Geol. Soc. Malaysia, Bulletin 16, December 1983; pp. 71–85

Palaeomagnetism, geochronology and petrology of the dolerite dykes and basaltic lavas from Kuantan, West Malaysia

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Abstract: Dolerite dykes and basaltic lavas, which are closely associated spatially in the Kuantan area of west Malaysia, differ in petrology, age, and in palaeomagnetic direction and are thus not genetically related.

The dykes intrude granite of Late Permian to Early Triassic age. Compositionally they range from olivine tholeiite to quartz tholeiite and have evolved from an olivine tholeiite magma through low pressure fractionation. The K-Ar ages for the dykes range from 97 ± 2 Ma to 129 ± 2 Ma, with a mean age of 104 ± 10 Ma (Cretaceous: base Aptian to Middle Cenomanian) favoured as most likely.

25 of the 27 dykes sampled have palaeomagnetic vector directions in the same population, with a mean of D = 333, I = 40. This corresponds to a palaeomagnetic pole at 58°N, 52°E, and $\alpha_{95} = 5.6°$. One of the dykes has reversed magnetic polarity.

The lavas, which have been extruded over the granite, cover about 125km², with a total thickness of 20–25 m. The lavas are compositionally different from the dykes and include alkali olivine basalts, basanite, and olivine nephelinite. Basanites and alkali olivine basalts are probably genetically related while olivine nephelinite seems to have an independent origin. K-Ar ages for the lavas range from 2.5 ± 0.1 Ma to 1.2 ± 0.1 Ma, with average age of 1.7 ± 0.2 Ma. The three lava types cannot be separated in terms of age. Four sites in the basalt sampled for palaeomagnetic studies, gave a mean palaeomagnetic direction of D = 174, I = 10, indicating that the basalts were extruded during the Matuyama reversed magnetic epoch.

INTRODUCTION

The dolerite dykes and the basaltic lavas of Kuantan, West Malaysia (see Figure 1 for location and general geology) were first described by Fitch (1951). The dykes intrude granite of Late Permian to Early Triassic age (about 250 Ma, Bignell and Snelling, 1977a) over which occur the lava flows. Fitch (1951) considered these dykes as representing feeder fissures to the lavas implying a consanguineous relationship between them. However, Bignell (1972, see also Bignell and Snelling, 1977b) dated one sample from a dyke at 111 ± 4 Ma and a sample of lava at 1.6 ± 0.2 Ma by the K-Ar method, indicating a long time interval between the two igneous events. The editors of the standard work on the region (Gobbett and Hutchison, 1973) although aware of the K-Ar dates evidently did not consider these isolated determinations to be compelling

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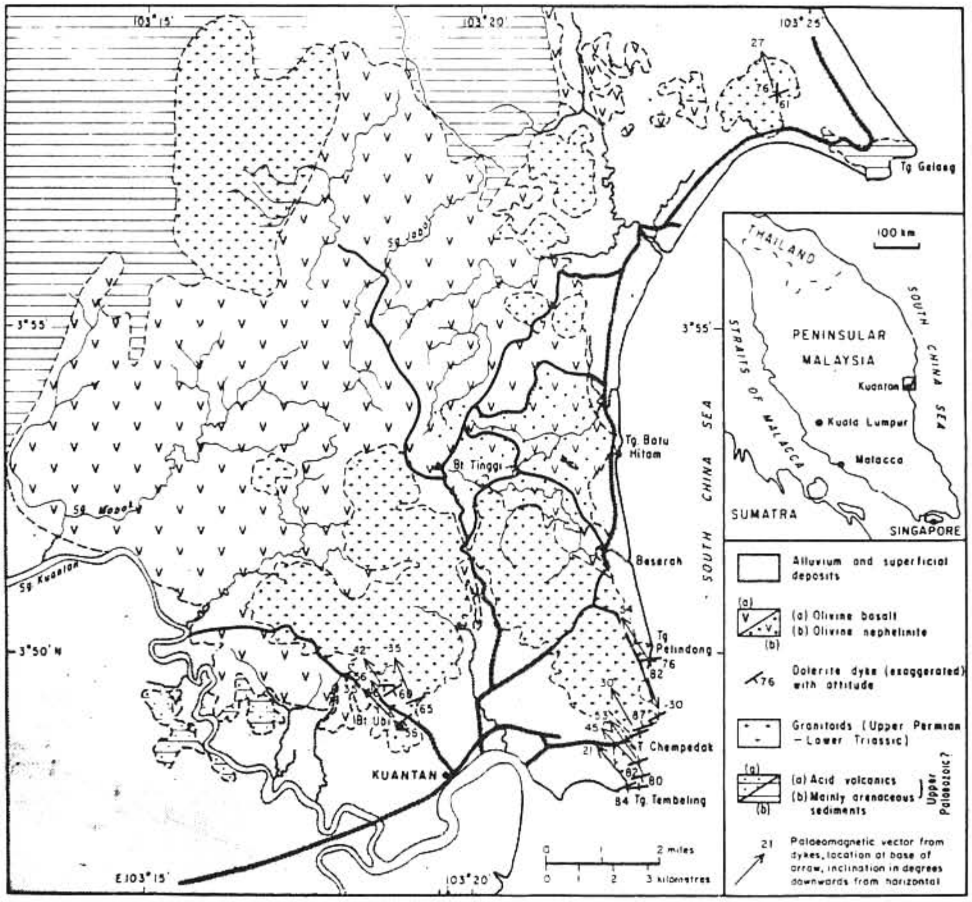

Fig. 1 Geological sketchmap of the Kuantan area, Pahang, West Malaysia, showing palaeomagnetic vectors from dykes.

and repeat the idea that the dykes represent feeders to the lavas (Gobbett and Hutchison, 1973, p. 204).

