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Granite emplacement and tectonic subdivision of Peninsular Malaysia

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Abstract: Peninsular Malaysia can be subdivided into four major tectonic regions-the Western Stable Shelf, the Main Range Belt, the Central Graben, and the Eastern Belt. Large granitic batholiths of predominantly Permian to Triassic age characterise the Main Range and Eastern belts.

The granites of the Main Range Belt are commonly coarsely porphyritic and their alkali feldspar is invariably perthitic maximum microcline as determined by X-ray diffraction and 2V. Their country rocks are phyllitic and isoclinally folded and contact metamorphic aureoles are generally absent. Rb: Sr and K:Ar dates are strongly discordant. These features together imply that the Main Range Belt has been uplifted since the Triassic by several kilometers. Uplift is suggested along the major ophiolitic melange zone of Bentong-Raub. The nature and position of the western limit of the Main Range Belt is as yet undefined, but it probably lies close to the west coast of Penang Island.

The granites of the Eastern Belt are characterised by an equigranular to weakly porphyritic texture and their alkali feldspar is in the range orthoclase to intermediate microcline. Their country rocks are gently deformed sedimentary, volcanic and pyroclastic formations, and several well developed contact aureoles have been mapped. The Rb:Sr and K:Ar dates are consistently concordant. These features together imply that the granitoid rocks were emplaced epizonally and the Eastern Belt has been stable since the Triassic.

The granites of Langkawi are of the Western Stable Shelf. They contain intermediate microcline and have a pronounced contact metamorphic aureole.

Granites are few in the Central Graben, and confined to a complex belt passing through Gunung Benom and Gunung Stong, in which high-grade metamorphic rocks have been uplifted. Unlike the Main Range, the Benom granite has high-level characteristics. Highly sodic fine grained granitoid rocks also characterise parts of this region.

Late Cretaceous granites occur locally and have high-level characteristics. They are apparently devoid of tin mineralization. The style of mineralization is dramatically different in the Main Range and Eastern belts, and this can be ascribed to their different sialic basements and tectonic histories. Rock geochemistry and strontium isotope ratios indicate that a well established continental sialic basement underlies the Main Range and Western Stable Shelf belts, unlike the other two tectonic regions.

Extrapolation of the tectonic belts into Indonesia, Thailand and Burma must await detailed mineralogical studies of the granitoid rocks of those countries.

INTRODUCTION

The Southeast Asian tin and tungsten province accounts for more than half of the non-communist world production of tin. The main belt extends from the Indonesian island of Billiton over 2700 km through the Malay Peninsula to Thailand and Burma. Within this province, the tin deposits are closely associated with sub-parallel arcuate belts of granitic rocks. A general distribution map was published by Mitchell and Garson (1972).

The tin and tungsten deposits of the Southeast Asian Province are separated from the Far East Province of China, Siberia and Japan by the North Vietnam Suture Zone in the Black River region of Tonkin (Hutchison, 1975A) and from the Australian Province by the presently active arc-trench system south of Timor (Hutchison, 1975B).

Since the general description of the granitic rocks of the Southeast Asian tin province was presented (Hutchison, 1973A), much new and relevant data make appropriate a general re-appraisal of the granitic rocks of the region. The attempt at a tectonic-petrological re-classification of the granitic rocks in this article represents a strong departure from my previous general overview of the granitic province (Hutchison, 1973A) which may assist the economic geologists in their correlation and extrapolation of the belts of different kinds of mineralization throughout the region.

THE FOUR TECTONIC SUBDIVISIONS

Peninsular Malaysia can be conveniently subdivided into four zones which are characterised by different tectonic histories.

1. *The Western Stable Shelf* (Fig. 1) is characterised by the oldest rocks of the peninsula. The Lower and Upper Palaeozoic miogeoclinal sedimentary formations, exposed on the Langkawi islands, Perlis and Kedah, are gently folded, and generally unmetamorphosed. Granite is not abundant in this tectonic zone. On Langkawi the granite is surrounded by a contact metamorphic aureole in which the Carboniferous Singa Formation is metamorphosed to spotted hornfels containing incipient chiastolite (Miskin, 1964). Limestone in contact with the granite is characterised by a strong development of vesuvianite and garnet in a skarn zone (Hutchison, 1973C). Outside the aureole the country rocks are completely unmetamorphosed (Foo, 1964). Work now in progress on Penang Island may allow a closer delineation of the poorly defined boundary between this zone and the Main Range Belt.

2. *The Main Range Belt* (Fig. 1) is characterised by the huge Main Range batholith whose axis forms the mountain range extending from the region of Malacca towards Thailand. The country rocks of the Main Range granite are predominantly of isoclinally folded phyllitic Lower Palaeozoic metasediments including marble, and less strongly folded Upper Palaeozoic formations. Because of the phyllitic nature of the country rocks, no broad contact aureoles have been seen and the contact zones usually exhibit only a very local increase of dynamothermal metamorphic grade. In most cases no increase of metamorphism is discernible at the contact.

3. *The Central Graben* is characterised by gently folded Triassic and Mesozoic sedimentary formations underlain by more strongly folded Permian rocks. Pyroclastic rocks are common. The sedimentary environment changes in the Late Triassic from marine to continental. The Central Graben is largely devoid of granitic rocks, except along a narrow line through Gunung Benom and Gunung Stong which is marked by granites and gneiss domes as well as a variety of uplifted high-grade metamorphic rocks. Jaafar (1976) has described rhyolites and porphyries along this line which are strongly sodic and of uncertain age. Elsewhere in the Central Graben, the sedimentary formations are characteristically unmetamorphosed (Gobbett and Hutchison, 1973).

The Central Graben is separated from the Main Range Belt by the Bentong-Raub ophiolite line (Hutchison, 1975A) which has the character of a phyllitic melange in which blocks of serpentinite and metabasic rocks occur along with radiolarian chert and conglomerate. This ophiolite was thought by Hutchison (1973B) to represent a former subduction zone. Mitchell (this bulletin) has also taken it as a suture but with a rather different tectonic interpretation.

