

The Search for Tin

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In this final section of his article the author discusses the dispersal and concentration of cassiterite, reviewing the question of the mineral's solubility and its relation to geochemical and physical survey. Dealing finally with the search for tin supplies, he carefully reviews the newer techniques now available.

WHILST only the tin in cassiterite and in a few sulphides in which it is a major component is at present of interest to the miner, the applied geochemist must concern himself with the distribution of tin throughout the whole of the mineral kingdom if he is to make really adequate interpretations of the data he obtains by analysing rocks, soils, individual mineral species, etc. As will be seen later, minor and trace amounts of tin, proxying for other metals, particularly in sulphides and ferromagnesian minerals, may be the source of anomalous concentrations of the metal in superficial material and plants, and if the causes of such anomalies are not appreciated they might lead to further abortive, yet expensive prospecting programmes.

The Dispersal and Concentration of Tin

The stability in the zone of weathering of those species in which tin occurs, or may occur, in quantities of prime importance to the applied geochemist, varies enormously. Cassiterite, a fairly inert mineral, tends to be concentrated in the oxidised portions of lodes, particularly if it were originally associated with readily decomposable sulphides or sulpho-salts, and it is subsequently dispersed in the neighbouring soil, or directly into fluvial sediments should the orebody be intersected by a stream. The ease with which it is dispersed in the soil obviously depends on such factors as the nature of the terrain, vegetation, climatic conditions, character of the country rock, etc., but it will also depend, to no small degree, on the mineralogical character of the parent deposit. A mineral deposit consisting, for example, of cassiterite with large proportions of sulphides and a little inert gangue, is readily decomposed in humid climates and the products are rapidly disintegrated. On the other hand, one composed of cassiterite, quartz and tourmaline is virtually unaffected by the naturally occurring chemical agents found in the near surface environment, and so dispersion of the cassiterite is less pronounced as it is solely dependent on the physical agents of disintegration.

Other things being equal, the ease with which cassiterite will be transported from the site of the parent deposit will depend on the size of the cassiterite aggregates and individual crystals and on the extent to which it is liberated at an early stage, from associated species. For example, much of the cassiterite in a sulphide-poor hypothermal lode may occur in the overburden in composite grains associated with quartz, tourmaline, chlorite and sericite, which, because of their comparatively low specific gravity, are fairly readily transport-

ed by surface run off should the outcrop occur on a slope. Because the tin in the soil adjacent to cassiterite-bearing lodes is dispersed essentially by mechanical means it does not move far from the source in fairly flat terrain, and, as tin lodes are commonly not more than a few feet wide, it follows that when geochemical soil samples are employed to locate such sub-outcropping bodies the sample point interval along traverses at right-angles to the assumed strike of the lodes should be small—in Cornwall not greater than 20 ft.

During oxidation most of the tin in sulphides is likely to be liberated as soft earthy varlamoffite (impure hydrated stannic oxide) which is somewhat less inert than cassiterite, so some of the metal may go into solution. Indeed, it is probably that whenever plants contain appreciable quantities of the metal, that it was derived initially from a sulphide source rather than from cassiterite. Millman (1957, pp. 85-93) demonstrated that in the vicinity of cassiterite-bearing lodes in the West of England, species of *Quercus*, *Betula*, *Fagus* and *Salix* contained a maximum of 1 p.p.m. tin even when growing in soils containing as much as 250 p.p.m. Even here it is not certain that the 1 p.p.m. tin was derived from cassiterite: it might just as well have come from say, sphalerite.

Solubility of Tin

Although the presence of tin in both extant and fossil plant demonstrates that some tin must be solubilised by processes of weathering it represents, in any given situation, only a very small percentage of the total tin present. It has been suggested, for example, that some of the Bolivian wood tin has developed from tin mobilised by the oxidation of stannite but the evidence in support of this is very suspect. In 1881 Collins reported that an antler found in the Pentuan stanniferous alluvials contained more than 2 per cent stannic oxide and suggested that this was a chemical precipitate. Further studies by the writer (Hosking, 1960), on the same antler, gave strong reason for believing that the broken end, which Collins had analysed, contained detrital cassiterite which had been washed into the Haversian canals, etc.

Unpublished studies by the writer also established that a water sample from the Red River, which carries the tailings from South Crofty mine, after being filtered contained 16 micrograms of tin per litre. However, this may well have been due to colloidal, or near colloidal-size, suspended particles which had passed through the filter paper. That abrasion, by natural processes, or by man during the milling

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...e, must cause the development of fine particles of oxide, some of which are truly colloidal, and may facilitate the liberation of tin ions into solution, is not clear, but the ease with which the colloidal particles are adsorbed and the tin ions are absorbed, or otherwise incorporated into the sediments of a stream, is unknown. Before the writer placed a crystal of rather brittle white cassiterite between several layers of paper and crushed it with a single hammer blow. The product was then placed in a beaker filled with tap water and the water remained clear for several days. Finally the dispersed cassiterite (colloidal?) was flocculated by the addition of a solution of sodium sulphate.

Obviously the question of colloidal and soluble "tin" calls for further study because as yet it has not been demonstrated, without doubt, whether studies of the tin content of natural soils would or would not facilitate the search for tin deposits.

