

14

THE RELATIONSHIP BETWEEN
PRIMARY DEPOSITS AND GRANITIC
ROCKS

by

K. F. G. Hosking

MSc, PhD, MIMM, FGS

Dr. K. F. G. Hosking
is Head of the Department of
Geology and Applied Geochemistry,
Camborne School of Metalliferous
Mining, Cornwall

THE RELATIONSHIP BETWEEN AND GRANITIC ROCKS

Sound prospecting programmes for tin deposits are usually based, to no small extent, on the relationship between such deposits and granitic rocks.

The literature contains scores of papers on this relationship, but commonly without having described the question as to whether or not it is left unanswered: on the other hand, many of the conclusions made are not valid.

This paper is an attempt to discuss the temporal, chemical/mineralogical and structural aspects which are capable of being tested in the field.

As far as possible the writer has tried to avoid relationships which require consideration of granitising agents and ore-forming agents and of the chemistry of ore-forming agents, because he believes that a good prospecting programme is essentially on facts, and that a good prospecting programme is based on concepts, however sophisticated they may be, than one which requires only that a map in a map in order to find a tin deposit.

Introduction

It has been said that military operations are conducted without full knowledge of the terrain, made on partial evidence only (M. J. 1944). Then the search for "new" tin deposits is conducted both the general's and the tin explorer's to no small extent, on the number of tin deposits they are preparing their plans of operations into effect. It is, of course, necessary to be aware, and, more particularly, to differentiate between the two.

It is good that papers dealing with tin deposits and related branches of science should be theses and generalisations, as these are the theses which climb towards the truth, but there are many theses and the like, which have assumed the form of a somewhat modified form they are theses and the like, because of the standing of the theses.

It is worth remembering that the primary ore-bodies is not known, the primary ore-bodies was transported from its source to the primary ore-bodies, chemical reactions known which we

THE RELATIONSHIP BETWEEN PRIMARY DEPOSITS AND GRANITIC ROCKS : K. F. G. HOSKING

Synopsis

Sound prospecting programmes designed to locate "new" primary tin deposits are usually based, to no small degree, on the designers' views concerning the relationship between such deposits and granitic rocks.

The literature contains scores of references to one aspect or another of this relationship, but commonly when a particular facet of the relationship is described the question as to whether it is of local, regional or world significance is left unanswered: on the other hand, generalisations are all too frequently made which are not valid.

This paper is an attempt to clarify the situation with respect to those temporal, chemical/mineralogical and spatial aspects of the relationship which are capable of being tested in the field, mine or laboratory.

As far as possible the writer has refrained from discussing those questions of relationship which require consideration of the sources of granite magmas, granitising agents and ore-forming ones, and theories of the nature of these agents and of the chemistry of ore-genesis. He has adopted this line of action because he believes that a good exploration programme must be based essentially on facts, and that a programme founded largely on theoretical concepts, however sophisticated the latter might appear to be, is little better than one which requires only that a blind-folded person should stick a pin in a map in order to find a tin deposit.

Introduction

It has been said that military operations are an art, not a science, because they are conducted without full knowledge of the facts, most decisions being made on partial evidence only (McKee, 1966, p. 59). If this view is correct then the search for "new" tin deposits is also an art, but it is obvious that both the general's and the tin explorationist's chances of success must depend, to no small extent, on the number of relevant facts available to them when they are preparing their plans of operation and when the latter are being put into effect. It is, of course, necessary to see clearly which facts are relevant and, more particularly, to differentiate between fact and fiction.

It is good that papers dealing with some aspects of economic geology and related branches of science should contain theories, suppositions, hypotheses and generalisations, as these are steps up which further workers will climb towards the truth, but there are, unfortunately, all too many theories, and the like, which have assumed the cloak of absolute fact, either because in a somewhat modified form they have been repeated by one writer after another or because of the standing of those who first uttered them.

It is worth remembering that the source, or sources, of the tin in the primary ore-bodies is not *known*, that it is not *known* in what form the tin was transported from its source to the site where it was deposited nor are the chemical reactions *known* which were responsible for the deposition of cassite-

rite and other tin-bearing species. Fortunately, to the searcher for further tin deposits of economic interest such things are really of little importance. It is the contention of the writer that mineral exploration programmes should *not* be guided by some underlying philosophy of ore-genesis, as Darnley suggests (1965, p. 108) — at least, not ones designed to find more tin deposits — but by known relationships between tin deposits and associated rocks — relationships which have been determined in the field, the mine and the laboratory and which can, for the most part, be rechecked at will. Probably there are many who would favour Darnley's view, not the writer's view, yet they would find it difficult to show how any theories concerning the genesis either of the gold in the South African Banket, or of the Banket itself, facilitated further exploration in the gold-field after the initial discovery had been made and the early limited workings had demonstrated that economically interesting concentrations of the precious metal were essentially confined to the conglomerate!

Because it is a fact that the overwhelming majority of known primary tin deposits occur within, or close to, intrusive or effusive granitic rocks*), spatial and any other relationships which may exist between these two groups are of the utmost importance to those designing tin exploration programmes. In particular, it is vital that they should know which relationships are found only in one or a few localities and which appear to be common to all well-investigated tin-fields.

This paper, which is an amplification of a section of another published recently (Hosking, 1965) concerns itself with the relationships referred to above. In it the writer has confined himself, as far as possible, to facts: in particular, he has deliberately excluded, whenever it has been reasonable so to do, theories which have been proposed to account for the various relationships, although he has more than a passing interest in them.

*

There are many granitic regions whose geology is well-known which are virtually devoid of tin deposits, and others in which the known tin deposits are of limited or of no economic importance — at least, at present. Scotland

*) 1. The term "granitic" is used in this paper to cover both acid and intermediate rocks.

2. Small quantities of minerals in which tin is an essential component do occur, but not in economically interesting amounts, in certain deposits which are not closely spatially related to granitic rocks and which are not generally thought to owe any of their characters to processes intimately connected with the formation of granitic rocks. Examples of such deposits include the Mbeya carbonatite, in which a little cassiterite has been reported (Fawley and James, 1955, pp. 580-581), and the dunite, platinum-bearing pipe at the Driekop mine, Eastern Transvaal. In the concentrates from this mine Stumpfl (1961, pp. 840-841) found a new mineral whose formula is $Pt_4Sn_3Cu_4$.

3. Stempok (1963, p. 69) records that in 1960 he made a statistical analysis of the literature data on the position of Sn-W-Mo deposits with respect to granitic rocks and that this "established the fact that the deposits are closely connected with acid or intermediate igneous intrusive rocks. That chemically similar effusives were not considered in this study is surprising. From 285 (100%) ore deposits taken into consideration 114 (40%) are associated with the endocontact zone of intrusive bodies, 83 (29%) occur in the exocontact as well as endocontact zone and 70 (24.5%) deposits are limited only to the exocontact zone of granitic intrusions. In 18 (6.5%) cases no data on the position of the deposits to granites were available".

provides a good example of the first of the second.

From the point of view of the writer, the differentiation between the stanniferous and the non-stanniferous granites, and his work on the differentiation between the stanniferous and the non-stanniferous granites, could be achieved without having to do so.

It is also well-known that within the west of England, much of the exposed rocks are devoid of mineralisation. Obviously, in such an area, it is of the utmost importance to know about the controls which determine the primary tin deposits there and the secondary tin deposits.

There can be no doubt that, in the search for new tin deposits any area covered by the saturation methods of prospecting (and the selection of targets — regardless of the views held by the selector) will be determined by the views held by the selector. Always such views will determine the exploration programme, and the results from most, if not all, stages of the search.

In the following portion of the paper, the temporal, chemical and "granite"/tin relationship.

Temporal

Despite the fact that tin deposits of all ages from Pre-Cambrian to Tertiary are of rather greater importance to the search for tin than is thought to be the case in the past.

Rankama's investigations (1956) of the elements (Rb, Cs, Li, Be, Ba, some of which are enriched, in trace amounts, in the older granites, were insufficient to enable him to distinguish between the older and the younger granites, including tin. There seems, however, to be a difference between those granitophiles and those granites, and so it might be argued that the concentrations of tin are also more likely to be higher in the older granites than with the 'older' ones. The facts that there is no absolute proof that tin deposits are genetically related to granites, and, in addition, the trace tin content of granites from different provinces but from different sampling points to same (this paper will prove), so it is doubtful if it is as some of the other granitophile elements.

*) The word 'stanniferous' is generally used to describe rocks with which primary tin deposits are closely associated.

provides a good example of the first and the North American continent of the second.

From the point of view of the tin explorationist there are certainly granites *and* granites, and his work would be vastly facilitated were he able to differentiate between the stanniferous *) and the barren, particularly if this could be achieved without having to do much field or laboratory work.

It is also well-known that within a tin province, such as that of the south-west of England, much of the exposed granite and invaded country rock is devoid of mineralisation. Obviously, during the search for further tin deposits in such an area, it is of the utmost importance to know as much as possible about the controls which determined the spatial relationships between the primary tin deposits there and the associated granite.

There can be no doubt that, unless the view is taken that when searching for new tin deposits any area containing granites is worth subjecting to saturation methods of prospecting (and a case might be made for such a view), the selection of targets — regardless of their size — must be largely determined by the views held by the selector concerning granitic-rock/tin relationships. Always such views will determine, to a little or great extent, the nature of the exploration programme, and they will colour the interpretation of the results from most, if not all, stages of the work.

In the following portion of the paper are considered, in the following order, the temporal, chemical and mineralogical, and spatial aspects of the "granite"/tin relationship.

Temporal aspects

Despite the fact that tin deposits are associated with granitic rocks ranging in age from Pre-Cambrian to Tertiary, the age of a given granitic body may be of rather greater importance to the tin explorationist than was generally thought to be the case in the past.

Rankama's investigations (1946) indicated that certain granitophile elements (Rb, Cs, Li, Be, Ba, some rare earths, Ta and Pb) become progressively enriched, in trace amounts, in successively younger granites, but his data were insufficient to enable him to comment on the behaviour of certain others, including tin. There seems, however, no reason why tin should behave differently from those granitophile elements which Rankama investigated thoroughly, and so it might be argued that economically interesting concentrations of tin are also more likely to be closely associated with the 'younger' granites than with the 'older' ones. Against such lines of reasoning are the facts that there is no absolute proof that granites and spatially related primary tin deposits are genetically related — they may be neighbours, not kinsfolk: and, in addition, the trace tin content of granites of the same age, not only from different provinces but from the same province, is commonly widely different from sampling point to sampling point (as data presented later in this paper will prove), so it is doubtful if tin does show the same distribution trend as some of the other granitophile elements.

*) The word 'stanniferous' is generally used in this paper to describe granitic bodies with which primary tin deposits are closely spatially related.

Nevertheless, Pereira and Dixon (1964—65, pp. 518—520), as a result of a statistical study, claim that known tin deposits become progressively more plentiful on ascending the geological time scale from the Pre-Cambrian to the Tertiary. This, they think, suggests that tin is "progressively concentrated by granitization processes".

That the Pre-Cambrian granites appear to be associated with comparatively few tin deposits has been commented on by Sullivan (1948, p. 476) who observes that "tin is normally associated with acid granite and Daly... has estimated that nine-tenths of the acid granites occur in the Pre-Cambrian", but in spite of this "the early Pre-Cambrian terrains are conspicuously poor in tin, despite their high proportion of acid granites".

It might be argued that in part, at least, Pre-Cambrian granite terrains have few tin deposits because erosion has eliminated many of them. Certainly, the tin potential of an area is to no small degree determined by the extent to which it has been eroded. That xenothermal tin deposits of Pre-Tertiary age are exceedingly rare (the deposit at Mount Pleasant, New Brunswick is a notable exception) is probably because such deposits develop near the surface and hence are generally quickly destroyed by sub-aerial agents. On rare occasions they have been preserved by a series of fortuitous events such as depression followed by their rapid burial by sediments laid down under tranquil conditions.

Erosion may simplify exploration and subsequent mining by exposing the granites and related ore-bodies and, on occasion, by releasing cassiterite from numerous sub-economic veinlets (as in Nigeria) or from low-grade stanniferous pegmatites (as in the Congo) and then reconcentrating the tinstone to such a degree that economically important placers are developed.

A study of the form of a stanniferous batholith and the nature and amount of erosion to which it and the invaded rocks have been subjected may go some way towards indicating broadly where primary tin deposits of importance are most likely to occur and where placers should be sought. Thus, in Malaya, the granitic mass which extends from one end of the country to the other, is characterised by a series of ridges whose strikes broadly parallel the long axis of the peninsula. The granite ridge (the Main Range) fringing the eastern side of the Kinta Valley was intruded to a greater height above a given datum than the remaining granite, and ridges to the east of it were emplaced at progressively lower horizons. Consequently, as a result of erosion, in the vicinity of the Kinta Valley little more than the roots of lodes are preserved and most of the cassiterite recovered has been from placers. On the east coast, on the other hand, many of the granite cusps and ridges are still buried and many of the associated tin lodes are still largely intact; consequently, there one finds a number of hard-rock tin mines (of which Pahang Consolidated is by far the most important) but not a single stanniferous placer of major importance. *)

Within a given region granitic masses of widely differing ages may occur and tin deposits may be associated with only one of these: alternatively, the nature of the tin deposits may vary according to the granite with which they

*) There are a few small gravel-pump mines there, and cassiterite was recovered by dredging in the vicinity of the abandoned Bundi (hard rock) mine, but these operations are of slight importance when compared with scores in the Kinta Valley.

are associated. Thus, in Thailand the Younger (late Cretaceous) Granite (Triassic?) Granite (Brown *et al.*, 1949, p. 236) "... in the Wales and in the contiguous Stanthorpe Blue Tier district of Tasmania, the barren granite (granodiorite or adamellite) that the Karagwe District of Tanzania of granite gneiss which was, at a comparatively late stage, invaded by a magma which consequently gave rise to the tin veins occurring in Nigeria, stanniferous pegmatites, of which are scattered in the Older Granites whilst the rich cassiterite placers, the tin-bearing veins and from the granite itself in which. According to Jacobson, *et al.* (1964, p. 168) results from the Older Granites suggest a complex orogeny during the late Cambrian age is clearly indicated for the Younger C

Bilikin (1955) notes that although a number of separate occasions within a deformation to be deposited in association with ultra-acidic and pegmatites of the middle (M3) stage hypabyssal and volcanic equivalents of the Ta and Nb, that of the late stage tends to be possibly W and Mo.

The writer believes that Bilikin has overestimated the number of "igneous" rocks and mineral deposits which develop. It is considerably more variable than the latter is broadly correct then it can still be of great targets in certain areas whose geology is relatively unexplored for tin deposits. (1962) have demonstrated that this is so in the recent recognition of tin at Mount Pleasant, New Brunswick. We would have listed the sulphide-cassiterite mineral assemblage expected and, if mineralised with the rhyolitic wall rocks, it is of the correct

Finally, although it has sometimes been stated that tin does not develop until after the associated major activity have been completed, this is, by no means true. At Wheal Fortune, Cornwall, a swarm of cassiterite veins and displaced by a porphyry dyke (Collins, 1912, p. 94). The problems which such phenomena pose are obvious and need not be commented on. Fortunately, they are rare.

are associated. Thus, in Thailand primary and secondary deposits occur with the Younger (late Cretaceous) Granite but rarely, if ever, with the Older (Triassic?) Granite (Brown *et al.*, 1958, pp. 27—28). According to Edwards and Gaskin (1949, p. 236) "... in the New England district of New South Wales and in the contiguous Stanthorpe district of Queensland, and again in the Blue Tier district of Tasmania, the "tin-granite" has invaded an earlier barren granite (granodiorite or adamellite)". Pereira (1963, pp. 17—18) notes that the Karagwe District of Tanzania consists essentially of a mobilised dome of granite gneiss which was, at a comparatively late stage in the history of the area, invaded by a magma which consolidated as granite and which, in turn, gave rise to the tin veins occurring in the phyllite fringing the gneiss. In Nigeria, stanniferous pegmatites, of minor economic importance, are widely scattered in the Older Granites whilst the Younger Granites are the source of rich cassiterite placers, the tin-bearing mineral having been derived from small veins and from the granite itself in which it is locally sparsely disseminated. According to Jacobson, *et al.* (1964, p. 168) "... available (age determination) results from the Older Granites suggest that they were emplaced in one complex orogeny during the late Cambrian and early Ordovician. A Jurassic age is clearly indicated for the Younger Granites ...".

Bilikin (1955) notes that although granitic rocks may develop on a number of separate occasions within a deforming geosyncline, tin is only likely to be deposited in association with ultra-acid potassic granites, alaskites, aplites and pegmatites of the middle (M3) stage and with the granites and their hypabyssal and volcanic equivalents of the late (L2) stage. He also suggests that whilst the middle tin stage may be associated with W, Mo, Bi, F, Li, Be, Ta and Nb, that of the late stage tends to occur with Pb, Zn, Ag, As and possibly W and Mo.

The writer believes that Bilikin has over-generalised; but even if the "igneous" rocks and mineral deposits which develop in a deforming geosyncline are considerably more variable than the latter states, if the picture he draws is broadly correct then it can still be of great value during the selection of targets in certain areas whose geology is reasonably well-known but which have been but little explored for tin deposits. Indeed, McCarthey and Potter (1962) have demonstrated that this is so in the Canadian Appalachians. These geologists state (*op. cit.*, p. 87) that "had this paper been written a few years ago, we would have listed the sulphide-cassiterite assemblage (L2) expected in the late phase (Mississippian in the Appalachians) as 'missing', yet the recent recognition of tin at Mount Pleasant, New Brunswick, is exactly the mineral assemblage expected and, if mineralisation is roughly synchronous with the rhyolitic wall rocks, it is of the correct age".

Finally, although it has sometimes been stated that primary tin deposits do not develop until after the associated major and minor phases of "igneous" activity have been completed, this is, by no means, always the case. At Great Wheal Fortune, Cornwall, a swarm of cassiterite-bearing veins has been cut and displaced by a porphyry dyke (Collins, 1912, p. 74) and at Zinnwald stanniferous veins are cut by aplite dykes (Thomas and MacAlister, 1920, p. 94). The problems which such phenomena pose during prospecting are obvious and need not be commented on. Fortunately, they are comparatively rare.

Chemical and mineralogical aspects

Both for academic and for strictly practical reasons geologists and others have long attempted to give an unequivocal answer to the question: Are there recognisable chemical and/or mineralogical differences between granitic rocks with which tin deposits are associated and those which do not have such associations? In other words, is it possible to differentiate between "stanniferous" and "barren" granites? To anticipate the nature of the evidence about to be presented, the answer is that whilst chemical/mineralogical studies enable differentiation to be made between stanniferous and barren granites in some regions they do not do so in others.

