PRIMARY ORE DEPOSITION IN CORNWALL

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Abstract

The author deals with the ores genetically connected with the Carbo-Permian granites: the primary zones, mineral sequence and associations, ore shoots; wall rock alteration and modern theory of the method of deposition. Reference is freely made to the published work and with the author's research and field work, this paper summarises present knowledge of the Cornish lodes, and corrects some misconceptions. It forms the sequel to the author's "Fissure Systems in Cornwall" : Trans. Roy. Geol. Soc. Corn. : Vol. XVIII, p.9.

MINERALISATION AND GRANITE INTRUSION

The problem of why abundant lodes are found associated with some granites and not with others of apparently identical chemical composition has been occupying the minds of geologists for years, and it has been suggested that the difference is due to the fact that in one case the country rock undergoing granitisation contained the elements which were later concentrated into lodes, and in the other case the country rock did not contain those elements in quantity. The latest variation of this theory has been put forward by Sullivan[1] who considers that the elements of the minerals now found concentrated in lodes associated with granites, were introduced into the crust by "volcanic" rocks, where they later resided as minor constituents in the ferro-magnesian minerals. Later, as a result of granitisation of these volcanic rocks, those elements which could not, by reason of ionic radii differences, be incorporated into the granite minerals (felspar, quartz, muscovite) became concentrated into the magmatic residuum and were finally deposited in contraction fissures.

Whilst undoubtedly the introduction of the elements into a given crystal lattice is controlled largely by the ionic radii of the elements concerned, yet other, as yet obscure factors must also exert some considerable influence, for Garretty[2] in discussing Sullivan's paper has shown that the average Pre-Cambrian granite contains sufficient ferro-magnesian minerals to permit of sufficient tin concentration within the granite, to make the whole rock, a valuable ore-body.

Edwards[3] has pointed out a further snag in Sullivan's theory by citing several examples of lode bearing granites which were intruded into pre-existing barren granites.

In Cornwall, there is a fairly close association between "volcanic" rocks (the greenstones) and the granite exposures, but all the evidence points to the Cornish granite as being of a subsequent type, (i.e. intruded into the country rock rather than developed from it). There is, of course, the possibility of granitisation in depth and subsequent refusion of the product followed by injection into higher horizons, but there is little evidence of this.

Following the granite intrusion phase, PEGMATITES (often with aplites), and small quartz-felspar veins, were injected near the contact. Sometimes the weak pegmatites were re-opened during the hydrothermal lode phase and valuable minerals (notably cassiterite and wolfram) deposited by replacement and fissure filling : such "metallised" pegmatites were found at Altarnun (Bodmin Moor), E. Pool, Dolcoath, etc.

There is little field evidence of this re-opening, but that small felspar-quartz veins closely allied to pegmatites, were re-opened, is shown by specimens the author has found on scores of mine-dumps in W. Cornwall. The "complex lode" of South Crofty is a pegmatite re-opened under waning temperature with the consequent deposition of first, cassiterite, tourmaline and quartz ; and later wolfram, chalcopyrite, quartz, chlorite and fluorite. Only two pegmatites, lacking heavy metals, have proved of economic value.

At Trelavour Downs, St. Dennis, a vein of banded pegmatite consisting essentially of coarse felspar and lithium mica has been worked to some extent for the mica from which lithium was obtained. No work has been done on this pegmatite for some years.

At Tresayes Downs, Roche, a dyke of very coarsely crystalline pegmatite consisting of felspar, quartz and tourmaline is situated in the slate very close to the granite contact and has been quarried for its felspar which was used in the ceramic industry. This pegmatite was worked to some extent during the last war. The rock was simply broken and the felspar extracted by hand picking.

Apart from these, small pockets of pegmatite and aplite occur commonly, well within the granite, e.g. De Lank, Long Downs, etc. They are of no economic value and probably represent trapped pockets of flux-rich magma.

Cornwall has no normal PYROMETASOMATIC ore deposits of economic value, but the characteristics of this type may be seen in the calc-flintas around the Bodmin and St. Austell granites, especially that carrying pyrrhotine, at Camelford.

The manganese deposit at Treburland with rhodonite, tephroite, etc., and pyrolusite, is an unusual type, which became of economic value as a result of secondary oxidation.

