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Known relationships between the 'hard-rock' tin deposits and the granites of Southeast Asia[1]

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"*Whosoever shall entertain high and vaporous imaginations, instead of a laborious and sober inquiry of truth, shall beget hopes and beliefs of strange and impossible shapes.*"

Francis Bacon (Essays)

"*Lines and zones are intellectual tools and jigs, even when they represent what engineers call high tolerance concepts and even if later intermediate zones have to be postulated.*"

Anabel Williams-Ellis
Extract from "Darwin's Moon".
A biography of Alfred Russel
Wallace. Blackie, London. 1966)

Abstract: The Southeast Asian Tin Province, which stretches for c. 1,800 miles, from Mainland Burma and Northwest Thailand to the Tin Islands of Indonesia, may be divided into an east and a west belt.

In each belt granites of several distinct ages occur and the primary tin deposits are spatially closely associated with them. It is not known if all tin deposits are genetically related to their associated granites, but the evidence suggests that such may be the case.

The East Belt granites are dominantly epizonal whereas those of the West Belt are mainly mesozonal, although in the latter belt some small plutons are epizonal.

The granites of the two belts differ significantly in their mineralogical character and trace-element content. There are also marked differences between the types of tin deposit found in the two belts. In the West Belt, for example, stanniferous pegmatites and skarns bearing malayaite are known, but are absent from the East Belt. In the East Belt, on the other hand, stanniferous lodes of the Cornish type, and tin/iron skarns are to be found, but are not present in the West Belt. Also, the variety and nature of the tin-bearing species differ markedly in the two belts. In the West Belt, for example, number of localities contain malayaite and also a number contain stannite, but no malayaite has been recorded from the East Belt and stannite has only been found in two places.

Whilst it is not unusual to find, in the West Belt, cassiterite that is pleochroic from strong red to a pale colour, due to the presence of tantalum in the lattice, such cassiterite is extremely rare and found only in greisen-bordered veins in the East Belt.

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[1]Throughout this paper I have conformed to local practice by using the terms 'granite' and 'granites' instead of 'granitoid' and 'granitoids' which are more correct as many of the so-called granites of the region are, in fact, adamellites and granodiorites.

The marked differences between the tin mineralisation of the two belts suggest that each derived its tin from separate crustal sources and these sources were tapped on a number of separate occasions. It is thought, however, that material carried by subducting plates may have been the source of the 'mineralisers' (chloride and sulphide ions, etc.) that played important roles in the mobilisation of the tin and its transportation from its crustal reservoirs to the sites where it was redeposited.

The data presented also indicate that much more work needs to be done before a generally acceptable plate tectonics model can be constructed. In particular, many more radiometric age determinations of the granites and of appropriate components of the tin and other primary deposits are required before the temporal aspects of the tin province can be fully understood.

INTRODUCTION

The object of this paper is to review what is *known* about the relationships between the 'hard-rock' tin deposits and the granites of the Southeast Asian Tin Province, and to highlight certain, largely local, topics that need to be further investigated before a generally acceptable plate tectonics model of the region can be constructed.

THE DISTRIBUTION PATTERN OF THE TIN DEPOSITS

The tin province stretches from Mainland Burma and Thailand, via the peninsular portions of these countries and Malaysia, to the Tin Islands of Indonesia (Fig.1).

This province, which is at least 1,800 miles in length, is composed of an East and West Belt, approximately parallel, but locally fault-displaced. In Malaysia, where the two belts are most clearly defined, they are separated by one in which granites are poorly-developed and from which only a few small tin deposits are recorded[1]. In this Central Belt there are many, generally small, deposits of gold, iron, barite and base metal sulphides, and of these only the gold at Raub have proved to be economically important.

How, where and why the tin belts are terminated to the north and south are questions that still await satisfactory answers. They will not be considered further here, except to note that in the south, near Belitung, the belts, *perhaps*, swing east and north into West Kalimantan where sub-economic concentrations of tin have been recorded (Katili, 1974, pp. 8-9).

East of the main tin belts a little cassiterite has been recorded from the Anambas and Natuna groups of islands (Bothe, 1925). In the Natunas the tin deposits are associated with granites of Late Cretaceous age (Haile, 1970).

THE GRANITES OF THE TIN BELTS

In both the East and West Belts the tin deposits are spatially closely related to granites which still require much more investigation. Hutchison (1975) when discussing the Malaysian granites, pointed out that whilst those of the West Belt are dominantly mesozonal, those of the East Belt are essentially epizonal, but that late epizonal elements occur in the West Belt. He also recorded distinct mineralogical differences between the granites of the East Belt and those of the West Belt.

[1]Jones (1925, p. 205) records that the granitic Benom Range of the Central Belt "is only slightly mineralised, carrying a little tinstone only in a very few places, one being on the Nanai, a right tributary of the Semantan."

