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Age and MORB geochemistry of the Sabah ophiolite basement

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Abstract: A late Jurassic to early Cretaceous (Neocomian) age is most likely for the ophiolite basement of Sabah, consistent with the Barremian-Aptian age of the overlying ribbon cherts. Attempts at dating have been confined to the K:Ar method, unfortunately unsuited to this rock suite because of its low potassium and high atmospheric argon contents. Our data confirm the need for interpreting part of the extensive ophiolite terrane of the Segama Highlands as consisting of continental lithosphere of Jurassic age — only limited exposures of calc-alkaline granite are known in the Litog Klikog Kiri vicinity of Ulu Segama. The ophiolite suite of the Labuk and Segama Highlands is of low-K tholeiitic affinity and the trace element geochemistry indicates MORB characteristics, typical of magma formation at a mid ocean ridge spreading centre. Before uplift, the Sabah ophiolitic basement may be interpreted as having formed an integral part of either the western Pacific or the eastern Indian Ocean, extant beneath sea level in the Argo Abyssal Plain west of Australia.

INTRODUCTION

In May 1994 a ten-day transect was made across Sabah and samples for study collected from the localities shown in Figure 1. The specimen localities were refined in the field using a Magellan GPS satellite positioning device. The specimens collected and referred to in this paper are:

1 = pillow basalt, Wonod river near Telupid, GPS readings 5°39.5', 117°4.4' (medium grained, composed of 0.5 to 2 mm plagioclase phenocrysts and altered pyroxenes in a plagioclase- and chlorite-rich groundmass. Amygdules and veins are filled with chlorite and calcite); **2** = gabbro block, Segaliud estate, 5°45.0', 117°47.6' (massive altered, medium grained, composed of altered 0.5 to 2 mm plagioclase and 0.4 to 1 mm pyroxene in a chlorite-rich matrix); **3** = microgabbro block, Segaliud estate, 5°43.6', 117°47.7' (massive altered medium grained, composed of 0.5 to 2 mm altered plagioclase, 0.4 to 1 mm pyroxene, and 0.4 mm olivine in a chlorite-rich matrix); **4** = pillow basalt, Segaliud estate, 5°43.3', 117°45.7' (massive, slightly altered, very fine grained, composed of < 0.1 mm plagioclase and < 0.1 mm pyroxene in a chlorite-rich matrix; veins of < 0.5 mm filled with silica); **5** = meta-ultrabasic cumulate, Silam quarry, 4°59.8', 118°13.3' (sheared 1 to 2 mm medium grained equigranular, composed of 70% kinked plagioclase and 25% amphibole); **6** = metagabbro, KTS road, N.W. Silam, 5°0.3', 118°11.5' (sheared medium to coarse grained equigranular, composed of subequal amounts of plagioclase and 2 to 3 mm amphibole, with abundant chlorite and calcite alteration, cut by < 1 mm calcite veins). The following two specimens were provided from the rock collection of the Geological Survey, Kota Kinabalu: **7** = two-mica granite (86A) from Bole River, Ulu Segama, 5.1117°N, 117.8783°E (coarse grained equigranular, composed of ~40 vol.% each of quartz and 2 to 5 mm sodic plagioclase, with 10% K-feldspar, ~10% biotite, and < 5% total of muscovite, epidote, apatite, zircon and sphene); **8** = amphibolite gneiss (layered metagabbro) (87A), Silumpat island, Darvel Bay, 4.7633°N, 118.3817°E (strongly sheared and foliated medium grained, composed of ~60% 0.1 to 1 mm amphibole, ~40% 0.2 to 2 mm plagioclase).

The rocks of the ophiolite suite of Sabah have been described by Kirk (1968), Dhonau and Hutchison (1966), Hutchison and Dhonau (1971) and Leong (1974), and their petrology and metamorphism described by Hutchison (1978). Omang (1993), Omang and Barber (1996), Omang (1995), Omang and Sanudin (1995) and Omang (1996a, 1996b) have studied the ophiolite suite of Sabah. They suggested that the pillow basalt of Telupid (locality 1, this paper) has boninitic characteristics.