Later Lee (1977) described a dolerite dyke 3 cm thick at Bukit Ubi quarry Kuantan, which appears to be cut by the intruded granitic rock, and suggested that the host rock was still hot and plastic at the time of intrusion of the dyke, thus implying that the dykes and granite are contemporaneous. It seems more likely, however, from Lee's photograph (1977, figure) that the dyke is introduced into a discontinuous fracture, rather than being cut by the granite.

Preliminary palaeomagnetic works (Haile, 1974), and petrological and geochemical studies (Hanif, 1975; Chakraborty, 1977; Chakraborty *et al.*, 1980; Sita Ram *et al.*, 1980) showed that the dykes are compositionally different and have different magnetic vectors than the lavas, thus lending support to the conclusion evident from the radiometric dating by Bignell (1972). These preliminary studies have been followed by more detailed investigations on palaeomagnetism (NSH), petrology (KRC) and geochronology (RDB & TH). The results of these studies are integrated and presented here. Although the results bear directly on the question of the dyke-lava relationship, they also have relevance to broader and important problems concerning the regional tectonomagmatic evolution.

FIELD RELATIONS

Dykes. The dykes are exposed mainly along the coast (notably at Tanjung Tembeling, Tanjung Cempedak and Tanjung Pelindung) and in several quarries at Kuantan town and at the new port site at Tanjung Gelang (see figure 1). Most of the dykes strike between NE and E: exceptions are five N-S dykes at Tanjung Gelang and a N-S dyke at Tanjung Pelindung: at both places the N-S dykes are cut by NE-striking dykes. It appears, therefore, that the N-S dykes are relatively older than the more common NE- to E-striking dykes. The dykes are mostly planar and near vertical, but some are curved and undulating and may have dips as low as 55°. The dykes range in thickness from a few centimetres to about 5 m. Thicker dykes commonly show chilled margins and a regular inward increase of grain size. Cooling cracks normal to chilled surfaces occur in some dykes. Vesicles, where present, are restricted either to the margin or to the central part. Some dykes locally contain angular to subangular inclusions of the host granite. A number of dykes show splitting upwards (e.g., at Citra Quarry at Tanjung Gelang) and laterally (e.g., at Tanjung Pelindung) which, together with thinning to dykelets a few millimetres thick, suggests that the magma was of low viscosity.

Lavas. The present extent of the outcrop of the lavas is about 125 km^2 and the total thickness is about 20–25 m (Hanif, 1975). Due to poor exposure, the thickness and extent of the individual lava flows are difficult to ascertain. A few outcrops show vertical columnar jointing, suggesting that the lava flows are horizontal and have not been tilted since extrusion.

The lavas include alkali olivine basalt, basanite and olivine nephelinite. The alkali olivine basalt is more widespread, followed by olivine nephelinite. Basanite is very rare and found only in a small section along Sungai Ayer Jerneh. The areal distribution of the two dominant lava types is shown in Figure 1. The temporal relationship between the three lava types is not adequately known, but olivine nephelinite appears to be the youngest phase.

The lavas are usually dense and massive, but some are highly vesicular. In general, alkali olivine basalts are coarser than the olivine nephelinites and basanites, a useful distinguishing criterion in the field. Xenoliths (up to 10 cm across) of altered granite may occasionally be found, but ultramafic xenoliths are virtually absent.

PETROLOGY

The dykes are fine to medium grained and are usually nonporphyritic or sparsely porphyritic. Highly porphyritic dykes are not common. Fresh dykes are made up mainly of plagioclase and clinopyroxene, and display either intergranular or ophitic subophitic texture. Olivine occurs as phenocrysts in a few dykes. Opaque oxides are quite abundant. Quartz is a common groundmass constituent. The dykes are chloritized and/or carbonatized to varying degrees.

The lavas are aphanitic and commonly microphyric. Alkali olivine basalts are holocrystalline consisting mainly of olivine, augite and plagioclase with intergranular to subophitic textures. Alkali feldspar and/or analcite occur interstitially in minor amount. Basanites are hypocrystalline and contain mainly olivine, augite and brownish glass. Primary felsic minerals are notably absent. Olivine nephelinites are holocrystalline and are essentially made up of olivine, augite and nepheline. Feldspar is conspicuously absent. Resorbed and strained xenocrystic clinopyroxene occurs in the lavas, particularly in the basanites.

Chemical compositions of the dykes and the three lava types are summarized in Table 1 where the ranges (in wt %) of major element oxides are given. The normative compositions and the alkali-silica relationships of the analysed rocks are shown in Figures 2 and 3 respectively.