Primary Mineral Zones

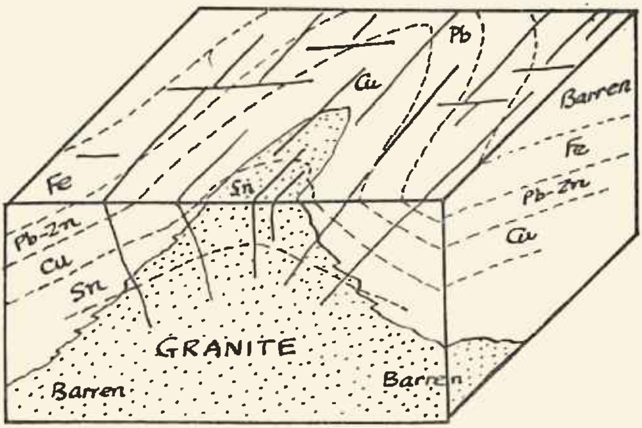
The most heavily mineralised areas in Cornwall are included in a zone about ten miles wide, which extends from St. Just to Tavistock, but the lode pattern seems to be controlled by granite ridges which may converge somewhat at those places where the granite is now exposed. It is evident from geological maps that within this ten mile zone there are several centres of mineralisation and that as one moves away from these centres, the lode content changes progressively. Near a given centre, tin is found and gives place laterally to copper, and the copper to lead and zinc ; such a state of affairs is clearly seen around the St. Agnes centre for example. These centres of mineralisation (termed by Dines "emanative centres") may be in the middle of the large granite outcrops as at Balleswidden, on the fringe of a granite outcrop as at Tresavean or associated with a small granite cupola as at Kit Hill. Dines[4] considers these emanative centres to be places where fissuring was sufficiently deep-seated and intense, to tap the magmatic end products.

As a result of extensive mining operations, it has been clearly established that the lode minerals of Cornwall tend to reach their maximum concentrations at different horizons, and these horizons have been termed primary zones. It has long been believed that this pattern has largely been controlled by temperature and Davison[5] erroneously visualised the zones as being parallel to the granite contact. In his opinion the deepest of the zones, the tin "zone," extends from a short distance above the granite (in the slate) down to a considerable depth (but probably not much below 3,500 feet) in the granite, followed by a copper-tungsten-arsenic zone extending "from some distance above the granite in the slate, to a shallow depth in the granite itself" so that it overlapped the tin zone to give a tin-copper zone, then followed by a lead-zinc-silver zone extending "well up into the slate, beyond the zone of contact alteration produced by the granite, down below the top of the copper zone, and finally followed by the iron-manganese zone which occurs in the slate well outside the zone of contact metamorphism downwards into the zinc zone."

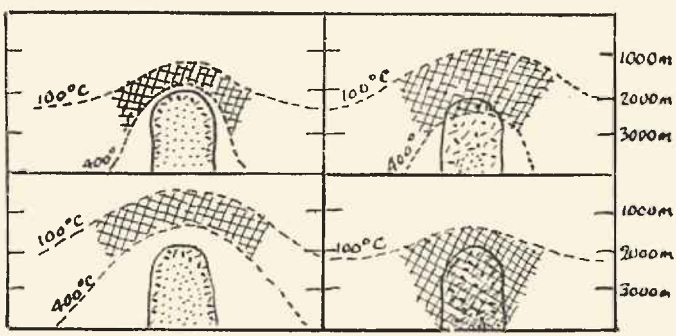
Whilst the order of the zones given above is correct and their positions with regard to the granite very approximately so, there is ample evidence to show that the primary zones are only very roughly parallel to the granite contact, that their boundaries are, in fact, much less steeply inclined.

Much work has been carried out on this subject by Dines who believes that immediately after the granite emplacement the isogeothermal surfaces were parallel to the granite surface, but that later, due to the variation in depth of the granite below the surface of the land that they tended to flatten out.

The shape of the isogeothermal surfaces derived by Dines from studies of the ore-bodies themselves agrees quite closely with the shape of those derived by Schneiderholn[6] from a more theoretical approach (fig. p.313). From this hypothesis, two important points emerge : that if temperature controlled the deposition of the lode minerals, they could occur equally well in the slate or in the granite provided the required temperature limits existed ; and, due to the variation in the distance between the granite and the surface, primary zones associated with a given emanative centre would be narrowest where the granite was nearest the surface and wider where the granite was deeper. Dines has produced ample evidence in support of the first point, but evidence of the second point is not available.



BLOCK DIAGRAM SHOWING ARRANGEMENT OF PRIMARY ZONES RELATIVE TO GRANITE – SLATE CONTACT. THE HIGHER ZONES ARE MORE EXTENSIVE LATERALLY.

