Geol. Soc. Malaysia, Bulletin 44, July 2000; pp. 139-150

Age, petrochemistry and modelling of the Bukit Mertajam-Kulim granite, northwest Peninsular Malaysia

AZMAN A. GHANI, BORHAN M. DOYA AND G.H. TEH

Department of Geology
University of Malaya
50603 Kuala Lumpur

Abstract: The Bukit Mertajam-Kulim granite consists of three units, namely, the Mertajam, Bongsu and Panchor granites which were emplaced in a relatively short time span between 180 to 224 Ma. All three units consists of rocks ranging from equigranular fine to coarse grained syeno- to monzogranite with subordinate porphyritic types. The essential minerals in all granites are K-feldspar, plagioclase, quartz, biotite, muscovite, tourmaline, apatite, zircon, garnet and opaque phases. The range of SiO_2 for each of the units overlap: Mertajam granite (71.49–74.73%), Bongsu granite (73.59–76.27%) and Panchor granite (70.21–73.91%). The rocks in many aspects, are comparable to the 'S' type granites from the Lachlan Fold Belt of Australia. The mineral mixes predicted in the major elements modelling confirm the dominance of plagioclase and K-feldspar in the fractionation process.

INTRODUCTION

The Bukit Mertajam Kulim (BMK) granite is an isolated body located at north-west Peninsular Malaysia. The granite, which lies to the west of the Bintang batholith, is part of the Western Belt granite of Peninsular Malaysia (Fig. 1). To the west of this granite lies the Penang granite which makes up the whole of Penang Island.

In this paper we present the first detailed account of a petrochemical study of the granitic rocks in Bukit Mertajam-Kulim area. This study chiefly resulted from detailed field mapping and geochemical work done by the second author (Borhan M. Doya, 1995). The area is suitable for geochemical study as a lot of quarries have developed in order to provide rock aggregates for the North-South highway construction. In this paper we have suggested a new subdivision of the BMK granite. Detailed modelling of the large ion lithophile (LIL) and major elements emphasizes the differences between the three subdivisions that we have suggested.

AGE OF THE GRANITE

Work on the geochronology of the BMK granites began when Bignell (1972) reported K-Ar mineral ages for biotite separates from pink porphyritic Penanti granites (north of Bukit Mertajam) defined an age of 196±8 Ma. K-Ar mineral ages for biotite and muscovite separates for the Karangan biotite granite (north east Kulim) gave an age of 190±10 and 180±10 Ma respectively. Cobbing and Mallick (1987) published the whole rock Rb-Sr isochron on the Panchor granite (known as Bongsu granite by Cobbing and Mallick, 1987). A single isochron was drawn through the granite data set which defined an age of 224±5 Ma. A same method applied to the Bongsu granite (known as Jelutong microgranite by Cobbing and Mallick, 1987) gave an age of 211±9 Ma. Thus, based on the granite ages, the younging sequence of the granites is as follows: Mertajam granite (180±10 to 196±8 Ma) – Bongsu granite (211±9 Ma) – Panchor granite (224±5 Ma). The isotopic ages from the BMK granites indicate that they are emplaced in a relatively short time span between 180 to 224 Ma.

FIELD ASPECT

The Bukit Mertajam granite has been subjected to many subdivisions (Courtier, 1974; Liew and Page, 1985; Cobbing *et al.*, 1992; Cobbing and Mallick, 1987). Courtier (1974) and Liew and Page (1985) distinguished two granites suites, the Penanti (corresponding to the Mertajam granite in this study) and the Bongsu (corresponding to the Bongsu and Panchor granites in this study). Cobbing *et al.* (1992) and Cobbing and Mallick (1987) distinguished three rock units, namely the Bongsu granite, the Jelutong microgranite and the Mertajam microgranite. Their map, however, is different compared to ours, Courtier (1974) and Liew and Page (1985) (Fig. 2). Interestingly, the eastern part of this granite which consists of small granite hills is not indicated in the Cobbing and his co-workers' map. Furthermore, Cobbing *et al.* (1992) map did not differentiate the coarse grained granite from the microgranite, two rock types which

Paper presented at GSM Western Belt & Paleozoic of Peninsular Malaysia Seminar '99

dominate in this part of the BMK granite. In their map, this area has been marked with coarse primary textured biotite granite.

On the basis of age, field relations and geochemical data, we have divided the BMK granites into three, that is (from north to south), the Mertajam, Bongsu and Panchor granites (Fig. 1). The Mertajam granite is located at the north and northwest portion of the study area. The granite is dominated by medium to coarse grained biotite granite and sparsely porphyritic microgranite. Good outcrops of the Mertajam granite can be found at Bukit Mertajam, Juru, Kulim and Penanti areas. The Bongsu granite constitutes about 65% of the granitic rocks in the study area. The rock grades from medium to coarse grained biotite muscovite granite with porphyritic varieties occurring north of the Bongsu pluton. The granite is characterised by muscovite crystals which sometimes can exceed 1 cm across. The granite can be found at Gunung Bongsu, Terap and Sungai Karangan. The most southerly granite, the Panchor granite consists of fine to coarse grained porphyritic biotite granite. This is the smallest unit of the BMK granite. Good outcrops of this granite can be found at km 168–171 along the North-South highway.

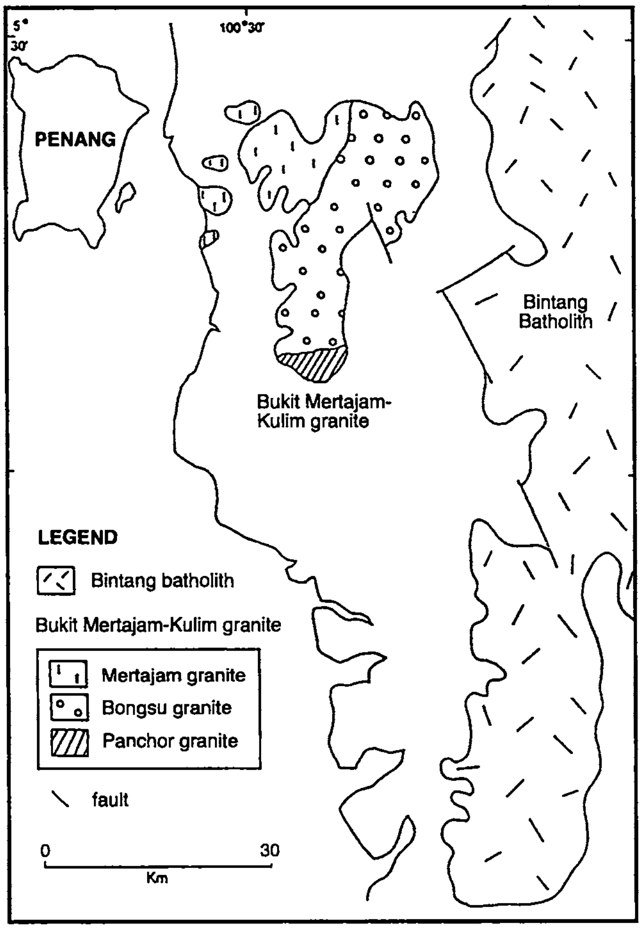

Figure 1. Geological map of the Bukit Mertajam-Kulim granite.

