Geol. Soc. Malaysia, Bulletin 17, December 1984; pp. 323–356.

The stanniferous placers of Cornwall, Southwest England.

G.S. CAMM[1] and K.F.G. HOSKING[2]

"And still they gaz'd, and still the wonder grew,"
Goldsmith, "The deserted village"

SUMMARY: The widespread and numerous stanniferous placers of Cornwall have been exploited intermittently from the Bronze Age to the present.

Although a variety of placers are known, the fluviatile ones, some of which extend under the sea, are, by far, the most important. Superimposed, in part, over the wholly natural placers are others which have developed by the natural beneficiation of the mill tailings from hard-rock tin mines.

Generally the natural fluviatile placers consist of a basal layer of stanniferous sand and gravel, overlain, in the upper reaches, by peat and fluviatile sediments. In the lower reaches of the valleys the cover consists of peat and estuarine and marine sediments.

The stanniferous province of Cornwall is made up essentially of Devonian and Lower Carboniferous non-calcareous metasediments and intercalated metabasites into which was emplaced, during the Permo-Carboniferous, a polyphase granitoid batholith whose surface was ornamented by ridges with undulating crestlines. Many granitoid dykes were then emplaced and these tend to strike about parallel to the granitoid ridges. The vein swarms and hydrothermal breccias were generated in and about the high spots (cusps) on the ridges, and lodes, often zoned, and containing tin, copper, etc., were established with strikes about parallel to neighbouring ridges and dykes. Mesothermal lodes with such species as galena, siderite and sphalerite were formed later in fault structures striking approximately at right angles to the tin lodes.

Little is known about the palaeogeography of the region before the Pliocene, but there is reason to believe that parts of the granite batholith were unroofed in the Permian, and subsequently from that time there was progressive destruction of the primary tin deposits with accompanying release of cassiterite which may have been concentrated in placers, in part only to be reworked on a number of later occasions.

The destruction of the primary tin deposits occurred under a number of very different climatic conditions. From the Permian to the end of the Tertiary, hot and arid conditions prevailed. From the Palaeocene until the end of the Oligocene the climate was becoming more temperate but during the time of the Alpine Storm all but the highest parts of the region were submerged. Subsequently, in the Pliocene, or possibly a little earlier, when a temperate climate prevailed, there was emergence in stages which led to the development of a number of platforms of which on those at 229 metres and 131 metres respectively, there are the so-called mid- to high-level tin gravels. Of all the platforms developed during and after the Pliocene the 131 m one is by far the most extensive. Elevation continued in stages throughout the Pleistocene when permafrost conditions prevailed and 'Head', a periglacial solifluction and mass wasting product, some of which was tin-bearing, migrated during the warmer interglacial and interstadial times on to lower ground and into the valleys which, when

[1]Billiton (U.K.) Ltd., Exploration Division, Wheal Andrew Farmhouse, Chacewater, Truro, Cornwall, England.
[2]Camborne School of Mines, Pool, Redruth, Cornwall, England.

occupied by water, were deepened rapidly due to the rejuvenation, the drainage systems were undergoing. At the end of the Pleistocene and during the early part of the Recent (Flandrian) the climate ameliorated and the 'Head' and other debris in the valleys were subjected to marked natural beneficiation which resulted in the final stages of development of most of the placers known today. During the later phases of placer generation, cassiterite from marine sediments on the Pliocene platform were washed into the drainage systems, and, in addition, as the valleys were being deepened cassiterite was liberated from lodes transected by the streams and rivers. Subsequent changes in base sea-level resulted in the partial drowning of the valleys with the formation of rias and the forest-covered adjacent lowlands thus creating the present situation in which some of the placers lie beneath the sea.

Finally, it is abundantly clear that when endeavouring to understand the disposition, nature and genesis of the placers under review it is necessary to take into account the nature and geographic disposition of hard-rock sources of the cassiterite, the characteristic of the host-rocks, the varying climatic environments to which the region has been exposed since the primary deposits were uncovered, the variations in land and sea relationships, the history of drainage development and Man's activities. All these factors have been dealt with, at some length, in this paper which concludes with pictorial summaries of the disposition of the placers, largely with respect to the marine platforms, and of the authors' views of the genesis.

INTRODUCTION

A year or so ago Hutchison, when researching material for his book "Economic deposits and their "tectonic setting" (1983) mentioned to one of the authors that there was a paucity of satisfactory accounts of stanniferous placers. It was in part because of this observation that we thought it worthwhile to write a paper on the stanniferous placers of Cornwall (U.K.) based not only on details scattered throughout the literature but also on our own personal experience of these deposits and the results stemming from the investigation of a number of them over the past seven years. In addition, we believe it worthwhile also to publish our views, thoughts, and questions (not by any means wholly answered) concerning the genesis of the Cornish placers, if only because they serve to highlight certain problems relating to the formation of stanniferous placers generally which, hitherto, have been largely or totally ignored.

That an overview of the Cornish placers should be written is evident when it is realised that the last, by Henwood, appeared in 1873. Since that time a number of not unimportant papers, dealing with one aspect or another of the deposits, has been published [see, for example, Dines (1956); Hosking and Camm (1980) and Camm, Taylor, Hartwell and Scarborough (1981); Taylor and Beer (1981)] but no comprehensive paper has appeared. The major object of writing this paper is to fill this obvious gap in the literature, and by publishing it in Malaysia it will be readily accessible to those most likely to find it of use, namely those who are concerned with the search, etc., for stanniferous placers in the Southeast Asian Tin Province from which about 70 percent of the World's tin production, largely from placers, is derived.

PRELIMINARY OBSERVATIONS ON THE DISTRIBUTION, NATURE AND EXPLOITATION OF THE CORNISH PLACERS

Numerous stanniferous placers both autochthonous and allochthonous are known on the peninsula of Cornwall while others occur offshore (Figure 1). The majority of these bodies are rather small and with few exceptions they are covered by an overburden of modest thickness.

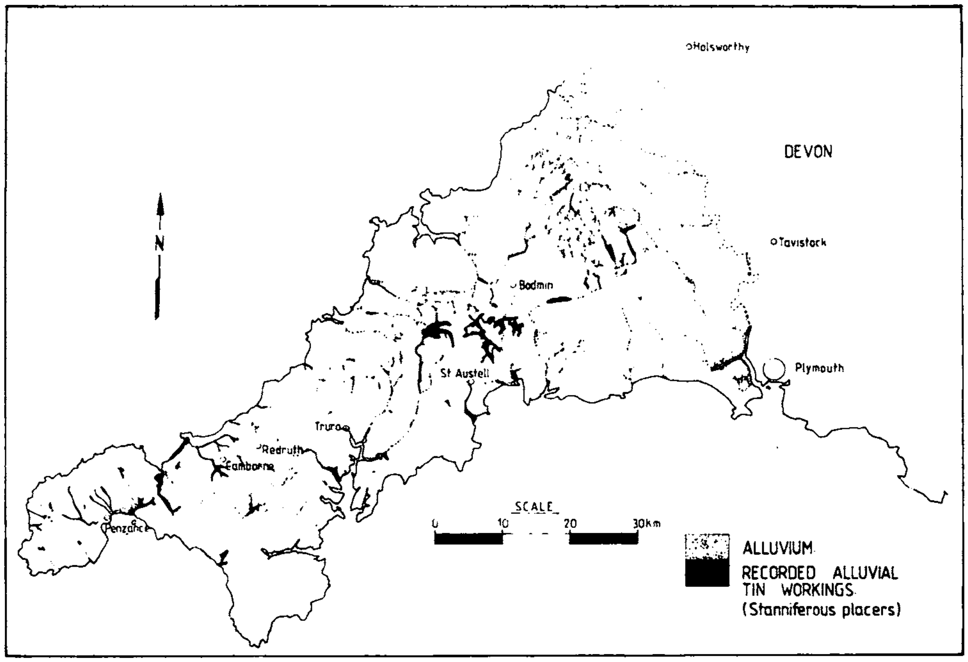


Fig. 1. Geographic locations of alluvium and alluvial tin workings.

Most of the major types of placers are observed and include residual, eluvial and colluvial bodies, but the alluvial ones, fluvial, lacustrine, estuarine, littoral and submarine types, are collectively, by far the most important from an economic point of view. The mechanisms involved in the concentration of heavy minerals to form placers is well explained by Kartashov (1971) and will not be enlarged upon in this paper. The overwhelming majority of the placers occupy basinal features on the 229 m and 131 m Tertiary marine-excavated platforms and in valley systems which transect these, and later platforms, and also extend beneath the sea.

In addition to those placers which owe their origin entirely to natural processes there are others that contain cassiterite which largely, or entirely, has been derived from the tailings of hard-rock tin mines. These tailings were usually, and still are, allowed to enter neighbouring streams, and their cassiterite, in part, concentrates in the superficial fluviatile sediments, and, in part, enters the sea where it may report as concentrates below low-water and/or on the beaches. All these placers, in which Man has played a part in their development, have been exploited, and some of them are currently being worked.

Figures 2 and 3 provide, from earlier accounts, details of some of the placers, whilst Figure 4 contains sections resulting from recent studies. Collectively these serve to demonstrate the major characteristics of some of the more important fluviatile placers of the region. From these figures it will be clear that the cassiterite is

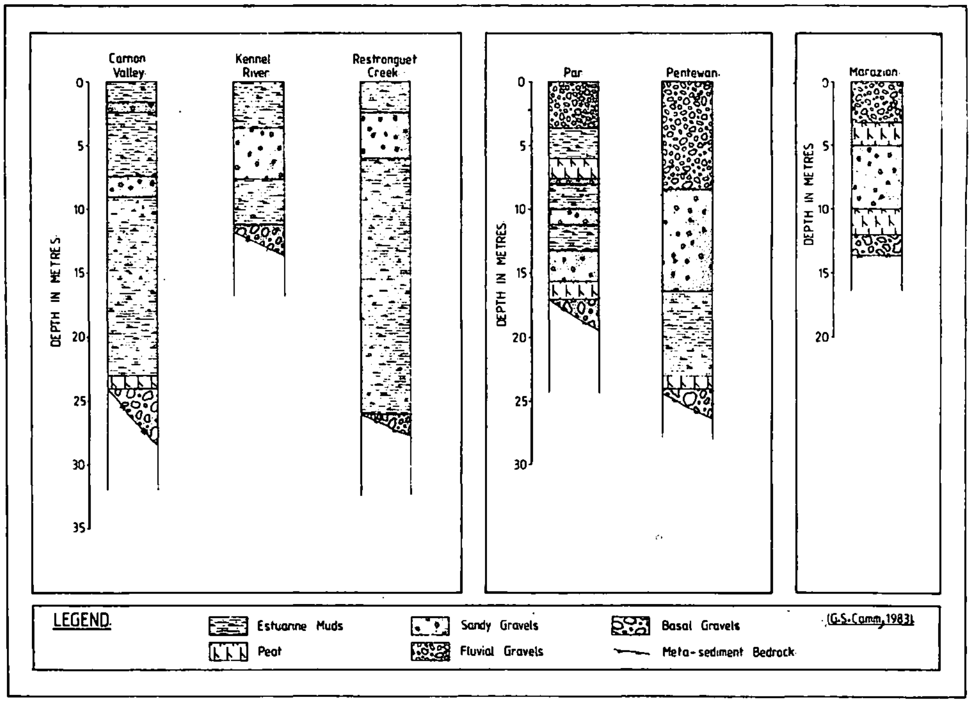


Fig. 2. Sections of some low level alluvial tin deposits. After Dines (1956), Henwood (1874), and Robson (1944).

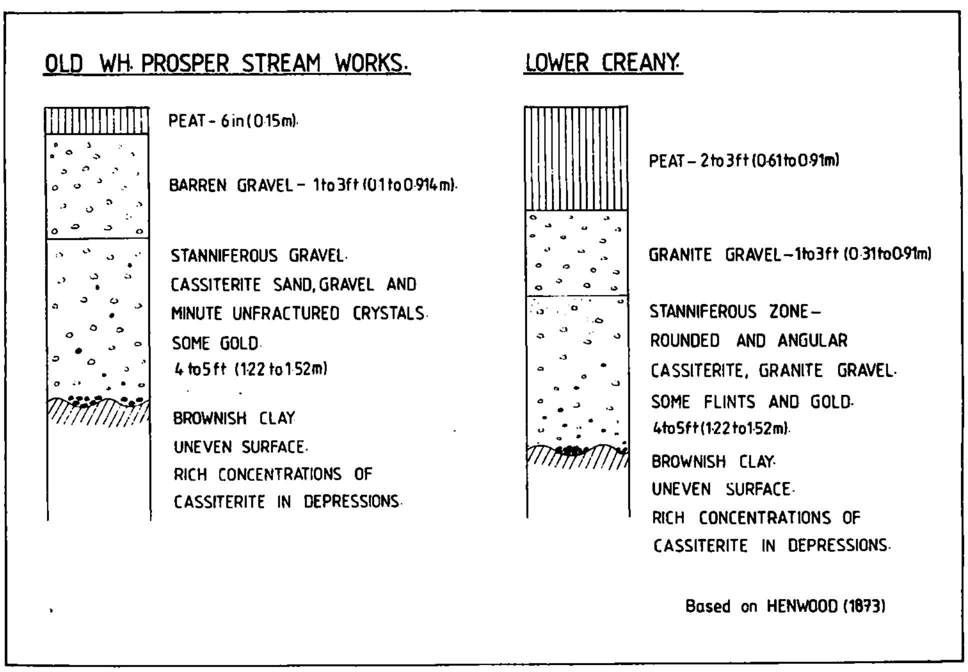


Fig. 3. Redmoor Sn Placers (St. Austell district).