The dykes range in composition from olivine tholeiite to quartz tholeiite (Fig. 2) and show a distinct iron enrichment trend (Fig. 4). They display regular variation trends when major element oxides are plotted against FeO/(FeO + MgO), and the chemical variation patterns suggest that they have evolved from an olivine tholeiite parent magma through low pressure fractionation. A single analysis of a porphyritic "older"

TABLE 1

COMPOSITIONAL VARIATIONS IN DYKES AND LAVAS OF KUANTAN

	Dykes**	Alkali olivine basalt	Basanite	Olivine nephelinite
SiO_2	46.87–48.28	46.42–51.01	44.88–45.59	39.93–42.01
Al_2O_3	13.96–15.39	13.77–14.57	13.42–14.02	11.98–12.74
TiO_2	1.78–3.06	1.82–1.96	1.93–2.02	1.98–2.53
FeO*	10.67–14.25	9.93–12.15	10.89–11.03	11.91–13.81
MgO	4.50–10.26	6.68–9.92	9.67–10.59	9.54–10.69
CaO	7.67–9.83	7.81–9.01	9.08–9.46	11.23–12.55
Na_2O	1.79–2.59	3.05–3.93	3.60–3.91	3.38–4.10
K_2O	0.87–1.29	1.31–1.95	1.77–1.95	1.65–2.30
P_2O_5	0.32–0.78	0.41–0.79	0.85–0.89	0.76–1.13
$\frac{100\ FeO^*}{FeO^* + MgO}$	51.49–76.00	51.89–60.26	50.70–53.04	52.72–59.14
$\frac{100\ An}{An + Ab}$	54.91–64.81	34.64–50.11	47.71–57.56	
Number of analyses	12	14	3	10

FeO* = Total iron as FeO.
**Excluding the analysis of an "older" dyke.

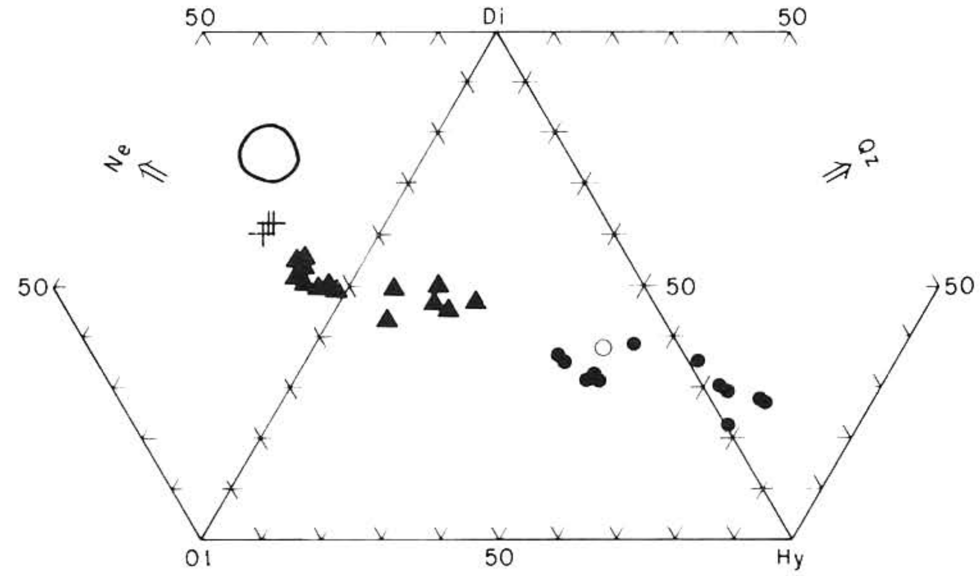

Fig. 2. Normative mineralogy of the analysed Kuantan dykes and lavas projected into the basalt tetrahedron (from plagioclase). All olivine nephelinites plot within the small circular area outlined in the Ol-Di-Ne plane. Symbols in this and other diagrams are: open circle = "older" dyke; solid circle = dyke; solid triangle = alkali olivine basalt; cross = basanite; solid square = olivine nephelinite.

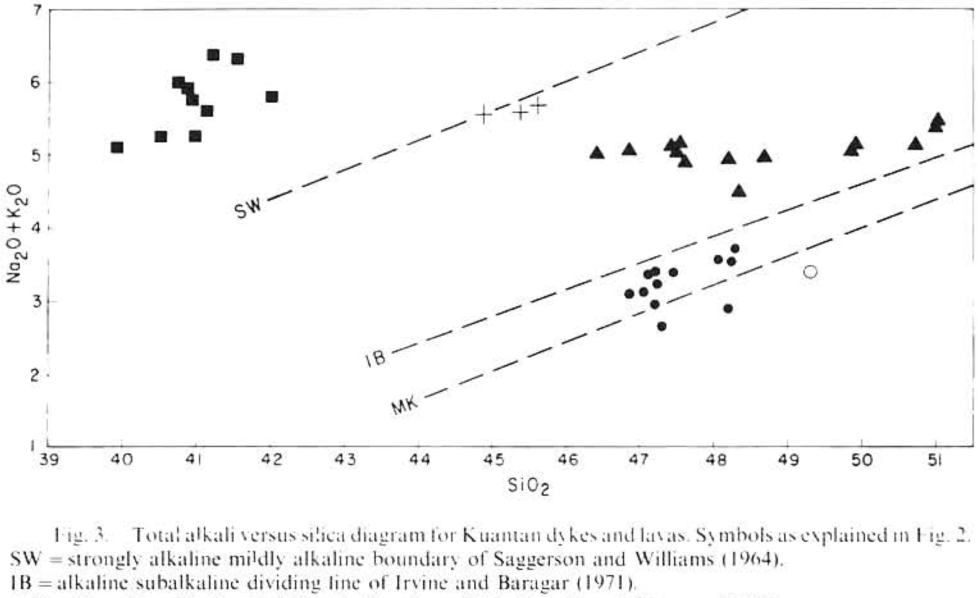

Fig. 3. Total alkali versus silica diagram for Kuantan dykes and lavas. Symbols as explained in Fig. 2.
SW = strongly alkaline mildly alkaline boundary of Saggerson and Williams (1964).
IB = alkaline subalkaline dividing line of Irvine and Baragar (1971).
MK = Hawaiian alkaline tholeiite dividing line of MacDonald and Katsura (1964).

