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A historical review of ways and means of searching for ore deposits in the Southwest of England.

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"As, therefore, the productiveness of lodes depends on so many conditions, both in the mechanical structure and mineral composition of the rocks, as well as of the lodes themselves, and as experiences seems to show that the same characters assume a different value in different districts, it is evident that the difficulty of forming an opinion on the probability of success in mining is very great.

It must be confessed that neither theory, nor practical knowledge forms any very certain ground, in the present state of this branch of science. A more extended experience, and a more careful generalisation of facts seem to afford the only remedy. But when the vast variety of everchanging circumstances is considered, we can only hope that our conjectures will at length attain a greater probability, and that if they fail of absolute certainty, they will, at least, lead to a closer approximation to the truth."

(Henwood, W.J., 1843. pp. 234–235.)

Synopsis Many varieties of mineral deposit have been exploited in the Southwest of England. These include deposits which have been worked primarily for one or more of the following:—tin, tungsten, copper, lead, zinc, iron, manganese, arsenic, cobalt, uranium, pyrite, arsenic and barite. From an economic point of view the copper and tin producers collectively have proved to be by far the most important.

A summary is presented of our present knowledge of the nature and distribution of the mineral deposits and the spatial and temporal relationships between these and the igneous rocks, particularly the granitoids.

Finds of mineral deposits based on chance, on quasi-scientific techniques and on scientific ones are noted and the evolution of the science-based aids to mineral exploration is traced in some detail.

It is pointed out that particularly since 1945 great strides have been made in the development of aids to mineral exploration. But although these aids have been used to varying degrees, and have proved to be of great use, the advantages accruing from their availability have to some appreciable extent been nullified by the increasing limitation of ground available for mining. This limitation is largely due to the need to preserve the environment. The common difficulty of establishing mineral ownership also militates against mineral exploration in Cornwall and Devon.

PREFACE: One may ask why a historical review of ways and means of searching for ore deposits in the Southwest of England should appear in a Malaysian journal. There are a number of good reasons why. In its time each Malaysia and the Southwest, has been the major tin producer of the World. The Cornish mines have played a considerable role in the production of tin from Malaysia, and particularly from its major hard-rock mines. Indeed the exploration, mining and beneficiation methods employed at the major underground tin producer, the P.C.C.L's mines at Sungai Lembing Pahang, have been largely Cornish inspired. However during the times which are reliably documented most of Malaysia's tin has been won from placer deposits whilst most of Cornwallis tin has been recovered from hard-rock mines, largely of the underground type. Now, when it is becoming progressively more difficult to locate viable stanniferous placers in Malaysia, the Geological Survey, and others are searching for viable hardrock tin and other deposits, and with some success. This is the time, then, when Malaysia may benefit from the long experience of those who searched, and are searching from hard-rock deposits in a region that is some thousands of miles away from it. This then is the major reason for presenting this paper, in this place, at this time.

K.F.G. Hosking
Feb., 1982.

INTRODUCTION

Those mineral deposits or portions thereof which are being exploited at a given point in time or are then thought to be worth exploiting for one or more of their components are, at that point in time, ore deposits. It follows that what is a mineral deposit today may become an ore deposit tomorrow.

During the long period of mining in the Southwest of England a surprising variety of mineral deposits has been exploited, with varying degrees of success, and these have yielded products of value primarily because they contained considerable percentages of one, or sometimes more of the following elements:- tin, copper, tungsten, arsenic, iron, zinc, lead, silver, antimony, cobalt, nickel, uranium and manganese. Others have yielded products of value because of the presence of a particular compound such as pyrite or barite. Of all the products, those containing tin or copper have, from an economic point of view, been by far the most important.

In presenting this historical review of the ways and means of searching for ore deposits in the Southwest of England I shall adopt a plan which is sometimes used by film makers. That is, I shall start by providing a brief account of what is now known of the development, distribution and nature of the mineral deposits of the region and then I shall trace how and by what means we have arrived at our present state of knowledge of them.

It is relevant to express the hope that that which appears in the section which follows immediately will provide the reader with the key distribution pattern to the mineral deposits of the region and which, with library research, must form the basis of further exploration in the Southwest. Of course, some may well feel that it is in need of modification. In addition, when a given part of the region is selected for examination then, at the outset, its mineral deposit distribution pattern should be assembled in as detailed a manner as possible.

The development, distribution and nature of the mineral deposits of the Southwest of England

If one ignores the Lizard, Dodman and Start peninsulas, which are of little interest to the metal miner, the metallogenetic province of the Southwest of England consists, essentially, of a peninsula of Devonian and Carboniferous, largely non-calcareous metasediments and intercalated intrusive and extrusive metabasites which were invaded in Permian times by intrusions of granitic magma and locally thermally metamorphosed by them. Consolidation of the granitic magma resulted in the formation of the polyphase batholith which extends from the eastern edge of

Dartmoor to the submerged Haig Fras mass to the west. Late fractions of the magma were also responsible for the emplacement of small aplite and pegmatite bodies and many extensive dykes of microgranite which are often porphyritic. These dykes are locally termed elvans. Possibly, also, late aqueous fractions from the granite magma migrated along faults and other channelways and deposited minerals in and near such passages, thus creating many of the primary ore deposits of the region.

To the east of the Camel estuary and in the Launceston area there is an abundance of spilites. Antimony and lead have been recovered from the former and manganese from the latter. In both cases the ore deposits may be genetically related to the spilites, but some of the Launceston protore was certainly metamorphosed by the granite before it was converted to ore proper by oxidising processes.

The possibility that metal-rich sedimentary deposits have been converted to ore deposits in the region under review also exists. Are the cupriferous skarns of Belstone Mine examples of the results of such a process?

The moulding action of the rocks invaded by the granite magma was responsible for the surface of the batholith being ornamented by a series of ridges with undulating crest-lines. Probably the surfaces of later phase granites which invaded the earliest phase were ornamented in a manner which roughly corresponded to that of the granite overlying it.

The high-spots (cusps) on the granitic ridges frequently became the sites where greisen-bordered veins, containing cassiterite and wolframite, developed, or over which similar vein swarms were formed. Also in this situation, and particularly near elvans, hydrothermal breccias, some of which contained economically interesting concentrations of cassiterite, were generated (Fig. 1).

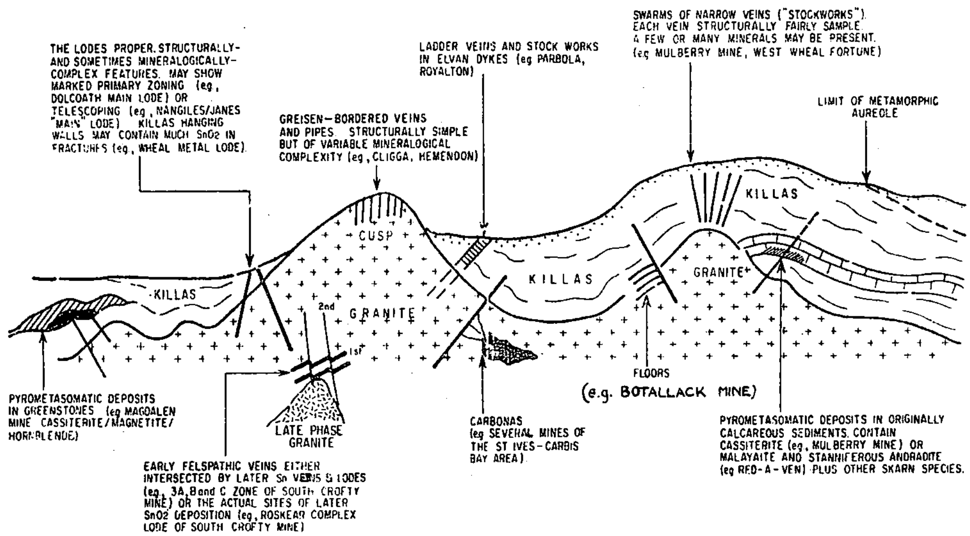


Fig. 1. Major types of primary tin deposits in the south-west of England (K.F.G. Hosking)

The granitic ridges were often flanked by elvans and early lodes. The lodes are faults which have been mineralised and repeatedly reopened during the period of mineralisation and they are often most richly mineralised and strongly developed in the general neighbourhood of the granite cusps, although there is no relationship between the intensity of mineralisation of the cusps and that of the nearby lodes.

In a given area, the granite ridges, early lodes and dykes are generally crudely parallel to each other. The granite ridge of Carn Brea with its associated dykes, lodes and the greisen-bordered tin/tungsten veins in its crest, collectively is a good example of this relationship.

In the west of the province the dominant trend of the ridges, dykes, and early lodes is about N.N.E.-S.S.W. whilst in the east it is about E.W. However, examples of both trends can be seen in both halves of the province and in the Gwinear area they are spatially closely associated (fig. 2) although there the distribution of the postulated buried ridge has yet to be satisfactorily demonstrated.

Although most of the elvan dykes post-date the granite and pre-date most of the early lodes and veins, from which the hard-rock mines of the region have obtained all the tin, tungsten and virtually all the copper they have produced, there are a number of exceptions to this sequence. The feldspathic, wolframite-bearing 'lode' of Hawk's

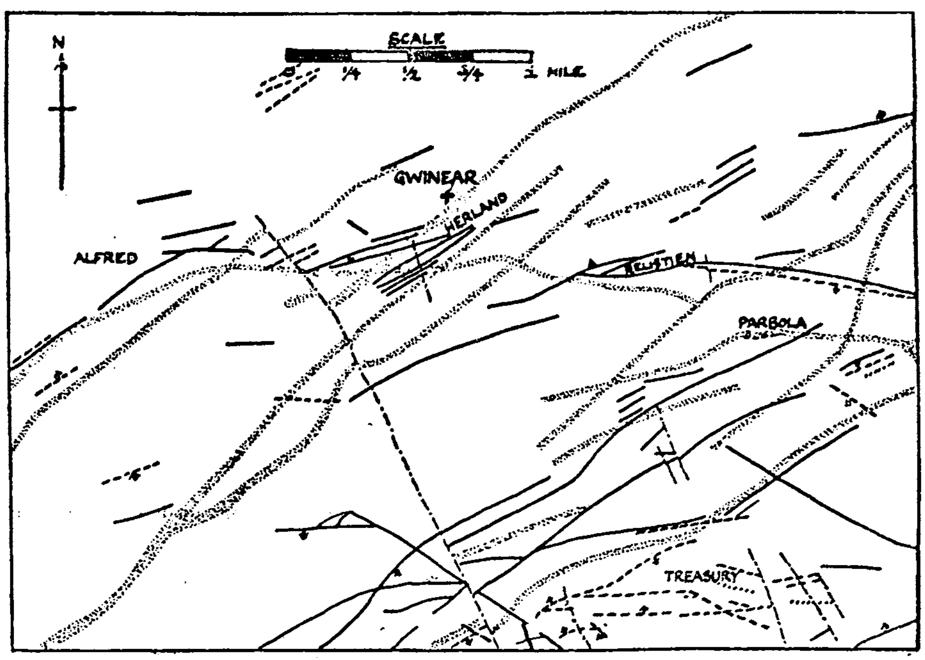


Fig. 2. Sketch map of a part of the Gwinear Area. Lodes full and broken lines: dykes stippled. (Reproduced from H.G. Dines' *The Metalliferous Mining Region of South-West England*, Vol. 1. Pub. H.M.S.O. London, 1956).

Wood Mine has been intersected by an elvan dyke, whilst at Castle-an-Dinas (St. Columb) the wolframite lode pre-dates the granite seen in the mine.

In the province there are also many faults (the so-called cross-courses) which often strike at about right-anlges to the dominant trend of any nearby early lodes. Some of these faults pre-date the associated early lodes and it is possible that wrench movements along pairs of such faults generated the fractures which became the loci of lode development, and by repeated movements kept the lode systems open. I think the Wheal Vor lodes, for example, owe their development to such a process. In course of time some of these wrench faults were mineralised, but invariably the mineralisation was of a mesothermal type.

The early lodes are also commonly displaced by wrench faults which may have become active in mid-Tertiary times. Whilst some of these are filled with barren quartz or fault clay others contain a mesothermal suite of minerals (galena, sphalerite, siderite, etc.). Fig. 3 shows the general relationship of the granite outcrops, their metamorphic aureoles, the elvan dykes, lodes and cross-courses.

During most of the Mesozoic most of the region was land, and at this time the higher parts of the granite were uncovered. The arid climate which then prevailed allowed some of the ore-bodies to be deeply oxidised, and the gozzan which occurred locally at the 182.88m (200 fathom) horizon in Phoenix United Mine (Collins, 1912, p.250) is probably a product of this time, although it might possibly have developed during the active life of the mine as a result of the development of a cone of depletion due to pumping, together with the slow downward progress of the mining operation. The desert conditions which then prevailed allowed ready disintegration of the rocks and the consequent development of a cover of detritus which locally must have contained an appreciable amount of cassiterite. At a later date some of the liberated cassiterite may have contributed to the stanniferous placers of the region. However, following the Alpine disturbance much of the area was submerged and was then little more than an archipelago of essentially granite islands. Later the land emerged in stages which is now indicated by the presence of marine platforms of which the 131.064 m (430ft.) Pliocene one is the most extensive. However, the last of the now raised marine platforms to develop was the so-called 10ft. one on which a raised-beach is often to be seen along coastal exposures (for example, at Godrevy). This platform is of Pleistocene age. After its development and because of the thawing of the ice, much of the surface debris of the higher levels was swept into the valleys and on what is now the 10ft. raised beach and in some cases on to the 131.064 m (430 ft.) platform. This debris must have included cassiterite liberated by frost action from the bare rock surfaces and also locally that occurring in unconsolidated marine sediments on the higher platforms. The debris continued to be carried into some valleys in such quantity that they were virtually obliterated. These debris deposits consist of a heterogenous mixture of angular country rock, sand and clay, a mixture termed 'Head of Rubble' or simply 'Head'. The continued elevation of the land stimulated the flow of the post-Glacial rivers causing many to degrade their channels rapidly and to tend to concentrate the dense resistate minerals such as cassiterite in them, by a method akin to sluicing, just above the bed-rock.

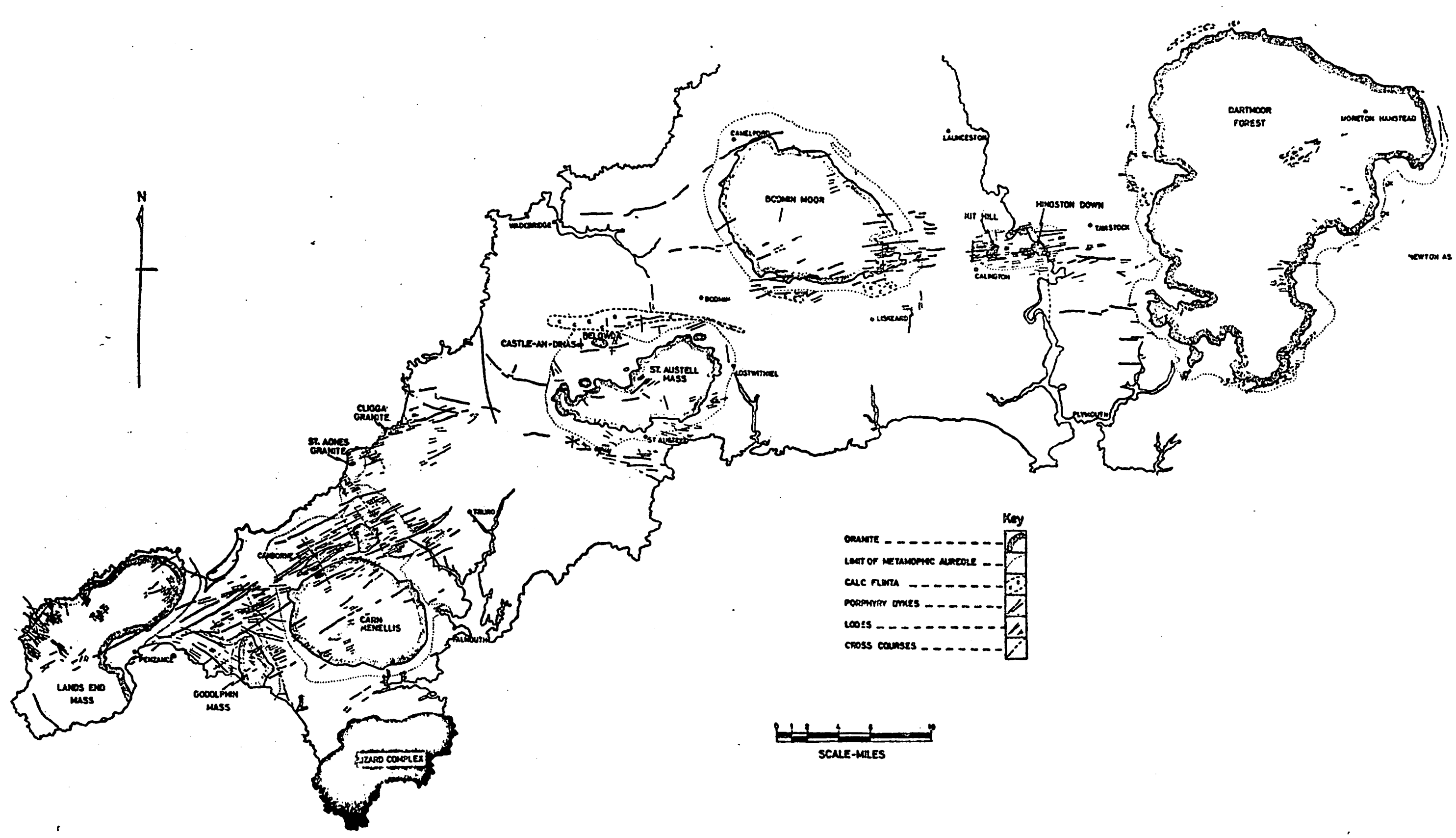


Fig. 3. General Relationship of Granite Outcrops, their metamorphic aureoles, the elvan dykes lodes and cross-courses. (*By permission of the Royal Geological Society of Cornwall*).