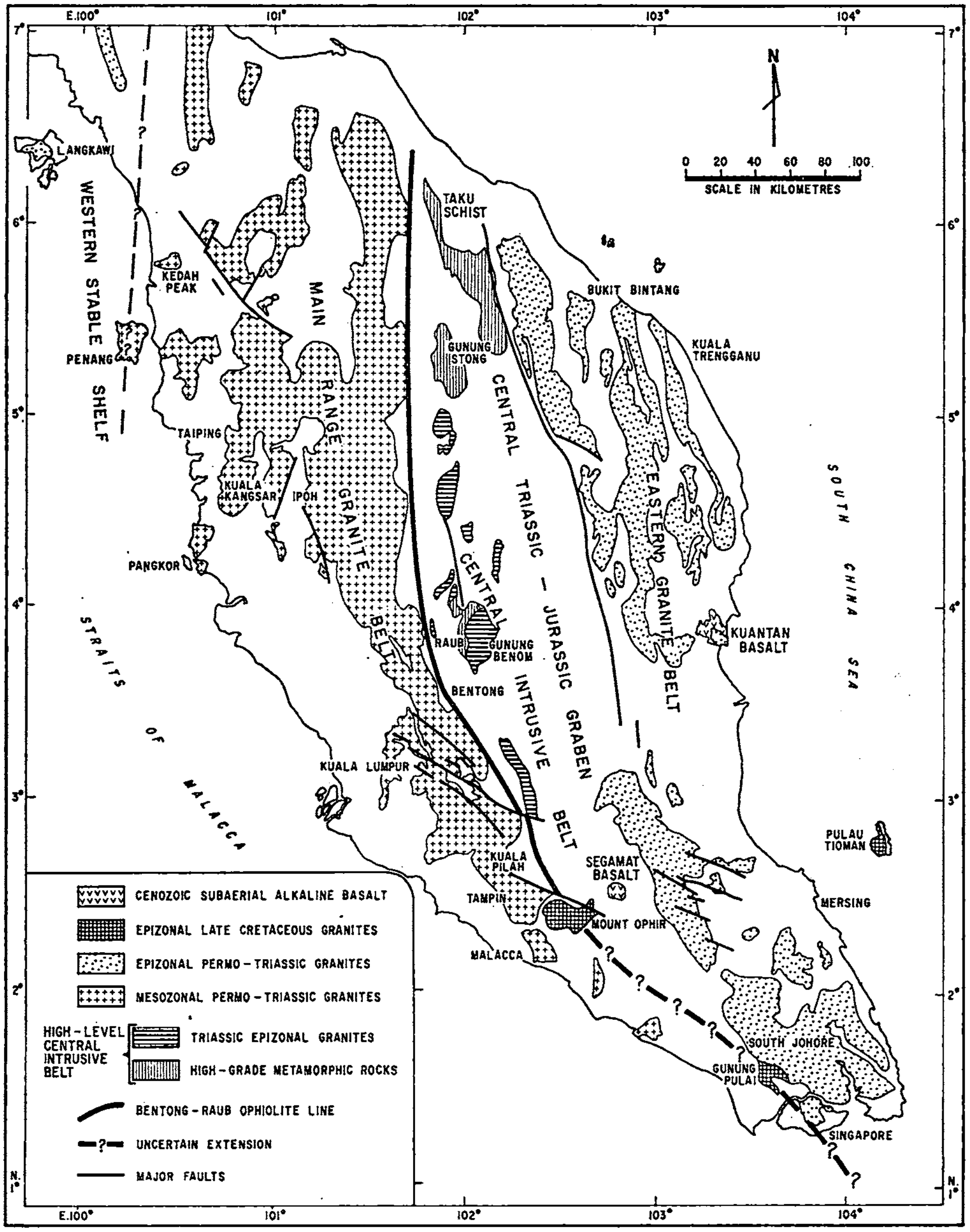

Fig. 1. Outline summary map of Peninsular Malaysia showing the granite distribution in relation to the tectonic pattern.

The Central Graben is separated from the Eastern Belt by the Lebir Fault and its southern extensions. This is by no means such a major tectonic feature as the Bentong-Raub line, but in the north an ignimbrite dike of impressive dimensions has been intruded along the Lebir Fault zone (Aw, 1967), and serpentinite occurs in the zone at the Bukit Ibam mine in Ulu Rompin (Jaafar, personal communication).

4. *The Eastern Belt* is characterised by numerous elongate granitic plutons intruded through gently deformed, predominantly Permo-Carboniferous sedimentary formations with associated pyroclastic and volcanic rocks of acid to intermediate composition. Triassic sedimentary formations outcrop on the southern flanks. The granites are characteristically surrounded by prominent contact metamorphic aureoles up to 3 km wide superposed on unmetamorphosed and fossiliferous country rocks (Yeap, 1966; Au, 1974; Goh, 1973). Continental Mesozoic formations locally unconformably overlie the granites and the Palaeozoic formations. Triassic sub-aerial rhyolitic flows and ignimbrite occur along the southeast coast (Grubb, 1968). Although the country rocks of the Eastern Belt are generally unmetamorphosed outside of the contact aureoles, the coastal outcrops extending from Trengganu to South Johore are strongly folded and phyllitic.

THE RADIOMETRIC EVIDENCE

From the detailed radiometric dating study of Malayan granites and other rocks, recently completed by Bignell (1972), the following major conclusions can be drawn:

1. Granites of the Main Range yielded good Rb:Sr isochrons and ages ranging from 360 to 140 my with two pronounced statistical modes around 300 and 210 my ago (Fig. 2.) Older dates of around 450 my from peculiar labradorite granodiorite rocks in the Main Range between Kuala Lumpur and Bentong are excluded from this discussion because of their uncertain genesis.

In strong contrast, the K:Ar dates for the same granites (Fig. 2) range from 210 to 40 my with a statistical mode around 190 my. The K:Ar dates therefore do not give the intrusive age (Armstrong, 1966), but are related to cooling of the granites during uplift.

The data in Fig. 2 indicate that the Main Range Belt granites were emplaced over an extended period from Late Carboniferous to Late Triassic. Major uplift of the Main Range Belt took place in the Jurassic and Cretaceous as evidenced by the K:Ar maxima.

2. Post-orogenic Late Cretaceous granites are known only in the neighbourhood of Mount Ophir and Gunung Pulai (Fig. 1). They give concordant Rb:Sr and K:Ar dates of around 60 to 90 my. They are included in Figure 2 under the Malacca pattern. Since these granites are only local and were epizonally emplaced after the major uplift of the Main Range Belt, they are not used in establishing the tectonic subdivisions of the Peninsula. The two known occurences of Late Cretaceous granites appear to lie along the extrapolation of the major Bentong-Raub tectonic line (Fig. 1) which may indicate that it was active in the Late Cretaceous to Early Tertiary.

3. The Eastern Belt granites have Rb:Sr dates ranging from about 340 to 180 my. The few Rb:Sr dates which lie outside of this range represent other events which are not part of the main granitic activity. Of particular importance is the strong concordance of the Rb:Sr and the K:Ar dates (Fig. 3), both showing prominent statistical modes in the Permian to Late Triassic range. The similarity of the Rb:Sr and K:Ar

dates indicates that the Eastern Belt granites have not been significantly uplifted since their crystallization in the same way that the Main Range Belt granites have. We can therefore conclude a greater tectonic stability for the Eastern Belt than for the Main Range.

N.J. Snelling (personal communication), who together with J.D. Bignell, has written up the radiometric data of Bignell (1972) for publication by the Institute of Geological Sciences of London, indicated that the Late Carboniferous dates should now be re-interpreted as Permian. Hence we can conclude that the major part of the granitic intrusive activity in both the Main Range and the Eastern Belts was in the Permian to Triassic.

Figures 2 and 3 clearly indicate that the two main granitic belts were active simultaneously and that emplacement age (radiometric dating) cannot be used for differentiating the granites of the Peninsula. Only the post-orogenic Late Cretaceous granites of Mount Ophir and Gunung Pulai can be distinguished radiometrically from the others.