OVERLYING OCEANIC SEDIMENTS

The first sediments to be deposited on the pillow basalts of the ophiolite were ribbon cherts. These contain radiolaria. However the palaeontological determinations in the older literature, based improperly on thin section identifications, may be confidently discounted. More recent determinations, based on three-dimensional morphology of radiolaria extracted by acid digestion, have shown from four widely separated localities that the cherts are Lower Cretaceous (Barremian to Aptian, 115–125 Ma) age. The localities so determined are — the Segama Highlands (Leong, 1977), Silam (Aitchison, 1994), Kudat (Basir *et al.*, 1985) and Telupid (Basir, 1992). Since the ribbon cherts represent the sedimentary layer of the ophiolite (Layer 1), then Layer 2 (the pillow basalts) and Layer 3 (gabbro) must stratigraphically pre-date the Barremian.

The term 'Chert-Spilite Formation' is entrenched in Sabah literature (Kirk, 1968). The spilite represents Layer 2 of the ophiolite and the chert Layer 1. Unfortunately abundant sandy turbidites and rare limestones have traditionally been included in the 'Chert-Spilite Formation' and they have yielded micro-fossil ages ranging from Cretaceous to Eocene. Although they all represent

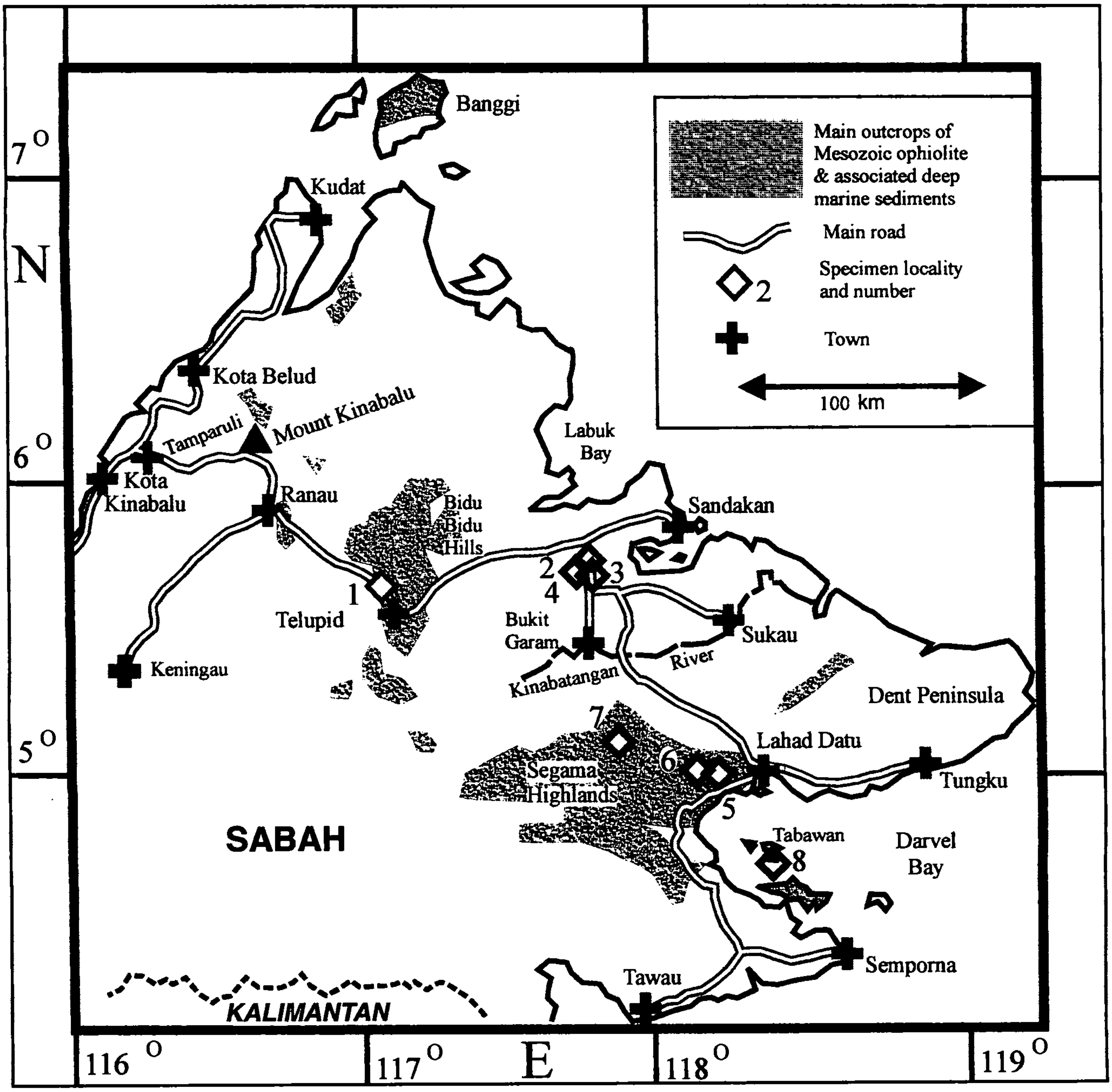

Figure 1. Locality sketch map of Sabah showing where the ophiolite samples of this study were collected.

Table 1. Age of the ophiolite basement.

Locality	Age	
Layer 1 (Ribbon cherts) dated by radiolaria to be Lower Cretaceous (Barremian to Aptian)	115–125 Ma	(Leong, 1977; Basir *et al.*, 1985; Basir, 1992, Aitchison, 1994).
Layers 2 and 3 (basalt and gabbro): K:Ar dating		
Amphibole from amphibolite gneiss (layered gabbro), Silumpat Island (J1060)	101 ± 15 Ma	
Epidote amphibolite (meta-basalt) from Adal Island, Darvel Bay (J1166)	140 ± 20 Ma	(Dhonau and Hutchison, 1966; Hutchison and Dhonau, 1971)
Gneissic amphibolite from Tanna island (J5500A)	87 ± 2.5 Ma	(Leong, 1974)
Gabbro in Bole River (Segama Highlands)	137 ± 6 Ma	(Rangin *et al.*, 1990)
Gabbro in mélange, north of Mount Silam	33.4 ± 1.7 Ma	(Rangin *et al.*, 1990)
Amphibole from massive meta-gabbro from Kampong Singah Mata, 0.5 mile east of Lahad Datu (LD6)	164 ± 7 Ma	(Omang, 1993)
Amphibole from massive meta-gabbro from southern Silumpat island (S14a)	179 ± 11 Ma	(Omang, 1993)
Locality: Silumpat Island (8, Fig. 1).		