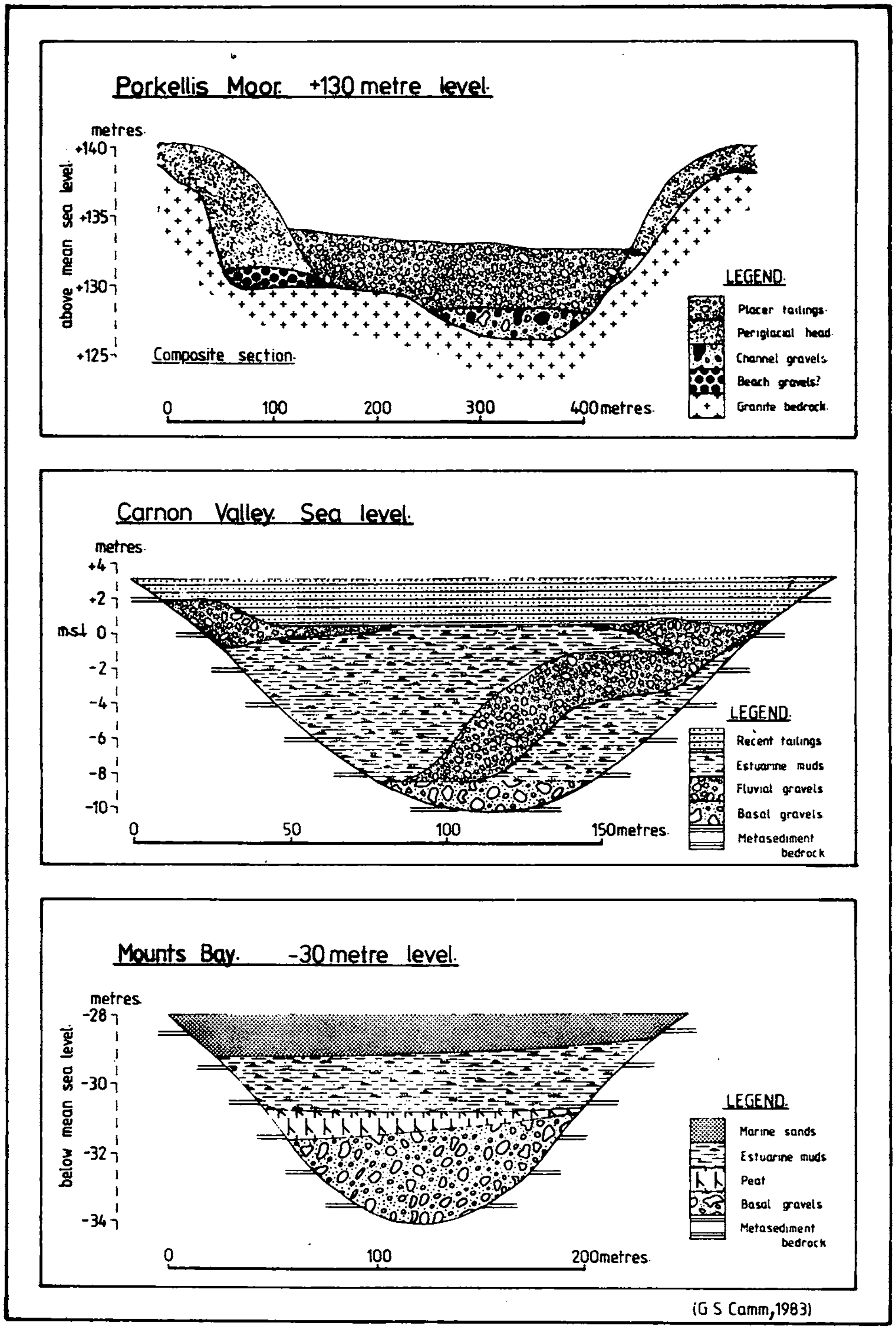


Fig. 4. Sections of some placers.

concentrated essentially in the basal sections and that peat often occurs somewhere in the section above the basal gravels. The peat is of two-fold interest in that authigenic pyrite and marcasite developed in it which, on occasion, found their way by the help of natural agents and/or Man into the basal stanniferous sections, and because pollen analysis of peat samples has provided ages of c. 8,000 years B.P., suggesting that the underlying tin-rich sediments are probably of late-Devensian to early-Boreal age. Barren of weakly stanniferous fluviatile sediments occur in the placers occupying the higher reaches of the valley systems whilst in the lower reaches estuarine and marine sediments, occasionally weakly stanniferous, may also be present. In addition, in some of the valley systems, 'Head', a periglacial solifluction product, occurs also, and was probably often an important transporting medium for the cassiterite into the valley systems.

The mineralogy of the basal stanniferous sections of the placers has not been studied in sufficient detail for it to be dealt with in anything approaching a comprehensive manner. It is appropriate to note at this stage that cassiterite is the only mineral of significiant economic importance occurring in the basal sections of the alluvials, although a little gold, and some wolframite, have been recovered from a number of them. The extent to which the cassisterite occurs as liberated grains depends essentially on the nature of the primary parent and on the distance from the parent source. Near primary deposits cassiterite may occur in all the size fractions from cobbles to, say, silt. The size of liberated cassiterite crystals depends on the primary source, and the largest of those from greisen-bordered veins, for example, are with extremely rare exceptions, considerably larger than any from the lodes proper. The colour of the cassiterite is also subject to considerable variation and, on occasion, this may suggest the nature of its primary source. Thus, the crimson cassiterite grains of the Breney Common/Redmoor placers, in the northeast of the St. Austell granite area, match the cassiterite of hydrothermal breccia deposits a few miles away near the western margin of the granitic area.

Associated with the cassiterite in the basal gravels are usually cobbles, etc., of the country rocks which are essentially granitoids and non-calcareous metapelites, and grains of resistate species which include the white micas, tourmaline, quartz, rutile, anatase and garnet. Pyrite (framboids and discrete crystals) and marcasite (spherulites, etc.) are sometimes present. Digenite investing framboids has been observed and, as noted above, wolframite and gold occasionally occur.

In the placer deposits derived from tailings a variety of minerals, some of which are unstable in an oxidising environment, occur, and include such species as chalcopyrite and arsenopyrite. Past working of some fluviatile placers has locally resulted in the admixing of mine tailings components, with those of the natural placers, and, in addition, it sometimes exposes authigenic pyrites and marcasite to an oxidising regime so that they converted to pseudomorphs of iron oxide [Hosking and Camm (1980)].

The Cornish placers have been exploited from the Bronze Age until the present time, and the ways which they have been worked (by panning, gravel-pump operations, dredging, etc.) are summarised in Figure 5.

A. <u>VERY EARLY EXPLOITATION OF READILY ACCESSIBLE PLACERS</u>

1. PANNING - the earliest method used, say 2000 years ago.

B. <u>EXPLOITATION OF LITTORAL (MODERN) PLACERS</u>

1. COLLECTION, BY HAND, OF SN/W-BEARING COBBLES, ETC., Blasting boulders to obtain cass./wolframite. Transportation. by hand, in sack, to simple 'mill' at home. (e.g. Cligga Beach)

2. SKIMMING 'BLACK SANDS' WITH CORNISH SHOVEL FROM BEACHES AFTER STORMS. Transportation to mill by carts. Beneficiation by tin-streamer's plant. (e.g., Gwithian. Early 20th century).

3. MECHANICAL DIGGING OF BEACH SAND (by scrapers etc.) Transportation, in part, by overhead system (e.g. Gwithian/Upton Towans, c 1930). Beneficiation by gravity methods. Tabling, etc.

4. SAND COLLECTION AND TREATMENT OF BEACH IN SLUICE BOXES (e.g., Perranporth and Trevaunance, St. Agnes. 20th Century).

C. <u>EXPLOITATION OF OFFSHORE (MODERN) PLACERS</u>

1. SUCTION DREDGE. Humphrey spiral concentration on dredge. Further concentration in land-based mill. 1960's. (e.g., St. Ives Bay: mill at Hayle.)

D. <u>EXPLOITATION OF ESTUARINE PLACERS ('NATURAL')</u>

1. UNDERGROUND (e.g. Carnon Valley. 19th Century.)

E. <u>EXPLOITATION OF HIGH LEVEL PLACERS ('NATURAL')</u>

1. HAND-EXCAVATED FEED TO SLUICE-BOX (e.g., Redmoor. Early 20th Century.)

2. GRAVEL PUMP FEED TO SLUICE-BOX (e.g. Redmoor. 20th Century.)

3. MECHANICAL DIGGER, FEED TO JIG PLANT. (e.g. Altarnum District cass/wolframite by-product in plant making concrete blocks).

4. SMALL BUCKET DREDGE. (e.g. Goss Moor. 20th Century.)

F. <u>EXPLOITATION OF LOW LEVEL VALLEY PLACERS - 'NATURAL' AND 'MODERN'</u>

Long history of exploitation of natural placers.
Excavation by manual (early) and mechanical (later) methods.
Beneficiation varied. Simple gravity methods (sluices, etc.)
Tin streamer's gravity plant (buddles, etc.).
Modern gravity plant +/- flotation of cassiterite (in some instances, as part of mill of hard-rock mine (e.g., South Crofty)).

Fig. 5. Methods of exploiting Sn placers that have been employed in Cornwall

The importance of the placers waned, in part, as the most readily accessible and often the richest parts were worked out. However, their popularity also diminished as the hard-rock underground tin mines expanded as a result of the marked advances in mining methods and the change from copper to tin lodes as the mines became deeper. Nonetheless, the exploitation of the natural placers has continued in an erratic way up to the present, although, with very rare exceptions, the profits must have been very modest. Placers derived from tailings have a long history of exploitation. One supposes that generally these operations have proved to be profitable ones and in the past they have made very significant contributions to Cornwall's output of tin. Thus, for example, Thomas (1913, p. 57) records that in 1890 the fifteen mines operating in the Camborne-Redruth district sold 7,131 tons of tin concentrate for £386,029, while streamers recovering cassiterite from the tailings of these mines in the Red and Portreath rivers sold, during the same period, 1,730 tones of concentrate for £69, 208.

That major tin-mining companies have largely neglected the Cornish placers until the last few years has resulted largely from the fact that it was generally assumed that all the onshore placers were known and the more extensive of these had been worked and reworked over a period of many centuries so that they were unlikely to have any real potential. Indeed as recently as 1956 Dines (1956, p.19) aired this view when he wrote *"the alluvial deposits of the region were not of high grade, the tin content of the 'pay-dirt' being usually much less than that of the poorest of the worked lodes. This combined with the sporadic and irregular occurrence, characteristic of alluvials, renders any that may remain unprofitable for exploration today, except, perhaps in a small way. Alluvial tinstone is however, freer from objectionable gangue minerals than that of the lode ores."*

In spite of the jaundiced view of many, which the remarks of Dines, quoted above, convey, during the past seven or so years mining companies have shown an interest in the Cornish onshore and offshore placers. This stems, in part, from the greatly increased value of tin in recent years, but perhaps, more particularly, because, from the viewpoint of the Western European countries, for strategic reasons, it is important to obtain most of the metal or concentrate needed from indigenous or nearby sources. This recent interest has resulted in the investigation of both onshore and offshore placers in which both well-tried and innovative techniques have been employed.

In that which follows it is proposed to deal first with an outline of geological events leading up to and responsible for the development of the stanniferous placers, and then with the present geomorphological character of the region in which the placers occur. These will be followed by an examination of some of the factors responsible for the development and distribution of the placers and, finally, a summary of the genesis of the placers of Cornwall will be presented.

AN OUTLINE OF THE GEOLOGICAL EVENTS LEADING UP TO AND RESPONSIBLE FOR THE DEVELOPMENT OF THE CORNISH STANNIFEROUS PLACERS. (FIGURE 6.)

Ignoring the southern peninsulas of the Lizard, Bolt, and Start, which are marginal to the Tin Province, Cornwall consists essentially of Devonian and Lower

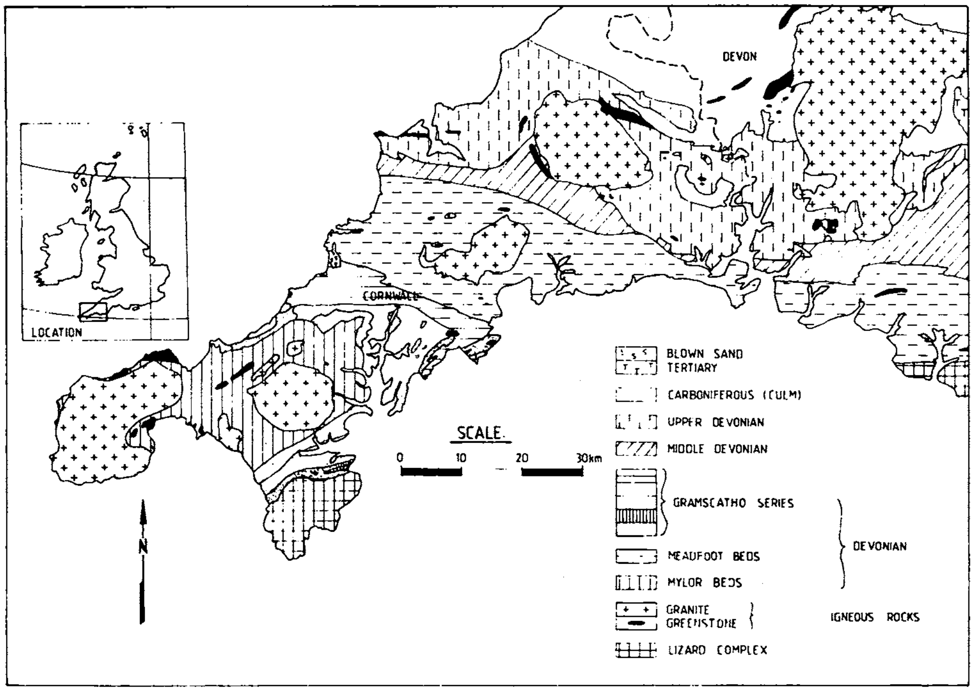


Fig. 6. General geology of south-west England.