Iron can proxy for iron and magnesium in ferromagnesian minerals. These minerals vary considerably in the ease with which they are decomposed by weathering agents, but the tin content of soils overlying barren rocks must be due in part to that present in fresh ferromagnesian species and in part to tin derived from them and which occurs, perhaps, as monofite, or something akin to it, or in the ionic form adsorbed by colloids.

In areas containing tin skarns, such as the Red-a-Ven area in northern Dartmoor, the tin in the soil must occur in tin-bearing minerals, andradite, grossularite, and, due to the decomposition of the garnets, as secondary products much the same as those derived from the decomposition of ferromagnesian minerals.

In humus-rich soil horizons, tin derived from the decomposition of plant remains (and conceivably from ascending solutions) probably occurs in organic complexes; however, on barren ground the amount so held will be slight, but in tin-bearing sulphide bodies it may well be considerable though this has not yet been demonstrated. Certainly the tin in the soil horizons down slope of orebodies, but not immediately over them in Cornwall (Hosking, unpublished data) and in Malaya (Tooms and Kaewbaidhoon, 1960-61) contain a higher concentration of tin than underlying rocks, but this may be largely due to concentration of cassiterite at the surface as a result of sheet wash preferentially removing the lighter components. Over orebodies the concentration of tin in residual soil invariably increases with distance, though not necessarily in a regular manner.

Anomalous Dispersion

In the vicinity of primary tin deposits the nature of the anomalous dispersions of tin in the soil will obviously depend on many factors. The extent of the anomaly, in plan, will depend on the mineralogical character of the orebody, its size and shape, the amount and nature of the erosion to which it has been subjected, the distribution and other characteristics of the shoots, within it, and the distribution of mineralised fractures adjacent to it. It will also depend on the various recent climatic conditions to which the terrain has been subjected, the topography, and the relationship between the trends of the dominant topographic features (ridges and valleys) and the strikes and dips of the tin-bearing body.

The partition of tin between the various size fractions of a sample of soil will similarly depend on many factors,

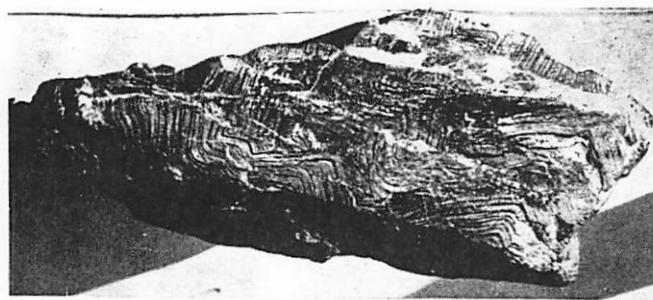


Fig. 6. Stanniferous slate in which some of the laminae have been preferentially replaced by tourmaline (black in the photograph) whilst others have been replaced essentially by cassiterite or by quartz; the specimen, which is c. 5 in. long, is from St. Agnes, Cornwall.

but the size of the cassiterite crystals and aggregates in the parent body, together with its textural and mineralogical characteristics, are probably the most important ones. Particularly in areas which are not flat, the finer soil fractions tend to contain (for obvious reasons) anomalous concentrations of tin at appreciably greater distances down-slope of the ore-body than do the coarser fractions. For this reason, and because sample preparation is easier, it is common practice during geochemical prospecting for tin involving analysis of soil samples to confine one's attention to the minus 80 mesh (B.S.S.) fraction. However, on occasion, greater contrast between barren and lode areas may be obtained by analysing coarser fractions: for this reason Tooms and Kaewbaidhoon (1960-61) analysed the minus 20 mesh fraction during their studies in the Sungei Lembing tinfield of Malaya.

In areas of non-residual overburden surveys of the tin content in the cover may or may not be rewarding, but any tin distribution patterns which may be established in it are invariably much more difficult to interpret than those in residual soil, and can never be interpreted satisfactorily until a detailed knowledge of the geological history of the area between the time of the initiation of the development of the transported overburden and the present is known in considerable detail.

Geochemical Surveys

During glaciation, for example, the superficial parts of cassiterite-bearing lodes may be planed off by the first ice sheet and transported for small and great distances from the source. Subsequent ice sheets, whose directions of movement may well differ from the first, may severely distort the original secondary tin distribution pattern, and during warm inter-glacial phases and subsequent to the final stage of glaciation the pattern may be further modified by sheet wash. Additional difficulties may arise as a result of the tin-bearing cover being mantled by barren, perhaps far-transported, glacial debris. Tin dispersion trains in pre-glacial valleys may also become deeply buried by such debris and so, from an economic point of view, be rendered inaccessible to the geochemical prospector. In any case, the presence of such valleys may only be revealed after a detailed geological survey of the area involving considerable photo-geology as they may be quite unrelated to the post-glacial drainage systems. Finally, the active sediments in the post-glacial streams in the vicinity of primary tin deposits may not contain markedly anomalous concentrations of tin, because of the comparative immaturity of the drainage system.