There are certainly granites and granites, when one is thinking of their genesis, and from the same point of view there are probably tin deposits and tin deposits. So little is known with certainty about the source of the tin in primary deposits. In one instance it may have been derived from the same source as the magma from which the associated granite originated: in another the granite magma and the tin may have originated from quite different "primary shells" of the Earth: in yet another the tin may have been mobilised during the granitisation of stanniferous sediments. In the writer's opinion it might be expected that granite associated with tin deposits which originated in the first way noted above might contain significantly higher trace amounts of tin, and possibly other elements associated with tin in lodes, etc., than other truly magmatic granites which are barren of tin deposits. In the second case noted above stanniferous and barren granites might contain essentially the same primary trace elements and in essentially the same concentrations, whilst in the third case it seems likely that the concentration of trace tin in the stanniferous granites would be appreciably greater than that of their barren counterparts.

Attempts to solve the problem as to whether stanniferous and barren granites are generally chemically and/or mineralogically different have suffered because generalisations have commonly been made which have been largely based on the results of comparisons between stanniferous and barren portions of the same batholith and by comparing the trace element content of granites from different regions without taking into account variations which might be related to such factors as the distance of sampling points from mineral deposits, the nature of the mineralisation and the location of the sampling points with respect to the various topographic features of the original surface of the granite.

If it were conceded that *all* stanniferous batholiths originated in either the first or third way mentioned above, then it is conceivable that any sample of granite, which had not been altered by post-consolidation processes, from a stanniferous batholith would contain a significantly greater concentration of tin than a similar sample from a barren batholith regardless of the mode of origin of the latter. Unfortunately, and contrary to what some have claimed, the trace tin content of random samples of unaltered granite will not permit one always to say whether they were taken from stanniferous batholiths or not. If the tin content of the whole granite sample or of its biotite is high then the batholith is likely to be stanniferous, but if it is low then it may or may not be barren: data which appear later in the paper will confirm this observation.

It is pertinent to consider a few differences which have been noted between barren granites which, in most cases, are lithologically similar to the barren granites, and to record and consider the differences concerning the significance of the differences.

At the outset it can be stated that the "ore elements" content of samples from the same batholith are to be expected to be similar, such as the fact that batholiths at the same place may, for same reason or reasons, contain large amounts of tin, etc. Assimilation and dilution of some of the trace metals may occur. Trace elements may tend to accumulate in the cusps and ridges, and those cusps and ridges ore-bodies closely associated with them. They have been, on occasion, preferred components and therefore became enriched in amounts of the "ore elements". The envelopes of anomalously high concentrations around the mineral deposits and the rock alteration.

Considerable data are available (Hawkes and Webb, 1962, p. 52) and (Hawkes, 1962, p. 100, fig. 1, wall), a limited number of samples have been analysed (Hawkes, 1962, p. 52) as mapped by Ghosh (1934), and (Hawkes, 1962, p. 52, fig. 1, wall) "successive phases of the granite intrusions" (Hawkes, 1962, p. 52, fig. 1, wall) the heart of the Cornish tin field (Hawkes, 1962, p. 52, fig. 1, wall) characteristics despite the geographical isolation (Hawkes, 1962, p. 52, fig. 1, wall). Subsequent work (Hosking, 1965, p. 100, fig. 1, wall) 2 granites are, in fact, one phase (Hosking, 1965, p. 100, fig. 1, wall) mass do not possess distinctly different characteristics (Hosking, 1965, p. 100, fig. 1, wall) has been demonstrated (Hosking, 1965, p. 100, fig. 1, wall) that samples of whole granite and (Hosking, 1965, p. 100, fig. 1, wall) phase commonly display marked differences (Hosking, 1965, p. 100, fig. 1, wall).

Trace element variation

Carnm

(After Hawke

<i>Element</i>	<i>Concentration Phase 1 Granite</i>
Cu	8
Ni	10
Sn	25
Li	700

It is pertinent to consider at this point chemical and mineralogical differences which have been noted in various regions between stanniferous and barren granites which, in most cases, are probably portions of the same batholith, and to record and consider the conclusions arrived at by various workers concerning the significance of these differences to the tin explorationist.

At the outset it can be stated that great variation in the tin and "associated elements" content of samples of granite taken from different parts of the same batholith are to be expected. This variation is due to a number of causes such as the fact that batholiths are composite bodies, and each granitic unit may, for same reason or reason unknown, contain distinctly different trace amounts of tin, etc. Assimilation of country rock might cause a locally marked dilution of some of the trace metals and enhance the concentration of others. Trace elements may tend to accumulate in structural traps such as the tops of cusps and ridges, and those cusps, etc., which were subsequently to have ore-bodies closely associated with them might, even in the pre-lode stages, have been, on occasion, preferred routes for some of the early ore-forming components and therefore became particularly endowed with high trace amounts of the "ore elements". Finally, during the phase of ore-genesis, envelopes of anomalously high concentrations of ore elements may develop around the mineral deposits and extend well beyond the zones of obvious wall-rock alteration.

Considerable data are available in support of the above. Webb (see Hawkes and Webb, 1962, p. 52) analyzed, from the Carnmenellis Mass (Cornwall), a limited number of samples of granite from each of the three phases, as mapped by Ghosh (1934), and concluded from the results (Table 1) that "successive phases of the granite constituting the Carnmenellis intrusion in the heart of the Cornish tin field have widely differing trace metal characteristics despite the geographical proximity to all phases of mineralisation". Subsequent work (Hosking, 1965, p. 6) has shown that Ghosh's Phases 1 and 2 granites are, in fact, one phase and that the two phases which make up the mass do not possess distinctly different trace element patterns. In addition, it has been demonstrated (Hosking, 1965, p. 6 and 1964, Table 7, opp. p. 238) that samples of whole granite and of biotite from different parts of the same phase commonly display marked differences in their trace content.

Table 1
Trace element variation in the various phases of the
Carnmenellis Granite

(After Hawkes and Webb, 1962, p. 52)

Element	Content in fresh rock (p.p.m.)		
	Phase I Granite	Phase II Granite	Phase III Granite
Cu	8	4	2
Ni	10	4	2
Sn	25	5	30
Li	700	1,500	3,000

Jedwab (1955), having studied the lithium and tin content of the micas and feldspars of two neighbouring granitic masses in Morbihan, France, one of them, at La Villeder, having tin lodes associated with it and the other, at Guehenno, being barren, made the following conclusions:—

i. The arithmetic mean of the lithium content of the feldspar samples of La Villeder is significantly greater than that of the corresponding Guehenno samples (141 p.p.m. *v.* 36 p.p.m.) and the same applies to the tin content of the biotites (110 p.p.m. *v.* 67 p.p.m.) and the muscovites (120 p.p.m. *v.* 71 p.p.m.).

ii. The tin content of both feldspars and micas increases significantly in the vicinity of lodes.

The comparatively small number of samples analyzed by Jedwab militates against the unqualified acceptance of his conclusions.

Others have noted both obvious and subtle chemical and mineralogical differences between certain stanniferous and barren granites. Some of the observations are based simply on the examination of two masses (as was Jedwab's, which is noted above, and Jones', which is cited below) and all the remainder (for a number of obvious reasons) are based on data obtained from work on only a modest fraction of the exposed granites of the world. On these scores alone it follows that of the declared differences between stanniferous and barren granites, which are given below, some may be widely applicable whilst others may have a comparatively restricted application.

Further work may demonstrate that there are certain mineralogical and/or chemical differences between, say, stanniferous and barren Tertiary magmatic granites in one metallogenetic province, but that they are distinctly different from those which permit a similar distinction to be made between Tertiary granites of another province. In addition, significant differences displayed by stanniferous and barren Tertiary granites may be quite distinct from those characteristics of their Hercynian counterparts, and so on.

The nature of certain declared differences between stanniferous and barren granites is indicated by the following selection, but it must be pointed out that the workers never state whether they believe the differences to be due to pre-ore or post-ore development processes, though in some cases there is little doubt what their views are.

Jones (1925, pp. 54—55) contends that stanniferous granites are of the acid type and states that the highly stanniferous granite of the Main Range of Malaya differs from the virtually barren one of the neighbouring Benom Range in this respect. He also notes that, whereas lepidolite and muscovite are abundant and hornblende is rare or absent in the former granite, the opposite is the case in the latter. Doubtless, Sullivan (1948) might argue that the Benom Mass lacks significant tin deposits because the element is probably 'locked up' in the hornblende and, though analyses are not available to test such a view, the writer cannot think of a single major tin field in which hornblende granite is dominant.

Ingham (1949, p. 21) is of the opinion that it is unlikely that any profitable tin deposits will be found in the Malayan Main Range area "to the south-west of the Ulu Tangli to Ulu Benus-Kenabou lineation" because there the granite, unlike that of the tin-mineralised parts of the Main Range, shows

"no obvious indications of usual granite of rather different texture". It is a generalisation, made by Western geologists of Malayan and other islands, that the granite of Langkawi Island is intensely tourmalinised (and greisenised) by quartz/tourmaline dykes which occur in the granite — (e.g. Leow, 1963)!

It is claimed by the author of "South Africa" (on p. 299 of the Printer in Pretoria, in 1959) that in the extensive Archaean granite area being, in the main, granodioritic "silica". The only known deposits are tites, containing cassiterite and tantalum. The 64,000 dollar question was the geologic environment from that which prevailed elsewhere to questions such as this are desperate.

Edwards and Gaskin (1949, p. 22) tin deposits are associated are truly mafic, low in calcium and magnesium, and the ferrous granites from Australia and Tasmania. The writer believes, for reasons given later, are associated with magmatic granites and not with stanniferous granites. He also knows that magmatic granites have precisely the same chemical character. He knows the differences between the SiO_2 , CaO and FeO contents of the tin deposits and that of the mafic granites. The contents of Table 2 will substantiate Rabinovic's claims.

Rabinovic claims that granitic rocks of metallogenetic zones, have unique mineralogical features which enable them to be recognized and made between them and the equally unique "polymetallic" metallogenetic zones. The conclusions summarised in Table 3. In support of some of the writer's fairly stated that these tabulated characteristics of the tungsten zone are, indeed, broadly those of the writer has first-hand knowledge. The Corroboration of most of the characteristics that he mentions, that they have enhanced amounts of Nb and Ge nor are they

of Aranyakanon's (1961) investigations of
Haad Som Pan (Ranong Province, Thailand),
following conclusions: —

i. The magnetite content of the stanniferous
of the barren ones.

"no obvious indications of usually associated tourmaline and topaz" and "is of rather different texture". It is interesting to compare this view with certain generalisations, made by Westerveld and noted later in this paper, concerning the nature of Malayan and other "stanniferous" granites. It is also to be noted that the granite of Langkawi Island, off the west coast of Malaya, is locally intensely tourmalinised (and greisenised), particularly in the vicinity of certain quartz/tourmaline dykes which contain topaz amongst their accessory minerals, yet there no tin deposits — economic or otherwise — are known (Hutchinson and Leow, 1963)!

It is claimed by the author of "The mineral resources of the Union of South Africa" (on p. 299 of the 4th edition: published by the Government Printer in Pretoria, in 1959) that the almost complete lack of tin mineralisation in the extensive Archaean granite and gneiss of the Transvaal "is due to their being, in the main, granodioritic in composition and not markedly rich in silica". The only known deposits are a few comparatively unimportant pegmatites, containing cassiterite and tantalite/columbite near Palakop in the Klein Letaba area. The 64,000 dollar question, which remains to be answered, is in what respect was the geologic environment different in the vicinity of Palakop from that which prevailed elsewhere in the Archaean granite terrain. Answers to questions such as this are desperately needed.

Edwards and Gaskin (1949, p. 236) contend that the granites with which tin deposits are associated are truly magmatic, very rich in silica and unusually low in calcium and magnesium, and they cite portions of analyses of stanniferous granites from Australia and Tasmania in support of their contention. The writer believes, for reasons given later, that most tin deposits, but not all, are associated with magmatic granites and he agrees that the chemical character of stanniferous granites is generally as stated by Edwards and Gaskin; but he also knows that magmatic granites from tin-barren provinces may possess precisely the same chemical character. He also knows that there are no marked differences between the SiO_2 , CaO and MgO content of granites associated with very "strong" tin deposits and that of granites associated with very "weak" ones. The contents of Table 2 will substantiate these observations.

Rabinovic claims that granitic rocks, from what he terms tin-wolfram metallogenetic zones, have unique mineralogical and chemical characteristics which enable them to be recognized and which allows differentiation to be made between them and the equally unique granites of the molybdenite and "polymetallic" metallogenetic zones. The characteristics of these granites are summarised in Table 3. In support of some of Rabinovic's findings it can be fairly stated that these tabulated characteristics of the granites of the tungsten zone are, indeed, broadly those of the stanniferous granites of which the writer has first-hand knowledge. The Cornish granites, for example, possess most of the characteristics that he mentions, though the heavy fractions do not have enhanced amounts of Nb and Ge nor are the zircons ever opaque.

Aranyakanon's (1961) investigations of stanniferous and barren granites of Haad Som Pan (Ranong Province, Thailand) allowed him to draw the following conclusions: —

- i. The magnetite content of the stanniferous granites is lower than that of the barren ones.

Table 2
The silica, magnesia, and lime content
of stanniferous and barren granites

Stanniferous Granites							
Locality	Type	Per cent			Remarks	1. Types according to accessory minerals	a. Apatite b. Apatite c. Fluorite d. Fluorite monazite
		SiO ₂	MgO	CaO			
Malaya:							
1. Kledang Range	Biotite granite	74.38	0.51	0.98			
2. Main Range	Tourmaline micro-granite	73.29	0.08	0.70		2. Major accessory minerals	Apatite, m fluorite, il xenotime, cassiterite.
3. Tronoh area	Biotite granite	77.38	0.14	0.67			
S. Africa (Transvaal):							
4. Zaaipplaats mine	—	72.56	0.61	1.63		3. Uncharacteristic or absent accessory minerals	Titanite, m
5. Groenfontein mine	—	72.67	0.79	2.13	The Lease granite		
N.W. France:							
6. Nozay	2 mica granite	74.15	0.40	0.40		4. Characteristics of the zircon	Often opa U and T 1.0%
7. St.-Renan	2 mica granite	71.60	0.60	1.60			
S.W. England:							
8. Carnmenellis	Porphyritic biotite granite	71.95	0.69	1.47	Major tin-fields near by	5. Characteristics of the apatite	Contains elements
9. Dartmoor	Coarse porphyritic biotite granite	71.20	0.60	1.60	Only minor tin-fields near by	6. Characteristics of the fluorite	Often lilac considerab ties of Y, rare earth
Portugal:							
10. Lagares-do-Estanho	Porphyritic 2 mica granite	69.96	0.29	1.82		7. Characteristics of the pyrite	Contains
Barren Granites							
N.W. France:							
11. Bécon	2 mica granite	69.60	1.65	1.5	No SnO ₂ , but MoS ₂ /CuFeS ₂ /ZnS deposits present	8. Characteristics of the heavy fraction	Enhanced of Sn, Ti, Ge, F
Gt. Britain:							
12. Charnwood Forest	Sodic leucogranite	76.70	0.65	1.10		9. Characteristics of the biotite	Enhanced of Ti, Sn,
13. Arran (Scotland)	Biotite-hornblende granite	75.65	0.15	0.91	From Central Ring-Complex	10. Average amounts in the rock	Sn, 10 g/ Mo, 0.5-4 Pb, 20-50
North America:							
14. Elk Peak, Montana	Biotite-hornblende granite	72.48	0.15	1.04		11. Nature of the distribution of the elements	Sn-Biotite cassiterite Mo-Feldsp ilmenite Pb-Feldsp Ti-Biotite Fe-Biotite.
15. New Hampshire	Biotite granite	72.5	0.20	1.10			

Complete analyses, and other details, of the rocks included in the above table may be obtained from the following sources: - Nos. 1-3. Ingham and Bradford (1960.

Complete analyses, and other details, of the rocks included in the above table may be obtained from the following sources: - Nos. 1-3, Ingham and Bradford (1960, p. 60); Nos. 5 and 6, Strauss (1954, p. 56); Nos. 6, 7 and 11, Chauris (1965, pp. 87, 107 and 140); Nos. 8 and 9, Hosking and Shrimpton (1964, p. 139); No. 10, Coteló Neiva (1944, p. 8); No. 12, Hatch, Wells and Wells (1949, p. 192); Nos. 13-15, Turner and Verhoogen (1962, p. 265).

Table 3
(After Rabinovic)

Characteristics of granitic rocks of metallogenetic zones

		Tin-tungsten zone	Molybdenum zone	Polymetallic zone
Remarks	1. Types according to accessory minerals	a. Apatite b. Apatite-monazite c. Fluorite d. Fluorite-monazite	a. Titanite-type	a. Zircon-type for rocks of the late development stages
	2. Major accessory minerals	Apatite, monazite, fluorite, ilmenite, xenotime, thorite, cassiterite, zircon	Titanite, magnetite, apatite, zircon, orthite, molybdenite	Zircon, ilmenite, fluorite
	3. Uncharacteristic or absent accessory minerals	Titanite, magnetite	Monazite, xenotime, cassiterite, thorite	Titanite, magnetite, monazite, xenotime, cassiterite
The Lease granite	4. Characteristics of the zircon	Often opaque with U and Th up to 1.0%	Transparent: highly radioactive (up to 0.5% U and Th)	Transparent: U and Th under 0.1%
	5. Characteristics of the apatite	Contains rare earth elements	Rare earths are not characteristic	Apatite is not characteristic
Major tin-fields near by Only minor tin-fields near by	6. Characteristics of the fluorite	Often lilac; contains considerable quantities of Y, Th and rare earths	White; transparent contains an insignificant mixture of rare earths	White; transparent
	7. Characteristics of the pyrite	Contains Sn and Pb	Contains Mo and Pb	Contains Pb
	8. Characteristics of the heavy fraction	Enhanced amounts of Sn, Ti, Th, Nb, Ge, F	Enhanced amounts of Ti, Mo, Ni, Co	Enhanced amounts Zr, Ti, F
No SnO ₂ , but MoS ₂ /CuFeS ₂ /ZnS deposits present	9. Characteristics of the biotite	Enhanced amounts of Ti, Sn, Li	Enhanced amounts of Cu and Ba	—
	10. Average amounts in the rock	Sn, 10 g/t Mo, 0.5-4 g/t Pb, 20-50 g/t	Sn, under 10 g/t Mo, 1-2 g/t Pb, 15-25 g/t	Sn, under 10 g/t Mo, 1-2 g/t Pb, 20-30 g/t
From Central Ring-Complex	11. Nature of the distribution of the elements	Sn-Biotite, ilmenite, cassiterite Mo-Feldspar, ilmenite Pb-Feldspar Ti-Biotite, ilmenite Fe-Biotite, ilmenite	Sn-Titanite Mo-Feldspar, titanite Pb-Feldspar Ti-Titanite, biotite Fe-Magnetite, biotite	Sn-Biotite, ilmenite Mo-Feldspar Pb-Feldspar Ti-Biotite Fe-Biotite, ilmenite

d in the above table
and Bradford (1960,
hauris (1965, pp. 87,
139); No. 10, Cotel
); Nos. 13-15, Turner

ii. The cassiterite deposits occur in albitised granite except where limestone has been assimilated.

iii. Feldspar thermometry indicates that the temperature of formation of the tin-bearing granites was lower than that of their barren counterparts.

