. Both of them suggest that they are in fact synplutonic to the host rock. This can be further confirmed by the field evidence such as necking, disrupting or pinching and swelling along the dyke length. It further confirms a notation given by previous authors (Moore and Hopson, 1961; Pitcher, 1991; Roddick and Armstrong, 1959; Hageskov, 1997) that the dyke magma was injected into the mobile semi solid syenitic magma.

The age range of the dyke, particularly the lower limit (79 Ma) coincides with the age of Cretaceous granitic magmatism (Cobbing et al., 1992) which occurs as individual scattered plutons in the

### Table 1: Major and trace element analyses of the Eastern Belt basaltic dykes.

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<th>PH4</th>
<th>G4</th>
<th>RED</th>
<th>CAK3</th>
<th>G4</th>
<th>H6K2</th>
<th>TBJSP</th>
<th>G5</th>
<th>PTIAN</th>
<th>CAK7</th>
<th>BB2</th>
<th>BH5</th>
<th>DY1</th>
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<td>49.93</td>
<td>44.26</td>
<td>56.26</td>
<td>50.12</td>
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<td>2.78</td>
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<tr>
<td>MgO</td>
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<td>CaO</td>
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<td>Na₂O</td>
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The samples i.e. PTIAN and PLANG gave an even older age that is 178.46 ± 1.05 Ma and 179.14 ± 0.75 Ma respectively. Both of them suggest that they are in fact synplutonic to the host rock. This can be further confirmed by the field evidence such as necking, disrupting or pinching and swelling along the dyke length. It further confirms a notation given by previous authors (Moore and Hopson, 1961; Pitcher, 1991; Roddick and Armstrong, 1959; Hageskov, 1997) that the dyke magma was injected into the mobile semi solid syenitic magma.
Eastern and Central Belts of Peninsular Malaysia. Some of the basalt dykes also intruded Cretaceous granite, e.g. those in the northern part of Tioman granite with zircon U-Pb age 80.1 ± 0.8 Ma (Searle et al., 2012).

There is however no age difference between the dykes from the northern part as compared to dykes from the southern part of the study area. There is also no correlation between main dyke trend and the age of the dyke. Geochemical study also shows that there is no geochemical difference between the younger dykes (~79 Ma) and the dykes (~129 Ma).

6.2. Magmatic affinities

The overall geochemical similarities of the dykes indicate a common mode of origin. Major and trace element bivariate plot vs. XMg and Zr indicate that the magma has undergone
differentiation. The present study also indicate that the basalt dykes exhibit features expected for those found in a continental affinity setting, being within-plate basalts with olivine to quartz normative compositions. Chakraborty, (unpublished work, in Sita Ram et al. (1980)) also noted that the dolerite from the Kuantan area (Fig. 1), ranges in composition from olivine tholeiite to quartz tholeiite and bears affinities to the tholeiites in continental settings. Within-plate volcanism in a continental setting is not uncommon. The best example is the Cameroon Line, which is a unique within-plate volcanic province which straddles on continental margin (Fitton and Dunlop, 1985). It consists of a chain of Tertiary to Recent, alkaline volcanoes stretching from the Atlantic island of Pagalu to the interior of the African continent (Fitton and Dunlop, 1985). They showed that basaltic rocks in the oceanic and continental origin are geochemically and isotopically indistinguishable which suggests that they have identical mantle sources.

Multi-element spidergram patterns of the studied dykes show very diverse patterns (Fig. 15). Most of the samples are characterized by enriched Th, La, Pb and Nd. Nb depletion in few of the

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**Fig. 8.** CIW vs. major elements oxides for the dykes from the study area.

**Fig. 9.** FeO/MgO vs. selected major and trace elements of the basaltic dykes from the Eastern Belt.

**Fig. 10.** Total alkali (Na₂O + K₂O) vs. SiO₂ of the basaltic dykes from the Eastern Belt. Both of the older dykes plot in the basaltic field.
samples may have attributed to (1) subduction-related enrichment of lithospheric mantle (Kepezhinkas et al., 1997) or (2) chemical interaction between lithospheric mantle and asthenosphere-derived magmas having incompatible elements but little Nb (Arndt and Christensen, 1992; Patchett et al., 1994; Gladkochub et al., 2006), (3) crustal contamination and (4) originated from sub-continental lithospheric mantle (SCLM) (e.g. Wang et al., 2008). The younger age of the dyke preclude the possibility that the dyke magmatism was related to late Triassic subduction. The age is too young and by this time (79–129 Ma) subduction is already ceased. Thus it is likely that the Nb depletion is caused by either interaction between lithospheric mantle and asthenosphere-derived magmas or crustal contamination or directly partial melting of sub-continental lithospheric mantle (SCLM) (e.g. Wang et al., 2008). The younger age of the dyke preclude the possibility that the dyke magmatism was related to late Triassic subduction. The age is too young and by this time (79–129 Ma) subduction is already ceased. Thus it is likely that the Nb depletion is caused by either interaction between lithospheric mantle and asthenosphere-derived magmas or crustal contamination or directly partial melting of sub-continental lithospheric mantle (SCLM). Direct melting of SCLM seems to be the most plausible mechanism for the Nb depletion. As the subduction already already ceased the melting of the SCLM may be caused by mantle plume that impinge beneath the continental lithospheric of the Sundaland and caused conductive heating and partial melting of the SCLM particularly along the thin and weak crustal structure (e.g. Wang et al., 2008). The mafic SCLM magma experience some degree of crustal contamination during ascent and/or residence in crustal magma chamber (Mohr, 1987).