However, geochemical surveys in which the determination of tin in soil has played the dominant role, have proved successful in such terrain, as, for example, at Mount Pleasant, New Brunswick (Hosking, 1963). There, particularly along the fairly flat top of the ridge, whose long axis approximately parallels the direction of ice movement, and where the cover is comparatively thin, the tin distribution pattern in the soil could be correlated with the disposition of underlying orebodies: there was, however, a "down-ice" displacement between the two. It is relevant to note that particularly during the early phases of exploration the relationships between the distribution of tin in the cover and in the hard rock was established by the simple expedient of removing the overburden along traverse lines by means of a traxcivator and then mapping the exposed rock floor, and occasionally analysing, by geochemical methods, samples from it.

In periglacial regions, for example, in the South West of England, the solifluction product known as "Head of Rubble" may locally seriously militate against the employment of geochemical methods in the search for tin. This non-residual cover occurs, for example, as accumulations of the order of 100 ft. in thickness in indentations in the Pliocene cliffs which lie at c. 430 ft. O.D. Such thick accumulations occur, for example, locally along the fringes of the Carnmenellis granite mass and the soil overlying this Head is characterised by interesting tin distribution patterns. These are lenticular in plan and their long axes are parallel to the general strikes of the lodes of the district. They are not reflections of underlying lodes but are due essentially to the deposition of tin by surface streamlets emerging from minor valleys beyond the Head which were excavated along lodes. (Hosking, unpublished studies.) In this same area there is reason for believing that the zinc and copper distribution patterns in the soil over the Head may, in fact, reflect the presence of sub-outcropping lodes, despite the considerable thickness of overburden.* In Canada, in areas quite thickly covered with glacial moraine, copper and zinc in the uppermost soil horizons also sometimes reflects the presence of underlying orebodies. It seems, therefore, when attempting to locate tin deposits in such environments by geochemical means, that a study of the distribution of mobile pathfinder elements such as copper, zinc and molybdenum should be given a high degree of priority.

Other Cover

The search for hard-rock tin deposits beneath a sand dune cover has as yet received little attention, however, preliminary, and as yet unpublished studies by the writer on the stabilised dune area of Perranporth, suggest that mobile pathfinder elements may accumulate in the hard pan horizons overlying, or in the vicinity of, buried lodes there. Furthermore, work by Lakin and others (1963) indicates that in arid terrain the trace metal content of desert varnish may indicate the presence of hidden ore-deposits, but here, also, only mobile elements, not tin, will accumulate. However, this evidence, in conjunction with other geologic data, may

* Determination of the "total-heavy-metal" content of groundwater samples obtained from springs, wells or even bores drilled expressly for the purpose, may reflect the general distribution of tin lodes provided the latter contain oxidising "heavy metal" sulphides, and in deeply dissected terrain lodes which do not outcrop may be revealed. Hosking, Deric, and Lwin (1963) demonstrated that the Belowda Beacon tinfield (Cornwall) although characterised by lodes comparatively poor in sulphides, is, nevertheless, haloed by groundwaters whose heavy-metal contents are five, or more, times heavier than the regional background.

suggest a target area for the tin prospector which can be further examined by drilling.

Cassiterite, together with other primary and secondary tin-bearing species, may either be liberated directly into the drainage systems or may travel to them under the influence of gravity, sheetwash, "micro" drainage systems, possibly wind, and ice. Whenever there is a marked change in slope cassiterite tends to accumulate and so not only may deposits of economic importance occur at the base of hills (as in Phuket, Thailand) but even in their absence anomalous concentrations of tin there (which may be established by chemical analysis or by panning) may indicate the presence of primary deposits of possible importance up-slope. However, in such an environment, sampling to bedrock may well be necessary as the horizons of interest may be covered by barren over-burden.

Within the river systems the concentration of tin in the active sediments may increase steadily towards the source of the metal, and often the bulk of the metal tends to occur in progressively coarser fractions as the source is approached. However, where conditions are favourable local concentrations of tin may occur below the source (*i.e.*, displaced anomalies develop) and on occasion the highest concentration of tin may occur in a coarser fraction of a sample taken, say, a mile below the source, than in one taken only half a mile below it (See Hosking, Naik, Burn and Ong, 1962.)

Due to the local concentration of tin-bearing ferromagnesian minerals in a drainage system samples of the sediments may be shown to contain, by chemical methods, appreciable concentrations of the element under review: concentrations which might, when considered alone, suggest that the area might contain tin deposits of possible economic interest when, in fact, none exist. In order to guard against such a conclusion it is important to test tin-high sediments for the presence of cassiterite (for example, by panning a concentrate and applying the tinning test to it) and to clearly appreciate the significance of the results should they be negative.

Physical Considerations

For various reasons the degree of rounding of alluvial cassiterite is not necessarily indicative of the distance the material has travelled from the parent source. Thus, in Malaya, large cassiterite masses entrapped in limestone potholes close to their source may be well rounded, whereas there, and elsewhere, small cassiterite fragments may travel vast distances and yet show little sign of abrasion. On the other hand acicular, but not particularly small, crystals of cassiterite are unlikely to remain long in the active sediment zone of a river, or to travel far, without being fractured, and so the presence of undamaged specimens in a sample is strong indication that the primary orebody is not far removed from the point at which the sediment was collected.