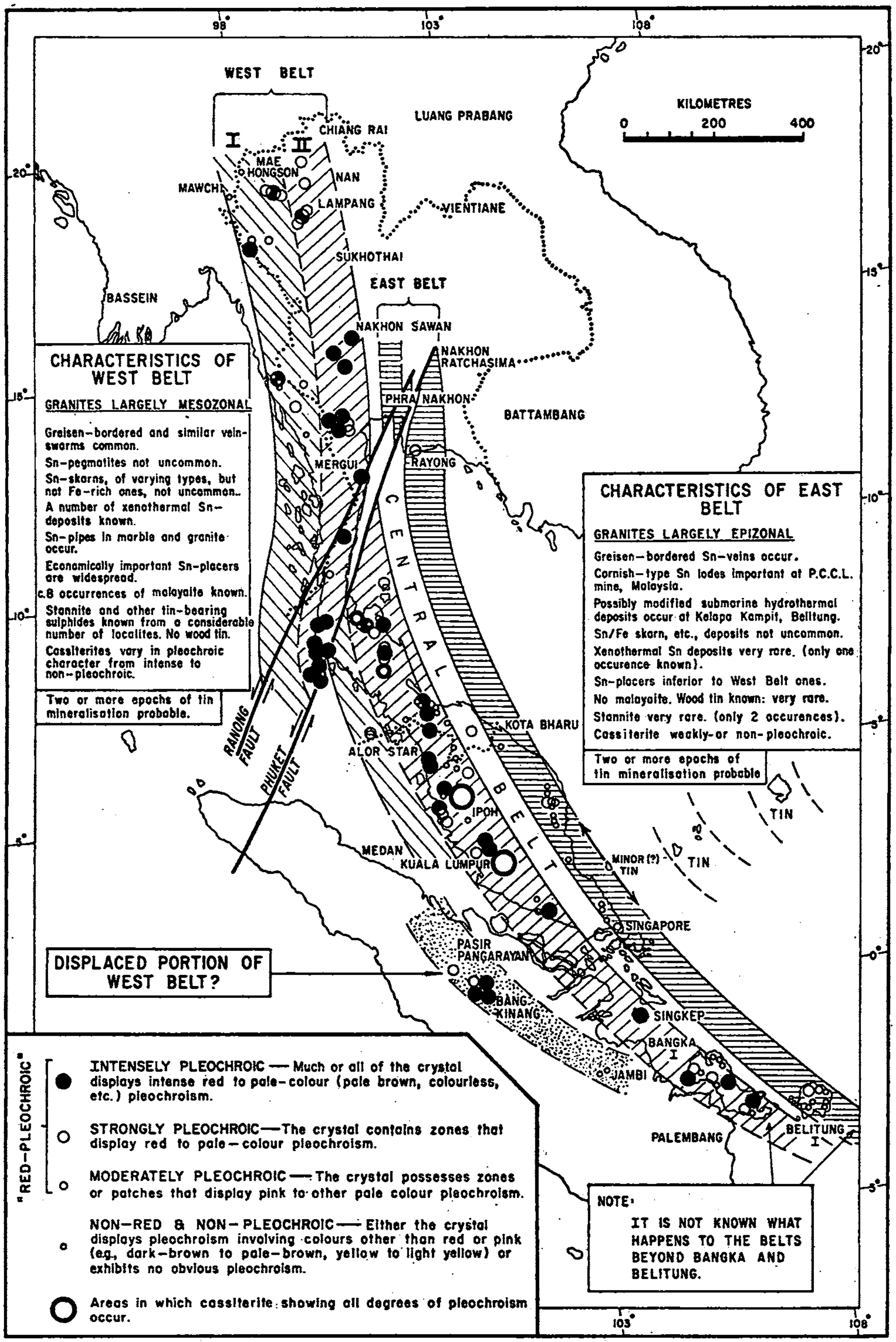

Fig. 1. Tin Belts of Southeast Asia and the pleochroic character of the cassit erites within them.

In recent years, radiometric studies, particularly those of Bignell (1972), established that the Malaysian granites have a long and complex history. Bignell concluded that in Malaysia major granitic instrusions occurred in both belts in the Late Carboniferous/Early Permian (300–270 m.y.); that in the Early Triassic (255–240 m.y.) there was a major development of granite in the East Belt and a minor one in the West Belt; that in the Middle to Late Triassic (225–200 m.y.) there was major granitic activity in the west Belt and minor granitic activity in the East one, and that in the Late Cretaceous (80 m.y.) there were a number of minor intrusions of granite in the West Belt (of these, the best known is that of Mount Ophir) and a very minor one in the East Belt, in Kelantan.

By comparison, the ages of the granites of the extra-Malaysian parts of the belts have been little investigated. Bignell (1972) records Late Carboniferous/Early Permian dates and Middle/Late Triassic ones for some of the granites of peninsular South Thailand, and a Late Cretaceous date for a sample of granite from Phuket. Granite from Renong (Peninsular Thailand) has been assigned a Middle Cretaceous age by Burton and Bignell (1969, p. 685) who also dated granites from Rayong and Chantaburi, south-south-east of Bangkok, as Carboniferous/Permian and Triassic/Jurassic respectively (op. cit., p. 685). Von Braun (1970) recorded that in Northwest Thailand, where there are tin-fields, there are granites of Lower Carboniferous, Triassic and Tertiary ages, and thought that pre-Cambrian meta-granites also may occur there.

Recently Priem and others (1975), having dated a considerable number of samples of granite from the Indonesian part of the tin province, concluded that "cassiterite mineralisation (in Indonesia) is associated with both Upper Cretaceous and Upper Triassic granitic masses, but major tin deposits are related only to Upper Triassic plutons" (op. cit., p. 61). The question of the temporal relationships between the tin deposits and the Southeast Asian granites will be discussed later.

In Malaysia, Yeap (1974) established that the trace-element pattern of the granites of the West Belt differs significantly from that of the East Belt. Yeap's analytical results (Table 1) enabled him to make the following observations and conclusions:-

Generally the concentrations of the studied trace elements in the investigated granites of the West Belt are as follows:-

(i)	Rubidium	—	More than 300 ppm.
(ii)	Strontium	—	With the exception of the Bintang Range granite, less than 110 ppm.
(iii)	Zirconium	—	Excluding a few 'anomalous' results, less than 120 ppm
(iv)	Barium	—	Less than 800 ppm.
(v)	Tin	—	Excluding certain 'anomalous' results, less than 6ppm.
(vi)	Niobium	—	Greater than 5.8 ppm.
(vii)	Tungsten	—	Generally greater than 2 ppm.

The granites of the East Belt have, generally, higher concentrations of Sr, Zr and Ba, and lower concentrations of Rb, Sn, Nb and W than those of the West Belt. The granites of Mount Ophir, Gunong Pulai and Singapore possess concentrations similar to those of the East Belt granites. The first two of these granites, which are of Late Cretaceous age, are epizonal, like the majority of the East Belt ones.

The Benom granite, of the Central Belt, while possessing similar concentrations of Rb, Sn, Nb and W as the granites of the West Belt, has higher concentrations of

TABLE 1

AVERAGE CONTENT, IN PPM, OF CERTAIN TRACE ELEMENTS IN THE GRANITES OF PENINSULAR MALAYSIA AND SINGAPORE (AFTER YEAP, 1974.)