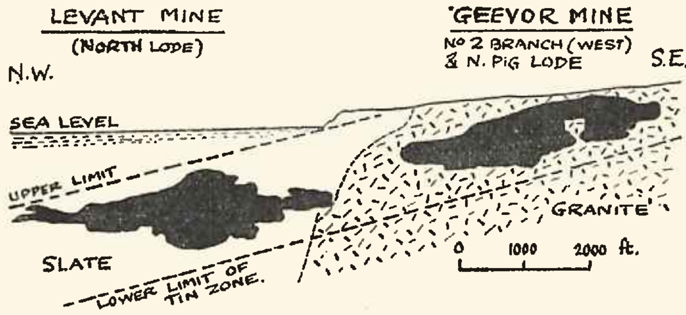


TEMPERATURE-PRESSURE CURVES DURING INTRUSION FOR HYDROTHERMAL MINERALS AT 100° & 400°C.

Fluid rock   crystallised rock

Favourable region for ore

(After H. SCHNEIDERHÖLN)



Projection of stoped areas (black) on same plane (after H. G. Dines)

Regarding the first point, tin was found almost entirely in the slate at Levant and almost entirely in the granite at Geevor, and by a suitable projection, it is clear that these two occurrences are members of the same temperature zone. Similarly, at Wheal Vor, tin was found entirely in the slate. Dines has also clearly shown that the higher the primary zone of a given series the greater its lateral extent and this he believes to be due to the greater fissuring of the rocks nearer the surface : for this reason, the rich copper-bearing lodes of the St. Day area produced little or no tin when explored in depth ; and copper has never been found in any quantity beneath the lead in the Newquay area. The section drawn by Dines (4, p.295) from Tresavean mine to Newquay, is very convincing and explains the facts as shown by mining operations.

The theory of primary zoning is of paramount importance to the mining engineer in that it enables him to supply answers to the following questions :—

1. Where are mineral deposits of a given element likely to be found ?

2. What minerals are likely to be associated with a given mineral in the Cornish fissure lodes ?

3. Will a mine which has produced copper become a tin producer if it is developed in depth ?

Mineral sequence in the Primary Zones

A great deal of work has been done on this subject and the relative spatial arrangement of both gangue and economically valuable minerals according to the beliefs of some of the more well known investigations, has been published.

MacAllister's sequence[7] of three zones, is one of the earliest, and not comprehensive. Cronshaw's sequence [8] was built up as a result of combined field work and microscopic examination of the lodes of the Camborne district and although it has been derived from studies in only one portion of Cornwall, it probably can be applied in a general way to the whole of the County. It does contain certain omissions (e.g. Co, Ni, U) because of the comparative rarity of certain minerals in the district in which he was working. Davison's sequence[9] was derived from microscopic study of veinstones and ores supplemented by much field work extending over many years. It was the most comprehensive to date.

Dewey's sequence[10] is of considerable value because the estimated thickness of the zones has been incorporated. For reasons given earlier, however, these thicknesses may vary considerably. The large vertical range of some vein minerals is also shown.

A more complete sequence is shown in the accompanying table : the lodes fall readily into two sets roughly at right-angles : there is however some overlapping in both direction and mineral-content.

PRIMARY ZONES OF CORNISH LODES

Gangue	Zone	Ore-minerals		Metals
Calcite.	7.	Barren : (pyrite).	MESO/EPITHERMAL. Lodes generally at rt. angles to granite ridges.	
Chalcedony, Baryte.	6.	Haematite, Göethite, Jamesonite, Stibnite, Pyrargyrite, Bournonite, Tetrahedrite, Siderite, Pyrite, Marcasite.		Fe Sb Ag
Dolomite.	5.	Argentite Pitchblende, Galena, Niccolite, Sphalerite, Colbaltite, Smaltite, (Bismuth, bismuthinite).		Pb Ag Zn U Co Ni Bi
Quartz, Fluorite	4.	Chalcopyrite, (sphalerite), Wolfram, Arsenopyrite, Pyrite.	HYPOTHERMAL. Lodes generally parallel to granite ridges.	Cu
Chlorite	3.	Chalcopyrite, (Stannite, molybdenite), Wolfram, Arsenopyrite, Cassiterite, wood tin.		W As
Tourmaline	2.	Wolfram, Arsenopyrite, Cassiterite.		Sn
Felspar, Mica	1.	Cassiterite, Specularite, (Earliest).		Fe

Order of arrival of Minerals

Whilst the foregoing sequence gives the relative position of the different minerals in relation to each other and to the emanative centre, the order in which they are arranged also appears to be the order in which they arrived generally in the fissures. This has been shown largely by examination of intersecting veins, but has been further indicated by the relationships exhibited among different entities in a given vein, for example, a brecciated mineral was formed earlier than the mineral cementing it. Thus it is to be expected from the table that cassiterite was deposited in fissures before chalcopyrite, and at a higher temperature, and that the former was the case is indicated in the North Pig Lode, Geevor, where brecciated cassiterite is cemented by chalcopyrite, and that the latter was the case was shown by direct temperature of formation measurements made by Smith on cassiterite and chalcopyrite obtained from a Cornish source.