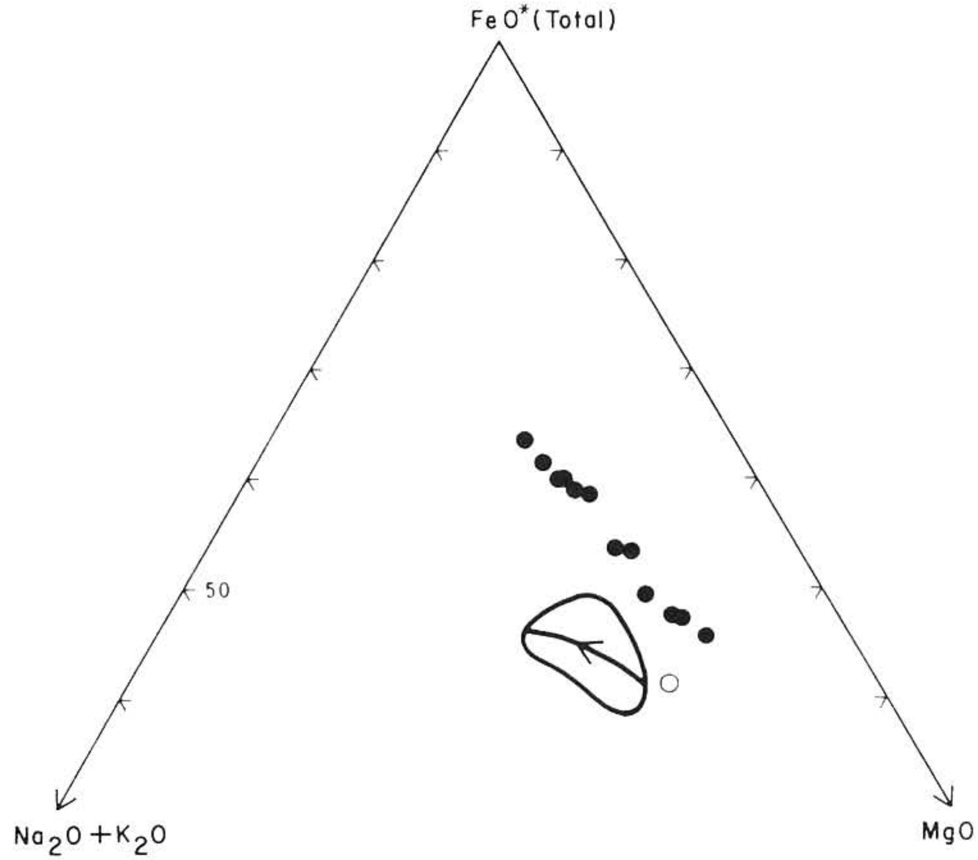

Fig. 4. $Na_2O + K_2O$: FeO^*: MgO variation diagram of Kuantan dykes and lavas. Individual plots of the lavas are not shown but all lie within the outlined area. The arrow line shows the trend of alkali olivine basalts. Symbols as in Fig. 2. FeO^* = Total iron as FeO.

dyke is available, and this does not fit well into the overall chemical variations of the dykes. More analyses of "older" dykes are needed to evaluate their petrogenetic relations with the other dykes.

The alkali olivine basalts are nepheline to hypersthene normative and thus straddle the critical plane of silica undersaturation (Fig. 2). Many of them may be termed hawaiite following Coombs and Wilkinson (1969). The hypersthene-normative alkali olivine basalts are more evolved inasmuch as they have higher FeO/(FeO + MgO) and lower normative anorthite contents. The evolution of nepheline-normative alkali basalts to hypersthene-normative compositions is an uncommon trend and the possible mechanisms have been discussed by Chakraborty (1980). The alkali olivine basalts and basanites share common variation trends (see, for example, Fig. 5), and, therefore, a direct genetic link between them is likely. The olivine nephelinites, on the other hand, have significantly higher CaO and lower Al_2O_3 compared to the basanites