PETROLOGY

Modal analyses for the BMK granites are plotted on a Q-A-P diagram (Streckeisen, 1976) (Fig. 3). All granite samples plot in the syenogranite and monzogranite fields. The modal plot also shows there is no systematic sequence between the different granite units that is the samples from all units overlap.

Mertajam granite

This granite consists of two main types, namely medium to coarse grained biotite granite and the sparsely porphyritic microgranite. Both granites are of similar composition except that the former also contains traces of galena, pyrite and garnet. The essential minerals in the granite are K-feldspar, plagioclase, quartz, biotite, muscovite, sphene, apatite, zircon and opaque phases.

Medium to coarse grained biotite granite

This rock is characterised by large, subhedral to anhedral alkali feldspars, up to 6 cm across which often gives the rock a distinctly porphyritic appearance in hand specimen. The main K-feldspar type is microcline microperthite. Plagioclase is euhedral to subhedral and ranges in size between 1 to 2 mm across. It usually shows albite, Carlsbad-albite and pericline twinning. Both feldspars frequently altered to sericite or secondary muscovite. Quartz is anhedral and also occurs as interstitial to feldspar which suggests late crystallization. Biotite is subhedral to anhedral and occurs as individual crystals or as biotite clots. Inclusion of accessory zircon is fairly common. The crystals are commonly altered to chlorite and secondary sphene. Secondary muscovite occurs almost everywhere in the rock mainly from alteration of plagioclase crystals. Euhedral sphene associated with quartz suggests that the mineral is magmatic. This feature is odd, considering that the Western Province granite is generally accepted as 'S' type granite which is devoid of accessory sphene (Chappell and White, 1992).

Sparsely porphyritic microgranite

This rock consists mainly of microgranite and porphyritic microgranite occurring at the north of the BMK granite. The former outcrops mainly at the Eastern part of the Mertajam granite. The rocks are fine grained with pink coloured euhedral K-feldspar as the main phenocryst. The phenocryst/matrix ratio is low usually up to 15%. The main phenocryst type is orthoclase usually showing a

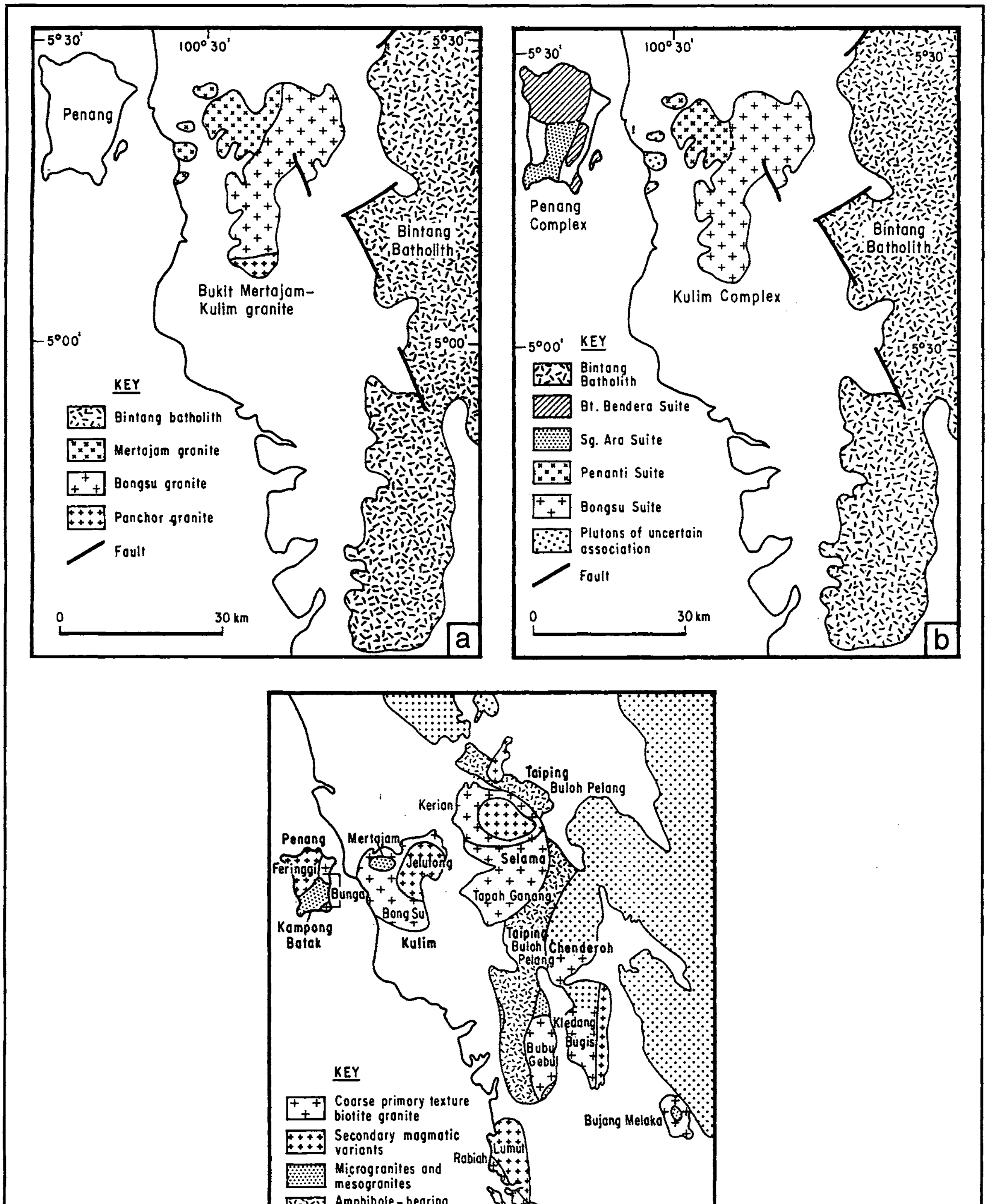

Figure 2. Bukit Mertajam-Kulim granite subdivision (a) subdivision used in this paper, (b) subdivision by Courtier (1974) and Liew and Page (1985) and (c) subdivision by Cobbing *et al.* (1992).

coarse perthitic texture with the lengths up to 1.5 mm. Microcline is a common K-feldspar type in the matrix with the size ranging from 0.1 to 0.4 mm across. Biotite is the main mafic mineral. Inclusions of small euhedral to subhedral plagioclase, rounded quartz and biotite are common. The K-feldspar type in the matrix is microcline. Mymerkite texture occur at the margin of the crystal indicating intergrowth at the eutectic composition. Micrographic intergrowths between K-feldspar and quartz is another common feature found in this rock. Plagioclase occurs in small amounts usually up to 5% and commonly has albite twinning. Inclusions of small, acicular (0.05 mm length) apatite crystals are quite common.

