

## **Granite magmatism and tin-tungsten metallogenesis in the Kuantan-Dungun area, Malaysia**

MICHAEL O. SCHWARTZ<sup>1</sup> AND A.K. ASKURY<sup>2</sup>

<sup>1</sup>Bundesanstalt für Geowissenschaften und Rohstoffe

P.O. Box 510153

D-3000 Hannover 51

Fed. Rep. of Germany

<sup>2</sup> Geological Survey of Malaysia

P.O Box 1015

Ipoh

Malaysia

**Abstract :** The Kuantan-Dungun area (6000 km<sup>2</sup>) is an important tin district which produced about 40 % of all tin mined in the Eastern Granite Province of Peninsular Malaysia. It is the most important wolframite-producing district in Malaysia. The largest underground tin mine of Malaysia (Sungei Lembing) is also located in this area.

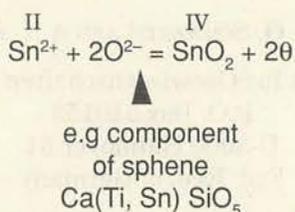
The granitoids that occupy about 30% of the area have a Permian age (240 – 275 Ma) except for a Triassic stock at Paka near Dungun (220 Ma). The composition of the granitoids ranges from gabbro to biotite granite (monzogranite). The largest part is occupied by biotite granite which exhibits characteristics of both S-type granite derived from a sedimentary source rock and I-type granite derived from an igneous protolith. Hornblende-biotite granite (to granodiorite) and gabbro (to quartz diorite) are subordinate.

The basic to intermediate rocks have affinities to tholeiitic magma and are not genetically linked to the granites by fractional crystallization. But the gabbroic rocks and the granites may have had a common heat source.

Only in hydrothermally altered portions, the Kuantan-Dungun granites show elevated Sn concentrations (up to 34 ppm Sn). The tin concentrations in unaltered rocks are low (averaging 3 ppm Sn). The Kuantan-Dungun granites have in common with other granites in the Eastern Province, tin concentrations that seem to be unrelated to the differentiation stage, i.e. tin is a decoupled element. Both the low tin concentrations and the decoupled behavior of tin are unusual features of granites associated with tin deposits.

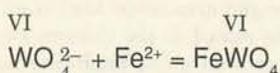
The metallogenesis of tin in the wolframite-cassiterite area of Kuantan-Dungun is different from that in cassiterite-dominated S-type granite systems with very subordinate wolframite in the Main Range, of which the Bujang Melaka pluton in the Kinta Valley is a typical example. The Main Range batholith, in general, and the Bujang Melaka pluton, in particular, show a significant increase in tin concentration with increasing degree of magmatic differentiation, i.e. tin is much higher in late-stage differentiates than in less evolved rocks. But for the Kuantan-Dungun granites, the distribution coefficient of tin between melt and solid must have been near 1 during most of the crystallization history of the magma. Tin enrichment did not take place until the residual fluids separated from the crystallizing magma.

The behaviour of tin during magmatic evolution is related to the role of oxygen fugacity for the partitioning of metal between melt and crystallizing solid. Tin occurs in both the divalent and the tetravalent state. Low oxygen fugacity favours the partitioning of tin into the melt relative to the crystallizing solid. Low oxygen fugacity shifts the equilibrium to the left side of the reaction:



Tin exhibits incompatible behaviour (with respect to the solid crystallizing from the granite magma) in a low oxygen fugacity environment and tends to decoupled behaviour (independent of magmatic evolution) under an intermediate oxygen fugacity.

Tungsten occurs mainly in one valence state only (W<sup>VI</sup>) in the liquid phase as well as in the solid phase. The reaction is less dependent on oxygen fugacity than the corresponding reaction for tin:



The distribution coefficient of tungsten is relatively insensitive to oxygen fugacity, and tungsten enrichment in residual liquids may be produced under a wide range of oxygen fugacities.

The mixed ilmenite-series/magnetite-series characteristics (intermediate oxygen fugacity) of the Eastern Province, in general, and the Kuantan-Dungun area, in particular, constitute a less favourable environment for tin mineralization than the exclusively ilmenite-series Main Range batholith (low oxygen fugacity). This is reflected by the differences in total mine production of tin in Malaysia: 94% has come from the Main Range and 6% from the Eastern Province although the two areas are approximately the same size.

Mixed ilmenite-series/magnetite-series granitoids and pure ilmenite-series granitoids are equally favourable for wolframite mineralization because of its relative independence on oxygen fugacity. This is in agreement with the mine production of wolframite which is approximately equal in the Main Range and the Eastern Province.

## INTRODUCTION

Peninsular Malaysia is commonly subdivided into two Permo-Triassic granitoid provinces (Cobbing *et al.*, 1986; Fig. 1) separated by a central basin filled with Paleozoic and Mesozoic sediments (Hutchison, 1977; 1979). The granitoids of the Eastern Province, whose ages fall in the range of 200 – 275 Ma, apart from some minor Late-Cretaceous intrusive events, show mixed I-type and S-type affinities (Chappell and White, 1974) and range in composition from gabbro to monzogranite.

The Main Range is mainly composed of S-type biotite granites, which cover a narrow compositional range. The emplacement ages of the granites vary be-

tween 200 and 220 Ma (Bignell and Snelling, 1977; Liew, 1983; Liew and McCulloh, 1985).

Peninsular Malaysia hosts the largest tin deposits in the world. But there are distinct differences in their regional distribution. The Main Range has the most important alluvial tin fields. It produced about one-third of the tin mined in the world (nearly 5 million tonnes Sn); more than 90 percent of the Malaysian tin production came from the Main Range (Lahner, 1982). The alluvial tin fields of the Eastern Province are usually on a smaller scale, but there are large primary deposits. The Eastern Province supplied approximately 6 percent of the Malaysian tin production (Bradford, 1961; Lahner 1982).

The Malaysian wolframite deposits are of minor importance. The largest ones are located in the Kuantan-Dungun area which produced 4200 tonnes of wolframite between 1912 and 1956 (Bradford, 1961). The Kuantan-Dungun area is also an important tin district which produced about 40% of all tin mined in the Eastern Province (Taylor *et al.*, 1985).

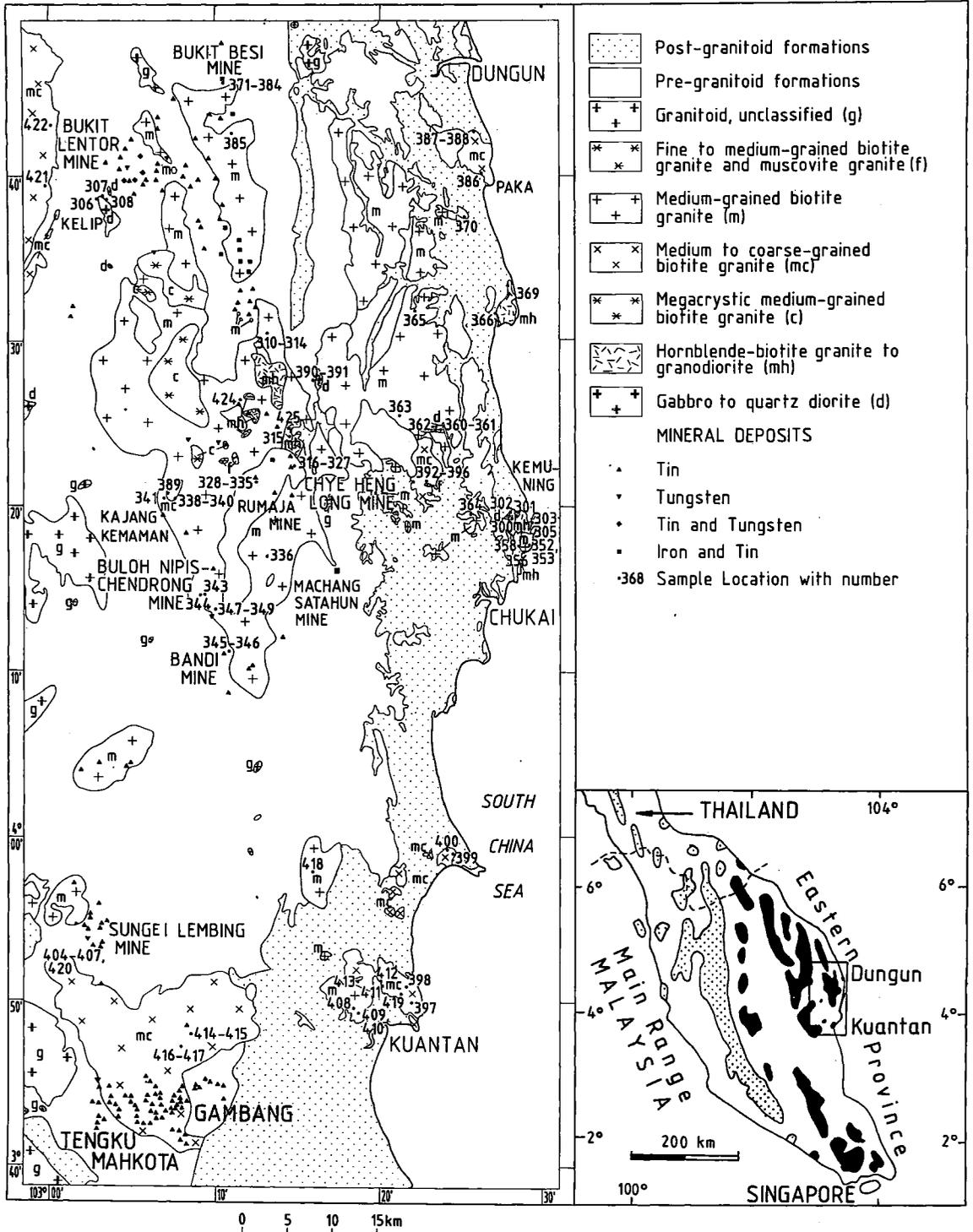
The wolframite production is approximately equal in the Eastern Province and the Main Range. Why are the two granite provinces, which are approximately the same size, distinguished by their tin production but not by their wolframite production? The comparison of the granite magmatism of a typical wolframite producing district in the Eastern Province, such as the Kuantan-Dungun area, with the magmatism of the Main Range may provide an answer to this question (scheelite deposits are excluded from the consideration because of the additional complication caused by the availability of carbonate host rock).

### **TIN (-TUNGSTEN) DEPOSITS IN THE KUANTAN-DUNGUN AREA**

The Kuantan-Dungun area shows a characteristic distribution of tin (-tungsten) deposits along a N/S trending belt in the western part of the area (Fig. 1). In the eastern part of the study area, tin (-tungsten) deposits are practically absent.

The *Sungei Lembing* mine, which produced 80 tonnes Sn per month up to 1985, consists of veins with cassiterite, pyrite, chalcopyrite, arsenopyrite, sphalerite, galena, pyrrhotite, quartz, chlorite and calcite (Fitch, 1952; Yeap, 1966; Singh 1970; Robert, 1977; Tee, 1980). The veins are emplaced at a considerable distance from the granite contact (usually more than 500 m) in the metasedimentary country rock.

Most of the quartz-cassiterite-(-wolframite) sulphide veins in the *Buloh Nipis-Chendrong* mining area (Goh, 1973; Jalil, 1981) were emplaced in clastic metasediments close to the granite contact. The quartz-cassiterite-sulphide veins of the *Kajang Kemaman* mine are in graphite-chlorite schist (Amran, 1980).



**Figure 1 :** Geological map of the Kuantan-Dungun area, Malaysia, modified after Geological Map of Malaysia 1:63,360 of the Geological Survey, with sample locations.

The lodes with cassiterite, wolframite, quartz and sulphides of the *Bandi* mine are located in metasediments as well as in granite. The metasediments, which are composed of clastic and calcareous rocks, also contain a magnetite orebody (Tan, 1977).

*Bukit Lentor* is an important tungsten deposit where wolframite has been mined from veins in clastic metasediments (Lee, 1971; Chand, 1978). Together with the other tungsten (tin) deposits in the Kuantan-Dungun-area, they constitute the most important source of wolframite in Malaysia.

The *Chye Heng Long* mine is in a small skarn deposit with cassiterite, almandine, quartz, pyrrhotite and other sulphides (Tan, 1979). There are other skarn deposits mined for iron which contain several hundred ppm Sn such as *Bukit Besi* (Bean, 1969) and, possibly, *Machang Satahun* (Lim, 1972). At *Batu Tiga* close to Bukit Besi, cassiterite associated with magnetite and iron sulphides has been mined as major product (Chong, 1970, Leong, 1970); it is probably a skarn mineralization.

The primary deposits in the *Gambang* mining area, which has the most important alluvial tin fields in the Kuantan-Dungun area, consists of greisen-bordered veins and vein swarms both in granite and in the metasediments. Wolframite-quartz-sulphide lodes emplaced in meta-siltstone at *Lombong Tengku Mahkota* also carry native gold (Lim, 1971).

The mineralization in the *Rumaja* mine consists of greisen-bordered vein swarms in granite with cassiterite, quartz, tourmaline, pyrite, pyrrhotite, chalcopyrite, galena and molybdenite.