From the combined results of Cronshaw and Davison, Rastall[11] has prepared the following table showing the order of arrival of the various minerals :—

Stages	Gangue	Ore Minerals
10	Calcite	Iron ores.
8, 9 / 7	Quartz	Zinc blende, galena, Chalcopyrite.
6	Chlorite	Arsenopyrite, Cassiterite, Wolfram, Chalcopyrite.
5	Fluorite	
3, 4	Tourmaline	
1, 2	Quartz	

As by far the greater quantity of low temperature minerals (galena, siderite, sphalerite, etc.), are found far from the emanative centres and there is a well marked zonal pattern in space to be seen, it would appear that the greater proportion of the magmatic residuum was deposited in a geologically short space of time. However, there is evidence to show that low temperature mineralisation did "drag on" for a long period of time under conditions of waning temperature, with a result that occasionally a given vein carries in the same horizon hypothermal and mesothermal minerals, but a still commoner indication is the finding of high temperature lodes intersected by later fissures, carrying lower temperature minerals at the same horizon. From the relative frequencies of these two types, it is apparent that though an early formed fissure may have re-opened many times, these re-openings usually covered a comparatively short space of geological time and often became completely sealed by the time low temperature minerals were being deposited in great amounts. On the other hand, Davison[12] and others believe that originally many of the tin-copper lodes may have carried at higher horizons, lead, zinc, etc., minerals, and that these have since been removed by erosion.

Surges of Mineralisation

Whilst Rastall's conception of the order of arrival of minerals is generally correct, the tables of Davison and Cronshaw show that a given mineral, e.g. cassiterite, was on occasions deposited at several different intervals of time, i.e. in a series of "surges" rather than a smooth undisturbed manner : this may have been due to a temporary blocking of the mineralising channels.

The onset of a surge would no doubt be accompanied by a local rise in temperature effected by the solutions themselves, and the degree of increase would vary from surge to surge. Thus if one surge quickly succeeded another, a given mineral might well be deposited during the later surge at a slightly higher horizon than the first. If, however, there was a considerable time interval between surges, it is possible that the associated temperature increase would be offset by the regional decrease, so that the second period of deposition of that mineral would take place at the same or even lower horizon than initially. This would explain why two definite wolfram zones have occurred at South Crofty.

It is believed that within a mineral-surge, any given mineral was always laid down within the same temperature range. The following diagram may clarify the possibilities :—

Surge 1	Surge 2 soon after Surge 1	Surge 2 considerably after Surge 1
$\dfrac{\text{Mineral B}}{\text{Mineral A}}$	$\dfrac{B\;\frac{B_1}{A_1}}{A}$ or $\dfrac{B\;B_1}{A\;A_1}$	$\dfrac{B}{A\;\frac{B_1}{A_1}}$ or $\dfrac{\frac{B}{A}}{\frac{B_1}{A_1}}$

Reaction between earlier deposited minerals and later mineral-solutions has frequently been demonstrated, and must be borne in mind when considering primary zoning, e.g. argentiferous galena may have been attacked by later solutions which liberated some of the silver and re-deposited it at a higher horizon.

The following examples are relevant to the above discussion :—

(a) LODES CARRYING HYPOTHERMAL AND MESOTHERMAL MINERALS, AT DIFFERENT HORIZONS.

West Seton. Sphalerite and copper ores to below the 100 fm. level and tin ore below that horizon.

Tresavean Mine. The shallowest lodes carried some sphalerite, replaced in depth by copper ores and they in turn, by cassiterite.

South Crofty. Reeves Lode carried chalcopyrite and sphalerite in the upper, and cassiterite in the lower horizons.

Dolcoath Mine. Several of the tin and copper lodes in the north of the sett, yielded much silver in their shallower portions[13].

(b) LODES CARRYING HYPOTHERMAL AND MESOTHERMAL MINERALS AT THE SAME HORIZON.