Bongsu granite

Bongsu granite generally consists of medium to coarse grained biotite muscovite granite with the grain size is up to 2 cm across. The essential minerals in the granite are K-feldspar, plagioclase, quartz, biotite, muscovite, tourmaline, apatite, zircon, garnet and opaque phases. Porphyritic varieties also occur at the northern part of the Bongsu granite. In this rock, muscovite can be seen in hand specimen and K-feldspar size is up to 4 cm in length. Euhedral, rounded garnet is associated with biotite. Hall (1965) discussed the genesis of garnet from the Donegal granites suggesting that it was a late magmatic mineral formed by accumulation of manganese which eventually reached sufficient concentration in the magma to enable almandine-spessartine garnet to crystallize. Both brown and red biotite occur in this rock (up to 1.5 mm in size). Reddish biotite occur as anhedral crystals with prominent blackish pleochroic haloes. Chappell and White (1992) reported the occurrence of the reddish coloured biotite (pleochroism X = black brown and Y = foxy red brown) in a 'S' type granite from the Lachlan Fold Belt of Australia. Chloritisation of biotite is quite common.

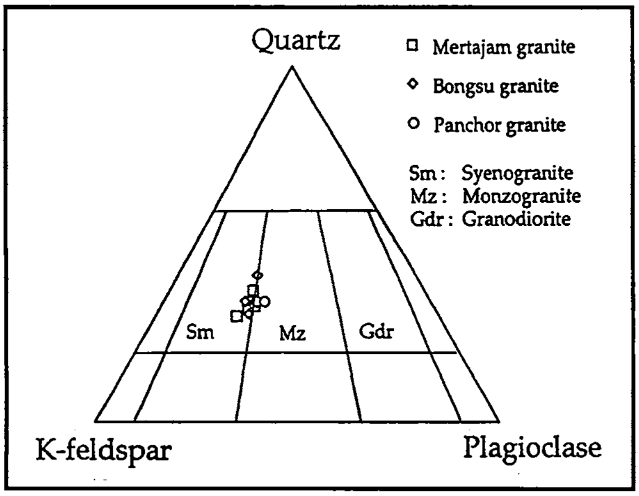

Figure 3. Q-A-P classification of the Bukit Mertajam-Kulim granite.

Panchor granite

The Panchor granite is the most southerly granite body of the BMK complex. The granite consists of both equigranular and porphyritic varieties. The latter consists of phenocrysts ranging from 1 to 5 cm set in a medium grained matrix. In some places the phenocrysts show some alignment which probably formed resulting from the magmatic flow of partially crystallized magma. The essential minerals in the granite are K-feldspar, plagioclase, quartz, biotite, muscovite, tourmaline, apatite, zircon and opaque phases. Biotite occasionally occur as inclusions in microcline-microperthite. Tourmaline occurs as interstitial secondary crystals to plagioclase and K-feldspar. Muscovite occurs as a secondary phase altered from K-feldspar and plagioclase. The muscovite sometimes forms radiating crystals together with chloritised biotite.

GEOCHEMISTRY

20 samples (10 from the Mertajam granite, 6 from the Bongsu granite and 4 from the Panchor granite) have been analysed for major and trace elements (Table 1). In general all the three granite samples analysed in this study have SiO_2 more than 70%. The rock analyses from Cobbing *et al.* (1992) gave the lowest SiO_2 of 68.7%. However the data set from Cobbing *et al.* are not included in this study as all the samples are poorly located and they are using a different granite subdivision (see field aspect section). The Panchor granite has the lowest SiO_2 content, 70.9%. The highest SiO_2 is recorded from the Bongsu sample i.e. 76.3%. The range of SiO_2 for each of the units overlap: Mertajam granite (71.49–74.73%), Bongsu granite (73.59–76.27%) and Panchor granite (70.21–73.91%). Harker variation diagrams for major elements are shown in Figure 4. In general, Fe(tot), TiO_2, Al_2O_3, CaO and MgO decrease whereas Na_2O increases with increasing SiO_2. K_2O and P_2O_5 show no significant trend with SiO_2. A SiO_2 compositional gap occur in the sample from Panchor granite probably related to undersampling. Average normative corundum for all the granites is 1.4%, only four samples from Mertajam granite have normative corundum below 1%. The rocks have high alkali contents, with the $Na_2O + K_2O$ ranges from 7.3 to 8.9%. Classification by the alumina saturation index (ASI) of Shand (1927) and Zen (1986) indicates that all of the granite samples are peraluminous (ASI > 1). The general trend show

Table 1. Major and trace elements analyses of the Bukit Mertajam-Kulim granite.

Pluton Sample	Mert Mgr-1	Mert TB1	Mert LSC	Mert LITI	Mert KGN	Mert BB	Mert KP(W)	Mert KP(P)	Mert JKR1	Mert JKR2	Bongsu SM1	Bongsu SM2	Bongsu LD1	Bongsu LD2	Bongsu FGB1	Bongsu FGB2	Panchor LB1	Panchor LB2	Panchor HW1	Panchor HW2
Major Element wt%																				
SiO_2	72.73	73.08	73.96	73.17	72.85	73.54	71.49	72.66	73.96	74.73	73.59	73.73	74.31	74.63	76.27	76.00	71.21	70.92	73.91	73.58
TiO_2	0.27	0.27	0.27	0.35	0.37	0.31	0.42	0.34	0.23	0.24	0.30	0.29	0.19	0.19	0.21	0.19	0.38	0.37	0.27	0.29
Al_2O_3	14.03	14.18	13.04	13.78	14.06	13.08	14.30	13.95	13.99	12.92	13.89	13.94	14.16	14.06	12.89	12.88	14.72	14.77	13.74	13.76
Fe(tot)	2.01	1.79	1.71	2.17	2.27	1.99	2.67	2.16	1.96	1.93	2.00	1.97	1.59	1.57	1.79	1.64	3.55	3.62	2.27	1.96
MnO	0.04	0.02	0.05	0.06	0.06	0.04	0.07	0.06	0.05	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.06	0.07	0.06	0.05
CaO	1.18	1.36	1.17	1.55	1.74	1.60	2.21	1.40	0.92	0.61	1.21	1.21	0.82	0.80	0.85	0.89	1.98	1.99	1.08	1.24
K_2O	5.64	5.71	5.36	5.27	4.94	5.14	4.83	5.18	4.87	4.67	5.25	5.26	5.35	5.26	4.88	4.60	5.77	5.87	4.88	4.91
P_2O_5	0.13	0.11	0.12	0.11	0.12	0.11	0.15	0.12	0.11	0.15	0.12	0.12	0.21	0.21	0.14	0.11	0.14	0.14	0.15	0.19
MgO	0.37	0.26	0.41	0.45	0.49	0.38	0.63	0.51	0.24	0.32	0.35	0.31	0.21	0.23	0.24	0.11	0.26	0.27	0.34	0.41
Na_2O	2.83	2.54	3.10	2.64	3.02	3.08	2.90	3.01	3.11	3.40	3.00	2.87	2.81	2.93	3.08	2.69	2.49	2.37	3.06	3.18
LOI	1.00	0.67	0.55	1.07	0.86	0.25	0.64	0.85	1.38	1.20	0.83	0.65	0.60	0.86	0.53	0.78	0.32	0.48	1.01	0.64
Total	100.21	100.30	99.73	100.60	100.80	100.23	100.31	100.24	100.82	100.20	100.60	100.40	100.30	100.80	100.90	99.90	100.90	100.90	100.80	100.20
Trace Element in ppm																				
Zn	45	49	39	41	45	32	50	37	51	31	41	41	50	49	44	39	87	88	52	52
Ni	10	7	12	11	8	5	6	3	12	10	8	12	7	8	12	11	7	7	13	9
Co	6	6	6	10	11	8	9	9	9	9	6	12	7	4	8	5	13	8	9	8
Cr	337	332	393	438	353	353	328	360	337	364	341	375	304	284	443	465	327	294	501	332
Ba	498	477	454	525	535	515	662	711	268	209	516	437	227	209	172	118	431	435	281	378
Nb	31	27	27	25	27	26	23	18	25	23	33	28	36	30	18	12	26	25	26	17
Zr	185	193	168	205	170	152	198	164	119	124	171	180	108	107	110	112	204	199	140	138
Sr	157	156	137	158	170	166	246	245	88	90	149	142	64	64	71	63	146	140	93	95
Rb	566	533	540	503	475	494	402	405	559	515	574	578	540	552	497	472	500	485	536	540