It is interesting to note that the tin/albitised granite association is not by any means confined to Thailand. Serebryakov (1959), for example, notes that tin mineralisation is only associated with those parts of the granite massifs of the upper reaches of the Kolyma River which have been subjected to sodium auto-metasomatism.

Westerveld's (1936) studies led him to conclude that the stanniferous granites of Malaya, Indonesia, Cornwall and Saxony are all essentially biotite or biotite/muscovite types and commonly prophyritic and that they do not possess any macro characteristics which are different from those of mica-bearing barren granites. He did, however, conclude that "there are some indications of a higher content of rare elements which distinguish them (i.e., the stanniferous granites) from common granites: there is an exceptional content of rare earths in the granites of Malaya; small quantities of tin in the black mica, in the quartz and the feldspar of the Banka granites, some traces of Li, Sn, Bi, Cu, Co and U in the zinnwaldite mica of the tinbearing granites of Saxony, and of Ga, Sn and W in the biotite of the East Pool mine near Redruth, Cornwall".

The danger of giving much weight to Westerveld's conclusions lies in the fact that his samples cannot be considered as truly representative of the tin-fields of interest to him. In addition, he has ignored macro differences between stanniferous and barren granites in at least one of his regions *) and though such differences *may* be due largely, or entirely, to post-consolidation processes they are, none-the-less, of real importance to the tin explorationist. Finally, he, in common with other workers on much the same problem, does not make it clear where the boundaries lie in a given region between the tin-bearing granites and the barren ones.

Barsukov and Pavlenko (1956) having analyzed, by spectrographic methods, samples of stanniferous and barren granites from the U.S.S.R. concluded that (p. 4) "the granite massifs which do not bear tin mineralisation contain tin in quantities below 5 g/t, which corresponds with the Clarke figure for it. But massifs with which tin is genetically connected, in varieties of rock that have not been changed by post-magmatic processes and other processes occurring close to the contact, contain tin in 3 to 5 times larger quantities than

*) Davison (1930, pp. 6-7), after studying mineralisation in Cornwall for many years, concluded that:

i. In areas without lodes the granite usually contains much biotite, but seldom tourmaline.

ii. In areas which are highly mineralised the granite always contains some tourmaline, usually accompanied by much muscovite.

iii. Near poor lodes of low tin content biotite is usually present, but near rich lodes it is invariably absent.

He also observed that "it appears that the granite composition does help one to distinguish between hopeful and hopeless areas. The texture is also a useful indicator. In highly mineralised country the feldspar crystals of the granite are ill-formed and are usually much sericitised and kaolinised, and in unmineralised country the feldspars are fresh and unaltered, of large size, and often idiomorphic, or nearly so".

the Clarke figure for its distribution revealed that the biotites contain more tin than barren granites.

Whilst observations concerning tin are not pertinent to note here that the work was done by a geologist and his co-worker explained just what they meant by "granite massifs". Are they referring to small exposures, such as the Land's End granite, or even to whole batholiths?

Rattigan (1963), having carried out the work just described, arrived at much the same conclusion. He also notes that where tin deposits occur in granites "the trace tin content (in ppm) is much higher from that of nonstanniferous granites". This is not surprising as the Australian workers have found a difference between modal biotite and absolute tin content, although variations in the trace tin content of the same granite do occur, a concentration of 50 p.p.m. appears to be significant for the granite concerned. Certainly, his contention is correct.

Despite the close agreement between the Australian and Russian workers and Hosking, Roberts and Ahmad (1963) who found a content of 33 "whole granite" samples from the stanniferous Carnmenellis mass (Cornwall) of 2 to 5 g/t, by the gallein/methylene blue method, 2 of the granite samples, and 5 of the barren samples (Figure 1 and Table 5). That the tin content is largely substantiated by the results of the Russian granites from the Carnmenellis mass (Cornwall) by Webb (1947) in his unpublished work.

It is to be emphasised that as the tin content is not composed of particularly large tin lodes, the richest tin lodes ever recorded from the Carnmenellis mass.

Chauris (1965, pp. 114-118) has observed that with tin, etc., mineralisation associated with a convincing chemical evidence in the tin content of the whole granite massifs. The clue as to whether a given granite mass is stanniferous. Thus Chauris' findings broadly agree with those of Cornwall, but they are diametrically opposite to those recorded earlier) which arose from the tin content.

In order to demonstrate still further the tin association problem it can be added that the Nigerian "Younger Granite" migmatites.

*) Chauris' exact observation (p. 114) "avoir de liaison directe entre les teneurs en étain et l'efficacité stannifère".

the Clarke figure for its distribution, i.e., 16 to 30 g/t". Their analyses also revealed that the biotites contain almost a hundred per cent of the tin in the granites.

Whilst observations concerning these results will be made later it is pertinent to note here that the work would have an enhanced value had Barsukov and his co-worker explained just what they had in mind when they spoke of "granite massifs". Are they referring to small granite cusps or to large exposures, such as the Land's End mass, which occupies 100 square miles, or even to whole batholiths?

Rattigan (1963), having carried out in Australia a similar study to the one just described, arrived at much the same conclusions as the Russians, but he also notes that where tin deposits are associated with highly leucocratic granites "the trace tin content (of the latter) is not significantly different from that of nonstanniferous granitic rocks", a fact which, in his opinion "is not surprising as the Australian and Soviet data show a close relationship between modal biotite and absolute tin content" (p. 140). Also, in his opinion, although variations in the trace tin content of biotites from different parts of the same granite do occur, a concentration of tin in a biotite sample in excess of 50 p.p.m. appears to be significant in indicating a tin association for the granite concerned. Certainly, his published results (Table 4) strongly support his contention.

Despite the close agreement between the conclusions reached by the Australian and Russian workers their findings are not of universal validity. Hosking, Roberts and Ahmad (Unpublished Studies, 1964) determined the tin content of 33 "whole granite" samples and of their biotites from the stanniferous Carnmenellis mass (Cornwall) whose exposure occupies about 50 square miles, by the gallein/methylene blue colorimetric method, and found that only 2 of the granite samples, and 5 of the biotite ones, contained 50 p.p.m. tin (Figure 1 and Table 5). That these low figures are not due to analytic errors is largely substantiated by the results of earlier spectrographic analyses of granites from the Carnmenellis and other stanniferous Cornish granites included by Webb (1947) in his unpublished Ph.D. thesis (Table 6).

It is to be emphasised that associated with the Carnmenellis Mass, which is not composed of particularly leucocratic granites, are some of the largest and richest tin lodes ever recorded from anywhere in the world.

Chauris (1965, pp. 114-118), in an extremely valuable memoir dealing with tin, etc., mineralisation associated with the Armorican Massif, produces convincing chemical evidence in support of his view that in N.W. France the tin content of the whole granite samples and of biotites (Table 7) gives no clue as to whether a given granite mass is likely to be stanniferous or barren *). Thus Chauris' findings broadly agree with those resulting from the work in Cornwall, but they are diametrically opposed to those of Jedwab (which have been recorded earlier) which arose out of his studies in N.W. France!

In order to demonstrate still further the complexity of the tin/granite association problem it can be added that analyses of whole samples of Northern Nigerian "Younger Granite" might commonly yield spectacularly high tin

*) Chauris' exact observation (p. 117) is as follows: "Il ne semble donc pas y avoir de liaison directe entre les teneurs en étain des granites du Pays de Léon et leur efficacité stannifère".

Type

Loc

Quartz-diorite
Granodiorite
Granodiorite
Adamellite
Adamellite
Adamellite

Mt. Morg
Hartley, N
Pokolbin,
Hartley, N
Cullen Ri
Cloncurry

Adamellite
Adamellite
Adamellite
Adamellite

Torrington
Tingha, N
Herberton
Mt. Cam

Granite
Granite
Granite
Granite
Granite
Granite
Granite
Granite
Granite

Stanthorpe
Tenderfie
Tingha, N
Herberton
Heemskirk
Mt. Cam
Aberfoyle
Ardlethan
Ardlethan

The frequency of
of tin in s
Carn

(After H

Tin Content (p.p.m)

51+
41-50
31-40
21-30
11-20
1-10

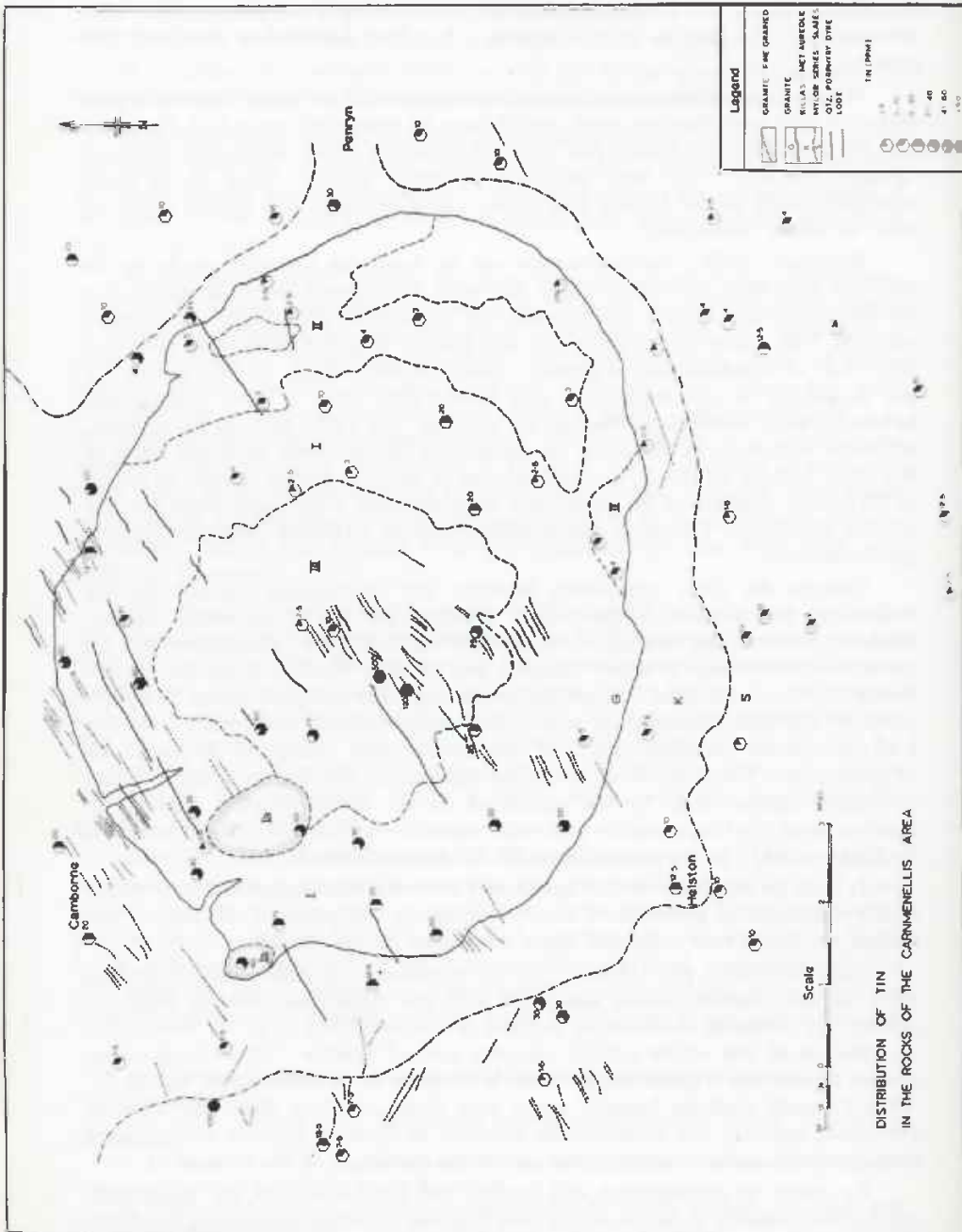


Figure 1

[The Roman numerals and broken lines inside the granite contact indicate Ghosh's (1934) granite phases.]

Table 4
Tin in biotites of Australian granitic rocks
(After Rattigan, 1963)

<i>Type</i>	<i>Location</i>	<i>Sn in biotite (p.p.m.)</i>	<i>Category</i>
Quartz-diorite	Mt. Morgan, Q'ld.	5	
Granodiorite	Hartley, N.S.W.	20	Non- stanniferous provinces
Granodiorite	Pokolbin, N.S.W.	15	
Adamellite	Hartley, N.S.W.	30	
Adamellite	Cullen River, N.S.W.	15	
Adamellite	Cloncurry, Q'ld.	15	
Adamellite	Torrington, N.S.W.	15	Stanniferous provinces — not closely associated with tin
Adamellite	Tingha, N.S.W.	45	
Adamellite	Herberton, Q'ld.	20	
Adamellite	Mt. Cameron, Tas.	55	
Granite	Stanthorpe, Q'ld.	170	Stanniferous granites — tin provinces
Granite	Tenderfield, N.S.W.	75	
Granite	Tingha, N.S.W.	85	
Granite	Herberton, Q'ld.	285	
Granite	Heemskirk, Tas.	190	
Granite	Mt. Cameron, Tas.	325	
Granite	Aberfoyle, Tas.	75	
Granite	Ardlethan, N.S.W.	90	
Granite	Ardlethan, N.S.W.	285	

Table 5
***The frequency of occurrence of various concentrations
of tin in samples of granite from the
Carmenellis Mass, Cornwall***
(After Hosking, Roberts and Ahmad, 1964)

<i>Tin Content (p.p.m.)</i>	<i>No. of samples in each group</i>
51+	2
41—50	3
31—40	1
21—30	1
11—20	7
1—10	19

Table 6
The tin content of samples of granitic rocks
from the Cornish tin province

(After Webb, 1947)

Locality	Nature of sample	Tin content (p.p.m.)
Carnmenellis	Normal granite	30
Carnmenellis	Normal granite	30
Carnmenellis	Normal granite	20
Carnmenellis	Normal granite	5
Carnmenellis	Normal granite	5
South Crofty mine (Carn Brea granite)	Normal granite	5
Carnmenellis	Granite porphyry	20
Carn Brea	Granite porphyry	30
Carn Brea	Aplite	5
Praze		
(Carnmenellis granite)	Fine granite	50
Land's End	Fine granite	5

Table 7
A comparison between the tin content of certain
stanniferous and barren granites from the
Pays de Léon, France

(Data after Chauris, 1965, pp. 114-117)

	Locality	Average Sn content of granite samples in p.p.m.	Average Sn content of biotite samples in p.p.m.
Stanniferous granite	St. Renan	11 (range, 9-16)	62
	La baie de Morlaix	10	
	L'Aber - Ildut	11	
Barren granite	Ploudalmézeau	14	100
	N. E. du Pays de Léon	15	
	Ste-Catherine	20	

values, as Williams, Meehan (1957) cassiterite is not common within any granite may vary. One might generally interpret that granite had been subject to leaching to be found in the region, but it is to mine by hard-rock methods. Younger Granite is devoid of cassiterite as such.

Some would claim that the fundamental question as to whether they are different, which they would claim that the granite was deposited by post-consolidation claim is untenable? Stanniferous cassiterite disseminated in granite (there) is identical with the very probably in the course of the stage of post-magmatic tectonics cannot be accepted without discussion of cassiterite under discussion that they are the same in composition. In the writer's view the element patterns of the cassiterite particularly if there is, as I understand the relationship between the temperature of formation and the element content *).

Summary of the rôle of cassiterite in granite samples of the Pays de Léon

From the evidence presented it is clear that whilst in some regions the granites are distinctly richer in tin than in these regions, if strongly stanniferous whole granite samples also contain cassiterite there are other important factors which may not exist. It follows, therefore, that the results of an exploration program should not occur in a region in which the tin content is little or no value — in fact, particularly disappointing areas in which outcrops of granite are covered by a thick layer of wind-blown material.

In possible tin regions the results of examination and in which

*) Briefly, Dudykina's work shows that in the course of formation the Ti, Nb, Ta, Zr, Hf, Sn, Pb, Ag, As and Sb content increases.

anitic rocks
ince

Tin content (p.p.m.)

30
30
20
5
5
5

20
30
5

50
5

ent of certain
s from the

4-117)

Sn
t of
amples
m.
Average Sn
content of
biotite samples
in p.p.m.

62

9-16)

100

values, as Williams, Meehan, *et al.* (1956, p. 324) note that "primary (accessory) cassiterite is not confined (there) to any one granite and the value within any granite may vary from nothing to over one pound per cubic yard". One might generally interpret such results as indications that provided the granite had been subject to marked erosion, important tin placers are likely to be found in the region, but that major lode systems, which would be profitable to mine by hard-rock methods, would be unlikely to occur there. Certainly the Younger Granite is devoid of major lodes, unless the one at Lirue is classified as such.

Some would claim that this Nigerian data are not entirely relevant to the fundamental question as to whether granites which have tin deposits associated with them are different, *when first emplaced*, from those which do not, because they would claim that probably the so-called primary (accessory) cassiterite was deposited by post-consolidation processes. Has anyone shown that such a claim is untenable? Stemprok (1965, p. 173) makes such a claim for the cassiterite disseminated in the Cinovec granite: he says "the 'primary' cassiterite (there) is identical with the cassiterite in the greisen zones. It originated very probably in the course of cassiteritization of the granite during the greisen stage of post-magmatic transformations". Stemprok's conclusion, however, cannot be accepted without question because although he says the two classes of cassiterite under discussion are identical, it is not certain whether he means that they are the same in *all* respects or simply that they are physically the same. In the writer's view, unless Stemprok has established that the trace element patterns of the cassiterites are identical, the case still remains open, particularly if there is, as Dudykina's work (1959) suggests, a definite relationship between the temperature of formation of cassiterites and their trace element content *).

Summary of the rôle of chemical/mineralogical studies of readily accessible samples of granite in tin exploration programmes

From the evidence presented above it would seem reasonable to conclude that whilst in some regions the stanniferous granites contain biotites which are distinctly richer in tin than those from their barren neighbours, and that in these regions, if strongly leucocratic granites are excluded, the tin content of whole granite samples also permits the same differentiation to be effected, there are other important tin regions in the world where such relationships do not exist. It follows, therefore, that during the reconnaissance stages, at least, of an exploration programme designed to locate any tin fields which might occur in a region in which no tin deposits had ever been recorded, the determination of the tin content of samples of granite or of biotite would be of little or no value — in fact, the results could be quite misleading. This is particularly disappointing to one who might wish to search for tin deposits in areas in which outcrops generally are limited because of a widespread superficial cover of wind-blown sand, glacial debris or even recent alluvium.