## RADIOMETRIC DATING AND ISOTOPE CHEMISTRY

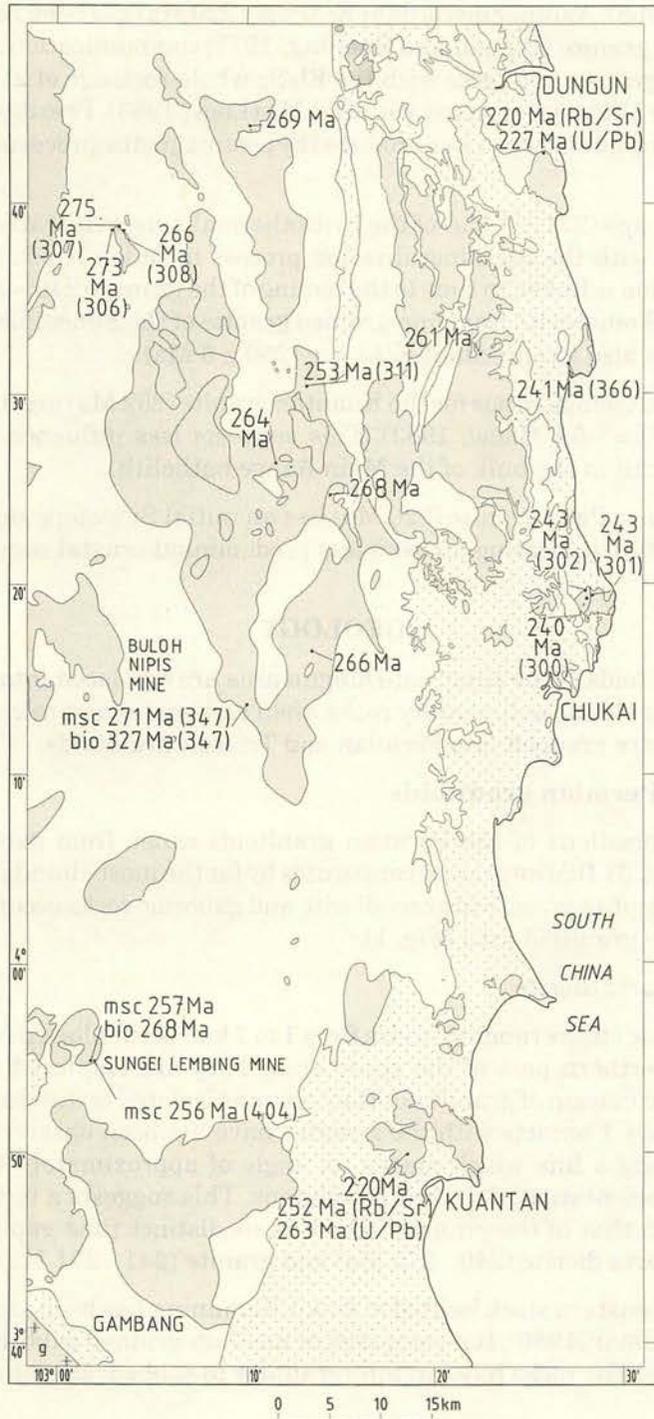
The K/Ar ages of 11 mica concentrates prepared in the Geological Survey of Malaysia (GSM) laboratory were determined in the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) (Table 1). Seven K/Ar determinations by Bignell and Snelling (1977), two U/Pb determinations of zircon (Liew, 1983) and two Rb/Sr whole rock isochrons based on data by Bignell and Snelling (1977), supplemented and recalculated by Liew (1983) are available for the granitoids which have been investigated in Kuantan-Dungun area (Fig.2). The data suggest a Permian age (240-275 Ma) for the granitoids in the Kuantan-Dungun area except for the small granite stock at Paka for which a Triassic age has been determined for zircon (227 Ma) and whole rock (220 Ma).

The K-Ar age of biotite ( $327 \pm 3$  Ma) from the hydrothermally altered sample Ms-347 (intensely muscovitized granite) does not fit this generalized picture. But the muscovite from the same sample yields a concordant K/Ar age ( $271 \pm 3$  Ma). Probably, the K/Ar age of the biotite is not reliable because biotite may take up argon from hydrothermal solutions, which produces an apparently older age

Table 1: K-Ar analyses of mica in granite from the Kuantan-Dungun area, Malaysia.

Sample Nr.	Rock type	Mineral	K/Ar-age* (Ma)	Potassium weight-percent	Argon(Nnl/g)	
					rad.	atm.
MS-300	diorite	bio	240 (2)	6.67	66.6 (0.5)	0.85 (0.1)
301	hbl-bio granite	bio	243 (2)	7.08	71.3 (0.5)	0.72 (0.1)
302	diorite	bio	243 (2)	6.77	68.3 (0.5)	0.73 (0.1)
306	"	bio	273 (3)	2.16	24.7 (0.2)	0.57 (0.1)
307	"	bio	275 (3)	5.65	65.1 (0.5)	0.66 (0.1)
308	gabbro	bio	266 (4)	3.80	42.4 (0.3)	0.93 (0.2)
311	medium grained bio granite	bio	253 (3)	4.59	48.5 (0.4)	1.15 (0.3)
347 B	fine-grained	bio	327 (3)	5.15	71.7 (0.6)	1.45 (0.3)
347 M	"	msc	271 (3)	8.69	98.8 (0.8)	0.17 (0.3)
366	hbl-bio granite	bio	241 (3)	6.63	66.2 (0.5)	1.03 (0.4)
404	fine-grained msc granite	msc	256 (3)	5.89	62.8 (0.5)	0.76 (0.2)

\* The constant recommended by IUGS (Steiger and Jäger, 1976) has been used. The error (in parentheses) represents the 95% confidence limit of the analytical precision. The K/Ar age of the glauconite standard GL-O is 1% younger than the average in the review by Odin (1982).



**Figure 2:** Map of radiometric age dates for granitoid rocks from the Kuantan-Dungun area, Malaysia. All the data are K/Ar mineral ages except for notations with Rb/Sr or U/Pb in parentheses. The K/Ar data for biotite (bio) and muscovite (msc) have been taken from Bignell and Snelling (1977; recalculated by Snelling, written communication, 1989) except for those with the sample number in parentheses (series MS-, see Table 1). The Rb/Sr whole-rock data and U/Pb zircon data are from Liew (1983).

(Stockwell, 1963). Another discordant K/Ar age (220 Ma) has been recorded from the Kuantan granite (Bignell and Snelling, 1977; communication by Snelling, 1989). This age does not agree with the Rb/Sr whole-rock age of 252 Ma (Liew, 1983) and the U/Pb age of zircon with 263 Ma (Liew, 1983). Possibly, the biotite age is too young due to argon loss produced by postmagmatic processes (supergene alteration?).

The K/Ar age ( $271 \pm 3$  Ma) of the hydrothermal muscovite (MS-347), which is associated with the tin mineralization process in Buloh Nipis, implies that muscovitization is linked in time to the cooling of the granite (240–273 Ma). The hydrothermal muscovite from fine-grained granite of the Sungei Lembing mine (MS-404) has also a concordant K/Ar age ( $256 \pm 3$  Ma).

The initial isotope ratios for the Kuantan granite (252 Ma) are 0.713 for  $^{87}\text{Sr}/^{86}\text{Sr}$  and  $_{\text{Nd}}(\text{T}) = -5.6$  (Liew, 1983). This suggests less influence of a crustal component than in the bulk of the Main Range batholith.

The Triassic Paka granite (220 Ma) has an initial Sr isotope ratio of 0.7074 Ma (Liew, 1983), indicating an even less predominant crustal component.

## GEOLOGY

The granitoids of the Kuantan-Dungun area are emplaced into Carboniferous to Triassic clastic sedimentary rocks, shelf carbonates and calc-alkaline volcanics. They are grouped into Permian and Triassic granitoids.

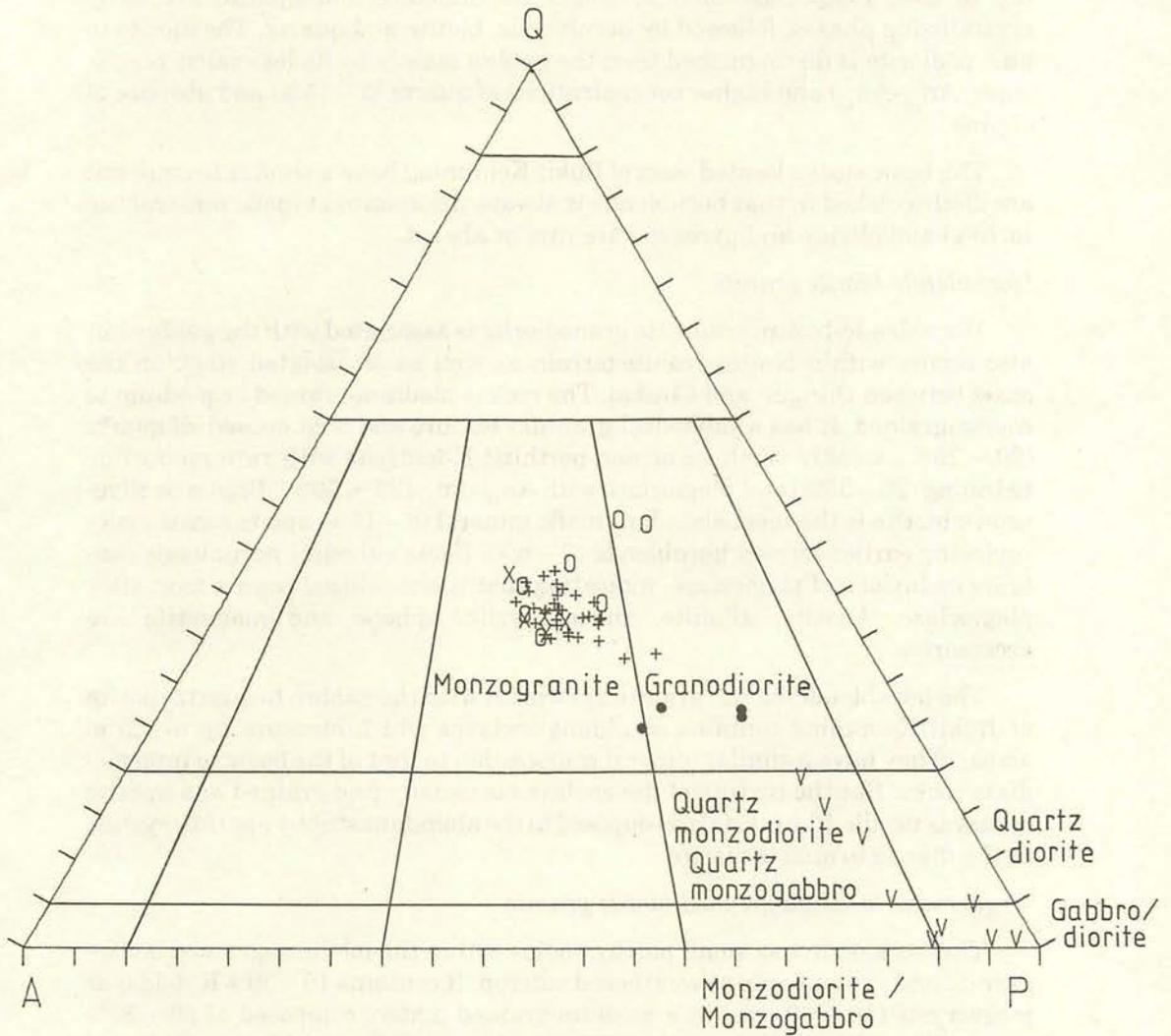
### Geology of Permian granitoids

The compositions of the Permian granitoids range from gabbro to monzogranite (Fig. 3). Biotite granite constitutes by far the most abundant rock type. Hornblende-biotite granite to granodiorite and gabbroic rocks occupy only a few percent of the granitoid area (Fig. 1).

#### *Gabbro to quartz diorite*

Small basic stocks ranging in size from 1 to 7 km<sup>2</sup> occur along a NW-trending line in the northern part of the study area. They are emplaced in a granite terrain, at the margin of granites or they occur as isolated bodies surrounded by metasediments. Contacts with the granites have not been observed. The basic stocks lie along a line which makes an angle of approximately 45° with the general N/S-orientation of the granite plutons. This suggests a tectonic setting different from that of the granites. There is no distinct time gap between the gabbro to quartz diorite (240–275 Ma) and granite (241–271 Ma).

The most eastern stock located at Bukit Kemuning has been studied by Goh (1973) and Kumar (1980). It is composed of medium-grained gabbro, diorite and quartz diorite. The rocks have an intergranular to subhedral-granular texture.



**Figure 3 :** QAP ternary diagram (after Streckeisen, 1974) based on CIPW normative value (Q = Qz, A = Or, P = An + Ab) for Permian granitoids in the Kuantan-Dungun area, Malaysia.

- O = Fine- to medium-grained muscovite granite
- X = Fine- to medium-grained biotite granite
- + = Medium-grained biotite granite and medium- to coarse-grained biotite granite
- = Hornblende-biotite granite to granodiorite
- V = Diorite to quartz diorite and gabbro

Cumulate phases have not been recognized. The gabbro composed of plagioclase with  $An_{50}$ - $An_{72}$  (50 - 75 vol. -%), hornblende (up to 15%), orthopyroxene (up to 15%), clinopyroxene (up to 10%), olivine (up to 4%), biotite (up to 10%) and quartz (up to 5%), Plagioclase olivine, magnetite, ilmenite and apatite are early crystallizing phases, followed by hornblende, biotite and quartz. The diorite to quartz diorite is distinguished from the gabbro mainly by its less calcic plagioclase ( $An_{16}$ - $An_{48}$ ) and higher concentrations of quartz (5 - 15%) and absence of olivine.