Wheal Vor. At the 162 fm. level in part of the Wheal Metal lode "wood tin occurred intermixed with ordinary crystallised tinstone, together with much chlorite, chalcedony, dolomite, felspar and pyrites." At the 70 fm. level "a bed from 2—7 feet thick came in from the Sozen Lode . . . full of veinlets of quartz, oxide of tin and blende."[13]

Wheal Trenwith. The east branch of the lode at 35 fms. contained quartz, slate, oxide of tin, vitreous copper (chalcocite) and pitchblende!

Trevaskis Mine (Gwinear). At 66 fms. in the lode striking 35° S. of W. contained "quartz, slate, blende, arsenical pyrites, oxide of tin, copper pyrites, galena, chlorite and traces of chalcedony, all mixed without any apparent arrangement." This is probably the best Cornish example of what Spurr terms a "telescoped ore-body."

Binner Downs (Crowan). "The lode contents between the walls are, besides much oxide of iron, native copper with its oxide, carbonates, and sulphides, in great variety, also blende, a little galena, much iron pyrites with chlorite and oxide of tin, often the whole mingled with slatey clay."[14]

South Crofty. A micro-section of the High Burrow Lode showed a stringer of quartz and tourmaline traversed by a stringer of fluorite and calcite.

Bellan Mine (St. Just). A lode of this mine carried cassiterite on both walls and as a result of later re-opening was infilled with comby quartz and finally with siliceous iron ore.[15]

South Tresavean Mine. ". . . the Engine Lode was worked for a considerable distance along the outcrop and at adit level it varied in width up to about three feet and yielded low grade tin ore. Pitchblende with Kupfernickel, native silver, and rich argentiferous galena also occurred."[7] (At the same horizon?—Author).

Perran Silver Mine. Regarding the silver lode of this mine, Jones[16] has written as follows :—"It appears to be of later date than the tin-copper lode, but the evidence on this point is not quite clear, for though the lode contains iron and silver ore, it yields also occasional masses of tin stone. It may be a spur from the main lode, re-opened and filled with new minerals at a later date."

Carclaze. A little galena and blende has been found in the predominantly tin-tourmaline veins in the kaolinised granite of this clay pit.

Holman's Quarry (Nr. Camborne). In this granite quarry a vein appeared to have had the following history of formation.

(i) Formation of fissure and deposition of quartz, garnet and tourmaline.

(ii) Brecciation, leaving fragments of the foregoing enclosed in mylonitic dust.

(iii) Deposition of green biotite and cassiterite.

(iv) Fracturing and deposition of fluorite and sulphides.

Wheal Verrant. According to Jones, a sample of tin from this mine, yielded nearly 100 ozs. of silver to the ton.

At this stage three somewhat exceptional examples may be cited :—

Wheal Towan : the Great Lode carried earthy brown iron ore, pyrites, quartz, chlorite, tin ore, copper pyrites and some blende in its upper levels, whilst in the depper levels, the lode was found to carry copper and iron pyrites and quartz coated with carbonate of iron.[7] (But apparently no tin ore — Author). Is this a case of a second generation of copper occupying a tin lode at a lower horizon than the tin and having associated with it, sphalerite of about the same age which occupied the same horizon as the earlier cassiterite ?

West Wheal Virgin. According to Carne, the Great Capel Lode which carried tin in the shallower parts of the mine became poorer in depth in tin but became richer in copper.

South Crofty. The Complex Lode of this mine carries wolfram and cassiterite and is being worked at the 315 fathom level, a horizon far below that in which the wolfram values of the mine had hitherto been obtained, as is clearly indicated by the Survey Memoir which says, "the distribution of the wolfram (at South Crofty) is irregular : it is most abundant in the middle levels and cannot be depended on below 245 feet."

This phenomenon, as well as that met with at Wheal Towan and West Wheal Virgin, might be the result of the very late injection of members of the same phase of mineralisation, or they both may be associated with a later period of granite intrusion. If the latter be the case, then some of the mesothermal ores found in the same horizon as hypothermal ores may belong to this later period of mineralisation.

Economically, the question is most important, for if the latter suggestion proves to be correct, then there may be another deep-seated tin zone below Carn Brea. It is, however, premature to discuss this subject further as the Complex Lode has not yet been sufficiently developed in depth.

(c) LODES CARRYING HYPOTHERMAL MINERALS, INTERSECTED BY LODES CARRYING MESOTHERMAL MINERALS AT THE SAME HORIZON.[13]

Wheal Metal. "The first great deposit (of tin) in the Metal Lode, was found at the outcrop of a cross-course (Woolfe's) carrying lead running nearly north and south . . ."