Although stanniferous placers were formed at all sorts of elevations between the then existing sea-level but now 12.192 metres (40 feet) below low water, and the highest granite hill, it is usual to distinguish only two types, the so-called high-level and low-level alluvials.

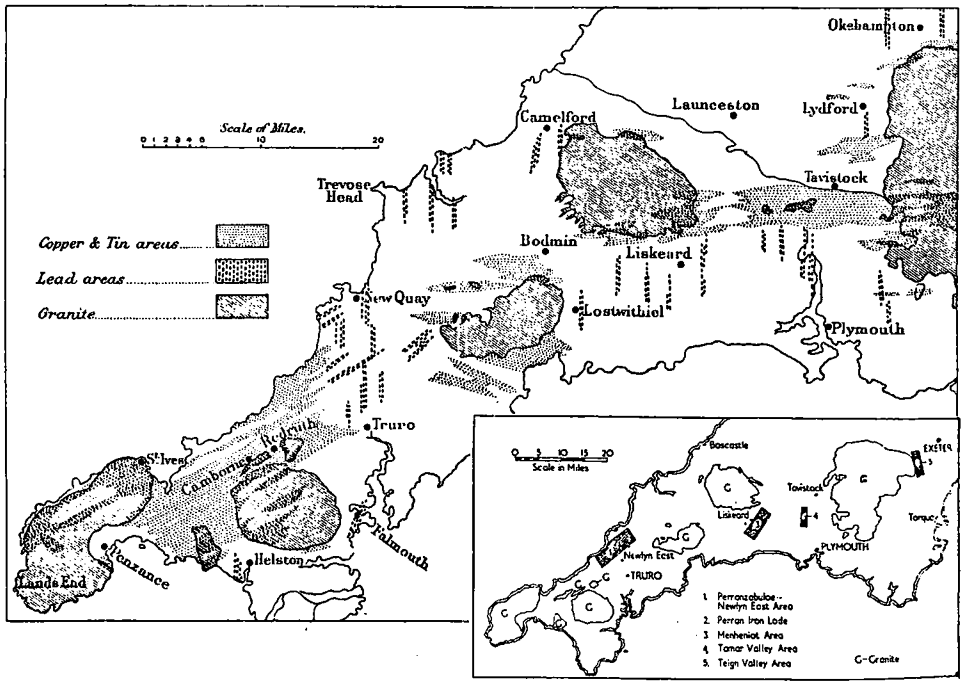
As the climate became more equable the region became heavily forested, and vegetable matter accumulated over the tin deposits. This stage was followed by a depression which resulted in the formation of drowned valleys of the ria type and consequent depression of the low-level gravels to as much as 12.192 metres (40 feet) below sea level. Also the tin ground and overlying peat became covered by a considerable deposit of sand, gravel and silt.

The depressions and elevations to which the region was subjected subsequent to the oxidation of the hard-rock deposits was such as to subject some of the oxidised ore to reducing conditions so that sulphides were generated from it. This, I think, must have happened often, but the only certain example was found at Wheal Hope near Perranporth. There, due to such processes, pseudomorphs of galena after pyroporphite occurred. Since that distant time when Man first discovered, perhaps by chance, that this region contained minerals of use to him the scene has been drastically altered. Then most of the region was covered with forest. Here and there he could find cassiterite and even a little gold in the streams. Cassiterite and copper minerals were also to be found in cliff lodes and in boulders etc., of the adjacent beaches. From the raised beaches he could obtain a little oxide iron ore as he did at Godrevy. Further iron ore could be extracted from the oxidised outcrops (the gossan) of lodes, particularly on hillsides, but it was probably a long time before he became aware of the full significance of a gossan. Today, most of the forests have disappeared and have been replaced by fields containing introduced plants. As a result, much of the natural flora which might have provided evidence of suboutcropping mineral deposits by the distribution of plant species or the presence of unusual ones is lost to us. Lode outcrops have been destroyed by mining and agricultural activity, and many areas can no longer be explored for buried mineral deposits by surface methods because they are covered by roads and buildings. Man's additions to the rivers by accident or design, have locally caused geochemical methods of exploration involving the analysis of river water and sediments to be of little or no value. Even some of the beaches and offshore areas have been contaminated by Man's mining activities but these contaminations are locally such that they have provided him with further possible sources of tin ore.

Having drawn a broad picture of the distribution of mineral deposits in the Southwest it is now necessary to look in some greater detail at some features of the pattern and this I shall do in that which follows.

The intensity of mineralisation pattern (Fig. 4)

Early tin/tungsten/copper mineralisation is most intense in the Godolphin/Carn Brea/Carn Marth/St. Agnes zone and decreases progressively to the southwest and northeast, so that in the Scilly Isles a few greisen-bordered veins and a solitary cassiterite-bearing veinlet are the nearest approach to economically interesting mineralisation, whilst on the eastern fringes of Dartmoor hypothermal lodes are few in number and neither large nor rich.



Lead and zinc mining areas of South-West England.

Fig. 4. Sketch map showing the relation of the principal ore-deposits to the granite and killas respectively. (After Collins, 1903)

The mesothermal intensity of mineralisation pattern is distinctly different from the equivalent tin/tungsten/copper pattern described above. Although the mesothermal veins are widespread they are usually rather small and sub-economic, and the major lead areas (lead being the most important element of the mesothermal bodies if they are considered collectively) are Newlyn East, the Perran Iron Lode district, Menheniot, the Tamar and Teign valleys. Precisely why this lack of coincidence occurs between the two intensity of mineralisation patterns is unknown although it could be used in support of the view that the early tin/tungsten/copper deposits are genetically related to the Permian granites whilst some or all of the later lead/zinc/iron, etc., deposits owe their origin to later igneous events, perhaps in Jurassic and/or Tertiary times (Hosking, 1964, pp.214).

The centres of mineralisation pattern

The centres of early tin/tungsten/copper, etc., mineralisation are, I think, in the vicinity of original high-spots on the granite ridges. Such ridges and high-spots have been partly or entirely eliminated from those parts of the batholith which are now exposed. In plan the tin and tungsten mineralisation is close to the high spots (Dines' (1956. p.7) emanative centres) whilst the copper deposits which are slightly later than the tin and tungsten ones tend to occupy a greater area around the high spots. Those lead/zinc deposits which are only a little younger than the copper deposits may extend

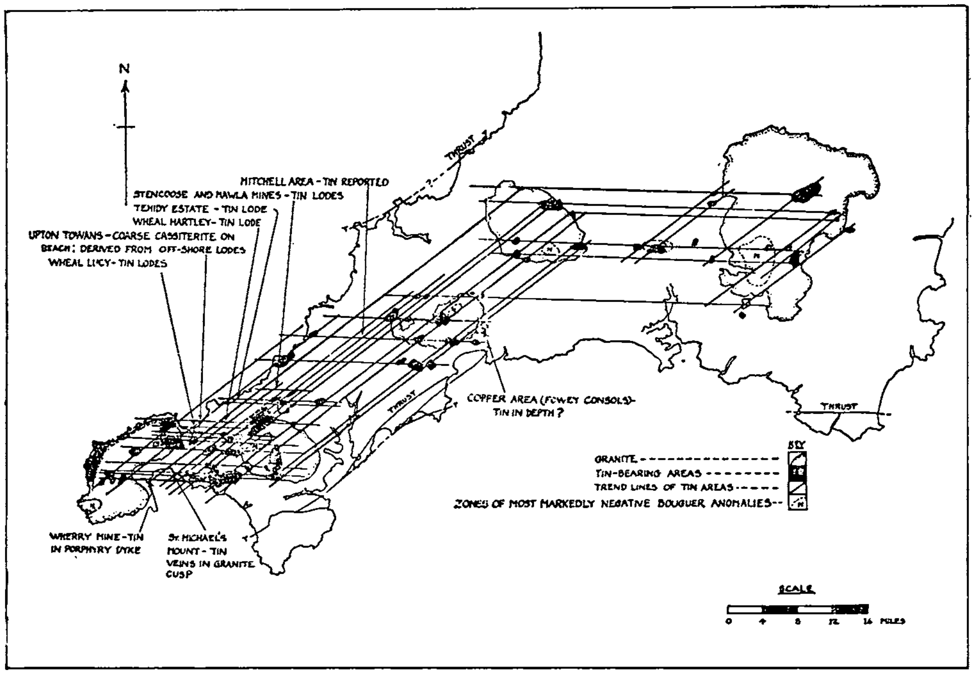


Fig. 5. Map showing the distribution pattern of the tin-bearing areas and of the zones of biggest negative Bouguer anomalies. The material on which this map is, in part, based, has been derived from Dines (1956, Figs. 3a and 3b) and from Bott, Day and Masson-Smith (1958, Fig. 2).

over a greater area then the latter. So the Southwest displays regional metal zoning. (The question of zoning will be returned to later.)

Fig. 5, which I prepared some time ago (see Hosking, 1964, p.213), is a plot of the tin fields of the region exactly as Dines (1956, pp. 12–13) plotted them, and, in addition, two series of lines have been drawn, one with an approximately N.E.-S.W. strike and the other with an E.-W. strike through the centres of all the small tin areas. (The strike directions were chosen because they approximate to the two commonest early lode trends in the region and the grid lines were drawn through the centres of the smallest tin fields because these points must be approximately coincident with the emanative centres of these areas. The positions of the emanative centres of the large tin fields are far less certain and, in addition, each of the large fields were probably fed from a number of sources.)

Many of the lines which have been drawn pass through several tin fields thus demonstrating that in the region there are preferred lines of mineralisation. Furthermore, the tin fields figured by Dines occur at some of the points where E.-W.-trending preferred lines of mineralisation intersect those with a N.E.-S.W. trend. It seems, therefore, that the locations of the tin fields were determined by a set of controls which operated in the same way throughout the region. It follows, therefore, that tin deposits should be looked for at those intersections of preferred lines of mineralisation which are at present blank. That this approach is likely to be worthwhile is indicated by the fact that several tin deposits which were not shown by Dines do occur at the intersections under discussion: these are included in fig. 5. Associated with all the intersections at which tin deposits occur I would expect granite cusps, often containing mineralised greisen-bordered veins. However, the mineralisation in any field may be more closely spatially, and possibly genetically related to late granite cusps which occur within an earlier granite. (See Hosking, 1964, p. 212.)

Paragenesis, wall-rock alteration, ore textures and primary zoning

I propose to deal only briefly with the topics listed in the title of this section as they have been discussed at length by me in a number of earlier papers (See, for example, Hosking, 1964, 1969 and 1979).

The paragenesis of virtually any of the mineral deposits of the Southwest is proving to be much more complex than was thought to be the case even twenty years ago because of the ever improving ways and means of examining the material in question. It is therefore becoming progressively more difficult to provide a meaningful table of the paragenesis of the vein and lode deposits of the Southwest as a whole. Generally speaking wolframite, cassiterite and arsenopyrite are collectively or singly the first group of the ore minerals to be deposited. These are followed, probably under conditions of progressively waning temperature, by sulphides, siderite and pitchblende. The general order of appearance of the more important is, I think, chalcopyrite/sphalerite/stannite (and other tin-bearing sulphides), nickel and cobalt sulphides (arsenides and sulpharsenides), pitchblende, 'low-temperature' sphalerite, galena, silver-bearing sulphosalts, jamesonite and stibnite, and siderite.

Of the common gangue minerals the common order of deposition is (apart from quartz) muscovite and tourmaline, chlorite, hematite, fluorite (in part perhaps deposited earlier), carbonate (siderite, ankerite, dolomite, and calcite) and baryte. Quartz is deposited more-or-less throughout the phases of mineralisation, but during the latest phases some of the silica reports as chalcedony.

Of course few, if any, veins or lodes contain all the minerals listed above.

The following types of wall-rock alteration, which are listed in general order of development, are common in areas of granitic rocks or non-calcareous metasediments:—greisenisation (in granites, sericitisation in metasediments), tourmalinisation, chloritisation, haematitisation, and kaolinisation. Some silicification of the wall-rock accompanies all these types of alteration and, on occasion, it may be the dominant type of alteration. In some instances the altered wall-rock may be rather complex by virtue of the fact that it is the product of a series of different types of alteration.

When the mineral deposits have developed within carbonate rocks or metabasites, and when these rocks are not far removed from the later granite, the gangue and adjacent wallrock may be composed essentially of skarn species in which might be mentioned garnet, zoisite, axinite, epidote, and calcite.

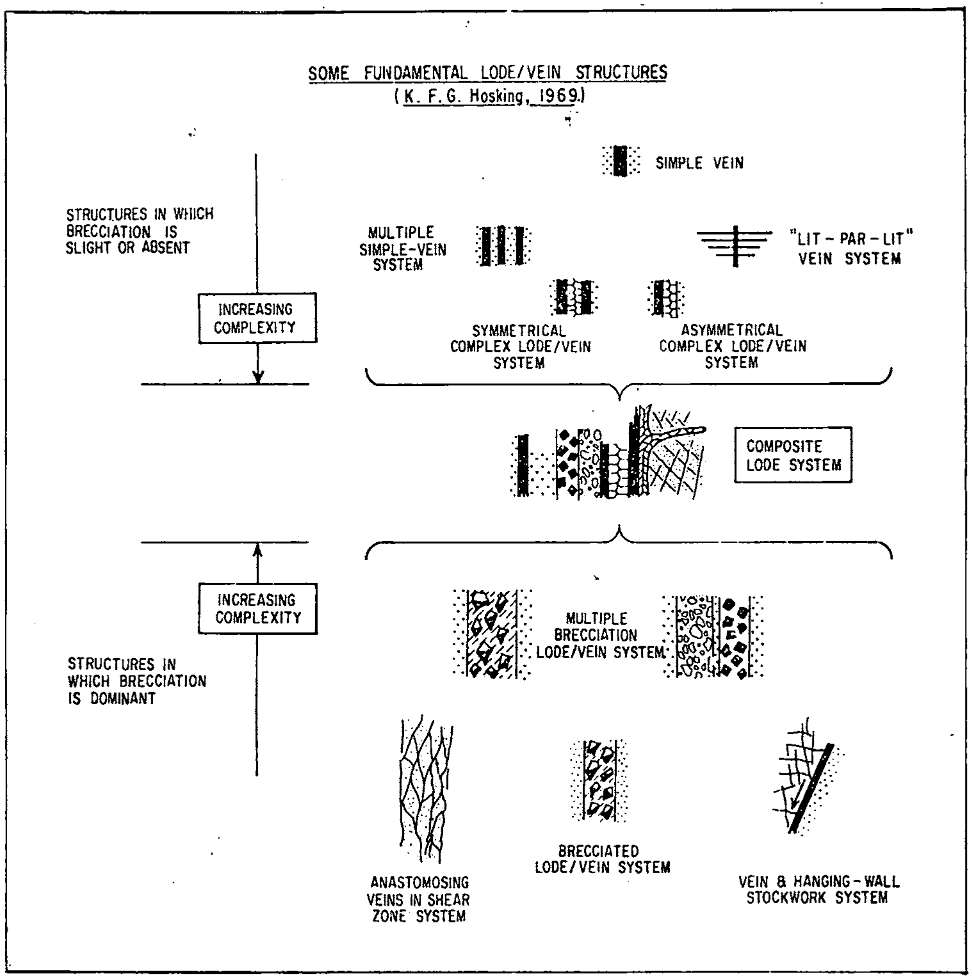


Fig. 6. Some fundamental lode/vein structures (K.F.G. Hosking, 1969.)