The basic stocks located west of Bukit Kemuning have a similar texture but are distinguished in that hornblende is always the dominant mafic mineral (up to 70%) and olivine and pyroxene are rare or absent.

#### *Hornblende-biotite granite*

Hornblende-biotite granite to granodiorite is associated with the gabbro but also occurs within biotite-granite terrain as well as an isolated stock on the coast between Dungun and Chukai. The rock is medium-grained or medium to coarse-grained. It has a subhedral-granular texture and is composed of quartz (20 - 25%), weakly perthitic or non-perthitic K-feldspar with rare microcline twinning (25 - 35%) and plagioclase with  $An_{16}$ - $An_{44}$  (25 - 50%). Brown to olive-brown biotite is the most abundant mafic mineral (8 - 15%) and is occasionally replacing earlier formed hornblende (3' - 6%). Some euhedral hornblende contains inclusions of plagioclase, indicating that it crystallized from a melt after plagioclase. Apatite, allanite, zircon, pyrite, sphene and magnetite are accessories.

The hornblende-biotite granite associated with the gabbro to quartz-diorite at Bukit Kemuning contains abundant enclaves which measure up to 1.5 m across. They have a similar mineral composition to that of the basic to intermediate rocks. But the texture of the enclaves is usually fine-grained and apatite occurs as needle-like crystals as opposed to the abundant stubby apatite crystals in the diorite to quartz diorite.

#### *Megacrystic medium-grained biotite granite*

This rock occurs as small patchy bodies within the medium-grained biotite granite and present only as weathered outcrop. It contains 10 - 30% K-feldspar megacrysts (10 - 60 mm) in a medium-grained matrix composed of 20 - 25% quartz, 20 - 25% plagioclase, 15 - 25% K-feldspar and 5 - 8% chloritized biotite. No suitable samples for chemical analysis were collected.

#### *Medium-to coarse-grained biotite granite*

The medium- to coarse-grained biotite granite is abundant in the Gambang mining area which constitutes the most important alluvial tin field of the study area. The rock has a subhedral-granular texture and is composed of 20 - 35%

quartz, 30–45% K-feldspar, 10–30% plagioclase and 2–12% biotite. K-feldspar rarely exhibits cross-hatched twinning and is occasionally weakly perthitic. Plagioclase usually is subhedral. Occasionally, it is normally zoned ( $An_{12} - An_{28}$ ). Muscovite occurs in minor quantities (1–3%) and is usually an alteration product of plagioclase. Both brown and green biotite is present. Some biotite flakes are weakly bent. Apatite, zircon, sphene, allanite and fluorite are accessories.

#### *Medium-grained biotite granite*

Medium-grained biotite granite is the most abundant plutonic rock outside the Gambang area. It usually has a subhedral-granular texture. Locally, the rock has a seriate texture, transitional to bi-modal grain size distribution (two-phase granite according to the terminology of Cobbing *et al.*, 1986). The rock is composed of 25–35% quartz, 20–35% non-perthitic to weakly perthitic K-feldspar with rare microcline twinning, 25–35% plagioclase ( $An_{16} - An_{42}$ ) and 2–15% green and brown biotite which is partly chloritized. Muscovite (1–4%) occurs as an alteration product of both plagioclase and biotite. Accessories are apatite, allanite, zircon, sphene and fluorite. In a few cases, the rock exhibits a weak degree of deformation with bent biotite and contorted plagioclase lamellae.

#### *Fine- to medium-grained biotite granite*

Fine- to medium-grained biotite granite is very subordinate. It occurs as small bodies up to 20 m thick or as dikes intersecting the medium-grained biotite granite. The rock has an anhedral-granular texture and is composed of 25–40% quartz, 20–40% K-feldspar, 15–30% plagioclase ( $An_4 - An_{14}$ ) and 3–8% biotite which is partly chloritized. Muscovite (2–5%) occurs mainly as alteration product of plagioclase but is also present in interstitial position. Locally, the rock contains some K-feldspar phenocrysts (7–10 mm).

#### *Fine- to medium-grained muscovite granite*

Fine- to medium-grained muscovite granite is a hydrothermally altered rock which is rarely encountered in outcrop. Most samples were collected from the mine dumps of Bandi and Sungei Lembing. The rock has fine-grained matrix with interlocking grain boundaries. It is composed of quartz, K-feldspar and plagioclase ( $An_4 - An_{14}$ ) which are present in approximately equal amounts.

This texture has been modified by late muscovite (up to 30%). There is also some chlorite (up to 5%) which represents altered biotite although some of the biotite originally present has probably been converted into muscovite. Calcite is also a common alteration product of plagioclase whereas fluorite is rare. Occasionally, the rock contains phenocrysts of plagioclase, K-feldspar and/or quartz constituting up to 30 percent of the rock volume.

### Geology of the Triassic granite at Paka

Most of the Triassic granite at Paka is similar in texture and mineral composition to the Permian medium to coarse-granite. But there is a rare phase of very fine-grained biotite granite which has no equivalent in the Permian granite terrain. It has a groundmass composed of equal amounts of quartz, K-feldspar and plagioclase as well as subordinate biotite (2%). The grain size of the matrix minerals varies between 40 and 400  $\mu\text{m}$ . Phenocrystic aggregates of myrmekitic quartz/K-feldspar intergrowths (1 – 4 mm across) constitute 20% of the rock volume. There are also phenocrysts of plagioclase (5%), quartz (5%) and biotite (0.5%).

### GEOCHEMISTRY

The rock samples were analysed for 32 major and minor elements by X-ray fluorescence (BGR), F and FeO (both in the GSM laboratory). The samples of the series MS-300 to MS-419 were collected during the field work in November-December 1987. MS-420 was collected during a visit to the Sungei Lembing mine (Gagak, level 10) in 1984. MS-421, MS-422, MS-424 and MS-425 are samples from the GSM collection taken by Fateh Chand; the corresponding GSM sample numbers are 30080, 30081, 30083 and 30084, respectively.

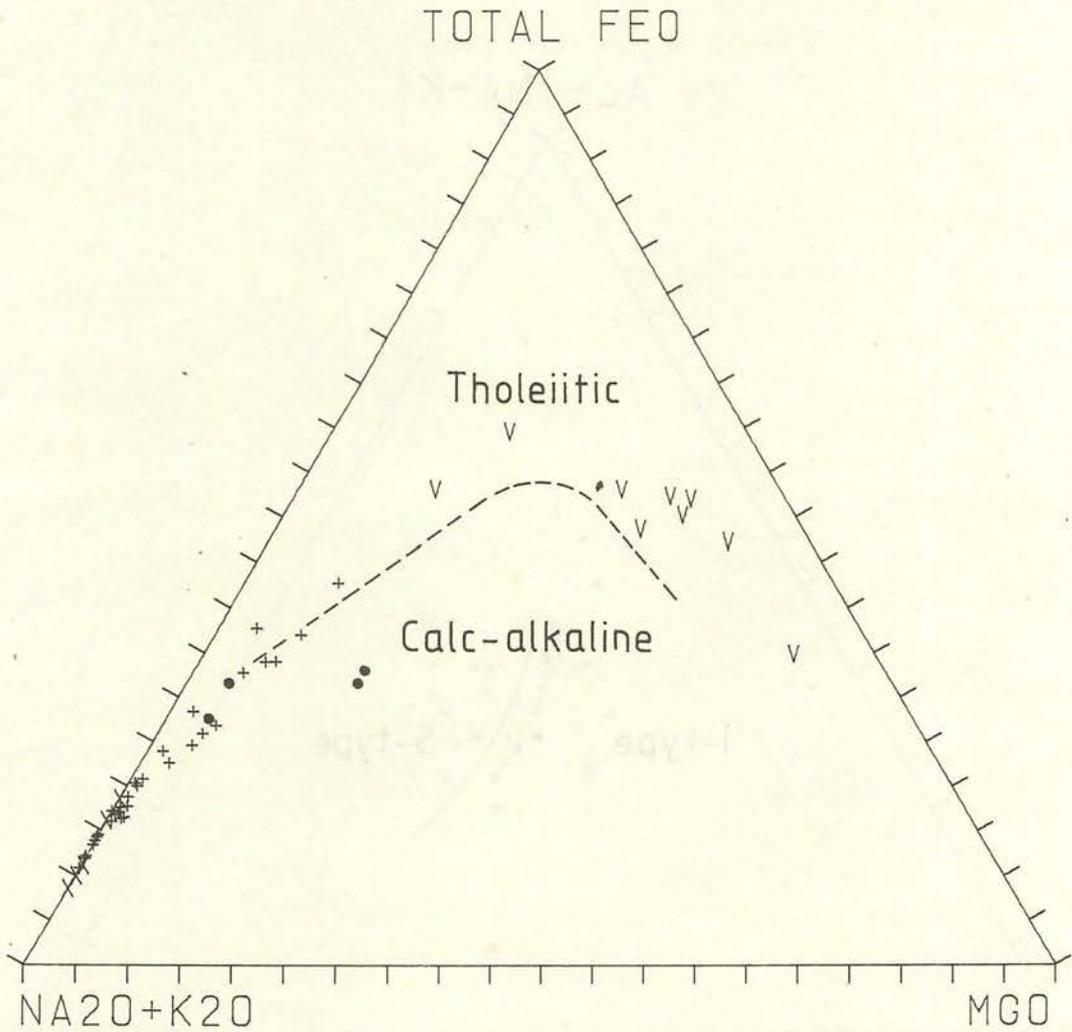
#### Gabbro to quartz diorite

The gabbro-quartz diorite suite covers a range of 46 – 56%  $\text{SiO}_2$ . Its high FeO concentration and its high FeO/MgO ratios classify it as tholeiitic series (Fig. 4). It forms a group of its own which cannot be genetically linked by fractional crystallization to the granites in the area. Linking the two groups would imply a completely unrealistic high ratio (more than 90%) between fractionated solid and liquid. The gabbro-quartz diorite suite and the granites may have had a common heat source or, as Liew (1983) suggested, the basic mantle-derived melt delivered the heat to the lower crust and initiated the melting of the rocks from which the granites have been derived.

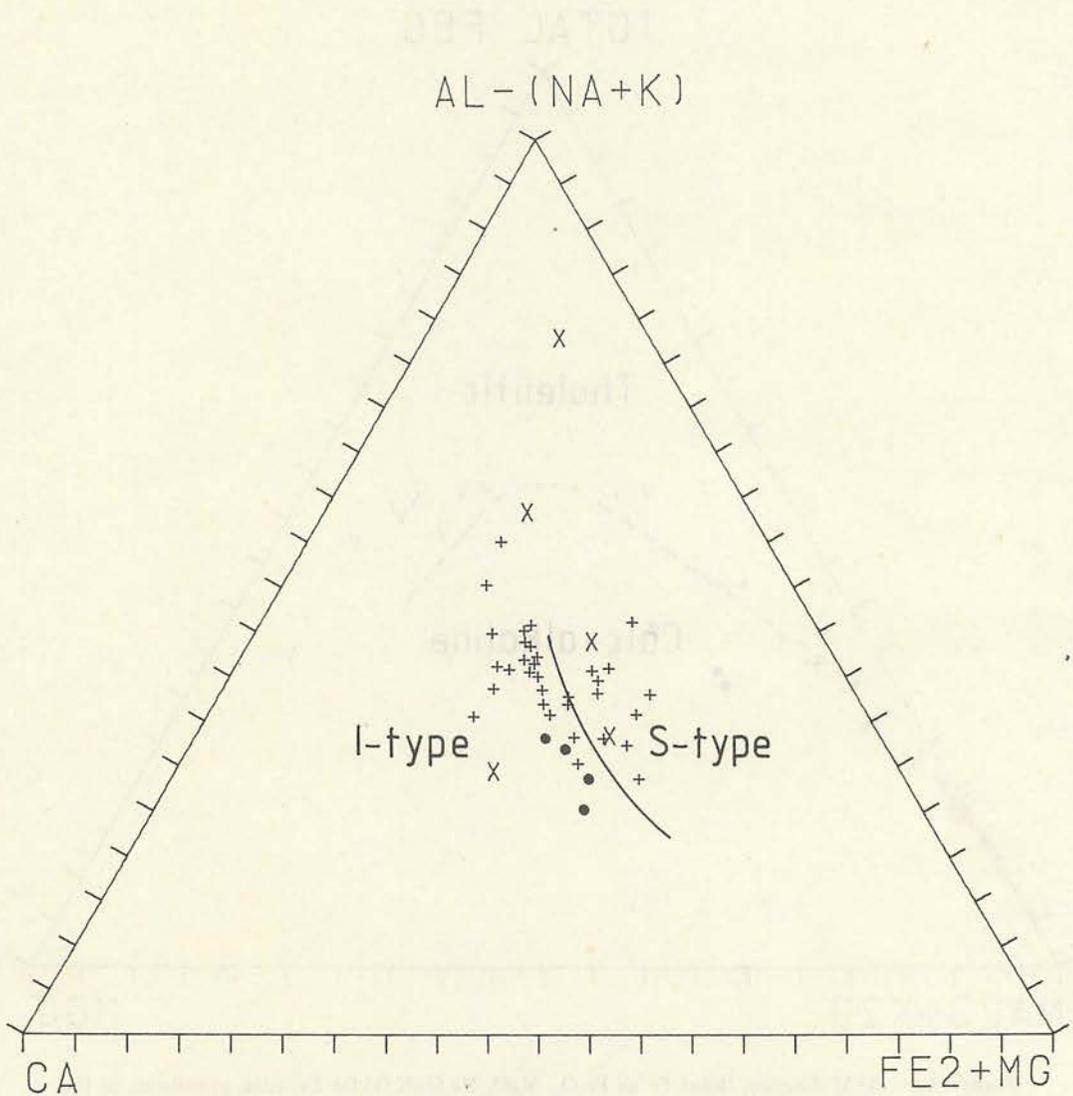
#### (Hornblende) -biotite granite

The association of basic to intermediate plutonic rocks with granites characterizes the terrains of I-type granite derived from an igneous source rock, as opposed to terrains with S-type granite with a sedimentary protolith (Chappell and White, 1974).