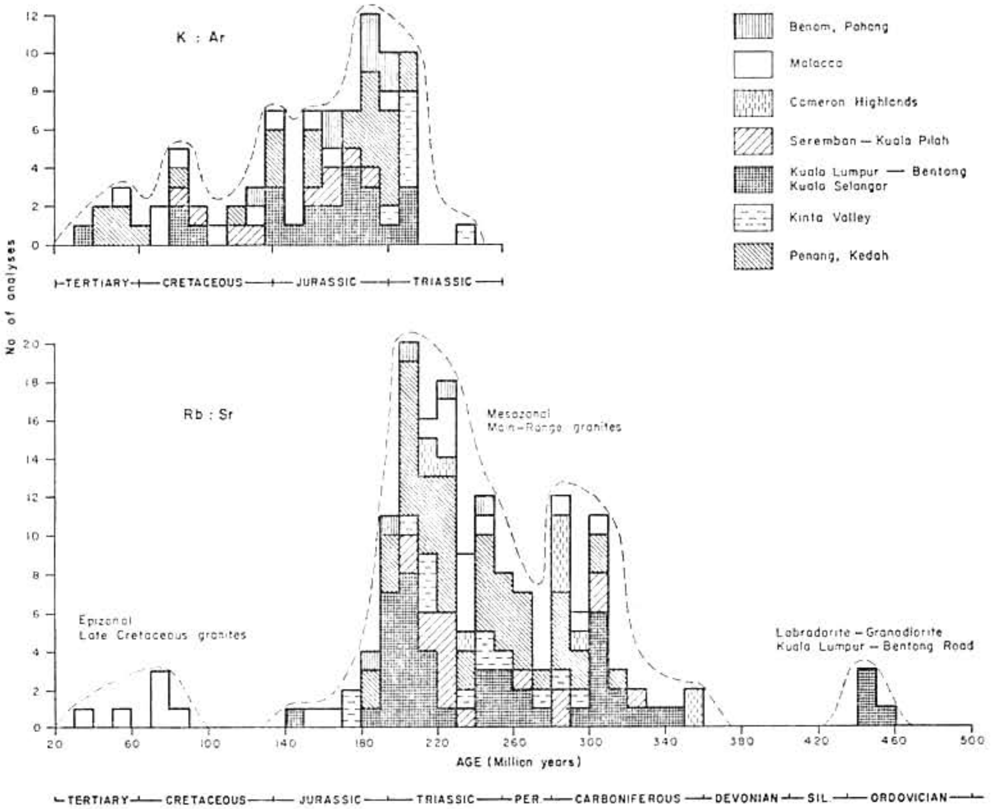

Fig. 2. Histogram of the radiometric dates on granites from the Main Range Belt, including Gunung Benom (From Bignell, 1972). Note the lack of concordance between the K:Ar and the Rb:Sr dates.

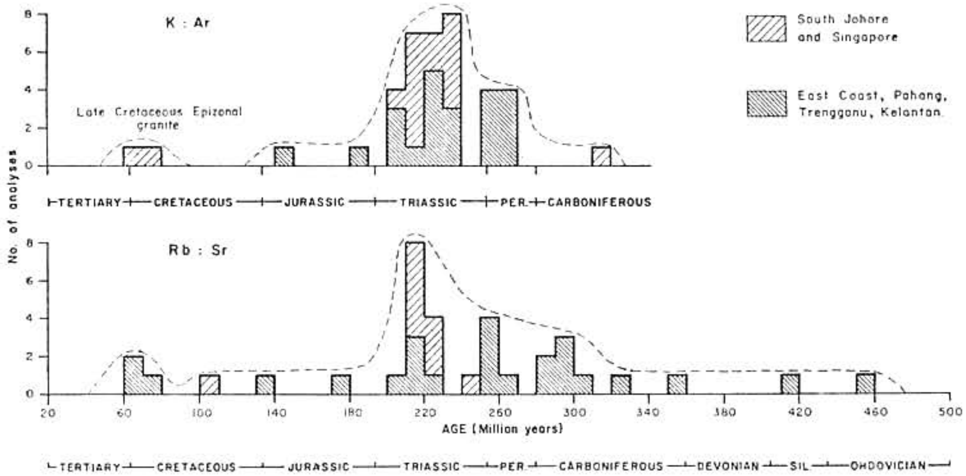

Fig. 3 Histogram of the radiometric dates on granites from the Eastern Belt (From Bignell, 1972). Note the concordance between the K:Ar and the Rb:Sr dates.

THE PETROLOGICAL EVIDENCE

Late Cretaceous epizonal granite

It is usually medium grained and granular in texture. Only very rarely is it porphyritic and then only weakly so. The alkali feldspar, commonly pink when slightly weathered, lacks the cross-hatched twinning of microcline, and is probably orthoclase (Voon, 1972). The texture (Fig. 4) is similar to that which Tuttle and Bowen (1958) describe as hypersolvus. However not all the sodic feldspar is within the perthite, and separate plagioclase crystals are present in small amounts. The alkali feldspars are strongly perthitic, but the exsolution lamellae, blebs and stringers, are usually no thicker than 5μm (Ng, 1974). Many alkali feldspars appear non-perthitic in thin section but are cryptoperthite or the X-ray perthite of Tuttle and Bowen (1958). Zoning, which is common in the alkali feldspars (Ng, 1974), is often oscillatory, with repeated zones commonly concentric. In places the zoning is present as a core and rim of different extinction under crossed polars (Ng, 1974). The degree of development of perthitic exsolution varies from zone to zone. The outer zones usually have better developed coarser perthitic textures. This feature may suggest potassium metasomatic replacement of zoned plagioclase, already suggested for the zoned alkali, feldspar porphyroblasts near Gunung Benom to the north (Hutchison, 1971).

Late Triassic Langkawi granite

It is a coarse grained biotite granite, somewhat porphyritic with phenocrysts up to 20 mm long. The alkali feldspar is grey, coarsely perthitic, has imperfectly developed cross-hatched twinning (Miskin, 1964), and is probably intermediate microcline. The granite is strongly tourmalinized and greisenized (Hutchison, 1973A).

Permian to Triassic Main Range Belt granites

They are usually coarse to very coarse grained and everywhere porphyritic, most commonly very coarsely porphyritic with phenocrysts up to 5 cm long. (Fig. 4). Of