The lode/vein structures depend, essentially, on the nature of the initial fracturing which provided the passage ways for the mineralising agents, together with that which occurred within or very close to the mineral deposit during and after its development. In addition, it depends on when, how often and to what extent the developing body became a site of active faulting. Broadly speaking the major lode/vein structures fall into the three following groups:- those in which brecciation is dominant, those in which it is slight or absent, and those composed of a mixture of brecciated elements and others which lack brecciation. Fig. 6 illustrates some of the variations which are met with.

The ore textures depend on the same factors as those which determine the lode/vein structures together with the types, and relative percentages and crystal dimensions of the species which were deposited, and on the number of generations of each of the species present. They also depend on the extent to which earlier components were modified by faulting and/or by reactions between them and later mineralising agents. Clearly the possible textural variations are very great in number. Whether an 'ore' can or cannot be successfully beneficiated depends to some considerable extent on its texture so this must be investigated before any decision to exploit the material is made.

In the Southwest some of the lodes change markedly in mineralogical character with depth, a phenomenon termed 'Primary Zoning'. The Dolcoath Main Lode is the most often quoted example of this. The upper portions of this lode were stoped for copper, the intermediate ones for copper and tin, whilst the deepest ones provided only tin ore. The zones became more restricted laterally with depth and this fact plus the further fact that the zones are much flatter than the local granite/'killas' contact give the lie to Davison's early model of primary zoning and support that of Dines (fig. 7). However Dines' model is not entirely acceptable because it does not account for the fact that from a number of the major lodes, including the Dolcoath Main Lode, of the Camborne/Redruth field, tin-ore was recovered from their uppermost parts and below these parts first copper ore and then at still lower horizones tin-ore were found. Indeed, this state of affairs was so common that it was the general belief amongst mining men that copper was likely to be found below tin. I shall amplify this tin above copper story later. None-the-less, given an opportunity, in a tin/copper lode, copper may be deposited beyond the tin zone. Thus, in 1966 it was established that of the numerous mineralised fractures of the 9.E.1. cross-out of Geevor Mine "which in part is above the tin-zone" those which were high in copper were the fringe zones of lodes, which in the heart of the mine were exploited for tin-ore which contained little or no copper (Garnett, 1968, pp. 158–159).

It has not generally been appreciated that many of the Cornish lodes are distinctly telescoped. One polished section of material from the Wheal Baddern lode, for example, may contain cassiterite, arsenopyrite, sphalerite, galena, chalcopyrite and stannite whilst ore samples from the Mount Wellington Mine may provide a still greater number of ore-minerals. (Kettenah, 1977). So, from what little appears above it should be clear that no simple model can be erected to account for the distribution of the minerals even in, say, a single mine such as South Crofty. Indeed, this subject which includes the question of primary zoning is in need of much further investigation and is far too big a topic to be discussed at length here. Notwithstanding this I must of necessity return to it later. Perhaps the most important item to emerge from the more recent studies regarding the distribution of ore in the Southwest is the fact that it would be very unwise to follow a mineral exploration programme which is largely based on any of the primary zoning models which have been proposed.

It is generally considered, and to some measure substantiated, that temperature played a major role in determining where, for example, within a developing lode, a given ore-mineral should be deposited, but in the Southeast there are, clearly, several other factors which determined the distribution of ore. There are a number of examples of mineralised veins and lodes which are essentially confined to a given rock unit and in such instances the relative competence of the unit containing the lodes or veins and that

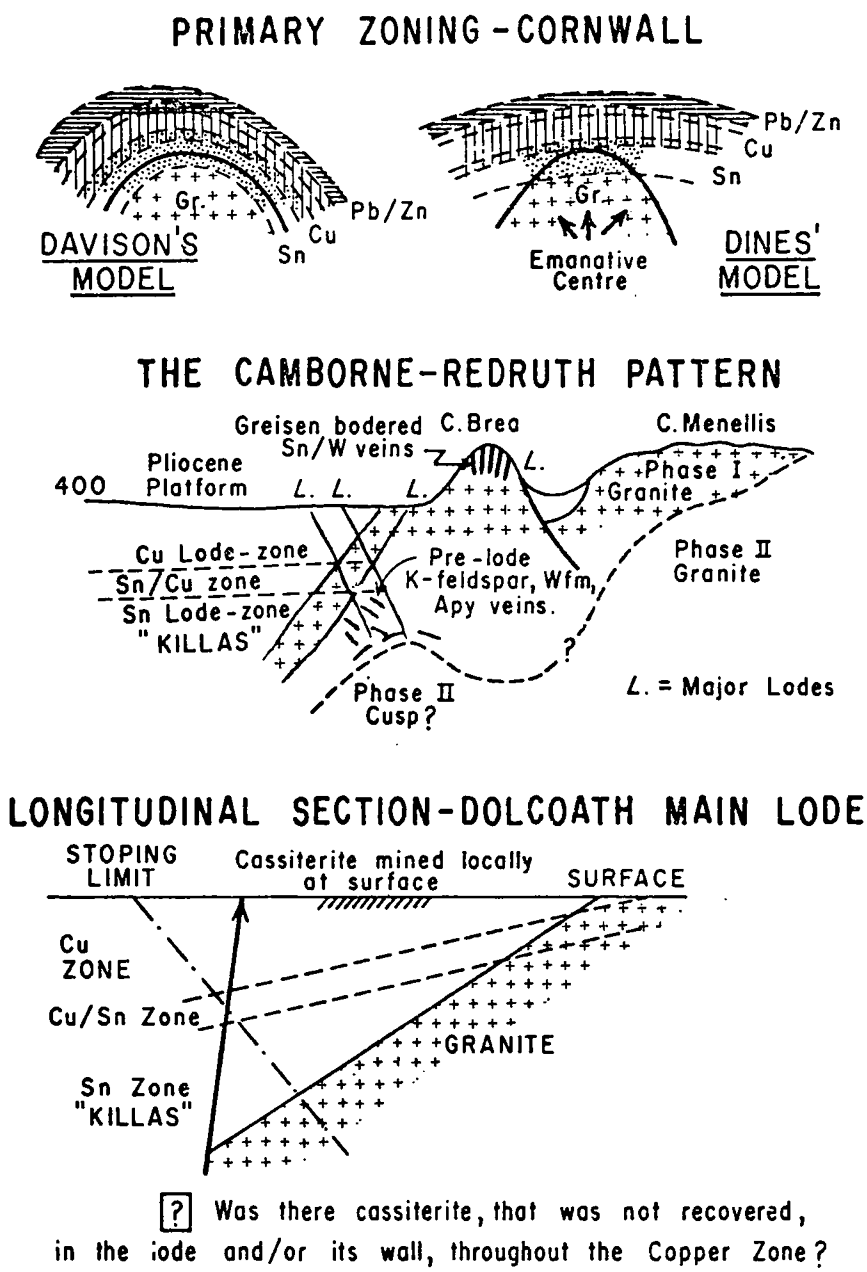


Fig. 7. Aspects of the Cornish primary zoning patterns.

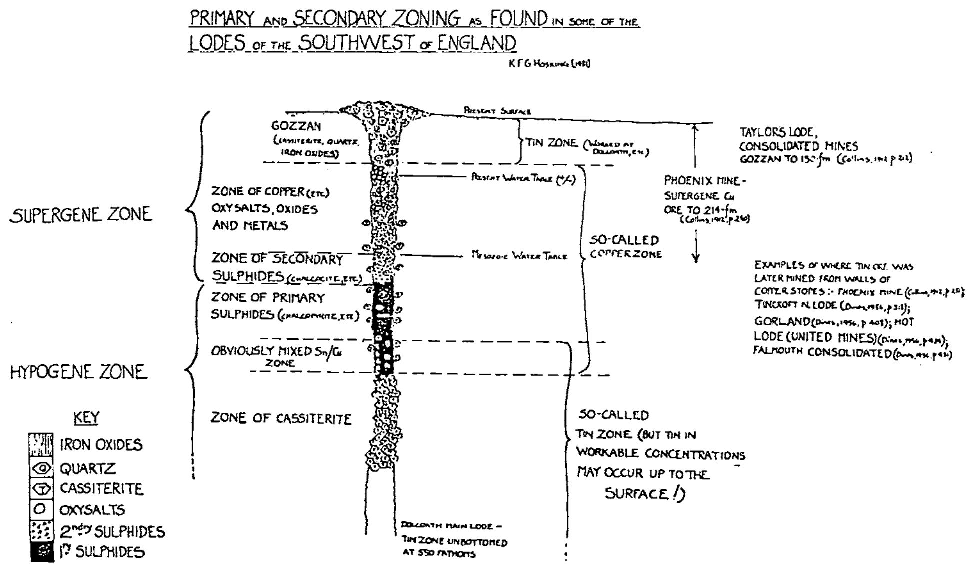


Fig. 8. Primary and secondary zoning as found in some of the lodes of the Southwest of England. K.F.G. Hosking (1981).

of the adjacent rocks must have been the major factor which determined the distribution of the ore. At Cligga, for example, the tin/tungsten veins are essentially confined to the granite cusp; at Parbola the tin-bearing veins are within the elvan and the tin-ore of Magdalen Mine (Ponsanooth) occurs solely within a metabasite. Fig. 8 illustrates these and a number of other impounded bodies which have been recorded from Cornwall. Within a given deposit the nature and/or distribution of the ore minerals commonly change when the dip or strike directions change, or when there is a marked variation in the width of the body. In many of the tin and copper mines the steepest parts of the lodes are the richest. At Bridford Barite Mine the lode consisted of wide barite-rich zones joined by narrow sulphide-rich ones.

Riches are commonly found at lode intersections. Thus at Wheal Vottle (St. Agnes) where a vertical lode was displaced by a flat lode, a rich concentration of tin-ore was found. (Collins, 1912, p. 113.) At Herland Mine (Gwinear) the richest silver ore occurred where a crosscourse intersected copper lodes (Collins, 1912, p. 183).

The wolframite ore shoot which haloes a post-lode granitic tongue in Castle-an-Dinas Mine would seem to be the result of remobilisation (see Hosking, 1964, p. 324).

Finally it would appear that basically one rock type is not more favourable than another as far as the deposition of ore is concerned: workable tin deposits occur, for example, in granite (South Crofty), porphyry (Wherry Mine), metabasite (Magadalen Mine) and in hornfels (St. Agnes) To some extent the composition of the host rocks has determined the composition of some of the minerals in the lodes. Thus, for example, whilst wolframite is the dominant tungsten species of lodes/veins in the granites and non-calcareous hornfels, scheelite is the dominant one of the lodes in metabasites and skarns.

The evolution and nature of the ways and means of searching for mineral deposits in the Southwest

Although many different metals have been recovered from the mineral deposits of the Southwest most of them received little or no attention from the miner until after the late eighteenth century (See Table 1). The most notable exceptions are tin, lead and silver and of these tin was mined for many centuries before the other two. Indeed, it is not known when the winning of tin-ore first took place in this region but it probably pre-dates the Roman Invasion and the fact that Britain was, at that time, a major or even the major tin producer in the world known to the Romans may have been one of the reasons for the invasion.

It seems reasonable to suppose that cassiterite was first recovered from placer deposits and that it could be recognised by the early prospectors and miners by its more obvious physical properties, namely colour and density, and, on occasion, shape. Although they probably first collected individual pieces by hand from stream gravel, etc., it is virtually certain that in due course a method of producing a concentrate of cassiterite, which depended on its specific gravity, was developed. Most of these ideas are not new as the following remarks of Pryce (1778, p. iii) prove:—"*I hope the reader will not judge it improbable, if we suppose that the first inhabitants of Cornwall and Devon, after the flood, were well acquanted with Tin in its richest Mineral state; for it requires no uncommon degree of intellectual examination to comprehend, that, in the earliest ages from that grand epocha, our richest shode and stream tin must have been found plentifully disseminated upon the surface of our vallies, and the sides of our hills and mountains. Those fragments and nodules, by their colour, shape, and gravity, must have attracted the notice and consideration of the first natives, if they did not allure the attention of those immediate emigrants who were scattered over the face of the earth when the sons of men multiplied in the land. We have, therefore, much plausibility on our side to conjecture, that Tin was known as a metal among our progenitors, so long as four and thirty centuries ago.*"

So the first prospectors in the region relied for their success on mineralogy and knowledge of the likely places were stanniferous placers might be found.

Probably a wooden pan was used many centuries ago by these prospectors who wished to establish the presence of cassiterite and the approximate amount in stream sediments and other unconsidered superficial material. We do not know who introduced panning to the Cornish nor when it was introduced. However, we do now know that nearly four centuries ago the pan was used by mineral dressers to obtain the final cassiterite concentrate as Carew in 1602 (see Halliday, 1953, p.94) wrote about the matter as follows:—"*After it is thus washed (i.e. the crude cassiterite concentrate), they put the remnant into a wooden dish, broad, flat and round, being about two feet over and having two handles fastened at the sides, by which they softly shog the same to and fro in the water between their legs as they sit over it, until whatsoever of the earthy substance that was yet left be fritted away.*"

TABLE 1

KEY DATES FOR THE MINING OF CERTAIN METALS AND MINERALS IN THE SOUTHEAST OF ENGLAND. (DATA AFTER DINES 1956 pp 20–33).

METAL/MINERAL	KEY DATES	OTHER INFORMATION
TIN	c. 1000 B.C.	Tin from placers and at, perhaps, some considerably later date from cliff lodes (by means of adits) and gossans (by pitting and open cast methods).
	15th Century	Deep mining above ground-water level.
	c. 1870	Peak production, c. 10,000 tons.
COPPER	Bronze Age	Possibly small recovery from outcrops for local bronze-making.
	16th Century	Systematic mining for Cu but in a small way until 17th Century.
	c. 1860	Peak production, c. 15,500 tons.
ARSENIC	1870	Became valuable because of demand by chemical industry. Then produced c. 50% of world's output. Largely by-product from Sn & Cu mines.
PYRITE	c. 1850	Demand for manufacture of H_2SO_4, mainly from 1850-1875. By-product from c. 70 mines produced c. 150,000 tons during this period.
TUNGSTEN	1858	First recorded yield.
	c. 1900	Serious production commenced. Obtained from W and Sn/W mines as by-product from some Sn mines.
ZINC	Pre 19th Century	Zinc blende discarded.
	1850 - 1885	Maximum production.
	1885 1911	Small production, largely from dumps.
LEAD	13th Century	Bere Old Mines active.
	16th Century	Mines of Mount's Bay district active.
	1800 - 1850	Period of maximum output.
SILVER	13th & 16th Centuries	Recovered from lead ore.
	1788	First discovery of true silver ore at Wheal Mexico.
	19th Century	2,000 tons of true silver ore recovered in the S.W.
ANTIMONY	pre-18th Century and 18th Century	c. 300 tons antimony from Wadebridge area (the chief Sb locality).
	1915 - 1918	c. 10 tons Sb obtained from lead mines.
IRON	17th Century	Iron lodes known but not exploited.
	18th Century	Iron lodes exploited. Between 1855 and 1865 output fluctuated between 24,000 and 87,000 tons p.a. In 1867 it was 37,000 tons. By 1875 it was 87,000 tons then it declined. Since 1884 only c. 6,500 tons have been raised.
MANGANESE	Mid 19th Century	Chief period of working, but Chillaton and Hogster Mine worked until c. 1907 and produced c. 50,000 tons.
URANIUM	Early 19th Century	At Wheal Trenwith much ore discarded because U was adversely affecting the copper concentrate.
	1845	From this date and until the discovery of radio-activity the small production was used to make a yellowish-green glass.
	1913 - 1925	Uranium ore recovered from South Terras Mine dumps for the production of radium and other radioactive salts.
BARITE	20th Century	Only recovered from lodes in Teign Valley
FLUORSPAR	1815 - 1839	1,500 tons from Camborne district.
	1845 - 1886	3,000 tons from Bere Old Mines (Callington) - the region's major producer: obtained from lead lodes.
BISMUTH, COBALT, NICKEL, MOLYBDENUM AND GOLD	19th and 20th Centuries	Small amounts of these metals have been recovered, on rare occasions, as by-products.
CHINA CLAY, UMBER, OCHRE, FULLERS' EARTH		China Clay is now, from a value point of view, the region's most important raw product. The other substances have been worked in a small way in the past. The members of this group are not discussed in this paper.