Carboniferous much-deformed and largely non-calcareous metasediments and intercalated metabasites. This unit was subjected to a magma invasion in Permo-Carboniferous times which resulted in the generation of a composite highlevel, granitoid batholith with a marked topography occasioned by the presence of well-defined ridges with undulating crest lines. Generally this event was followed by the establishment of minor apatitie and pegmatitic bodies and by many granitoid dykes which may well have been the feeder channels of acid volcanics which have since been removed. Then there was a period of mineralisation during which tin and sometimes other metals were concentrated in economically interesting amounts in a variety of deposits. The earliest of these were vein swarms and hydrothermal breccias spatially associated with granitoid high-spots (cusps). These were followed by the major hydrothermal tin, etc., lodes which generally trend approximately parallel to the long axes of spatially closely associated granitoid ridges and dykes and not uncommonly flank earlier cusp-associated tin deposits. The various type of primary tin deposit found in the region are shown in Figure 7, and further details concerning primary mineralisation of the region generally are to be found in Dines (1956), Hosking (1970) and Jackson (1979). Sometime after the formation of the tin-bearing lodes referred to above, perhaps mainly during Tertiary times, lodes were developed with mesothermal mineral assemblages (galena, sphalerite, siderite, etc.) which generally strike at about right angles to the tin lodes and sometimes intersect and fault the latter. Also present are largely dextral wrench faults whose trends broadly coincide with the mesothermal

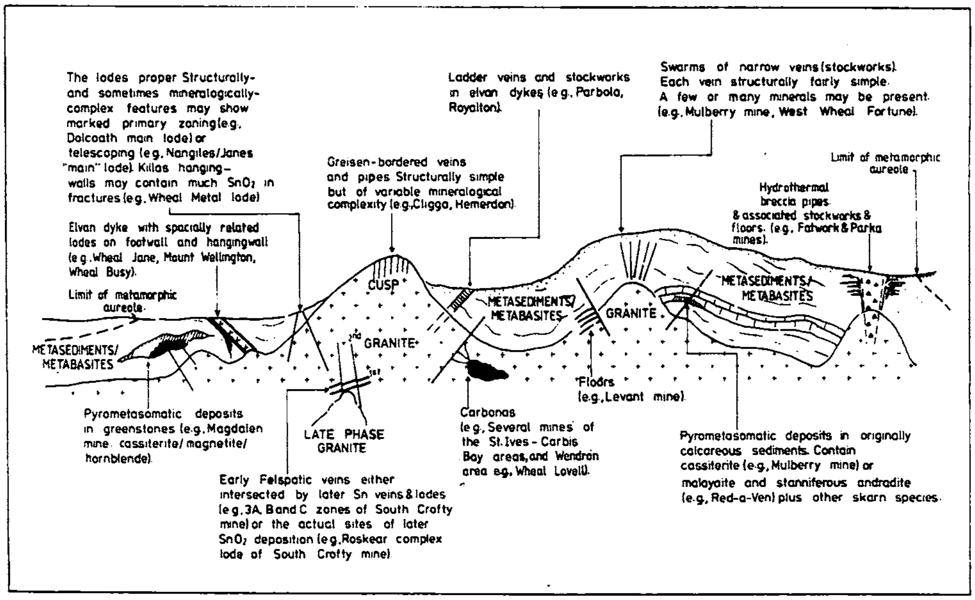


Fig. 7. Major types of primary tin deposits in the south west of England (After K.F.G. Hosking, 1969).

lodes and which are regarded by some as having been initiated during the Alpine Storm. Some of these faults appear to displace the tin lodes and maybe of the age suggested above, but there is little doubt that others pre-date the tin lodes and played an important role in the development of the latter.

There is some evidence in support of the veiw that locally the granite was uncovered early in the Permian and since that time only a modest thickness has been removed (Hawkes, 1974, p. 1136). If this is so then some of the primary tin deposits must have been exposed to sub-aerial agents soon after (geologically speaking) they were developed. Certainly during most of the Mesozoic Era, and perhaps during its entirety, Cornwall was land and subjected to arid-climate conditions. It is possible that during the Cretaceous a limited marine transgression took place, but if this were so then the only direct evidence for this at present is the occurrence in some 'late' superficial deposits, including some of the stanniferous placers (see Figure 3) of flints, which in some locations, might have been left more-or-less in situ after the chalk, in which they originally occurred, had been completely removed. However, the common occurrence of flints in some of the present beaches give some reason for thinking that they may have been derived from Palaeocene or Eocene flint-rich deposits lying beyond the present shoreline. There are, however, no deposits of these ages known in Cornwall, the nearest being at Haldon, Devon. It is also possible that some of the flints found in the superficial platform deposits may have been brought in by early man for the making of implements. Furthermore, in the mining areas flints were used in ball mills. It should be noted, therefore, that in Cornwall flints provide pitfalls for the unwary.

The geological history of Cornwall from the beginning of the Palaeocene to the beginning of the Pliocene is almost blank as there are no known deposits of this period, other than the St. Agnes beds of probable Oligocene age, in the County. In the adjacent county of Devon, the lacustrine deposits of Bovey Tracey and Petrockstowe, which are of Mid- or Upper-Eocene to Mid-Oligocene age, derived some of their components from the west where the granite was locally unroofed, and these, together with the plant material of the deposits, suggest that the sub-tropical climate of the Eocene when, according to Edwards and Freshney (1983, p. 233) deep lateritic weathering profiles developed, persisted during the Oligocene in the Southwest of England. During the Oligocene Cornwall was land and probably more extensive than at present, however, *"no conclusions can be drawn as to how Cornwall looked then"* (Robson, 1943–44, p. 135). Doubtless the progressive destruction of some of the primary tin deposits which started, probably in the Permian, continued up to and during the Oligocene, and the released cassiterite was concentrated locally in some of the drainage systems while some of it was transported to the bordering seas. Of the Oligocene fluviatile placers the one at St. Agnes is the only known Cornish example.

Probably in consequence of a marked disturbance occasioned by the Alpine Storm a very considerable fluctuation of land-level took place during the Miocene. This resulted initially in the submergence of most of the peninsula, to be followed by the emergence of the land in stages when, during stillstands, several marine platforms were cut. Relative sea-level changes continued into Recent times. Of the numerous platforms recognised in the Southwest of England those which are above 229 m (O.D.) are now generally thought to be due to subaerial weathering. The main one in this category, the so-called 305 m platform, which is, for example, representative of most of the surface of the Bodmin Moor granite, may be of Oligocene age, although the lack of signs of warping suggests that it may post-date the Alpine orogeny and be of late Miocene age (Edmonds, *et al.*, 1969, p. 78).

During the Miocene, according to Edmonds, *et al.* (1969, p. 78), a pause in the emergence of the land permitted the cutting of a marine platform that was subseqently raised above sea-level and now stands at c. 229 m. Remnants of this now stream-intersected platform are to be seen, for example, on the Carnmenellis and St. Austell granitic masses and at Withey Brook on the Bodmin Moor granite. The last mentioned locality is of particular interest in that recently placer tin deposits have been examined there, and it is at the highest level at which such deposits are known to occur in Cornwall. Robson (1943–44, p. 136) remarks that *"most of the deeper valleys are occupied by streams which have cut their present channels since the initiation of this uplift (outstanding examples are the ...... Camel, Luxulyan, Fowey .....). The development of gorges and falls, where the streams leave the platform, is frequent, e.g., ... De Lank, below which the stream forms a broad alluvial flat."*

Considerable uncertainty exists as to how many marine platforms are present which post-date the 229 m one. This is due to the common difficulty of correlating one fragment of a given sloping platform with another fragment of it. Robson, for example, (1943–44, p. 136) was well-aware of this. When discussing the question of the possible presence of a 183 m platform he mentions that whilst platform remnants at 183 m O.D. are to be found in the Land's End and Carnmenellis areas *"they may be lower portions of the shelf whose line was near 750 ft (229m) and which sloped down to the next definite cliff-foot at 400 ft (122 m)"*.

A prolonged stillstand during the emergence of the land in the Pliocene allowed the largest of the marine platforms in Cornwall to be established. Its degraded cliff-line is now c. 131 m O.D. This platform slopes seawards and is terminated by the present cliffs which have an average height of c. 91.5 m. The sea excavated this platform in all types of rock and only rarely is its cliff-line coincident with the granite/metasediment contact. To the north of Carn Brea, for example, there is no change in slope as one walks south along the platform over the metasediment/granite contact towards the remnants of the granite cliff. This platform is best seen in West Cornwall, particularly in the Cambrone/Redruth and St. Agnes areas, whilst perhaps the best inland extensions of the platform are at Goss Moor and the 'plateau' above the Luxulyan Valley at Criggan Moor.

A few small superficial deposits are scattered over the platform which are unrelated to the present drainage and so must pre-date the time when the 131m platform was uplifted. These occur at Polcrebo, Trenhale, Trebarwith, Crousa Common, St. Agnes, St. Erth and Pendarves (near Camborne). All but the St. Erth and St. Agnes beds are thought to be of Pliocene age. Estimates of the age of the St. Erth Beds have varied from Eocene (Milner, 1922) to Pleistocene (Mitchell, 1966), whilst palynological evidence indicates age *"must now be considered to be basal remnants of a late-Oligocene continental, mainly fluviatile deposit of yet unknown extent"* (Atkinson, Boulter, et al., 1975).

Of the deposits mentioned above, those at Polcrebo, Crousa Common and St. Agnes contain a little cassiterite. At Plocrebo a patch of 'gravel' occupies a granite 'bay' and consists of pebbles and boulders of vein quartz and a few angular pieces of granite and tin-stone, the whole embedded in clay. The larger masses of barren rock and the tin-stone occupy the base of this small deposit. Possibly it is a high-water littoral placer.

At Crousa Common a deposit, from c. 1.8 to 3.6 m thick, rests on gabbro. It consists, essentially, of quartz gravel and sand, plus a little tin-stone, all in a matrix of clay. As this deposit, like that at Polcrebo, is composed of coarse, unsorted and unstratified material it is probably also a littoral deposit of material which has been derived from the north.

At St. Agnes the stratified superficial deposit varies considerably in thickness but is locally as much as 9 m. The deposit consists essentially of 'head' (a Pleistocene periglacial solifluction product) followed, in depth, by bluish-grey plastic clay, moulding sands of various colours and a basal cobble layer resting on metasedimentary or granitic bedrock. A little tin-stone is found in the basal cobble deposit.

On the 131 m platform there are also a number of stanniferous placers of considerable economic interest but they are all fluviatile in character and associated with river systems which, in essence, developed, as noted earlier, after the elevation of this platform. Collectively the placers on the 131 m platform and the 229m one, are termed, in the earlier literature, high-level (stanniferous) gravels. Economically, the most important ones, all of which have been exploited, on the 131 m platform, are on the Goss Moor, Criggan Moor and Redmoor/Breney Common (both associated with the St. Austell granite) and Porkellis Moor (on the Carnmenellis granite).

Emergence of the land in stages continued up to and throughout the Pleistocene with the concomitant lengthening of consequent streams across the emerging platforms and their attendant rejuvenation. During this time an uncertain number of minor platforms were excavated and on some of these Pleistocene and later deposits are to be found. Robson (1943–44, p. 144) notes that there is evidence for a 55 m platform between St. Ives and Cape Cornwall and elsewhere in West Cornwall, and for a 30.5 m platform near Marazion. The highest definite raised beach (i.e. beach deposits on a raised marine platform) is best observed at Penlee Quarry, Mousehole. There is a raised beach, or possibly a group of them (Edmonds et al., 1969, p. 80) lie at c. 15 to 18 m. However, the most widespread and youngest group of raised platforms, which is usually covered by beach deposits, occurs between c. 1.5 and 7.5 m O.D. In the older literature these raised beaches were regarded as one and termed the 10ft (c. 3 m) beach (see, for example, Robson, 1943–44, p. 144).

Relative sea-level changes continued after the establishment of the 3m beach. This has been established, in part, by recent offshore exploration for placer tin in submerged valleys whose bases are locally as much as 30 m below present mean sea-level. However, the time of development of some of the emergent features of the sea floor around the coast is still uncertain. Cullingford (1982, p. 275) records that Devon and Stride (1975) claim, on the basis of detailed Admiralty surveys, that three degraded cliffs occur around Cornwall and Devon with bases at −38 m to −49 m, −48 m to −59 m and −58 m to −69 m O.D. respectively, to which Wood (1976) added platforms at −18 m and −26 m O.D. These workers ascribed a late-Tertiary age rather than a Quaternary one to these features. Whatever the ages of these features the age of the tin deposits of the submerged river valleys is probably Late Devensian to Early Boreal.