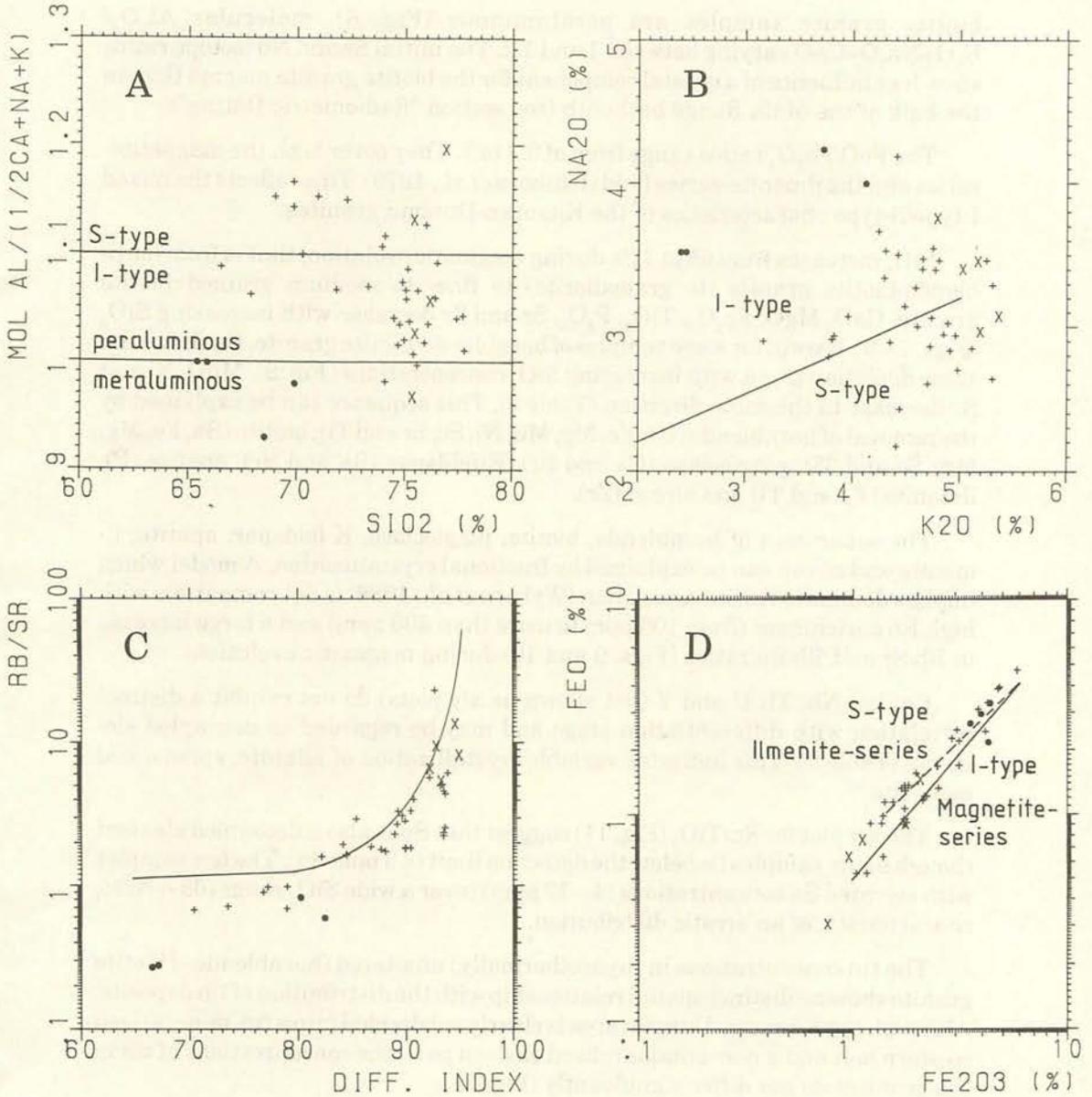
The hornblende-biotite granites can be classified as I-type granite but the biotite granites do not allow a clear-cut distinction between I-type and S-type. The data for biotite granite are in both the I-type and S-type fields in all diagrams generally used for distinguishing the granite types (Hine *et al.*, 1978), i.e. the ACF diagram (Fig. 5) and the x/y plots for  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  and  $\text{FeO}/\text{Fe}_2\text{O}_3$  (Fig. 6). Most



**Figure 4 :** AFM diagram (total Fe as  $\text{Fe}_2\text{O}_3$ , MgO,  $\text{Na}_2\text{O}+\text{K}_2\text{O}$ ) for Permian granitoids in the Kuantan-Dungun area. Classification of the tholeiitic and calc-alkaline series according to Irvine and Baragar (1971). For symbols, refer to Figure 3.



**Figure 5 :** ACF diagram showing the molecular ratios of  $Al_2O_3-(Na_2O+K_2O)/CaO/FeO+MgO$  for Permian granitoids in the Kuantan-Dungun area, Malaysia. The boundary between the fields for S-type and I-type granites has been taken from data in Hine *et al.*, (1978). For symbols, refer Figure 3.



**Figure 6:** x/y plots for Permian granitoids in the Kuantan-Dungun area, Malaysia. For symbols refer to Figure 3.

- Molecular  $Al_2O_3 / K_2O + Na_2O + CaO$  versus  $SiO_2$  (wt%) plot.
- $Na_2O$  versus  $K_2O$  plot. S-type/I-type classification after Chappell and White (1974).
- Rb/Sr versus T.T. differentiation index (normative  $qz+or+ab$ ) plot. The line which shows the lower limit (low Rb/Sr) for Main Range granites has been taken from Pitfield (1987).
- $FeO/Fe_2O_3$  (total Fe) plot. I-type/S-type classification (dotted line) after Hine *et al.*, (1978) and magnetite-series/ilmenite-series classification (solid line) after Ishihara *et al.*, (1979).

biotite granite samples are peraluminous (Fig. 6), molecular  $\text{Al}_2\text{O}_3/\text{K}_2\text{O}+\text{Na}_2\text{O}+\text{CaO}$  varying between 1 and 1.2. The initial Sr and Nd isotope ratios show less influence of a crustal component for the biotite granite magma than in the bulk of the Main Range batholith (see section "Radiometric Dating").

The  $\text{FeO}/\text{Fe}_2\text{O}_3$  ratios range from 0.3 to 7. They cover both the magnetite-series and the ilmenite-series field (Ishihara *et al.*, 1979). This reflects the mixed I-type/S-type characteristics of the Kuantan-Dungun granites.

$\text{SiO}_2$  increases from 65 to 77% during magmatic evolution, that is from hornblende-biotite granite (to granodiorite) to fine- to medium grained biotite granite. CaO, MgO,  $\text{Fe}_2\text{O}_3$ ,  $\text{TiO}_2$ ,  $\text{P}_2\text{O}_5$ , Sr and Zr decrease with increasing  $\text{SiO}_2$  (Figs. 7–9). Except for some samples of hornblende-biotite granite, Ba shows the same depletion trend with increasing  $\text{SiO}_2$  concentrations (Fig. 9). MnO, Ni and Sc decrease in the same direction (Table 2). This sequence can be explained by the removal of hornblende (Ca, Fe, Mg, Mn, Ni, Sc, Sr and Ti), biotite (Ba, Fe, Mg, Mn, Sc and Ti), plagioclase (Ca and Sr), K-feldspar (Ba and Sr), apatite (P), ilmenite (Fe and Ti) and zircon (Zr).

The separation of hornblende, biotite, plagioclase, K-feldspar, apatite, ilmenite and zircon can be explained by fractional crystallization. A model which implies dominate restite separation (Wyborn *et al.*, 1986) is not compatible with high Rb enrichment (from 100 ppm to more than 300 ppm) and a large increase in Rb/Sr and Rb/Ba ratios (Figs. 9 and 10) during magmatic evolution.

Ce, La, Nb, Th U and Y (not shown as x/y plots) do not exhibit a distinct correlation with differentiation stage and may be regarded as decoupled elements (Table 2). This indicates variable crystallization of allanite, sphene and monazite.

The x/y plot for  $\text{Sn}/\text{TiO}_2$  (Fig. 11) suggest that Sn is also a decoupled element though many samples lie below the detection limit (< 3 ppm Sn). The few samples with elevated Sn concentrations (4–12 ppm) cover a wide  $\text{SiO}_2$  range (65–76%), characteristic of an erratic distribution.

The tin concentrations in (hydrothermally) unaltered (hornblende-) biotite granite show no distinct spatial relationship with the distribution of tin deposits. Although the Kuantan-Dungun area is clearly subdivided into a tin-mineralized western belt and a non-unmineralized eastern part, the concentrations of tin in the granites do not differ significantly (Fig. 12).

The behaviour of tungsten during magmatic evolution can not be evaluated because most samples of (hornblende-) biotite granite have concentrations below the detection limit (< 7 ppm W; see Fig. 11).