During the present century, and at least during some of the previous one, the pan has given way to the vanning shovel which is still used by some to separate the cassiterite from gangue minerals in samples composed of discrete grains. The samples may be taken directly from unconsolidated natural deposits or may be those prepared by grinding hard rock samples. In the hands of an experienced operator the vanning shovel enables much finer cassiterite to be recovered than is generally possible when a pan (dulang) is used. However, the vanning shovel sample is much smaller.

The ability to recognise cassiterite doubtless led, in the course of time, to the discovery of it in lodes and veins in the cliffs and in the outcrops of some inland lodes. It is likely that early cliff mining was done in the St. Just and St. Agnes areas and at Cligga, whilst inland opencast mining probably took place where tin-bearing outcrops of lodes occurred in soft, readily dug rock such as is found in the china-clay areas of the St. Austell granite. It is easy to believe that cliff mining led to adit mining and that adit mining would also be used to reach the deeper parts of lodes that outcropped on the upper parts of hills. Mining involving the sinking of shafts was resorted to when it was desirable to reach portions of ore-deposits which could not be explored or exploited by opencast means or by adits. The presence and quantity of water limited the depth to which an orebody could be exploited.

Little, if anything, but tin seems to have been mined until perhaps the 13th century. The Combe Martin Silver-Lead mines were working in 1293 and in that year 270lb. of silver were accounted for at the Treasury. According to Dines (1956, p. 758) the mining operations possibly continued until 1364, and that although attempts were made to reopen the mines in 1659 this did not take place until the end of the 17th. century and then without success. These mines were in action again on several occasions during the first half of the 19th. century.

The mining of the copper which has been financially far more beneficial to the Southwest than the mining of tin, only became important in the 18th. century and according to Pryce (1778, p. XI) *"the little which had been raised before, being adventitious, and accidently met with in pursuit of Tin"*. Pryce believed that the reason why only modest amounts of copper were recovered from the Southwest until the 18th century was because, in his view, good copper ore generally occurred at considerably greater depths than good tin ore. He remarks (*op. cit.*, p. viii) *"It is very seldom that tin continues rich and worth the working, beyond fifty fathoms deep; and it is absolutely certain, that copper is not often wrought in great abundance, till past that depth, to an hundred fathoms or more."* We now know that his views regarding the depths at which good tin ore may be found are very wide of the mark, but the hint that copper ore may occur beneath tin ore is, I think, a hint at a truth, to which I have already briefly referred, which has been largely forgotten by mining men during this century. In the literature of the last century it is not uncommon to read of a lode being mined first for tin then, in depth, for copper. Thus, for example, Phillips (1814, pp. 121–122) states that *"tin is frequently, if not mostly, found at a small depth in veins, afterwards proving rich in copper"* and he cites Huel Unity and Cook's Kitchen as mines which were first worked for tin *"without any suspicion of their veins being rich in copper beneath it"*. He further mentions that *"it ought to be noticed that some parts of that portion of the lode which principally contained copper ores, had been left, in the presumption of not yielding* *ore of any sort .... Some of these have since been found to produce tin which may consequently be said to have prevailed more or less from the surface to the bottom of the present working" (which was then at 192.024 m or 210 fathoms)*. It is also relevant to record that about a century after Phillips wrote the above, Collins (1912, p.196) when the western section of Dolcoath Main Lode, states that *"above the adit there were in places a fine gozzan carrying a good deal of tin ore, often in brilliant crystals. From the adit to the 100-fathom level the lode was moderately, and to the 160 very rich in copper. Between the 160 and 190 copper and tin occurred together, while from the 190 to the present bottom of the mine it has yielded tin almost exclusively." (Fig. 9.).*

Collins (1912, p. 298) also makes the following relevant remarks:—*"It should perhaps be remarked here that though the succession of zones of different minerals at different depths is notable enough .... in fact it cannot be said to be established anywhere in the West of England except in the neighbourhood of Carn Brea, and perhaps at the Phoenix Mines, near Liskeard. In these localities it is true to this extent.*

(1) The upper portions of the lodes were worked for tin, little or no copper being present. But the character of these portions plainly indicates the former existence of sulphides now removed, and there is great reason to suppose that these sulphides were cupreous.

(2) Several of these lodes subsequently proved to be rich in copper and ceased to be worked for tin. But there is reason to believe that notable quantities of tin were still present, though lost sight of in the abundance of sulphuretted minerals. An examination of the burrows at Wheal Clifford shows that even there tin occurred with the copper.

(3) It is certain that in the notable instances referred to above the (probably) once mixed tin and copper ores have given place to tin alone, the copper having altogether disappeared and the tin increased in quantity".

Such observations point to the imperfections of the primary zoning models of Dines and others, and indicate that telescoping is a much more common lode phenomenon in the Southwest than has been generally appreciated. (There are, of course, far more spectacular examples of telescoping in the region, than those noted above, and I have mentioned some of these earlier.) These observations trigger thoughts about the tin/copper lodes particularly of the Camborne/Redruth area. Does tin-ore occur in the walls of the abandoned copper stopes? Was the tin, largely unknowingly, disposed of in the copper concentrates sold to the smelters? The above notes also serve to emphasise the importance, indeed the ever growing importance, of that aspect of mineral exploration which I call library research and they also stress the need to preserve all books, documents and plans relevant to the search for and exploitation of minerals in this region. Ideally the old original plans and the rare documents should be maintained and catalogued by experts and housed in places where they will not be allowed to deteriorate but where they can be readily examined by interested parties.

Throughout the long period of mining in Cornwall and Devon those searching for ore-deposits were becoming progressively more efficient as a result of making use of the

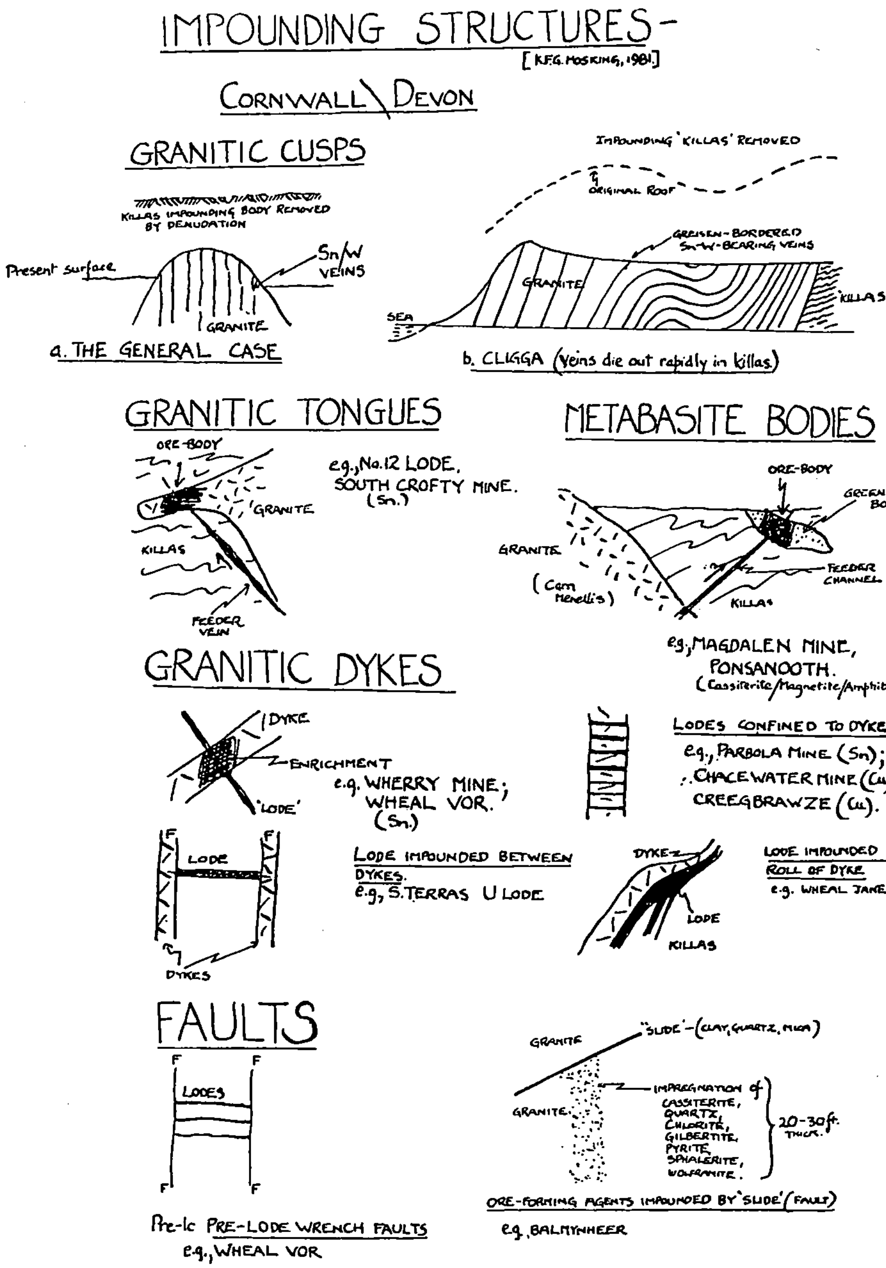


Fig. 9. Impounding structures 'K.F.G. HOSKING, 1981.°

knowledge gained by those who had gone before them and of utilising the discoveries in other 'scientific' fields. Probably until well into the 18th century the views regarding the genesis and nature of the deposits and how best to search for such deposits were passed on verbally from mining father to mining son. That by this time there was a great deal known about the nature of the mineral deposits and of ways and means (not all scientific) of searching for such deposits, is apparent from Pryce's compilations in his work Mineralogia Cornubiensis (1778). This same work provides evidence that both mining and mineral dressing had reached stages of considerable competence, that underground surveying was being done by the use of the miner's dial, and the mine products were being evaluated fairly effectively by chemical assays which were largely of the dry type.

In the 19th century impetus was given to mining by the Industrial Revolution, and in that century great strides were made in all the branches of science. These resulted, for example, in the discovery of important new uses for certain elements which previously were of little or no value, elements such as uranium and tungsten, and in improving mining methods, for example, more effective pumps which, in turn, caused the miner to look for ore at every-increasing depths.

The somewhat intermittent search for ore that has taken place in the 20th. century in the region under review has come to rely ever more on what are often regarded as new methods but which in fact have all developed from old ones. I think particularly of geochemical prospecting, which is a natural development from panning and the crude testing of underground waters by tasting them, and diamond drilling which may be regarded as the modern equivalent of driving adits for the purpose of prospection. It is relevant to note that Price (1778) opined that *"the expense of an adit is slow and small; Therefore it is easily borne. Two or three hundreds pounds a year is scarsely felt by eight or ten persons, than whom seldom fewer are concerned; and this too upon the chance of finding a vein, or veins, that may throw up an amazing profit presently after discovery"*. The Pool Adit, initially a prospect adit, intersected a large and rich copper deposit which, from 1747–60 gave the Basset family a regular income of £10,000 or £11,000 a year (Hamilton Jenkin, 1927, p. 94).

Through the 19th century and up to the present time the search for viable hard-rock mineral deposits has become progressively more difficult. One is now largely concerned with the search for deposits lacking obvious surface expressions or targets beneath earlier mine excavation. Dines (1956, p. 324) notes that at South Crofty Mine" *........ lodes, proved in the crosscuts north of Robonson's and New Cook's Kitchen shafts, constitute the chief source of ore to-day. They are all 'blind' lodes, i.e., are not proved above the 225-fm Level and some peter out upwards at greater depth, but most are carrying workable values in depth."* In addition, certain areas worth exploring are not available because they are national parks or private estates, or because it is thought that a mining operation might adversely affect the environment. A further difficulty arises sometimes because the prospecting company cannot trace the owners of the mineral rights of the ground it wishes to investigate. This difficulty can, however, be overcome, but it is a slow process. Those who are concerned with the search for placer deposits, either for those on the land or under the sea, are presented with similar problems.

In this century and in all those which preceeded it every known ore deposit in the Southwest was discovered by chance, or by means not dependent on the conscious application of scientific principles, or by scientific methods. Each of these three will now be discussed.

Chance discoveries

Chance discoveries are those made by individuals when they are not looking for ore deposits and it is likely, I think, that many deposits were so discovered. The uncovering of sizeable lumps of tin-ore by a farmer ploughing at Factory Farm, near Porthtowan, some years ago, was a chance find which might yet lead to the discovery of the mother lode. The Bunny at Botallack Mine is well known because of the occurrence there of a number of flat primary tin-deposits which, although occurring more-or-less one above the other, were separated by layers of country-rock. The highest floor was virtually coincident with the surface 'and tradition reports it to have been discovered by some of the tinstone having been kicked up by horses going over it' (Hamilton Jenkin, 1927, p. 44.). Pryce (1778, p.50) records that the Cobalt Lode at Pengreep, which was subsequently mined, "*was discovered accidently by Mr. Beauchamp, in an adit that he drove through some part of his estate ....*", while Carne (1822, p. 114) mentions that Sir Christopher Hawkins had lately discovered some lead veins when he was draining a marsh in the parish of Newlyn. The name Wheal Boys (Endellion) suggests that boys may have discovered the mineralisation which led to the establishment of the mine. Phillips (1814, p. 125) records that the lode which was worked at Wheal Maggot, or Velenoweth, in the parish of Phillack "*was first seen by workmen employed in digging a trench for the foundation of a garden wall in a valley.*" The lode, which was soon exhausted, consisted of a 'rich' gossan which was followed in depth by galena which, in turn, gave way to copper ore. I have read somewhere that a lode was discovered in Cornwall because its position was indicated by a band of white arsenious oxide where the vegetation had recently been destroyed by fire. Apparently elsewhere, and long ago, ore deposits were revealed in this way. Pryce (1778, p. 111) notes that Lucretius ascribes the first discovery of metals to the burning down of woods, and records that "*Aristotle says, that some shepherds in Spain having set fire to certain woods, and heated the substance of the earth, the silver that was near the surface of it, melted, and flowed together in a heap ......*" Were the woods set on fire deliberately in an endeavour to find ore it would be applied geochemistry!

Discoveries not dependent on the conscious application of scientific principles

In Southeast Asia, dreams, the fortune teller and the bomoh have all, it is claimed, indicated the presence of ore deposits. Parallels can be drawn in the Southwest. Surely, for example, Wheal Dream may well owe its foundation to a dream. Carew, writing in 1602 (see Halliday, 1953, p.90) recorded that "*Some have found tin works of great value through means no less strange than extraordinary, to wit, by dreams; as in Edward the Sixth's time, a gentlewoman, heir to one Tresculierd and wife to Lanine, dreamed that a man of seemly personage told her how in such a tenement of her land she would find so great store of tin as would serve to enrich both herself and her posterity. This she revealed to her husband, and he, putting the same in trial, found him a work which in four years was worth him well near so many thousand pounds. Moreover, one Taprel, lately living, and dwelling in the parish of the hundred of War, called St. Neot, by a like dream of his* *daughter ... made the like essay, met with the effect, farmed the work of the unwitting lord of the soil, and grew thereby to good state of wealth."* According to Mr. Jack Symons (personal communication) the late Captain Arthur Stevens, who worked at South Crofty Mine between the two World Wars, told the then Managing Director, Captain Clarence Paull, on a certain Monday morning, that the previous night he had dreamed that were a crosscut driven from lode 2A, at the 79.248 m (260fm.) horizon in the Robinson's Section, a rich body of ore would be intersected. Only after repeated requests was the crosscut driven. It did intersect a rich deposit, and the stope from which the ore was recovered was called Arthur's Dream Stope. It seems to me that a rational explanation of this event is that Captain Stevens, who was an excellent and experienced miner, had noticed in the drive, without being consciously aware of it, a subtle wall-rock alteration which indicated the near presence of a lode. In his dream this fact was projected into the conscious part of his mind where it remained long enough for him to grasp its significance.

It was also thought that elves, known as 'knackers', lived and worked in the mines *"and the miners thought they did especially meritorious service by leading them to valuable mineral, as 'knackers' were rarely found working except in rich ground"* (Hamilton Jenkin, 1927, p. 295). I can make no useful comment about this belief.