Marked concentrations of cassiterite tend to occur in a river system wherever the bedrock gradient lies within the critical range. If the gradient is steeper than the critical range cassiterite will not accumulate; if less steep than it, grains of low specific gravity minerals will also accumulate with the tinstone. Mackay *et al.* (1949, p. 18) note that in Northern Nigeria "all major deposits (of alluvial cassiterite) ... come between average gradients of twenty-five and seventy-five feet per mile."

It is probable that the critical gradient range varies from one part of the world to another and depends on the nature

of the bedrock, the mineralogical and textural characteristics of the primary tin deposits, the dominant size and shape of the cassiterite crystals and aggregates liberated from the parent deposits, the amount and distribution of rainfall.

When primary deposits lie in terrain within the critical gradient range the richest alluvial deposits associated with the river systems lie virtually over the primary source of the cassiterite. This is so, for example, locally, on the Carnmenellis Mass. There the alluvials have been worked in the past by primitive methods and the richer the deposit the greater the quantity of cassiterite that was not recovered. In fact, by working these stanniferous alluvial deposits which lay just above bedrock and which were usually covered by considerable thicknesses of barren overburden, the streamers did the geochemist a service in that they inverted the superficial deposits so that today, in such areas, the tin content of the superficial sediments in the streams reflects surprisingly accurately the presence of the sub-outcropping lodes. (Hosking and Curtis, unpublished studies.)

In a little explored area it will not be possible to determine the critical gradient range during the preliminary stages of exploration and if the location of placer deposits is the major object then prospecting by Banka drilling, etc., must be confined to areas near granite contacts and particularly where the topography suggests that cassiterite might have concentrated, such as in basins, at a point where a gorge-like valley terminates, etc.

Although it is quite obvious it needs to be emphasised that although studies of the tin content in the active sediments of streams may indicate the presence of a possible tin field, and even the location of a lode, they give no indication whatever of the tin potential of the deeper alluvial zones: these can usually only be tested by drilling.

When carrying out a geochemical survey involving the determination of the distribution of tin in the active sediments of the drainage system samples must be taken from all tributaries, and the easiest places to obtain adequate samples are at the points where deceleration has occurred—that is, at the convex side of bends, where there is a marked decrease in slope, at the entrances to lakes, etc. It is also worthwhile taking samples from each bank at each sampling point as the tin content of these may, on occasion, indicate on which side of the river the source is to be found.

Because of its density, cassiterite which reaches an estuary may be concentrated in the distributary channels in much the same way as it is in a sluice box. In the Helford Estuary (Cornwall) it has been demonstrated that the sediments generally (not only those in the distributary channels) of the creeks fed by streams draining the tinfields contain much more tin than those fed by streams from barren areas. (Hosking, unpublished studies.) In addition, it has been established that the heavy fractions (plus 2.8 sp.gr.) of samples from Cornish beaches "fed" by rivers draining tin-mining areas contain a much higher concentration of tin than similar fractions from beaches "fed" by rivers from tin-barren areas. (Hosking, Ong and Krishnan, 1963.) However, the above does not hold if an estuarine tract separates the river proper from the beach. Thus the Hayle river, which drains a not insignificant tinfield, has contributed insignificant amounts of tin to the Hayle beach because the cassiterite which it carried was trapped in the intervening estuary. (Hosking, unpublished studies.)

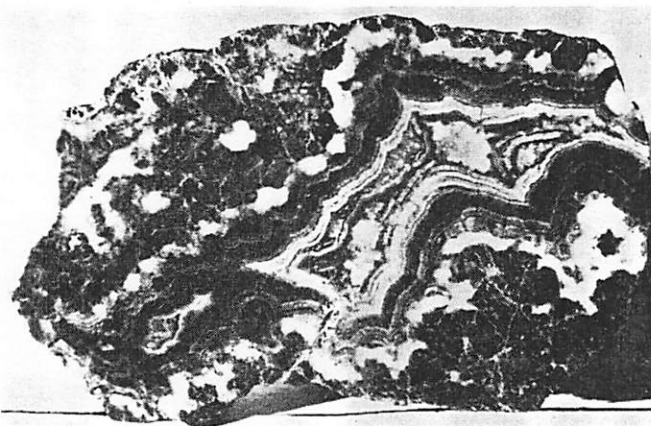


Fig. 7. Polished slice (c. 3 in. long) of a portion of a lode from West Wheal Kitty, St. Agnes, Cornwall, consisting of a 'core' of wood tin, flanked on either side by massive cassiterite and quartz.

The concentration of cassiterite in beach deposits is due to a complex interplay between many natural processes which usually cause the richest "streaks" to develop parallel to the cliff/beach line and between the spring and neap high tide lines. However, their distribution cannot be determined other than by systematic sampling and analyses, and, rapid geochemical methods can be employed to advantage in such work.