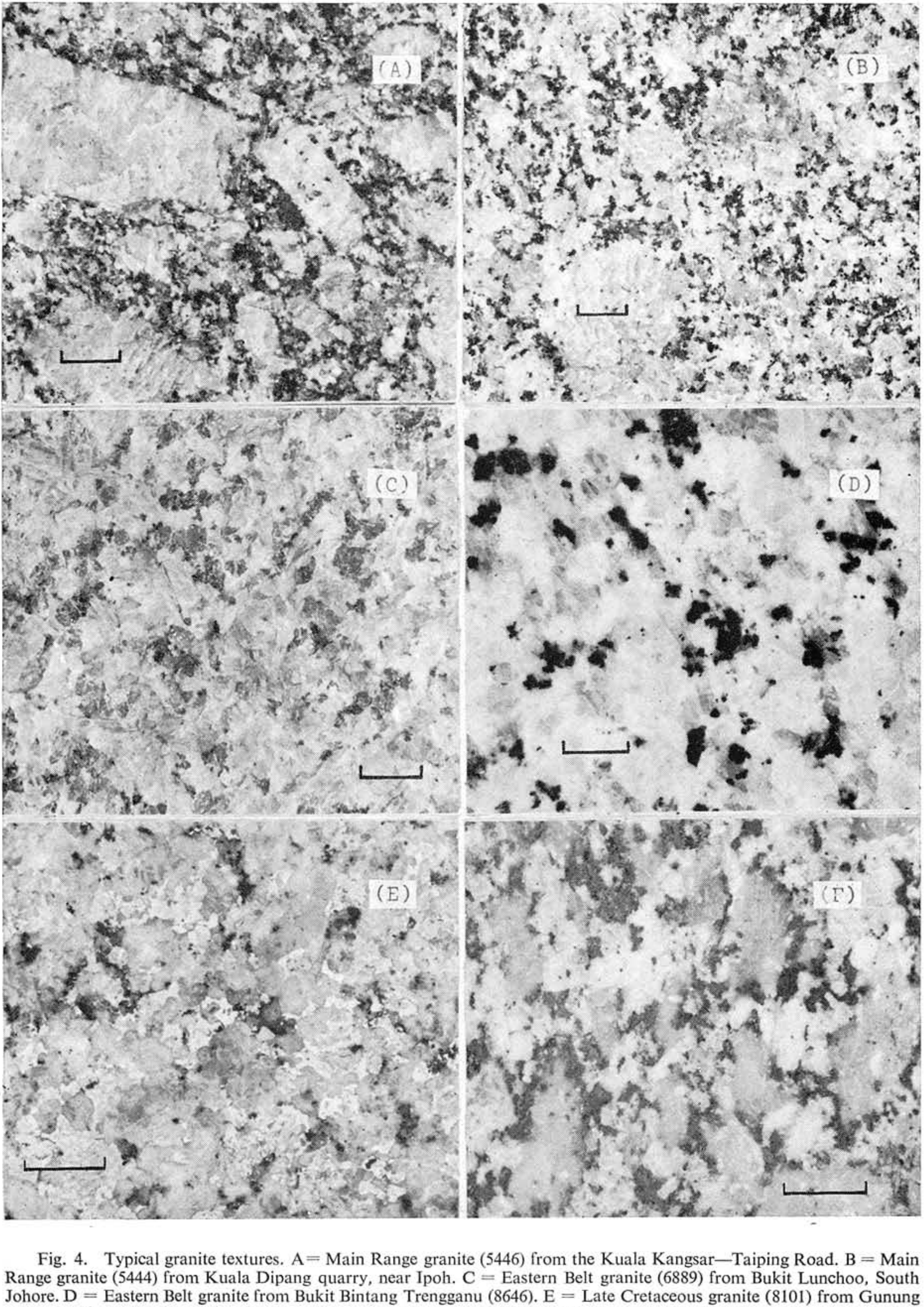

Fig. 4. Typical granite textures. A = Main Range granite (5446) from the Kuala Kangsar—Taiping Road. B = Main Range granite (5444) from Kuala Dipang quarry, near Ipoh. C = Eastern Belt granite (6889) from Bukit Lunchoo, South Johore. D = Eastern Belt granite from Bukit Bintang Trengganu (8646). E = Late Cretaceous granite (8101) from Gunung Pulai, South Johore (stained slab). F = Late Cretaceous granite (8359) from Mount Ophir peak (stained slab). Numbers are as recorded in the Geol. Dept. Univ. of Malaya. The scale is given by a bar of 1 cm length.

course, finer granied varieties do occur locally. The rock is invariably grey, The largest crystals are of alkali feldspar, forming megacrysts with parallel to sub-parallel alignment. Many exhibit perfectly developed cross-hatched twinning characteristic of maximum microcline. None of the alkali feldspar is zoned, but commonly displays concentric distributions of inclusions especially of plagioclase and quartz (mantled crystals). The alkali feldspars apparently underwent subsolidus recrystallization and growth (Ng, 1974). The alkali feldspar crystals are coarsely perthitic, with exsolved lamellae and stringers up to 50 μm wide. Plagioclase is also present as separate distinct crystals. Biotite forms large euhedral crystals.

Permian to Triassic Eastern Belt granite

The granite has a texture resembling the Late Cretaceous epizonal variety of Mount Ophir and Gunung Pulai. It is medium to coarse grained and non-porphyritic to only weakly porphyritic (Au, 1974; Ng, 1974). Towards the south of the belt, the granite is even grained but locally better described as porphyritic micro-adamellite in which 60 to 70% of the rock consists of even grained phenocrysts in a fine grained matrix. The alkali feldspar has been determined as orthoclase microperthite (Hutchison, 1964). Porphyritic micro-adamellite has also been described from farther north (Hutchison and Snelling, 1971), where the alkali feldspar is untwinned and only slightly microperthitic. Elsewhere throughout the Eastern Belt, the alkali feldspar is untwinned, except for patchily developed cross-hatched twinning characteristic of intermediate microcline (Au, 1974). The granites of the Eastern Belt may be grey or pink when weathered, and both colours may coexist in the same outcrop.

The alkali feldspar appears from thin-section study to range from orthoclase to intermediate microcline and no examples of maximum microcline have yet been found. Biotite and or hornblende occur in the granite, but the biotite is rarely as well formed as in the Main Range granite. Hornblende is more common in granodiorite varieties.

THE OPTIC AXIAL ANGLE EVIDENCE

Using the orthoscopic extinction methods of Hartshorne and Stuart (1970) on a four-axis universal stage, a large number of determination of 2V have been made on the alkali feldspars from the various granites by the author, Ng (1974), Goh (1973) and Loy (1974). 2V varies within a narrow range within a single thin-section. The Main Range Belt granites contain alkali feldspars whose $2V\alpha$ ranges from about 65° to 95° with a pronounced statistical mode at about 83° (Fig. 5). This range is that to be expected from maximum microcline (Wright and Stewart, 1968, Stewart, 1975A) and is in agreement with the consistently present crossed-hatched twinning.

The Eastern Belt granites contain alkali feldspars whose $2V\alpha$ ranges from about 45° to 74° with a pronounced mode at about 60° This is in agreement with the range of structural state from orthoclase to intermediate microcline (Wright and Stewart, 1968) and with the general absence or only a poor development of crossed-hatched twinning. Stewart (1975A) gives a 2V 60° for the orthoclase structural state and 60° to 83° for intermediate microcline.

The 2V determination from the Late Cretaceous epizonal granites is not included on Figure 5, but Ng (1974) and Voon (1972) showed a peak at about 60° with a range within a single sample of usually less than ± 20° but occasionally up to ± 30°. The 60°