Dowsing, or the search for mineral deposits by the use of the divining rod (originally a forked twig, but there are many variations) was first described by Agricola in 1556 (see Hoover and Hoover, 1950, pp. 38–41). He remarks that *"there are many great contentions between miners concerning the forked twig, for some say it is of the greatest use in discovering veins, and others deny it."* Later Agricola concludes that *"...... a miner, since we think he ought to be a good and serious man, should not make use of an enchanted twig, because if he is prudent and skilled in the natural signs, he understands that a forked stick is of no use to him, for as I have said before, there are the natural indications of the veins which he can see for himself without the help of twigs. So if Nature or chance should indicate a locality suitable for mining, the miner should dig his trenches there: if no vein appears he must dig numerous trenches until he discovers an outcrop of a vein"*. However, Carew, in 1602 (see Halliday, 1953, p.90) pointed out that the investigation of areas likely to contain ore-deposits by pitting and shafting did not always, for a variety of reasons, prove to be profitable to those who had invested in the ventures. He wrote *"But you may not conceive that every likelihood doth ever prove a certainty, for divers have been hindered through bestowing charges in seeking and not finding, and many undone in finding and not speeding, whilst a fair show tempting them to much cost hath in the end failed in substance and made the adventures bankrupt of their hope and purse."*

Doubtless dowsing was introduced into the region by one of the mining men from Continental Europe who were employed in the Southwest from time to time. In spite of the fact that there are still in Cornwall and Devon those who believe that suboutcropping lodes can be located and traced by dowsing, I do not know of a single record of a hitherto unknown lode having been found by this method. Before the sewerage tunnel was driven from the valley of the Red River, Mr. Tom Fiddick, a well-known dowsing expert, determined where he thought lodes intersected the line of the tunnel and declared the nature of the lodes he claimed to have found. This was done by using a dowsing cone, his own invention. When the tunnel was driven, the lodes it intersected were mapped. In my view there was very little correlation between the distribution of the lodes in the tunnel and Fiddick's findings. However, when a geochemical survey, involving the collection of soil samples along the line of the tunnel and their subsequent analysis was conducted, the results corresponded very well with the known facts regarding the actual distribution and nature of the lodes which the tunnel had located. (Hosking, 1955–56, pp. 78–80).

Whatever one's views about dowsing, in this day and age, no one would think of using it to find suboutcropping mineral deposits as there are now dependable methods available which are based on solid scientific principles.

Finally there is the question of the Lode Lights which some equate with the Jack-o-Lanterns, and which in the Wendron district are called "Tin Lanterns" *"on account of their supposed virtue in showing where metal exists"* (Hamilton Jenkin, 1927, p. 296). Jack-o-Lanterns are due to the spontaneous combustion of methane generated in a marsh: they have no relationship to mineral deposits other than the fact that placers may occur in marshy ground. However, in about 1850, when the fortunes of North Basset Mine (Redruth) were running low, an old lady, Grace Mill, directed the mine's owners to a rich lode on the property which, she claimed, she knew of because she had seen the Jack-o-Lanterns burning over it. Subsequently profits of over £90,000 were made from the working of this lode, and because of this discovery Grace was given a pension and a new dress annually. As the lode occurred on a hill-side it is difficult to believe that methane would accumulate there. Did she, by chance, come upon some gozzan from the largely vegetation-covered lode and then invent the Jack-o-Lantern story because it seemed to sound better to her than the truth?

Discoveries depending on the application of scientific methods

The scientific approach to the search for mineral deposits depends, essentially, on the establishment of mineral/metal distribution patterns, the interpretation of them and extrapolation from them. With time the patterns become more detailed, their interpretation more closely approximates to the truth and, consequently, extrapolations into unexplored or partially explored terrain can be made with ever increasing confidence. The development of the patterns depends on the collection and analysis of data. Until the present century the relevant data collected at or very near the surface was of a limited kind. It consisted essentially of the recognition and interpretation of gozzans and the location of sub-outcropping mineral deposits by pitting and trenching. On occasion the results of these operations were quantified by vanning and dry assaying. In addition, as I have noted earlier, when the topography was suitable, adits were driven, not only to drain mines but also for exploration purposes. In the mid-eighteenth century it became a favoured technique because of some great finds which had resulted from its early employment. The driving of the tunnel mentioned earlier from the Red River Valley to the Camborne North Cliffs, in the nineteentwenties, which is used to carry sewage to the sea, also enabled the lodes in that block of ground to be examined. It may be regarded, therefore, as one of the last of the major adit-type explorations to be conducted in the region. The Excelsior Tunnel at Kit Hill, is another example of a recent similar exploration in that although it was begun in 1881 it was continued at intervals until 1938, but the lode finds in it were far more disappointing than even those on the Cliff Tunnel.

When Pryce was writing it was generally well-known that gozzans were the surface expressions of certain mineral deposits, and probably the saying that 'a good lode has an iron capping', which is mentioned by Collins (1912. p. 102), was familiar to the mining fraternity. Pryce (1778, p. 7) was aware that there are "*several kinds of gozzans, from the different appearances of which, experienced miners form very strong and well grounded conjectures ....*". It is also clear that the miners of Pryce's time knew that blue and green minerals in the oxidised portion of a lode indicated that it was copper-bearing whilst a 'pale yellow ochre' was a characteristic of the gozzans of lead lodes (1778, p. 44). However, even in the eighties of the last century a gozzan that was indicative of the presence of underlying copper ore was not recognised by many of the miners if we are to believe Captain Charles Thomas, then Managing Director of Dolcoath Mine. (See Collins, 1912, p. 131.) Earlier in the nineteenth century de la Beche (1839) had a somewhat better opinion of the miners' ability to 'read' gossans as he wrote that "*... the good miner readily detects that character (of the gossan) which is most indicative of a good copper lode, though it is one that can scarcely be expressed in writing.*" From the writings of Brande (1816, p. 4) it is clear that in his time the miners were able to 'read' the outcrops of lodes and veins quite well. Brande remarks that "*Among the substances met with in the early working of veins, regarding as indicating their produce, an ochrey earth or Gossan, and compact iron pyrites, are most promising for copper, and green earth or soft chlorite for tin. Abundance of quartz is rather an ill omen.*" Today the above is generally acceptable but for the observation about pyrites. One may find residue masses of pyrite in an extensively gossanised part of a deposit but one would not regard it as a strong indication that the body would be copper-bearing at depth.

It was probably known for many centuries that as a lode disintegrated on, say, a hillside, the debris, under the influence of gravity and sheet-wash, moved down slope generating eluvial and colluvial deposits and sometimes it contributed to the sediments in the drainage systems. It was early appreciated that systematic pitting and trenching around the hills, and vanning in the streams, enabled the miner to locate the mother lodes.

The early location of exploration targets within the known mining fields which depended on observations at the surface was facilitated, on occasion, by the deposition of opencast workings and perhaps, more often, by the frequent ventilation and other shafts along the lines of lodes which had been exploited. These indicated sites where lode-extensions might be sought and with improvements in pumping where comparatively deep-seated unwrought ore might occur. In addition, and largely as a result of data obtained from underground mining, they suggested where virgin parallel lodes might be found. Underground observations also served to emphasise, amongst other things, the importance, when seeking ore-deposits at the surface, of contacts, particularly granite/country rock contacts, and those between elvan dykes and their host rocks, and elvan/lode patterns (fig. 10). That long ago the prospectors were well-aware that abandoned mines were, an occasion worth reinvestigating is confirmed by the following remarks of Carew which were written in the early seventeenth century

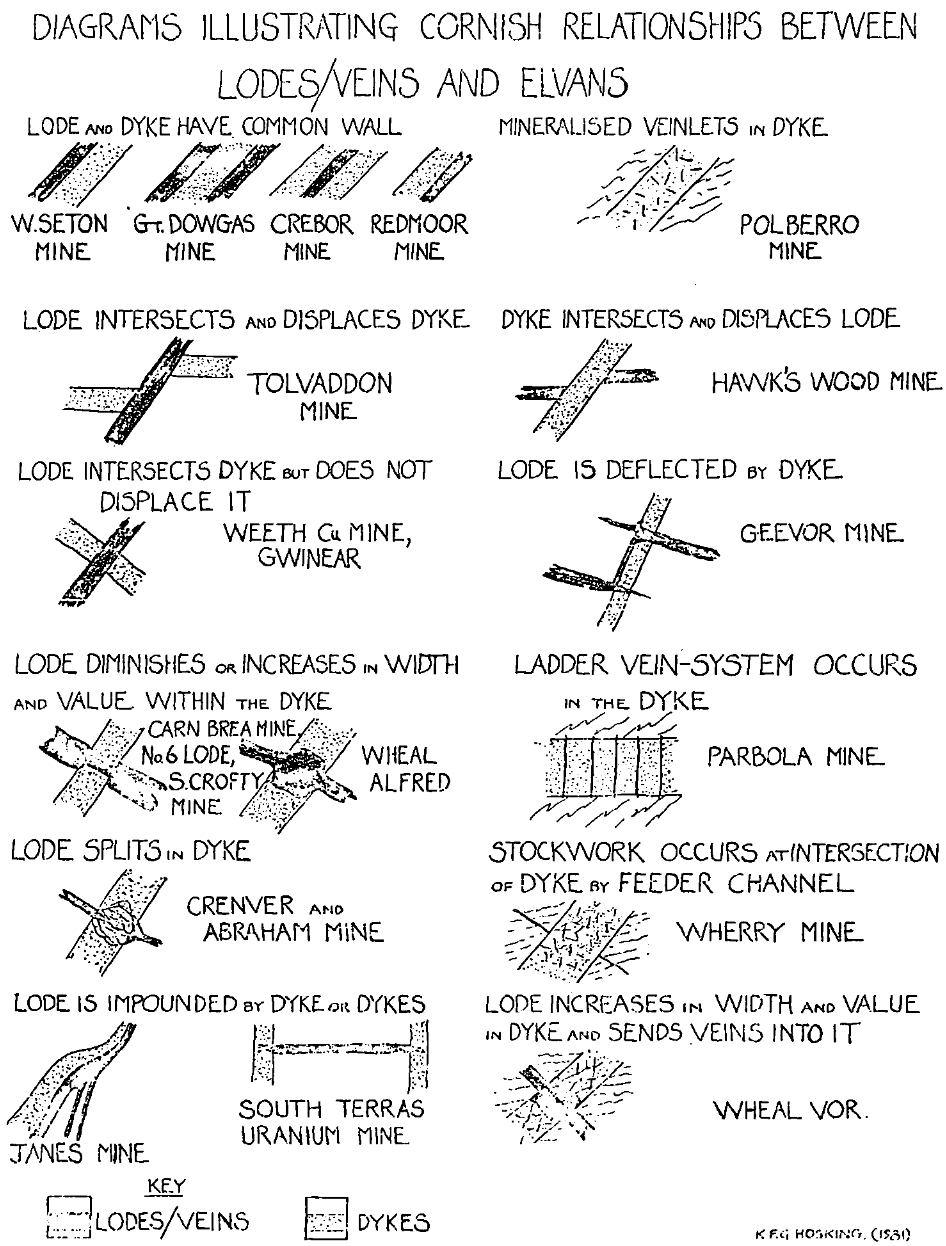


Fig. 10. Diagrams illustrating Cornish relationships between lodes/veins and elvans.

(see Halliday, 1953, pp. 90–91). He stated *"There are, that leaving these trades of new searching, do take in hand such old stream and load works as by the former adventurers have been given over, and often times they find good store of tin, both in the rubble cast up before, as also in veins which the first workmen followed not."*

It is pertinent to remark that such targets have continued to be investigated up to the present time and even now some of them, on investigation, are providing viable ore-deposits.

The work of the prospector is, of course, greatly helped by the availability of reliable topographical and geological maps, and as surveying techniques and equipment improved so did the maps. It was in the Southwest of England that de la Beche commenced geological surveying in 1820. *"Later he was commissioned to colour geologically the Ordnance Survey one-inch maps and his "Report on the Geology of Cornwall, Devon and Somerset," 1839, was the first memoir published by the Geological Survey. This report was the first treatment of the geology and of the ore deposits based on scientific concepts supported by geological mapping".* (Dines, 1956, iii.)

One wonders if the endeavours of de la Beche and of the Henwood (who published a vast amount of data on the lodes in the operating Cornish mines in 1843, and about which more later) were not catalyzed by the remarks of Phillips of page 5 of his most important paper on the veins of Cornwall which was published in 1814. Phillips remarks that *"In the counting houses of the most successful mines the only information ever committed to paper, in regard to the working of the veins are the expenditure and income, together with a section of the vein from which the profit is reaped, without a single notice in regard to the tract of country through which it passes. Of the generality of unsuccessful mines, which form by far the greater proportion, all that is registered is the loss or expenditure; other information can only be obtained by a recourse to personal inquiries of the conductors or captains."*

As a result of underground mining, and particularly during the 19th century, a vast amount of data was accumulated regarding the nature of hardrock mineralisation of the region. It was then appreciated that many of the lodes displayed zoning. It was known where enrichment, as for example at lode intersections, might occur, and that the steepest parts of lodes were generally the richest. It was understood that changes in the strike or a dip of a lode were commonly associated with changes in the grade of the ore. (See the remarks of Captain Charles Thomas, which were made in 1859, and which are recorded by Collins (1912, pp.121–122).)

It was also known that in a given mine ore was more likely to occur in certain host rocks than in others, but what does not seem to have been generally understood by the miners was the fact that strong mineralisation is often associated with marked wall-rock alteration, and that the signs indicating a favourable host rock had been superimposed on the rock as a result of mineralisation. However, certainly by the second half of the 19th. century, the more geologically educated members of the mining fraternity were well aware of the nature and significance of wall-rock alteration and, in general, how and when it had been effected. Collins (1912, p.128), for example, records that in 1863 the pupils of Mr. R. Pearce, after a visit to Carn Marth, and other mining localities, wrote a detailed account of the alteration adjacent to the lodes which they had seen. It is also quite clear that Collins appreciated, very well, the nature and significance of wall-rock alteration and how it came about. He writes (1912, pp.127–128) *"It is the richer parts of the lodes which are usually bounded by rocks exhibiting such notable marks of chemical alteration as discolouration, oxidation, hydration, softening or hardening, or general mineralisation by pyrites or other metalliferous substance, so that in some way or other the approach to a good mineral deposit is always heralded by signs unmistakable to eyes which are familiar with the mineral phenomena of that particular district."*

Above all, many of the important relationships between the disposition of ore and faulting were recognised, although, as Henwood (1843) noted, it was often not possible to explain the mechanics of the development of the carefully recorded relationships. Perhaps one of the major reasons why Henwood could not always account for the fault phenomena which he witnessed was because he did not take into account the fact that lodes are, on occasion, perhaps often, limited by earlier faults that strike very approximately normal to the lodes and which, in a post-lode era might themselves have become mineralised. Yet Henwood was aware of this possibility as, indeed, were others. Fox (1836, p.42) for example, states *"I think it can be shown, that the mere fact of intersection, ought not, apart from other considerations, to be taken as evidence of the relative ages of veins."* Henwood (1843, p.37) remarks that *"it has long been strenuously maintained, that when one vein intersects another, the vein intersected is older than that which intersects it: but the district under consideration affords so many exceptions to the generality of this law, that, in Cornwall, at least, it must be received with some limitation."* This important matter was for years totally lost sight of in the Southwest until Garnett (1961) demonstrated the importance of pre-lode faults at Geevor Mine. I am quite sure that today there are some who are concerned with the mineral deposits of this region who do not appreciate that tin lodes are likely to stop at faults because the latter are pre-lode faults and that, for obvious reasons, it is of prime importance, although not always easy, to establish during a mining operation, which of the crosscourses are pre-lode and which are post-lode.

At one stage during the 19th century, the Southwest was the centre of the Industrial Revolution and so there were many living there who were alive to the importance of applying the results of the numerous advances which were then being made in the sciences. This awareness led to the establishment of societies in which scientific topics could be discussed and researches could be encouraged, and which, by the publication of transactions, enabled the results of such researches and other relevant scientific data to be broadcast and preserved. Such a society was the Royal Geological Society of Cornwall, which was founded in 1814, and, is the second oldest body of its kind anywhere in Western Europe. Henwood's great work on the metalliferous deposits of Cornwall and Devon, which was published in 1843, was volume 5 of the transactions of the Society. It is to be noted that Henwood would never have been able to make this great contribution had not his investigations been supported financially by *"many of the Noblemen and Gentlemen resident in, and connected with, Cornwall ....!"* The work, which culminated in the publication of volume 5, extended over a period of 14 years, during which time Henwood examined more than 200 mines and travelled nearly 2,000 miles underground. He remarks (1843, p.386) that *"in the prosecution of these underground investigations my life has been* *frequently in imminent danger; and I have sustained many severe injuries ......* ". In spite of all the difficulties he recorded and subsequently analyzed underground geological data in a manner which was not matched in the region until the importance of such work was re-established by Garnett (1961) at Geevor Mine and Taylor (1966) at South Crofty Mine.