Budnick. ". . . the elvan near its intersection by the lead lode contained much tin and some copper in places."

Wherry Mine. The stanniferous porphyry was intersected by a lode carrying cobalt, nickel and uranium minerals.

Herland. The tin-copper lodes were intersected by a cross-course carrying "capillary native silver, acompanied by argentite and mispickel." (Probably this argentite was primary — Author).

St. Austell Consols. "Besides copper and tin, this mine yielded nickel, cobalt and uranium, but these mainly occurred in certain north and south veins which intersected the tin lodes."

Newton and Queen Mine. The Harrowbarrow Lode, carrying a little cassiterite and pyrite was intersected by the Well Lode, the minerals of which comprised "native silver, pyrargyrite, and argentite, mingled with chalybite . . ."

(d) LODES WHICH REPEATEDLY RE-OPENED FOR BOTH HYPOTHERMAL AND MESOTHERMAL MINERALS TO BE DEPOSITED.

Balleswidden and Wheal Castle. "The lode varied from 4 to 7½ feet and consisted of quartz, limonite, and oxide of tin, with some pyrites, galena and blende, pearl spar."

Botallack. The primary minerals in the Crowns Lode were : cassiterite, arsenic, antimony, quartz, aragonite (primary?) bismuth, bismuthinite, sphalerite, cobaltite, chalybite, magnatite, mispickel, tetrahedrite, pyrrhotite.[18]

This mineral assemblage ranges from hypothermal to possibly epithermal.

Dolcoath Mine : primary minerals given by Collins, who says that "nearly, if not quite all" were found in the Main Lode :—amethyst, argentite, arsenic, bismuthinite, blende, cassiterite, chalcopyrite, chalybite, cobaltite, dolomite, fluorite, chlorite, tourmaline, quartz, chalcedony, galena, garnet, marcasite, mispickel, orthoclase, pitchblende, proustite, pyrargyrite, pyrites, smaltite, wolfram.

THE MINERALS OF THE PRIMARY ZONES

Examination of the various primary zone tables indicates that in general they are in agreement. The author believes that it is safe to assume that the order of the major gangue minerals was :—tourmaline, chlorite, fluorite and carbonates, and that quartz is formed in all but the latest zone : and that the order of the major economically valuable minerals was :-cassiterite, wolfram, chalcopyrite, cobalt, nickel and uranium ores, sphalerite, galena and siderite.

Because some elements did not generally occur in economic quantities, or because they did not exist in certain areas, or because the element or mineral in question seemed to occupy different zones in different areas, there are omissions to be found in all the tables. The following notes will supplement the tables.

(A) The gangue minerals.

Orthoclase.

Both orthoclase and microcline have frequently been found in high temperature lodes and the gradual decrease in felspar content, when the series granite—pegmatite—"metallised" pegmatite—hypothermal vein, is considered, clearly indicates that the processes of mineralisation is the concluding phases of igneous activity. It is possible that some of the lodes carrying felspar, are in truth pegmatites which have been re-opened and mineralised by filling and replacement. It is also possible that some of the lodes may be found to pass into granite pegmatites in depth, as indeed a small quartz-arsenopyrite vein is seen to do at Tremearne. On the other hand the inclusion of certain minerals in felspar, seems to indicate that on some occasions at least it can be considered as a true gangue mineral. It is included in Zone 1.

Examples : South Crofty. At Hosken's stope (when seen by Cronshaw) the New Lode was enclosed in slate walls and had an outer zone of felspar enclosing crystals of mispickel and traversed by fine stringers, followed by the intermediate bands which "contain intimately associated, mispickel and chalcopyrite, out of which grow long idiomorphic and undisturbed crystals of quartz, which go to make up the central portion of the lode."

Wheal Owls. A lode striking 15° S. of W. contained at a depth of 16 fathoms below surface "brown iron ore, pale buff-coloured felspar, schorl and oxide of tin."[14]

Botallack. The south branch (69 fms.) contained "numerous minute veins of buff felspar and crystallised oxide of tin, with very little iron pyrites."

Albite was found at Wheal Metal associated with wood tin, crystallised cassiterite, chlorite, chalcedony, dolomite, pyrite and sphalerite. It is of interest to compare this example with an example described by Kutina from Krupka (Bohemia) where the succession quartz-cassiterite-albite-fluorite carbonates of Ca, Fe, Mg was established.[19] Albite was also recorded in a pegmatite, together with garnet and cassiterite at Dolcoath.