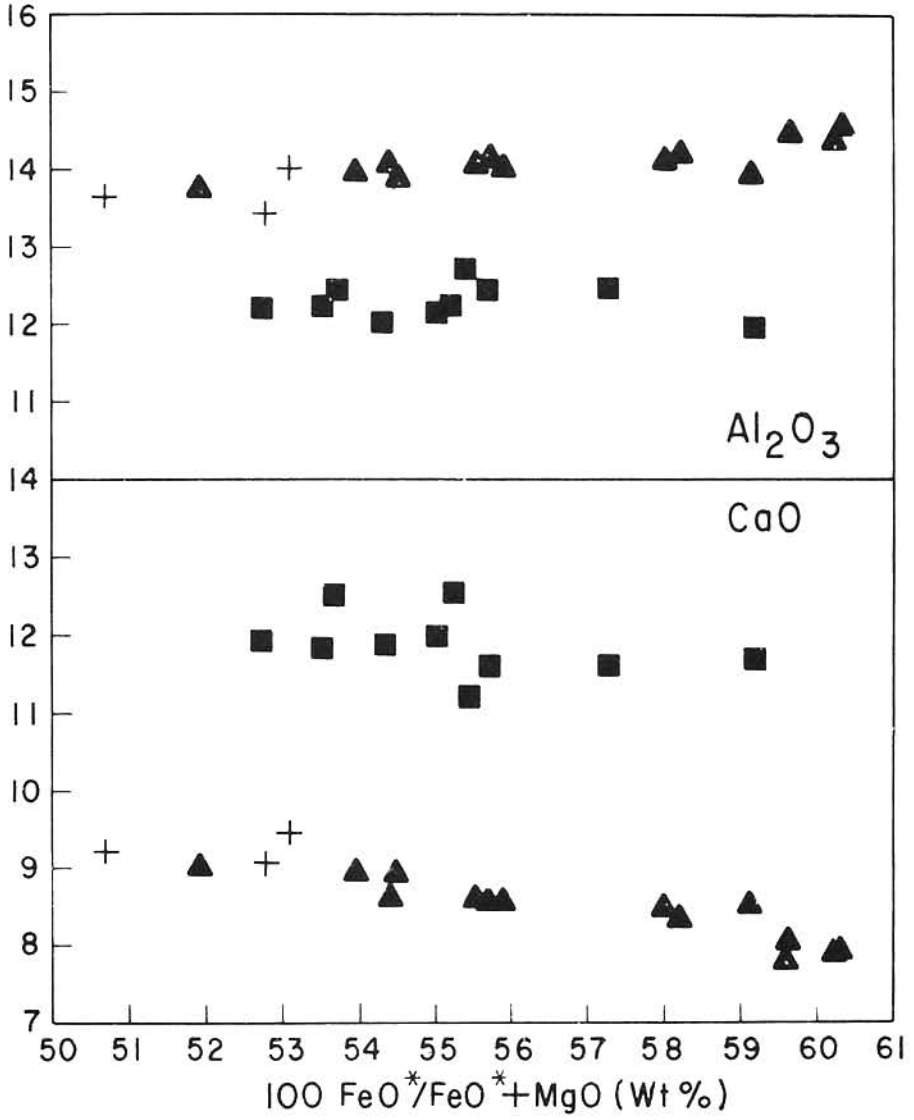

Fig. 5. Al_2O_3 and CaO versus 100 FeO* (FeO* + MgO) variation diagrams for the Kuantan lavas. Symbols as in Fig. 2. Note that the basanites and alkali olivine basalts define a single trend.

and alkali olivine basalts, and define distinctly different chemical variation trends (Fig. 5). Evidently, the olivine nephelinites cannot be related to the other lava types in terms of an evolutionary sequence.

GEOCHRONOLOGY

Analytical Methods

Ten dyke samples and eleven lava samples were selected for K-Ar age dating. The rock samples were crushed and sieved. Size fractions of between 60 and 100 mesh were used for determination of both potassium and argon contents. Potassium contents were determined in replicate by flame photometry using an IL543 instrument and an internal lithium standard. Argon contents were determined by fusion *in vacuo* and isotope dilution using a 38Ar tracer with a 'spike' volume of about 1 nano-litre which is ideal for such young samples as the Kuantan lavas. Argon isotope ratios were measured with an automatic V.G. MM1200 mass spectrometer run statically by a Hewlett-Packard microcomputer. The analytical errors were estimated at ± 1 % for the potassium values and calculated individually for the argon analyses using errors on the argon isotope ratios computed from the precision of the least squares regressions of the measured values to zero time, combined with calculated errors on the spike volume and appropriate enhancement for the atmospheric argon correction. The results obtained in the present studies are listed in Table 2 together with the two ages published by Bignell and Snelling (1977b). All these dates have been calculated using the decay constants recommended by Steiger & Jäger (1977).

Age of the Dykes

The K-Ar ages for the dyke samples show a considerable range from 79 ± 2 Ma to 129 ± 2 Ma, which spans both too long an interval to be likely to reflect a real range in the ages of intrusion of the dykes and about twenty-five times the analytical error associated with the individual age determinations. Note that different samples from the same dyke e.g. H636 and H637 yield very different ages. Furthermore the palaeomagnetic data are consistent with a relatively short period for the intrusion of the dyke swarm since the mean palaeomagnetic pole direction carries an error (α_{95}) of 5.6° and only one dyke yields a reversed magnetisation (see below).

This range of K-Ar ages could be due to loss of radiogenic 40Ar or the presence of excess 40Ar affecting some of the dated whole rock samples or both of these familiar problems in K-Ar dating. As a result of these problems in interpreting the significance of the K-Ar data the age of the Kuantan dykes has not been established as certainly as might be desired. It is fairly certain, however, that these dykes must be at least 79 ± 2 Ma old, regarding the youngest age as a minimum. An alternative interpretation would be that the oldest ages (ca 129 Ma) are correct and that all the rest of the results reflect loss of radiogenic 40Ar to different extents. Finally, another interpretation of the data, which is perhaps the one most likely to be valid, is that the mean age of 104 ± 10 Ma (error 2 × S.E.) is the best estimate of the age of intrusion. It is evident that seven of the results fall within errors of this mean value. Omitting the four aberrant results these remaining seven ages average 103 ± 5 Ma (error 2 × S.E.). On this interpretation the two oldest ages (about 129 Ma) would reflect the sporadic presence of excess 40Ar and the two youngest ages (79 Ma and 83 Ma)would reflect some radiogenic 40Ar loss. According to the time scale of van Hinte (1976) 104 ± 10 Ma falls stratigraphically somewhere between the bottom of the Aptian and the middle of the Cenomanian stages of the Cretaceous.