Specimen: Amphibole (K wt% = only 0.15) from amphibolite gneiss.	131 ± 6 Ma	(Swauger *et al.*, 1995)

the deep marine sedimentary cover, only the Barremian–Aptian ribbon cherts should be taken as part of the ophiolite basement.

K-AR RADIOMETRIC DATING

Table 1 lists the relevant K-Ar dates for the igneous layers of the ophiolite, from which a Neocomian age (140–122 Ma) may be accepted, consistent with the stratigraphic Barremian–Aptian (125–115 Ma) age of the ribbon cherts. The two K:Ar ages of 164 ± 7 and 179 ± 11 Ma (Omang, 1993) may indicate that in part the ophiolite dates back to the Lower Jurassic. However the high proportion of atmospheric Ar^{40}, ranging from 47 to 73%, and the relatively low K content, ranging from 0.12 to 0.22 wt%, strongly indicate the possibility that the Jurassic ages may be spuriously excessive.

A problem in interpreting the radiometric ages of the igneous rocks is presented by the pervasive though incomplete metamorphism of the basalt to epidote amphibolite and the layered gabbro to banded amphibolite gneiss, both rich in metamorphic amphibole. However, Hutchison (1978) has shown that even the most metamorphosed rocks contain igneous relicts. The generally untwinned plagioclase is of bi-modal composition — an original labradorite-bytownite and a co-existing albite-oligoclase — the former igneous, the latter metamorphic. The metamorphism has consistently been somewhat patchy and incomplete (a common condition of ophiolites worldwide) and Hutchison (1978) proposed that it resulted from sub-sea-floor hydrothermal action, but this cannot be proved. Omang and Barber (1996) proposed that the metamorphism took place adjacent to a transform fault, but this remains an abstract hypothesis that cannot be demonstrated in the field. Because all ophiolite mineral assemblages are partly igneous and partly metamorphic (Hutchison, 1978), the exact meaning of a whole rock K:Ar age is uncertain, but a K:Ar determination on separated amphibole is likely to represent the age of metamorphism. Also the low K and high atmospheric Ar^{40} contents of the rocks result in the K:Ar method being less than perfect. It is unlikely that the ophiolite behaved as a closed system during metamorphism. Argon was undoubtedly lost, so that the majority of the K:Ar dates will be significantly low. The gain in atmospheric argon would have resulted in significantly high K:Ar dates for other samples.