Many aids to the search for ore deposits in the Southwest stemmed from the great scientific advances of the 19th century. Not the least of these aids was the holding of courses of instruction for young miners and would-be miners in various parts of Cornwall, which culminated, in 1888, in the creation of the Camborne School of Mines. These schools directly and indirectly helped mineral exploration in a number of important ways. They equipped mining engineers with knowledge and experience necessary to take advantage of the 'modern' scientific aids to exploration. Thus, surveyors were made available capable of utilising the ways and means of producing plans and sections of a greater accuracy than before. The graduates were also reasonably competent in geology, mineralogy, and assaying, amongst other things. In addition, the schools attracted a number of people who, in due course, became internationally recognised authorities in their chosen fields. H.R.Beringer, for example, was amongst the best inorganic analytical chemists of the day. One of his many achievements was the development of a wet assay for tin-ore and concentrates which superseded the much inferior dry culm assay. In later days others from the school made equally important contributions to those branches of sciences which facilitate the search for ore.

Apart from de la Beche's contribution in 1839 the advances in exploration methods which were made in the Southwest during the remainder of the century were generally achieved by those directly associated with the mines, or the places of mining instruction, or the societies concerned with mining and/or subjects allied to mining. Of course, these advances were often the products of the application of scientific discoveries which had been made elsewhere. Thus, for example, blow-pipe analysis, for the examination of minerals, which was introduced by A.F. Cronstedt *"although it was left to Jons Berzelius and Johann Hausmann, to bring about its general application"* (Pierce, 1962, 5, p.395) was popularised in the Southwest by Collins (1871) who provided details of it in a book which also covered the mineralogy of Cornwall and Devon. Collins, at the time his book was published, was lecturer and assistant secretary to the Miner's Association of Cornwall and Devon.

During this time Henwood's great work, which has been referred to often in this paper, was the treasure house of data of value to the searcher of ore in the Southwest. However, particularly during the last quarter of the century a great deal of knowledge of direct and indirect value to the prospector and explorer was preserved not only in the transactions of local societies but also in national ones. Indeed, one of the greatest contributions made to the relevant literature of the subject under review was Collins' paper 'On some Cornish Tin-stones and Tin-capels' the first part of which appeared in th Mineralogical Magazine, in April, 1880. Much of the content of this paper depended on the results of examination of thin sections of tin-ore under the petrological microscope, a technique developed in the second half of the century. It provided, for the first time, some real understanding of the intimate character of those ores with which the majority of the mining companies were primarily concerned.

At the turn of the century, and from the point of view of those concerned with the search for ore-deposits, an important event occurred. The Geological Survey resumed its work in the region, having concluded that there *"complex and fundamental problems in the stratigraphy, metamorphism, and petrology, as well as the mining activity of the region, required further scientific investigation". .... "The survey covered most of Cornwall and the southern part of Devon .... Results were published in the one-inch sheet memoirs, each with a mining appendix......"*. (Dines, 1956, iii.). They contain a wealth of information about the mineral deposits which was based, as far as possible, on field work by experts supplemented by studies of the country-rock and ore in thin section under the microscope, and the results of chemical analyses, and illustrated by photographs of lodes in situ, hand specimens of ore and photomicrographs. They, together with Collins' (1912) *"Observations on the West of England Mining Region"* and certain of the Geological Survey's Special Reports on The Mineral Resources of Great Britain' which were published in the early twenties (see Dewey, 1920, 1921 and 1923) collectively constituted the Bible of those concerned with the search for ore until, perhaps, the beginning of the 2nd World War, in 1939. However, during the war Trounson's analysis of the mining literature of the region and his mining experience led him to select a number of mines which might be worth reopening, and his publications on the subject constituted a further important addition to the ore searchers' Bible. (See Trounson, 1942.)

The period of 45 years, up to the end of the 2nd. World War, was one in which a great deal of information was accumulated about the nature of the lodes—particularly those containing tin and tungsten. This was due, to no small extent, to the studies of thin sections of such ores under the microscope by Dunham an Phemister of the Geological Survey, by Davison of the Camborne School of Mines and by Cronshaw (1920–21). The studies led to a better understanding of the problems posed by the region's tin ore to the mineral dresser (see Davison, 1922) and of the paragenesis of the ores (see Cronshaw (1920–21) and Davison (1930). They also led to renewed thinking about the patterns of distribution of ores of the various major metals of economic importance. One of the outcomes of this was Davison's primary zoning model (Davison, 1930, and fig. 7 of this paper,) which was accepted without critiscm by Jones who remarks (1925, p. 111) *"The recognition of different zones of deposition for different metalliferous minerals is of great economic importance, and it is possible that some of the mines in Cornwall and Devon, formerly worked only for copper ores, and not followed in depth, may in future be reopened on the theory that a tin zone may occur below the old workings"*. The statement of Jones indicates very clearly how Davison's views influenced exploration thinking at the time, and it was not until 1934 that Dines (1934) pointed out that a given copper zone generally had a considerably greater areal extent than the associated tin zone and that these zones were usually appreciably flatter than neighbouring granite/metasedimentary contacts. These are facts that any geologist might have appreciated in the last century had he bothered to study the longitudinal section of Dolcoath Main Lode which was published by Burrow and Thomas (1893). The history of exploration since the Second World War has suggested that those valid elements of the copper/tin-zone relationship had gone unheaded by some.

In the pre-war period under review, whilst there was a considerable accumulation of field and laboratory data relating to mineralisation in the region which is of considerable value to those concerned with the search for ore there now, it was a period when earlier observations were neglected, consciously or subconsciously, and particularly when they could not be incorporated into, or did not support currently popular theories. It was also a time when naive and gross over simplification was the order of the day. Dewey (1935) for example, pontificated about the thickness of the mineral zones and provided figures which are best ignored by the searchers for ore. He also made a map of Cornwall with a mineralised belt running c. N.E. through it. This belt, whilst embracing most of the important copper, tin and lead mines of the County serves only to misguide by its simplicity, the prospector who needs to concern himself with the true and much more complicated ore-distribution patterns which occur there.

The oft repeated story of the search for mineral ground, the development of a mine, the exploitation of the ore and the eventual abandonment of the venture continued into the first forty or so years of this century and it still continues. There is always the problem of finding more ore. In the earlier part of this century the operating underground mines sought further ore by examining ground which was suggested to them by the local lode pattern and the metal distribution patterns within the lodes. This search was effected by cross-cutting, driving along lodes which had become impoverished and by deepening the mines. On occasion the work was aided by diamond drilling although then, as now, too much importance was placed on the grade of any possible ore-body which was intersected, and during any particular exercise the number of holes drilled was rarely sufficient to provide data which, looked at with the eye of experience, would provide a reasonable view of the likely importance of any mineral deposit which was intercepted. Mr. Trounson told me that not long before the closure of Tresavean Mine the core from a single exploratory drill-hole provided a rich intersection which when examined by cross-cutting proved to be only a small and isolated concentration of rich ore 'about the size of a rugby ball'! He also mentioned that on obtaining the intersection the mill capacity was increased by about 50 per cent in order to cope with the anticipated increased tonnage of ore which would have to be beneficiated when the intersected body was exploited! This misuse of diamond drilling continued after the Second World War when a single hole which was drilled north from the Robinson Section of South Crofty provided a core containing a band of tin-ore whose grade and length were both impressive. When, after considerable work, the body from which the ore in the core was opened up, and was named the No. 12 Lode, it was shown to be only a very small carbona which had developed in a granite tongue (fig. 8).

Exploration for further hard-rock ore-deposits followed, with few exceptions, which are discussed later, the already old plan of selecting an abandoned mine, which on analysis of relevant plans and reports, and sometimes hearsay, suggested that the ore occurring within the mine or within easy access of the existing workings was of such tonnage and grade that it would support a viable mining proposition. Then, as now, exploration groups were on the look out for geologically favourably located old Cost Book Company mines in which little or no crosscutting had been effected and/or which had been abandoned because of such factors as low metal prices or an excess of incoming water. During the first half of the 20th. century, not surprisingly, mines were reopened which, on being explored, sometimes over a period of several years, were shown to lack ore-deposits which would support a profitable mining operation. Some examples are Budnick Consols, Wheal Vlow, Polberro and Peevor, (See Dines, 1956, pp.448, 449, 475 and 376). Furthermore, no major mine resulted from such ventures, but some old mines which were rehabilitated, were successful over short periods, and one such example was the Basset and Grills (or Porkellis Mine) (Dines, 1956, pp.251–256). Others in this category were Wheal Reeth and the Giew Mine. I think it could be argued that these were the two most successful of the tin mines which were reopened. (See Dines, 1956, pp. 128/130 and 234/237.) During the investigations of abandoned properties diamond drilling from the surface seems to have been little used. Only two bore holes, for example, were put down during the quite extensive, but intermittent, investigations of Mount Wellington and adjacent properties during the period 1923–1941 (Dines, 1956, p. 428).

The search for ore was also effected by the sinking of shafts in what was regarded as favourable ground. Thus, in 1926 a shaft was sunk to develop the ground between the abandoned Pohigey Moor Mine and Calvadnock Mine. The new mine, known as Polhigey Mine, closed in 1930. During the time of its working it produced *"about 35 tons of 65 per cent concentrate monthly for a few months"* (Dines, 1956, p. 248).

The New Roskear Shaft was sunk in 1929 *"to prove the ground beneath the rich copper zone that had been worked in South Roskear and North Roskear Mines"* (Dines, 1956, p. 282). A number of lodes were located and limited development and stoping resulted in a little ore being sent to the mill, but the lodes were not sufficiently encouraging to attract further capital. Now the set is part of South Crofty Mine.

New Tolgus Shaft was sunk during the period 1923–1927 to develop the tin ground which was thought to occur beneath the copper deposits which had been worked in the vicinity. The shaft, 2000-feet deep, together with its associated crosscuts and diamond drill holes, failed to intersect any promising tin deposits. Dines (1956, p.296) concludes that the venture affords supporting evidence for the idea that tin deposits are limited to the emanative centres while rich copper ores may extend far beyond.

On occasion, during the period under review, underground investigations were preceeded by surface exploration. Thus, in 1938, as a result of fragments of wolfram-bearing ore being found on the dumps of Paull's Shaft of South Wheal Hawke, Great Northern Downs, and in the hedges of neighbouring fields, costean trenches were dug in what proved to be an unsuccessful attempt to locate the mother lode. In 1942 Paull's Shaft was opened and investigations were carried out underground which although resulting in the location of wolframite—and cassiterite-bearing bodies, found nothing to merit the establishment of an underground venture. However, the results of surface prospecting at Castle-an-Dinas (St. Columb) were very different. Dines (1956, p.523) records the finding of the wolfram lode there, which subsequently proved very profitable to exploit, as follows:- *"The Castle-an-Dinas wolfram lode was not known before 1915. In that year, when wolfram was in demand for war purposes, it was reported that the alluvial deposits worked in the 18th and 19th centuries in the valley skirting the north of the hill, carried both wolfram and tinstone up to a certain point although the* *tinstone continued further upstream to the east. This indicated a source of wolfram in the hill; systematic examination of the ground was done and the lode located by costeaning at points 200yds. N. and 500yds. S. of the ancient earthwork. A trial shaft sunk on the northern development commence by four adit levels."*

So, from what appears in the preceeding pages it will be seen that during the first half of the 20th century the approach to the search for hard-rock deposits was much the same as those of prospectors a few centuries earlier. During the period of the 2nd World War (1939–45) and, for the most part, in an endeavour to find readily accessible tin and tungsten ore, exploration was largely confined to the examination of likely deposits via already existing shallow shafts or by pitting and trenching and adits, the deposits often being selected on the basis of what might be termed library research. In 1942, for example, a known tungsten-bearing lode at East Calstock was re-investigated and a costean pit exposed the lode beneath 6ft. of overburden. This body contained irregularly distributed masses of ferberite in a quartz matrix. It was not exploited owing to wartime shortage of labour. (Dines, 1956, p.648.)

During the war the upper horizons of Treburland Mine were reopened and yielded about 2000 tons of ore of which, 1,600 tons of selected ore was treated at the Prince of Wales mill at Gunnislake, yielding $7\frac{1}{2}$ tons of concentrates which contained 55.38 per cent WO_3, 16.34 per cent tin metal and a small quantity of arsenic (Dines, 1956, p.586). Because of the need for home-recovered tungsten and tin were great during the war years, deposits were exploited which would not then have been had the conditions been normal. The tin/tungsten deposits of Cligga and Hemerdon fall into this category, both, after years of neglect were worked during the war period, although in both cases minor work commenced a little while before war declared; at Cligga in 1938 and at Hemerdon in 1937–8. This 'beating the gun' stems, I think, from the realisation by the parties concerned that it was likely that war was just around the corner. It is also of interest to note that the outcropping Hemerdon veins which occupy a granitic spur, were investigated by sinking three shafts, each 60ft. deep, and driving N.W. and S.S.E. from the bottoms of each, also eight pits, each 20ft. deep. Analyses of samples from these excavations and beneficiation tests indicated that at the then price of wolfram the property was not an attractive proposition. However, as a result of the urgent wartime need for tungsten, a mill capable of treating 3000 tons per day of ore was erected, but before the mill could reach full production the operation was suspended (in 1944)" *for wolfram acquired from abroad reduced the urgency for home products* .... ". (Dines, 1956, p.689.)

During this period, however, superficial deposits were not ignored. The tin/tungsten placers of the Buttern Hill area were reinvestigated, but because of the grade, limited yardage and the presence of a considerable percentage of fine cassiterite *"that is difficult to recover by gravity methods"* (Dines, 1956, p.580) the area was not developed. However the stanniferous placers of the Hayle River valley, which were investigated in the Malayan manner by means of a Banka Drill in 1942, by the London Tin Corporation, Ltd., on behalf of the Non-ferrous Minerals Development Ltd., were worked until April, 1945, by which time the tin position had improved considerably. (See Gregory, 1947.)

Perhaps largely as a result of the need to locate easily won tin and tungsten deposits, a number of papers appeared during the war years in publications dealing with mining and allied topics which provided data relating to most of the mining fields to the Southwest and pointing out mines which in the writer's view would pay to reinvestigate. Some of the mines listed could be rapidly rehabilitated whilst others would require considerable time and funds. The advertising campaign was further boosted by the actions of the Cornish Mining Development Association which was formed in 1948, and by the papers presented on its behalf by Hosking and Trounson (1959) and Trounson (1959) at a symposium arranged by the Institution of Mining and Metallurgy on *"The future of non-ferrous mining in Great Britain and Ireland"* (1959). As stated on the dust-cover of the collected papers of the meeting *"the object of the Symposium was to review the mineralised areas of Great Britain and Ireland and discuss technical and economic problems affecting their exploration and development; to make an appraisal of the potentialities of the non-ferrous mineral industry, and to point the way to its revival."*

It is necessary to point out that immediately after the end of the war, when a number of 'for the duration' mining operations were being terminated, there was briefly a thought that contraction of the mining industry might give way to expansion. This was prompted, primarily, by the reopening of the New Great Consols, in 1946. Underground exploration turned up nothing of great account and the mine closed in December 1952, having produced 170 tons of black tin and 2 tons of wolfram (Dines, 1956, p.651).

During the working of this mine its geology was investigated in some detail by Vokes and Jeffery (1954–55), two post-graduate students. They and Webb (1947) whose post-graduate researches involved considerable work at South Crofty Mine, were amongst the first of the few who began to convert Mining Companies to the belief that mining geologists had something worthwhile to offer them and that it would be in their best interests to employ one or more on a full-time basis.

Between the end of the war and the sixties there was little exploration in the Southwest other than that carried out in the operating mines and that organised by the Atomic Energy Division of the Geological Survey of Great Britain in conjunction, later, with the Atomic Energy Research Establishment, Harwell, which was aimed at the location of uranium deposits. The search for such deposits began in Cornwall in 1946, but the multi-tube Geiger-Muller counter *"did not prove sensitive enough to detect lode-type uranium deposits."* The development, by 1955, of the much more sensitive scintillation counters permitted the ground to be explored in a satisfactory manner using portable equipment, and then proved that good results could be obtained there by means of airborne radiometric surveys, and by 1957 the whole of Cornwall, much of Devon and a part of Somerset had been flown. *"Five virgin lodes were discovered........ and a belt of abnormally high radioactivity along the southern margin of the St. Austell granite was clearly delineated"* (Bowie, 1959, pp. 483–485). These explorations and subsequent work have not yet resulted in the establishment of a uranium mine, but investigations continue. According to the draft copy of the 32nd. Annual Report of the Executive Committee, for the year 1980, of the Cornish Mining Development Association, the Central Mining Finance Limited continued prospecting for uranium deposits jointly with Minatome and supported by E.E.C. funding. They used 'regional and detailed radiometrics, deep soil sampling and trenching'.

While between the end of the war and the sixties surface exploration activity by mining companies was minimal, it was, as it were, a period when the exploration forces were developing and testing new techniques and reassessing the nature of the terrain in which they were to operate in and after the sixties. One of the great aids to the establishment of exploration targets was Dines' magnum opus 'The metalliferous mining region of the South-west England' (1956). When it was published it became, as it still is, one of the major source books of the mineral explorationist.