Search for Tin Deposits

From what has already been written it will be apparent that a clear understanding of "recent geology" (the term is used here in a somewhat broader sense than that which is usual in geological literature) is an essential to the scientific search for both primary and secondary tin deposits in glaciated terrain and also where permafrost conditions, leading subsequently to the development of "Head", recently prevailed. A study of the recent geology of tin provinces may also lead to the conclusion that as a consequence of elevations and depressions of the land, placer deposits are to be expected on elevated marine platforms (as on the Goss Moor, Cornwall), in the drowned extensions of valleys (as in the Carnon Valley, Cornwall, and in Indonesia) and in valleys which have been entirely drowned (as in the submarine tract to the east of Phuket, Thailand). Investigations of the buried pre-basalt drainage systems and the unrelated post-basalt systems of the Plateau of Northern Nigeria have contributed, and are contributing greatly, to the knowledge of the factors which determined the distribution of placers there, and so where as yet unexploited placers are likely to occur.

In the search for placers it is obviously not enough to consider only recent geological events: data relating to these must be integrated with all other relative geological, and other, information. The location, for example, of submarine placers several miles off the east coast of Phuket was based on the assumption that not only were recently drowned N.-S.-trending valleys there but also that the major rock units, and hence favourable contacts, possessed the same trend, and that as the placers, etc., on Phuket were confined to the central third of the island, where the granite ridges were surmounted by cusps, so similar cusps and associated

tin deposits were likely to occur between the same parallels offshore. Subsequent exploration confirmed these views.

Prospecting Technique Reviewed

The search for economically important tin deposits must involve the following to varying degrees:

- (1) Location of a tin province.
- (2) Establishment of outcropping and hidden effusive and intrusive granitic bodies within the province.
- (3) Location of tin fields within the province and the establishment, as far as possible, of spatial and other relationships between the primary and secondary ore fields and the granitic rocks.
- (4) Location of primary orebodies and the distribution pattern of these in each field.
- (5) Establishment of the structural controls operating in each primary field.
- (6) Investigation of the presence of primary zoning.
- (7) Investigation of mineralogical and structural variations in individual orebodies along strike and down dip.
- (8) Determination of the effect of erosion on the primary bodies.
- (9) Establishment of the spatial relationships between primary and secondary deposits, and of the relationships between the latter and the major rock units.
- (10) Establishment of the relationships between secondary ore deposits and those geological events which took place between the phase of primary orebody formation and the present.

It is obvious that although a given province may have been a major producer for a considerable period of time many of the relationships, etc., embodied in the above 10 points may only be very imperfectly understood, and it may well be that most of the tin worth winning may be discovered in such a field by exploration which is never far removed from wild catting. However, if the search for further deposits is to be economically sound then the programme must be built on a geological foundation in which the characteristics of tin provinces and their common components play a major part, and answers to the questions implicit in the above 10 points must be sought as early as possible. Virtually every known prospecting technique can play an important role in the search for these answers, but whereas one may be of major value in one part of the world it may be of little or no use in another. It is quite beyond the scope of this paper to discuss, even briefly, any but those facets of prospecting which are of unusual importance to the searcher for tin deposits.

Geophysical Methods

Airborne geophysical methods may be used to advantage to locate the disposition of buried granite masses as the contacts between these and the invaded rocks are likely zones of mineralisation. To this end airborne aeromagnetic and radiometric surveys have been made over Malaya. (See Agocs, 1958.)

Photogeological studies, particularly in glaciated areas and in areas with heavy vegetation which have been imperfectly mapped, may reveal, in a short space of time, a great deal of important structural and other geological data. Ground

geophysical methods may be used to delineate the form of the granite and so, by tracing the mass under invaded rocks, indicating its probable offshore extension, etc., indicate further target areas for the tin explorationist. Bott, *et al.* (1958) have, for example, established the form of the batholith of the South-west of England by gravity survey on the ground.

In those cases where the orebodies are sulphidic, self- or induced—potential methods may facilitate the delineation of sub-outcropping orebodies. However, tin lodes are commonly very narrow and often not particularly rich in sulphides and hence the employment of these methods is by no means always an unqualified success, particularly if the overburden is thick.

In West Cornwall, for example, attempts to use induced potential methods to locate tin lodes with a little sulphide lying beneath 80 to 100 ft. of non-residual cover proved to be of no value. (Hosking, unpublished studies.)

At Mount Pleasant (New Brunswick) preliminary studies indicate that there may be sufficient differences between the magnetic properties of the country rock and the tin-bearing bodies for the latter to be located when sub-outcropping, by means of a magnetometer. (Hosking, 1963.)

On land, magnetic seismic and electric resistivity methods have been used to delineate the bedrock profile of alluvial-filled river valleys, basins, etc., whilst Shaw and Cole (1961) have demonstrated that electrical resistivity methods may be used to locate and trace deep cassiterite leads occurring below volcanic material on the Jos Plateau, Nigeria.

Offshore, sonic methods have been used in Indonesia (Van Overeem, 1960) and Phuket, Thailand (G. W. Simms, Esq., private communication) to delineate the bedrock profile and the thickness of the superficial, and locally stanniferous, cover.