The 'emergence' of the Southwest during the Pleistocene was doubtless due, in part, to the removal of water from the sea and its deposition on the land to the north as ice, together with isostatic adjustment which such a loading would demand.

During the Pleistocene ice-sheets covered most of the British Isles, only the land approximately south of a line between Bristol and London largely remaining free of them. However, on one occasion, probably during the Wolstonian stage of the Upper Pleistocene, the northern coast of Devon was generally close to the southern edge of the ice-sheet and locally in contact with it (Cullingford, 1982, p. 251). Throughout the Pleistocene Cornwall was subject to a number of cold phases which alternated with ones when the climate was temperate. Finally, following the cold Devensian stage of the Upper Pleistocene, at c. 10,000 years BP, in the opening stage, the Flandrian, of the Holocene, the climate ameliorated and continued to improve until it reached its present state.

During the colder phases of the Pleistocene Cornwall was subject to permafrost conditions. Then, as a result of nivation, bowl-shaped valley heads and hollows were created and valleys were enlarged and overdeepened. Then, also, the higher exposed rock masses, in particular, were subject to frost-shattering and riving (gelifraction), and most markedly during the warmer phases and, especially during the Flandrin, the resulting debris was transported down slope, largely by solifluction or mass wasting. This transported product of solifluction known as 'head', or 'head of rubble', was, as noted earlier, locally an important transporting medium of cassiterite and, we believe, often a major intermediate source of cassiterite which was concentrated in the fluviatile placers, particularly during the Flandrian stage. It has been observed that the cassiterite fraction from samples taken from placers up to 5 km or more from the parent source has a high content of angular to subangular grains suggesting that for part of its transport solifluction was the major carrier, the cassiterite was protected by clay from attrition by saltation in running water.

The 'head" consists, in essence, of angular pieces of rock, of a wide range of sizes, embedded in a brown clayey matrix. Deposits of it vary in thickness from c. 3m to c. 30m. It is not bedded and 'merges into subsoil rudely stratified at times and sandy in parts (Robson, 1943–44, p. 149). It usually occurs as a single sheet, but occasionally, as, for example, at Trebetherick, separate deposits of head are interbedded with sand and boulder beds, and perhaps there was a local transgression of the sea during the period of head accumulation. The head does show textural variations from one exposure to another and those displayed by a given exposure have been interpreted in more than one way. The interpretation by Cullingford (1982, p. 269) of the variations seen in the head exposed at Middleborough, in Croyde Bay (Devon) is based, in the authors' views, on valid concepts which should form the basis of interpretation of the textural features displayed by the Cornish head. At Middleborough the head consists of a layer of coarse, angular slate fragments underlain and overlain by finer material consisting of smaller slate fragments in a sandy matrix. Such variations, according to Cullingford, *"can readily be explained in terms of one cold phase (the Devensian) during the onset of which the downslope transfer was mainly of previously weathered material, this being followed by a period when the stripped rock faces, exposed to severe frost action, yielded abundant gelifracts (shattered frost fragments), after which there was renewed transfer of finer material when the climate had ameliorated sufficiently for frost-riving of bedrock to give way in importance to chemical weathering and the comminution of existing rock fragments."*

The head is widely distributed in the West of the County and the best exposures occur along the coast where it may completely fill valleys and commonly, also, rests on the c. 3m raised beach, as, for example, at Godrevy. Inland it may also be preserved in protected V-shaped stream channels for heights up to 152 m O.D. The east of the County is relatively free from head except between Bodmin and Lanreath, at a height of 122 m O.D. This general paucity of head in this part of the region is, in Robson's view (1943–44, p. 149) due to the material being swept down by post-glacial torrents from the higher ground to hollows and valleys near the coast.

It is appropriate to return here to examine in greater detail certain Late Pleistocene/Early Holocene events. At the beginning of the Flandrian stage of the

Holocene (Recent), at c 10,000 years B.P., there was, as noted earlier, a period of rapid warming, which led to today's climate. Just before this time, according to palynological evidence from the Bodmin Moor (Brown, 1977), at about 11,069 +/− 200 BP, i.e., at the end of the Late glacial Interstadial, a marked deterioration of the climate resulted in the destruction of the birch cover and gave rise to solifluction of upland soils and grass sedge mires (Cullingford, 1982, p 281). This was during the last cold phase of the Devensian. In the early Flandrian (c. 10,000 BP), as a result of the amelioration of the climate, the hillsides became covered first with Empetrum and juniper and later with hazel and oak, while willows and birches occupied the valleys.

The improvement in the climate leading to a general thaw and increased rainfall, allowed, during the initial stages, considerable quantities of superficial material on the hillslopes to be transported by sheet-wash, etc., into the neighbouring drainage systems.

Robson (1943–44, p. 151) suggested that whilst there is the possibility that some or all of the stanniferous placers occurring, as at Goss Moor, on the 131 m platform, may have resulted from the accumulation of cassisterite carried by streams during the Pliocene into estuaries, as they are associated with the present drainage system, it is more likely, in his view, that essentially they are alluvial flats or fans deposited where the melt water and run off from the high ground spread over the Pliocene platform in Recent times. One cannot believe that cassiterite was not transported by Pleistocene and earlier streams and deposited in lower reaches including estuaries and even seas. Very little is known as to what extent such deposits contributed to the presently known placers. However, cassiterite grains examined from the Goss Moor, at an elevation of 131 m, below 'head' material, exhibit marked rounding and chatter markings indicative of possible marine action (Camm; unpublished studies), this may represent a relic Pliocene marine placer. Furthermore, possible relic beach gravels below a degraded cliff line at Porkellis Moor have been discovered during recent alluvial exploration. It is intriguing to note that samples of placer cassiterite collected during the last century and to be seen in local museums have a high content of components exhibiting strong sphericity. Samples from recent investigations show that cassiterite transported a great distance from the parent source has a low sphericity content. It is possible that the historic samples were mainly from the more readily exploited platform deposits and hence may have a Pliocene origin.

Beyond doubt, when, in the Flandrian, the more-or-less temperate climate allowed a good cover of vegetation to be established, mass transfer of rock debris down slope was effectively stopped. From then on, the river systems, provided with ample supplies of water, continued the programme of rejuvenation dictated by the 'recent' 'uplift' of the land. This was accompanied by natural fluviatile beneficiation processes involving reworking the head and earlier stanniferous sediments deposited during the warmer phases of the Pleistocene, and concentrating cassiterite from material released from lodes exploited by the down-cutting rivers and from stanniferous marine sediments carried in from the drainage-transected platforms. Thus were generated the stanniferous placers of major importance which are found on 229 and 131 m platforms and in the lower reaches of the rivers.

Perhaps largely as a result of increase in the volume of seawater due to release of melt water from the contracting ice-sheets the lower reaches of the rivers became graded. Generally at this time the basal gravels of the rivers became covered with finer-grained alluvium and upon these, bogs were developed. On the higher marine platforms these were of the acid, sphagnum moss type, whilst in the lower tracts they were of the fen-type and were alkaline. In the course of time these bogs were overwhelmed by further river alluvium in the upper parts of the drainage systems whilst in the lower reaches estuarine and marine sediments were superimposed as the sea-level continued to rise with respect to the land. In addition, with this continuing change in sea base-level, valleys were drowned and forests on the low-lying coastal stretches were submerged and overlain by marine sediments.

These events were followed by the development of the modern beaches and sand-dunes, the latter generally where a sizeable beach was backed by a low cliff and exposed to the prevailing west-southwest winds.

Finally, as mentioned earlier, stanniferous placers have been generated as a result of hard rock mine tailings being, in some cases, deposited into the rivers. Such placers occur in the rivers themselves, as in the Red River Valley and Carnon Valley, or their estuaries, for example at the debouchment of the River Hayle in the Hayle estuary, and the Carnon River at Restronguet Creek. A lacustrine placer has formed in the Loe Valley where tailing derived sediments from the River Cober have been trapped behind

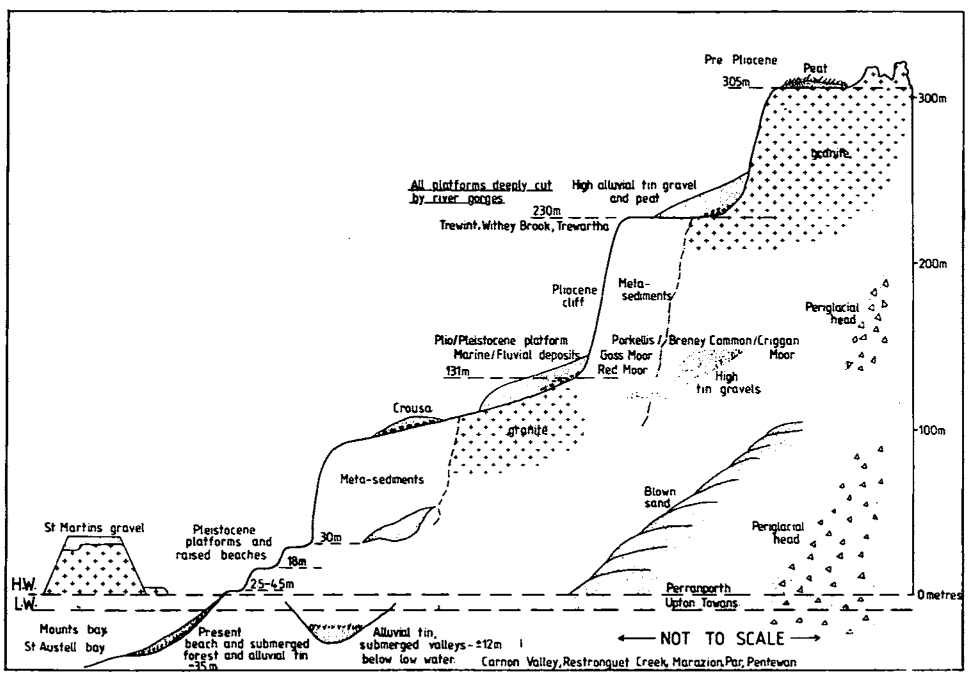


Fig. 8. Diagram showing relative positions of alluvial tin deposits and marine platforms. (After Robson, 1943–44. Slightly modified).

a shingle and sand bar at the rivers mouth to the sea. Marine offshore placers have formed where fluvially transported tailings have reached the sea, for example, the St. Ives Bay, and also, as a consequence of sea deposited tailing or marine deposits have been formed by long-shore drift, for example, at Upton Towans and Perranporth.

The general relationships between the marine platforms, the stanniferous placers and other superficial deposits is shown in Figure 8 which is a slightly modified version of Robson's diagram (1943–44, p. 161).

THE GENERAL GEOMORPHOLOGICAL CHARACTER OF CORNWALL

Having outlined the events leading up to and responsible for the development of the Cornish stanniferous placers it is pertinent, at the risk of some repetition, to present a brief account of the geomorphological character of Cornwall in order to provide a suitable background against which the distribution patterns of the placers can be apprciated and questions concerning the genesis and nature of the placers can be embarked on.

Cornwall is a peninsula characterised by the presence of deep, narrow, V-shaped valleys and flat-topped interfluves which descend in step-like formation to the coast. The watershed is so disposed that most of the larger and longer rivers flow to the south and southeast. Many of the major rivers are extended consequents upon a number of

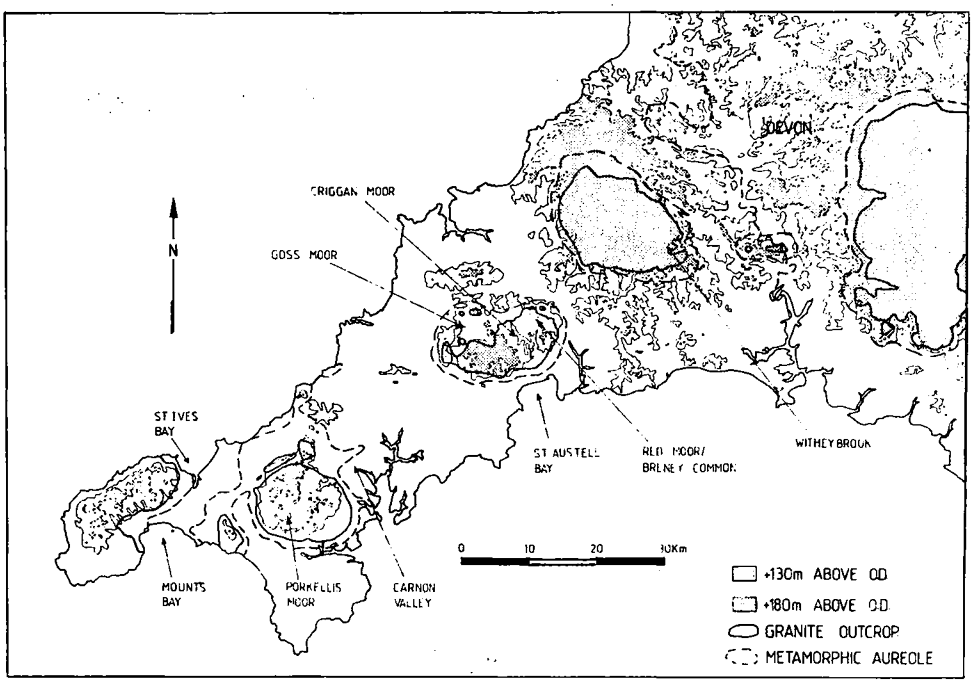


Fig. 9. 130m & 180m above o.d. elevations in Cornwall. (G.S. Camm, 1983)

marine platforms which largely or entirely the result of a fall in base sea-level, although the possibility that minor uplift also played a part cannot be entirely ruled out.