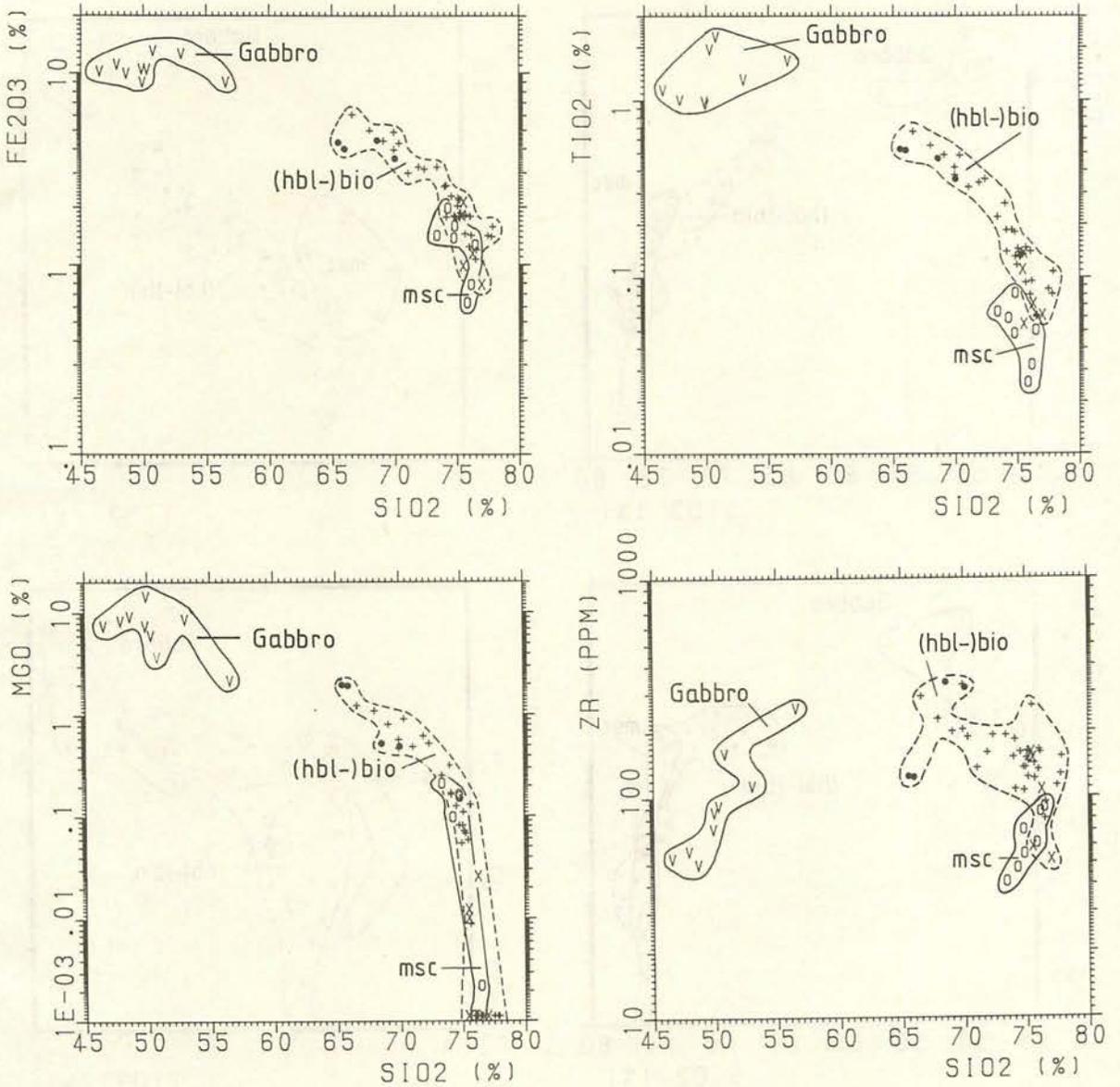
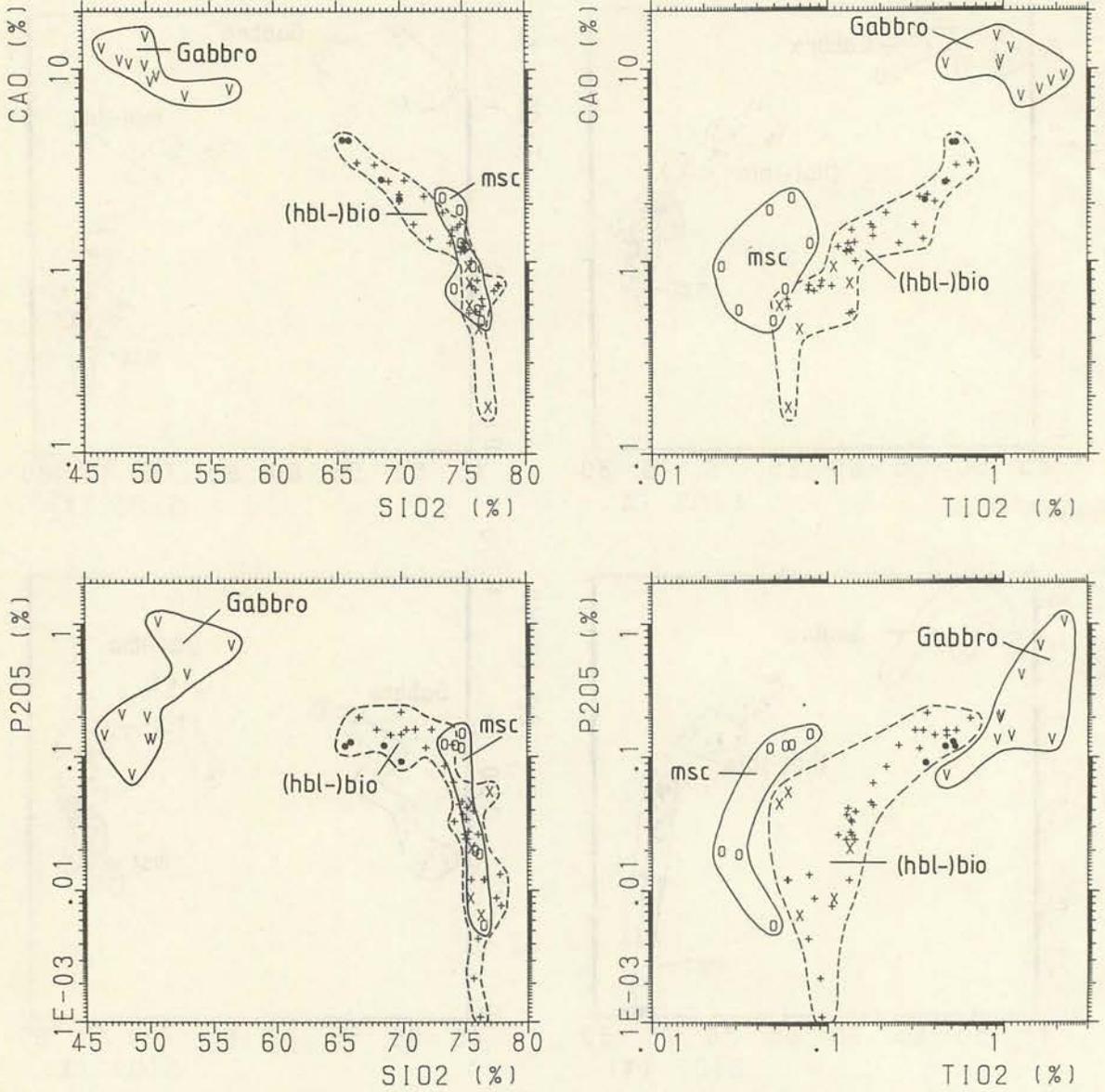
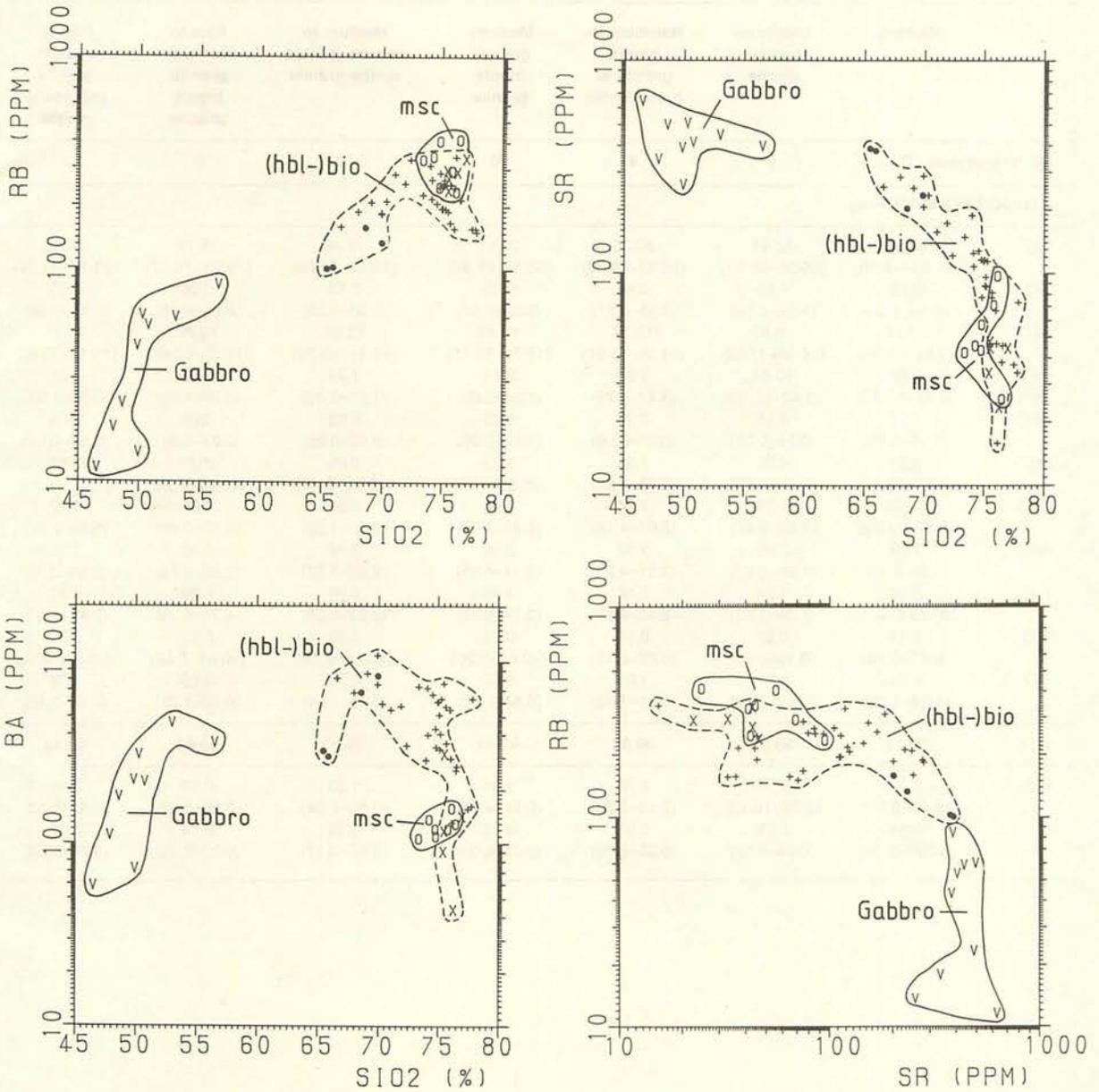


Figure 7: Fe<sub>2</sub>O<sub>3</sub>/SiO<sub>2</sub>, TiO<sub>2</sub>/SiO<sub>2</sub>, MgO/SiO<sub>2</sub> and Zr/SiO<sub>2</sub> plots for Permian granitoids in the Kuantan-Dungun area, Malaysia. For symbols, refer Figure 3.



**Figure 8:** CaO/SiO<sub>2</sub>, CaO/TiO<sub>2</sub>, P<sub>2</sub>O<sub>5</sub>/SiO<sub>2</sub> and P<sub>2</sub>O<sub>5</sub>/TiO<sub>2</sub> plots for Permian granitoids in the Kuantan-Dungun area, Malaysia. For symbols, refer to Figure 3.



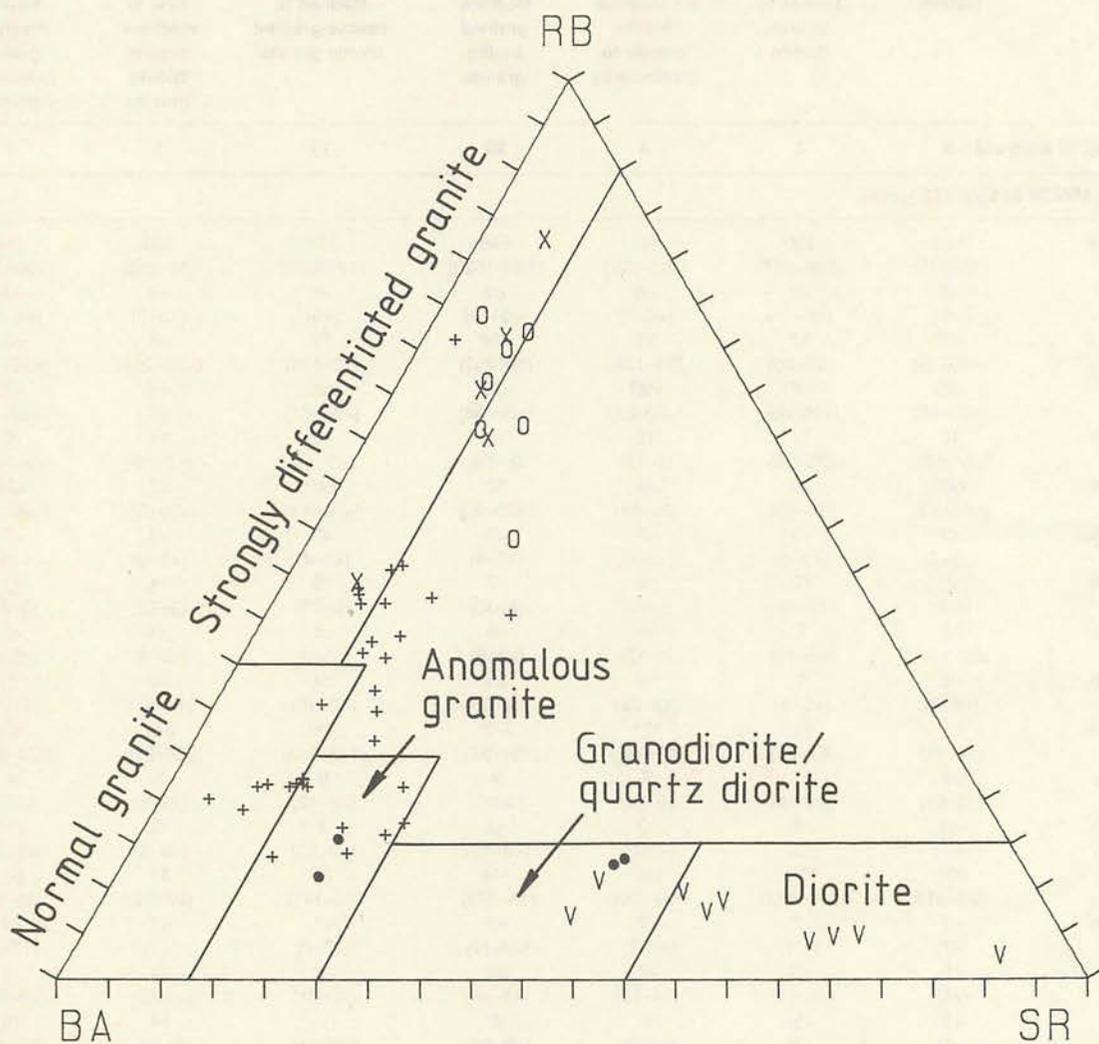
**Figure 9:** Rb/SiO<sub>2</sub>, Sr/SiO<sub>2</sub>, Ba/SiO<sub>2</sub> and Rb/Sr plots for Permian granitoids in the Kuantan-Dungun area. For symbols, refer to Figure 3.

Table 2: Averaged abundances and ranges of major and minor elements of Permian granitoids in the Kuantan-Dungun area, Malaysia.