Geochemical Methods

Particularly during reconnaissance surveys, geochemical methods, involving the distribution patterns of tin and associated elements in stream sediments, beach and estuarine deposits, are of major importance. Further widespread work may demonstrate that, as at Carnmenellis, the collection of a comparatively small number of sediment samples from well distributed but widely scattered points, and their subsequent analysis for lithium (or possibly other pathfinder elements) may rapidly delineate areas most likely to contain tin deposits and therefore worthy of more intensive examination.

During reconnaissance surveys the possibility of differentiating between granitic masses with which tin deposits may occur and those which are likely to be barren, by analysing hard rock samples, or specific minerals separated from them, should not be overlooked, although there is still some doubt as to the value of this exploration technique.

Establishment of the distribution patterns of tin and associated elements in soils is an extremely powerful, cheap and rapid means of locating new lodes in a known field, and of tracing extensions of known orebodies, provided the soil is residual and has not been subject to excessive contamination as a result of previous mining activity. If the cover is non-residual, geochemical methods may still prove useful but this can only be determined by first carrying out a well planned orientation survey.

During diamond drilling, studies of the tin content of the sludge by rapid semi-quantitative methods may serve to differentiate between barren vein zones in much altered

country rock and those which contain cassiterite but which yield cores that are superficially identical to the former. (It must be remembered that visual examination of a core containing several per cent cassiterite may not establish that it is, in fact, tin-bearing.)

Sludge examination may also indicate, by a local rise in the tin content, that an orebody is present even though the drill has not penetrated it.

Analysis of rock samples by rapid geochemical methods in order to trace offshore extensions of known lodes and to discover new ones is an attractive possibility which is only now receiving attention. In Cornwall, and doubtless in many areas, the major difficulty associated with such work is due to the fact that commonly for some hundreds of yards offshore a thick sand cover blankets much of the hard-rock platform and so seriously militates against sampling the latter in such a way that adequate coverage is achieved. Clearly, a drill capable of operating on the sea bed and of penetrating such an unconsolidated sand cover and extracting a small hardrock core is required.

Drilling

Characteristically the cassiterite in lodes is very erratically distributed, and the lodes commonly vary markedly in mineralogical character, structure and width in comparatively small distances along both strike and dip directions. It follows then that unless a given lode is intersected by a vastly greater number of drillholes than is economically reasonable the potential of the lode cannot be established. All that can be hoped for is that drilling will establish the presence of a lode, enable it to be traced along strike and down dip, and that its structure and mineralogical character will indicate that it may contain cassiterite in economic amounts. Whilst it is only natural to hope that the drill on intersecting a lode will yield a core rich in cassiterite, such a core, in fact, only indicates that during the period of ore genesis conditions were at one stage locally favourable within the lode for the marked deposition of cassiterite: it must be borne in mind that had the intersection been but an inch different the core might have been, to all intents and purpose, barren of cassiterite.

Most that need be said about Banka drilling and other forms of alluvial evaluation has already been said by Harrison (1954). However, the following observations are not irrelevant.

In Malaya, Banka drilling is cheaper than percussion, and other forms, for depths of up to c. 100 ft. In addition, the Banka drill can be set up and operated in situations which militate against the use of other types, for example, in the midst of a swamp or offshore from a pontoon.

Off the coast of Phuket a Banka drill has been used from a pontoon to obtain samples from the sea bed beneath 40, or more, feet of water. Such an operation is, however, difficult and at Phuket considerable casing was lost, as a result of the latter fracturing at a point where it entered the alluvium, when drilling had to be abandoned quickly as a result of the weather freshening. Because of the difficulties attendant on Banka drilling off Phuket the latter was abandoned in favour of a method involving grab dredging in which a quarter of a cubic yard grab was employed. Briefly, after the first sample was grabbed the surrounding alluvium was removed by the grab and then the second sample was taken from the middle of the cleared area. Thus the completed pit had the form of an inverted stepped pyramid. Fortunately

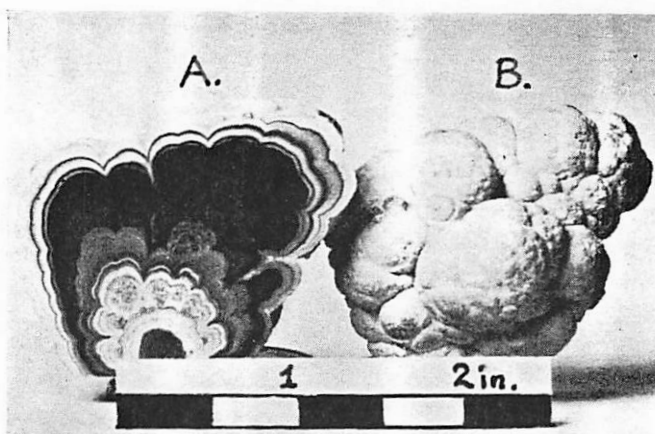


Fig. 8. A sliced nodule of wood tin from Mexico showing its internal texture (A) and external form (B).

the "ground" contained sufficient clay to prevent wall collapse: in coarse sandy deposits such a technique would have been impossible. Comparison of the evaluation of a near-shore area by Banka drilling and grab dredging indicated that results obtained by the two techniques were not significantly different. Despite this, there is obviously a need for a new method of evaluating alluvials under considerable depths of water which involves the employment of comparatively cheap, light and mobile equipment which can be operated from small craft.