Age of the lavas

The ages for the Kuantan lavas listed in Table 2 yield a consistent age pattern and are therefore much more satisfactory than those for the dykes discussed above. Despite the analytical difficulties of determining the radiogenic 40Ar contents of such young samples the results range from 2.5 ± 0.1 Ma to 1.20 ± 0.1 Ma. The average age is 1.7 ± 0.2 Ma (error 2 × S.E.) which may be accepted as the best available estimate of the age of extrusion of the lavas. There is no correlation between K content and age and thus no evidence for the presence of excess 40Ar. Stratigraphically the Kuantan lavas may be assigned to the Pleistocene, which fits well with their mean palaeomagnetic vector being close to the direction of the present field but in a reversed sense. In more detail they must have been extruded during the Matuyama reversed epoch which has been dated at between about 0.7 and 2.4 Ma.

PALAEOMAGNETISM

Methods

Between one and seven independently oriented hand samples or field cores (25 mm diameter) were collected from each of the site sampled. Two or three cores, 25 mm diameter, were drilled from each handsample, and one or more cylindrical specimens 25mm long cut from each core, and measured on a DIGICO complete results magnetometer in the palaeomagnetic laboratory of the Department of Geology, University of Malaya. Pilot specimens from each site were demagnetised step by step at 5mT intervals to 60mT, using a Schoenstedt AF demagnetizer. The demagnetising field in the interval giving the least angular change of direction of the magnetic vector was determined using the palaeomagnetic stability index (PSI) of Symons and Stupavsky (1974) and the remainder of samples from that particular site were partially demagnetised at that value, to remove unstable secondary magnetisation. Vector directions from specimens from each sample were meaned, and the means of all samples from each site were meaned to give a mean direction; each dyke was treated as a site.

Palaeomagnetic results are given in Table 3 (dykes) and 4 (lavas) and shown in Figures 1, 6 and 7.

Dykes

Most of the dykes sampled (24 out of 27) have northwesterly magnetic declinations, and positive (downwards) inclinations. A dyke from Tanjung Pelindung (samples H284, 286 to 291), a N-S dyke which is cut by a presumably younger ENE-trending dyke, shows a magnetic vector along the same direction as the majority, but with a reversed polarity; it presumably was intruded during a reversed polarity epoch or interval, and the direction has been reversed and included in the overall mean. A dyke from N of Telok Cempedak (H272 to 277) and the cross-cutting, youngest, dyke at

TABLE 2

K-Ar DATA FOR THE DYKES AND LAVAS OF KUANTAN, MALAYSIA

Sample number		Mean K %	^{40}Ar-radiogenic %	nl/g	Age and error (Ma)
	DYKES				
H196.1		1.477	71	6.150	104 ± 2
H194.1		0.599	65	3.101	129 ± 2
H197.1		1.139	66	3.751	83 ± 2
H198.1		0.773	56	2.992	97 ± 2
H272		0.314	49	1.630	129 ± 2
H277		1.360	91	5.600	103 ± 2
UM8686		0.653	60	2.817	108 ± 2
UM8687		0.950	71	3.601	95 ± 2
H636		0.976	88	3.882	100 ± 2
H637		0.955	87	3.011	79 ± 2
JB71 E		0.505	—	2.286	113 ± 4*
	LAVAS				
QB16		1.209	16	0.0705	1.5 ± 0.3
QB7A		1.769	25	0.1648	2.4 ± 0.3
QB36		1.310	11	0.0975	1.9 ± 0.2
QB8		1.655	17	0.0765	1.2 ± 0.1
QB40		1.434	23	0.0863	1.6 ± 0.3
QB-49C		1.774	16	0.0966	1.4 ± 0.1
QB38		1.529	20	0.0872	1.5 ± 0.1
H192.3		1.567	19	0.1061	1.7 ± 0.3
QB41		1.524	27	0.1077	1.8 ± 0.2
QB7		1.695	24	0.1095	1.7 ± 0.1
QB12		1.538	18	0.1479	2.5 ± 0.1
JB2		1.700	—	0.1064	1.6 ± 0.2*

*Bignell and Snelling, 1977b

Localities:
H194.1 Bukit Ubi Quarry, E. side
H196.1 Lee Quarry
H197.1, H198.1 Chen Foong Koon Quarry
H272 Coast exposure N of Telok Cempedak
H277 Coast exposure N of Telok Cempedak
H636, 637 Citra Quarry, Tanjung (Cape) Gelang (both specimens from the same cross-cutting dyke: see text)
UM8686 Coast exposure, Tanjung (Cape) Pelindung, E-W dyke
UM8687 as UM8686; N-S dyke
JB71 E Jeram Kuantan Estate, about 8 km N of Kuantan
QB-16 Sungai Patong (Alkali olivine basalt)
QB-7A Sungai Ayer Jerneh (Basanite)
QB-36 Kuantan Jeram Estate Road (Alkali olivine basalt)
QB-8 Sungai Ayer Sagu (Olivine nephelinite)
QB-40 Sungai Ayer Batu (Alkali olivine basalt)
QB-49C Sungai Ayer Jerneh (Olivine nephelinite)
QB-38 Tanjung Batu Hitam (Olivine nephelinite)
QB-41 Sungai Karang, Kuantan Jeram Estate (Olivine nephelinite)
QB-9 Sungai Jeram Estate (Olivine nephelinite)
QB-12 Kuantan Jeram Estate Road (Alkali olivine basalt)

NOTE: Dates have been calculated using the decay constants recommended by Steiger and Jager (1977).