AREA	Rb	Sr	Zr	Ba	Sn	Nb	W	No. of samples	Remarks
1. MAIN RANGE	531	53	103	365	7.3	7.2	4.3	160	
a. Bujang Melaka	340	25	154	475	6.4	7.0	1.8	4	
b. Fraser's Hill	583	51	100	280	6.3	8.5	7.6	28	
c. Cameron Highlands I	709	21	60	124	7	9	5	4	
d. Cameron Highlands II	468	65	195	497	5.7	7.8	4.7	14	
e. Negeri Sembilan	511	68	111	396	7.4	8.7	2.4	48	
f. Genting Sempah I	574	56	133	358	9.1	7.3	1.8	8	
g. Genting Sempah II	342	101	186	725	5.4	7.7	5.3	6	
h. Chenderiang	384	64	176	877	6	n.d.	n.d.	1	
i. Kuala Lumpur-fringe area	528	59	92	482	10	9	3	14	
j. Kinta Valley	603	4	61	219	7	8	6.5	3	M
k. Kuala Lumpur	658	25	69	145	8	7	5.7	30	M
2. BINTANG RANGE									
a. Taiping	738	41	64	6	11	7	7.2	3	M
b. Other areas	426	164	243	577	5.6	7.7	1.8	8	M
3. KLEDANG-KINTA VALLEY	624	13	77	183	6	8	9.2	5 5	
4. PENANG	466	40	85	330	7.9	7.4	1.3	13	
5. KULIM	481	109	115	550	9.1	5.8	1	6	
6. JOHORE									
a. South Johore	348	19	109	253	5.4	9.2	3.2	10	
b. Bekok	222	122	125	1441	5	6	1.3	3	
7. LUMUT	652	4	77	149	8.7	7.5	5.3	4	M
8. GUNONG BENOM	323	186	16.2	694	6.3	6.9	5.8	17	
9. MOUNT OPHIR	289	207	128	825	5	5	1.2	5	
10. GUNONG PULAI	146	193	135	808	5.8	5.7	1.3	4	
11. SINGAPORE	186	66	107	984	4.3	3.2	1.5	11	
12. EAST COAST	216	158	142	838	5.6	6	1.6	45	

(M — Area of strong mineralisation)

Sr, Zr and Ba than the latter. Hutchison (1973) considered the Benom granite to be chemically and petrographically similar to the majority of the Main Range granites, but Yeap's studies indicate that the similarity may not be very close.

Some years ago Jaafar Ahmad studied the Malaysian granites in much the same way as Yeap has done, and his unpublished work also showed marked differences in the trace-element patterns of the granites of the three Malaysian belts, similar to those found by Yeap.

The findings of Yeap and Jaafar Ahmad indicate real differences between the trace element content of the mesozonal granites of the West Belt and the epizonal ones of the East Belt. But do these differences exist because the magma from which the granites in question of the West Belt originated was derived from a different source from that of the East Belt granitic magma, or is it simply due to differences in the level of intrusion? The latter possibility cannot be ignored as the epizonal granites of the West Belt have a trace-element pattern that differs from that of the mesozonal granites there. But as the mesozonal and epizonal granites of the West Belt are of different ages they might well have been derived from different sources.

To what extent the 'original' trace-element content of the granites has been modified by additions made during the period of ore-development is not known, but Yeap (op. cit) demonstrated the presence of aureoles of anomalous concentrations of certain elements around some primary mineral deposits. Of course, one may sample such an aureole without being aware of it because the primary mineral deposit does not happen to outcrop. In addition, the 'normal' trace-element content of a granitic magma may be modified significantly by processes of assimiliation, and by invasions by later, and perhaps much younger, granitic magma. To what extent the trace-element content may vary from place to place in a given granite body of limited extent, say, a cusp, is also not known. Such knowledge is required before possible genetic links between the granites and the spatially related tin deposits, and other metal deposits can be established. No certainty exists as to whether the trace-element patterns of those granites with which tin deposits are closely associated, and the patterns of those with which they are not, were significantly different before mineralisation. The tin content of the so-called tin-productive granites may, for example, be significantly greater (as some think) than that of the tin-barren ones simply because the former has had tin added to it during the development of primary tin deposits.

Beyond doubt, good reason exists for continuing trace-element studies of the type discussed above, both in Malaysia and elsewhere. If and when such studies are made a much more critical selection of the sampling sites should be made than in the past. However, because of the paucity of good natural outcrops of fresh granite owing to the deep secular weathering in the humid tropics, the best samples are obtained from coastal exposures, quarries and opencast mines, but those from the last source must always be suspect because of the common presence of primary deposits in them.

A COMPARISON BETWEEN THE TYPES OF 'HARD-ROCK' TIN DEPOSITS FOUND IN THE TWO BELTS

Figure 2 indicates the types of tin deposit found in the Southeast Asian tin province and no elaboration of its content is necessary.

In the West Belt, unlike the East one (Table 2), stanniferous pegmatites and stanniferous aplites are quite common. In Indonesia and Malaysia they are generally quite small and only rarely have they been worth exploiting, as, for example, at Gunong Bakau, in the Main Range of Malaysia, where both stanniferous pegmatites and aplites occur. However, in those parts of the West Belt that lie within these two countries, such stanniferous bodies have locally probably made significant contributions to the placers. Both at Bakri (Johore), and at Gunong Jerai (Kedah), for example, most or all, of the placer cassiterite and associated Nb/Ta species are thought to have been derived from pegmatites, although exposures of these bodies in those areas lack these species. Further north, small stanniferous pegmatites, most very kaolinised, have been frequently noted in the opencast mines of Phuket, whereas at the hard-rock Chon mine, in Peninsular Thailand, cassiterite is recovered from a pegmatite/aplite body. A series of unzoned lithium/tin pegmatites, which are locally exploited for their cas-

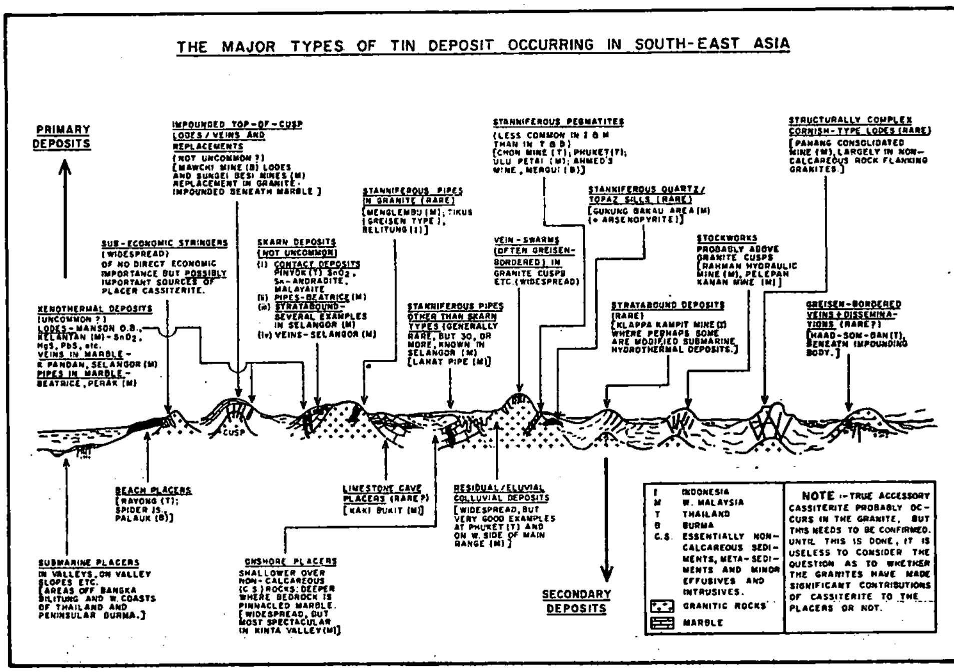

Fig. 2

siterite content, follow the northeast-trending Phuket fault system that transects the Belts in Peninsular Thailand. The East Belt, in contrast to the West Belt, contains to my knowledge no bona fide stanniferous pegmatites nor aplites.