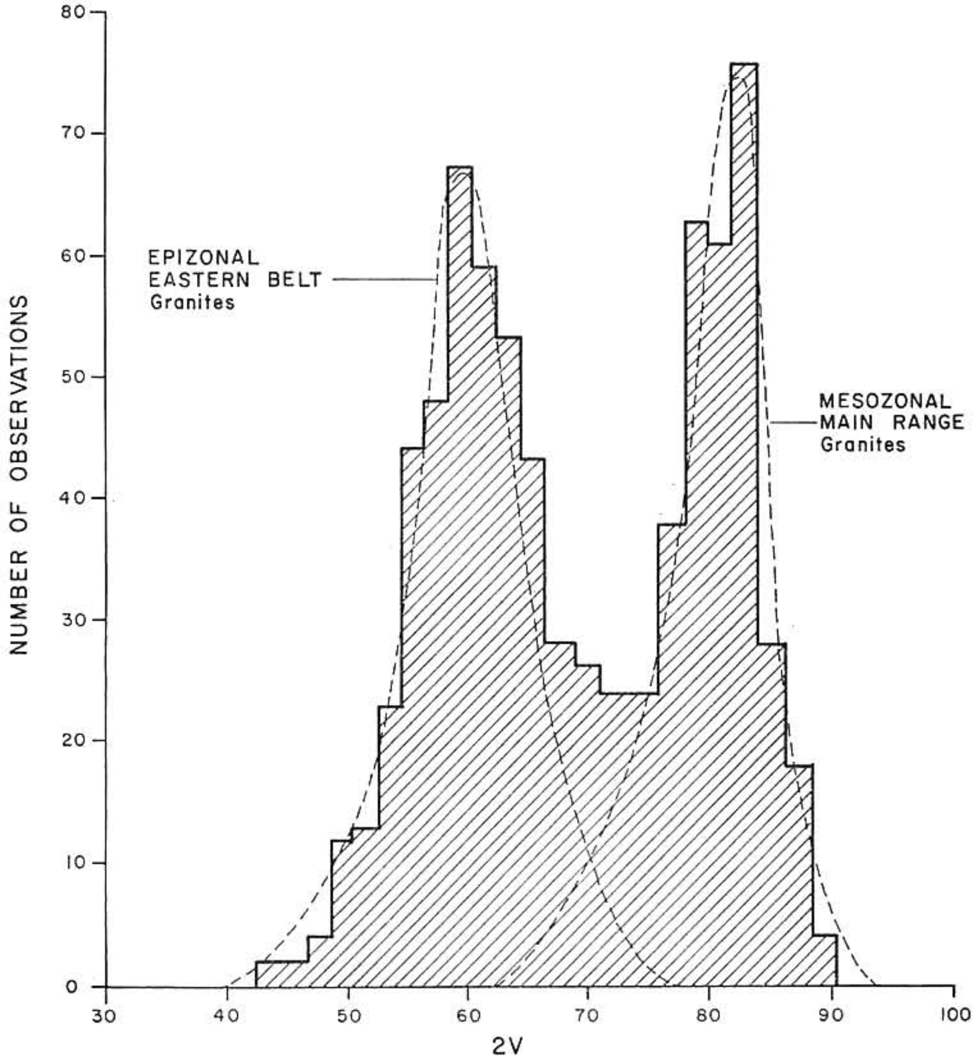

Fig. 5. Histogram of 2V (optic axial angle) determined on alkali feldspars (microcline or orthoclase) from granites of the Main Range Belt and the Eastern Belt, excluding the Late Cretaceous epizonal granites.

mode is consistent with an orthoclase structural state. The distribution of 2V in the Late Cretaceous granites is closely portrayed by the left-hand normal curve of Figure 5. Accordingly the alkali feldspars of the Eastern Belt granites are similar to those from the Late Cretaceous epizonal granites.

THE ALKALI FELDSPAR STRUCTURAL STATE EVIDENCE

Alkali feldspar crystals were extracted from a large number of granite specimens from the different regions. For coarse grained rocks this could be done on the hand specimen using a pointed pick or chisel. For finer grained rocks the separation usually entails crushing of the rock and separation by methods outlined in Hutchison (1974, chapter 5). Powder smears of alkali feldspar slurried with acetone are made on a glass slide according to the method of Hutchison (1974, chapter 6), and diffractograms made using CuKα radiation over a 2θ range 20 to 53° on a well aligned goniometer, following the settings of Hutchison (1974, pp. 189–195). Internal 2θ standards such as potassium bromate or silicon may be used to obtain accurate 2θ measurements for the alkali feldspars.

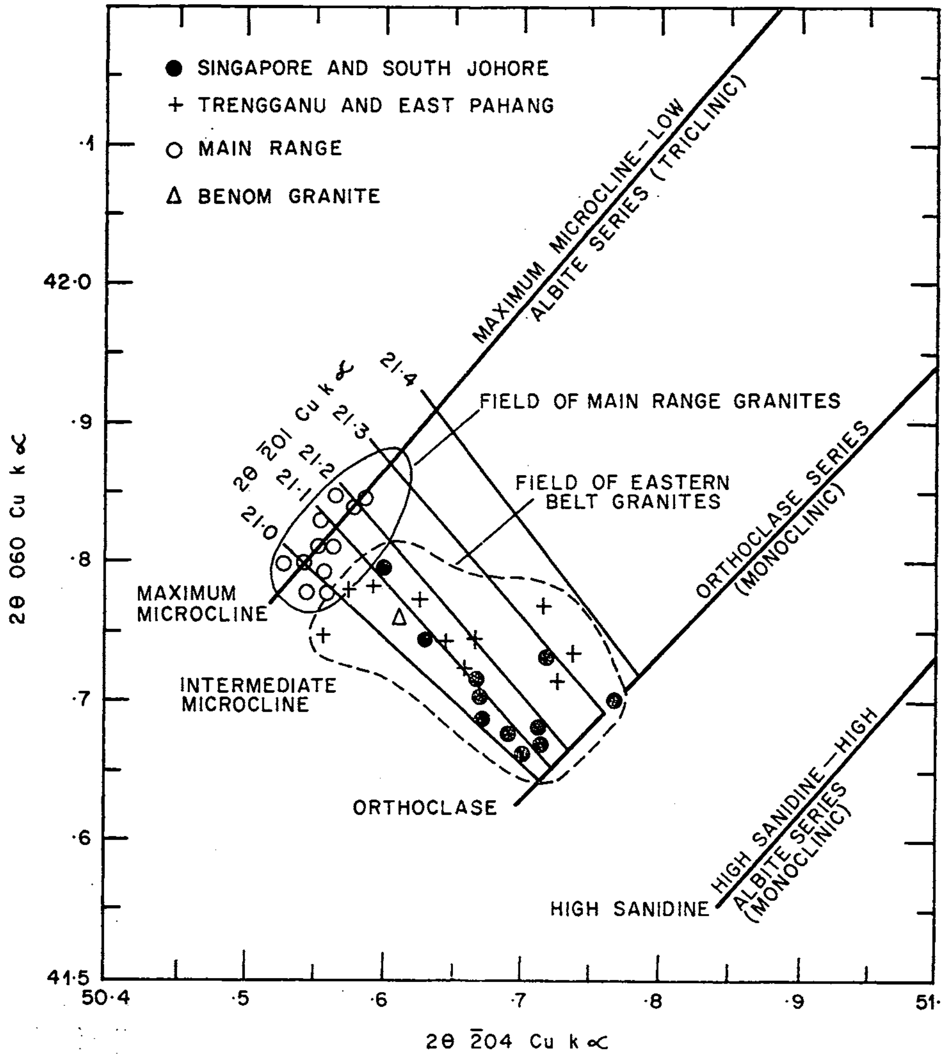

Fig. 6. Relationship between 2θ (CuKα) 060, $\bar{2}04$, and $\bar{2}01$ of K-feldspar for granites of the Main Range and Eastern Belts. Late Cretaceous granite is excluded, but would lie on the orthoclase line. The style of the plot is after Wright (1968).

Typical diffractograms of the K-phase of alkali feldspars were published by Borg and Smith (1969). A quick distinction may be made between the structural states by noting the 2θ separation of the 131 and $1\bar{3}1$ peaks. In orthoclase both peaks are superimposed because of the monoclinic symmetry. As departure from monoclinic symmetry increases, the peaks separate through intermediate to maximum microcline. For maximum microcline 2θ CuKα, 131–$1\bar{3}1$ is -0.791 degrees (Stewart, 1975B). The triclinicity index may be calculated as 12.5 (d_{131}–$d_{1\bar{3}1}$) as proposed by Goldsmith and Laves (1954). The Late Cretaceous granites of Mount Ophir and Gunung Pulai have triclinicity indices of near zero, consistent with orthoclase. The Main Range Belt granites have triclinicity indices near unity, as consistent with maximum microcline. The Eastern Belt granites have a range of triclinicities from zero to about 0.7, as consistent with a structural state range of orthoclase to intermediate microcline. The triclinicity index, though rapid to determine, is rather imprecise.