TABLE 3

PALAEOMAGNETIC RESULTS FROM DYKES, KUANTAN

Site (each dyke = 1 site)	D	I	N	κ	α_{95}	R	mT
H194	329	56	3	35.2	21.0	2.94	15
H196	327	42	3	33.8	21.5	2.94	15
H197	340	35	3	41.4	19.3	2.95	15
H198	333	44	2	631.3	9.9	2.00	15
H244	328	55	4	79.4	10.3	3.96	15
H245	334	28	2	34.2	44.0	1.97	10
H246	330	56	2	127.4	10.9	2.98	20
H247	354	55	3	343.9	6.6	2.99	10
H248	319	43	3	65.1	15.3	2.97	30
H250–253 (Dyke 6)	324	51	3	225.0	8.2	2.99	25
H254–258 (Dyke 7)	318	45	5	26.2	15.2	4.85	20
H259–263 (Dyke 8)	328	56	5	18.3	18.3	4.78	15
H264–270	323	21	7	32.2	10.7	6.81	20
H271	356	13	1	—	—	—	20
H272–274	234	38	3	2	> 90		15
H275–277	331	30	3	6.1	54.5	2.68	20
H281–283	330	54	3	43.3	18.9	2.95	30
H284, 286–291	163	30	7	5.4	28.5	5.90	15
H301–303 (Dyke 10)	328	53	3	96.3	12.6	2.98	20
H304–307	334	25	4	15.7	23.9	3.81	20
H309, 310 (Dyke 12)	336	40	2	464.9	11.6	2.00	20
H128	335	29	1	—	—	—	15
H129	336	41	1	—	—	—	15
H130	309	35	1				15
H636, 637	284	33	2	26.8	50.3	1.96	10
H638, 639, 640	345	27	3	177.4	9.3	2.99	15,30
H641	346	26	1	—	—	—	15
MEAN[1]	333	40	25	28.2	5.6	24.15	

[1] Reversing H234, 286–291; omitting H272–274; H636, 637 – see text

Localities:		
	H194, H128–130	Bukit Ubi Quarry, E side
	H196	Lee Quarry
	H197, 198	Chen Foong Koon Quarry
	H244–284	Tanjung Tembeling, N side
	H264–270	Tanjung Tembeling, S side
	H271 H272–277	N of Telok Cempedak
	H281–283	N-S dyke, Tanjung Pelindung
	H284–291	E-W dyke, Tanjung Pelindung
	H301–303	Bukit Ubi Quarry
	H304–307	Bukit Ubi Quarry
	H309–310	Bukit Ubi Quarry
	H636, 637	Citra Quarry, Tanjung Gelang (Cross-cutting dyke)
	H638–641	Citra Quarry, Tanjung Gelang

D, I = declination east of true north, inclination (positive down) of cleaned remanence;
R = length of resultant of N unit vectors;
κ = precision parameter;
α_{95} = radius of circle of 95 percent confidence about mean;
mT = demagnetizing field.

TABLE 4

PALAEOMAGNETIC RESULTS FROM LAVAS, KUANTAN

Site	D	I	N	κ	α_{95}	R
H191	193	−20	3	121	11	2.98
H192	151	29	3	110	12	2.98
H193	176	19	3	18.4	30	2.89
Mean of site means	174	10	3	6.2	54	2.68

Note: Site Localities: H191: River Air Jerneh 3.9°N, 103.4°E; Grid 513 678
H192: River Air Jerneh 3.9°N, 103.3°E; Grid 498 682
H193: River Pa Panjang 3.85°N, 103.25°E; Grid 392667

Grid references from sheet 83, Series L7010, Edition 3-PPNM, 1:63 360
Abbreviations as on table 4.
Demagnetizing field 30 mT except for one sample from H193, 40mT.
Initial intensities range from 1960nT to 43300nT; cleaned intensities range from 523nT to 3395nT.