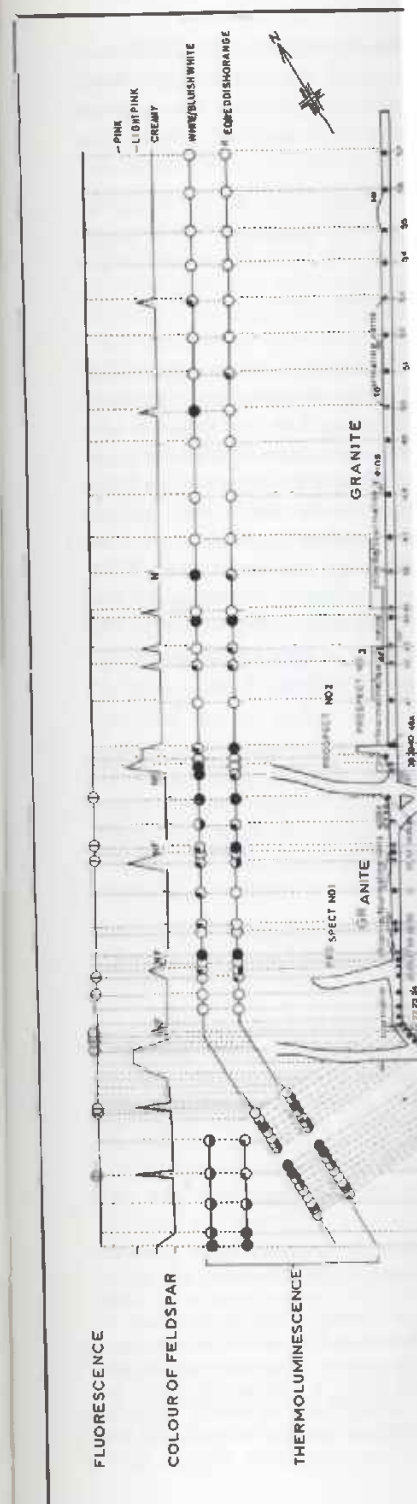
In possible tin regions which have not been subject to intensive geological examination and in which granitic and other outcrops are reasonably plentiful,

*) Briefly, Dudykina's work led him to conclude that with decreasing temperature of formation the Ti, Nb, Ta and Sc content of cassiterites decreases whilst their Pb, Ag, As and Sb content increases.

targets for further study may in part be located by mapping areas of marked alteration, particularly in the vicinity of contacts between granitic and other rocks, though many such areas may prove to lack economically interesting tin deposits or even ones which are of little more than of academic interest. On occasion*) such studies may be advanced by conducting radiometric and thermoluminescent surveys as ore-deposits (not necessarily tin-bearing ones) may be associated with anomalous zones, capable of being revealed by such work, which are much more extensive than the zones of obvious wall-rock alteration. (For further details see Zeschke (1963) and McDougall (1966).) Particularly in areas of marked rock alteration, any veins, but especially mineralised ones, and the rock in the vicinity of such veins should receive special attention, and selected material from them should be subjected to chemical and mineralogical examination of a type specifically selected not only to reveal the presence of cassiterite and other minerals (e.g., stannite, malayite) in which tin is a major constituent, but also to uncover any of the more subtle indications that the granitic rocks are stanniferous. The mineralogical/chemical indications assembled by Rabinovic fall into this category as, in the broad sense, they may be universally valid, as do also trace element studies, particularly of sulphides, which are based on the findings of Warren and Thompson (1945) and El Shazly *et al.* (1956-57). Briefly, Warren and his co-worker concluded that in British Columbia gold, galena, tetrahedrite and sphalerite from tin deposits all contain anomalously high concentrations of tin and so might be used as "pathfinders" for stanniferous deposits. They make the point that "pathfinders" facilitate prospecting because "some elements and minerals which are of economic importance are hard to discover and determine in the field, but are distributed in minute amounts in other minerals which can more readily be found and determined" (*op. cit.*, p. 311).

El Shazly, Webb and Williams, during a study of the trace element contents of epigenetic sphalerites and galenas from many mining centres, found that the sphalerites with the highest concentrations of tin were those from the tin-fields of Cornwall, N.W. France and Portugal (with average tin contents of 156, 200 and 400 p.p.m. respectively). However, sphalerite, which is intimately intergrown with galena, from the essentially tin/zinc Liruei Lode of Northern Nigeria contains only 50 p.p.m. tin — an unexpected result which might be due to the fact that galena, which has "a marked affinity for tin at high temperature", has here taken the "lion's share". It is not unimportant to note that the Liruei galena does contain 500 p.p.m. tin — a high figure — particularly when it is realised that all but one of the Cornish galenas investigated contained less than 100 p.p.m. of the element under discussion. It also indicates the danger of assuming that the findings of trace element studies in one region are necessarily going to be just the same as those of similar ones made in another. Clearly, it would be wrong to assume — as one might from the Canadian findings — that sphalerite from tin lodes will *always*

*) Figure 2, showing the results of a study carried out by Hosking and Ahmad (in 1964) at Geevor tin mine, Cornwall, indicates that there thermoluminescence studies are unlikely to be of much help during the search for further lodes by diamond drilling or cross-cutting. It does, however, just suggest that minor veins tend to increase as a major lode is approached, and that their mineralogical and trace-element character may give warning of the presence of a lode long before there is any other indication of it. Confirmation of this pattern has, in fact, been obtained at South Crofty mine, Cornwall, by Hosking & Burn (unpublished studies).



areas of marked
 granitic and other
 ally interesting tin
 emic interest. On
 radiometric and
 tin-bearing ones)
 revealed by such
 obvious wall-rock
 Dougall (1966).)
 as, but especially
 ns should receive
 be subjected to
 cally selected not
 als (e.g., stannite,
 ncover any of the
 ous. The mineral-
 o this category as,
 also trace element
 ndings of Warren
 efly, Warren and
 lena, tetrahedrite
 gh concentrations
 us deposits. They
 ecause "some ele-
 hard to discover
 amounts in other
 (op. cit., p. 311).
 trace element con-
 ng centres, found
 re those from the
 rage tin contents
 alerite, which is
 nc Liruei Lode of
 cted result which
 affinity for tin at
 t unimportant to
 a high figure —
 ish galenas inves-
 discussion. It also
 e element studies
 those of similar
 — as one might
 odes will *always*

osking and Ahmad
 uminescence studies
 y diamond drilling
 d to increase as a
 -element character
 other indication of
 outh Crofty mine,

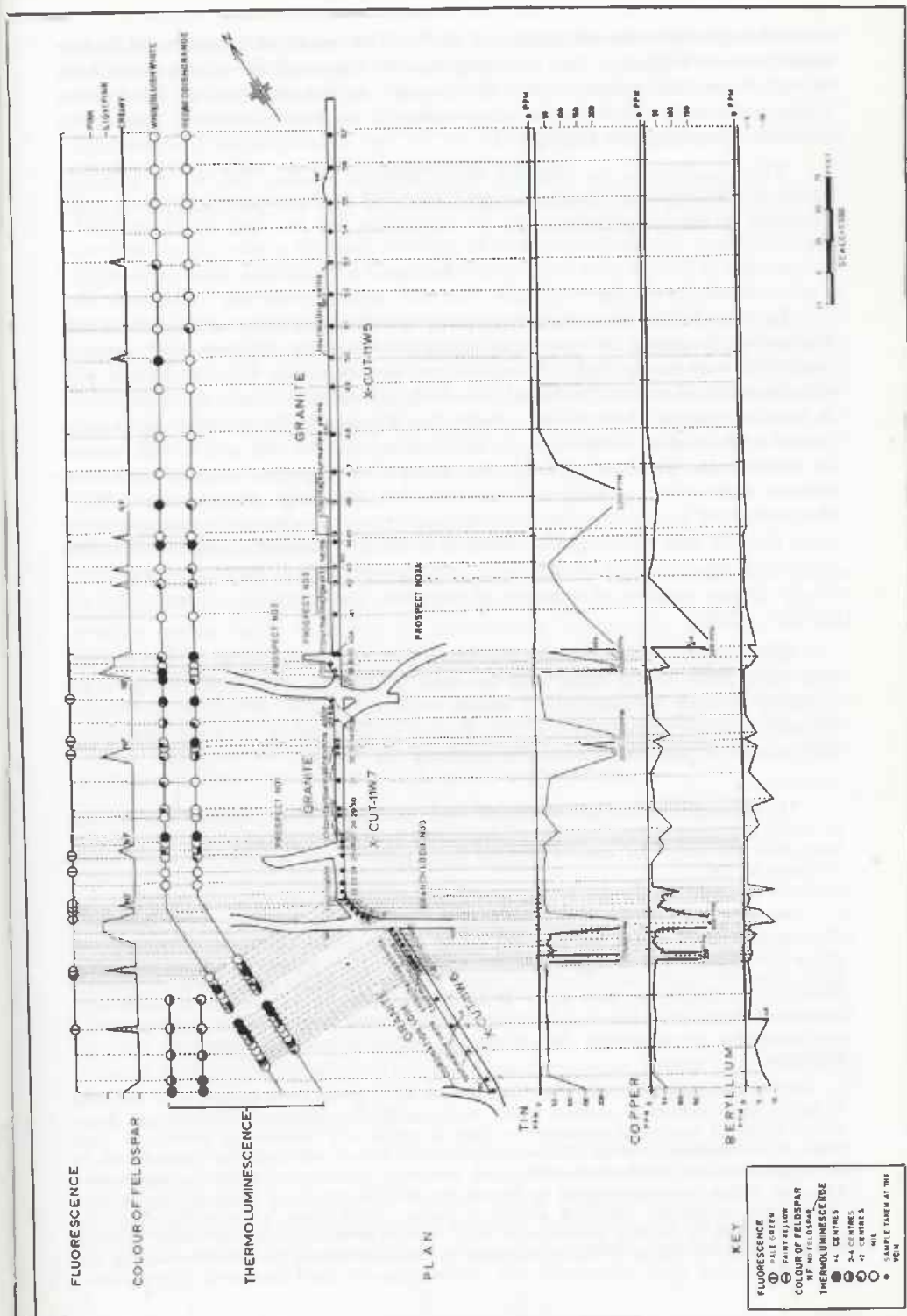


Figure 2

contain high trace concentrations of tin *). The results obtained by El Shazly and his co-investigators also indicated that in Cornwall the tin content, both of sphalerite and galena, tends to increase as the distance to the granite contact decreases. This further observation, if cautiously applied, might also assist in delineating tin targets.

The question as to whether trace element studies can be of material assistance during the detailed examination of the tin potential of a small area will be taken up later.

*

In view of the very imperfect state of our knowledge of the chemical/mineralogical aspect of the relationship between tin deposits and granitic rocks **) and in the light of experience, and omitting for the present any consideration of spatial relationships which, on occasion, may markedly assist in locating targets, there is little doubt that the search for tin deposits in large "new" areas and in comparatively small areas adjacent to and within known tin fields, can often initially best be carried out by geochemical studies of stream sediments, provided that adequate drainage systems exist ***). Naturally, the results are likely to be much more conclusive in non-glaciated areas than in ones which glacial debris is much in evidence, though even in the latter they may prove of considerable value, particularly if they are supplemented by similar studies of samples of moraine (and possibly of soil) and by boulder surveys.

On occasion sediment samples from dry river-beds in semi-arid regions may also yield useful data, and in such a climatic environment the trace element content of samples of desert varnish (Lakin *et al.*, 1963) might broadly indicate mineralised areas, though it is unlikely to yield any direct clue as to the possible presence of primary tin deposits.

*) Although the low tin content of some sphalerites from tin lodes may be due, as noted above, to competition, in others it may be because the mineral was deposited long after the major tin species, possibly from agents which originated from a source deficient in tin.

**) The following observation by Jedwab (1953, p. 178) concerning the application of hard-rock geochemical studies, particularly to the search for primary tin deposits, still constitutes a fair commentary on the subject: — "La prospection géochimique des gîtes primaires, encore dans l'enfance, risque d'être compromise par l'emploi de schémas théoriques incomplets ou périmés. — Il reste néanmoins que ces preuves encourageantes sont insuffisantes pour être immédiatement utilisées dans la prospection géochimique: il est nécessaire de multiplier les études de détail avant d'énoncer des lois très générales".

***) The geochemical studies carried out in a given investigation may be those in which the distribution patterns of tin, and possibly "companion" elements, are determined by rapid analytical methods, or those in which the distribution pattern of cassiterite, and possibly those of commonly associated heavy minerals, are determined by the employment of mechanical techniques involving gravity and magnetic separations, etc. The writer does not propose to discuss the relative merits of these approaches but, clearly, any sediments collected during a survey which have a chemically high tin content should be further investigated with a view to determining in which minerals the tin occurs: in skarn areas, for example, it could be almost entirely in malayite and garnets!

The virtue of exploration of sediments lies in the facts that they are easier to sample than hard rock ones and that mineralogical investigations are simpler and quicker when the target is in the sediments.

A study (completed in 1964) by Thomas, G. B. and not yet published, shows the distribution of elements in the minus-80-mesh fraction of stream sediments disposed streams draining the granite mass. The validity of the above claim that all known lodes but it also indicates that new lodes are believed to occur. The study also reveals the disposition of the high tin elements (particularly As and Sb) in the sediments. The study also reveals the distribution of tin and lithium, a fact which is of great importance on the eastern side of the mass and the distribution of the elements strontium and barium.

It is important to note that the study of elements in sediments from granite masses failed to reveal the distribution of lithium. This one fact is sufficient to show that the study of one comparatively small element (and mineralogical studies) is insufficient for the chemical/mineralogical study of the region, having studied only the distribution of one element certainly to make statements about the distribution of the other elements.

Particular mineralogical studies of minor granitic rocks

During the search for tin, the search for drilling, cross-cutting and the search for reasons which will be clear from the granitic cusp, even when the search is limited. It is also highly desirable to distinguish between stanniferous and barren rocks for tin deposits in many cases. The limited chemical/mineralogical studies (dykes) other than pegmatites are not, likely to be associated with tin.

If a granitic cusp is examined, the examination of the core will reveal the body. This is primarily because it invariably displays rapidly changing composition so that it, and the drill core, was amply demonstrated by the study.

The virtue of exploration methods involving the examination of stream sediments lies in the facts that the samples are easy to collect by comparison with hard rock ones and that they are often more representative of the area than are hard-rock samples. Further, regardless of whether chemical or mineralogical investigations are to be carried out, sample preparation is simpler and quicker when the sample is a sediment.

A study (completed in 1964 by Hosking, K. F. G., Hosking, J. A. and Thomas, G. B. and not yet published) of the distribution patterns of eleven elements in the minus-80-mesh fraction of sediments from the crudely radially disposed streams draining the Carnmenellis granite mass served to demonstrate the validity of the above claims. Not only did the work reveal the location of all known lodes but it also indicated a number of sites where hitherto unknown lodes are believed to occur. The zones of interest were indicated primarily by the disposition of the high tin values, but some of these zones were emphasised by the fact that their sediments also contained high concentrations of other elements (particularly As and Cu) which commonly accompany tin in the lodes. The study also revealed a surprising antipathetic relationship between tin and lithium, a fact which promoted further work in an area on the eastern side of the mass and this revealed the presence of a new tin vein, albeit almost certainly not one of economic importance. The general distribution of the elements studied is shown on Figures 3A and 3B.

It is important to note that similar unpublished studies of the distribution of elements in sediments from streams draining the Land's End and St. Austell granite masses failed to reveal an antipathetic relationship between tin and lithium. This one fact is sufficient to remind one that stanniferous parts, even of one comparatively small batholith, may and often do display marked chemical (and mineralogical) differences and that to make generalisations on the chemical/mineralogical aspect of the tin/granite relationship of the whole region, having studied only some of the stanniferous zones in detail, is almost certainly to make statements which are in part wrong.

*Particular mineralogical/chemical aspects of granitic cusps,
minor granitic intrusives and stanniferous skarns
Granitic bodies*

During the search for further tin deposits in a known tin field by diamond drilling, cross-cutting and similar methods, it is particularly important (for reasons which will be clear later) to be able to recognize the presence of a granitic cusp, even when the material from it, which is available for study, is limited. It is also highly desirable in a pegmatite field to differentiate rapidly between stanniferous and barren members, and it would facilitate the search for tin deposits in many new areas and known tin fields if comparatively limited chemical/mineralogical studies of minor granitic bodies (e.g., porphyry dykes) other than pegmatites would indicate whether tin deposits are, or are not, likely to be associated with them.