The gabbros of the Segama Highlands contain several low-potassium plagiogranite bodies, which are characteristically leucocratic and deficient in alkali feldspar (Yan, 1979). They are an expected integral part of the ophiolite suite, but have not been directly dated.

GABBROS AT SEGALIUD ESTATE

We paid particular attention to a cluster of gabbro outcrops in the Segaliud oil palm estate (localities 2 and 3, Fig. 1). Clennell (1992) interpreted these as gabbro intrusions into the Kulapis Formation. He stated that contact metamorphism was evident because a red mudstone was converted to purple hornfels spotted with epidote. However we found large neighbouring outcrops of pillow basalt overlain by ribbon chert, suggesting that the gabbro is more likely to belong to the imbricated ophiolite.

Our K-Ar dates (Table 2) confirm a Cretaceous age and even the apatite crystals have retained a similar fission track age. Therefore the gabbro outcrops belong to the basement ophiolite suite and the occurrences may represent blocks in the Garinono Formation mélange, which forms extensive surrounding nearby outcrops (Clennell, 1991).

EVIDENCE FOR CONTINENTAL LITHOSPHERE, SEGAMA HIGHLANDS

It has already been pointed out by Hutchison (1989) that the ophiolite region of the Segama Highlands may contain at least one terrane (block) of continental lithosphere. A granite containing 2.25 wt% K_2O has been described by Kirk (1968) from the Litog Klikog Kiri river (loc. 7, Fig. 1) and K-Ar ages of this and associated hornfels are given in Table 3. Such a granite cannot be derived from an ophiolite basement. It is likely that the Neocomian to Jurassic ophiolite may have been thrust over and is supported by continental lithosphere. Hutchison (1989) designated this region as a possible microcontinent and named it the *Segama Block*. The oldest K-Ar radiometric age determined from a granitoid in the nearby Kawag Gibong river, is 210 Ma ± 3 Ma (Early Jurassic) (Leong, 1974). We have added some additional dating to this province, which supports a Jurassic age (Table 3).

BULK DENSITY

A number of ophiolitic rocks were measured in the laboratory and the following values are recommended for future gravity modelling:

- Basalt and gabbro (2.77 ± 0.18 gm cc^{-1})
- Peridotite (2.82 ± 0.14 gm cc^{-1})
- Granite (2.67 ± 0.10 gm cc^{-1}).
- Chert (2.61 ± 0.06 gm cc^{-1}).

MAGNETIC SUSCEPTIBILITY

Measurements were made both in the field and in the laboratory, but there is extreme variability in the readings. The following average values are

Table 2. Age of gabbro blocks, Segaliud Estate.

Locality	**Specimen**	**K-Ar age**
2	plagioclase (K wt% = only 0.11) in gabbro	81.7 ± 4.3 Ma
3	plagioclase (K wt% = only 0.12) in microgabbro	52.0 ± 3.5 Ma
Locality	**Specimen**	**Apatite fission track age**
2	gabbro	76.3 ± 22.9 Ma

Table 3. K:Ar dates on non ophiolitic granite of the Upper Segama-Litog Klikog Kiri-Kawag Gibong area.

Specimen	**Age**	
biotite from tonalite (NB11714)	150 ± 6 Ma	(Leong, 1974)
biotite from associated hornfels and schist (NB10852)	160 ± 8 Ma	(Kirk, 1968)
biotite from tonalite (J5698B)	210 ± 3 Ma	(Leong, 1974)
granite (J5712)	120 ± 1.5 Ma	(Leong, 1974)

Locality (Fig. 1)	**Specimen**	**Age**
7	muscovite (K wt% = 8.6) from granite	156 ± 3 Ma
7	biotite (K wt% = 7.0) from granite	105 ± 2 Ma
7	plagioclase (K wt% = 1.5) from granite	99.5 ± 2.6 Ma
		(Swauger *et al.*, 1995)

Table 4. Major element geochemistry (wt%), of selected ophiolite rocks.