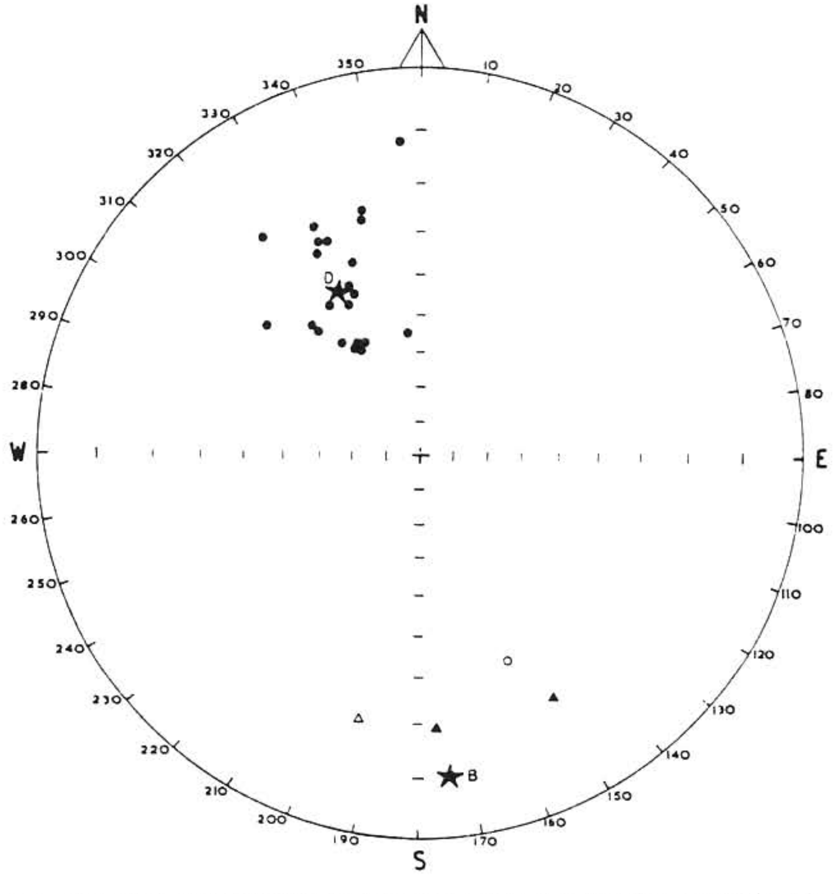

Fig. 6. Steregraphic projection of cleaned directions of magnetization observed in dykes (circles) and basalt (triangles). Solid symbols are on the lower hemisphere, open symbols on the upper hemisphere. Stars show mean directions: D = dykes; B = basalts.

Fig. 7. Palaeomagnetic pole calculated from the Kuantan dykes M(Ku), compared to those of Late Jurassic to Early Cretaceous red beds from Malaya M(J–Kl), West Kalimantan (WK), and West Sulawesi (WS).

Citra Quarry, Tanjung Gelang, gave directions not part of the main statistical population, and have been omitted from the mean; the former site shows poor agreement between the samples, and is thus not reliable.

From the overall mean thus obtained (D = 333, I = 40) a palaeomagnetic pole at 58° N, 52°E can be calculated, assuming that the samples cover a sufficient time range to average out secular variation, and that the region has not been tilted since the dykes were intruded. Statistical polar errors are: dp (latitudinal): 4°; dm (declination): 7°. It thus may be concluded that the Malay Peninsula has rotated 27 ± 7° anticlockwise since the Late Cretaceous, and moved south 19 ± 4° from a Late Cretaceous palaeolatitude of 23 ± 4° (at Kuantan).

Lavas

Samples from Tanjung Batu Hitam were magnetically unstable, but those from the other sites are stable, although showing some what dispersed directions, giving a mean declination of 174°, inclination 10°, that is, they are magnetised close to the direction of the present field but in a reversed sense.

DISCUSSION

The evidence presented here shows exclusively that the sampled dykes and lavas at Kuantan represent igneous events widely separated in time. The dolerite dykes at Kuantan are the most numerous dyke concentration in Peninsular Malaysia; similar dykes occur in Trengganu (one dated at Early Jurassic, 198 Ma, Bignell and Snelling) and in Johore. The occurrence of the only Cenozoic basaltic lavas in Peninsular Malaysia in the same area as this dyke concentration may be fortuitous, but may also imply a deep seated and long lasting zone of crustal weakness.

The Kuantan basalts may be regarded as an "outlier" of the large continental late Cenozoic alkali basaltic province extending through Thailand into Laos, Kampuchea, and Vietnam (Barr and Macdonald, 1979). The distribution of these basalts does not seem to bear any simple linear relationship to any major tectonic features.

The Kuantan dykes probably represent an episode in a long-lasting sequence of late Mesozoic dyke intrusion in the region, from at least the Early Jurassic (see above) culminating in widespread intrusion of dykes in West Kalimantan in Late Cretaceous, associated with granitic rocks in West Kalimantan, West Sarawak, South Sumatra, and islands and wells in the South China Sea which yield ages concentrated around 80 Ma (Haile *et al.* 1977, p. 140–141). Basalts at Segamat, Peninsular Malaysia, are possibly temporally related to the Kuantan dykes; a sample was dated by Bignell and Snelling (1977b) as at least as old as 62 Ma, and their palaeomagnetic vector directions are similar (McElhinny *et al.*, 1974, figure 2). The Segamat basalts certainly do not seem to relate to the Kuantan basalts, as has been postulated by some authors (see, e.g. Gobbett and Hutchison, 1973, p. 204–206). The Late Mesozoic granites and dykes may be related to the prevailing systems of plate subduction, which probably included a "proto-Java Trench" system, a zone along the Lupar Valley of Borneo, and complex interactions of the Pacific and the Philippine plates, or their precusors, to the east. Here again, the complexity of the regional tectonic picture is doubtless the reason for the lack of any simple linear distribution of the Late Mesozoic igneous rocks.

The palaeomagnetic pole calculated from the dykes is in the same general region as those from the Upper Jurassic-Lower Cretaceous redbeds of Malaya (Haile and Khoo, 1980), the Upper Cretaceous of West Kalimantan (Haile *et al.*, 1977) and Jurassic to Lower Cretaceous of West Sulawesi (Haile, 1978), as is shown in Figure 7. All these results indicate anticlockwise rotation and southward movement of those parts of Southeast Asia since the Cretaceous.

ACKNOWLEDGEMENTS

Petrological and palaeomagnetic studies including field work were financed by the University of Malaya, in part by F-vote grants; the contribution by AHH was made as part of his student project at the University of Malaya. The work by RDB and TH is published with the approval of the Director, Institute of Geological Sciences (N.E.R.C.). Robertson Research provided time and facilities to NSH for final writing.

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Manuscript received 14 June 1983.