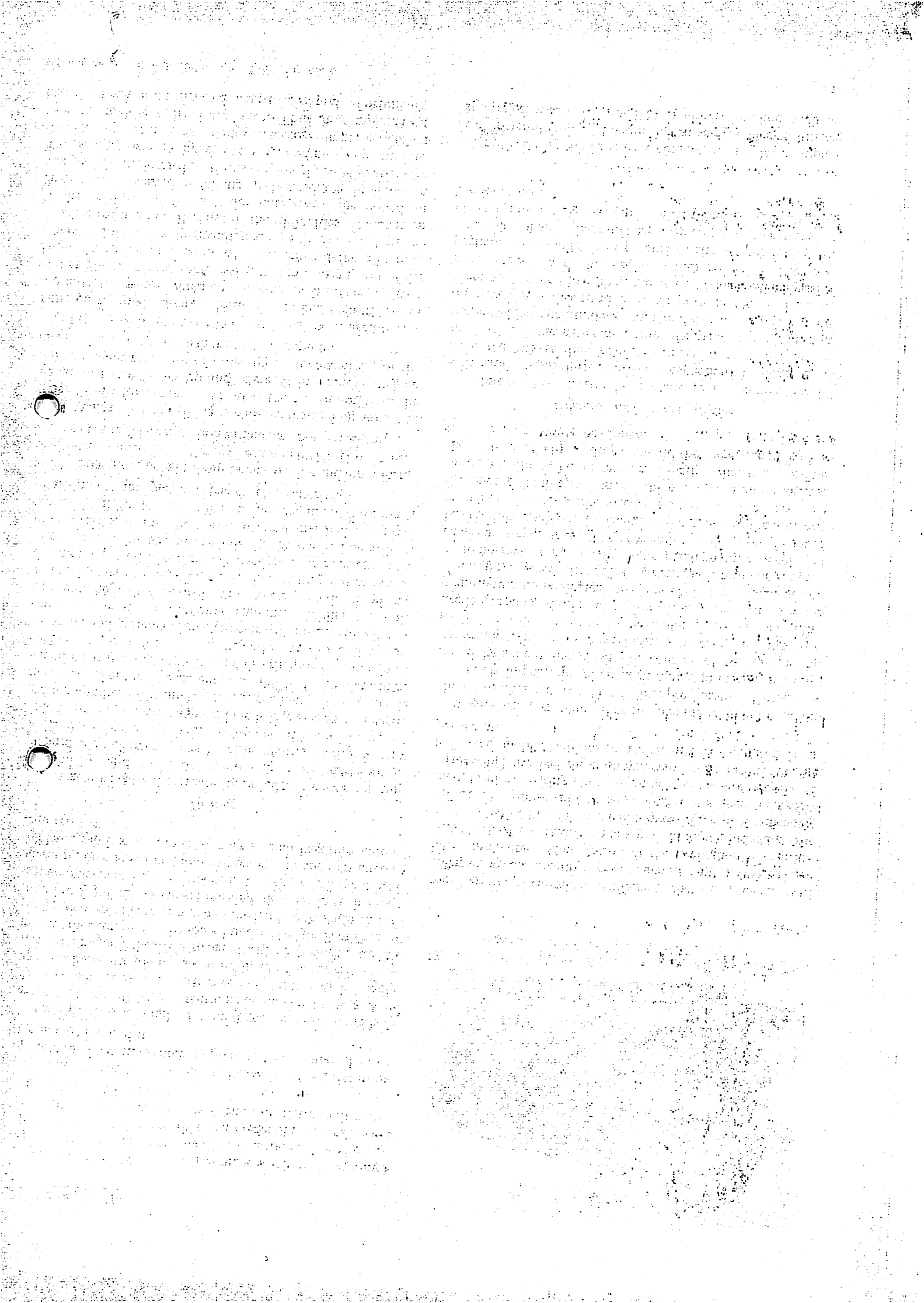
It goes without saying that the maximum of information should be obtained from any drilling programme. Unless it is absolutely impossible, when examining stanniferous alluvials not only should the cassiterite content of the ground be determined, but also the cassiterite should be subject to size analysis as this is of value to the explorationist as well as the dredge master and mineral dresser. Complete qualitative and quantitative mineralogical analyses should be made of the material recovered from at least a reasonable number of bores as tomorrow, if not today, some of them may be of real economic importance. The workability of the ground should be carefully assessed: for example, the nature of the horizons in which the cassiterite occurs should be noted and the presence of stiff clay bands, which might militate against dredging, should be looked for. Finally, whenever possible the nature of the bedrock should be determined and a bedrock map should be drawn.

Structural and Allied Studies

Reference has already been made to the importance of structural studies during surface prospection. Underground, also, structural studies are of the utmost importance if further ore is to be found with a minimum of expenditure of time and money. How such underground studies may best be carried out need not be discussed here, except to say that the bases of them are detailed mapping, the construction and analysis of mine models and the use of contoured lode diagrams, particularly Conolley and pounds cassiterite per ton types. The value of such diagrams has been amply demonstrated at Geevor mine by Garnett (1962) and at South Crofty mine by Taylor (1964).