On the extensive 131 m Pleistocene platform, drainage, controlled by the joint systems of the granite and adjacent argillised metasediments, resulted in the local development of protobasin-type features separated by narrow interfluves and now locally bordered by degraded cliffs. Typical examples occur at Porkellis Moor, Goos Moor, Breney Common and Redmoor, and in each area important mid- to high-level fluivatile placers were generated (Figure 9) whose economic potential has been reinvestigated in recent years. Now the Pliocene subaerial surfaces bordering the basins are difficult to establish as they are part of a mature land-form whose present features are to no small degree due to the effects of mass wasting and periglaciation which, amongst other things, have resulted in valleys being infilled with periglacial solifluction products (the so-called 'head) and fluviatile sediments (the 'alluvium' which may be stanniferous.

Rejuvenation of the rivers following uplift, largely during the Pleistocene, caused the erosion platforms to be dissected and was responsible for wide-spread river capture.

Subsequently, during the Holocene, there was a rise in base sea-level which resulted in the lower reaches of the river being converted to rias. A number of the drowned portions of these river systems, particularly along the south coast contain, or contained, economically interesting concentrations of cassiterite.

AN EXAMINATION OF SOME OF THE FACTORS RESPONSIBLE FOR THE DEVELOPMENT AND DISTRIBUTION OF THE CORNISH PLACERS

The regional distribution pattern of the Cornish placers is shown in Figure 1. Comparison of this figure with Figure 6 will enable the distribution of the placers in relation to the major lithological units to be appreciated. It will be seen that many of the placers are situated on or close to the granitic masses whilst most of the others occupy drainage systems which for the most part extend from the granitoid areas to the sea and locally beyond the present coastline. Dispersion along the coast, offshore and littoral placers occur which owe their cassiterite to mine tailings. Such tin deposits occur along the Gwithian/Godrevy portion of the coastal fringe of the St. Ives Bay, where cassiterite was transported from the beneficiation plants of the Camborne mines by the Red River.

Comparison of Figures 1 and 10 demonstrate that some placers occur in areas which lack primary tin deposits. Examples are to be found in the extreme southwest of the Land's End area and on the northeast part of the Bodmin Moor granite. Recently Beer and Scrivener (1982,p. 128) have made a similar observation about the stanniferous placers in and around the Dartmoor granite (Devon). They state that the stanniferous placers *"were not, apparently, more favourably distributed in the area where vein complexes are known to outcrop at present, but were derived from ore bodies in the roof zone of the granite which have largely been removed by erosion. The vallye of the*

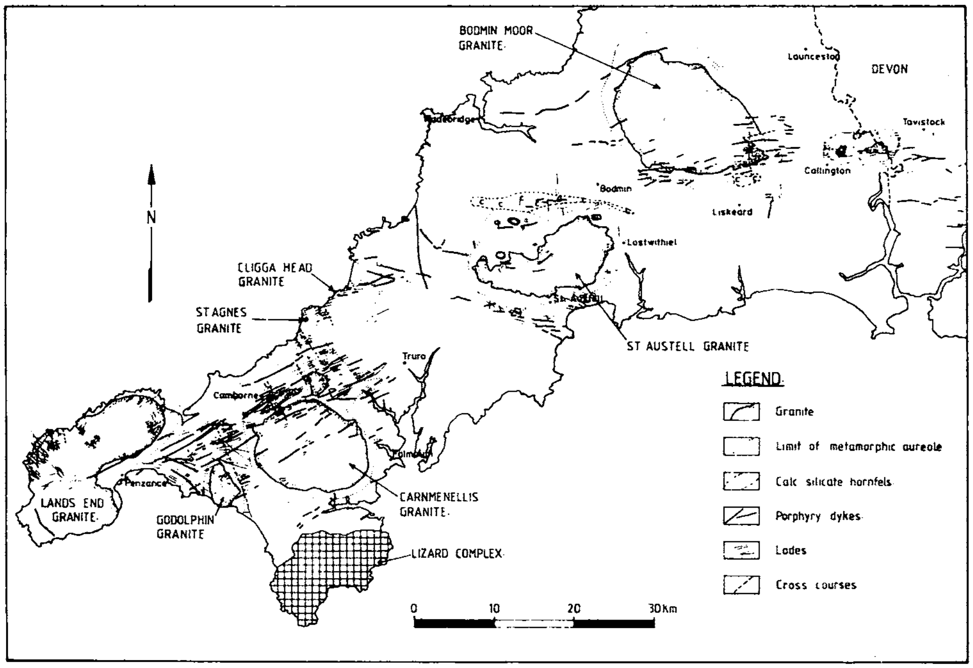


Fig. 10. Distribution of the granite outcrops, metamorphic aureoles, lodes and dykes in Cornwall (After K.F.G. Hosking, 1964)

River Walkham to the north of Merrivale Bridge ......, east of Tavistock, is an example of a tract of extensive former stream working which is remote from significent vein structures."

Clearly, at this stage, it is relevant to consider in some detail why the placers are geographically situated where they are. To do this it is necessary to supplement what has been written earlier in this paper by examining the following, to some extent, interrelated topics, some of which have been largely or entirely neglected in the literature:

(i) The disposition of the major types of primary tin deposit.

(ii) The structural, textural and mineralogical character of the primary tin deposits; the disposition patterns of cassiterite in them, and the nature of the wall-rocks.

(iii) The host-rocks of the primary tin deposits.

(iv) Climatic factors.

(v) Land/sea relationships.

(vi) Drainage.

(vii) Man's activities.

(i) The disposition of the primary types of tin deposit

The major types of primary tin deposits are shown in Figure 7, but for the purpose of this section it is sufficient to divide them into two groups, the early group, consisting of hydrothermal breccia deposits and greisen-bordered vein-swarms, which are associated with high spots on the granitoid intrusions, and the late group in which lodes are the dominant members. These lodes tend to flank granitoid ridges.

There is good reason for believing that areas of tin mineralisation occur at intersections of preferred lines of mineralisation which strike ENE-WSW and E-W respectively, and whose strikes are coincident with the dominant strike directions of the granite ridges, dykes and lodes in West Cornwall and East Cornwall respectively (Figure 11). Possibly some, at least, of the grid intersections shown in Figure 11, which are not at sites of known primary tin deposits, may represent localities where primary deposits once occurred but have since been entirely destroyed by natural processes. Some of the cassiterite released from such placers may be in placers which are now considerably removed from any known primary deposits.

During the denudation which led to the progressive uncovering of the higher parts of the granite batholith, commonly the first of the primary tin deposits to be subjected to destructive agents would be some of the hydrothermal breccias and vein-swarms surmounting granite cusps.Then the greisen-bordered vein-swarms within the cusps

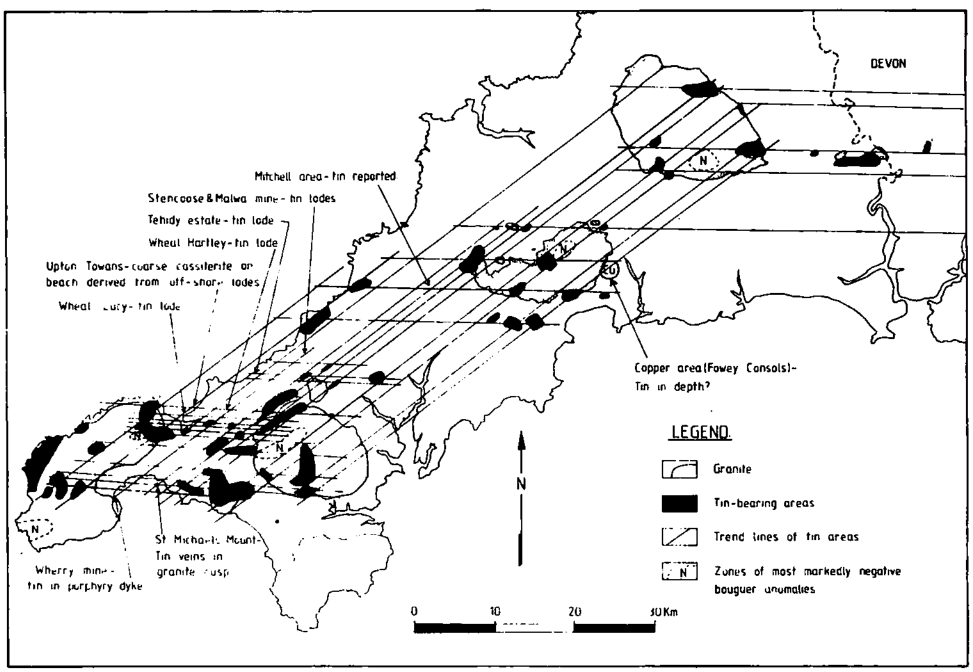


Fig. 11. Distribution pattern of the tin bearing areas and of the zones of biggest negative bouguer anomalies (After K.F.G. Hosking 1964 Derived from Dines; and from Bott, Day and Massan-Smith 1956 & 1958).

would come under attack, and finally the stanniferous parts of some of the lodes (Figure 12). Why the lodes should be generally the last to lose cassiterite is discussed later. As there is reason for believing that the high-level granites were part-unroofed in the early Permian (Hawkes 1975, p. 1136) it is reasonable to think that even in the Permian some vein-swarms in the metasediments had already been destroyed and others in the granite had come under attack. Whilst the destruction of the mineral deposits has continued from the Permian up to the present, and at rates which depended on climatic and other factors, it has failed to eliminate many early and late primary tin deposits and, if Hawkes' (1975, p. 1136) conclusions, noted earlier, are correct, the thickness of the granite removed from the large exposed masses in the southwest varies from c. 50m to 200 m—surprisingly modest figures. It is relevant to remark that in part because of the limited strike and dip lengths of the early types of primary tin deposit they could be completely destroyed if favourably located, in a much shorter space of time than an average primary tin lode with a far greater strike and dip-length, even when the lode was well sited for attack by sub-aerial processes. In addition, the products of natural destruction of an early type of tin deposit would be likely to be accommodated in a very limited type of tin deposit would be likely to be accommodated in a very limited drainage system. Indeed, should one of the early types of deposit be situated on the shoulder of a steep immature valley, and should the climate be of the humid tropical or sub-tropical type, such as was experienced in the region during the Eocene and Oligocene, much or all of the deposit might be deposited in the valley as a result of a single landslide. The Southeast Asian experience of one of the authors leave no doubt that this is a distinct possibility.

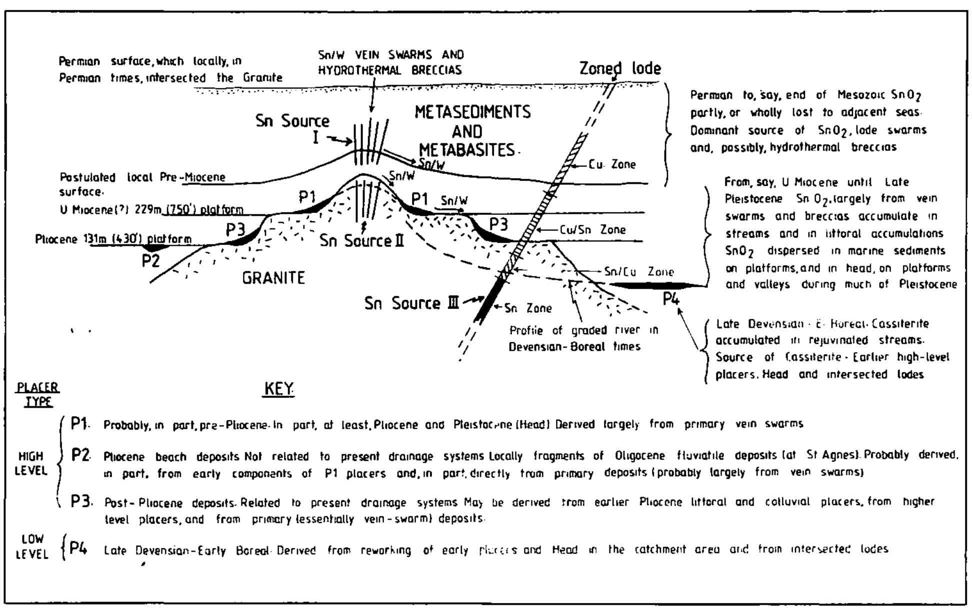


Fig. 12. A conceptual diagram indicating the relative times of destruction of the major types of primary tin deposits in Cornwall and the locations and order of development of the Sn-placers.

The destruction by sub-aerial agents, of a lode of considerable strike length, which, as is often the case, strikes at about right-angles to the major trend of the associated drainage systems, and the susbsequent distribution pattern of the liberated cassiterite, provide a picture which is significantly different from that which emerges when early stanniferous primary deposits are the source of the associated placer tin and which is described above.