A considerably more precise method (Wright, 1968) is to plot $2\theta_{\bar{2}04}$ against $2\theta_{060}$ of the alkali feldspar on a diagram such as is shown in Figure 6. Revised values for the structural state end members are given by Stewart (1975B). Excluded from this diagram are the Late Cretaceous epizonal granites, which all plot on the orthoclase line (Ng, 1974; Voon, 1972). Figure 6 shows quite cearly that the Main Range granites are without exception of maximum low temperature mineralogy, and contain maximun microcline, whereas the Eastern Belt granites of similar age contain orthoclase ranging to intermediate microcline. The data of Figure 6 were taken from Ng (1974), Seet (1974), Loy (1974) and Yeow (1974), except for the addition of a determination from the Benom granite, which shows it is more akin to the Eastern Belt granites, although it occurs within the Central Graben. Unfortunately no work has yet been done on the Langkawi granite, but in view of its well developed contact aureole, the alkali feldspar is suspected to be intermediate microcline.

THE GEOCHEMICAL EVIDENCE

Hutchison (1973B) gave a detailed comparison of the available chemical analyses of granites of the Malay Peninsula. The major differences are illustrated in plots of K_2O weight % and K_2O/Na_2O ratios versus crystallization index as calculated by the rules of Hutchison (1975C). The results are summarized in table 1.

TABLE 1

SOME CHEMICAL CHARACTERISTICS OF PENINSULAR MALAYSIAN GRANITES

Granite	Crystallization Index Range	K_2O wt % range and mode ( )	K_2O/Na_2O range and mode ( )
Late Cretaceous	0 to 6	2.9 to 5.2 (4.3)	1.3 to 2.8 (1.5)
Main Range	0 to 14	3.4 to 9.0 (5.0)	1.0 to 5.2 (1.7)
Benom (Central)	0 to 14	4.3 to 6.2 (4.7)	1.0 to 2.4 (1.4)
Eastern Belt	0 to 25	2.4 to 5.4 (4.1)	0.5 to 2.0 (1.3)

(Data are lacking from granites of the Western Stable Shelf.)

From Table 1 it can be seen that the granites of the Eastern Belt have a much wider range of crystallization indices, contain less K_2O wt.% on average and are relatively richer in Na_2O than the granites of the Main Range Belt. The Eastern Belt granites are less differentiated and appear to have been derived from a dioritic ancestor (Hutchison, 1973B). Progressing from east to west, the granitic belts become more differentiated, richer in K_2O and poorer in Na_2O. Jaafar (1976) has reported that fine grained rhyolites and quartz porphyries to the south of Gunung Benom in the Lanchang area are extremely rich in Na_2O.

Trace element analyses of the granites (Table 2) were reported by Yeap (1974).

TABLE 2

TRACE ELEMENT CONTENTS IN PPM OF PENINSULAR MALAYSIAN GRANITES. AVERAGE VALUES WITH RANGE IN BRACKETS

Element	Late Cretaceous	Main Range	Benom	Eastern Belt
Rb	217 (146–289)	531 (334–738)	323	243 (186–348)
Sr	200 (193–207)	53 (4–164)	186	91 (19–158)
Zr	131 (128–135)	116 (60–243)	16	120 (107–142)
Ba	816 (808–825)	374 (6–877)	694	879 (253–1441)
Sn	5 (5–6)	7 (5–11)	6	5 (4–6)
Nb	5 (5–6)	8 (7–9)	7	6 (3–9)
W	1	4 (1–7)	6	2 (1–3)

Two analyses of the Langkawi granite (Bignell, 1972) give Rb 348 and 582 and Sr 40 and 27 ppm.

The most outstanding difference between the two main belts is that the Eastern Belt granites are lower in Rb and higher in Sr than the Main Range granites. The Eastern Belt granites are characterised by average Rb/Sr ratios of about 2.7, whereas the Main Range averages 10.0. Bignell (1972), who brought attention to this, suggested that the Eastern Belt granites were derived from a more oceanic type of basement whereas the Main Range granites were derived from a well established sialic basement. The relatively low Rb/Sr average ratio of 1.0 for the Late Cretaceous post-orogenic granites suggests a deep seated origin from mantle material or from a strongly oceanic basement. The Benom granite, with an average ratio of 1.7 is quite unlike the Main Range granite and was probably derived from oceanic lithosphere. The high sodium contents of the fine grained acid rocks near Lanchang also support this.

THE STRONTIUM ISOTOPE EVIDENCE

In the course of his work, Bignell (1972) made several references to strontium isotope data from the granites (Table 3).

Again, these data suggest that the Main Range granites could have been derived from a well established sialic basement, and Bignell (1972) drew attention to this. The Eastern Belt and the Western Shelf, the Benom, and the Late Cretaceous granites all have low initial ratios suggesting derivation from more primary mantle or oceanic material.

TABLE 3

SUMMARY OF INITIAL STRONTIUM ISOTOPE RATIOS OF PENINSULAR MALAYSIAN GRANITES, BIGNELL (1972)

Granite	Average $^{87}Sr/^{86}Sr$ ratio	Range
Late Cretaceous	.708	only one isochron
Western Shelf (Langkawi)	.707	only one isochron
Main Range Belt	.711	.708 to .719 (20 isochrons)
Benom Central Graben	.706	only one isochron
Eastern Belt	.708	.707 to .709 (3 isochrons)

CONCLUSIONS

From a summary comparison of the various granites of the Peninsula (Table 4), the following interpretations can be made:

Main Range Belt. The granites were emplaced throughout the Permian and Triassic in a deep seated environment which allowed very slow cooling and permitted the alkali feldspars to invert to microcline. The emplacement of the granites into isoclinally folded phyllite and marble, and the general absence of pronounced contact aureoles indicates that the granites are mesozonal, and they were emplaced at a depth of at least 4 km (Buddington, 1959). The actual depth depends on the average regional geothermal gradient at the time of emplacement. The chemical and isotope data suggest that the granite was formed by anatexis of a well established continental sialic basement. Mitchell (1977) suggests that the unique deep seated Main Range granite resulted from continental collision.

Since the end of the Triassic, the Main Range has been dramatically uplifted and the grouping of K:Ar dates (Fig. 2) suggests that the major uplift was in the Early Jurassic and Late Cretaceous. The present outcrop level indicates that the roof of the batholith has just been uncovered, as evidenced by the distribution of mineralization predominantly in the upper parts, or cusps of the present granite outcrop topography. Miarolitic cavities containing tourmaline, for example on Penang Island, indicate accumulation of volatiles near the batholith roof which were unable to escape because of the deep seated environemnt. Extensive screens of country rock in part of the Main Range may extend deep into the granite but some appear from their structure to be shallow roof pendents,. We do not know the nature of the overburden of the granite which has been removed since the Triassic, but it would be unrealistic on the basis of the present evidence to assume that it consisted of even higher levels of the Main Range granite. Haile and others (in press) speculate on the nature of this overburden in the light of their studies in the Bentong, Raub and Genting Sempah areas. The present exposures seem to represent the upper levels of the granite as it existed in Triassic time. The overburden was likely to have been predominantly of a sedimentary nature.

The Eastern Belt. The granites were emplaced throughout the Permian and Triassic in a high-level environment so that fairly rapid loss of water did not allow the alkali feldspar to attain a stable structural state. Accordingly we now have a range of structural states from orthoclase to intermediate microcline.