It is probable that this mineral should be placed in Zone 1 and/or 2. This is to some extent confirmed by the fact that recently Smith synthesised both albite and tourmaline together.[20]

Topaz. At St. Michael's Mount topaz is found in veins and in the greisen bands bordering the veins and is associated with cassiterite, wolfram, fluorite, etc., whilst at St. Austell Hill Mine, it was found in a lode in the granite associated with cassiterite, quartz, tourmaline and felspar. It is a true but rare gangue mineral and should be placed in Zone 1.

Apatite. This is a comparatively rare gangue mineral, but has been found in several Cornish localities, usually associated with tourmaline, cassiterite, gilbertite and allied minerals.

It has been frequently seen in thin sections of the greisen of the St. Michael's Mount lodes, where some of it may be an original granite constituent but on the other hand, the author has found there, a boulder containing a portion of a vein filled with good blue apatite crystals.

Apatite occurred as a gangue mineral in some of the St. Agnes lodes and a specimen examined by Le Neve Foster, showed the following deposition sequence :—1. Quartz ; 2. Cassiterite ; 3. Tourmaline ; 4. Apatite.

Apatite crystals have also been found by the author in veins with quartz and gilbertite at Tregargus china-stone quarry and in the Tremearne pegmatites associated with gilbertite.

It should probably be placed in Zone 1.

Micas are found entirely in high temperature veins with minerals of the first two zones.

At Wheal Coates small veins in slate frequently show a border of white mica and an infilling of quartz and cassiterite.

Examples of the association of gilbertite with cassiterite and allied minerals have already been noted and Balleswidden supplied further examples of the gilbertite-cassiterite-tourmaline-quartz association.

Fluorite. Davison shows only one period of fluorite formation but Cronshaw shows two, one before and one after the deposition of galena. In making this statement, he has followed Le Neve Foster, who found at Wheal Mary Ann, that two periods of fluorspar deposition were separated by a period when galena was deposited.

Barytes has occasionally been found as a gangue mineral in Cornwall. At the Ale and Cakes Mine (Gwennap), there was a good deal of the mineral associated with chalcopyrite at the 170 fathom level. In the Mary Ann Trelawney Lode of East Cornwall, barytes was associated with calcite, siderite, galena and fluorite. At Trehane it was associated with fluorite. It should therefore be placed in Zone 5.

Celestine has only been recorded from Binner Downs Mine, where it was found in the South Lode associated with chlorite, cassiterite, blende and galena. Probably should be placed in Zone 5.

Calcite. Cronshaw has probably quite correctly placed calcite at the end of his table. Davison, however, omitted it, even though he was aware of its presence, as he notes that wolfram from the East Pool Mine altering to scheelite is often associated with calcite crystals.[21] Le Neve Foster noted at Wheal Mary Ann that calcite was a very late arrival. It should be placed in Zone 6.

Garnet. In Cornwall, garnet (a rare gangue mineral) has been found in metallised pegmatites in the granite, in somewhat peculiar hypothermal veins both within the granite and in "dolerite," and in mesothermal veins associated with dolerite.

Pegmatite in granite : at 360 fms. in Dolcoath new shaft a pegmatite was cut carrying pink garnet, quartz, orthoclase, albite, muscovite and cassiterite.[21]

Hypothermal vein in granite : at Holman's Quarry, Troon, a vein carried pink garnet (almandine), green mica, quartz, fluorite, cassiterite.

Hypothermal vein in dolerite : in some of the deeper workings of the South Lode of Botallack, and especially at the 338 fm. level, chalcopyrite and a cinnamon coloured garnet are closely intermixed to form a rock described by the miners as "spelter." The country rock is "dolerite" and slate. At Wheal Devonshire (St. Agnes), the lode carried in places, copper ore associated with fluorite and black brilliant garnets.

Mesothermal vein in "greenstone" : the lode at Great Retallack consisted of hornblende, brown garnet, sphalerite and calcite. It is probably associated with dolerite.

It is clear that garnet development outside the granite is associated with the reactions between the mineralising agents and the country rock. The occasional development of garnet in pegmatites and lodes within the granite is more obscure, but may possibly be correlated with absorption of, or reaction with basic clots or accidental xenoliths. A xenolith recently found at Luxulyan contained red garnet. The development of the high-pressure mineral garnet, both in hypothermal and mesothermal portions of the lodes, seems to suggest that high-pressure conditions prevailed in the lodes during the time of primary mineral formation and that they probably were not therefore in communication with the surface. This is in accordance with certain lode structures to be discussed later, which seem to indicate stagnant conditions during mineral deposition, a state of affairs hardly likely to have pertained had the fissures been open to the atmosphere. Garnet obviously cannot be referred to any special zone.