If a granitic cusp is intersected by a single drill hole near its apex, examination of the core will probably be sufficient to establish the nature of the body. This is primarily so because apical cusp granite usually, perhaps invariably, displays rapidly changing textural and mineralogical characteristics, so that it, and the drill core from it, often shows pseudo-bedded features. This was amply demonstrated recently when the Zinnwald cusp was drilled to a

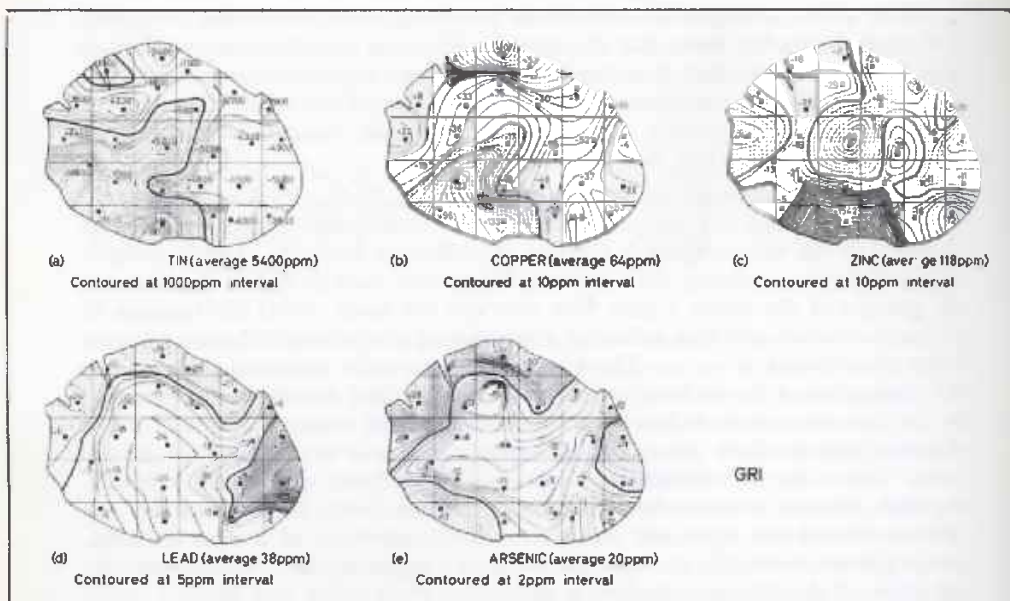


Figure 3A

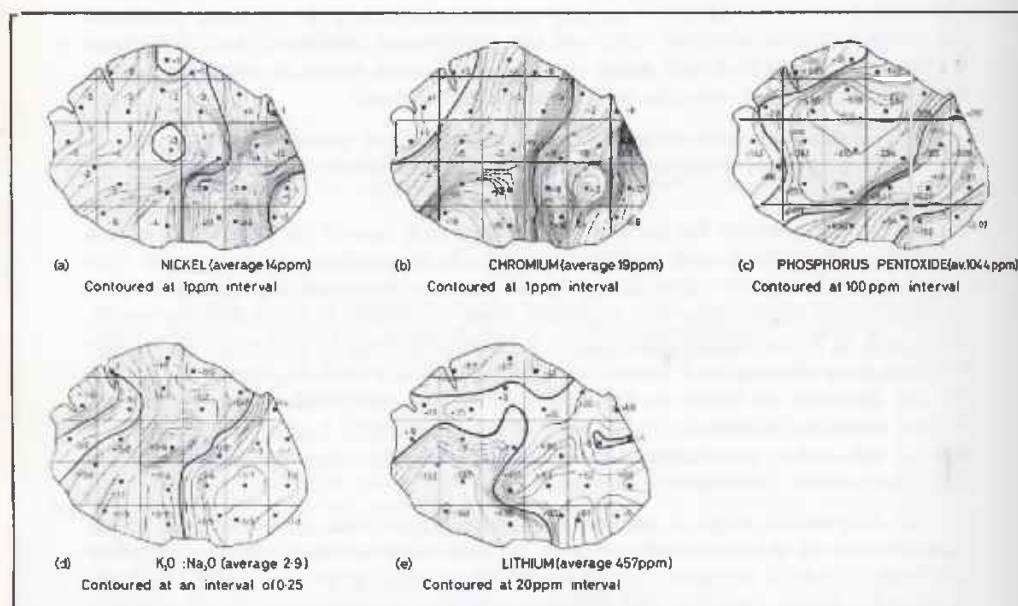


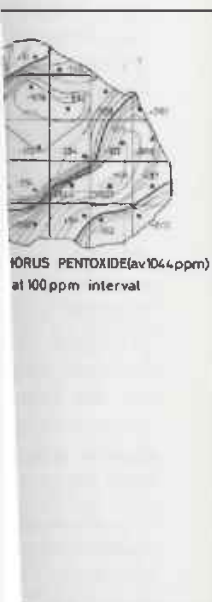
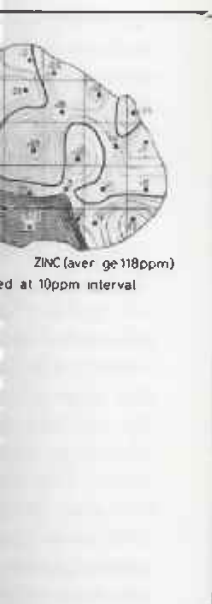
Figure 3B

depth of 1,200 m. The resulting Stempok (1964), contains 19,000 m. Further confirmation of the Cornish cusps has been obtained but details are not yet available.

That the "degree of banding" that of the Zinnwald cusp is a description of the granite of the Pahang Consolidated Co. away from its contact with the porphyritic biotite-granite. As the amount of biotite and an spar. Within a foot or two of the rich in phenocrysts, most of which of rock, composed almost entirely lies between the granite and the

In the apical portions of cusp common, as is alteration — p cusp may contain virtually all (as at Mawchi, Burma) but no economic interest (as at Cligga) occasion it may be devoid of s buried Pahang Consolidated c is largely confined to narrow associated with wolframite, and also be disseminated in the gran and contain visible cassiterite granitic rocks: in the latter case rite crystals on mica cleavage establishment of the fact that importance were one examining suggest that a centre of mine although the cusp might be, f might be flanked by tin lodes c

According to Rankama a greisens analyzed by Goldschmidt range. However, it would be contain such high concentration bearing veins do, as the data reasonable to conclude that if tin that the cusp, or invaded deposits of economic interest, h area may, or may not, contain the analyses of isolated sample content of greisenised granite another only a few inches away wall), which is sited in a star rock increases, with progressive inches from a silicified zone c



depth of 1,200 m. The resulting core, which is discussed in some detail by Stemprok (1964), contains 19 distinctly recognisable "bands" in the first 1,000 m. Further confirmation of the "pseudo-bedded" character of some of the Cornish cusps has been obtained during two recent drilling programmes, but details are not yet available for publication.

That the "degree of banding" is by no means always as spectacular as that of the Zinnwald cusp is indicated by Fitch's (1947, p. 15) following description of the granite of the cusps exposed underground in the mines of the Pahang Consolidated Co. Ltd. (Malaya): "In the mines the granite, away from its contact with the 'slate', is the normal, medium-grained, sparsely porphyritic biotite-granite. As the contact is approached there is a diminution in the amount of biotite and an increase in the number of phenocrysts of feldspar. Within a foot or two of the contact, the granite is leucocratic and very rich in phenocrysts, most of which lie parallel to the contact. A friable band of rock, composed almost entirely of large flakes of white mica, sometimes lies between the granite and the slate..."

In the apical portions of cusps, pegmatitic and aplitic bands, or knots, are common, as is alteration — particularly kaolinisation and greisenisation. A cusp may contain virtually all the economic concentrations of tin in the field (as at Mawchi, Burma) but more commonly it contains deposits of limited economic interest (as at Cligga and St. Michael's Mount, Cornwall) and on occasion it may be devoid of significant tin mineralisation (as is each of the buried Pahang Consolidated cusps). Commonly any cassiterite in the cusps is largely confined to narrow greisen-bordered veins in which it may be associated with wolframite, arsenopyrite, topaz, etc. A little cassiterite may also be disseminated in the granitic rocks and the greisen may be truly tin-rich and contain visible cassiterite, or just tin-rich by comparison with other granitic rocks: in the latter case, the tin may occur entirely as minute cassiterite crystals on mica cleavage planes. In the absence of visible cassiterite, establishment of the fact that the greisen was tin-rich would clearly be of importance were one examining an exposed cusp in a new area, as it would suggest that a centre of mineralisation might be present there, and that, although the cusp might be, from an economic point of view, tin-barren, it might be flanked by tin lodes of importance.

According to Rankama and Sahama (1952, p. 732) the tin content of greisens analyzed by Goldschmidt and Peters fell in the 800—8,000 p.p.m. range. However, it would be quite wrong to conclude that greisens always contain such high concentrations of tin, or even that those bordering cassiterite-bearing veins do, as the data in Table 8 show. On the other hand it is reasonable to conclude that if the greisen has a high "trace" concentration of tin that the cusp, or invaded rocks adjacent to it, are likely to contain tin deposits of economic interest, but if it contains a low concentration of tin the area may, or may not, contain tin deposits. As a rider it must be added that the analyses of isolated samples are useless in work of this kind as the tin content of greisenised granite may vary markedly from one sample point to another only a few inches away. Thus, at Cameron Quarry, St. Agnes (Cornwall), which is sited in a stanniferous cusp, the tin content of the granitic rock increases, with progressive greisenisation, from 20 to 700 p.p.m. At 3 inches from a silicified zone containing feldspar voids infilled with cassiterite

Table 8
The tin content (p.p.m.) of greisens
(Hosking, K.F.G. unpublished studies)

Locality	Nature of sample	Tin content
<i>England:</i>		
St. Michael's Mount, Cornwall	Sericite mica from greisen bordering cassiterite, etc., veins in granite cusp	17
Kit Hill, Cornwall	Greisen bordering cassiterite, etc., vein in granite cusp	10
Hemerdon, Devon	Greisen c. 1 in. from quartz vein and from where it contains wolframite	10
	Greisen c. 1 in. from quartz vein which is locally barren	175
Castle-an-Dinas mine, Cornwall	Somewhat greisenised granite. (A sample, collected from the mine dump, of the post-lode granitic "tongue")	10
St. Austell, Cornwall	Sericite mica from border of quartz vein in highly kaolinised granite	100
<i>Asia:</i> Phuket Is., Thailand	Greisen filling of a narrow vein in slate hornfels in the floor of an open-cast tin mine	10
<i>Africa:</i> Tanzania	Sericite adjacent to a cassiterite rich quartz vein in hornfels. (Not strictly mica from greisen!)	5,800
<i>North America:</i> New Ross tin-field, Nova Scotia	Sericite-rich greisen bordering cassiterite/quartz vein	25
Welsford, New Brunswick	Sericite from greisen bordering quartz vein at apex of granite cusp, which locally contain arsenopyrite, chalcopyrite, molybdenite and wolframite, but, apparently, no cassiterite	42
	Greisen (whole rock) from same spot	34

Note: The tin content of the above noted samples was determined colorimetrically by the gallein/methylene blue method.

the tin content is 350 p.p.m. in the silicified zone it is 5 p.p.m.

What has been already determined is the tin content in certain sulphides and needs no further elaboration.

Possible differences between the types of pegmatite much investigated, and this type of pegmatite may occur. Their outcrops may not enable one to predict the presence of cassiterite present is likely to yield a programme may fail to yield

Interesting concentrations of structurally and mineralogically zoned ones which may be met in the Bikita field of Rhodesia).

Ginzburg (1955, p. 748) of pegmatites reveals a series of pegmatites which predict the presence of various minerals. "the dark blue tourmaline (in the widespread in cases of intense tantalum-niobium and tin ore processes generally contain ore is a common mislead- isation which can be misleading with green tourmaline which is common in the Quarry, Devon) and one can predict the presence of some of which are economically important. Ginzburg's views. Thus, Derry usually present in the Hong Kong neither albite nor tourmaline. Chenderiang, Malaya, contains everywhere in Malaya. Derry the major stanniferous pegmatite of the Jack Nutt Mines Ltd. (orthoclase, cassiterite, garnet, or blue varieties). In the stanniferous, albite-rich pegmatite, there is some albite, but maline which is present is bluish stanniferous, albite-rich pegmatite rare: Tyndale-Biscoe (1951, p. 74) the body is known from one place. rubellite has been found in a number of nor green varieties have ever been found.

Ginzburg (*op. cit.*, p. 74) rich in cassiterite contain up to 10% tin. Devoid of tin the amount of

the tin content is 350 p.p.m.: at one inch away it is only 10, and just "outside" the silicified zone it is 5 p.p.m. (Hosking, 1964, p. 239)!

What has been already written concerning the value of determining the tin content in certain sulphides applies, of course, to sulphides found in cusps and needs no further elaboration.

*

Possible differences between tin-bearing and barren pegmatites have been much investigated, and this is in no small measure due to the fact that both types of pegmatite may occur in the same field and that visual examination of their outcrops may not enable them to be differentiated. Furthermore, because it is not usually possible to forecast where, in the body of a pegmatite, any cassiterite present is likely to occur, a financially reasonable diamond drilling programme may fail to yield conclusive results.

Interesting concentrations of cassiterite can occur both in unzoned, structurally and mineralogically simple pegmatites (as in Portugal) and in zoned ones which may be mineralogically and structurally complex (as in the Bikita field of Rhodesia).

Ginzburg (1955, p. 748) claims that "a detailed study of the mineralogy of pegmatites reveals a series of *mineral-indicators* which can be used to predict the presence of various rare metals in pegmatites" and states that "the dark blue tourmaline (indigolite) and green tourmaline ("verdelite") are widespread in cases of intensive albitization, which is generally related to the tantalum-niobium and tin ores, whereas the pegmatites devoid of replacement processes generally contain only black tourmaline (schorl)". This is a generalisation which can be misleading because one can "have" albite-rich pegmatites with green tourmaline which are quite devoid of cassiterite (as at Meldon Quarry, Devon) and one can also site examples of stanniferous pegmatites — some of which are economically important — which do not conform with Ginzburg's views. Thus, Davis (1958, p. 483) when noting the minerals usually present in the Hong Kong wolframite/cassiterite pegmatites mentions neither albite nor tourmaline! The important stanniferous pegmatite at Chenderiang, Malaya, contains tourmaline, but it is dark and opaque as it is everywhere in Malaya. Derry (1930, p. 151 and pp. 154-156) records that in the major stanniferous pegmatite (which is in the form of an arch-like sill) of the Jack Nutt Mines Ltd., Eastern Manitoba, one finds quartz, albite, orthoclase, cassiterite, garnet, apatite and black tourmaline (but not the green or blue varieties). In the stanniferous pegmatite of Lagares-do-Estanho, Portugal, there is some albite, but it is subordinate to orthoclase, and the tourmaline which is present is black (Cotelo Neiva, 1944, pp. 47 and 53). In the stanniferous, albite-rich pegmatites of the Bikita field, tourmaline is extremely rare: Tyndale-Biscoe (1951, p. 17) states that "black tourmaline in a pegmatite body is known from only one locality, near the Nigel tin mine, while rubellite has been found in a greisen on the Al Hayat claims." Neither blue nor green varieties have ever been seen there!

Ginzburg (*op. cit.*, p. 749) further claims "that the micas from pegmatites rich in cassiterite contain up to 0.4 to 0.5 per cent SnO_2 , whereas in pegmatites devoid of tin the amount of tin present in micas is negligible". Ahrens and

Liebenberg (1950), as a result of studying the tin content of pegmatite minerals from southern Africa, arrive at much the same conclusions as Ginzburg: they state "that if micas from a pegmatite area show a characteristic enrichment in tin, deposits of cassiterite are likely to have been formed, whereas if the muscovites are low in tin the area is probably barren of such deposits." They also state that "the other common pegmatite minerals, albite, microcline and quartz invariably do not contain detectable amounts of tin and would therefore be useless as possible prospecting indicators."

Jedwab (1953) disagrees entirely with the above observations. He has assembled, from several sources, data relating to the tin content of pegmatite minerals occurring in a number of European and African bodies. From these data he concludes that all micas from all pegmatites contain tin and that muscovites from barren and stanniferous pegmatites may contain approximately the same concentration of the metal. He further concludes that whilst the feldspars never contain much tin, the tin content of feldspars from stanniferous pegmatites is always so much higher than that of similar feldspars from barren pegmatites that it enables differentiation to be made between the two types. He stresses, however, that care must be taken in the selection of material for analysis because those feldspars (chiefly microcline) which crystallise before the cassiterite are appreciably richer in tin than those (chiefly albite) which are formed with or after the cassiterite.

Once more an impasse is reached. Further studies of the trace element content, and particularly of the tin content, of pegmatite minerals collected from as wide a variety of pegmatites as possible and from as many different regions as possible are clearly needed before pronouncements can be made which are likely to be of real help to those wishing to investigate the tin potential of these intriguing granitic units. In the meantime, it is well to remember that a single simple test may never be found for differentiating between stanniferous and other pegmatites because there are stanniferous pegmatites and stanniferous pegmatites, despite what has been written by some to the contrary. The writer believes that, whilst some may have developed solely from a magmatic fraction in an enclosed system, others owe their present character to the fact that though they were initially tin-free bodies they later (perhaps a long time after they were formed) became the preferred sites of cassiterite deposition for invading tin-bearing agents.

Porphyry and other granitic dykes commonly occur in the same areas as tin lodes and it is surprising, therefore, that practically no work has been done with a view to determining whether chemical and/or mineralogical examination of dyke material might indicate when tin-bearing lodes occurred in the neighbourhood. A study relevant to this problem has been started by the writer, but it is premature either to quote the results or to comment on them at length. It does seem, however, that indications that there may be a tin deposit in the vicinity are most likely to be obtained by determining the tin content, and that of tin's companion elements, of fillings of fracture and joint planes and of any highly altered wall rock material immediately adjacent to them. That this is so is not surprising, as the planes of contact between dykes and the country rock, and the numerous joints and fractures which often develop in such bodies, constitute excellent channels along which the ore-forming agents can leak away from the major centres of deposition.

It is well known that sl bearing. Sometimes most of ment solely as cassiterite in where it is associated with t Bradford, 1960, p. 131); on c cassiterite and various silica is in Pinyok, Thailand, and solely in silicates as at Re primarily in malayaite and grossularite (El Sharkawi an the search for tin deposits, a attention: initially both who for tin. Subsequent work she mine which species are the

Although it has been t this paper with the recording for other occasions, he mus reader that, if he believes t he takes concerning the rel they drifted apart might sug igate. He may well conclude up" during the fragmentatio ing. Wade (1940, p. 12), fo the basement complex of An drift on Gondwanaland con of economic importance wh southernmost continent.

To return to more ma important tin/granite spatia these, the fact that only a few and the further fact that, i generation of granite occurs mineralisation may vary ma already been discussed, and sections to further spatial r

Spatial relations and gra

A close spatial relations and granitic cusps (using th recognized in virtually every it seems probable that the

Stanniferous skarns

It is well known that skarn adjacent to stanniferous granites may be tin-bearing. Sometimes most of the tin may be present in such a geologic environment solely as cassiterite in veins, pipes, etc. as in the Beatrice mine, Malaya, where it is associated with tremolite, fluoborite, phlogopite, etc. (Ingham and Bradford, 1960, p. 131); on other occasions the tin may be partitioned between cassiterite and various silicates, such as arandisite, malayaite, andradite as it is in Pinyok, Thailand, and Arandis, South-West Africa, or it may be present solely in silicates as at Red-a-vê, South-West England, where it is found primarily in malayaite and andradite, but also in smaller concentrations in grossularite (El Sharkawi and Dearman, 1966, pp. 362-369). Clearly, during the search for tin deposits, any skarns which are located should receive special attention: initially both whole rock samples and garnets should be analyzed for tin. Subsequent work should, amongst other things, be designed to determine which species are the important tin carriers.

Spatial aspects

Although it has been the writer's avowed intent to concern himself in this paper with the recording of facts and, as far as possible, to leave theories for other occasions, he must briefly depart from this course to remind the reader that, if he believes that Continental Drift is a reality, then the views he takes concerning the relationships between the major land-masses before they drifted apart might suggest to him "new" possible tin regions to investigate. He may well conclude that certain stanniferous provinces were "broken up" during the fragmentation of the land which immediately preceded drifting. Wade (1940, p. 12), for example, as a result of studies of specimens of the basement complex of Antarctica and of the possible effects of continental drift on Gondwanaland concluded that tin, and other elements and minerals of economic importance which he lists, "are all likely to be present" in the southernmost continent.

To return to more material aspects, it can be stated that a number of important tin/granite spatial relationships have been firmly established. Of these, the fact that only a few of the many known granitic areas are tin-bearing and the further fact that, in a stanniferous province where more than one generation of granite occurs the nature of the tin deposits and the degree of mineralisation may vary markedly from one granitic unit to another, have already been discussed, and so one can turn immediately in the following sections to further spatial relationships.