TABLE 4

COMPARISON OF IMPORTANT PARAMETERS OF GRANITIC ROCKS FROM THE WESTERN STABLE SHELF (LANGKAWI), THE MAIN RANGE BELT, THE CENTRAL GRABEN (GUNUNG BENOM), THE EASTERN BELT, AND THE LATE CRETACEOUS EPIZONAL GRANITES FROM MOUNT OPHIR AND GUNUNG PULAI.

Property	Western Stable Shelf	Main Range Belt	Late Cretaceous granites	Central Graben (Benom)	Eastern Belt granites
abundance	rare	very great	rare	rare	very great
colour	grey	always grey	predominantly pink	grey	mainly grey but occasionally pink
grain size	coarse-medium	coarse	medium-coarse	coarse-medium	coarse-medium
texture	weakly porphyritic	frequently coarsely porphyritic	equigranular (rarely weakly porphyritic)	equigranular to weakly porphyritic	predominantly equigranular to microporphyritic
intrusive body	small plutons	extremely large elongate batholith	small plutons	small plutons and domes	very large elongate batholith
country rocks	Palaeozoic gently folded sediments	isoclinally folded phyllitic	Triassic unmetamorphosed sediments and older granites	Triassic to Permian gently folded sediments	Carbo-Permian gently deformed sediments
metamorphic effect	pronounced contact aureole	slight local increase of dynamothermal grade	pronounced contact aureole	uncertain, but contact aureole possible	Pronounced contact aureole
alkali feldspar	intermediate microcline	maximum microcline High 2V (70 to 90) high triclinicity	orthoclase medium 2V (50 to 70) Zero to low triclinicity	orthoclase to intermediate microcline medium 2V	intermediate microcline to orthoclase. medium 2V
Crystallization index	—	0 to 14	0 to 6	0 to 14	0 to 25
K_2O% wt average	—	5.0	4.3	4.7	4.1
K_2O/Na_2O average	—	1.7	1.5	1.4	1.3
Rb/Sr average	15.0	10	1	1.7	2.7
Initial $^{87}Sr/^{86}Sr$ average	.707	.711	.708	.706	.708
Rb:Sr age	Late Triassic	Permian to Late Triassic	Late Cretaceous	Triassic	Permian to Late Triassic
K:Ar age	—	Triassic to Early Tertiary	Late Cretaceous	Jurassic to Cretaceous	Permian to Late Triassic

In a high-level environment, a range of structural states can be present over a short distance, since the outer parts of a pluton will have rapidly lost water into the yet unmetamorphosed country rocks, while the inner parts retain water and experience slower cooling. The retention of water will promote the development of greater Si/Al ordering resulting in the formation of intermediate microcline, while the loss of water is likely to result in the low order structural state of orthoclase. The southern parts of the Eastern Belt (Johore and Singapore) appear to have been more consistently of a higher level than the northern parts, as witnessed by the more universal presence of orthoclase (Fig. 6), and the intrusions of granite into gabbroic and other rocks, in which the incorporation of xenoliths and their range of stages of assimilation by the granite can only be interpreted as a high level phenomenon (Seet, 1974; Hutchison, 1964).

The presence of good contact metamorphic aureoles in the gently deformed sedimentary formations allows the granites of this belt to be classified as epizonal (Buddington, 1959). The common occurence of volcanic and pyroclastic rocks, especially of Triassic age in the southern parts of the belt, lead to the conclusion that the granites, being of high level, actually must have broken surface and fed the flows of rhyolite and ignimbrite. The Eastern Belt granites were high level in Triassic times, and are now still exposed and not eroded away. Hence the region must have been extremely stable since the Triassic, experiencing little or no epeirogenic uplift. This conclusion is supported by the concordance of the Rb:Sr and the K:Ar dates (Fig. 3), which one would expect only from a region that had cooled relatively quickly after the emplacement of the granitic rocks.

The chemical and isotope data suggest that the underlying basement of the Eastern Belt is much less continental and sialic than that of the Main Range Belt, and the granites are much less differentiated, as if they had an intermediate or basic ancestor. The Eastern Belt may be interpreted as a plutonic-volcanic arc which was active in the Permian to Triassic over a continental margin, in which there was only a thin sialic basement. If that interpretation is probable, then the igneous rocks of the Eastern Belt would owe their origin more to an oceanic lithospheric or mantle origin, with less contribution from a continental sialic basement.

The Central Graben. The narrow belt of granites along the line of Benom to Stong appears to have been emplaced in the Triassic. The petrological characters of the Benom granite and the domes to the north of it (Hutchison, 1973A), and the fine grained rhyolite and quartz porphyries (Jaafar, 1976), suggest that the granites were high level, and are quite distinct from those of the Main Range Belt. The chemical and isotope data suggest a primitive oceanic or mantle source with less contribution from an underlying sialic crust. Indeed the oldest rocks known from the Central Graben are Devonian. They are overlain by Triassic sediments, which are marine in the beginning, then become continental by Late Triassic and Jurassic. The Central Graben may be interpreted as a marginal basin separating the Main Range Belt and the Eastern Belt, which became infilled and inactive in the Triassic. Evidence is lacking for any rocks older than Permian in the central part of the graben; Lower Palaeozoic rocks occur only immediately to the east of the Bentong-Raub line. In the central part of the graben, the Permain rocks may well be underlain by oceanic crust, as required by the model of a marginal basin.

Western Stable Shelf. Granitic plutons were emplaced in a high-level environment in the Late Triassic into unmetamorphosed Palaeozoic formations. The presence of a good contact aureole in the Langkawi islands allows the granites to be classified as epizonal (Buddington, 1959). The limited chemical data (Rb and Sr) suggest that the region is underlain by a thick sialic basement, but the low $^{87}Sr/^{86}Sr$ ratio is in conflict with this.

Late Cretaceous Granites. They are known only along the southern extrapolation of the Bentong-Raub line, which is considered to represent the tectonic dislocation along which the Main Range Belt rose, relative to the Central Graben, since the Triassic. The granites are without question high level or epizonal, and on Mount Ophir they have an impressive contact aureole containing andalusite and cordierite (Lim, 1972). The Rb/Sr and Sr isotope ratios suggest a primitive mantle origin, and their localization, perhaps along a major dislocation zone, suggests that they may have risen from a rather deep tectonic level.