A drainage system of considerable size would be needed to collect the liberated cassiterite from a lode disposed as mentioned above, and the cassiterite would be likely to be concentrated in many rather than a few streams. Although much of the cassiterite released into the smaller streams might, under favourable circumstances, be largely transported to the major stream and concentrated there, so providing a major placer deposit, it is probable that in the minor streams many small placers, surely in part, sub-economic, would occur.

It is, of course, obvious that a given drainage system might receive its cassiterite from a number of sources. Thus, for example, some of the cassiterite might be derived from a vein-swarm near the head-waters whilst additions might be made where stanniferous lodes were intersected by the streams. The cassiterite of the St. Erth valley placers, for example, came from a number of such sources, and in the valley, just below the points where lodes were intersected, the tin grade was considerably enhanced (Gregory, 1947).

(ii) **The structural, textural and mineralogical character of the primary tin deposits**

Generally speaking the members of the early primary stanniferous deposits (hydrothermal breccias and vein swarms) are structurally simple. The breccia deposits usually consist of highly tourmalinised host-rock fragments cemented by quartz, tourmaline and cassiterite and occur in tourmalinised metasediments and/or altered granite. It is to be noted that apart from the feldspar in the granite all the components of the system are resistate species. Such deposits and the quartz/tourmaline/cassiterite lode, better than all others, serve to underline the importance of processes of disintegration to the development of a superficial stanniferous deposit which, usually after beneficiation by natural processes, may result in a placer of economic interest.

Each individual vein of the greisen-bordered and other early vein-swarms usually consists essentially of a quartz leader, which is often quite dtusy and bordered by greisenised, or somewhat similarly altered wall-rock. Commonly, and in West Cornwall particularly, the cassiterite is virtually restricted to the quartz vein where it is often completely invested by quartz, although it is not uncommon to find it closely associated with wolframite and, on much rarer occasions with sulphides such as stannite and arsenopyrite. In Central and East Cornwall particularly, cassiterite, occurring in the vein and the greisenised wall-rock, has been recorded as, for example, at the Bunny Mine (Dines, 1956, p. 535) and at North Hill (Dines, 1956, p. 583), whilst at Carclaze (Dines 1956, p. 539) cassiterite was found disseminated in the granite and the metasediments near the veins. In these early vein systems and their altered wall-rocks the minerals present are largely resistate species [quartz, by far the most abundant, sericite, topaz and ones which are not generally rapidly attacked by surface agents (apatite, fluorite)]. However, others which are rather unstable in the chemical environment at or near the surface include feldspar and such species as pyrite, chalcopyrite, stannite, arsenopyrite and sphalerite.

If the unstable sulphides are present in considerable concentrations in those parts of the stanniferous body which are at or near the surface they may be attacked by subaerial agents and a gossan may develop. Although gossans vary considerably in their texture and composition they are generally mechanically weak on account of their scoriaceous nature. Particularly during cold climatic conditions gossans which developed during warmer periods are likely to be disintegrated as a result of water entering the system and turning to ice. Because gossan is often mechanically weak, lumps of it which find their way into drainage systems may be readily broken down with the concomitant release of cassiterite. It must be emphasised, however, that these unstable minerals, even when present in considerable concentrations in the primary deposit, as they sometimes are, are commonly included in unfractured quartz, and so, even when close to the surface of the land, they may be isolated from weathering agents.

The simple veins often have a comby texture and an abundance of small vugs (in this they resemble some of the lodes or portions thereof) and are structurally rather weak. They tend to fracture readily along their strikes when they are close to and trend parallel to a cliff or quarry face. This is readily confirmed at Cligga and St. Michael's Mount. In this respect they differ markedly from the early, well-cemented, brecciated bodies.

In marked contrast to the early deposits, discussed above, the tin lodes are often a metre wide and may be several times this width. They are usually structurally and often texturally quite complex. Without going into details of the paragenesis, which is fundamentally the same in all types of primary tin-bearing deposits, not only lodes, in Cornwall, the general order of deposition is silicates, oxides and 'sulphides'. There are known examples in which deposition departed from this sequence, but for the purposes of this paper they can be ignored. Quartz was deposited intermittently through the phase of lode/vein development. The cassiterite may invest earlier species such as quartz/tourmaline and mica and/or be invested by later species such as chlorite, hematite, sulphides and, of course, quartz (Figure 13). Some of the lode species are resistates whilst others, as noted above, will be decomposed more-or-less rapidly, depending on climatic conditions, when exposed to the near surface environment. The ease with which a given exposed lode is progressively destroyed by physical and/or chemical means depends on many factors, of these, mention will be limited at this stage to the structural and textural characters, the size range of each component, and the percentages of each mineral present. Particularly in a climate other than an arid one, variations in the above will dictate to a marked degree the importance of the role played by decomposition in the destruction of a given lode. In a hot, arid climate, in particular, these factors will largely determine how effective large diurnal changes in temperature will be in disintegrating the lode. The ease with which cassiterite released from a lode into a drainage system can be concentrated by natural wet gravity processes will depend on the shape and size of the liberated grains, the quantity of inclusions, for example, tourmaline, they contain and whether other gangue species are

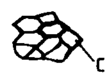
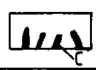
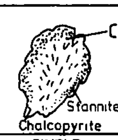
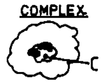
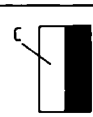
TYPE OF RELATIONSHIP	TEXTURES C = Cassiterite	MINERAL(S) ASSOC. WITH CASS.	LOCATIONS OF EXAMPLES	OTHER NOTES
1. 'INCLUSIONS' OF EARLIER MINERALS IN CASSITERITE.		Tourmaline Quartz Wolframite Sericite Magnetite	Bunny Mine (St Austell); South Crofty Mine. Wheal Vor. S. Crofty (3AB+C Lodes). Parc-an-Chy Mine. Magdalen Mine (Ponsanooth).	Specific gravity of grains may be appreciably lowered.
2. CASSITERITE DEVELOPMENT AROUND MINERAL AND ROCK FRAGMENTS.		Wolframite & Arsenopyrite Cassiterite Slate Quartz Tourmaline	Complex lode, Roskear. Dection, S. Crofty Mine. Wheal Kitty (St. Agnes). Relistian Mine. Garth Mine. Levant Mine.	A common phenomenon.
3. 'INCLUSIONS' OF CASSITERITE DUE TO BRECCIATION OR REPLACEMENT		BRECCIATION. Quartz & Tourmaline Chlorite Hematite Sulphides REPLACEMENT. Stannite Wolframite Quartz	 Dolcoath Main Lode. S. Crofty Mine. S. Crofty Mine. Wheal Jane. White Rocks Quarry. Cameron Quarry (St. Agnes). Wheal Kitty.	BRECCIATION A very common phenomenon. REPLACEMENT A rather rare phenomenon. Wood-tin part-replaced.
4. REPLACEMENT CASSITERITE		Feldspar Quartz	Penberthy Croft, Garth Mine. Polberro Mine (St. Agnes).	Perhaps quite a common phenomenon.
5. 'INCLUSIONS' OF CASSITERITE IN CONTEMPORANEOUS MINERALS.		Quartz	Wheal Primrose (St Agnes). S. Crofty.	Disseminated in quartz crystals. Crystals zoned-Quartz & (Quartz, cassiterite).
6. 'INCLUSIONS' OF CASSITERITE DUE TO PARTIAL DECOMPOSITION OF HOST.		Stannite	Cligga.	Cassiterite needles & (Chalcopyrite) in Stannite. A common form of alteration of Stannite by hypogene agents.
7. 'INCLUSIONS' OF CASSITERITE IN LATER MINERALS.	SIMPLE.  COMPLEX. 	Chlorite Hematite Sulphides	S. Crofty. S. Crofty. Wheal Jane / Mount Wellington.	Common. SnO_2 not readily released during grinding. Common. Flotation losses of Cass. common. The Cass. may be in composite inclusions e.g. Janes Sulphides ore.
6 WELDED TEXTURE.		Wolframite	S. Crofty	Locally where early Wolframite bearing veins are intesected by Cassiterite-bearing lodes. Result:- Cassiterite/Wolframite composite grains in mill.
NOTE:- In the zone of oxidation supergene species will replace the unstable minerals of column 3. E.g. Scorodite is likely to replace Arsenopyrite.				

Fig. 13. Intimate relationships between cassiterite and other minerals in the hard-rock deposits of Cornwall.

attached to the cassiterite. The cassiterite in the lodes proper is usually restricted to shoots in which it may be spatially closely associated with a few, or many, other species, but, on occasion, rich concentrations may occur in the wall-rock adjacent to the lode. In such circumstances the cassiterite is largely confined to narrow veins, as it was at Ding Dong, (Collins, 1912, p. 64), Pednandrea (Collins, op. cit., p. 77) and at Wheal Coates (Collins, op. cit., p. 78). If suitably exposed these much-veined and probably inherently weak wall-rocks are likely to be rapidly disintegrated.

The structural/textural character of individual lodes is generally much more complex than that of the early stanniferous veins because a lode is a fault system which was mineralised during a period when it was repeatedly reopened and invaded by mineralising agents whose chemical character changed with time. Generally speaking, lodes are brecciated or banded, or a combination of the two. Vugs are not uncommon. During lode development early-deposited species may be mylonitised and some of the cassiterite might be reduced to such small particles, say less than 5 microns, that, if liberated as individucal grains into a drainage system, natural wet gravity processes, like those devised by Man, would be quite unable to concentrate them. In addition, during the generation of a tin lode, the cassiterite often includes small crystals of tourmaline which may be present in it in such concentrations as to appreciably reduce its specific gravity and hence make it less amenable to a gravity concentration if released into a stream. Finally, the size of individual cassisterite crystals may be reduced in a lode as a result of their part-replacement by, say, stannite. This reduction in size also militates against the effective concentration of cassiterite after release into a drainage system.

It is relevant to note here that individual cassiterite crystals of the early primary deposits are commonly of a size which is only very rarely attained by those in the lodes and, in addition, the early cassiterite is rather stumpy, and often consists of a short prism and a simple [III] pyramidal termination: twinning is also common. The lode cassiterite is frequently in the form of elongate prisms and acute pyramidal terminations and it, also, is often twinned. Furthermore, in some lodes a proportion of the cassiterite may display a markedly acicular habit which, if it finds its way into the drainage system is almost certainly to be located in a resistance gangue species such as quartz. The only likely exception to this is when the acicular cassiterite has been generated as a result of the breakdown of a tin-bearing sulphide, say, stannite, then oxidation of the unstable initial breakdown products may allow the acicular cassiterite to be released. Commonly, a considerable percentage of the cassiterite in a lode occurs as sizeable aggregates of tightly packed crystals so that should the lode be destroyed by natural processes large masses, which are very rich in cassiterite, can result. It is reasonable to state that whilst members of all types of primary tin deposit can provide cassiterite in a form which allows it to be readily concentrated in fluviatile placers within a few km of the parent source, liberated, individual cassiterite crystals from the early vein systems, because of their size and shape, are more amenable to concentration in moving water than are their smaller, elongate counterparts from the lodes proper.

As minerals differ in their coefficients of cubical expansion/contraction it follows that this must be a factor to be taken into account when considering the disintegration of a primary tin deposit. There is no doubt that variations in the coefficients noted above play a major role in disintegration in hot arid climates where marked diurnal temperature changes are common. They also play an important role in the humid tropics where exposed rocks in, for example, shallow rivers, are strongly heated repeatedly by the sun and then quenched by heavy rain and rising stream water. The Cornish primary deposits have been subjected to both types of climate noted above.

Obviously how effective temperature changes, of the type noted above, are in disintegrating a primary deposit depends to no small degree on the number of mineral species present in it, their relative proportions and the texture. Of course, other factors also play a part, for example, the disposition of the deposit.

In this section only primary zoning remains to be dealt with.

The distribution of certain metals and minerals in zones in Cornwall has received considerable notice in the literature for a long time. (See, for example, Dines (1956, pp. 5–19) and Hosking, (1979, pp. 34–39) and so it need not be discussed in any detail here. Sufficient is it to mention that zoning has been noted in some of the early primary deposits and in many of the later lodes. Thus, for example, at Cligga, the greisen-bordered veins in the northern part of the granite porphyry cusp contain only quartz and tourmaline, whilst further to the south cassiterite, wolframite and, in some instances sulphides, as well as quartz and other non-metallic gangue minerals, are present. As far as the lodes are concerned in many of them a copper zone overlies and part overlaps a tin zone. The copper overlap is much thicker than was formerly believed and within the tin-fields erosion has commonly removed, according to one of the authors (Hosking, 1979) those parts of the lode that contained copper, but were tin-free, and some of the Cu/Sn zone. A number of lodes which had so suffered out-cropped on the 131 m Pliocene platform in the Camborne/Redruth tinfield. These lodes, when first discovered, consisted of a stanniferous gossan which was exploited for its cassiterite content. (Doubtless the Pliocene sea had earlier mined cassiterite from these deposits.) Beneath the gossan were copper-bearing sulphides and subsidiary cassiterite, which in depth changed to copper-free cassiterite ore.

Bearing in mind the spatial relationships between the various types of prmiary tin deposit and the granitoid ridges and cusps, and the tin/copper relationship in the lodes, it follows that it is likely that often early-type deposits were releasing their cassiterite to the drainage systems, and some may have been completely destroyed, at a time when perhaps the majority of the zoned tin lodes were only providing non-stanniferous material (Figure 12).