Mert: Mertajam granite; Bongsu: Bongsu granite; Panchor: Panchor granite

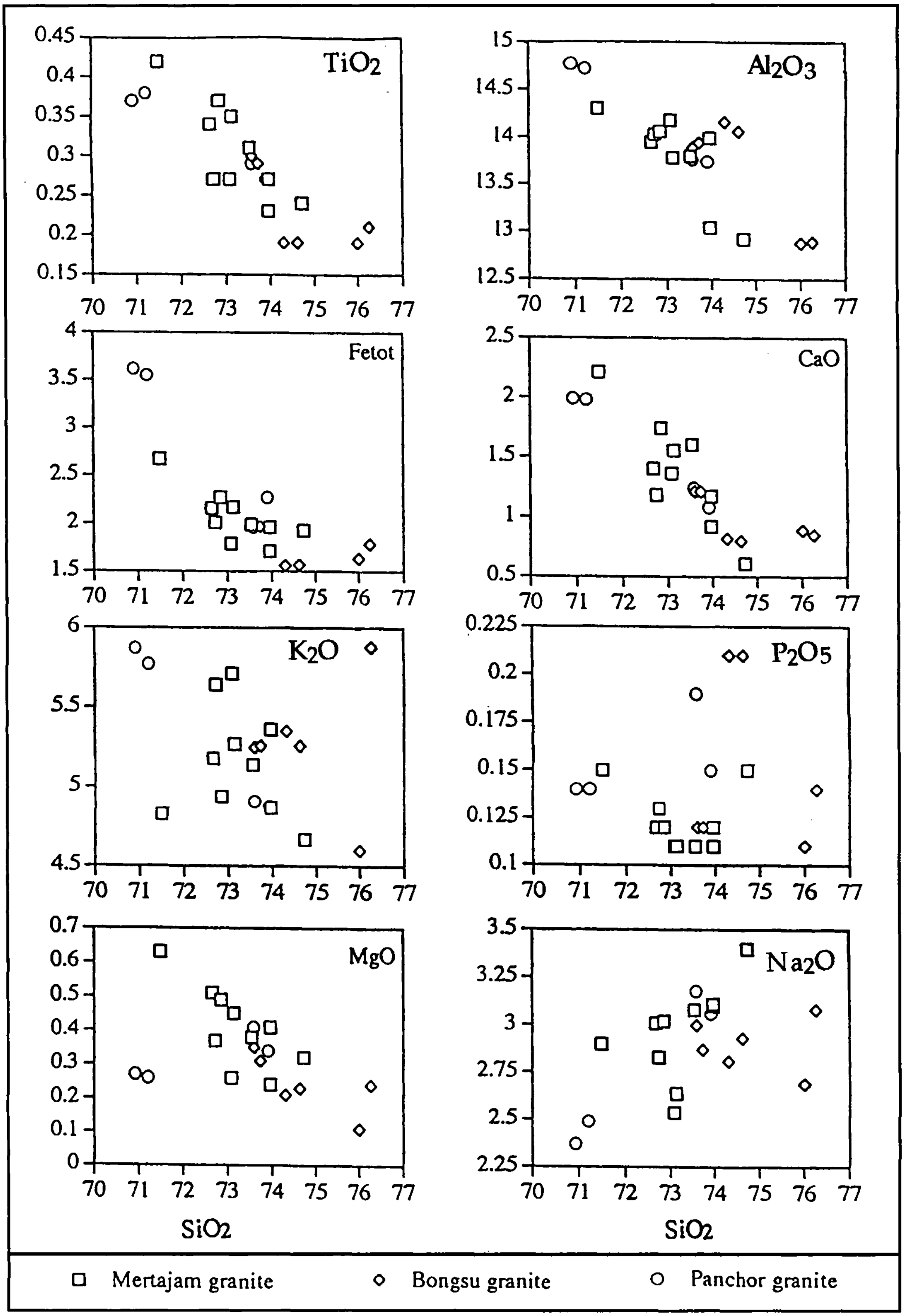

Figure 4. Harker plots of major elements oxides for the Bukit Mertajam-Kulim granite.

an increase of ACNK values with increasing SiO_2 (Fig. 5). All samples from the Panchor granite have ACNK values below 1.1.

Harker variation diagrams for trace elements are shown in Figure 6. General trend correlation is poor although Sr, Co, Ba, Zr and Zn decrease and Ni increase with increasing SiO_2. Contrasting behaviour of the three granites is shown in the Rb vs SiO_2 diagram. In this diagram samples from the Bongsu granite decrease whereas those from Panchor and Mertajam granites increase with increasing SiO_2. The Bongsu samples have high Zn and more restricted LIL (Rb, Sr and Ba) elements concentration compared to the other two granites. A good correlation between Sr and Ba in BMK granite is shown in Figure 7. The decrease of Ba concomitant with Sr shows that both K-feldspar and plagioclase are being removed in the differentiation sequence.

MODELLING OF THE GRANITES

In general, the variation in granitic rocks can be produced by one of several processes. These include fractional crystallization, effect of a vapour phase, restite unmixing, magma mixing, crustal assimilation and thermo gravitational diffusion. In the BMK granites crystal fractionation appears one of the processes operating, if not the dominant process, that produced the variation of the rocks. This is evident from the LIL inter-elements plot (Fig. 7) which suggests that plagioclase and K-feldspar are dominant in the magmatic evolution (see Clarke, 1992, pg. 103).