	Gabbro	Diorite to quartz-diorite	Hornblende-biotite granite to granodiorite	Medium-grained biotite granite	Medium to coarse-grained biotite granite	Fine to medium-granite biotite granite	Fine to medium-granite muscovite granite
No. of analyses	5	4	4	20	13	5	7
<b>I. MAJOR ELEMENTS (%)</b>							
SiO <sub>2</sub>	48.34 (46.31-49.70)	52.41 (50.05-56.31)	67.35 (65.33-69.83)	72.61 (65.35-75.94)	75.48 (72.14-77.65)	75.72 (75.21-76.77)	74.88 (73.17-76.24)
TiO <sub>2</sub>	0.85 (0.45-1.07)	1.68 (1.22-2.14)	0.45 (0.35-0.51)	0.25 (0.09-0.62)	0.13 (0.06-0.33)	0.08 (0.05-0.13)	0.05 (0.02-0.08)
Al <sub>2</sub> O <sub>3</sub>	17.14 (9.89-20.36)	16.67 (14.94-17.89)	15.14 (14.36-15.91)	13.49 (12.39-15.11)	12.55 (11.41-13.72)	12.72 (12.33-13.48)	13.11 (12.12-13.86)
Fe <sub>2</sub> O <sub>3</sub> (total Fe)	9.52 (8.42-10.37)	10.61 (8.42-12.30)	3.97 (3.47-4.29)	2.74 (1.34-5.68)	1.71 (1.01-3.03)	1.28 (0.74-1.99)	1.22 (0.59-1.86)
MnO	0.17 (0.16-0.19)	0.18 (0.14-0.21)	0.07 (0.07-0.08)	0.05 (0.02-0.09)	0.03 (0.02-0.05)	0.03 (0.01-0.04)	0.04 (0.01-0.06)
MgO	8.31 (6.57-12.83)	4.55 (1.94-7.62)	1.58 (0.48-1.90)	0.33 (<0.01-1.11)	0.09 (<0.01-0.47)	<0.01 (<0.01-0.02)	0.08 (<0.01-0.19)
CaO	11.26 (9.82-13.95)	7.74 (6.80-8.66)	3.24 (2.07-4.16)	1.56 (0.51-3.07)	0.93 (0.51-1.69)	0.55 (0.17-0.88)	1.07 (0.46-2.20)
Na <sub>2</sub> O	1.59 (1.09-2.15)	2.20 (1.00-3.22)	3.80 (3.51-4.22)	2.99 (2.14-4.15)	3.18 (2.80-3.52)	3.30 (2.93-3.73)	3.10 (2.54-3.78)
K <sub>2</sub> O	0.54 (0.29-0.97)	1.51 (1.35-1.81)	3.16 (2.40-4.11)	4.45 (3.14-5.28)	4.65 (3.93-5.28)	5.08 (4.76-5.34)	4.11 (2.41-5.37)
P <sub>2</sub> O <sub>5</sub>	0.14 (0.07-0.19)	0.52 (0.13-0.95)	0.11 (0.09-0.13)	0.08 (<0.01-0.20)	0.03 (<0.01-0.15)	0.02 (<0.01-0.05)	0.07 (<0.01-0.14)
L.O.I	1.55 (1.38-1.86)	1.47 (0.19-3.26)	1.03 (0.61-1.48)	0.90 (0.54-1.60)	0.79 (0.65-1.29)	0.85 (0.59-1.01)	1.76 (0.65-3.45)
Sum	99.41	99.54	99.90	99.49	99.57	99.63	99.49
FeO	7.77 (6.90-8.33)	8.75 (6.68-10.13)	2.70 (2.10-3.23)	1.95 (0.93-4.45)	1.03 (0.50-2.34)	0.77 (0.29-1.37)	0.80 (0.43-1.52)
F	0.11 (<0.01-0.38)	0.09 (0.06-0.12)	0.07 (0.05-0.09)	0.12 (0.01-0.03)	0.10 (0.07-0.17)	0.14 (0.03-0.36)	0.12 (0.05-0.34)

Table 2 continued ...

	Gabbro	Diorite to quartz-diorite	Hornblende-biotite granite to granodiorite	Medium-grained biotite granite	Medium to coarse-grained biotite granite	Fine to medium-granite biotite granite	Fine to medium-granite muscovite granite
No. of analyses	5	4	4	20	13	5	7
<b>II. MINOR ELEMENTS (ppm)</b>							
Ba	122 (55-213)	320 (208-437)	531 (300-827)	558 (123-1020)	373 (147-689)	133 (41-295)	118 (100-148)
Bi	<6 (<6)	<6 (<6-11)	<6 (<6-7)	<6 (<6-13)	<6 (<6)	<6 (<6-7)	<6 (<6-14)
Ce	<20 (<20-22)	57 (37-86)	85 (34-133)	108 (53-253)	79 (32-124)	68 (<20-206)	<20 (<20-32)
Co	<20 (<20-23)	<20 (<20-49)	<20 (<20-21)	<20 (<20-38)	<20 (<20-31)	<20 (<20)	<20 (<20-21)
Cu	40 (27-53)	31 (25-39)	10 (8-13)	13 (8-19)	12 (<7-24)	14 (10-19)	36 (9-110)
La	<20 (<20-22)	30 (24-33)	39 (26-56)	38 (<20-92)	<20 (<20-44)	20 (<20-55)	<20 (<20-22)
Mo	<3 (<3-3)	<3 (<3-5)	<3 (<3-4)	<3 (<3-6)	<3 (<3-4)	<3 (<3-3)	<3 (<3)
Nb	6 (4-8)	15 (11-19)	14 (8-22)	17 (8-36)	12 (8-20)	14 (5-23)	17 (8-23)
Ni	52 (22-141)	7 (<5-19)	8 (5-12)	<5 (<5-9)	<5 (<5-9)	<5 (<5-9)	<5 (<5-6)
Pb	<6 (<6-6)	6 (<6-9)	19 (13-25)	25 (12-35)	24 (10-38)	30 (11-67)	30 (8-56)
Rb	21 (11-41)	61 (51-80)	121 (99-156)	213 (151-323)	209 (143-313)	271 (225-318)	306 (222-390)
Sc	36 (25-61)	31 (23-36)	9 (6-14)	9 (3-20)	6 (<2-12)	3 (<2-5)	4 (3-5)
Sn	<3 (<3)	<3 (<3)	<3 (<3-3)	<3 (<3-12)	3 (<3-27)	<3 (<3-3)	<18 (<3-34)
Sr	406 (249-610)	419 (376-483)	297 (199-381)	144 (15-273)	73 (32-141)	37 (22-45)	51 (24-92)
Ta	<7 (<7)	<7 (<7)	<7 (<7-7)	<7 (<7-11)	<7 (<7-7)	<7 (<7)	<7 (<7-9)
Th	<5 (<5)	<5 (<5-11)	17 (14-19)	26 (14-46)	22 (16-31)	30 (<5-59)	19 (<5-51)
U	<5 (<5)	<5 (<5)	6 (<5-8)	8 (<5-21)	5 (<5-11)	14 (9-22)	19 (15-25)
V	289 (199-364)	241 (86-360)	31 (<15-55)	<15 (<15-39)	<15 (<15-30)	<15 (<15)	<15 (<15)
W	<7 (<7)	<7 (<7)	<7 (<7-11)	<7 (<7-17)	<7 (<7-9)	<7 (<7-7)	13 (8-24)
Y	19 (12-29)	29 (17-43)	30 (18-49)	60 (26-202)	43 (31-62)	46 (23-75)	49 (16-98)
Zn	84 (75-94)	103 (75-124)	64 (55-83)	52 (24-116)	39 (15-65)	35 (21-59)	45 (13-98)
Zr	60 (47-81)	147 (87-242)	221 (120-325)	172 (116-308)	126 (75-252)	100 (49-151)	61 (39-85)



**Figure 10:** Rb-Ba-Sr triangular plot for Permian granitoids in the Kuantan-Dungun area, Malaysia, with granitoid classification according to El Bouseily and El Sokkary (1975). For symbols, refer to Figure 3.

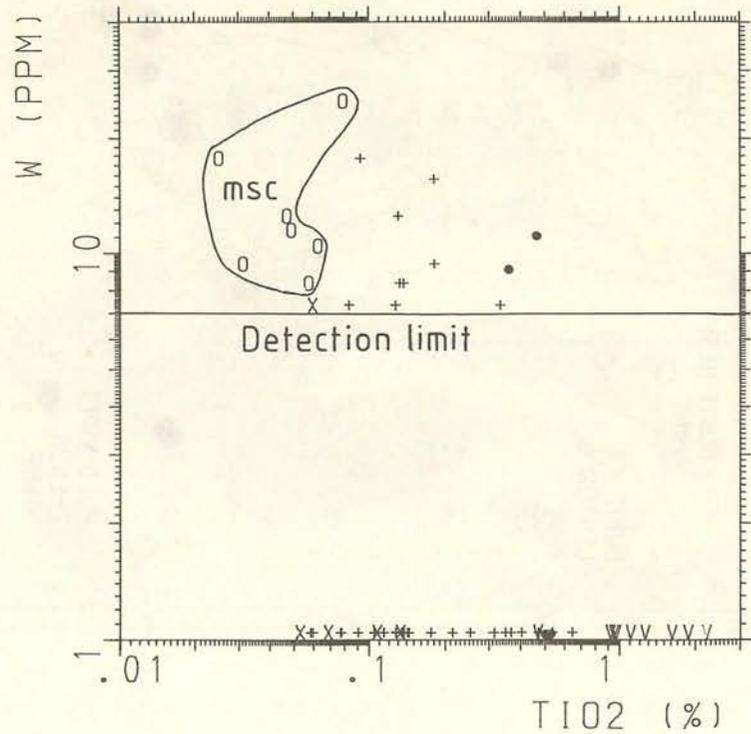
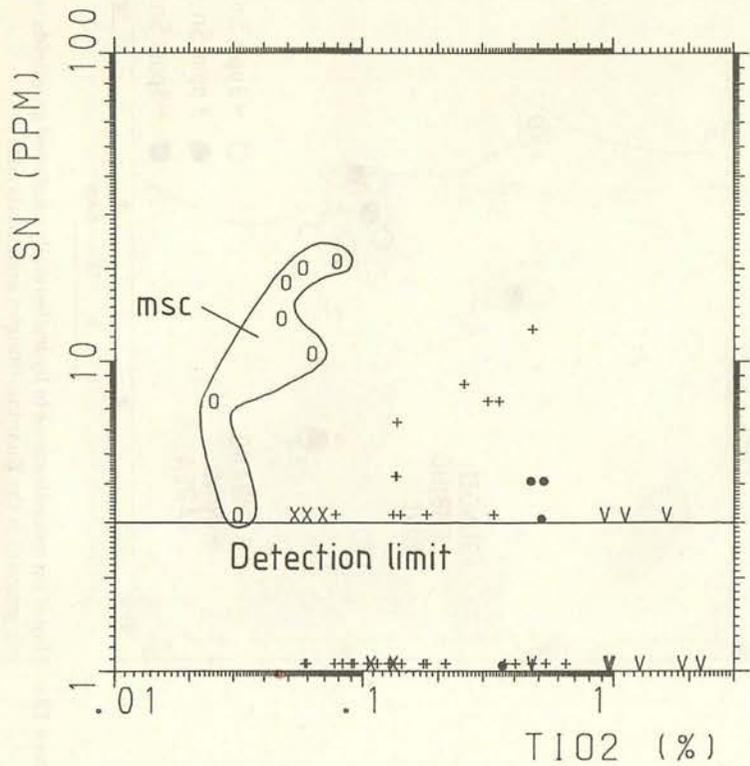
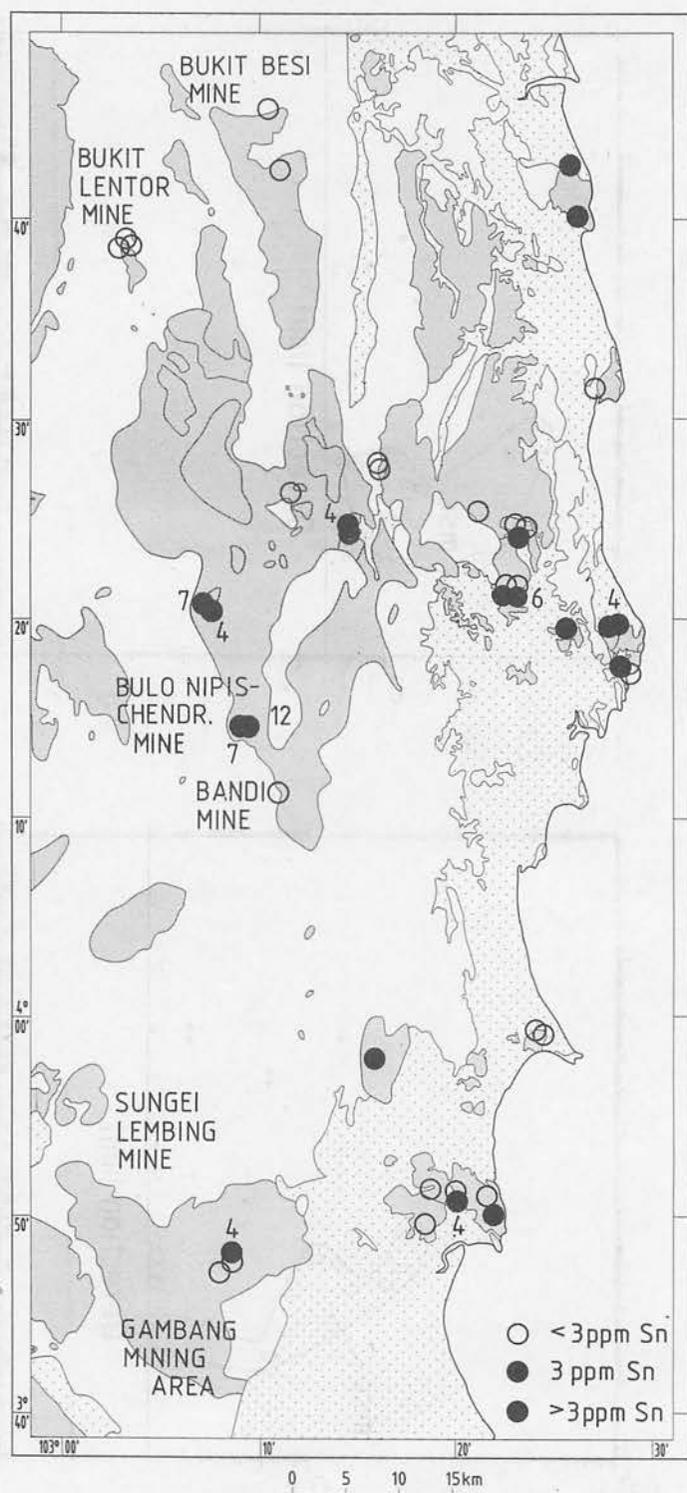


Figure 11: Sn/TiO<sub>2</sub> and W/TiO<sub>2</sub> plots for Permian granitoids in the Kuantan-Dungun area, Malaysia. For symbols, refer to Figure 3.