In September, 1953, Webb introduced geochemical prospecting to the United Kingdom by means of a course on the subject in which the theoretical, field and analytical aspects were considered. As a result of this I, having attended the course, was able to include it in the Camborne School of Mines syllabus. From that time until 1968 we were able to demonstrate under what conditions geochemical prospecting could be used to advantage in this much mined region. We made a number of surveys, some of which provided data of immediate value to mining companies (fig. 11) and in other cases of value, at a later date, when they came to appraise an area which we had already investigated (fig. 12). The results of much of this work appeared in the School of Mines Magazine for the period 1959–1968 and in the D.M.T. theses for the same period which are on open file in the School of Mines Library. By and large during the period analyses, which provided the necessary data, were of the semi-quantitative colorimetric type which were devised by members of the U.S. Geological Survey and by Stanton (1966) of the Imperial College, London. The latter was a constant friend who found solutions to our analytical problems and provided us with new methods, which he had developed, before they were generally released. Since the late sixties methods of analysis (A.A.S. and X.R.F.) have tended to replace the colorimetric ones because of their greater productivity and of the wider range of elements with which they are able to deal. Now also, more refined methods are available for the analysis of the results.

Although geophysical methods of prospecting had been used elsewhere in the world long before the post-war period, their employment in the Southwest had been almost entirely neglected. I have heard that they were used at Lambriggan in, I think, the thirties, in an endeavour to locate lead/zince lodes there, and that subsequent underground work failed to confirm the results of the geophysicists.

During the fifties Bott and his colleagues (1958) did gravity and magnetic surveys in Cornwall and Devon which delineated the plan form of the granite batholith and by so doing confirmed, in essence, my earlier work. (Hosking, 1949 fig. 13). The importance of this lies in the fact that it sets limits to the area in which, in particular, primary tin and tungsten deposits are likely to be found.

In more recent years further geophysical work (see Tombs, 1977) has provided a more precise picture of the topography of the granite but, as yet, it has not been possible, by such methods, to locate the small buried cusps with which vein swarms, and possibly lodes, are so often associated.

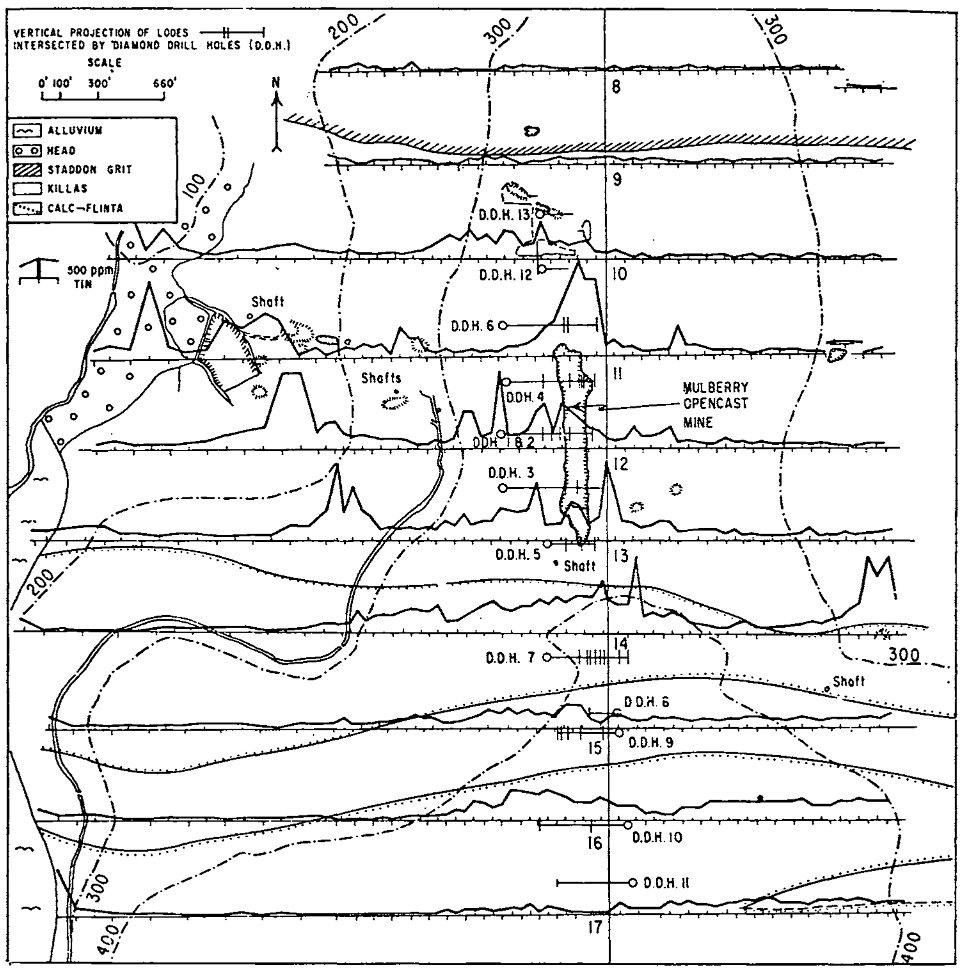


Fig. 11. Map showing the results of a geochemical exploration program in the neighbourhood of the Mulberry open-cast mine (Central Cornwall) in which the minus–80–mesh (B.S.S.) fractions of samples of soil were analyzed for tin (Hosking and Watters).

The use of ground geophysical methods has been largely neglected in the region as aids to the search for primary mineral deposits apart from radioactive ones. When they have been tried the results have generally been disappointing except when the search was for uranium-bearing ore. This is not surprising because the lodes are often narrow features, containing a spotty distribution of ore minerals which may be oxidised to considerable depths and they may be covered by a considerable blanket of overburden. In addition, the presence of overhead electric cables and buried metal pipes may complicate matters. In the early sixties an I.P. survey was done over the Pendarves area which provided nothing of value. On the other hand geochemical surveys, involving the analysis of soil samples, located the suboutcrops of lodes, as diamond drilling and subsequent underground work proved. The Pendarves experience, and others in

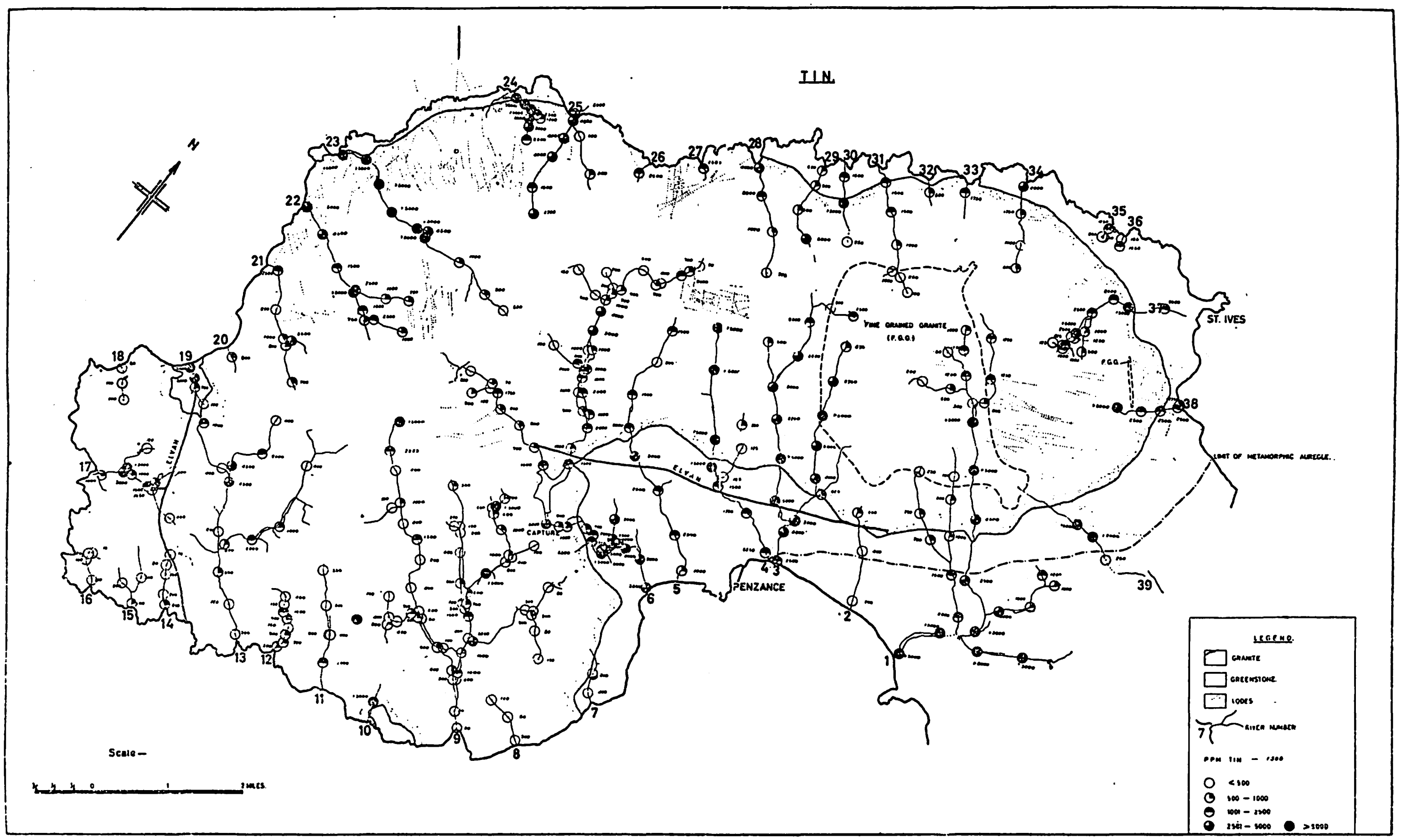


Fig. 12. Distribution of tin in the minus-80-mesh (B.S.S.) fractions of sediments from the streams of the Land's End Peninsula.

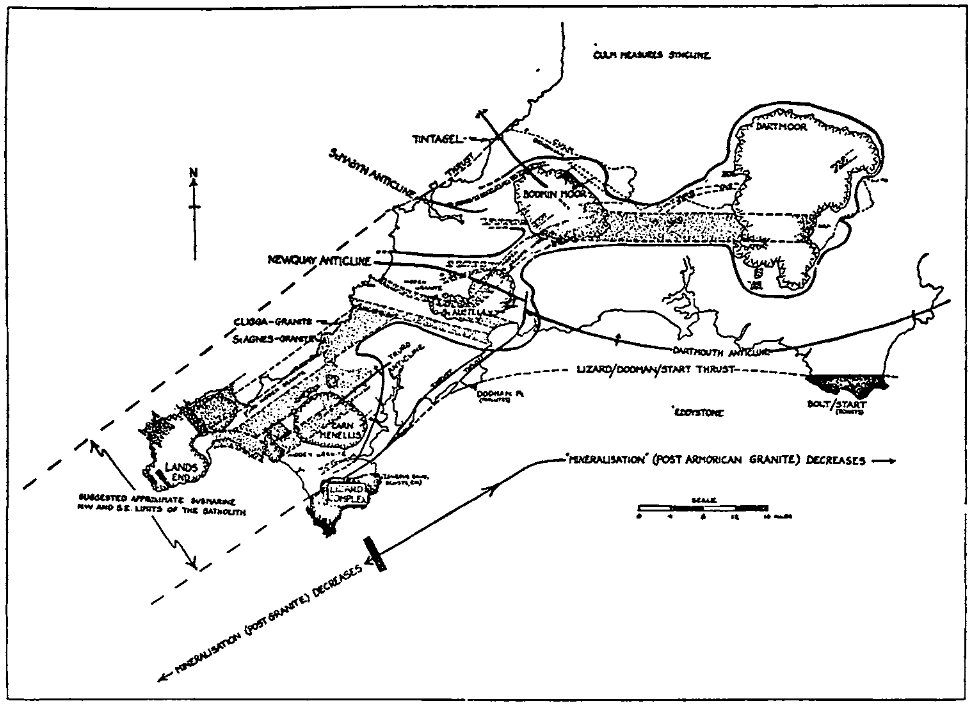


Fig. 13. Map of South-West England showing the postulated form of the batholith, the assumed positions of granite ridges, etc. (After Hosking, 1964)

Cornwall and overseas, make me increasingly certain that Fersman (1940) was not far off the mark when he wrote *"The problem of prospecting for mineral resources is in substance a geochemical problem!!."*

As far as the investigation of onshore placers is concerned I know of no instance either in Cornwall or overseas when geophysics has proved particularly useful when attempts have been made to use it to delineate the bed-rock profile to an acceptable degree of accuracy. Indeed, within my experience when the results of such surveys have been tested by drilling, etc., they have been found to be spurious. It is when offshore placers have been investigated during the past twenty-five years that geophysics has come into its own in Southeast Asia. There, Sparker and allied surveys have generally enabled the bedrock topography and the broad structure patterns of the overlying sediments to be clearly delineated; it is only when peat or similar organic beds occur in the alluvium that such surveys may yield indifferent results. Beyond doubt, such surveys should not be neglected during the investigation of submarine placers in the Southwest. Indeed, I believe that a Sparker Survey was run for this purpose off mid-Cornwall more than a decade ago.

Although thin sections of ore from the region have been examined and reported on for about a century, it was done rather sparingly until the last twenty years or so because of the time and skill needed to prepare the sections. Until comparatively recently photomicrographs, or even drawings of thin sections under the microscope, were little used in published literature, theses and company reports. This has now changed as a result of the rapid preparation of sections by mechanical means and because of the advance in photomicrography. Also, ore-microscopy involving the examination of polished sections of ore in reflected light, is now used routinely to study samples of ore and mill products. Ore-microscopy was used at the Imperial College and to a very minor extent at the Camborne School of Mines in the late twenties, but it was not used routinely until about twenty years ago when diamond dust abrasives were available and when identification of the opaque components had been greatly facilitated by the introduction of microscope attachments which enabled 'micro-hardness' and reflectivity to be measured with considerable accuracy. Now, the identification of 'difficult' species is also aided by diffractometry and the Scanning Electron Microscope.

The results of studying thin and polished sections of ore which I had collected from the Wheal Jane area provided one of the strong reasons for suggesting, first to a Canadian group and later to Goldfields, that the deposits there merited further investigation. Clearly the ore would not be easy to beneficiate but its mineralogical and textural characteristics were such as to suggest that as a result of the marked advances in beneficiation since the mines were last operating, it would not pose insuperable problems to the mineral dresser.

A few years earlier I had shown that at South Crofty Mine underground exploration could be aided by the fact that the correlation of portions of lodes separated by blocks of virgin ground could be affected, largely, by considering the nature of the cassiterite in thin section. Perhaps today similar correlations might be made elsewhere by Electron Probe when the cassiterite or other common minerals do not show obvious visual differences in thin or polished sections from lode to lode.

During the resurgence of interest in the mineral potential of the region in the past twenty years, diamong drilling has played a considerable role in the investigation of buried deposits from the surface and to investigate geochemical anomalies. It is now generally appreciated just what information diamond drilling can provide, and, in particular, it is now generally realised that the cores from a few bores that penetrated a given deposit will not provide data from which the grade of a body can be determined.

There is now some evidence that information, not readily available in the past, may be obtained by the analysis of bore-hole data by computer methods (Hosking, 1969).

Drilling of the deeper holes has been improved in recent times by the introduction of the wire-line drill (Anon., 1965). Core logging has been aided, particularly when one is searching for tin deposits, by the availability of the Portable Isotope Fluorescence Spectrometer (the P.I.F.). However, it has to be used with caution as it is essentially a surface scanner and, when tin is being determined, iron interferes. The introduction of a 'down-the-hole' P.I.F. some years ago, which was tested at the Janes Mines, has nothing to recommend it in my view, as the examination of the core and/or sludge from the bore hole can provide much more information.

For the past twenty years or so a considerable amount of work has been done and is still being done in an endeavour to locate viable hard-rock or placer deposits. Amongst the explorers have been a number of world-famous mining groups. The number of successes to date is modest, being only two, Pendarves Mine and the Janes Mines, or three if Mt. Wellington is added to the list. It may not have been entirely fortuitous, in view of the years I had worked on the Cornish mineral deposits, that it was I who introduced the Canadians to the Pendarves area, having selected it as a target because of its location with respect to neighbouring mines, hearsay, and the results of some geochemical work done there by my students and I. I also introduced the Janes/Wellington sets, first to the Canadians who were unable to get the go-ahead to work there, and then to Goldfields. My reasons for choosing this target are noted earlier.