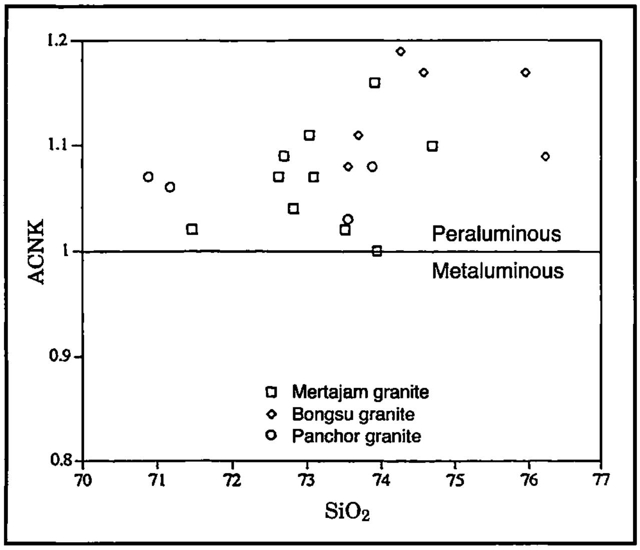

Figure 5. Molar $Al_2O_3/CaO+Na_2O+K_2O$ vs SiO_2 diagram for Bukit Mertajam-Kulim granite. Line at ACNK = 1 divides between peraluminous and metaluminous granites (Shand, 1927).

The LIL elements Ba, Sr and Rb are of considerable value in determining the type and amount of major phase fractionation in intermediate and acid rocks because:

(a) they are held predominantly in the major phases,
(b) Kd's for commonly occurring major phases are available,
(c) each element behaves somewhat differently; for example, Rb is taken up preferentially by biotite, Ba by biotite and alkali feldspar and Sr by plagioclase and K-feldspar.

Using Rayleigh fractionation equation ($C_l/C_o = F^{Da-1}$ where C_o: concentration of element 'a' in the original melt, C_l: concentration of element 'a' in residual melt, Da: bulk distribution coefficient for element 'a' and F: weight fraction of melt remaining) and the Kd values for rhyolitic liquid (Arth, 1976), we have calculated the net change in composition of the liquid after 30% Rayleigh fractionation by removing K-feldspar, hornblende, plagioclase or biotite. Figure 8 shows a log-log plot of Sr vs Ba of the granite samples from the Mertajam, Panchor and Bongsu granites. In general, the Sr value increases with increasing Ba and there is a good positive correlation. Rayleigh fractionation vectors for single mineral phases imply that the crystallization of alkali feldspar, plagioclase and biotite may have controlled the trends in all granites.

Precipitation of plagioclase is also evidenced from the Rb/Sr vs SiO_2 plot (Fig. 9). The 'J' shaped trend produced by the plot is similar to some superunits of the Coastal Batholith (Atherton, 1993). The plot shows the characteristic form due to fractional crystallization with plagioclase as the major precipitating felsic phase. The TiO_2 vs Zr diagram is important in constraining the role of zircon, magnetite and sphene as well as hornblende and biotite during crystallisation (Mahawat *et al.*, 1990) (Fig. 10). The vector diagram indicates that sphene, zircon and magnetite are more important in determining the trend of the Bukit Mertajam-Kulim granite (modes lack of hornblende). Thus the crystallisation options for the granite are zircon + sphene, zircon + magnetite, zircon + biotite and biotite + sphene or some combinations of these minerals.

Secondly the major elements have been used to determine the crystallizing proportion of the major phases such as plagioclase, alkali feldspar, hornblende and biotite and some of the accessory phases such as apatite, ore phases and sphene (Atherton *et al.*, 1992). This step uses a more sophisticated approach to model the effect of fractional crystallisation. For this purpose an arbitrary start and target using 8 major element

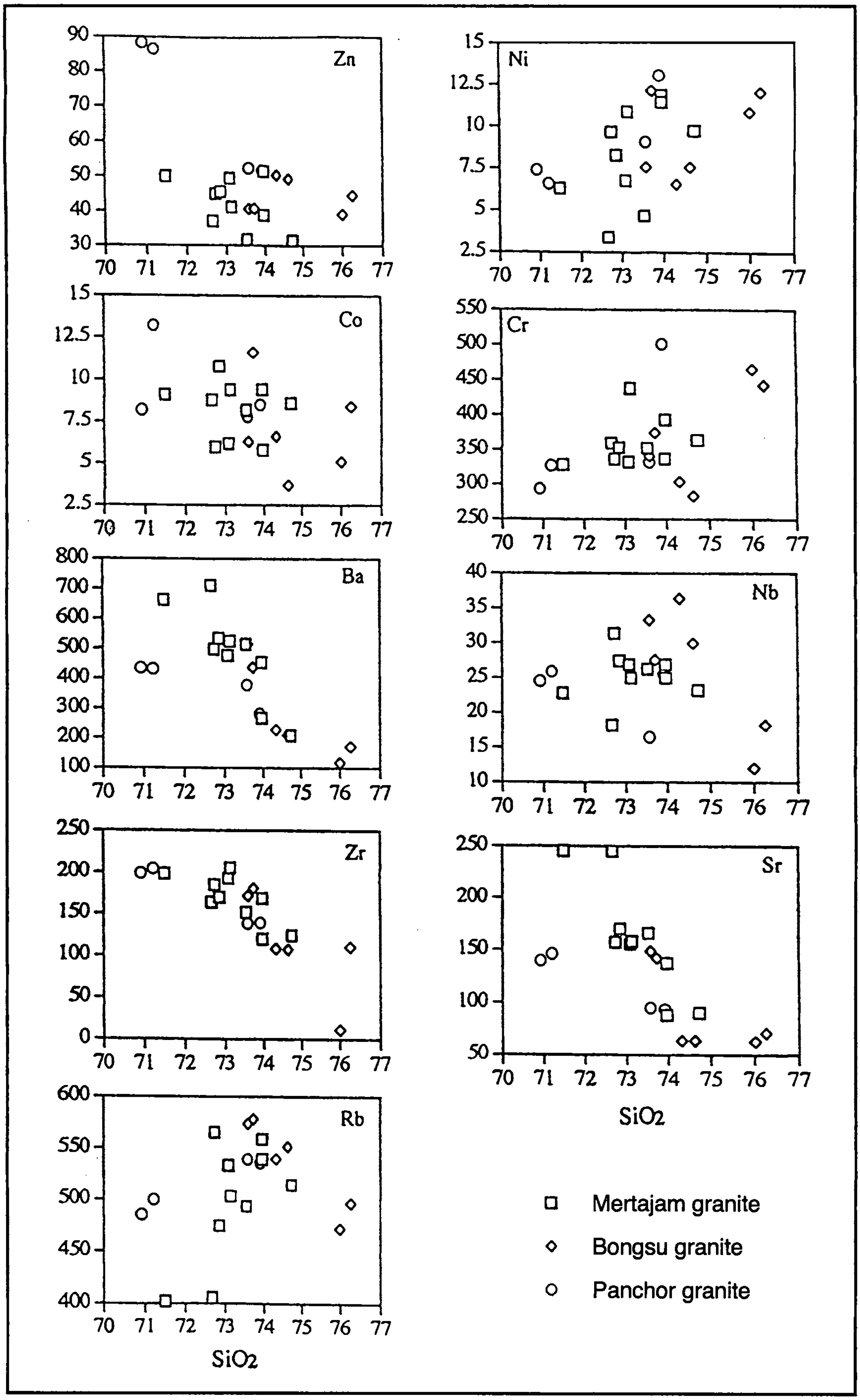

Figure 6. Harker plots of trace elements for the Bukit Mertajam-Kulim granite.