Spatial relationships between primary tin deposits and granitic cusps, ridges and dykes

A close spatial relationship between marked primary concentrations of tin and granitic cusps (using the last word in the widest possible sense) has been recognized in virtually every tin field of the world, and it is so common that it seems probable that the development of granitic cusps (or closely similar

bodies such as volcanic pipes) is an essential prelude to the genesis of primary tin deposits of direct interest to the miner *).

Evidence from many countries suggests that commonly in a given tin field the strongest primary mineralisation occurs within, or in the vicinity of, clearly defined steep-sided cusps and that as the cusps become less pronounced so also does the degree of concentration of tin in primary deposits **). One may compare the strong tin mineralisation in the vicinity of the marked cusps occupying the middle third of Phuket (Thailand) with the virtual lack of mineralisation in the cusp-free remaining two-thirds of the island, or the strong tin lodes haloing granite cusps in the Pahang Consolidated mine (Malaya) and in the Aberfoyle mine (Tasmania) with the almost complete lack of lodes in the Younger Nigerian granite which, as Mackay *et. al.* (1949, p. 571) have noted "may have had relatively flat tops, which would ... contribute to the dispersion of mineralisation."

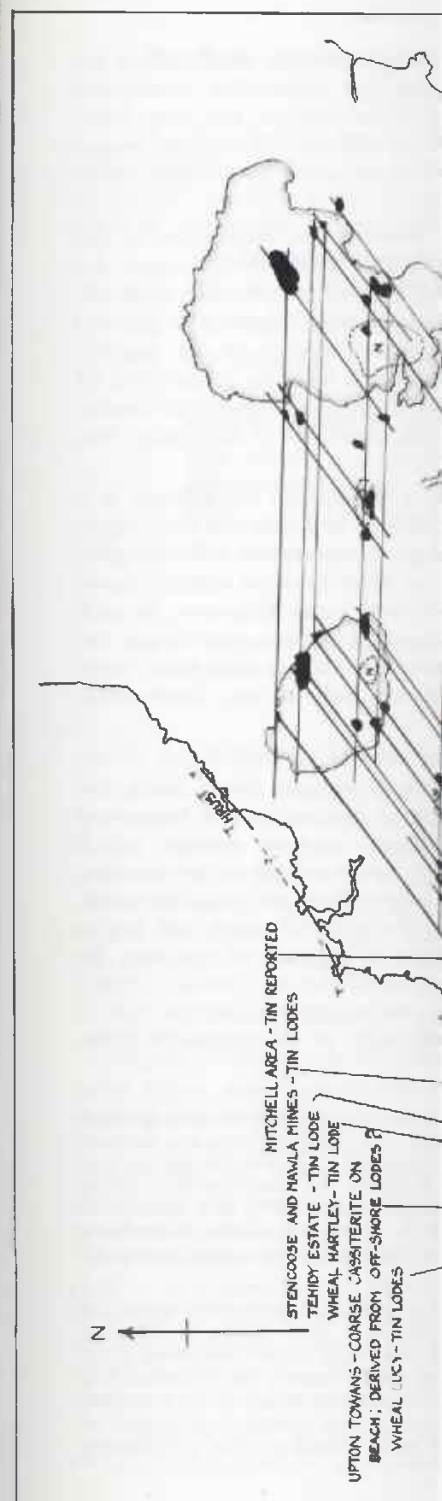
In Cornwall the existing cusps are local "high spots" on granite ridges and there is little doubt that other cusps and ridges locally existed on the original surface of those extensive portions of the batholith which have been uncovered but that they have since been eliminated. In Cornwall, also, the centres of tin fields and, therefore, the sites of the associated cusps, occur at the intersections of certain N.E.-S.W. and E.-W. lines (Figure 4) which are the major strike directions of the sedimentary rocks which were invaded by the granite. It seems likely, therefore, that the invaded rocks, by behaving as a mould, albeit one capable of being deformed, determined the surface form of the batholith and, in particular, where cusps and ridges were to develop. A natural site for cusp development would be where a pronounced E.-W. antiform intersected a strong N.E.-S.W. one. Possibly, however, on occasion, cusps also developed in some tin fields at the intersections of pre-granite major faults or where faults intersected antiforms.

To summarise, the writer believes that in the south-west of England the structure of the invaded rocks determined the disposition of the cusps and ridges and that the cusps determined where the centres of mineralisation were to be whilst the ridges established the general disposition not only of the major tin lodes but also of the granitic dykes. (For further details see Hosking (1962).)

Chauris (1965) has recently arrived at broadly similar conclusions on the spatial relationship existing between tin-bearing lodes and granites in N.W. France. Briefly, he recognizes that tin deposits are associated with those granites which have been intruded along zones of structural weakness but,

*) That this is not a novel view is indicated by the following observations of Harman (1935, p. 152): — "The association of tin mineralization with minor intrusions of the type described (i.e., with domes, cupolas and laccolites) seems to the author to possess more than local significance and to be of the greatest importance in the guidance of prospecting and in the explanation of the genesis of many occurrences. The abundance of domical structures may, it seems to him, be the source of the tin accumulated in the Kinta Valley of the Federated Malay States, while their decreasing frequency helps to explain the mineral impoverishment resulting northwards from Malaya through Siam to Burma".

**) It is probable that the lode/cusp relationship holds in many areas where it has not been demonstrated either because the cusp has been removed by erosion or because it has not been uncovered by nature or by man.



esis of primary

a given tin field
inity of, clearly
nounced so also
**). One may
marked cusps
virtual lack of
island, or the
solidated mine
almost complete
ay *et. al.* (1949,
would ... con-

granite ridges
existed on the
which have been
nwall, also, the
cusps, occur at
e 4) which are
ere invaded by
by behaving as
ne surface form
ere to develop.
nounced E.-W.
er, on occasion,
of pre-granite

of England the
the cusps and
eralisation were
ly of the major
asking (1962).)
clusions on the
unites in N.W.
ed with those
weakness but,

observations of
minor intrusions
the author to
n the guidance
es. The abun-
n accumulated
sing frequency
alaya through

s where it has
on or because

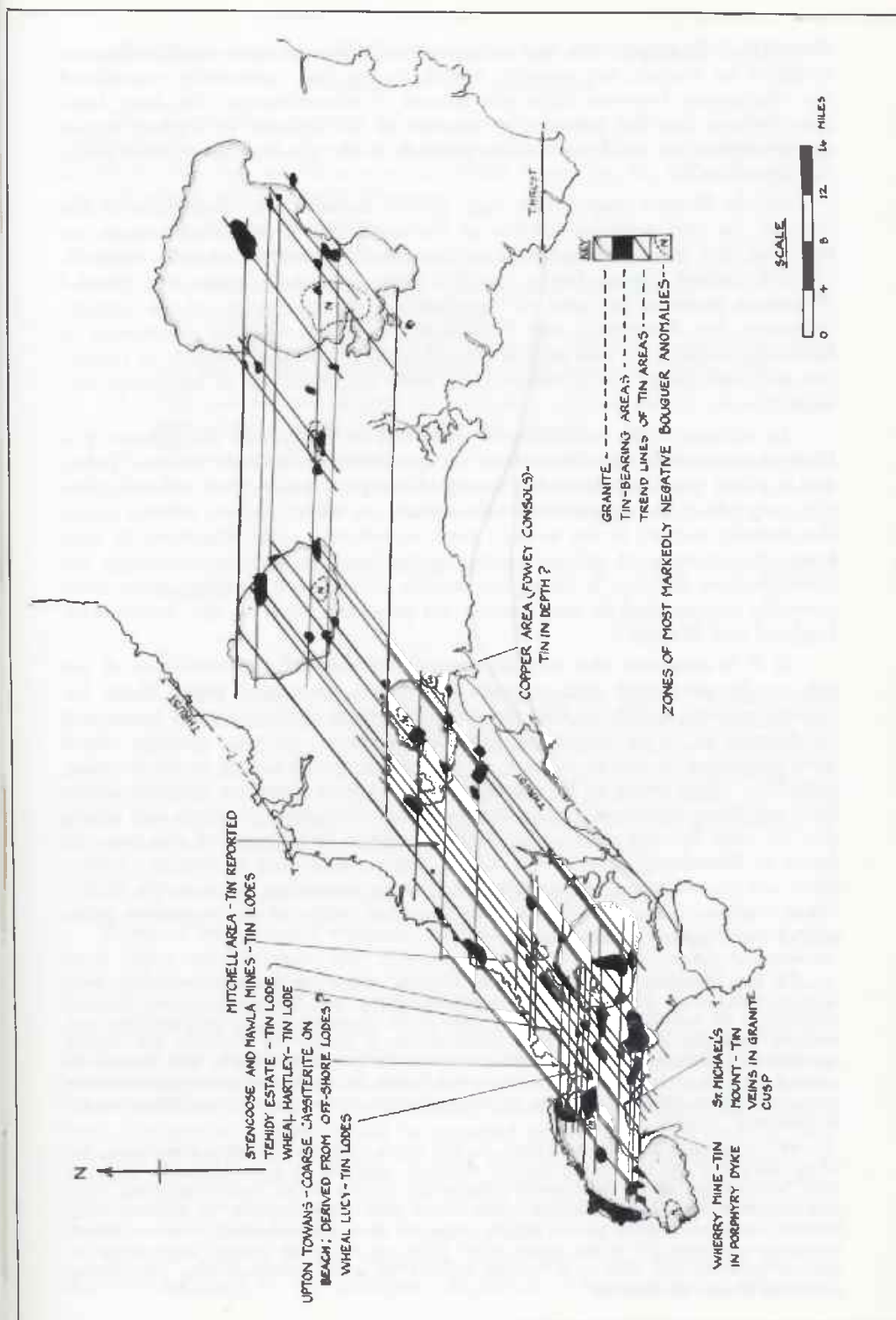


Figure 4

though he fully appreciates that such granites possess surfaces which, when not modified by erosion, are strongly ridged, he has not, apparently, considered the relationship between cusps and centres of mineralisation. He does, however, believe that the presence or absence of tin deposits in a given region do not depend as much on the composition of the granites as on their structural position *).

Cotela Neiva's map (1944, opp. p. 30), showing the disposition of the primary tin and tungsten centres of Portugal, also gives strong reason for believing that their locations were, as those in Cornwall, structurally controlled, and, indeed, Cotela Neiva (pp. 235-236) notes that "there is a parallel disposition between the axes of metallization, the elongation of the granitic intrusions, the Agnotozoic and Palaeozoic formations and the orientation of hercynian folding. . . . The axes of metallization of primary deposits of cassiterite and wolframite are interdependent with the directions of hercynian tectonic."

In volcanic areas containing xenothermal or epithermal tin deposits it is likely that granitic cusp-like masses occupy positions beneath volcanic pipes, and it might even be reasonable to regard the pipe and surface volcanic piles as a cusp which has penetrated to the surface, so what has been written above also broadly applies, in the writer's view, to volcanic areas. However, in such areas, due to repeated volcanic outbursts the fracture pattern, and hence the mineralisation pattern, is frequently locally much more complex than those generally encountered in non-volcanic tin provinces such as, say, South-West England and Malaya.

If it is conceded that deposits containing marked concentrations of tin are usually associated with strongly developed cusps and ridges then, for obvious reasons, it follows that the best chances of finding further important tin deposits lie in the vicinity of granitic intrusives, not near granites which have developed in situ as a result of granitising agents acting on pre-existing rocks **). There seems to be a possibility that where there are granites which have not been mobilised, pegmatites may take the place of cusps and ridges and tin may be concentrated in them. Evidence in support of this may be found at Brandberg, South-West Africa, where, according to Dennis (1959), there are stanniferous pegmatites and where, according to him (p. 1120), "field evidence appears to favour a replacement origin of the pegmatite dykes and of their parent granite body."

*) The following extract summarises Chauris' major conclusions concerning these aspects of his work which have just been considered: — "L'importance des facteurs structuraux est fortement soulignée: les principaux gisements stannio-wolframifères sont localisés dans des zones structurales particulières, à savoir, les bordures des vieilles cordillères cadomiennes septentrionale et méridionale qui constituent le bâti armoricain primitif. Ces zones marginales sont des zones faibles de l'écorce terrestre qui semblent avoir favorisé la concentration de la minéralisation (zone "structuro-métallogénique" de bordure)" (*op.cit.*, p. 12).

**) It is clear that Teale (1942, p. 61) came to much the same conclusion, for when discussing the search for further tin, etc., deposits in East Africa he observes that "with regard to the widespread distribution of granites of rather confusing types and relationship some considerable advance has been made recently in differentiating between extensive granitic masses largely migmatic in origin and others of more typical magmatic character. It is the latter which have an important genetic relationship to the ore deposits and thus it is to the vicinity of these intrusions that prospecting attentions should be directed".

Further aspects of the problem respecting

The distribution patterns of tin mineralisation and of the tin deposits are numerous, but they would appear to fall into a few groups, each of which will be briefly discussed.

- i. The degree of erosion
- ii. The disposition of "spots"
- iii. The disposition of bedrock
- iv. The presence of "pre-igneous" rocks
- v. The physical characteristics of the rocks and the nature of their mineralisation
- vi. The nature and degree of erosion immediately before and after mineralisation
- vii. The timing of fracturing
- viii. The temperature conditions of mineralisation also in the "body" of the granite
- ix. The chemical characteristics of the rocks.

i. The degree of erosion

Erosion will uncover and expose the granite in which large expansion joints are reached in which large expansion joints may be confined essentially to the surface (the major outcrops removed from the major outcrops exposed) occur. Any lodes existing in the granite tend to die out rapidly in depth where the erosion is a fact which, in Cornwall, has been well known.

ii. The disposition of "spots"

Spots of local crystal weakness occur beneath volcanic pipes, and because they are marked minor igneous intrusions they are of importance in formation and mineralisation. No doubt the writer has remarked that the relationship between the granites of the cassiterite association and the porphyries which indicate that the mineralisation took place in fields (certainly in South-West England) close to a granite contact should be worthy of particular attention. In addition, the area contains strong evidence of pre-igneous rocks which might pre-date the period of mineralisation (for reasons which will be discussed later).

Because spots of crustal weakness are much strengthened by the subsurface

Further aspects of the patterns of tin deposits with respect to the granites

The distribution patterns of tin deposits in the *vicinity* of centres of mineralisation and of the tin-rich parts (shoots) within such deposits are numerous, but they would appear to depend largely on the following factors, each of which will be briefly discussed:

- i. The degree of erosion.
- ii. The disposition of "spots" of local crustal weakness.
- iii. The disposition of bedding, cleavage and joint planes.
- iv. The presence of "pre-lode" faults.
- v. The physical character of all the major lithologic units of the field and the nature of their disposition with respect to each other.
- vi. The nature and degree of fracturing and of fissure development immediately before and during ore genesis.
- vii. The timing of fracturing and fissure formation during ore genesis.
- viii. The temperature conditions prevailing in the fissures, and possibly also in the "body" of the fissured and neighbouring rocks, during ore genesis.
- ix. The chemical character of the ore-forming agents and of the invaded rocks.

i. The degree of erosion

Erosion will uncover and eventually eliminate ore bodies. When a point is reached in which large expanses of a batholith are uncovered primary ore bodies may be confined essentially to the contact zone and to further areas removed from the major outcrops where marked granitic cusps (buried or exposed) occur. Any lodes existing well inside the granite contact are likely to die out rapidly in depth when compared with those near the contact (a fact which, in Cornwall, has been demonstrated repeatedly).

ii. The disposition of "spots" of local crustal weakness.

Spots of local crystal weakness determine the location of cusps and volcanic pipes, and because they remain weak they are commonly centres of marked minor igneous intrusive body development and of maximum fissure formation and mineralisation. Niggli (1929, p. 37) was struck by this lode/dyke relationship and remarked that "it is perhaps no mere coincidence that the granites of the cassiterite association are almost always accompanied by quartz porphyries which indicate that the local pressure was not very high". In tin fields (certainly in South-West England) strong granitic dyke development close to a granite contact should be regarded as an indication that the area is worthy of particular attention by those seeking further tin deposits. If, in addition, the area contains strong faults, striking about normal to the dykes, which might pre-date the period of ore genesis, it is worthy of still greater attention (for reasons which will be given later).

Because spots of crustal weakness which have been fractured are not much strengthened by the subsequent deposition of lode minerals within and

adjacent to fissures which developed from the fractures, the spots are prone to repeated fracturing. At South Crofty mine, Cornwall, for example, and within the granite, there are two localities where a late swarm of cassiterite/chlorite/fluorite/quartz veins intersects an earlier, more extensive, swarm of feldspathic wolframite/arsenopyrite veins. It is tentatively held that in each case the swarms are associated with a late granite cusp which was emplaced within the early phase granite. Because of the spatial relationship existing between the wolframite and cassiterite veins, the former are rightly regarded there, during underground exploration, as indicators of the possible presence of further swarms of cassiterite-bearing veins.

iii. *The disposition of bedding, cleavage and joint planes*

As noted earlier, parallelism commonly exists between the strikes of the granite-invaded sedimentary rocks, the axis of granite ridges, the trends of dykes and the strikes of tin-bearing lodes: to this list may be added one set of cleavage planes and one set of joints. It is not surprising, therefore, that some of these bedding, cleavage and joint veins often become preferred passage ways for ore-forming agents and the sites of ore deposition. In addition, minor cleavage and joint planes may be so disposed that they become open during the development of neighbouring major fissures and, by so doing, add local ornamentation to the major lode pattern. Thus, at Old Wheal Vor (Cornwall), steeply dipping cleavage planes in the killas hanging-wall of the lode had been opened during the descent of the latter, and were subsequently so in-filled with cassiterite that the wall, locally, was worth working for distances up to 50 feet from the main fissure.

iv. *The presence of "pre-lode" faults*

Pre-lode tear faults are of importance, particularly when they exist in the vicinity of cusps, because not only may movement along each of a pair generate tension fractures which form ideal sites for lode development, but the early faults may so impound the ore-forming agents that the tension fractures become the site of unusually rich concentrations of ore. The Nampet and Kautja lodes of the Klappa Kampit tin field (Billiton) appear to have developed in the manner mentioned above (Adam, 1960, p. 414) as do the lodes of Wheal Vor and some of those of Geevor mine, Cornwall (Garnett, 1961).

It is probable that pre-lode faults have played a much more important part in determining the disposition of tin lodes, and of rich parts in such lodes, than has generally been thought.