(iii) **The host-rocks of the primary tin deposits**

Clearly, the extent to which the immediate host-rock of a primary tin deposit can withstand the attack of the weathering agents to which it is exposed may determine, to no small degree, the rate at which the tin deposit is progressively uncovered and destroyed.The resistance of the wallrock to the actions of destructive agents depends essentially on its inherent structural weaknesses, also to weaknesses engendered in it as a result of chemical modifications effected by hypogene and supergene agents, and the morphological character of the exposure, which will change with time.

Here it is only necessary to consider the two major types of host-rock found in Cornwall, the 'granite' and the 'killas' (non-Calcareous metasediments). The inherent structural weakness of the granite stems from the nature of its jointing. Generally a close-jointed granite is likely to succumb to the attack of weathering agents more rapidly than one in which the joints, particularly the vertical ones, are more widely spaced. This is because there are more lines of entry per unit area for supergene agents into the closely jointed granite than in the other. Consequently the closely jointed rock may be weakened more rapidly as a result of kaolinisation and of the disrupting forces generated should water in the joints be turned to ice. This variation in intensity of jointing is, according to Linton (1955) the basic reason for tor development.

It is very probable that most of the kaolinisation of the Cornish granite was the product of hypogene processes which were operative later than those which were responsible for the genesis of the tin mineralisation, but regardless of how the kaolinisation was effected, concomitant with it would be a tendency towards reduction in the volume of the rock. As a result stresses would be created that might account for the segmentation of greisen-bordered veins into roughly square plates whose sides are, say, 10 cm in length, and which can be seen at Cligga Quarry and St. Michael's Mount where veins have been split lengthwise by Man and Nature respectively. Also at Cligga Quarry steeply-dipping, greisen-bordered veins are traversed by tension fractures which we think are due to slumping of the weak, intensely kaolinised granite, parallel to the free face of the exposed block which is also parallel to the strike of the veins. The processes noted immediately above provide two ways by means of which comparatively small pieces of inert stanniferous veins may be released from the parent, and of a size which constitutes a much more satisfactory feed for the natural beneficiation processes of crushing and grinding in moving water than do large blocks.

In addition to weaknesses due to joints, both granite and killas are further weakened by barren faults. Movement along the faults may be induced by lubrication and swelling of any clay they might contain by water and by the conversion of water in them to ice and the ice to water. Faults may be particularly important when erosion has provided a free face such as the cliff face at Cligga. Obviously the degree of importance depends, amongst other things, on the strikes and dips of the faults in question and particularly how these relate to the free face. At Cligga, extensive cliff falls occur in part, at least, as a result of movement along faults, and there the pounding of the cliffs by the sea during storms probably facilitates the falls. Such falls add significant concentrations of material carrying cassiterite and wolframite to the beach at Cligga where it is subjected to marine beneficiation. Doubtless falls of this nature also occurred from the cliffs fringing the Pliocene sea.

The weakness of the killas stems from the presence of cleavage planes, joints and faults which collectively are commonly much more abundant than planes of weakness in an equivalent volume of granite and so, when subject to cold climatic conditions, is much more likely to be disintegrated into smaller units than those resulting from similarly exposed granite.

(v) **Climatic factors**

From that which has been written earlier it will be evident that from the commencement of the destruction of the hard-rock tin deposits of Cornwall up to the present time the region has been subjected to a number of strongly contrasting climatic types. In that which follows are additions to, and elaborations on, the previously mentioned relationship between the climate and the generation of the stanniferous placers. Obviously what physical and/or chemical (including biochemical) changes a given orebody and its hostrock will undergo during a given period of time will depend to no small degree on the climate of the period. It must also be remembered that when a given orebody and its hostrocks are being subject to attack under, say, hot and humid conditions, it may have already been modified under other completely different climatic conditions. Climate will also dictate the pattern of transportation of material released from the parent deposit and hostrock and the extent and type of concentration of the released dense resistate species. Again, a change of climate is likely to cause a modification of the distribution pattern of the released dense resistate species which had been established earlier.

In a hot and arid climate, such as that experienced in Cornwall during the Mesozoic, there is usually a marked diurnal variation in the temperature which will promote exfoliation and granular disintegration: physical destruction (disintegration) rather than chemical breakdown (decomposition) is the prime agent. Released debris will migrate down slope under gravity unhampered by vegetation, and aided, on rather rare occasions, by violent rain storms which will also effect some concentration of the dense components on the slopes and, indirectly, by filling the generally dry valleys with water, promote the beneficiation of such sand, and the like, as have accumulated there. During dry phases winnowing may also lead to the generation of aeolian placers. Placers which develop under such climatic conditions are rarely if ever far from the parent source.

The previous statements indicate, we believe, that which was taking place on the land of the Cornish region during the Mesozoic. In the transition period when the climate was changing from the hot and arid to hot and wet, presumably during the earlier part of the Palaeocene, and before a strong cover of vegetation had been established, there must have been a most spectacular transfer of material released during the arid period down the slopes and via the drainage systems. One can only guess as to what happened to the cassiterite which participated in these migrations.

In an arid climate the water table is deep and under such a circumstance an orebody can develop a deep zone of oxidation. Provided the deposit contains component which are capable of being reached and attacked by supergene agents, and are present in significant concentrations, the body may be weakened to depths of up to, say, 900 m and so become more amenable to future destruction by weathering agents. In the region there is some evidence that deep oxidation experienced by certain of the lodes in the Mesozoic may, to some degree, have facilitated lode destruction during later times when the climatic conditions were radically different. Indeed, it is probable that even today some Cornish lodes may owe their deep oxidation to activity in the Mesozoic. Collins (1912, p. 250) for example, records that at the Phoenix Mine (East Cornwall) oxidation persists to c. 200 fathoms (366 m). There is also the probability that deep supergene activity occurred in the Camborne area during the Mesozoic. Indeed, MacAlister (1906, p. 194) states *"that oxidising influences in the Camborne* *region have been at work (on the lodes) from surface to a depth of at least 1,000 feet (305 m) and in all probability below this".*

Apart from the small stanniferous fluviatile deposits of Oligocene age at St. Agnes, nothing remains in Cornwall of the products of mass wasting which were generated between the end of the Mesozoic and the end of the Oligocene when the region was subject to a sub-tropical climate. At least, nothing remains that can be positively identified. During this period, as noted earlier, laterites and latosols were probably developed and locally they and the included core boulders were carried by landslides into the drainage systems where cassiterite was liberated and concentrated from the finer components. However, during this time it is likely that most of the cassiterite in the active sediments of the streams was obtained by destruction of primary tin deposits which transected the valleys, an operation which was of great importance later, during the post-Pleistocene times, and when the rivers were rejuvenated. What happened to these early placers? Perhaps they and the superficial tropical soil cover of the interfluves were destroyed and their components dispersed when, during the Miocene, the region was largely drowned by the sea. However, it seems not unreasonable to us to think that perhaps some of the alluvium and included placers survived, and, later, during the emergence of the land in stages, some of the valleys were incorporated into the later drainage systems and some of the old placers in them were reworked, whilst others, as yet unknown, may have survived, for example, the stanniferous Oligocene fluviatle deposit of St. Agnes.

We have nothing to add to that which we have written earlier concerning the relationship between the climate and the generation of placers from the commencement of the Pleistocene to the present time. This simply means that we have nothing more that is worthwhile saying about this relationship at present. We are are very well aware that this topic, in common with every facet of the development of the placers in question, needs much more investigation.

(v) **Land/sea relationships, drainage and man's activities**

The additional notes relating to the three subjects in the above title are, for convenience, placed in one section.

As mentioned earlier, the precise palaeogeography of the region from the Permian to the Pliocene is unknown, but during that time rivers must have locally concentrated cassiterite and also transported some into the surrounding seas. Certainly later, during the Pliocene, some rivers must have carried cassiterite to the sea where it was concentrated in beaches, in some instances together with cassiterite derived from mass wastage of primary deposits in the cliffs, and and also transported by longshore currents to be concentrated in a zone parallel to the coast and below low watermark as occurs today in the St. Ives Bay. The orange/red grains of cassiterite in the 'high-level' placers of Redmoor and Breney Common can now only be matched by the cassiterite occurring in the in situ hydrothermal breccia ore at Gaverigan, about 15 km to the west. If the source of the placer cassiterite in question was, indeed, at Gaverigan, and not from a closer source which has been completely destroyed, then longshore drift may have played a role in the transportation of tin-bearing grains although, doubtless, transportation by fluviatile agents also determined, to some unknown degree, the final sites of disposition of the grains. Further investigation by drilling may reveal strandline deposits below Pliocene-age degraded cliff lines protected by later Pleistocene solifluction and so concealed. Indeed during the investigation of hardrock deposits at Pendarves by diamond drilling a Pliocene beach deposit overlain by head was locally intersected but the tin potential was not investigated.

Subsequent elevation of the Pliocene platform and the development of drainage systems on it certainly allowed a percentage of the total cassiterite on the platform to be accommodated in certain of these drainage systems and to be concentrated along with cassiterite obtained from the Head (and protected from abrasion, etc., until released from it) and other sources, such as lodes transected by the valleys, which had not been subject to marine action. The cassiterite derived from the marine sediments in question is much more rounded than that from the other sources, and on the Goss Moor concentrates, for example, differentiation between the 'marine' and 'non-marine' grains can be readily effected. It is also relevant to note that in certain of the tributaries of the Fal, which bear no evidence of having been mineralised, cassiterite was found years ago by one of us (Hosking and Obial, 1966). Surely, as was suggested at the time (Mohan, 1967) this was cassiterite which was originally a component of the Pliocene marine sediments which had been transported some distance by longshore currents from the mouths of the rivers which had brought it from its primary source to the sea. However, the presence of cassiterite, particularly in the active sediments of streams which are now divorced from any known primary sources, cannot automatically be assumed to have been derived from Pliocene marine sediments. In some instances, as noted earlier, there may have been a primary source which has been eliminated by natural agents. On other occasions river capture may have concealed the primary source, and sometimes the river was the site of a customs mill, treating cassiterite ore, whose location had been chosen because of an abundance of water-power (see Hosking, 1971, p. 183).

Nothing further need be noted about the part that Man has played in the generation of stanniferous placers in Cornwall except to mention that the tailings from hard-rock tin mines which, locally have been allowed to collect in sites occupied by natural placers, have made the evaluation of the latter considerably more difficult than would have been the case had they not been contaminated by Man's activities. This was emphasised, for example, in recent years when some of the tailings-covered placers on the Carnmenellis granite mass were examined.

A SUMMARY OF THE GENESIS OF THE CORNISH STANNIFEROUS PLACERS

We have briefly discussed the nature, distribution and exploitation of the placers, and provided an outline of the geological events leading up to and responsible for the development of the placers under review. In addition, we have noted the geomorphological character of the terrain over which the placers are distributed, and examined in further detail some of the factors responsible for the development and distribution of the placers. Now it seems sensible to provide a summary of what has

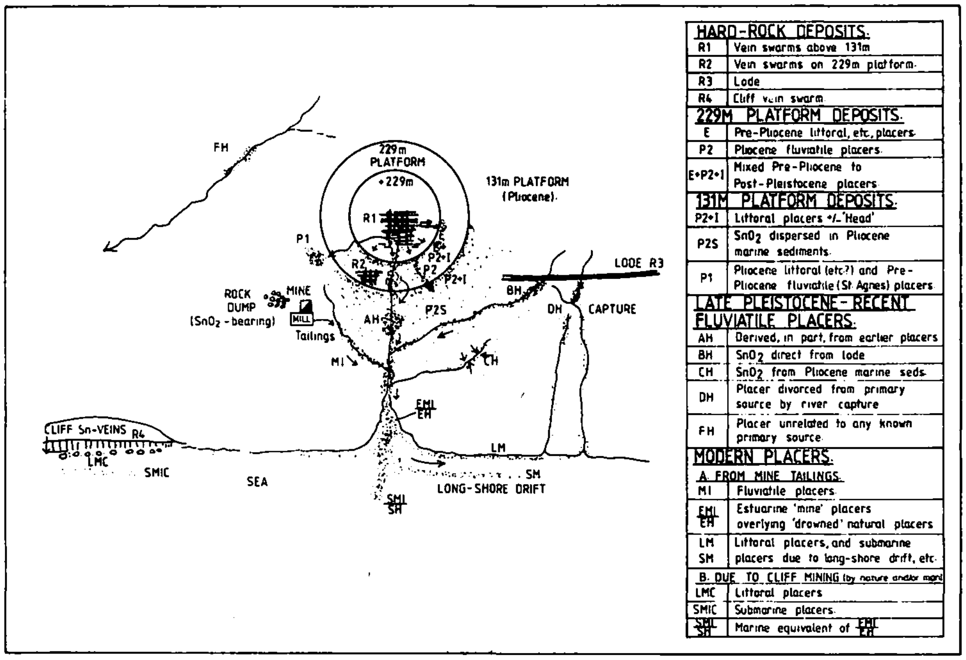


Fig. 14. Diagram indicating the types of stanniferous placer in Cornwall, together with their relative dispositions, ages and ancestry.

been written. This we have done simply by including Figures 14, 15 and 16, which we believe are self-explanatory.

Finally, it is our hope that this paper will serve to emphasise what is at last becoming apparent, that is, that placers generally, not only those in Cornwall, are deposits whose geneses are often exceedingly complex, and not at all subjects to be treated in a superficial way, and rapidly dismissed, as has been the custom of most who have written text-books on the geology of the ore-deposits.