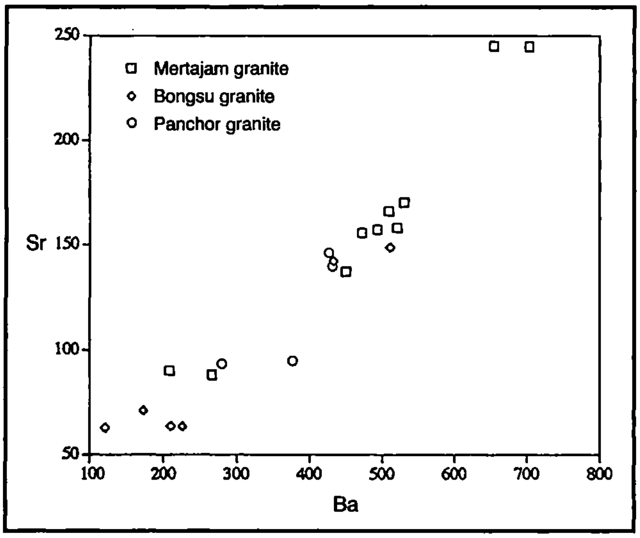

Figure 7. Sr vs Ba plot for the Bukit Mertajam-Kulim granite.

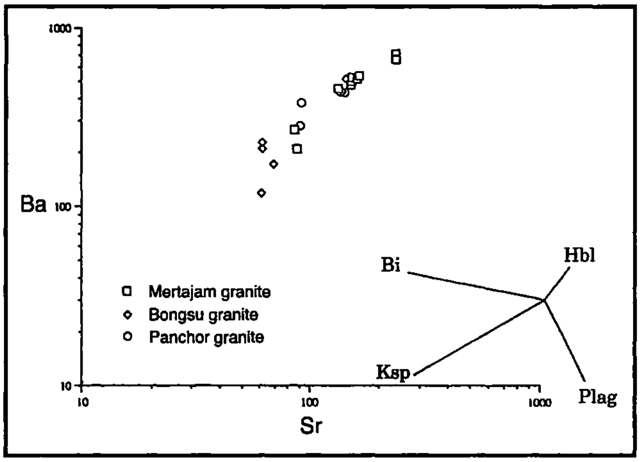

Figure 8. Log Sr vs log Ba diagram for the Bukit Mertajam-Kulim granite. Mineral vector indicates path of evolved liquids for 30% of mineral precipipating. Ksp: K-feldspar; Plag: plagioclase; Bi: biotite; Hbl: hornblende.

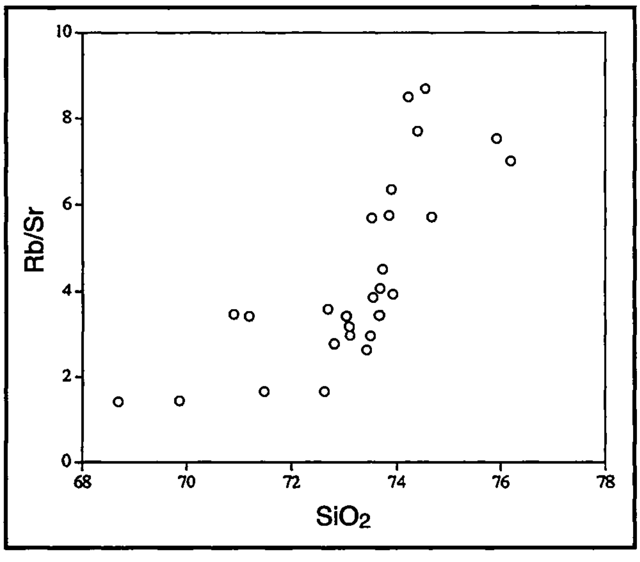

Figure 9. Rb/Sr vs SiO_2 diagram for the Bukit Mertajam-Kulim granite.

oxides is used to model the precipitated phases. The calculation of the major element modelling is determined by the following simple mass balance equation (Sanderson and Atherton, 1985, in Gamil, 1991).

$$M_k^{melt} = (M_k^o - S_k)/(1 - F)$$

where

M_k^{melt} = weight % of element oxide k in final melt after fractionation

M_k^o = weight % of element oxide k in the initial melt

F = fraction (0 – 1) of the melt crystallized

S_k = sum of k-th element oxide in the crystallized fraction.

Each unit has been modelled from its most basic to most felsic rock. The result of the modelling are as follows:

1. The Mertajam granite has been modelled from 71.49% to 74.73% SiO_2. The model target composition can be achieved at 25% fractionation and the mineral mix is plagioclase, biotite, alkali feldspar, apatite and magnetite (Table 2a).
2. The Bongsu granite has been modelled from 73.59% to 76.26% SiO_2. The model target composition can be achieved at 17% fractionation and the mineral extract is plagioclase, alkali feldspar, biotite, apatite and magnetite (Table 2b).
3. The Panchor granite has been modelled from 70.92% to 73.91% SiO_2. The model target

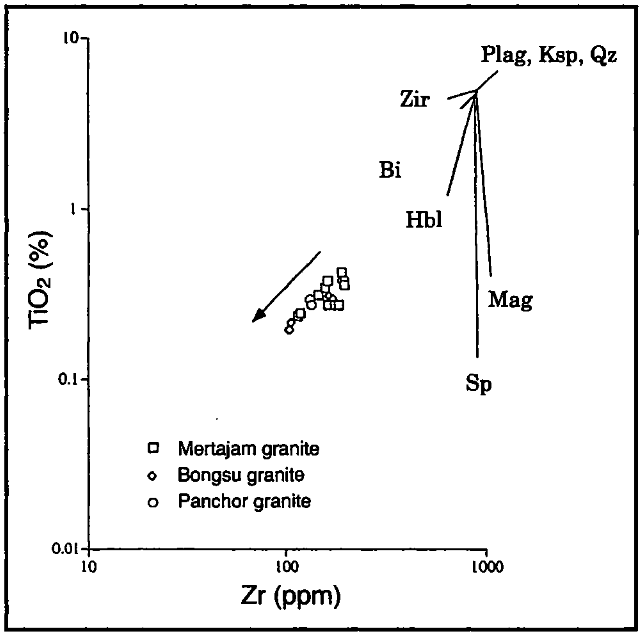

Figure 10. TiO_2 vs Zr plot for the Bukit Mertajam-Kulim granite. Mineral vector indicates path of evolved liquids for 15% of mineral precipipating. Plag: plagioclase; Ksp: K-feldspar; Qz: quartz; Zir: zircon; Bi: biotite; Hbl: hornblende; Sp: sphene and Mag: magnetite.