In Cornwall, years ago, many prominent mining engineers*) had no

*) Thus, in an unpublished letter, from Mr. W. A. Edwards, an Inspector of Mines, to Capt. J. Paull, of South Crofty mine, written on December 12th, 1927, the former makes the following remarks about the great fault (or cross-course) which runs through the eastern boundary of the Trink sett of West Cornwall: — "It carries tin at the junctions with the east and west lodes. Right along its entire length from St. Ives Wheal Allen to Wheal Cherry, lodes have "made rich" on either side of it. At Rosewall Hill and Ransom mine, rich values were encountered right up against this cross-course and immediately on the other side. St. Ives Consols proved rich. Balnoon raised large quantities of tin in and around this cross-course. Wheal Mary, west of it, was rich, and Fox's Section of Trencrom Mine, immediately east, was valuable ground and extended nearly ½ mile".

doubts about the rôle played by disposition of some of the shoots that they appreciated that some of their views, which were based on the reputation of the area, were not correct because it became clear that along many of these faults, and in a mesothermal suite of minerals, some of these important faults are

v. *The physical character of the fissures and the nature of the deposits*

This is a most important factor in the character of the fissures common to another: a single vein may be a porphyry, and fissures which are usually narrow on passing into the hanging-wall. There is no doubt that in tin fields, in the lithologic unit the deposits of which are one of these. This is not because the fissures are usually different from the rest, but because they are capable of promoting the deposition of ore. If the fissures were the fissures in the other unit, the one unit. For a fissure system to be of importance, its characteristics must, in the working of the ore-depositing agent is brought to the maximum cassiterite concentration of the "feeder channels" it can

vi. *The nature and degree of the ore immediately before and after the fissure*

This has been partly covered in the previous section. It is pointed out that a strong channel ways were open for all the ore that was available, and this was usually the case. When, however, the lode contained ore after the ore-forming agents ceased to be in value because of comminution of the minerals and the introduction of other minerals which are of some economic value, the increase in milling problems.

vii. *The timing of the fracturing*

This is covered in the foregoing section.

viii. *The temperature conditions in the "body" of the ore and the nature of the ore genesis*

In some tin fields the ore

doubts about the rôle played by some of the cross-courses in determining the disposition of some of the shoots in some of the tin lodes. There is no doubt that they appreciated that some of the cross-courses were pre-tin lode in age. Their views, which were based on observation in many mines, fell into disrepute because it became clear that post-tin lode movement had occurred along many of these faults, and because, in addition, some of them contain a mesothermal suite of minerals. Only in recent years has the true history of some of these important faults again been appreciated and amplified.

v. The physical character of all the major lithologic units of the field and the nature of their disposition with respect to each other

This is a most important factor because the fracture pattern and/or the character of the fissures commonly change markedly from one lithologic unit to another: a single vein may become a stockwork on passing from, say, slate into a porphyry, and fissures which are wide in granite may become exceedingly narrow on passing into hornfels, or they may die out at the contact. There is no doubt that in tin mines where there is more than one major lithologic unit the deposits of economic interest are commonly confined to one of these. This is not because the favoured unit is chemically or mineralogically different from the rest, but because fissures developed in it which were capable of promoting the deposition of cassiterite much more effectively than were the fissures in the other units or because the fissures were confined to the one unit. For a fissure system to induce the deposition of cassiterite its characteristics must, in the writer's view, be such that the velocity of the ore-depositing agent is brought within the critical range. As, in Cornwall, maximum cassiterite concentrations is found in the vicinity of the wide parts of the "feeder channels" it can be concluded that the critical range was low.

vi. The nature and degree of fracturing and of fissure development immediately before and during ore genesis

This has been partly covered in the previous section. It remains, however, to be pointed out that a strong tin lode would not normally develop unless its channel ways were open for all or most of the time when tin-depositing agents were available, and this was usually only achieved by progressive faulting. When, however, the lode continued to be opened for a considerable time after the ore-forming agents ceased to be tin bearers, it sometimes decreased in value because of comminution of the cassiterite, further additions of gangue minerals and the introduction of such minerals as the copper-bearing sulphides, which are of some economic value, but which by cementing the fine cassiterite increase milling problems.

vii. The timing of fracturing and fissure formation during ore genesis

This is covered in the foregoing section.

viii. The temperature conditions prevailing in the fissures, and possibly also in the "body" of the fissured and neighbouring rocks, during ore genesis

In some tin fields the ore-elements show some degree of zonal arrange-

ment around the centres of mineralisation. This is usually said to be due to the fact that as the ore-forming agents migrate along channels from their source towards the surface they become progressively cooler and that a given mineral is not deposited until the temperature has fallen to the critical point. It is not proposed, however, to discuss this, or other, ideas which have been put forward to explain primary zoning when it occurs, or the lack of it in some fields, but it is difficult not to believe that temperature plays some part.

When discussing primary zoning Cornwall is often cited as a "type" area but, unfortunately, many accounts of Cornish primary zoning are gross distortions of the truth. It is broadly true to say that the tin zones are centred around granite cusps and that these are overlain, and in part overlapped, by more extensive copper zones which in turn are overlain, and in part overlapped, by still more extensive lead/zinc zones. It is, however, equally true to say that copper, lead and zinc lodes are commonly found within the "so-called" tin zone and that associated with the cassiterite in most lodes are "stranger" minerals such as siderite, sphalerite and jasper. Because of such complications the search for further tin deposits is not always as simple as one would wish. For instance, even in the heart of a tin field, one cannot be sure whether a lode which is copper-bearing near the surface will be essentially tin-bearing in depth or whether it will remain copper-bearing throughout.

All that need be said about xenothermal deposits is that they are often telescoped or display some degree of lateral zoning. When they are telescoped the ore is complex and difficult to treat, and so a higher grade may be necessary for it to be worth mining than would be the case were it of the usual Cornish type. However, from the point of view of the prospector, the most important point of all is that in all the different types of primary deposit the tin is always near the emanative centre: the problem, on occasion, of course, is to determine just where the latter is likely to be!

ix. *The chemical character of the ore-forming agents and of the invaded rocks*

Although the chemical character of the ore-forming agents must largely determine the numerous variations of the mineralogical theme of the primary tin deposits, to discuss it would be to concern oneself to no small extent with theories and hypotheses, and so it falls outside the self-imposed terms of reference of the writer. However, the chemical character of the invaded rocks invites some comments. It has already been stated that major tin deposits can develop in almost any kind of rock. In the Rooiberg area they locally occur in arkose (Leube and Stumpf, 1963), in Billiton in sandstone, etc. (Adam, 1960) and in Cornwall in granite, porphyry, dolerite and slate. But can it be that there are so-called primary lodes which, in fact, are ancient placer deposits which have been reconstituted by ore-forming agents? Could it be that the "bed-veins" of Klappa Kampit (Billiton) fall into this category despite the fact that mineralogically they show pyrometasomeric characteristics (Adam, 1960, pp. 417-420)? If such transformations have not occurred then why is it that more ancient tin-rich placers have not been found? Of course, some are known: the lower Carboniferous conglomerates of the Boorda region, North Tien Shan, U.S.S.R., contains pebbles of quartz-carbonate veins, tetrahedrite or tennantite, chalcopyrite, galena, pyrite, sphalerite, native silver,

baryte, fluorite and cassiterite, particularly if the component would appear to be one capable of being subject to those agents which are responsible for the components of these same masses. On the other hand, it may be that so few of these elements (because the search has not been made in the close to granitic masses) or that the elements are granitising processes.

In this paper the writer is concerned with the relationship between the two groups, as he originally consists of those, all-too-many, who are invalid. In addition, he has not solved before the tin exploration problem on scientific foundations than many.

He is only too well aware of this, but, nevertheless, he hopes that the further tin deposits and by so much the more the tin industry will be able to supply which only they and their General Wolfe, can say with confidence, understand the disadvantages of the uncommon natural strength.

baryte, fluorite and cassiterite (Turovskiy, *et al.*, 1964). Such a mixture, particularly if the components were in the form of grains rather than pebbles, would appear to be one capable of undergoing profound changes if it were subject to those agents which effect the mobilisation and redeposition of the components of these same minerals when they occur in lodes. On the other hand, it may be that so few ancient tin-rich placers have been found, either because the search has not been in the right areas (though these should all be close to granitic masses) or because most of them have been obliterated by granitising processes.

Conclusion

In this paper the writer has gone some way towards sorting out the data concerning the relationship between granitic rocks and primary tin deposits, not into two groups, as he originally planned, but into three. The third group consists of those, all-too-many, pronouncements which may or may not be valid. In addition, he has indicated some of the problems which need to be solved before tin exploration programmes can be designed with much sounder scientific foundations than many of them have had to date.

He is only too well aware of the shortcomings of this particular "effort", but, nevertheless, he hopes that it may help those others who set out to find further tin deposits and by so doing embark upon a task fraught with difficulties which only they and their fellow travellers fully appreciate. They, like General Wolfe, can say with conviction: "People must be of the profession to understand the disadvantages and difficulties we labour under, arising from the uncommon natural strength of the country".

Bibliography

- ADAM, J. W. H.: *On the geology of the primary tin deposits in the sedimentary formation of Billiton*. Geologie en Mijnbouw, 405-426, 1960.
- AHRENS, L. H. and LIEDENBERG, W. R.: *Tin and indium in mica, as determined spectrochemically*. Amer. Mineral., 35, 571-578, 1950.
- ARANYAKANON, P.: The cassiterite deposit of Haad Som Pan, Ranong Province, Thailand. Rep. Invest. no. 4, Roy. Dept. Mines, Bangkok, Thailand, 1961.
- BARSUKOV, V. L. and PAVLENKO, L. I.: *Distribution of tin in granitic rocks*. Doklady Akad. Nauk, S.S.S.R., 109, 589-592, 1956. Translated into English by the D.S.I.R. (Lond.) and issued in May, 1961.
- BILIKIN, Y. A.: *Metallogenetic provinces and epochs*. Gosgeoltekhizdat, Moscow, 1955 (In Russian).
- BOTT, M. H. P., DAY, A. A. and MASSON-SMITH, D.: *The geological interpretation of gravity and magnetic surveys in Devon and Cornwall*. Phil. Trans., 251, 161-191, 1958.
- BROWN, G. F. et al.: *Geologic reconnaissance of the mineral deposits of Thailand*. Geol. Surv. Memoir no. 1, Roy. Dept. Mines, Bangkok, Thailand, 1953.
- CHAURIS, L.: *Les minéralisations pneumatolytiques du Massif Armoricaïn*. Mémoires du BRGM, no. 31, 1965.
- COLLINS, J. H.: *Observations on the West of England mining region*. Trans. R. Geol. Soc. Cornwall, 14, 1912.
- COTELA NEIVA, J. M.: *Jazigos Portugueses de cassiterite e de volframite*. Empresa Indust. Gráfica do Pôrto, Lda., 1944.
- DARNLEY, A. G.: *Ore genesis and mantle convection*. In "Some Guides to Mineral Exploration". Geol. Surv. Canada, paper 65-6, 108-123, 1965.
- DAVIS, S. G.: *Tungsten mineralisation in Hong Kong and the New Territories*. Econ. Geol., 53, 481-488, 1958.
- DAVISON, E. H.: *Handbook of Cornish Geology*. Oscar Blackford, Truro, Cornwall, 1930.
- DAVISON, E. H.: *Mineral associations in Cornish tin lodes*. Mining Mag., Sept., 1930.
- DENNIS, J. G.: *Notes on some cassiterite-bearing pegmatites near Brandberg, South-West Africa*. Econ. Geol., 54, 1115-1121, 1959.
- DERRY, D. R.: *Tin-bearing pegmatites in Eastern Manitoba*. Econ. Geol., 25, 145-159, 1930.
- DINES, H. G.: *The metalliferous mining region of South-West England*. 2 vols. H.M.S.O., London, 1956.
- DUDYKINA, A. S.: *Paragenetic associations of element-admixtures in cassiterites of different genetic types of tin-ore deposits*. Akad. Nauk S.S.S.R., Inst. geol. rudnykh mestorozhd., petrog., mineral., i geokhim., 28, 111-121, 1959.
- EDWARDS, A. B. and GASKIN, A. J.: *Ore and granitisation*. Econ. Geol., 44, 234-241, 1949.
- EL SHARKAWI, M. A. H. and DEARMAN, W. R.: *Tin-bearing skarns from the north-west border of the Dartmoor granite, Devonshire, England*. Econ. Geol., 61, 362-369, 1966.
- EL SHAZLY, E. M., WEBB, J. S. and WILLIAMS, D.: *Trace elements in sphalerite, galena and associated minerals from the British Isles*. Trans. Instn. Min. Metall., Lond., 66, 241-271, 1956-57.
- FAWLEY, A. P. and JAMES, T. C.: *A pyrochlore (columbium) carbonatite, Southern Tanganyika*. Econ. Geol., 50, 571-581, 1955.
- FITCH, F. M.: *The tin mines of Pahang Consolidated, Ltd.* Trans. Inst. Min. Metall., Lond., 57, 1-27, 1947-48.
- GARNETT, R. H. T.: *Structural control of mineralisation in South-West England*. Mining Mag., 105, 329-337, 1961.

- GINZBURG, A. I.: See CHILINGA indicators and their significance by A. I. Ginzburg. Econ. Geol., 4, 1959.
- GHOSH, P. K.: *The Carnmenellis gneiss*. Quart. J. Geol. Soc. Lond., 90, 1934.
- HARMAN, S. H.: *Some tin deposits*. Econ. Geol., 52, 148-152, 1935.
- HATCH, F. H., WELLS, A. K. and others: *Geology of the rocks*. 10th ed., Murby and Co., 1962.
- HAWKES, H. E. and WEBB, J. S.: *Geology of the rocks*. 10th ed., Murby and Co., 1962.
- HOSKING, K. F. G.: *The relation of the structure of South-West England to the geology*. Edited by Coc. Manchester Univ. 1962.
- HOSKING, K. F. G.: *Permo-Carboniferous wall and South-West Devon*. In "Cornwall and Devon", edited by Hosking, K. F. G. and Shrimpton, 201-245, 1964.
- HOSKING, K. F. G.: *The Search for tin*. 448-461, 1965.
- INGHAM, F. T.: *Report on the geology of the Federation of Malaya*, 1949.
- INGHAM, F. T. and BRADFORD, J.: *Geology of the Perak Valley, Perak, Federation of Malaya*, 1950.
- JACOBSON, R. R. E., SNELLING, J. and others: *Geology of the granites H.M.S.O. Lond.*, 168-171, 1962.
- JEDWAB, J.: *La signification des pegmatites*. Ann. Soc. Géologique de Belgique, 88, 201-245, 1964.
- JEDWAB, J.: *Sur la définition des pegmatites*. Géol. etc., LXII, 173-179, 1953.
- JEDWAB, J.: *Granites à deux micas*. Bull. de la Soc. belge de Géol., 88, 173-179, 1953.
- JONES, W. R.: *Tin fields of the world*. H.M.S.O., London, 1956.
- LAKIN, H. W., HUNT, C. B., DAVISON, E. H. and others: *element content of desert varnish*. Bull. de la Soc. belge de Géol., 88, 173-179, 1953.
- LEUBE, A. and STUMPFL, E. F.: *Geology of South Africa*. Econ. Geol., 58, 1-10, 1963.
- MACKAY, R. A., GREENWOOD, R. A. and others: *Plateau tin fields — resurvey 1959-1960*. Mining Mag., 105, 329-337, 1961.
- MCCARTNEY, W. D. and POTTER, J.: *deformation, igneous activity and metallogeny*. J., 83, 83-87, 1962.
- MCDUGALL, D. J.: *A study of the geology of the region*. Geol., 61, pp. 1090-1103.
- McKEE, A.: *Caen, anvil of victory*. Pa. Min. Metall., Lond., 1929.
- PEREIRA, J.: *Reflections on ore genesis*. Min. Metall., Lond., 74, 505-527, 1962.

- GINZBURG, A. I.: See CHILINGAR, G.V. Summary of *About minerals-geochemical indicators and their significance in prospecting for ores of rare metals in pegmatites* by A. I. Ginzburg. Econ. Geol., **60**, 748-750, 1955.
- GHOSH, P. K.: *The Carnmenellis granite: its petrology, metamorphism and tectonics*. Quart. J. Geol. Soc. Lond., **90**, 240-276, 1934.
- HARMAN, S. H.: *Some tin deposits of the Burma-Malayan peninsula*. Mining Mag., **52**, 148-152, 1935.
- HATCH, F. H., WELLS, A. K. and WELLS, M. K.: *The petrology of the igneous rocks*. 10th ed., Murby and Co., London, 1949.
- HAWKES, H. E. and WEBB, J. S.: *Geochemistry in mineral exploration*. New York, 1962.
- HOSKING, K. F. G.: *The relationship between the primary mineralisation and the structure of South-West England*. In "Some aspects of the Variscan Fold Belt", edited by Coe. Manchester Univ. Press, 135-153, 1962.
- HOSKING, K. F. G.: *Permo-Carboniferous and later primary mineralisation of Cornwall and South-West Devon*. In "Present views of some aspects of the geology of Cornwall and Devon", edited by K. F. G. Hosking and G. J. Shrimpton. Penzance, pp. 201-245, 1964.
- HOSKING, K. F. G. and SHRIMPTON, G. J.: See immediately preceding reference.
- HOSKING, K. F. G.: *The Search for Tin*. Mining Mag., **113**, 261-273, 308-383 and 448-461, 1965.
- INGHAM, F. T.: Report on the Geological Survey Department for the year 1948. Federation of Malaya, 1949.
- INGHAM, F. T. and BRADFORD, E. F.: *Geology and mineral resources of the Kinta Valley, Perak*. Federation of Malaya Geol. Surv. District Mem. no. 9, 1960.
- JACOBSON, R. R. E., SNELLING, N. J. and TRUSWELL, J. F.: *Age determinations in the geology of Nigeria, with special reference to the Older and Younger Granites*. H.M.S.O. Lond., 168-182, 1964.
- JEDWAB, J.: *La signification des traces d'étain dans certains minéraux communs des pegmatites*. Ann. Soc. Géologique de Belgique, **76**, 101-105, 1953. pp. 201-245, 1964.
- JEDWAB, J.: *Sur la définition des éléments typochimiques*. Bull. de la Soc. belge de Géol. etc., **LXII**, 173-179, 1953.
- JEDWAB, J.: *Granites à deux micas de Guéhenno et de la Villeder (Morbihan-France)*. Bull. de la Soc. belge de Géol., etc., **64**, 526-534, 1955.
- JONES, W. R.: *Tin fields of the world*. Lond., 1925.
- LAKIN, H. W., HUNT, C. B., DAVIDSON, D. F. and ODA, U.: *Variation in minor-element content of desert varnish*. U.S.G.S. professional paper 475-B, 28-29, 1963.
- LEUBE, A. and STUMPFL, E. F.: *The Rooiberg and Leewpoort tin mines, Transvaal, South Africa*. Econ. Geol., **58**, 391-418, 1963.
- MACKAY, R. A., GREENWOOD, R. and ROCKINGHAM, J. E.: *The geology of the Plateau tin fields — resurvey 1945-48*. Bull. no. 19, Geol. Surv. Nigeria, 1949.
- MCCARTNEY, W. D. and POTTER, R. R.: *Mineralisation as related to structural deformation, igneous activity and sedimentation in folded geosynclines*. Canad. Min. J., **83**, 83-87, 1962.
- MCDUGALL, D. J.: *A study of thermoluminescence around an ore deposit*. Econ. Geol., **61**, pp. 1090-1103.
- McKEE, A.: *Caen, anvil of victory*. Pan Books Ltd., Lond., 1966.
- NIGGLI, P.: *Ore deposits of magmatic origin* (translated by H. C. Boydell). Murby and Co., Lond., 1929.
- PEREIRA, J.: *Reflections on ore genesis and exploration*. Mining Mag., **108**, 9-22, 1963.
- PEREIRA, J. and DIXON, C. J.: *Evolutionary trends in ore deposition*. Trans. Instn. Min. Metall., Lond., **74**, 505-527, 1964-65.