To illustrate these interpretations the major differences between the various granites and their associated tectonic belts, both when they were emplaced and much later, are illustrated in Figure 7. The Bentong-Raub ophiolite line must have been active

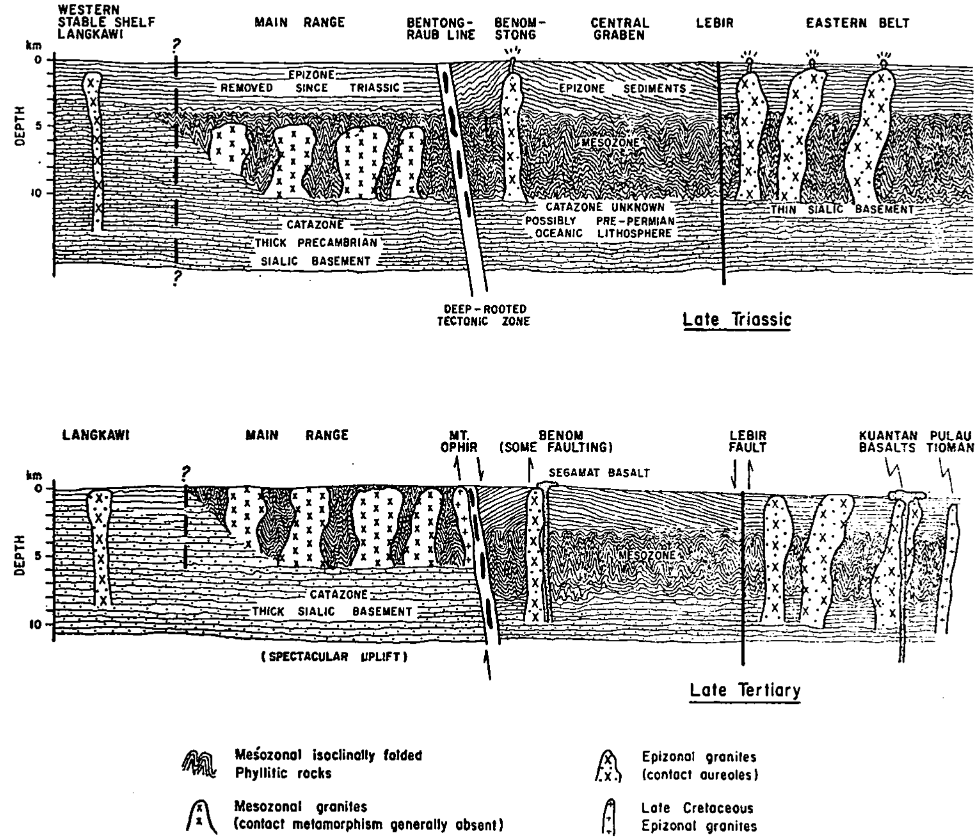

Fig. 7. Diagrammatic cross-section through Peninsular Malaysia, showing the tectonic subdivisions and the relative stability of the Eastern Belt and the Western Stable Shelf compared with the Main Range Belt, which has been uplifted several kilometers since the Late Triassic.

since the Triassic and to the west the Main Range Belt has risen spectacularly. The Schist Series, and the ophiolite melange of the Bentong-Raub line may mark an original subduction zone (Hutchison, 1975A), but it probably continued as a tectonic zone throughout the Mesozoic. The contact between the Western Stable Shelf and the Main Range Belt is uncertain.

RELATIONSHIP TO MINERALIZATION

Placer tin deposits are much more common in the Main Range Belt than in the rest of the Peninsula, and this is to be expected from the considerable uplift of the Main Range Belt with rapid erosion and redeposition of the mineralized zones. Hosking (1973) has documented the great differences in mineralization between the Main Range granite Belt and the Eastern Belt. The differences are further amplified in his later paper (Hosking, 1974) in which he classified the deposits as follows:

Pegmatite: confined to the Main Range Belt.

Pyrometasomatic: (with malayaite only) Main Range Belt.
(with Sn-bearing andradite) Main Range and Western Stable Shelf.
(with malayaite and cassiterite) Main Range and Eastern Belts.
(skarn minerals and cassiterite) Main Range Belt.
(skarn minerals, magnetite, cassiterite etc.) Eastern Belt only.

Hydrothermal: (simple veins) Main Range and Eastern Belts.
(massive replacement bodies) Main Range.
(lodes of simple to moderate complexity of mineralogy)
(a) of limited vertical extension: Main Range
(b) Cornish-type lodes: Eastern Belt only.
(xenothermal veins) Main Range and Central Graben.

Hosking (1974) also points out the following important differences: Highly pleochroic cassiterite is confined to the Main Range Belt. Cassiterite in the Eastern Belt is only weakly to non-pleochroic. Stannite and malayaite are confined to the Main Range Belt. Stanniferous xenothermal deposits are absent from the Eastern Belt. Tin/iron skarns are confined to the Eastern Belt.

The importance of stanniferous xenothermal deposits in both the Ipoh and Kuala Lumpur areas of the Main Range Belt is that they could not have been emplaced when the granite was deep seated, so that one is forced to conclude that the mineralization came much later, after the Main Range Belt had been uplifted.

With a few exceptions such as Bidor on the Main Range Belt, gold mineralization is strongly confined to the Central Graben (Hosking, 1973). Base metal sulfides occur sporadically within the Central Graben. There is a strong concentration of iron mineralization along the line of the Lebir Fault and its southern extensions.

EXTRAPOLATION

As shown on the map of Mitchell and Garson (1972), the tin belt granites extend southwards as far as the Indonesian island of Billiton. It would be useful to know whether it is the Main Range Belt or the Eastern Belt of the Malay Peninsula which continues southwards towards Billiton, but the literature (Aleva, 1960; Priem et al., 1975) unfortunately does not give enough diagnostic petrological information. X-ray diffraction and universal stage studies, especially, are needed. Aleva (1960) mentions coarsely porphyritic textures and the crossed-hatched twinning of microcline, but we do not know if that correlates with the maximum microcline of the Main Range Belt or the intermediate microcline of the Eastern Belt. Hosking (1974), on the basis of the pleochroism of cassiterite, included Billiton in the Eastern Belt, and from granitic specimens which I have seen from Billiton, I would agree with this correlation.

Recent dating (Priem et al., 1975) gives the age of the Billiton, Bangka and Tuju islands as Late Triassic (Rb:Sr age of 217 my) and the K:Ar ages are closely similar. The concordance of the ages by the two methods indicates a stable environment which might equate with the Eastern Belt of the Peninsula. However their initial $^{87}Sr/^{86}Sr$ ratios are high, around .715, and their average Rb/Sr ratio is around 5 (range 1 to 20). Together these suggest derivation from a well established continental basement. This interpretation is in conflict with the low K_2O of the rocks, around 4.2 average, and the K_2O/Na_2O average around 1.4 (Aleva, 1960). In summary, we can see that the age of the granites in the Indonesian islands, as far south as Billiton, is similar to that of South Johore and Singapore, but the available evidence at present does not allow a definite deduction as to whether they are correlatable with the Eastern Belt or the Main Range Belt. Priem et al. (1975) show that the Karimata islands contain Late Cretaceous granite, of age similar to Mount Ophir, Gunung Pulai and Pulau Tioman. In the Malay Peninsula, this is the youngest plutonic episode and is not significantly associated with tin mineralization.

The tin belt granites extend northwards through Thailand and Burma. No mineralogical work on the Thai or Burma granites is published which would allow a comparison with those of the Malay Peninsula. Bignell (1972) shows that the Thai granites have Rb:Sr dates which spread broadly from 560 to 50 my with no well defined peak. Perhaps the most important cluster of the dates is in the range 90 to 220 my (Triassic to Cretaceous). This is quite different from that obtained by him from Malaysia. The 90 to 140 my (Early Cretaceous) granitic ages of Thailand appear to have no equivalent in Peninsular Malaysia. The Thai K:Ar dates range from 30 to 220 my, similar to the Main Range spread. This points to a similar stability of Thailand as the Main Range Belt. Initial $^{87}Sr/^{86}Sr$ ratios for the Thai granites are consistent at .708 for 6 isochrons. This indicates derivation from a more primitive basement than the Main Range granite belt, and a similarity with the Eastern Belt granites. On the other hand, the Rb/Sr ratios average 13 with a spread from 1 to 65. The data on the Thai granites are inconclusive and detailed mineralogical work will need to be carried out if the pattern, which has been established for Peninsular Malaysia, is to be extended northwards.

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