Table 2. Summary results obtained from major element modelling of the (a) Mertajam granite, (b) Bongsu granite and (c) Panchor granite.

(a) Major element modelling for Mertajam granite

	Start composition KP(W)	Liquid composition at 25% fractionation	Target composition JKR2	Mineral extract proportion
SiO_2	71.49	74.91	74.73	Pl: 31.0
TiO_2	0.42	0.43	0.24	Bi: 11.0
Al_2O_3	14.30	12.51	12.92	Mag: 0.1
Fe(tot)	2.16	1.98	1.93	Ksp: 57.8
MgO	0.51	0.39	0.32	Ap: 0.1
CaO	1.40	1.41	0.61	
Na_2O	3.01	2.91	3.40	
K_2O	5.18	3.57	4.67	
Total	98.47	98.11	98.82	

(b) Major element modelling for Bongsu granite

	Start composition SM1	Liquid composition at 17% fractionation	Target composition FGB1	Mineral extract proportion
SiO_2	73.59	76.31	76.26	Pl: 32.0
TiO_2	0.30	0.26	0.21	Bi: 14.0
Al_2O_3	13.89	12.71	12.89	Mag: 0.1
Fe(tot)	2.00	1.71	1.64	Ksp: 53.8
MgO	0.35	0.20	0.11	Ap: 0.1
CaO	1.21	1.15	0.85	
Na_2O	3.00	2.92	3.08	
K_2O	5.25	4.34	5.88	
Total	99.59	99.60	100.92	

(c) Major element modelling for Panchor granite

	Start composition LB2	Liquid composition at 24% fractionation	Target composition HW1	Mineral extract proportion
SiO_2	70.92	73.89	73.91	Pl: 35.89
TiO_2	0.37	0.38	0.27	Bi: 10.00
Al_2O_3	14.77	13.14	13.27	Mag: 0.01
Fe(tot)	3.62	4.01	2.27	Ksp: 54.00
MgO	0.27	0.11	0.34	Ap: 0.10
CaO	1.99	2.09	1.08	
Na_2O	2.37	1.95	3.06	
K_2O	5.87	4.77	4.88	
Total	100.18	100.34	99.08	

composition can be achieved at 24% fractionation and the mineral extract is plagioclase, alkali feldspar, biotite, apatite and magnetite (Table 2c).

PETROGENESIS

Petrographic study and modal analyses show that all the Mertajam, Bongsu and Panchor granites are similar in terms of their mineral content (Table 3). All granites have associated fine grained granite which in some cases can be porphyritic with conspicuous pink K-feldspar phenocrysts. In the Mertajam granite, this fine grained granite show sharp contacts with their host. The contacts can be found at the Bukit Juru on the east and at Bukit Mertajam area. Further north this microgranite grades into sparsely porphyritic microgranite with pink K-feldspar phenocrysts which can be up to 2 cm across. Cobbing *et al.* (1992) mapped this microgranitic rock as the Mertajam microgranite. Atherton *et al.* (1992) interpreted that the porphyritic microgranite from the Tak batholith, Thailand, represent a quenched liquid plus crystal

Table 3. Comparison some of the rock types, age and mineralogical features of granitic rocks from the Bukit Mertajam-Kulim area.

	Mertajam Granite	Bongsu Granite	Panchor Granite
Rock Type	Medium-coarse grained biotite granite Porphyritic microgranite (%Pheno/matrix: 15%)	Medium-coarse grained biotite muscovite granite Minor fine grained facies	Medium-coarse grained biotite granite Minor fine grained facies
Q-A-P Classification	Syenogranite to monzogranite	Syenogranite to monzogranite	Syenogranite to monzogranite
Age	180±10 to 196±8 Ma	211±9 Ma	224±5 Ma
Mineralogy	K-feldspar, plagioclase, quartz biotite, muscovite, sphene, apatite, zircon, opaque	K-feldspar, plagioclase, quartz biotite, muscovite, sphene, apatite, zircon, opaque, garnet, tourmaline	K-feldspar, plagioclase, quartz biotite, muscovite, sphene, apatite, zircon, opaque
Muscovite	Mainly subsolidus	Primary and subsolidus	Subsolidus

formed on decompression with or without volatile loss with the matrix partly annealed. The importance of the porphyritic rocks in the Mertajam granite is that they indicate the character of the near liquidus phase. Thus the textures, composition and zoning of the phenocrysts are useful in establishing the early conditions of the crystallising granitic magmas as well as the compositions of the evolved liquids (cf. Atherton *et al.*, 1992).

Previous classifications of the Western Belt granite indicate that the rocks in many aspects, are comparable to the 'S' type granites (Chappell and White, 1974; White and Chappell, 1988; Hutchison, 1996; Azman, 1999). This is comparable to the rocks from the BMK granite which also have many 'S' type features. Among the features are (1) hornblende is absent in the rocks, (2) garnet, muscovite and tourmaline are present (3) average normative corundum for all the granites is 1.4%, (4) Na_2O is generally less than 3.2% in rocks with approximately 5% K_2O, (5) $^{87}Sr/^{86}Sr$ generally > 0.705 (0.712–0.723) (Liew, 1983; Cobbing *et al.*, 1992) which suggests a crustal input and (7) the SiO_2 range for the BMK granites are typically of 'S' type granites elsewhere (e.g. Le Fort, 1988). All these features are consistent with 'S' type granites which imply that the BMK magma derived from melting of the crustal material of metasedimentary origin. The restricted range of SiO_2 content of the BMK rocks suggests that they were derived from SiO_2 rich source. However the composition trend in both major and trace elements shows that the granites are individual batches of melt.

Major and trace elements geochemistry show that it is difficult to discriminate the different granite units in terms of their geochemical content. All granites have overlapping SiO_2 compositions. The Mertajam granite, however has slightly higher Sr, Ba and Zn elements compared to the other granites. MgO contents from Panchor granite increase with increasing SiO_2 in contrast to MgO contents in the other two granites which decrease with increasing SiO_2. All units show consistently decreasing Zr, Sr and Ba with increasing SiO_2. The decreasing of Zr with SiO_2 indicates that zircon was an early liquidus fractionating phase which was continually removed. Such a pattern according to Liew (1983) is expected of Zr saturation behaviour and is consistent with the general preservation of zircon inheritance in these granites. In Figure 11, the multi element variation pattern of the BMK and Western Belt granites are compared (normalizing values are after Sun and McDonough, 1989). The latter profile was constructed from samples with SiO_2 ranging from 67.3% to 76.6% (Data for both granites are taken from Cobbing *et al.*, 1992). The profiles are similar which may suggest that the BMK granite has a common origin to the other Western Belt granites. They are notably depleted in Ba, Sr, P and Ti, which is probably related to fractionation of feldspars, apatite, sphene and Fe titanium mineral.