- RABINOVIC, A. V.: Ueber die geochemische Grundlage einer Verknüpfung der endogenen Mineralisation mit den Intrusivgesteinen. Published in Russian and German by the United Soviets Geological Institute, Leningrad.
- RANKAMA, K.: *On the geochemical differentiation in the Earth's crust*. Bull. Comm. Geol. Finlande, no. 137, 1-24, 1946.
- RANKAMA, K. and SAHAMA, Th. G.: *Geochemistry*. University of Chicago Press, 1952.
- RATTIGAN, J. H.: *Geochemical ore guides and techniques in exploration for tin*. Australian Inst. Min. Metall., no. 207, 137-151, 1963.
- SAHA, A. K.: *A simple grid deviation technique of study of the areal composition variations in granitic bodies*. Geol. Mag., **101**, 145-149, 1964.
- SEREBRYAKOV, V. A.: *Autosomal alteration of granitoids and association of tin mineralisation with the zone of sodium-potassium metasomatism*. Sovetskaya Geologiya, **2**, 61-80, 1959.
- STEMPROK, M.: *Distribution of Sn-W-Mo formation deposits around granites*. Symposium — Problems of postmagmatic ore deposition, Prague, **1**, 69-71, 1963.
- STEMPROK, M.: *Traces of sulphide and greisen mineralisation in the deep parts of the Cinovic (Zinnwald) granite massif*. Zvláštní otisk vestníku ústředního ústavu geologického, **39**, pt. 3, 211-213, 1964.
- STEMPROK, M.: *On the relation of tin-tungsten-molybdenum ore mineralisation to granites*. In "Contributions to the geology and petrology of crystalline complexes". Prague, 163-183, 1965.
- STRAUSS, C. A.: *The geology and mineral deposits of the Potgietersrust Tinfields*. Union of South Africa Geol. Surv. Mem. no. 46, 1954.
- STUMPEL, E. I.: *Some new platinoid-rich minerals, identified with the electron microanalyser*. Min. Mag., **32**, 833-847, 1961.
- SULLIVAN, C. J.: *Ore and granitisation*. Econ. Geol., **43**, 471-498, 1948.
- TEALE, Sir EDWARD.: *East African Mining*. Mining Mag., **66**, 53-62, 1942.
- THOMAS, H. H. and MACALISTER, D. A.: *The geology of the ore deposits*. Edward Arnold, London, 1920.
- TURNER, F. J. and VERHOOGAN, J.: *Igneous and metamorphic petrology*. McGraw-Hill Book Co., Inc., N. York, 1951.
- TUROVSKIY, S. D., MAKAROV, V. A. and NOSYREV, I. V.: *Ore pebbles from Lower Carboniferous conglomerates of the Boorda region, north Tien Shan*. Dokl. Acad. Sci. U.S.S.R., Earth Sci. Sect., **147**, 165-166, 1964.
- TYNDALE-BISCOE, R.: *The geology of the Bikita tin field, Southern Rhodesia*. Trans. Geol. Soc. S. Africa, **44**, 11-23, 1951.
- WADE, A.: *The geology of the Antarctic Continent and its relationship to neighbouring land areas*. Proc. Roy. Soc. Queensland, **52**, no. 4, 1-12, 1940.
- WARREN, H. V. and THOMPSON, R. M.: *Sphalerites from Western Canada*. Econ. Geol., **40**, 309-335, 1945.
- WEBB, J. S.: *The origin of tin lodes in Cornwall*. Unpub. Ph. D. Thesis, Univ. of London, 1947.
- WESTERWELD, J.: *The granites of the Malayan Tin-Belt compared with tin — granites from other regions*. Proc. Kon. Akad. Wetenschappen Amsterdam, **39**, no. 10, 1199-1209, 1936.
- WILLIAMS, F. A., MEEHAN, J. A., PAULO, K. L., JOHN, T. U. and RUSHTON, H. G.: *Economic geology of the decomposed columbite-bearing granites, Jos Plateau, Nigeria*. Econ. Geol., **51**, 303-332, 1956.
- ZESCHKE, G.: *Thermal glow tests as a guide to ore deposits*. Econ. Geol., **58**, 800-803, 1963.

Dr. Hosking added the fol

"I mentioned that we w porphyry dykes which accomp England and elsewhere. The w men of a dyke from a point wh veins and analyses it, if it conta in a tin field and tin deposits reported, then one may be at way from it."

Mr. R. D. Schuiling asked biotites were high in tin, on Dr. Hosking said that he did did not believe it was always developed, as some had suggested granite, then in such circumstances but low tin in the biotites of t because biotites were high in ti More work was needed in that present stage to assume that hi

Mr. T. T. Bartels said th origin for the so-called "bed-v not seem very probably to him mation so far no conglomerate sandstones and shales, and pro

As a rule the lateral exten many of them were more or le great lateral extent occurred, chert, and thus clearly marine. strata that the so-called "beddi of those bedding-plane veins fo northern contact of the radiola horizon. It seemed probable tha made them suitable for subsequ they also had a somewhat spe

In that connection it migh of iron minerals in the bedding iron sulphides and silicates, su content), ilvaite, and in some the bulk of the vein material.

Discussion

Dr. Hosking added the following to his paper:

"I mentioned that we were studying the distribution of metals in the porphyry dykes which accompany hypothermal deposits in the South-west of England and elsewhere. The work to date has shown that, if one takes a specimen of a dyke from a point where it is not obviously intersected by mineralised veins and analyses it, if it contains a high trace amount of tin then the dyke is in a tin field and tin deposits are close at hand. However, if a low value is reported, then one may be at the heart of strong tin mineralisation or a long way from it."

Mr. R. D. Schuiling asked whether the author would agree that, where biotites were high in tin, one would expect the area to be stanniferous. *Dr. Hosking* said that he did not. It obviously was so in some areas, but he did not believe it was always the case. It could be that if tin deposits had developed, as some had suggested, as a result of the leaching of the biotites in a granite, then in such circumstances one would expect not high tin in the biotites but low tin in the biotites of the stanniferous zones. He did not believe that because biotites were high in tin that it meant one was in a stanniferous area. More work was needed in that and other fields, but it would be unwise at the present stage to assume that high tin in the biotites meant a stanniferous zone.

Mr. T. T. Bartels said that the author had suggested a possible placer origin for the so-called "bed-veins" of Klapper-Kampit. Such an origin did not seem very probable to him (*Mr. Bartels*). In the local sedimentary formation so far no conglomerates had ever been found. The series consisted of sandstones and shales, and probably originated as a delta deposit.

As a rule the lateral extent of the individual strata was very limited, and many of them were more or less lenticular in shape. Only very few strata of great lateral extent occurred, the most important of them being radiolarian chert, and thus clearly marine. It was particularly along those more extensive strata that the so-called "bedding-plane veins" occurred. The most important of those bedding-plane veins followed rather closely either the southern or the northern contact of the radiolarian chert, which served as an excellent guide horizon. It seemed probable that the great continuity of those particular strata made them suitable for subsequent mineralisation. It might be, however, that they also had a somewhat special composition.

In that connection it might be relevant to mention the very high content of iron minerals in the bedding-plane veins. Those minerals were iron oxides, iron sulphides and silicates, such as amphiboles, chlorides (with high iron content), ilvaite, and in some cases even fayalite. Those minerals constituted the bulk of the vein material. The iron-olivine fayalite was not found in the

Klapper Kampit mine but in a similar bedding-plane vein in Seloemar mine, about 17 miles S.E. of Klapper Kampit.

In undisturbed parts of those veins the tin content was usually rather low (less than 1 %) but, in regions where the veins had been broken up by several transverse faults, their tin content was much higher. That increase in tin content was usually accompanied by an increase in quartz in the gangue, and with a recurrence of fluoride, arsenopyrites and sometimes small amounts of other sulphide minerals. There was probably a connection with the tin mineralisation in the fissure veins.

Dr. Hosking said in his paper he had asked the question and did not make a statement. He asked the question to provoke further discussion about the major problem which was why ancient sedimentary rocks were not found, for instance, containing appreciable quantities of cassiterite. It seemed not impossible, despite the mineral assemblage mentioned, that one could start with some sort of sedimentary deposit. It might be possible to introduce everything else but utilise the tin that was already there.

As to the minerals mentioned by *Mr. Bartels*, almost everything had been found associated with cassiterite. In a mine in Cornwall, where a fissure intersected a dolerite dyke, there was a replacement deposit consisting of magnetite, hornblende and cassiterite. *Mr. Bartels* said that fayalite was an extraordinary mineral in association with tin ore. *Dr. Hosking* agreed that it was an unusual one to find with tin, but he simply suggested that the tin might have been there initially, and that other components came up and re-deposited it. Here was a problem of fundamental importance to anyone concerned with the genesis of tin deposits.

Mr. J. L. Lee referred to the work done on porphyry dykes. He had carried out work on veins containing porphyry dykes. In most cases he had found that the content in the dyke was much the same as in the vein. There were a few cases in which the tin content in the dyke was low — of the order of 2½ p.p.m. — and the vein with the common dyke contained as much as 350 p.p.m. Information given by veins could complement to some extent that obtained from the dykes. *Dr. Hosking* said he had held that it was the tin content of the veins in the dykes which was likely to be of real use when searching for tin deposits and other deposits. Dykes were often well jointed and appreciably veined, and the openings constituted good channel-ways in which ore-forming agents could leak away from the source.

Mr. A. D. Francis asked whether further thought should not be given to granitic rocks themselves as a source of cassiterite. *Dr. Hosking* had mentioned Nigerian deposits very briefly in his paper, but he (*Mr. Francis*) knew that the granite over large areas contained significant and persistent values of cassiterite which appeared to be an accessory mineral in the granite itself. It might be useful avenue for exploration in the future for tin deposits because, even though they might be low grade, if they persisted in areas subjected to tropical weathering so that the rock was soft, it might well be a major source of cassiterite in the future. *Dr. Hosking* suggested that the question was one of economics. For a long time a certain amount of cassiterite had been recovered

along with columbite from dec discuss the question whether ca interest to those concerned with for ore.

Mr. C. T. Sweet said that which were highly stanniferous other granites around. There large tonnages. There was a g but there was no association be

Mr. M. P. Jones said that be very interested in the occu rewards from low-grade prima than those to be obtained from

The Odegi granite in Nige 0.5 miles and is thoroughly d average tin content of this ma Every yard of depth of the ore 1 yard wide and assaying 1 p a similar length of 0.5 miles.

Decomposed granites simil land, Indonesia and also proba source of cassiterite and deserv

Dr. Hosking agreed, but it could be recovered, and what w sources and would have to rec The Odegi field was a columbit zircon there.

Dr. D. S. Singh said that gical features. In Malaysia, wh found in the north of Kuala granite. Using that as field cri particularly when dealing with entirely. If one found a local to use it. But what was dangero that a certain indicator told him to extend it and to say that the cause in most cases it was not might not in fact be useful in differentiate between the aid which was likely to be of univ arriving at that stage, but when would be greatly facilitated.

Mr. M. G. Oosterom said i areas with tin mineralisation,

along with columbite from decomposed Nigerian granites. He did not wish to discuss the question whether cassiterites were accessory or not. It was of great interest to those concerned with geology, but he was concerned with searching for ore.

Mr. C. T. Sweet said that the Air Montains in the Sahara had zones which were highly stanniferous and which were difficult to differentiate from other granites around. There was insufficient water in the area to think of large tonnages. There was a good deal of greisenisation in the neighbourhood, but there was no association between greisenisation and mineralisation.

Mr. M. P. Jones said that anyone engaged in mineral exploration should be very interested in the occurrences of primary tin minerals. The possible rewards from low-grade primary granite deposits are likely to be far greater than those to be obtained from comparatively high-grade lode deposits.

The Odegi granite in Nigeria outcrops over an area of about 0.5 miles x 0.5 miles and is thoroughly decomposed to depths of about 50 yards. The average tin content of this mass of readily-mined material is 0.06 per cent. Every yard of depth of the ore body contains 600 tons of tin, whereas a lode 1 yard wide and assaying 1 per cent of tin contains only 12 tons of tin in a similar length of 0.5 miles.

Decomposed granites similar to the Odegi granite occur in Nigeria, Thailand, Indonesia and also probably in Malaysia. They constitute a very important source of cassiterite and deserve to be studied in detail.

Dr. Hosking agreed, but it was again a question of economics. How much could be recovered, and what was the size of the cassiterite? They were major sources and would have to receive increasing attention in the next few years. The Odegi field was a columbite field primarily, but there was also thorite and zircon there.

Dr. D. S. Singh said that the explorationist must appreciate local geological features. In Malaysia, where there were two major granitic types, it was found in the north of Kuala Lumpur that tin always went with fine grain granite. Using that as field criterion, one could limit one's work in the field, particularly when dealing with a jungle terrain. *Dr. Hosking* said he agreed entirely. If one found a local indicator, then obviously the thing to do was to use it. But what was dangerous was for an individual to find in a given area that a certain indicator told him where to search for tin, and then to proceed to extend it and to say that the method was likely to be useful elsewhere, because in most cases it was not so. What might be useful in Malaysia locally might not in fact be useful in Cornwall. It was important to endeavour to differentiate between the aid which was of strictly local value and the aid which was likely to be of universal value. More work had to be done before arriving at that stage, but when that stage was reached, then the search for tin would be greatly facilitated.

Mr. M. G. Oosterom said it would seem from the remarks that, in granite areas with tin mineralisation, porphyry dykes might or might not contain

characteristic amounts of tin. That assumption might be valid perhaps for granitic rocks and biotites as well. In his view it was a statistical question and more work to that end should be done. *Dr. Hosking* agreed that more work needed to be done statistically. But, if one were thinking of a search for tin, it was most important to know from where the samples were taken. A number of samples might be taken from a given granite outcrop of limited extent, and might not be at all comparable with a similar quantity of samples taken by somebody else even from the same granite. In his view, in the past, people had not indicated sufficiently clearly from where samples had been taken. One must know precisely from where they had been taken from in the granite and how they were related to such features as cusps and valleys on the original granite surface, and how near they were taken to lodes, and to zones of obvious alteration. *Mr. Oosterom* agreed that a standardised approach should be worked out, and the results brought together.

Mr. M. A. Brooke referred to experience in Australia in the mining and treatment of granites, particularly in view of the statement of *Mr. Jones* that in Nigeria there was granite in respect of which the assay for tin went to about 0.06 %. There was a company working about 300 miles west of Sydney on hard granite. The softer portions of the granite had been worked about 50 years ago and the company, when it took up the area, found all the soft rock had gone. An investigation was carried out and estimated that there could be a 60 % recovery. In actual fact they found it was possible to obtain a 60 % recovery, but to get a 60 % recovery it was necessary to accept a concentrate of a grade of about 40 %. The company were successful and were able to pay their way with tin at the present price.

Dr. Hosking said that it depended in part on how badly the tin was needed. In Cornwall, some years ago, the face of a granite cliff, in which a swarm of greisen-bordered cassiterite-wolframite veins was exposed, was sampled. The value found was 2—3 lbs SnO₂ per long ton. There had been some selective mining there in the past: today there is little likelihood of working this deposit profitably even if large tonnages were mined and beneficiated daily.

Mr. M. P. Jones said that the comparison of the grades of various ore was made difficult by the use of varied and poorly-defined units. Some operators evaluate their ores in terms of "pounds of recovered cassiterite per ton of ore", others use the unit "pounds of recovered cassiterite per cubic yard of ore". He used the percentage of tin as a measure of the value of an ore and hoped that this unit would be more generally accepted. Low-grade alluvial material at present being worked in Malaysia was said to contain the equivalent of 0.01 per cent tin. By comparison, the 0.06 per cent tin in the decomposed Odegi granite showed it to be, potentially, a very rich ore. Many of the ore-bodies now being worked in South-East Asia were very similar in field characteristics to the Odegi granite. A research programme is being carried out at the Royal School of Mines to study the cassiterite content and the size distribution of the associated minerals in decomposed granites from Thailand and Malaysia. *Dr. Hosking* said he agreed on standardisation. It would be difficult to get people generally to standardise, however desirable it might be.

Mr. W. Fox (Secretary to the Council) had succeeded in getting the miners to give their returns in one form of concentrates. One would have thought that statistical field geologists might be able to do a better job of measuring the same thing uniformly.

Dr. Hosking said it was not too late to do this before geologists. The miners did not think that standardisation was good. He suggested different units to make it clear, and at least define the terms they used.

Mr. L. J. Fick supported the suggestion that not mobilised ancient tin places should be considered. Lodes were of a proved Permian age and the mineralisation were believed to be of the same age.

Mr. W. Fox (Secretary to the International Tin Council) pointed out that the Council had succeeded in the statistical field in persuading all countries to give their returns in one form, that is, in terms of long ton and tin-in-concentrates. One would have thought that what the Council could do in the statistical field geologists might be able to do in the quite peculiar system they had of measuring the same thing under about ten different names.

Dr. Hosking said it was not entirely the geologists. There were miners before geologists. The miners decided what units they would use. He agreed that standardisation was good. *Mr. Michael West* appealed to those who gave different units to make it clear what units they were using. They should at least define the terms they used.

Mr. L. J. Fick supported the view that the Klappa Kampit tin lodes were not mobilised ancient tin placers. The sandstone-slate of the bedding plane lodes were of a proved Permian age, whereas the granites which had brought about the mineralisation were believed to be of a Jurassic-Cretaceous age.

Mr. W. Fox (Secretary to the International Tin Council) pointed out that the Council had succeeded in the statistical field in persuading all countries to give their returns in one form, that is, in terms of long ton and tin-in-concentrates. One would have thought that what the Council could do in the statistical field geologists might be able to do in the quite peculiar system they had of measuring the same thing under about ten different names.

Dr. Hosking said it was not entirely the geologists. There were miners before geologists. The miners decided what units they would use. He agreed that standardisation was good. *Mr. Michael West* appealed to those who gave different units to make it clear what units they were using. They should at least define the terms they used.

Mr. L. J. Fick supported the view that the Klappa Kampit tin lodes were not mobilised ancient tin placers. The sandstone-slate of the bedding plane lodes were of a proved Permian age, whereas the granites which had brought about the mineralisation were believed to be of a Jurassic-Cretaceous age.