**Figure 12:** Map of tin concentrations in hydrothermally unaltered granitoids (excluding muscovite granite) in the Kuantan-Dungun area, Malaysia.

### Pressure estimate for the biotite granite

In the normative Ab-Or-Qz plot (Fig. 13), the composition of biotite granite plot in a field bounded by the minimum-temperature melt compositions for 4 – 7 kb (for Ab/An = 2.9) and for 1 kb (Ab/An = 4 and Ab/An = 10.4). The Ab/An ratios for these experimental data correspond approximately to the Ab/An ratios of the rock samples. A pressure range of 1 – 5 kb can be derived from these data. However, such an assumption represents a gross generalization because the temperatures of the granite magma may have been above these minima and the melt was certainly undersaturated in water.

### Muscovite granite

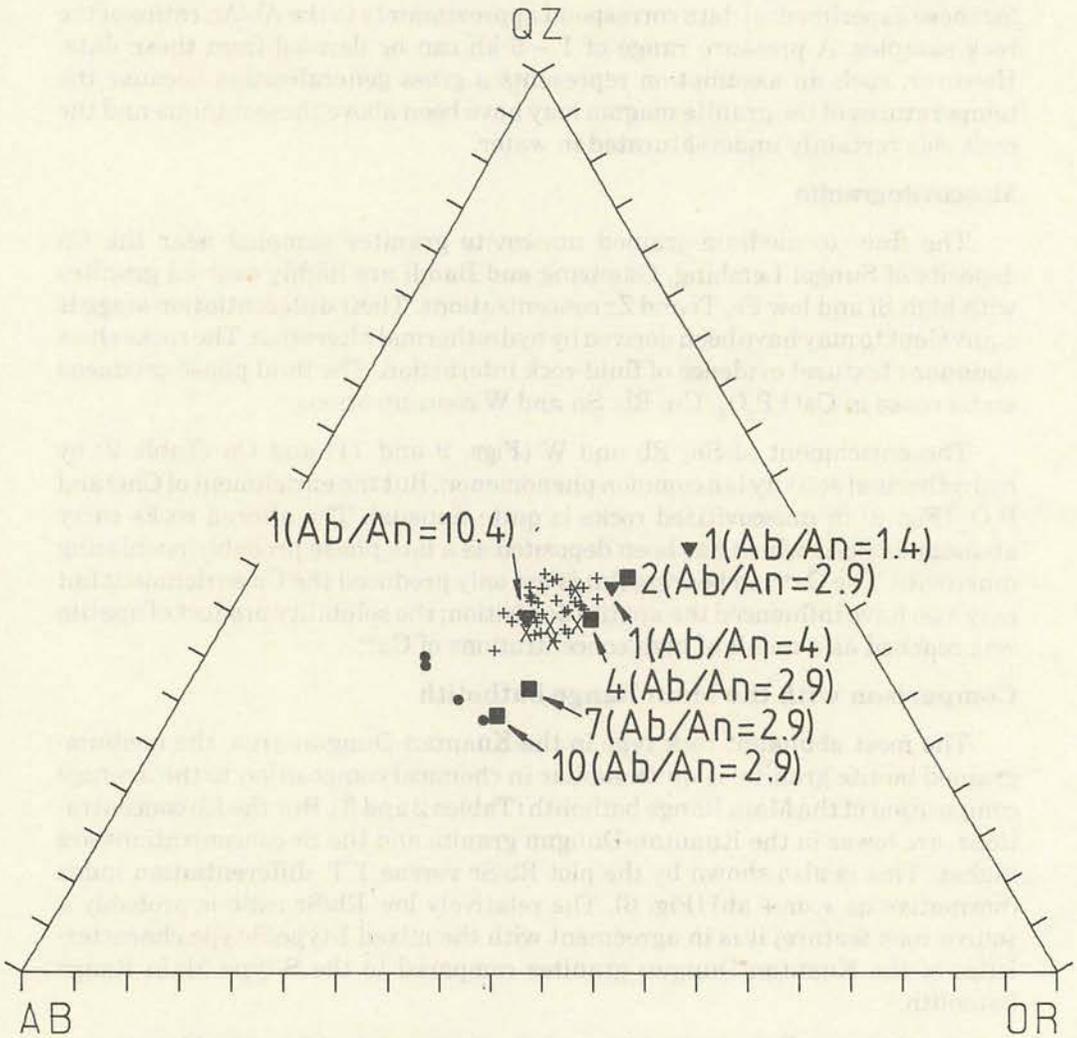
The fine- to medium-grained muscovite granites sampled near the tin deposits of Sungei Lembing, Gambang and Bandi are highly evolved granites with high Si and low Fe, Ti and Zr concentrations. Their differentiation stage is equivalent to may have been derived by hydrothermal alteration. The rocks show abundant textural evidence of fluid-rock interaction. The fluid phase produced an increase in CaO,  $P_2O_5$ , Cu, Rb, Sn and W concentrations.

The enrichment of Sn, Rb and W (Figs. 9 and 11) and Cu (Table 2) by hydrothermal activity is a common phenomenon. But the enrichment of CaO and  $P_2O_5$  (Fig. 8) in muscovitized rocks is quite unusual. The altered rocks carry abundant calcite which has been deposited as a late phase probably postdating muscovite. The  $Ca^{++}$  ion bearing fluids not only produced the Ca enrichment but may also have influenced the apatite deposition; the solubility product of apatite was reached as a result of high concentrations of  $Ca^{++}$ .

### Comparison with the Main Range batholith

The most abundant rock type in the Kuantan-Dungun area, the medium-grained biotite granite, is quite similar in chemical composition to the average composition of the Main Range batholith (Tables 2 and 3). But the Rb concentrations are lower in the Kuantan-Dungun granite and the Sr concentrations are higher. This is also shown by the plot Rb/Sr versus T.T. differentiation index (normative qz + or + ab) (Fig. 6). The relatively low Rb/Sr ratio is probably a source rock feature; it is in agreement with the mixed I-type/S-type characteristics of the Kuantan-Dungun granites compared to the S-type Main Range batholith.

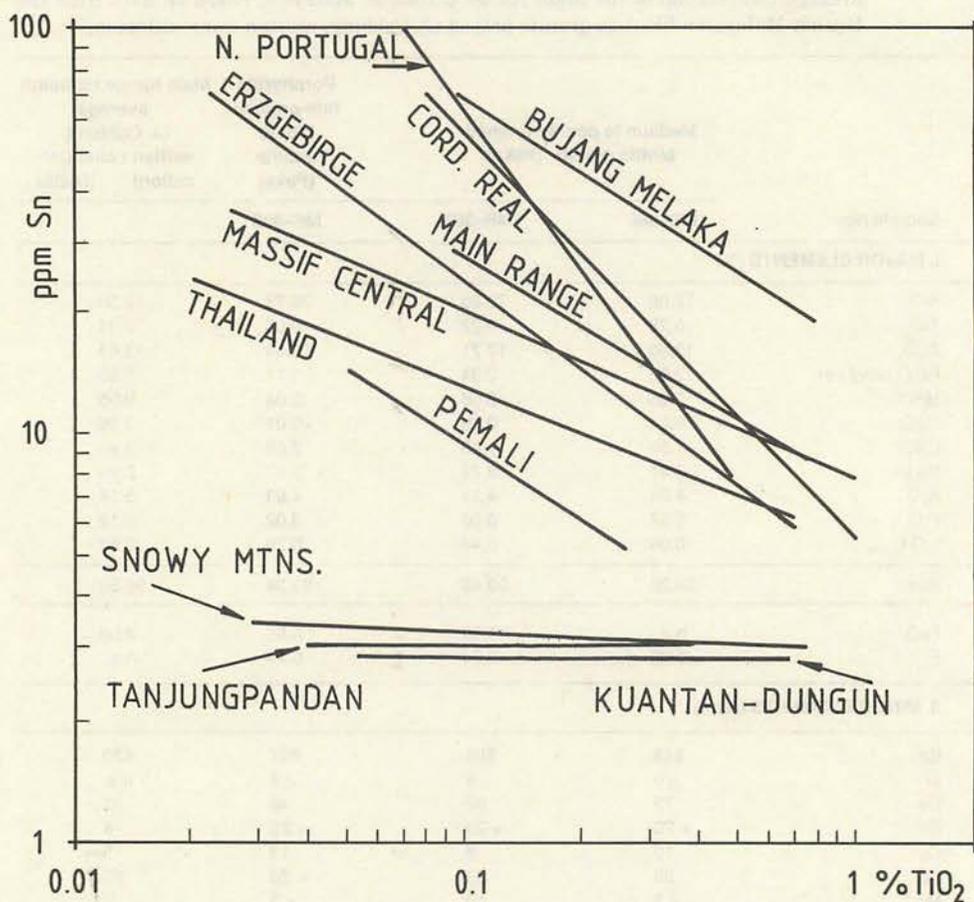
The Kuantan-Dungun granites are also distinguished from the Main Range by the behaviour of Sn. The average Sn concentration in the biotite granites is low (approximately 3 ppm Sn) compared to the Main Range average (17 ppm). Although the Kuantan-Dungun granites cover a wide compositional range (65 – 77%  $SiO_2$ ), their Sn concentrations are unrelated to differentiation stage. In contrast, the Main Range exhibits a significant increase in Sn with differentiation, taking  $TiO_2$  as differentiation index (Fig. 14).



**Figure 13 :** Normative composition of (hornblende-)biotite granites in the Kuantan-Dungun area, Malaysia, in terms of quartz, albite and orthoclase. The experimentally determined composition of minimum temperature melts are shown for comparison. The solid squares are data for water-saturated melts with albite/anorthite = 2.9 at 2, 4, 7 and 10kb (von Platern and Höller, 1966). The triangles are data for water-saturated melts at 1 kb with albite/anorthite ratios of 1.4, 4.0 and 10.4 (James and Hamilton, 1969). For symbols, refer to Figure 3.

**Table 3:** Chemical analyses of Triassic granites of the Paka area, Dungun, Malaysia, and the average composition of the Main Range batholith, Malaysia, based on data from the British-Malaysian SE-Asia granite project (J. Cobbing, written communication)

Sample No.	Medium to coarse-grained biotite granite (Paka)		Porphyritic fine-grained biotite granite (Paka)	Main Range batholith average (J. Cobbing, written communi- cation) (N=56)
	MS-386	MS-387	MS-388	
<b>I. MAJOR ELEMENTS (%)</b>				
SiO <sub>2</sub>	72.06	72.93	76.73	72.50
TiO <sub>2</sub>	0.28	0.22	0.05	0.34
Al <sub>2</sub> O <sub>3</sub>	13.50	13.71	12.44	13.63
Fe <sub>2</sub> O <sub>3</sub> (total Fe)	2.82	2.34	1.11	2.50
MnO	0.06	0.06	0.04	0.05
MgO	0.31	0.19	<0.01	0.66
CaO	1.53	1.43	0.58	1.45
Na <sub>2</sub> O	3.91	3.72	3.47	2.96
K <sub>2</sub> O	4.04	4.31	4.83	5.14
P <sub>2</sub> O <sub>5</sub>	0.07	0.06	0.02	0.12
L.O.I.	0.66	0.48	0.29	0.63
Sum	99.26	99.43	99.54	99.98
FeO	n.a.	1.58	0.86	2.06
F	0.09	0.04	0.14	n.a.
<b>II. MINOR ELEMENTS (ppm)</b>				
Ba	548	598	237	420
Bi	< 6	6	< 6	n.a.
Ce	73	82	48	91
Co	< 20	< 20	< 20	4
Cu	10	9	13	5
La	30	33	< 20	53
Mo	< 3	10	< 3	2
Nb	19	20	15	19
Ni	< 5	< 5	< 5	13
Pb	11	20	23	44
Rb	157	180	242	397
Sc	6	5	< 2	n.a.
Sn	3	3	4	17
Sr	162	151	35	103
Ta	< 7	< 7	< 7	2
Th	13	16	22	38
U	< 5	< 5	12	11
V	24	< 15	< 15	27
W	< 7	< 7	7	11
Y	39	30	35	59
Zn	59	37	17	38
Zr	252	217	87	165



**Figure 14 :** Trend line for long Sn/log  $TiO_2$  in biotite granite from the Kuantan-Dungun area (Malaysia) compared to granites from other areas. The tin-mineralized reference granites are from Northern Portugal, Cordillera Real (Bolivia), Erzgebirge (German Democratic Republic), Bujang Melaka (Kinta Valley, Malaysia), Main Range excluding Bujang Melaka (Malaysia), Pemali (Bangka, Indonesia), Massif Central (France) and Thailand. Non-mineralized granite is from Snowy Mountains (N.S.W., Australia). The data for the reference granites are taken from the review by Lehmann (1987), except for the Main Range in Malaysia (written communication by B. Lehmann), Pemali, and Bujang Melaka (Schwartz and Askury, in press).

## CONCLUSIONS

Only in hydrothermally altered portions the Kuantan-Dungun granites show elevated Sn concentrations (up to 34 ppm Sn). The tin concentrations in unaltered rocks are low (averaging 3 ppm Sn) and correspond to the average granite concentration of Vinogradov (1962). A feature that the Kuantan-Dungun granites have in common with other granites in the Eastern Province (Liew, 1983) is that the tin concentrations seem to be unrelated to differentiation stage, that is tin is a decoupled element.