I think other viable deposits may have been established had the exploring companies made greater use of local knowledge. There were occasions when they failed to examine good targets adequately because those in charge of the exploration programmes had not been long enough with the deposits of the Southwest to appreciate their characteristics and/or because their thinking was conditioned by earlier experiences gained by working with deposits completely different from those of the region under review.

Having made these observations it is necessary to say that the programme currently under way at Hemerdon is, in my view, by far the best of its kind ever to be mounted in the Southwest. There, the best techniques are being used and the whole operation is being run by a team of experts who have, I think, appreciated how best to solve the problems which have to be solved before a reliable pronouncement of the viability of the Hemerdon deposit can be made.

I believe it is also true to say that the programmes designed by Shell-Billiton to investigate certain stanniferous placers in the Southwest and their present implementation are far in advance of any earlier ones. This Group, like Amax, is making the maximum use of the best aids available. In particular, the quantitative and qualitative data which this Group obtains from its bores permit a far better appreciation of the potential of the investigated deposits than would be possible were the Malayan-derived traditional approaches followed. (Figs. 14, 15 and 16.)

Today the search for mineable deposits will continue to be based on library research which has been further facilitated in recent years by Hamilton Jenkin's copious writings on the less well-known mines of the region which were based to no small degree on the almost unused material contained in the files of the Mining Journal. (see, for example, Hamilton Jenkin, 1962). Also the old search methods involving pitting, trenching, driving adits, sinking prospect shafts, rehabilitating and sampling old mines, will still be employed, on occasion, and with good reason.

Now, however, there are many aids which were generally not available before the end of 1945. The most important of these, although not arranged in order of importance, are geochemical surveys, advanced structural geology techniques, instrumental methods of analysis, modern means of preparing and investigating thin

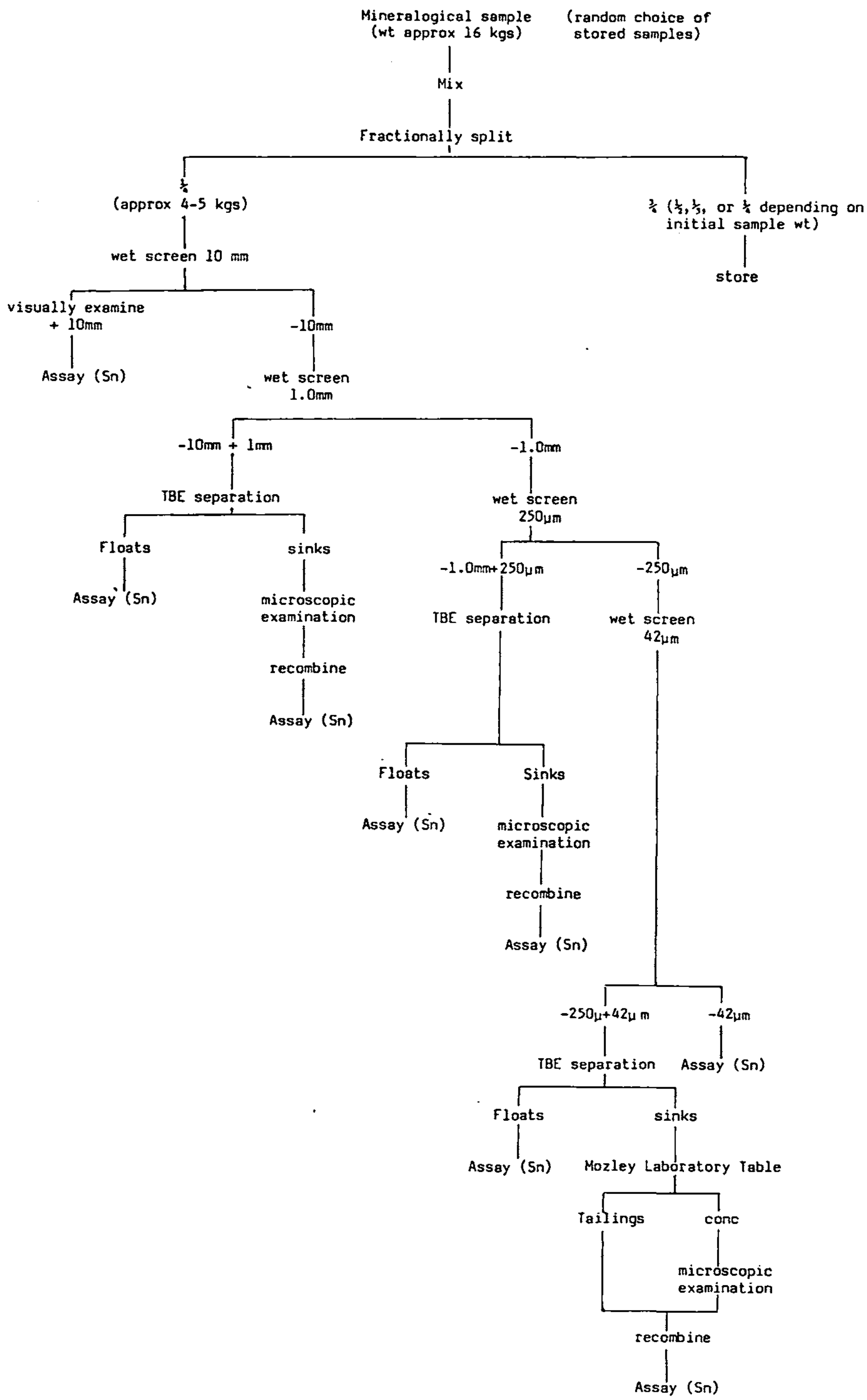


Fig. 14. Mineralogical sample flow sheet—Shell-Billiton (May, 1981) (S. Camm, Esq., Personal Communication)

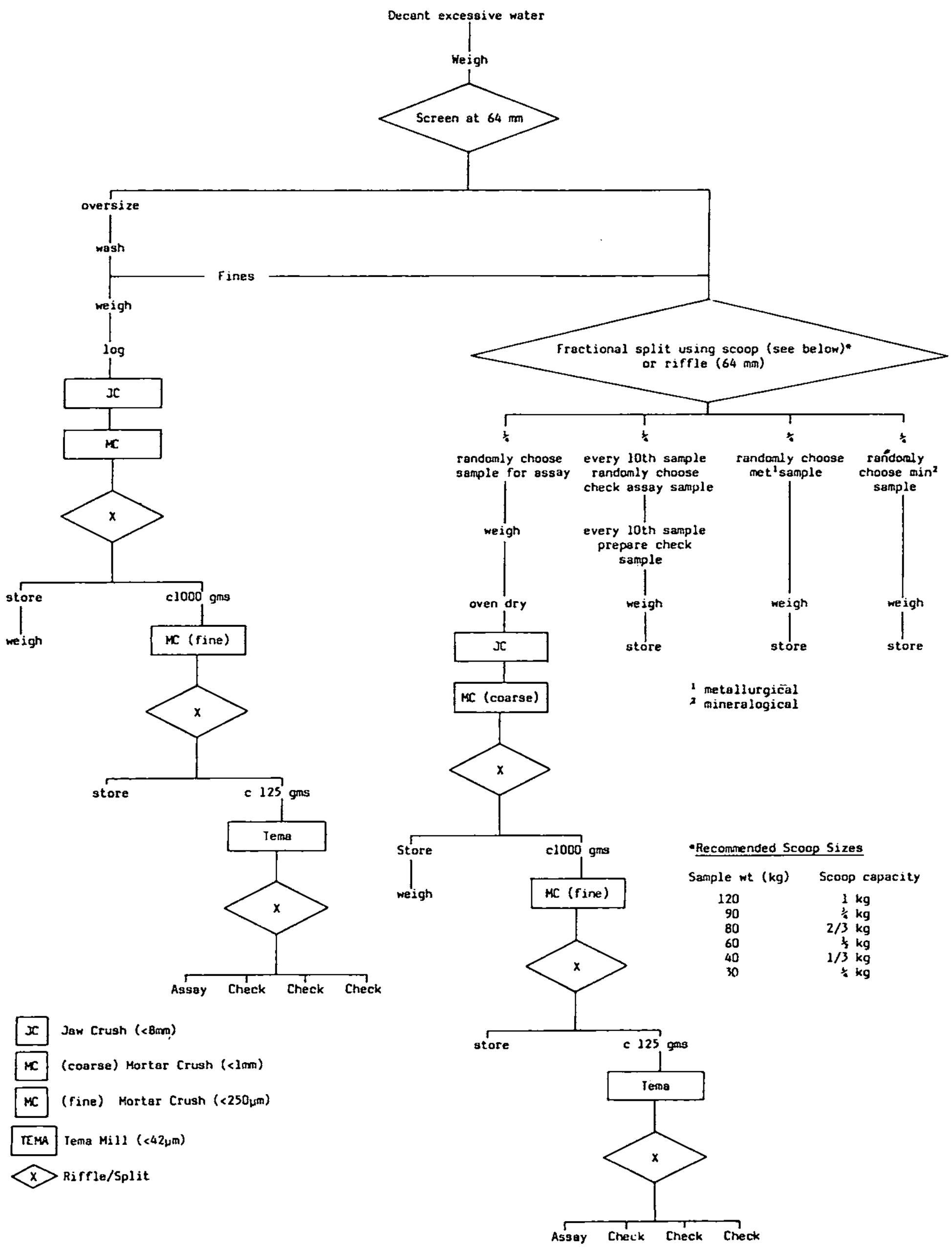


Fig. 15. Sample preparation flow sheet Shell Billiton (May, 1981) (S. Camm, Esq., Personal Communication)

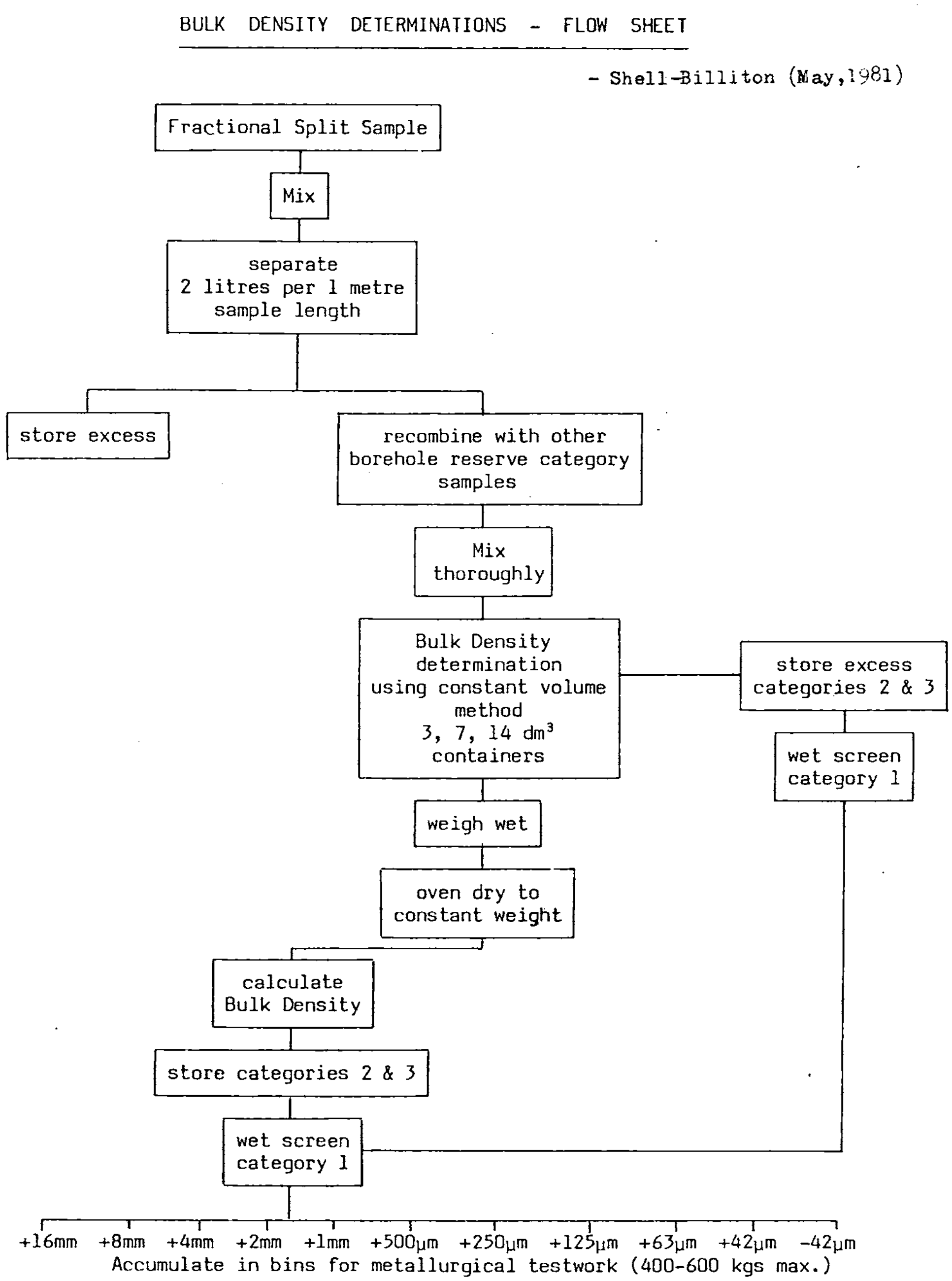


Fig. 16. Bulk density determinations—flow sheet (S. Camm, Esq., Personal Communication)

and polished sections of ore, etc., statistical approaches to the assessment of exploration data, photo-geology and satellite imagery, geophysical aids, particularly those which facilitate offshore placer exploration, the search for uranium deposits, and investigations concerning the topography of the buried granite. All these aids are presently being used.

Generally, radiometric age determinations and fluid inclusion studies may help, in the long term, by establishing more reliable temporal and spatial mineralisation models. However, if the results of the study of Bradshaw and Stoyel (1968) of the filling temperatures of inclusions in minerals collected from 185 Cornish localities are valid, then they will have provided a further valuable aid to local exploration. These workers concluded *"that a definite and fairly restricted temperature zone exists for each mineral"*: that, *"after careful sampling of a vein, the maximum filling temperature obtained is an indication of the upper limit (in terms of temperature) of the portion of the zone which is here represented,"* and that there is evidence in support of the view *"that filling temperatures in vein material can be used to determine the relationship between a particular vein and the economic zonal sequence"*.

What the Australians term *"geological technology"* may, if used in the Southwest, suggest targets for exploration in, perhaps, largely neglected areas. Geological technology is a sort of 'hotted up' comparative geology. Haynes (1979) who should be consulted for further details about this subject, writes that *"geological technology in mineral resource exploration consists of two parts. The first is the geological conceptual model or set of geological concepts which describe the geological environment of the mineral deposit or deposits of interest. ...... The other part of geological technology in mineral resource exploration is the application of the conceptual model as a target selecting device in mining exploration programmes."*

The ready accessibility of mine plans of the region and relevant reports is also a comparatively modern aid.

Finally there are those aids to exploration which stem from the original work of the officers of the Institute of Geological Science and of the teaching staffs of the universities and of the schools of mines. Until, say, the nineteen sixties one did not get, nor did one expect, much help from the then Geological Survey when one was endeavouring to investigate one aspect or another of the mineralisation of Cornwall and Devon. All this completely changed when Professor (now Sir Kingsley) Dunham, became the Director. Also until about the nineteen sixties the geological departments of the British Universities showed little interest in the Southwest. I think this lack of interest arose largely from the mistaken belief that there were few 'pure' geological problems worth investigating there, and/or that it really was not 'done' for a geologist to demean himself by investigating the mineral deposits, or indeed, by engaging in any research which had the slightest economic flavour. Happily outlooks have changed as the titles of papers published, for example, in the Transactions of the Institution of Mining and Metallurgy, will demonstrate.

One hopes that the search for viable mineral deposits currently being undertaken in Cornwall and Devon will result in some successes. It is a matter of considerable interest to not 'getting out of the groove' operations taking place in that once again deposits other than those containing tin and/or tungsten are being sought. It is also most gratifying to know that, in spite of the present bad times for the mining industry, some companies are continuing to spend money on surface and underground exploration. After all, that is what logic demands, but sometimes the lack of funds or the policy of those holding the purse strings may prevent this from happening.

Although partially unavoidable, it is most unfortunate that today, as prospecting aids and know-how increase so also do the problems which face the searchers for ore. A long time ago the prospector in Cornwall and Devon was free to seek for tin almost wherever he felt inclined to do so. Now, as I have mentioned earlier, largely to preserve the environment, this is very far from the case. In addition, the question of the ownership of mineral rights may also hold up exploration and mining to a point when would-be investors in a project abandon the idea.

What the searchers for viable mineral deposits have gained on the scientific swings has been to some considerable extent lost on the political roundabouts.

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