The different granite units also show a coherent pattern especially in the major and LIL elements modelling. Major and LIL elements modelling of the BMK granites indicate that the evolution of each unit is controlled by the same minerals viz plagioclase, alkali feldspar and biotite but in different proportions. The mineral mixes predicted in the major elements modelling confirm the dominance of plagioclase and K-feldspar in the fractionation process (Table 2). However there is no systematic sequence shown by the three granitic bodies. Both the Mertajam and Panchor granites require more or less the same degree of fractionation, i.e. 25% and 24% respectively. On the other hand, the Bongsu granite requires a lesser degree of fractionation of 17%.

ACKNOWLEDGEMENT

AAG acknowledges the F-vote research grant VOT FL 0523/98 for field work received from University of Malaya and Noran A. Shaarani for fieldwork assistance. En. Roshdy and En. Ching are thanked for drafting the figures.

REFERENCES

ARTH, J.G., 1976. Behaviour of trace elements during magmatic processes — a summary of theoretical models and their applications. *Jour. Res. U.S. Geol. Surv. 4.*, 41–47.

ATHERTON, M.P., MAHAWAT, C. AND BROTHERTON, M.S., 1992. Intergrated chemistry, textures, phase relations and modelling of a composite granodioritic-monzonitic batholith, Tak, Thailand. *Jour. Southeast Asian Earth Science, 7(2/3)*, 89–112

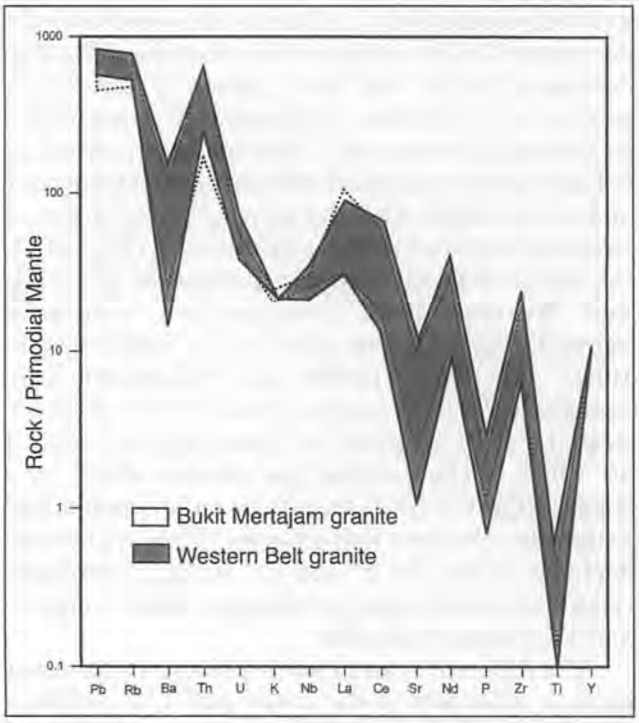

Figure 11. Comparison of multi-element variation pattern of the BMK and the Western Belt granite (Data from Cobbing *et al.*, 1992), illustrating the similar profiles. Elements are arranged with increasing incompatibility, right to left, for spinel-lherzolite mantle assemblage. Normalizing values after Sun and McDonough (1989).

ATHERTON, M.P., 1993. Granite magmatism. *Jour. Geol. Soc. London, 150*, 1009–1023.

AZMAN A. GHANI, 1999. Systematic classification of the granitic rocks from Western province, Peninsular Malaysia. *Abstr. & Progs. Ann. Geol. Conf. 1999*. Desaru Johore.

BIGNELL, J.D., 1972. *The geochronology of Malayan granites.* Unpubl. D.Phil. thesis, Oxford University.

BORHAN M. DOYA, 1995. *Petrologi dan geokimia granitoid kawasan Bukit Mertajam, Pulau Pinang-Kulim, Kedah-Semanggol Perak dan kajian geologi am.* Unpubl. B.Sc thesis, University of Malaya.

CHAPPELL, B.W. AND WHITE, A.J.R., 1992. I- and S-type granites in the Lachlan fold belt. *Trans. Roy. Soc. Edibh: Earth Sciences, 83*, 1–26.

CHAPPELL, B.W. AND WHITE, A.J.R., 1974. Two contrasting granite types. *Pacific Geol., 8*, 173–174.

CLARKE, D.B., 1992. *Granitoid Rocks.* Chapman and Hall, 283p.

COBBING, E.J. AND MALLICK, D.I.J., 1987. Southeast Asia granite project: field report for Peninsular Malaysia. *Report of the Overseas Directorate, British Geological Survey, No. MP/87/19/R*, 1–29

COBBING, E.J., PITFIELD, P.E.J., DARBYSHIR, D.P.F. AND MALLICK, D.I.J., 1992. *The granites of the South-East Asian tin belt. Overseas Memoir 10*, British Geological Survey.

COURTIER, D.B., 1974. Geology and mineral resources of the neighbourhood Kulim, Kedah. *Malaysian Geol. Surv. Map Bull. 3.*

GAMIL, A.S., 1991. *Petrology and geochemistry of Shetland granites.* Unpubl. Ph.D. thesis, Univ. of Liverpool.

HALL, A., 1965. The origin of accessory garnet in the Donegal granite. *Min. Mag., 35*, 628–633.

Hutchison, C.S., 1996. *Geological Evolution of South-East Asia.* Geol. Soc. Malaysia, 368p.

LE FORT, P., 1988. Granites in the tectonic evolution of the Himalaya, Karakoram, and southern Tibet. *Phil. Trans. Roy. Soc. Lond., 326*, 281–299.

LIEW, T.C., 1983. *Petrogenesis of the Peninsular Malaysia granitoid batholith.* Unpubl. Ph.D. thesis, Australia Nat. University.

LIEW, T.C. AND PAGE, R.W., 1985. U-Pb zircon dating of granitoid plutons from the west Coast Province of Peninsular Malaysia. *Jour. Geol. Soc. Lond., 142*, 515–526.

MAHAWAT, C., ATHERTON, M.P. AND BROTHERTON, M.S., 1990. The Tak Batholith: contrasting granites types and implication for tectonic setting. *Jour. Southeast. Asian Earth Sci., 4*, 11–27.

SHAND, S.J., 1927. *Eruptive rocks. Their genesis, composition, classification and their relation to ore deposits.* Murby, London, 444p.

SUN, S.S. AND MCDONOUGH, W.F., 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. *In:* Saunders, A.D. and Norry, M.J. (Eds.), Magmatism in the Ocean Basins. *Geological Soc. Lond. Spec. Publ., 42*, 313–345.

STRECKEISEN, A.L., 1976. To each plutonic rock its proper name. *Earth Sci. Rev., 12*, 1–33.

WHITE, A.J.R. AND CHAPPELL, B.W., 1988. Some supracrustal (S-type) granites of the Lachlan Fold Belt. *Trans. Roy. Soc. Edinb., 79*, 169–181.

ZEN, E. AN, 1986. Aluminium enrichment in silicate melts by fractional crystallisation. Some mineralogic and petrographic constraints. *Jour. Petrol., 27*, 1095–1118.

Manuscript received 7 December 1999