Oxide	1	2	3	4	5	6
SiO_2	50.8	48.1	50.7	48.4	36.5	46.8
TiO_2	1.08	0.76	0.99	1.28	0.76	0.13
Al_2O_3	14.3	14.6	15.1	14.8	15.0	20.3
Fe_2O_3	3.57	1.85	2.47	4.54	0.82	0.99
FeO	4.5	6.0	6.3	4.5	4.0	2.7
MnO	0.11	0.16	0.18	0.30	0.10	0.08
MgO	5.93	8.40	6.85	6.60	27.60	7.86
CaO	12.00	10.40	9.48	10.00	4.22	12.70
Na_2O	1.83	2.96	3.48	2.83	0.58	2.60
K_2O	< 0.01	0.10	0.23	0.33	0.02	0.20
P_2O_5	0.12	0.08	0.09	0.12	0.02	0.02
S	0.2	0.0	0.2	0.0	0.0	0.0
H_2O^+	4.40	5.30	2.80	2.70	6.90	3.90
H_2O^-	0.40	1.30	0.60	1.40	0.10	0.30
CO_2	< 0.01	0.08	0.04	0.08	< 0.01	< 0.01
Total:	99.25	100.09	99.21	97.88	96.62	98.58

Table 5. Trace element contents (in ppm) of the Sabah ophiolite.

Element	1	2	3	4	5	6
F	90	< 20	< 20	190	10	< 20
Cl	68	94	181	66	94	< 50
Sc	30	35	32	41	37	21
V	222	199	219	225	166	45
Cr	230	320	160	340	650	660
Co	30	33	31	36	49	27
Ni	71	91	49	54	808	134
Cu	47.0	20.5	56.7	102.0	16.4	61.3
Zn	48.2	42.6	54.5	73.7	29.6	13.1
Mo	4	< 1	2	1	2	2
Ag	0.6	< 0.1	0.6	0.6	< 0.1	0.3
Au*	< 2	< 2	< 2	< 2	4	< 2
Rb	5	8	21	5	< 2	< 2
Li	5	19	17	36	6	1
Os	0.8	1.2	2.1	1.2	0.5	< 0.5
In	< 0.5	< 0.5	0.8	0.6	0.6	0.6
Sn	10	10	8	15	9	9
Sr	28	292	137	155	16	330
Ba	23	94	155	94	70	92
La	3.0	1.6	2.3	3.2	1.8	0.4
Ce	9.2	5.2	7.1	9.9	4.4	1.1
Pr	1.6	0.9	1.3	1.8	0.7	0.2
Nd	8.6	5.5	7.3	9.7	3.0	1.0
Sm	3.3	2.4	3.1	4.0	1.1	0.4
Eu	1.17	0.83	1.11	1.42	0.42	0.37
Gd	3.9	2.7	3.7	4.5	1.5	0.6
Tb	0.7	0.5	0.7	0.9	0.3	0.1
Dy	4.7	3.6	4.7	5.6	1.8	0.7
Ho	1.07	0.82	1.02	1.23	0.39	0.15
Er	3.0	2.2	3.0	3.5	1.1	0.4
Tm	0.5	0.3	0.4	0.5	0.2	< 0.1
Yb	3.0	2.2	2.9	3.2	0.8	0.3
Y	26	20	25	29	8	3
Zr	83	41	62	81	36	< 10
Nb	7	3	6	4	7	3
Hf	1.8	1.2	1.7	2.1	0.8	< 0.3
Ga	22	16	18	18	15	12
Ge	14	13	< 10	< 10	< 10	< 10
As	0.7	0.5	0.4	1.5	< 0.1	< 0.1

*Au in ppb

in micro cgs units.

Gabbro (field) 500 ± 400, (laboratory) 570 ± 500. Basalt (field) 1,410 ± 1,400 (lab.) 1,340 ± 1,700. Serpentinite (field) 1,960 ± 1,450. Peridotite (field) 560 ± 324 (laboratory) 820 ± 900. These values may be used to calibrate the results of shipborne magnetic surveys, but the extreme variability of the measurements must be stressed.

GEOCHEMISTRY

Major element contents were determined by conventional X-ray fluorescence spectroscopy, minor and trace elements using a variety of wet chemistry, ICP-MS, DCP, XRF and other techniques in X-ray Assay Laboratories, Toronto. Analytical uncertainties are < 1–5 relative % for major elements (present in concentrations > 10 wt%) and 5–20 relative % for minor and trace elements. The details are contained in an unpublished ARCO report (Swauger *et al.*, 1995). The results are given in Tables 4 and 5.