A few samples show negative Ba anomaly may be either due to alteration or involvement of K-feldspar, hornblende and/or biotite crystallization during magmatism (Kumar and Ahmad, 2007).
6.3. Tectonic implication

The general trend of the dykes in the study area gradually changes from N–S in the northern (Perhentian Island) to E–W to the southern (Kuantan) part of the study area (Fig. 1). Between these two areas the dykes shows a NW–SE and SW–NE trends. The general trend of dykes both in the Perhentian and Kuantan areas is generally consistent with the trends of sedimentary basins off-shore the eastern coast of Peninsular Malaysia. Two Cenozoic sedimentary basins are present off the east coast of Peninsular Malaysia: Malay and Penyu Basins (Fig. 2). Offshore faults inferred from overlying sediments and magnetic/gravity anomalies indicate the following different structural domains for these two basins: (1) the southern Malay Basin and Penyu Basin, the dominant trends directions are E–W and NW–SE and (2) the northern Malay Basin, dominated by the N–S fault direction (Khalid et al., 1996; Mazlan et al., 1999). The tectonic development of these two offshore basins has been discussed by various workers (Khalid et al., 1996; Tjia and Liew, 1996; Mazlan and Watts, 1998; Tjia, 1998, 1999; Mazlan et al., 1999). The best model for the development of Malay, Penyu and West Natuna basins in the South China Sea, South East Asia is by Tjia (1998). He proposed a failed triple junction model for Malay, Penyu and West Natuna basins developed as early as the Cretaceous. He suggested that the high heat flow of the Malay Basin (>110 mW/m²) resulted from a mantle plume located at the triple junction between the three basins. It is likely that the stress developed from the evolution of these two offshore basins east of Peninsular Malaysia and also fractures the mainland. The fractured then served as main conduit for mafic dyke emplacement at the eastern part of Peninsular Malaysia.

The age data suggest that the intrusion of the studied dykes lasts from 79 Ma to 179 Ma which much younger than the Permo-Triassic subduction event, precluding the notation that the dykes are related to subduction (Metcalfe, 2000). By 79–179 Ma, the subducted Tethys oceanic slab is expected to have mostly thermally equilibrated with the surrounding mantle beneath Peninsular Malaysia. The slab is likely to have sunk below the upper mantle. Several other models have been put forward to explain this phenomenon, for instance the slab breakoff model (von Blanckenburg and Davies, 1995; Davies and von Blanckenburg, 1995; Atheron and Ghani, 2002). In this model, the oceanic slab fell away and more enriched mantle would have become exposed. The process is similar to a plume impinging on a continental plate and leading to limited thermal erosion of continental lithosphere. In this case magma would have risen into relatively thin crust, which would easily permit the mantle magma to intrude along fractures more easily (Mege and Korme, 2004). By the end of the late Triassic, the crustal thickness of the Western, Central and Eastern Belts as estimated from Metcalfe’s model (Fig. 14 in Metcalfe (2000)) were about 43, 15 and 28 km respectively. Both the Eastern and Central Belts are about 13 km thinner, compared to the Western Belt. It is suggested here that the Western Belt contains very few basaltic dykes of the same age when compared to the dykes in the study area because it consists of much thicker continental crust. A thicker crust is more difficult to rupture with normal plate tectonic stress, and therefore serves to contain the rise of a mantle derived melt (Anderson et al., 1992). The thicker crust may be the result of the continental collision between the Indochina and Sibumasu blocks during the Permo-Triassic. This is supported by gravity work by Ryall (1982) which showed that the Central Belt of Peninsular Malaysia consists of thinner crust compared to both Eastern and Western Belts. Supporting this is the presence of high Ba–Sr rock...
in the Alkaline Series of the Benom Complex (east of the Bentong-Raub line) which, according to Ghani and Mustaffa Kamal (2004), was due to the presence of a mantle plume. The high Sr and Sr characteristics of the basalt rock probably resulted from penetration of the lower lithosphere by a small volume of mantle material that was enriched in those elements (cf. Ionov et al., 1993; Rudnick et al., 1993). Evidence of the interactions with mantle material is also provided by the occurrence of mafic enclaves and mafic syn-plutonic dykes everywhere in this area. Multiple injections found in the dykes from Terengganu Mainland also indicate that the magma was injected into fractures in one or more pulses.

7. Conclusions

The present Ar–Ar dating results from the present study, combined with previous geochronology data indicate that the basaltic dykes from the Eastern Belt of Peninsular Malaysia range from 79 ± 2 Ma to 179 ± 2 Ma. This is the age of the younger and older combined with previous geochronology data indicate that the basaltic of a mantle-derived melt (Fig. 16).


References