The stanniferous skarns of the West Belt in marked contrast to those in the East Belt, never contain magnetite nor other primary iron oxides, and the tin may be largely present in andradite (as at the Langkawi Islands), or in malayaite and cassiterite (as at Sungai Goh, Pahang, and at Chenderiang, Perak), or in andradite, malayaite and cassiterite (as at Pinyok, South Thailand), or solely as cassiterite (as in the Beatrice Pipe, Perak), or solely as malayaite (as at Rawang, Selangor).

In such skarns as occur in the East Belt, significant tin concentrations are present solely as cassiterite (as at Bukit Besi, Trengganu) or as cassiterite and andradite (as locally, at Pelepah Kanan, Johore). Also, in the East Belt, as hinted above, a number of stanniferous skarns are characterised by magnetite. Examples occur at Bukit Besi (Trengganu), Machan Satahun (Trengganu) and at Pelepah Kanan (Johore), and certainly some of the bedding-plane lodes at Kelapa Kampit (Belitung) fall into this class (Adam, 1960). Skarns are not the only deposits in the East Belt in which primary iron oxides and cassiterite occur in intimate relationship. At Bukit Besi (Trengganu) this relationship is to be found in metasomatic deposits as well. At Pahang Consolidated Mine (Pahang) hydrothermal lode material containing, quartz pyrrhotite, pyrite, magnetite, iron-rich chlorite and cassiterite, from an unknown source, has recently been isolated by the tramp-iron magnet in the mill. In Belitung, a number of deposits containing the tin/iron mineral association are known, and some have been exploited for their tin content. Of these, some have a skarn character and some appear to be 'normal' hydrothermal lodes and replacements. Others, at Kelapa

TABLE 2

A COMPARISON OF THE TIN MINERALISATION OF THE WEST BELT (IN WHICH MESOZONAL GRANITES ARE DOMINANT) WITH THAT OF THE EAST BELT (IN WHICH THE GRANITES ARE EPIZONAL) OF THE SOUTHEAST ASIAN TIN PROVINCE

WEST BELT	EAST BELT
Sn pegmatites and aplites occur. Nb/Ta species may also be present.	No Sn pegmatites known.
Sn skarns with cassiterite and/or malayaite, and/or Sn-andradite not uncommon.	Sn/Fe skarns present. Malayaite absent.
Contact, stratabound, pipe-like and vein-like skarns known.	Massive contact and stratabound Sn skarns only recorded.
Many rich and poor stanniferous veins, lodes and replacements, that occur singly or in swarms, and that have a very modest dip length, are known. Commonly associated with granite cusps.	Sn veins and lodes, singly or in swarms, with limited dip length, distributed rather sparsely in the Belt.
No Sn lodes or veins with considerable dip length known, but some hydrothermal pipes in the marble may have considerable dip lengths.	Sn lodes, with considerable strike and dip extensions, and of major importance, occur at Pahang Consolidated Mine, and perhaps elsewhere in N.E. Malaya. Sn deposits, of similar dimensions, also occur at Kelapa Kampit, but these, in part, may be stratabound ones.
Sn xenothermal veins and pipes are not uncommon, particularly in the Perak and Selangor fields of Malaysia.	Only one Sn xenothermal deposit known and that is the Manson Lode, in Kelantan, Malaysia.
Cassiterites that display red to pale colour pleochroism are common.	Cassiterites generally display dark-brown to pale-brown pleochroism, or are non-pleochroic.
No wood tin recorded.	Wood tin recorded from 2 localities.
Stannite not uncommon.	Stannite only recorded from the Manson Lode and from Kelapa Kampit mine.
Sb and Be species recorded from a number of Sn deposits.	No Sb species recorded from Sn deposits. Phenakite recorded from Kelapa Kampit mine.

Kampit and possibly elsewhere on the island, *may be* stratabound deposits, of Permian age, that have been modified by regional metamorphism and then by hydrothermal activity associated with the intrusion of the Triassic granites. (Unpublished studies).

It should be noted that perhaps not all of the iron/tin deposits of the East Belt are of the same age. Those in northeast Malaysia may be Upper Carboniferous/Lower Permian whilst those in the southeast may be Lower Triassic. In Belitung, as already noted, some are possibly Upper Permian whilst others are probably Upper Triassic.

In the West Belt only one magnetite/tin deposit is known to me, and that is a small cassiterite/magnetite/sulphide lode at Sungei Lah in the granite of the Main Range, in Perak. There are, of course, hard-rock iron oxide ore deposits in the West Belt that are devoid of tin (for example, near Tambun, Perak, and at Gunong Jerai, Kedah).

In the West Belt the commonest types of hard-rock tin deposits are the greisen-bordered vein-swarms in the granite and the similar vein-swarms, that halo buried granite cusps. These have, in all probability, been the major contributors of cassiterite to the placers. Veins in these swarms are generally very limited along strike and the cassiterite in them is restricted to a maximum of a few hundreds of feet down dip. In the West Belt stanniferous lodes are also present and some, as, for example, in the Kledang Range (Perak) have been profitably exploited by underground methods. However, even these lodes have rather modest strike and dip lengths. In a few places, in the West Belt, stanniferous replacements, similar to the Cornish carbonas, have been found in the granites. The best examples of these occurred at Haad-Som-Pan, in Peninsular Thailand, and at Sungei Besi, in Selangor, and both have been worked profitably by opencast methods. In the Kinta Valley many stanniferous pipes have been discovered in marble. Most are of little or no economic importance, but a few have been worth mining, and of these the Beatrice Pipe was the most rewarding. This pipe was mined to a depth of several hundreds of feet to the point where it was faulted abruptly against the granite. Some of the Kinta pipes are best termed skarn deposits but others lack the necessary gangue minerals to warrant such a name. Some of them appear to have considerably greater dip lengths than the majority of tin deposits in the West Belt.