A plot of wt% K_2O versus wt% SiO_2 places the pillow basalt and gabbro samples of the ophiolite suite clearly in the predicted low-K tholeiitic series (Fig. 2). Specimen 5 from Silam quarry cannot represent a magma composition because of its low SiO_2 content. It represents a cumulate layer, which in common with all ophiolite rocks here, has been metamorphosed. Other typical chemical parameters, plotted against wt% SiO_2 are shown in Figure 3. They are also typical of the low-K tholeiite series.

The rare earth element plots, showing the chondrite normalized concentrations plotted versus atomic number (57–72) of the Sabah ophiolite suite, have a characteristic horizontal-concave pattern with relatively low REE contents (< 10–20* chondrite). This pattern is indicative of mid-ocean ridge basalts (Fig. 4).

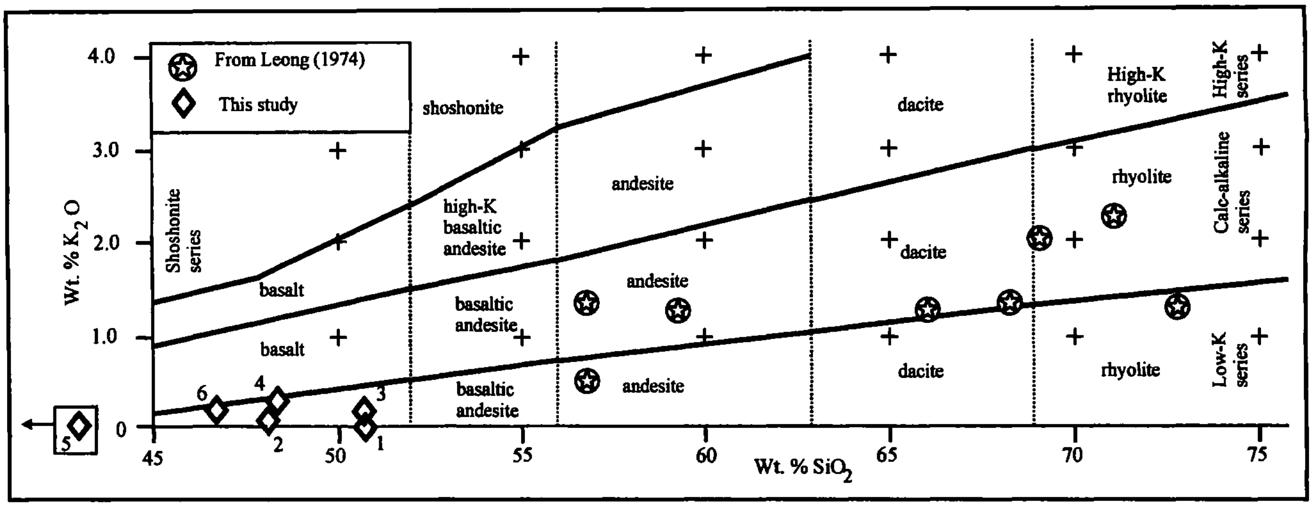

Figure 2. Plot of wt% K_2O versus SiO_2 showing that the ophiolitic rocks belong to the tholeiitic series. The subdivisions of the field follow Ewart (1982). The included more acidic rocks (from Leong, 1974) belong to the calc-alkaline series and could not have been derived from the ophiolite.