ACKNOWLEDGEMENTS

The writers are grateful to Billiton International Metals BV for permission to publish some of the Company's data, and to Consolidated Gold Fields who kindly provided the information on which the composite section of the Porkellis Moor deposit is based.

REFERENCES

ATKINSON, K., BOULTER, M.C. FRESHNEY, E.C., WALSH, P.T. and WILSON, A.C., 1975,. A revision of the St. Agnes outlier, Cornwall (Abstract). Proc. Ussher Soc., 3, 286–287.

BEER, K.E. and SCRIVENER, R.C., 1982. Metalliferous Mineralisation. pp. 117–147 of "The Geology of Devon", edited by E.M. Durrance and D.J.C. Laming, University of Exeter (346 pp.).

CAMM, G.S., TAYLOR, I.R., HARTWELL, P.A., and SCARBOROUGH, B.E., 1981. Carnon Valley, Cornwall, a placer tin deposit. British Geologist, 7, no. 3, 65–71.

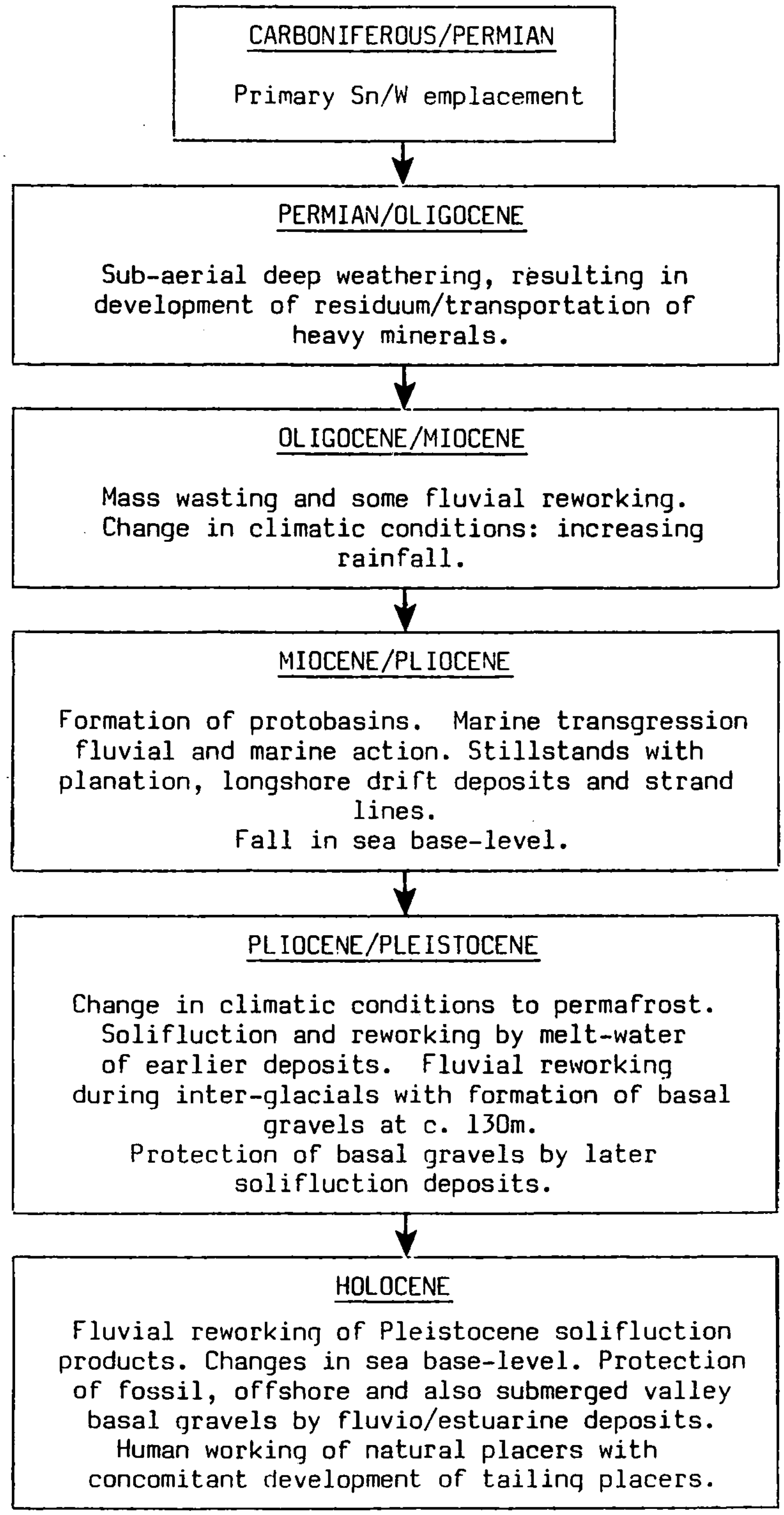


Fig. 15. Formation of placer tin deposits in S.W. England.

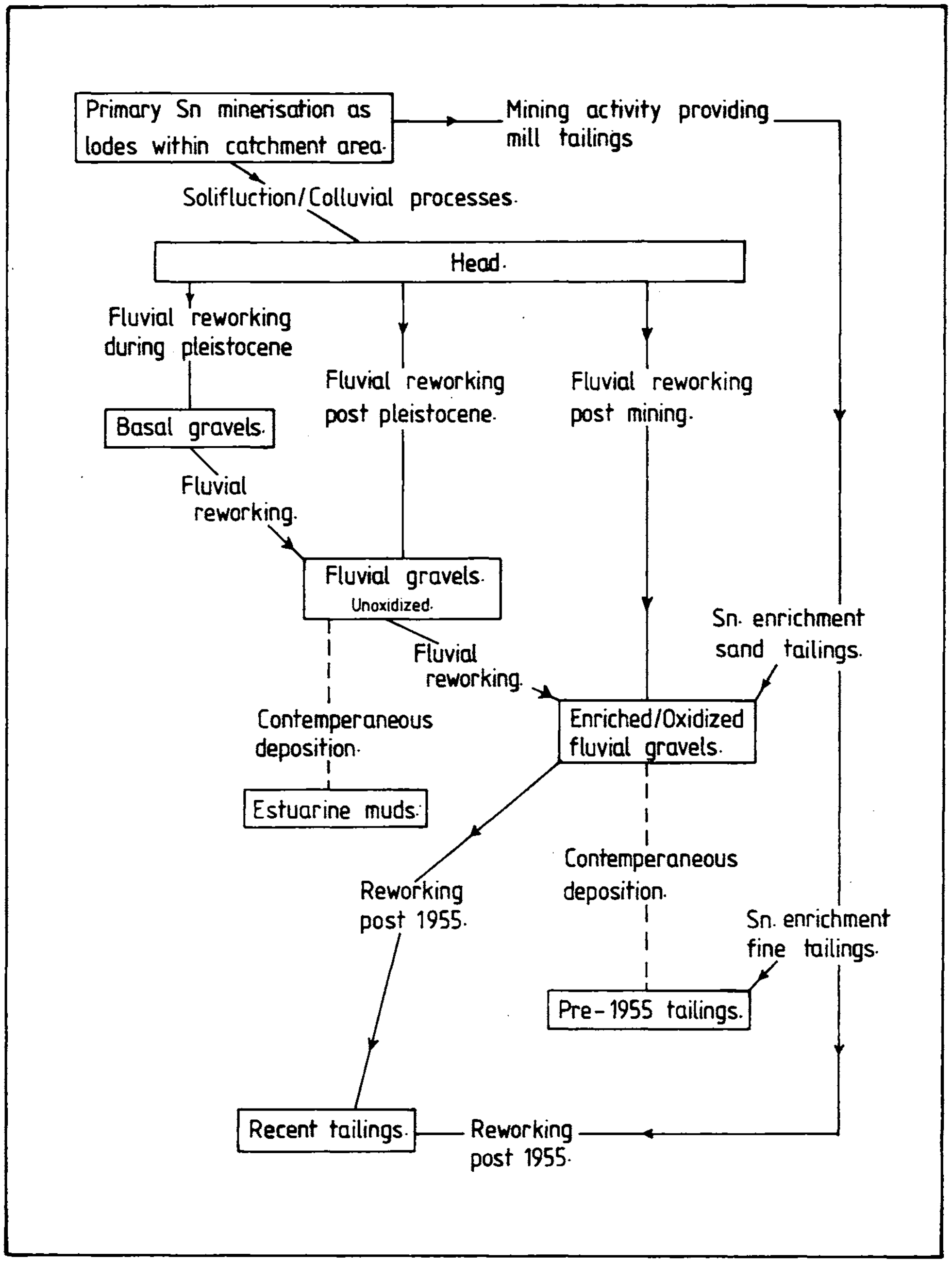


Fig. 16. Genesis of alluvial tin in the Carnon Valley. (After Camm, Taylor, Hartwell & Scarborough 1981).

COLLINS, J.H., 1912. Observations on the West of England Mining Region. Trans. R. geol. Soc. Cornwall, 12, (683 pp.).
CULLINGFORD, R.A., 1982. The Quarternary. pp. 249–290 of "The geology of Devon", edited by E.M. Durrance and D.J.C. Laming, University of Exeter (346 pp.).
DINES, H.G., 1956. The metalliferous mining region of south-west England. H.M.S.O., London. (2 vols).
DONOVAN, D.T. and STRIDE, A.H., 1975. Three drowned coast lines of probable Late Tertiary age around Devon and Cornwall. Marine Geology, 19, M35–M40.
EDMONDS, E.A., MCKEOWN, M.C. and WILLIAMS, M., 1969. British Regional Geology—South-west England (3rd edn.) H.M.S.O., Londong (130 pp.)
GREGORY, M., 1947. The St. Erth Valley, with particular reference to alluvial workings during the war. Trans. Cornish Inst., Min. Mech. and Metall. Engineers, 2, pt. 6 (New Series), 19–24.
HAWKES, J.R., 1974. Volcanism and metallogenesis: the Tin Province of South-west England. Reprinted from Bulletin Volcanologique, XXXVIII-4, 1125–1146. (Paper presented at the IAVCEI International Symposium on Volcanism and Associated Metallogenesis, Bucharest, Rumania, Sept., 1973.)
HENWOOD, W.J., 1873. The detrital tin ore of Cornwall. Journ. Roy. Inst. Cornwall., IV, 191–254.
HOSKING, K.F.G., 1970. The nature of the primary tin ores of the South-west of England. A second Tech. Conference on Tin, Bangkok, 1969, III, 1155–1243. Pub. I.T.C., London.
HOSKING, K.F.G., 1979. Tin distribution patterns. pp. 1–70 of "Geology of Tin Deposits", Bulletin of the Geol. Soc. Malaysia, No. 11.
HOSKING, K.F.G. and OBIAL, R., 1966. A preliminary study of the distribution of certain metals of economic interest in the sediments and waters of the Carrick Roads (West Cornwall) and of its 'feeder' rivers. Camborne School of Mines Mag., 66, 17–37.
HOSKING, K.F.G., 1971. Problems associated with the application of geochemical methods of exploration in Cornwall, England. pp. 176–189 of Proc. 3rd Internat. Geochem. Exploration Symposium, Toronto, 1970, special volume II, Canad. Inst. Min. Metall.
HOSKING, K.F.G. and CAMM, G.S., 1980. Occurrences of pyrite framboids and polyframboids in West Cornwall. Journ. Camborne School of Mines, 80, 33–42.
HUTCHISON, C.S., 1983. Economic deposits and their tectonic setting. Macmillan Press Ltd., London (365 pp.).
JACKSON, N.J., 1979.Geology of the Cornubian Tin Field 'A Review'. Pp. 209–237 of "Geology of Tin Deposits", Bulletin of the Geological Society of Malaysia, No. 11.
KARTASHOV, I.P., 1971. Geological features of alluvial placers. Economic Geology. Vol. 66, 879–888.
LINTON, D.L., 1955. The problem of tors. Geographical Mag., 121, 480–487.
MACALISTER, D.A., 1906. Mining. Part II of the Geology of Falmouth and Truro and of the Mining District of Camborne and Redruth. H.M.S.O., London.
MILNER, H.B., 1922. The nature and origin of the Pliocene deposits of the County of Cornwall, and their bearing on the Pliocene geography of the south-west of England. Quart. J. Geol. Soc., 78, 348–377.
MITCHELL, G.F., 1966. The St. Erth Beds—An alternative explanation. Proc. Geol. Associ., 76, 345–366.
MOHAN, SURENDRA, 1967. The significance of the distribution patterns of certain elements in the stream sediments and waters of the Carrick Roads, Cornwall. Unpublished thesis for the Diploma in Mineral Technology, Camborne School of Mines (on open file at the C.S.M.).
ROBSON, J., 1943–44. Recent geology of Cornwall. Trans. R. Geol. Soc. Cornwall, XVII, 132–163.
TAYLOR, R.T. and BEER, K.E., 1981. Raised beach and mined fluvial Deposits near Marazion. Proc. Ussher Soc. Vol. 5. Part 2. 247–250.
THOMAS, W., 1913. Losses in the treatment of Cornish Tin Ores. Trans. Corn. Inst. Min. Mech. Metall. Engrs., 1, 56–74.
WOOD, A., 1976. Successive regressions and transgressions in the Neogene. Marine Geology, 22, M23–M29.

(Manuscript received on 10th November 1983)