In the East Belt, greisen-bordered stanniferous veins and mineralogically similar ones in the country-rock above granite protruberances have been mined for cassiterite and some have been the parents of useful stanniferous placers. Such deposits, however, are much less abundant than in the West Belt. Such greisen-bordered veins occur, for example, in the Gambang tin-field of Pahang. At Tikus, in northwest Belitung, a pipe-like deposit has been mined to a depth of 105 metres. It, in fact, consists of a plexus of quartz veins containing, in addition to cassiterite, wolframite and sulphides, and fringed by topaz-rich greisen. The body is in the centre of a large area of pene-planed granite. Surely this is a top-of-cusp of deposit, of which little has been removed by denudation, and so it must be genetically related to a granite that is younger than the one generally exposed in the area (Fig. 3).

At Pelepah Kanan (Johore) is a felspathic (but not pegmatitic) veinswarm that cannot be matched mineralogically by any swarm in the West Belt (nor, for that matter, in the whole tin province). The economically important members of the swarm contain, besides cassiterite, K-feldspar, quartz, white mica, chlorite, fluorite and minor amounts of scheelite and sulphides. The host-rock, an amphiolite-rich skarn, contains appreciable concentrations of cassiterite and magnetite. These veins die out rapidly in an overlying body that was originally magnetite but which has now been largely converted to martite.

The lodes of Pahang Consolidated Mine, in the East Belt, have no counterparts in the West Belt. These ore-bodies, which are very similar to those in the major Cornish mines, are mineralogically rather complex and structurally very complex. They have considerable strike lengths, and economic concentrations of cassiterite occur over very much greater dip lengths than in any of the West Belt deposits.

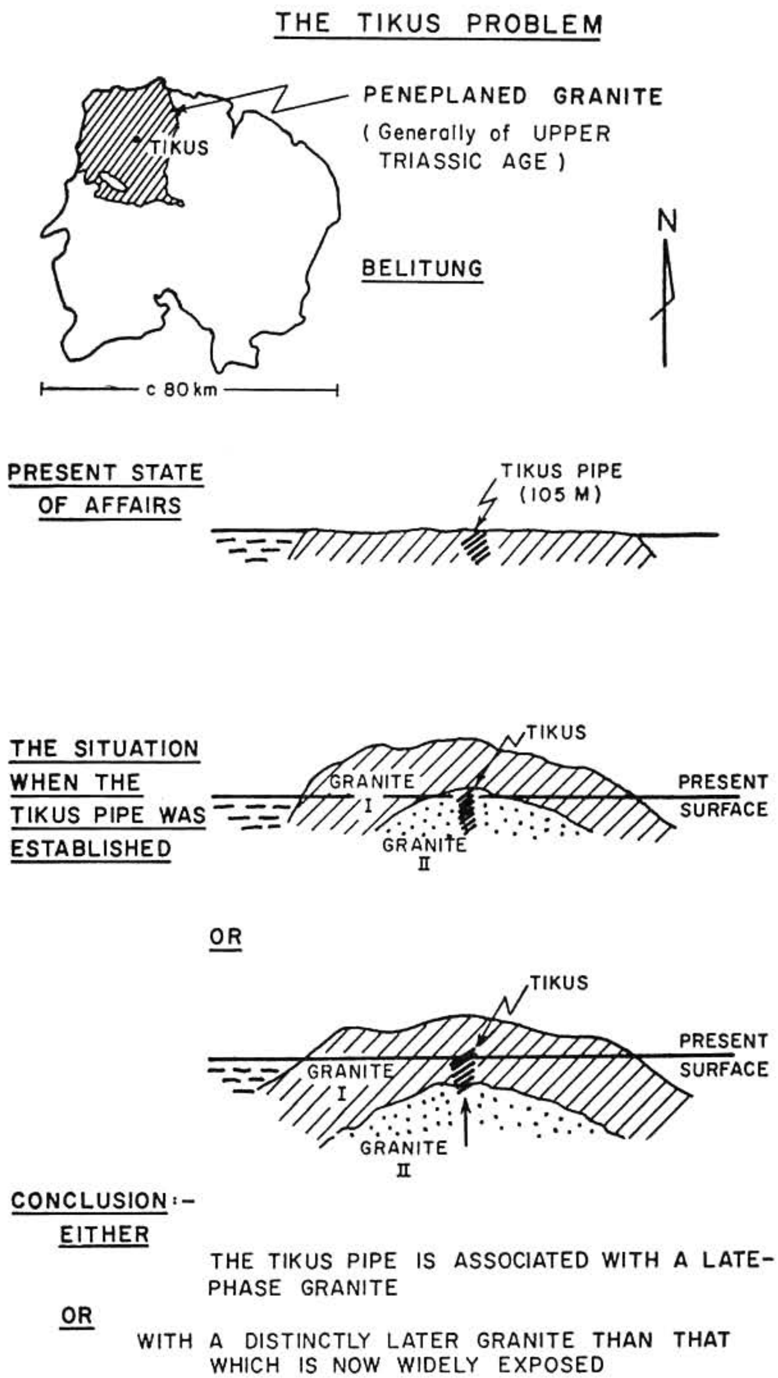
THE TIKUS PROBLEM
PENEPLANED GRANITE
(Generally of UPPER TRIASSIC AGE)
TIKUS
BELITUNG
N
c 80 km
PRESENT STATE OF AFFAIRS
TIKUS PIPE (105 M)
THE SITUATION WHEN THE TIKUS PIPE WAS ESTABLISHED
TIKUS
GRANITE I
GRANITE II
PRESENT SURFACE
OR
TIKUS
GRANITE I
GRANITE II
PRESENT SURFACE
CONCLUSION :-
EITHER
THE TIKUS PIPE IS ASSOCIATED WITH A LATE-PHASE GRANITE
OR
WITH A DISTINCTLY LATER GRANITE THAN THAT WHICH IS NOW WIDELY EXPOSED

Fig. 3

Lodes at Kelapa Kampit Mine (Belitung), also in the East Belt, match in dimension and grade those at Pahang Consolidated Mine. Some are essentially fault-controlled as are those at Pahang Consolidated Mine, but others are 'bedding-plane' veins.