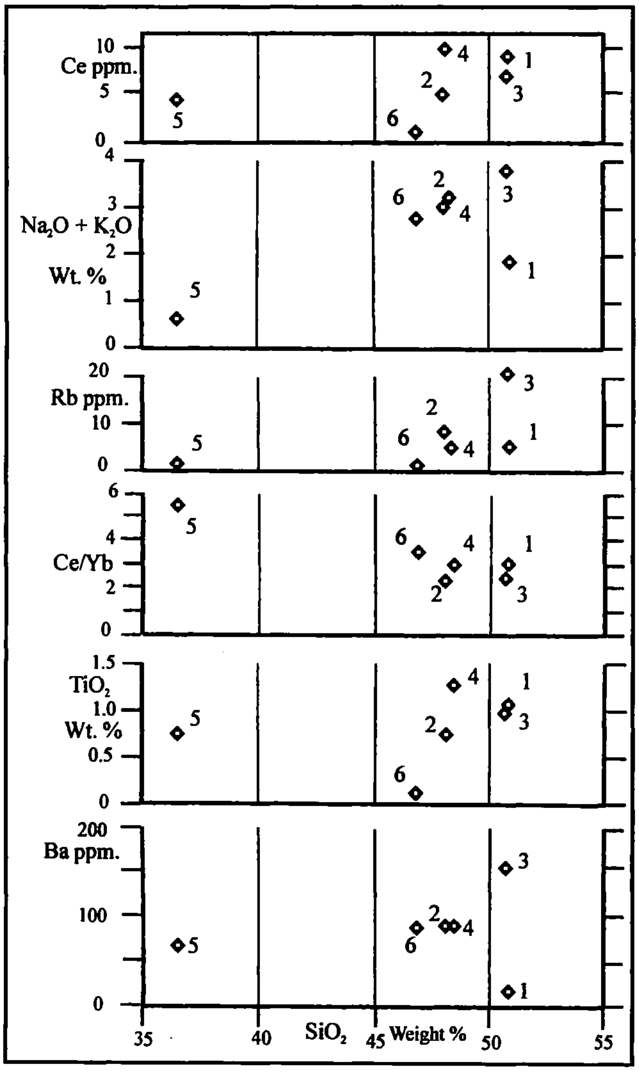

Figure 3. Plots of various chemical parameters against wt% SiO_2 consistent with the low-K tholeiite series.

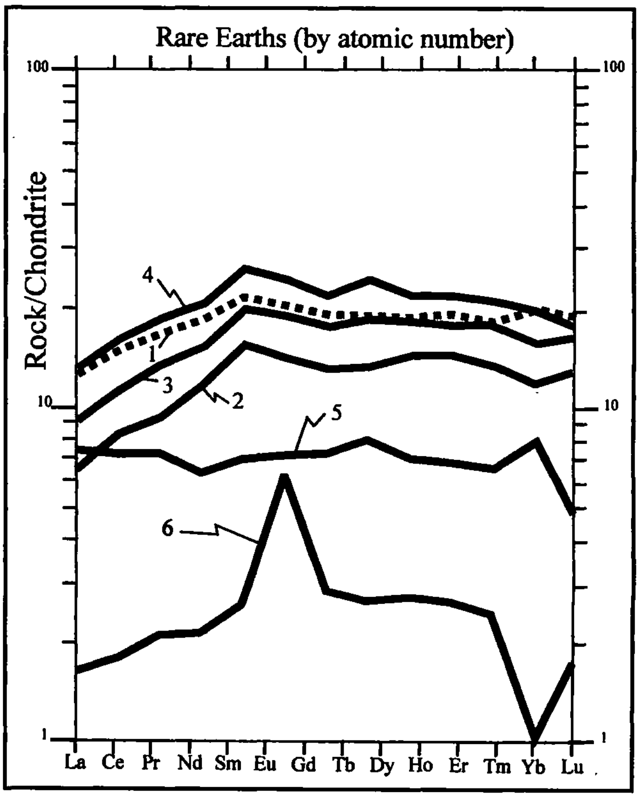

Figure 4. Chondrite normalized rare earth concentrations versus atomic number, indicating a MORB geochemical characteristic.

REGIONAL CONSIDERATIONS

The floor of the Argo Abyssal Plain of the eastern Indian Ocean, lying south of Java and the Sunda Trench, is characterized by NE-trending magnetic anomalies indicating a Neocomian age (Hutchison, 1989, p. 11). Before formation of the Cenozoic Sunda arc-trench system, this older part of the India Ocean would have continued northwards to the neighbourhood of what is now known as Borneo, to form continuity with the western Pacific. It may therefore be concluded that the ophiolitic basement of Sabah was in Neocomian times an integral part of the eastern Indian Ocean, subsequently uplifted to form the basement of Sabah, but still extant as ocean floor west of Australia. In Neocomian times, there is no known record of land in central or eastern Borneo, and the whole of Sabah was oceanic. Land was confined to western Borneo — the Schwaner Mountains and Kuching zone of Sarawak (Hutchison, 1996). Many authors refer to the oceanic lithosphere of Sabah as that of the "proto South China Sea". However, it had no genetic relationship to the present day South China Sea and N.S. Haile suggested a more appropriate term — the Danau Sea (see Hutchison, 1996).

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