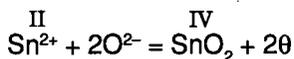
Both the low tin concentrations and the decoupled behaviour of tin are unusual features of granites associated with tin deposits. The Tanjung Pandan pluton of Belitung Island, Indonesia is the only known example in S.E. Asia outside the Eastern Granite Province showing the same unusual characteristic (B. Lehmann, written communication).

The Tanjung Pandan pluton also has small bodies of basic to intermediate rocks (gabbro, diorite and quartz syenite) which are contemporaneous with the granite. Both the Kuantan-Dungun area and the Tanjung Pandan pluton have important wolframite mineralization in addition to cassiterite.

The metallogenesis of tin in the two cassiterite-wolframite areas Kuantan-Dungun and Tanjung Pandan is different from that in a typical Main Range granite such as the cassiterite-dominated S-type Bujang Melaka pluton in the Kinta Valley (Schwartz and Askury, in press). The Main Range batholith, in general, and the Bujang Melaka pluton, in particular, show a significant increase in tin concentrations with increasing degree of magmatic differentiation, that is tin concentrations in late-stage differentiates are much higher than in less evolved rocks. But for the Kuantan-Dungun and Tanjung Pandan granites, the distribution coefficient between melt and solid must have near to 1; i.e. the concentration of Sn in the melt and in the crystallizing solid was more or less the same during most of the crystallization history of the magma. Tin was not enriched until the residual fluids separated from the crystallizing magma.

Decoupled behaviour of tin during magmatic evolution in terrains with both cassiterite and wolframite deposits is more than a coincidental connection. It is related to the different role of oxygen fugacity for the partitioning of metal between melt and crystallizing solid.

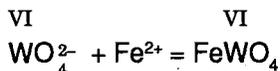
Tin occurs in both the divalent and the tetravalent state (Eugster, 1986). Low oxygen fugacity favours the partitioning of tin into the melt relative to the crystallizing solid. Low oxygen fugacity shifts the equilibrium to the left side of the reaction (written in schematic way):



e.g component  
of sphene  
Ca(Ti, Sn) SiO<sub>5</sub>

Tin exhibits incompatible behaviour (with respect to the solid crystallizing from the granite magma) in low oxygen fugacity environment and should tend to decoupled behaviour (independent of magmatic evolution) under an intermediate oxygen fugacity.

Tungsten occurs mainly in one valence state only (W<sup>VI</sup>) in the liquid phase as well as in the solid phase (Manning and Henderson, 1984). The reaction which is involved is less dependent on oxygen fugacity than the corresponding reaction for tin. It can be written in a schematic manner;



The distribution coefficient of tungsten is relatively insensitive to oxygen fugacity, and tungsten enrichment in residual liquids may be produced under a wide range of oxygen fugacities.

The mixed ilmenite-series/magnetite-series characteristics (intermediate oxygen fugacity) of the Eastern Province, in general and the Kuantan-Dungun area, in particular, constitute a less favourable environment for tin mineralization than the exclusively ilmenite-series Main Range batholith (low oxygen fugacity). This is reflected by the differences in total mine production of tin in Malaysia: 94% has come from the Main Range and 6% from the Eastern Province although the two areas are approximately the same size.

Mixed ilmenite-series/magnetite-series granitoids and pure ilmenite-series granitoids are equally favourable for wolframite mineralization because of its relative independence of oxygen fugacity. This is in agreement with the mine production of wolframite which is approximately equal in the Main Range and the Eastern Province.

#### ACKNOWLEDGMENTS

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#### REFERENCES

- AMRAN, B.H., 1980. *Geology, mineralisation and a geochemical study of the Kajang Kemaman area, Trengganu*. B.Sc. Thesis, University of Malaya, 55 p.
- BEAN, J.H., 1969. Iron-ore deposits of West Malaysia. *Geol. Survey West Malaysia Economic Bulletin* 2, 194 p.
- BIGNELL, J.D. and SNELLING, N.J., 1977. Geochronology of Malayan granites. *Overseas Geology and Mineral Resources* (Institute of Geological Sciences), London, No.47, 70 p.
- BRADFORD, E.F., 1961. The occurrence of tin and tungsten in Malaya. In Klompé, T.H.F., ed., *Proceedings 9th Pacific Science Congress Bangkok*, v.12, p.378-398.
- CHAND, F., 1978. The geology and mineral resources of the Ulu Paka area, Trengganu. *Geological Survey of Malaysia, District Memoir* 16, 124 p.
- CHAPPELL, B.W. and WHITE, A.J.R., 1974. Two contrasting granite types. *Pacific Geology*, v.8, p.173-174.
- CHONG, N.H., 1970. *The geology and mineralisation of Batu Tiga Old Pit, Bukit Besi, Trengganu, West Malaysia*. B.Sc. Thesis, University of Malaya, 115 p.
- COBBING, E.J., and MALLICK D.I.J., PITFIELD, P.E.J. and TEOH, L.H., 1986. The granites of the Southeast Asian tin belt. *Journ. Geol. Soc. London*, v.143, p.537-550.
- COBBING, E.J. and MALLICK D.I.J., 1987. South-East Asia Granite project - field report for Peninsular Malaysia. *British Geological Survey, Report No. MP/87/19/R*, 129 p.
- EL BOUSEILY, A.M. and EL SOKKARY, A.A., 1975. The relation between Rb, Ba and Sr in granitic rocks. *Chem. Geol.*, v.16 p.207-219.
- EUGSTER, H.P., 1986. Minerals in hot water. *American Mineralogist*, v.71, p.655-673.
- FITCH, F.H., 1952. The geology and mineral resources of the neighbourhood of Kuantan, Pahang. *Geological Survey Department Federation of Malaya, Memoir* 6, 143 p.
- GOH, L.S., 1973. *Geology, mineralisation and geochemical studies of the Chenderong-Buluh Nipis area, Trengganu*. B.Sc. Thesis, University of Malaya, 105 p.
- GOH, S.T., 1973. *Geology of the Kemaman area, Trengganu, Peninsular Malaysia*. B.Sc Thesis, University of Malaya, 88 p.

- HINE, R., WILLIAMS, I.S., CHAPPELL, B.W. and WHITE, A.J.R., 1978. Contrasts between I- and S-type granitoids of the Kosciusko batholith. *Journ. Geol. Soc. Australia*, v.25, pt.4, p.219-234.
- HUTCHISON, C.S., 1977. Granite emplacement and tectonic subdivision of Peninsular Malaysia. *Geol. Soc. Malaysia, Bull.* 9, p.187-207.
- HUTCHISON, C.S., 1979. Southeast Asian tin granitoids of contrasting tectonic setting. In Uyeda, S., Murphy, R.W. and Kobayashi, K., eds., *Geodynamics of the Western Pacific*: Tokyo, Center Academic Publications, p.221-232.
- IRVINE, T.N. and BARAGAR, W.R.A., 1971. A guide to the chemical classification of the common volcanic rocks. *Can. J. Earth Sc.*, v.8, p.523-548.
- ISHIHARA, S., SAWATA, H., ARPORNSUWAN, S., BUSARACOME, P. and BUNGBRAKEARTI, N., 1979. The magnetite-series and ilmenite-series granitoids and their bearing on tin mineralization, particularly of the Malay Peninsula region. *Geol. Soc. Malaysia, Bull.* 11, p.103-110.
- JALIL, A.B.M., 1981. *Geology, mineralization and geochemical studies of the Chenderong area (eastern part), Kemaman, Trengganu*. B.Sc. Thesis, University of Malaya, 55 p.
- JAMES, R.S. and HAMILTON, D.L., 1969. Phase relations in the system  $\text{NaAlSi}_3\text{O}_8$ - $\text{KAlSi}_3\text{O}_8$ - $\text{CaAl}_2\text{Si}_2\text{O}_8$ - $\text{SiO}_2$ . *Contr. Mineral. Petrol.*, v.21, p.111-141.
- KUMAR, S.C., 1980. The gabbroic suite and associated hornfelses of Bukit Kemuning, Trengganu, Peninsular Malaysia. *Geol. Soc. Malaysia Bulletin* 13, p.63-86.
- LAHNER, L., 1982. *Malaysia und Brunei*. Rohstoffwirtschaftlicher Länderbericht 26, Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 108 p.
- LEHMANN, B., 1987. Tin granites, geochemical heritage, magmatic differentiation. *Geologische Rundschau*, v.76, p.177-185.
- LEE, K.W.M., 1971. *The geology, mineralization and geochemical studies of the Bukit Lentor area, Trengganu, West Malaysia*. B.Sc. Thesis, University of Malaya, 123 p.
- LEONG, L.S., 1970. *Geology, mineralization of the Western Hill area, Batu Tiga, Bukit Besi Trengganu, West Malaysia*. B.Sc. Thesis, University Malaya, 123 p.
- LIEW, T.C., 1983. *Petrogenesis of the Peninsular Malaysian granitoid batholiths*. Ph.D. Thesis, Australian National University, 291 p.
- LIEW, T.C. and McCULLOH, M.T., 1985. Genesis of granitoid batholiths of Peninsular Malaysia and implications for models of crustal evolution: Evidence from a Nd-Sr isotopic and U-Pb zircon study. *Geochim. Cosmochim. Acta*, v.49, p.587-600.
- LIM, K.H. 1972. *The geology, mineralisation and geochemical survey of the Machang Satahun Area, Trengganu, Malaysia*. B.Sc. Thesis, University of Malaya.
- LIM, T.H., 1971. *Geology, mineralisation and geochemical studies of the western Gambang area, Pahang, West Malaysia*. B.Sc. Thesis, University of Malaya, 136 p.
- MANNING, D.A.C. and HENDERSON, P., 1984. The behaviour of tungsten in granitic melt-vapour systems. *Contrib. Mineral. Petrol.*, v.86, p.286-293.
- ODIN, G.S., 1982. Interlaboratory standards for dating purposes. In: Odin, G.S. (ed.): *Numerical dating in stratigraphy*, p.123-150. Chichester, Wiley.
- PITFIELD, P.E.J., 1987. South-East Asia Granite Project Report on the geochemistry of the tin islands granites of Indonesia. British Geological Survey Overseas Division, Report No. MP/87/9/R, 52 p.
- ROBERT, G., 1977. *The underground geology and mineralization of the Gakak 3 lode (extension), Sungei Lembing, Pahang*. B.Sc. Thesis, University of Malaya, 53 p.
- SCHWARTZ, M.O. and ASKURY, A.K., in press. Geologic, geochemical, and fluid inclusion studies of the tin granites from the Bujang Melaka pluton, Kinta Valley, Malaysia. *Econ. Geol.*

- SINGH, J., 1970. *A study of the distribution of tin and related elements in certain superficial deposits of north Pahang, West Malaysia*. M.Sc.Thesis, University of Malaya, 204 p.
- STEIGER, R.H. and JÄGER, E., 1977. Subcommission on Geochronology: convention on the use of decay constants in geochronology and cosmochronology. *Earth planet. Sci. Lett.*, v.36, p.359-362.
- STOCKWELL, C.H., 1963. Third report on structural provinces, orogenies, and time-classification of rocks of the Canadian Precambrian Shield. Geological Survey Canada, Paper 63-17, p.125-131.
- STRECKEISEN, A., 1974. Classification and nomenclature of plutonic rocks. *Geologische Rundschau*, v.63, p.773-786.
- TAN, I.B., 1979. *The geology, mineralisation and geochemical studies of the Chye Heng Long mine, Kemaman, Trengganu, Peninsular Malaysia*. B.Sc.Thesis, University of Malaya, 56 p.
- TAN, K.S., 1977. *Geology, mineralization and geochemical studies of the Bukit Bandi area, Trengganu, Peninsular Malaysia*. B.Sc.Thesis, University of Malaya, 87 p.
- TAYLOR, R.G., POLLARD, P.J. and TATE, N.M., 1985. Resource evaluation of primary tin potential of Eastern Peninsular Malaysia - a district analysis. Southeast Asia Tin Research and Development Centre, Ipoh, Malaysia, UNDP/ESCAP Consultancy Mission Report No.12, 118 p.
- TEE, T.S., 1980. *The geology and mineralisation of the Gakak mine, Sungai Lembing, Pahang, Peninsular Malaysia*. B.Sc.Thesis, University of Malaya, 34 p.
- VINOGRADOV, A.P., 1962. Average contents of chemical elements in the principal types of igneous rocks of the earth's crust. *Geochemistry 1962*, No. 7, p.641-664.
- VON PLATEN, H. and HÖLLER, H., 1966. Experimentelle Anatexis des Stainzer Plattengneises von der Koralpe, Steiermark, bei 2, 4, 7 und 10 kb H<sub>2</sub>O-Druck. *Neues Jahrbuch Miner. Abh.*, v.106, p.106-130.
- WYBORN, L.A.I., CHAPPELL, B.W. and WYBORN, D., 1986. Primary magmatic control on the distribution of Sn deposits of the Lachlan Fold Belt in N.S.W. and Victoria. Proceedings of Conference 30th June - 2nd July 1986, Canberra, Australia, IGCP project 220, Genesis of tin-tungsten deposits and their associated granitoids, p.78-79.
- YEAP, C.H., 1966. *Geology of the Sungei Lembing area, Pahang, West Malaysia*. B.Sc.Thesis, University of Malaya.