Stanniferous xenothermal deposits are not uncommon in the West Belt. Some of the Kinta pipes, in the marble, can be reasonably classed as xenothermal, and in the vicinity of Kampung Pandan, near Kuala Lumpur, many telescoped veins also occur in marble. The latter veins, over dip lengths of a few feet, contain beryl, helvite, sericite, tourmaline, cassiterite, wolframite, scheelite and many sulphides, of which stannite (several varieties) deserves special mention. In the East Belt, in marked contrast, I am aware of only one xenothermal deposit, the Manson Lode, in Kelantan, which I regard as being at the extreme western edge of the Belt, although others regard it as a highly anomalous member of the Central Belt. This outcropping lode, which has not been exploited, displays a marked telescoped character, and contains, besides cassiterite, an impressive assemblage of sulphides that includes cinnabar. Its most important economic component is argentiferous galena (Hosking, et al., 1970).

THE NATURE AND DISTRIBUTION OF THE TIN SPECIES IN THE TWO BELTS

The distribution patterns of the various tin-bearing species further emphasise the marked differences between the West and East Belts.

In the West Belt malayaite has been recorded from eight localities in Malaysia and from two in Peninsular Thailand, but has never been found in the East Belt.

Stannite has been collected from many localities in the Malaysian part of the West Belt and probably occurs unrecorded elsewhere in the Belt[1]. On the other hand, within the East Belt, stannite has been recorded only from the Manson Lode (Hosking et al., 1970) and from Kelapa Kampit Mine (Ramdhor, 1969, p. 554). In the latter it must be exceedingly rare as I have now examined scores of polished sections but have been unable to confirm its presence.

Wood-tin, on the other hand, seems to be confined to the East Belt, but is very rare even there (Smith and Hosking, 1974). Aranyakanon (1969) records wood-tin from the placers at Huai Tagrao in South Thailand, but I was unable to confirm its presence in a sample kindly provided by him. Also, material from Bukit Besi Mine, Trengganu, that was thought by the Mine Superintendent to contain wood-tin, proved to be devoid of the mineral in question.

The pleochroism of cassiterites emphasises, in a most spectacular manner, that the tin mineralisation of the one Belt differs significantly from that of the other (Fig. 1). In the West Belt cassiterites showing red to pale-colour pleochroism are common, whereas in the East Belt such cassiterites are very rare and none show the intense pleochroism in which the whole crystal changes in colour from blood-red to pale brown, or greenish, or near colourless. This red pleochroism is probably due to tantalum in the lattice. Certainly the specimens that display such pleochroism contain exsolved bodies that are either members of the mossite/tapiolite or the columbite/

[1]Since completing this paper, I have found stannite in a sample from a mineralogically complex lode which has been exploited for its cassiterite content at Koh Phangan, one of a group of islands lying off the east coast of Peninsular Thailand. These islands are within the West Tin Belt.

tantalite series (Santokh Singh and Bean, 1968). That such cassiterites are, indeed, tantaliferous is further indicated by the valuable tantalum-rich slags yielded by the tin concentrates, particularly from Phuket and the neighbouring mainland.

During a single epoch of tin mineralisation tantalum/niobum species tend to report in the pegmatites, if they report at all, and the cassiterite that is syngenetic with respect to the pegmatite body is likely to be more intensely red-pleochroic than cassiterite formed in later ore-bodies. In a tantalum-rich environment the greisen-bordered veins also commonly contain cassiterite that is intensely or strongly red-pleochroic, but any Nb/Ta species are *usually* relegated to exsolved bodies in cassiterite. Cassiterite in the still later hydrothermal deposits may show a weak red pleochroism but more commonly a dark-brown to pale-brown or none. If a deposit contains more than one generation of the cassiterite then each may be characterised by a different pleochroic effect.

The fact that intensely- and strongly-pleochroic cassiterite is common in the West Belt but is very rare in the East Belt suggests that much of the former was deposited in the early stages of one or more epochs of tin-deposit genesis, that is, when pegmatites, greisen-bordered, and similar veins were developing, whereas in the East Belt tin deposition was commonly delayed until later hydrothermal stages. But there is more to it than this, as a comparison of East Belt cassiterites from greisen-bordered veins and other supposedly early-developed deposits, such as the felspathic veins of Pelepah Kanan, with those from equivalent deposits from the West Belt indicates that in the West Belt the tin originated from sources rather rich in tantalum, whereas in the East Belt the tin was derived from different sources that were comparatively poor in tantalum. Evidence provided later indicates at least two important epochs of tin mineralisation in the West Belt, and that on every occasion tantalum-rich cassiterite was deposited. Therefore, the sources of the tin and tantalum are thought to be crustal ones which were tapped whenever circumstances permitted. By extension, I think that virtually all the tin throughout the tin province has been derived from crustal sources.

Another difference in the tin mineralisation of the two Belts is the fact that antimony minerals, albeit, never in economic amounts in Malaysia, are commonly encountered in the stanniferous deposits of the West Belt, but nowhere, as far as I am aware, in those of the East Belt. Boulangerite, tetrahedrite ane bournonite occur in tin-ore from the Selangor field, and in Perak jamesonite is associated with cassiterite at Chenderiang, whereas kobellite and tetrahedrite occur in the stanniferous veins at Tekka. Antimony species have also been commonly encountered by the smelters in cassiterite concentrate from Peninsular Burma.

Finally, beryllium species are much rarer in the East Belt than in the West Belt. In the West Belt beryl has been recorded from a number of localities in Perak (for example, from Chenderiang) and from Selangor (for example, from Sungei Besi Mines and the Kampong Pandan area). In addition, helvite occurs in the skarns of the Kampong Pandan area). In the East Belt only phenakite has been recorded and it was found at Kelapa Kampit, Belitung (Adam, 1960).

ZONING

In my opinion within the tin province large-scale regional zoning is only clearly defined in Malaysia where the East and West Tin Belts are, as noted earlier, separated by one in which gold, barite and base-metal sulphides are dominant. Regional zoning, of a much more spectacular kind, but on a much smaller scale, is encountered in that part of Perak which embraces the Kinta Valley, together with the Kledang Range to the West and the Main Range to the east. There, tin, tungsten, lead/zinc and iron deposits are arranged in zones that parallel the long axes of the granitic flanking ranges (Fig. 4). In addition, this region together with that area of Pahang immediately to the east of it, seems to be symmetrically zoned about a vertical plane marked by the crest-line of the Main Range. On both sides tin and tungsten deposits occur close to the granite contacts and on each side one finds an important source of gold. In the west it is the area presently being exploited by the Bidor dredge whilst in the east it is the Raub gold-field. Also, on both sides are deposits containing antimony minerals, scheelite and cinnabar.