Analysis

Until recently the cassiterite content of samples of superficial material (soils, alluvium, beach sand) collected during exploration was determined by a gravity method such as



panning, and it was held that the cassiterite so recovered represented the fraction likely to be won on a large scale by the mineral dressing methods employed on dredges, in gravel-pump operations and in comparatively simple mills generally.

Panning still plays an important role in the evaluation of superficial deposits, but with the general introduction of more efficient recovery methods it is felt by many that the fine cassiterite lost during panning should also evaluate and Williams (1960-61) has devised a method for this which involves the use of a small hydrocyclone, a half-size Holman sand table and a Haultain Superpanner.

When panning is used it is important to establish how much of the concentrate is cassiterite and what minerals make up the remainder. A crude estimation of the proportion of cassiterite present can be obtained by visual examination provided the cassiterite is first tinned so that each grain can be easily identified. Tinning can be achieved in a number of ways but one of the most convenient is to place the concentrate in a zinc tray and then adding dilute hydrochloric acid (1:1). After c. 5 min. the acid is poured off and any cassiterite present will normally be coated with matt grey metallic tin. It is important to note that some naturally occurring cassiterite will not tin and that cassiterite which has heated to c. 1,000 deg. C. for 10 min will also fail to react to this test (and should it have been originally magnetic, it will have lost this property). Qualitative and quantitative determination of minerals other than cassiterite in a panned concentrate can generally be made without great difficulty by employing heavy liquids and an isodynamic separator.

When searching for primary orebodies by the establishment of the tin distribution pattern in stream sediments, soils and hard rock it is usual now to employ the gallein colorimetric method of analysis which is simple and permits c. 100 dried and screened samples to be analysed by one person in an 8 hr. shift. (See Stanton and McDonald, 1961-62.) There are those who hold that this method offers no advantages over the traditional panning methods and some of the arguments for and against each occur in the discussions following Tooms and Kaewbaidhoon's paper (1960-61, pp. 614-622.) However, it is pertinent to note here that a reasonably intelligent and conscientious person, with no knowledge of chemistry, can, after a week's instruction, carry out the gallein method in a proficient way: on the other hand really adequate panners are scarce and the training of a person for this work is protracted. As stated earlier, there is often good reason for investigating the mineralogical character of panned samples during any exploration programme for tin in which chemical analyses are dominant.

Trace amounts of tin may be analysed by an X-ray fluorescent spectrometer instead of by the gallein method, but although the method is quick and simple the apparatus is expensive, not suitable for a field laboratory and demands the attention of a skilled person capable of effecting repairs if the analytical programme is not to suffer delays.

Recently Bowie and others (1964-5) have developed a portable radioisotope X-ray fluorescence analyser, weighing only 17 lb., capable of determining the tin content at points along a crosscut, for example, without prior removal of a sample, and also of assaying, for tin, hand specimens, drill cores, sludges, placer- and mill-products, in a matter of minutes. The degree of accuracy obtained varies with the nature of the sample, etc., but provided the test substance is

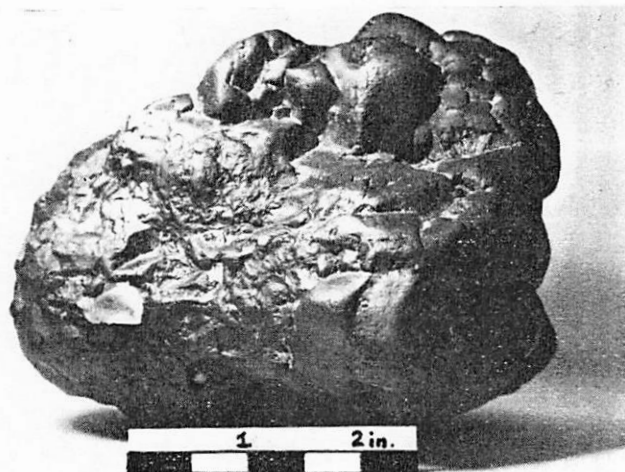


Fig. 9. Water-worn cassiterite from a Nigerian placer deposit.

first ground to an impalpable powder, and a suitable calibration graph is prepared, it can be very high. The limit of detection of the present model is 0.03 per cent (300 p.p.m.) tin, so that it is not likely to displace, without modification, other more sensitive analytical methods when the object of the work is to detect sub-outcropping deposits by methods involving the analysis of soil samples, or even, possibly, stream sediments. Nevertheless, the instrument is an extremely important addition to the aids available during the search for tin-bearing deposits and no exploration team engaged in such work should be without it.

Finally, studies of the variation in the trace element pattern of cassiterite, by spectrographic methods, throughout a tin province, in a tin field, or within the lodes of a given mine, may by throwing further light on the mode of ore-genesis, aid, perhaps indirectly, the search for further ore. Within a given mine such a study might also assist in the correlation of lodes in faulted areas. In this connection it might well be used in conjunction with general mineralogical studies of the lodes in question and particularly with investigations into the nature of the colour zoning of the cassiterite.

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