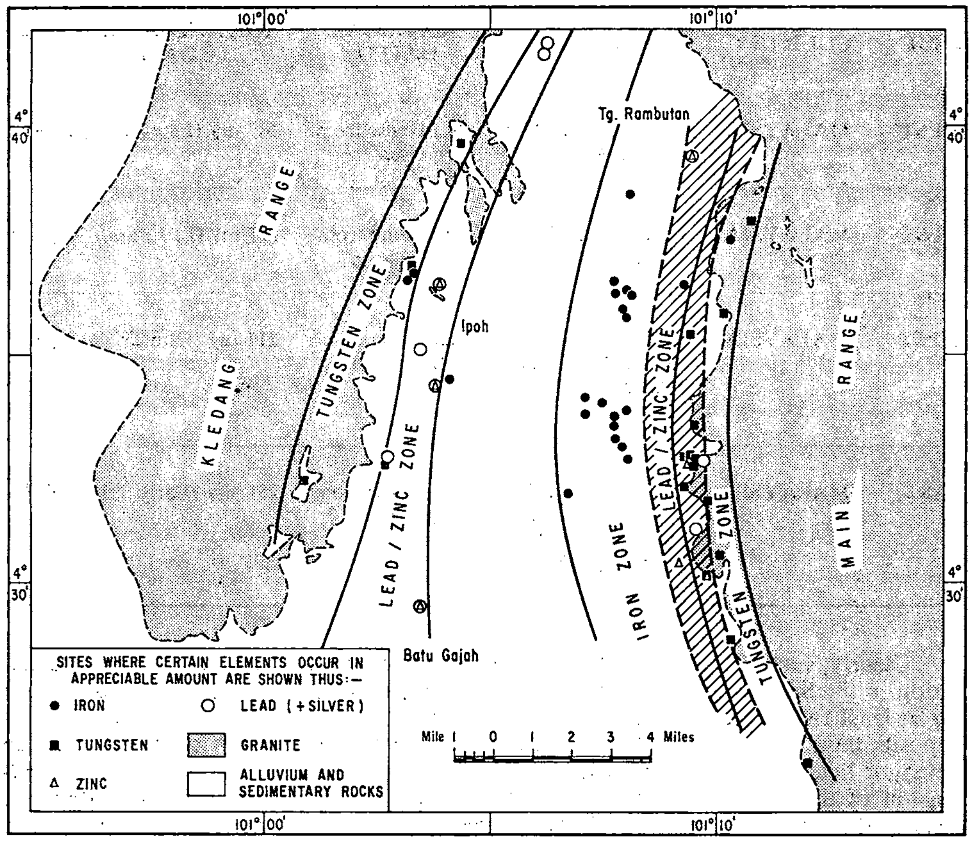

Fig. 4. Metal zones in the Kinta Valley. Based on data taken from the mineral distribution map (1966) of the Geological Survey of Malaysia (K.F.G. Hosking, 1973A).

CERTAIN TEMPORAL ASPECTS OF THE GENESIS OF THE SOUTHEAST ASIAN TIN DEPOSITS

To say that a tin deposit may not be approximately the same age as the granite with which it is spatially associated, is to provide a glimpse of the obvious, yet, over and over again this plain fact has been ignored. Reasons for thinking that the Tikus deposit may be appreciable younger than the surrounding granite, provided earlier, were responsible for the dating of the mica in the greisen there. This dating, organised by Bruce Reed of the United States Geological Survey, demonstrated that the deposit is 17 m.y. younger than the surrounding granite that had been dated by Priem and others (1975).

As far as I am aware, components from only four other deposits within the tin province have been dated and all have been provided by Bignell (1972). The results appear in Table 3.

TABLE 3

BELT	COUNTRY	LOCALITY	MATERIAL DATED	AGE AND METHOD OF DATING
WEST	MALAYSIA	CHENDERIANG (PERAK)	Muscovite from greisen	207 my (Late-Trias.) K/Ar.
WEST	MALAYSIA	CHENDERIANG (PERAK)	Lepidolite from pegmatite	175 my (L. Jurass.) Rb/Sr.
WEST	MALAYSIA	SIN KWONG NYAM'S MINE, LAHAT (PERAK)	Altered granite from lode	211 my (Late Trias.) K/Ar
EAST	MALAYSIA	WILLINK'S MINE (A part of Pahang Consolidated Mines, Pahang)	Muscovite from greisen	251 my (Early Trias.) K/Ar.

Clearly, such meagre data do not establish the number of epochs of tin mineralisation in the Southeast Asian province. However, as noted earlier, I can make a case for at least two in the Malaysian part of the West Belt. Locally in the West Belt tin deposits have been impounded in Triassic granite beneath 'pure' marble, yet in the Selangor field, at Kampong Pandan, and in close proximity to such deposits, an extension of the impounding marble contains stanniferous xenothermal vein deposits described earlier. This state of affairs may be accounted for as follows. During tin-ore development that followed the emplacement of the mesozonal Triassic granites, the adjacent marble, being deeply buried and hot, seems to have behaved in a manner unlike that of all the other invaded rock units in that it deformed but did not fracture on being subjected to regional and local stresses. In course of time erosion uncovered this marble or brought it near the surface. Then a further phase of granite emplacement and associated mineralisation occurred. The regional forces were then able to fracture the marble as it was cold and but lightly loaded. These fractures were filled with tin-bearing and other species in a comparatively shallow environment indicated by the strongly telescoped character of the deposits (Fig. 5).

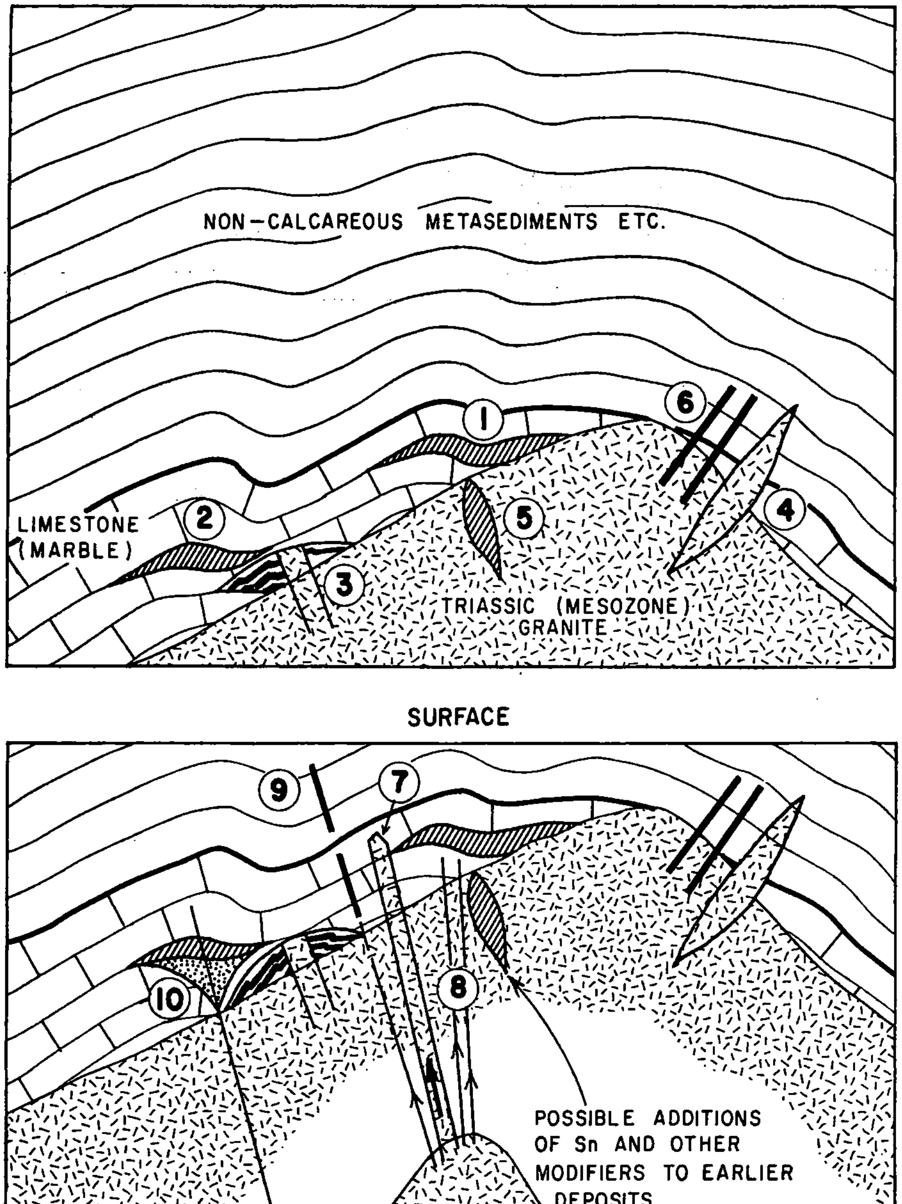

Fig. 5. The postulated major results, in West Malaysia, of superimposing mineralisation due to a high-level granitic invasion on that due to granite emplaced in the mesozone. (K.F.G. Hosking, 1973B,)

1) Strataform skarn.
2) Folded bed of non-calcareous sediment or metasediment.
3) Pegmatite, in part in a skarn host.
4) Pegmatite in granite/non-calcareous host rocks.
5) Tin orebody impounded beneath limestone.
6) Tin-bearing lodes/veins in granite/non-calcareous host rocks.
7) Pegmatite in granite/limestone host rocks.
8) Tin-bearing lodes/veins in granite, etc.
9) Xenothermal tin-bearing deposit in limestone. Possibly associated with vein- or pipe-like skarns.
10) Metasomatic tungsten-bearing deposit impounded in limestone by a metasedimentary folded bed.

These xenothermal deposits were probably associated with the emplacement of high-level granites of probable Upper Cretaceous age, members of which are known in Johore. The stanniferous xenothermal deposits of Perak may also be of this age, as may be some, at least, of the gold, antimony, scheelite and cinnabar deposits that are symmetrically arranged on either side of the Main Range.

The sequence of events in the Malaysian portion of the Tin Province seems to *broadly* conform to Bilibin's (1968) scheme. Bilibin maintained that tin deposits of the pegmatitic, skarn, and hypothermal vein/lode types are the first to develop, and *may* be followed, at a distinctly later date, by the formation of stanniferous xenothermal deposits. Much later, base-metal sulphide deposits associated with volcanics may be generated, and the ultimate event is the outpouring of basalt.

In the Malaysian part of the East Belt cassiterite deposits may have developed in the northeast soon after the emplacement of the Carboniferous granites there, and may have been followed by the establishment of the stanniferous xenothermal Manson Lode which *may* be of Permian Age. At Kelapa Kampit Mine, Belitung, Indonesia (also in the East Belt) the controversial bedding plane veins may be strataform deposits with a volcanic parentage. This would broadly fit into Bibilin's scheme, although the deposits are not xenothermal. Later, this Belt was again the site of granite emplacement in Triassic time, a complication not envisaged by Bilibin. An early epoch of tin mineralisation probably was associated with this granitic event, but, as far as I am aware, it was not followed by one in which stanniferous xenothermal deposits were formed. Bilibin, however, does not regard a xenothermal stage as necessary.

In the Malaysian part of the West Belt, perhaps some tin was deposited after the emplacement of Carboniferous granites there, for example, at Gunong Jerai. However, the major phase of granite emplacement took place in the Late Triassic and, as noted earlier the majority of the tin deposits, pegmatites, skarns, lodes and veins, were probably formed then. This was followed by comparatively minor granite emplacement in the Late Cretaceous, with, in my opinion, associated xenothermal deposits.

Certainly from the time of the last tin deposition Malaysia behaved as a unit. The Segamat basalts, with their minute veins containing galena, chalcopyrite, fluorite, Ba/Sr species and zeolites, and which are probably post-Triassic, occupy the correct place in Bilibin's sequence, and the Kuantan basalts, which according to Bignell (1972) are 1.6 million years old, provide the epilogue required by Bilibin's scheme.

CONCLUSION

Finally, as a parting shot, I must again emphasise that in my opinion the South-east Asian Tin Province provides good reason for thinking that the bulk of the tin in the 'hard-rock' deposits there was derived from the crust. Subducted sediments may have permitted the recycling of some tin during the early evolution of the Tin Province, but recycling apparently has not been important since. Nor do I believe that the mantle made important contributions of tin to any of the known primary deposits *in the Tin Belt*. Nevertheless, the load of sediments carried by subducting plates may have played an important role in the genesis of the tin deposits, as such sediments would contain 'mineralisers' or parents thereof. The ascent of the 'mineralisers' might well have released tin from its crustal sources and transported it to centres of deposition.

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