Amphiboles and Pyroxenes are only rarely found as gangue minerals and where they do occur, they have obviously resulted from interaction between the mineralising agencies and dolerite. The case of hornblende occurring at Great Retallack has already been mentioned. Hedenbergite also occurs here. At Magdalen Mine (Ponsanooth) the lode consisted of a very dark banded rock which, examined in thin section, resolves itself into green actinolite — rich bands, actinolite-cassiterite bands, and magnetite-actinolite bands.

At Pendour Cove where granite veins are injected into dolerite, specimens (of veins?) have been obtained which in section show an association, of orthoclase, green hornblende and cassiterite.

Tourmaline, Chlorite.

Discussion of these minerals has been deferred until wall rock alteration has been dealt with.

(B) The ore minerals.

Molybdenite.

This mineral has been found by the author in the greisen of Cligga and at Carn Brea, bordering veins which carry wolfram and cassiterite but usually no chalcopyrite, and must therefore be a mineral associated with the first three zones.

At Wheal Unity, however, it was found associated with the following primary minerals : sphalerite, chalcopyrite, mispickel, fluorite, jasper and iron pyrites, and therefore it may well be a member of Zone 3 ; this is indeed where Davison suggested it should be.

Davison made the following relevant comment : "The lodes (i.e. those situated in the neighbourhood of ridges and granite cupolas) are of coarser texture than usual and sometimes show a pegmatite-like structure, the chief minerals being quartz, chlorite, mispickel, wolfram and cassiterite ; tourmaline is not usually present in large quantities, fluorspar is often present, and molybdenite, stannite and pyrite are occasional constituents."

Cassiterite-Wolfram.

Much discussion has taken place as to whether cassiterite was formed before wolfram or vice-versa. Dines has made the following remark, "The lode here (i.e. in the West of England) is often of a complex nature, the wolfram occurring in quartz, sometimes at one wall, sometimes the other, but usually in small strings ramifying irregularly across the tin lode."

Jones as a result of examination of evidence obtained directly by himself in the field and that obtained by others, is of the opinion "that deposits in which cassiterite and wolfram occur in intimate association, were formed in a lower temperature zone than were the bulk of the tin deposits free from wolfram and that cassiterite is a higher temperature mineral than wolfram."[22]

MacLaren[23] has made the following observations on this problem as a result of study of the East Pool lodes :—

> "The wolfram zone occurs near the top of the tin zone. In the Great Lode, wolfram was most plentiful from the 140 to 190 fm. levels. In the Rogers Lode, so far as it has been explored, wolfram is most abundant on the 196 fm. level. In the latter lode, however, the top of the tin zone is some 25 to 30 fathoms lower than in the Great Lode. The downward succession of economic minerals in the East Pool is roughly : copper ores from surface to 140 fms., wolfram from 140 to 200 fms., and tin 140 to 340 fms. (south dipping lodes) and possibly to 450 fms. (north dipping lodes). It is impossible to ascribe the vertical succession of minerals to any other cause than to decreasing temperature of metalliferous solutions with approach to surface."

Campbell who is in the opposite camp to those quoted above, visited (1920) several of the Cornish mines in which wolfram and cassiterite occur together, to study their order of deposition. In his opinion many specimens showed wolfram preceding cassiterite, but others who examined them did not agree. He considers that wolfram is earlier than cassiterite in Burma also.[24]

The author of the Tungsten and Manganese Memoir, in commenting on the wolfram deposits at Cannaframe (Altarnun) says that wolfram occurs as an original constituent of pegmatites whilst cassiterite is only found there in later veins. It is possible, however that the wolfram may have been introduced later into the pegmatites and therefore may be later than the cassiterite of the area.

Williams, who is of the opinion that wolfram may have formed before cassiterite in the Stewart Island veins, put forward the following suggestion as to why sometimes wolfram is formed before cassiterite and sometimes the reverse appears to hold :—"Cassiterite is probably produced in accordance with Daubrée's reaction ; and it is possible that wolframite is produced by the action of H_2O on WF_6 in the presence of iron and manganese. Reactions in such reactive systems are governed by the law of mass actions. If the ratio W/Sn were large, wolframite would be deposited before cassiterite ; if it were small, the minerals would be precipitated in the reverse order. The physical state of the reacting substances has no influence on the actual reactions . . ."[25]

Smith[26] by direct measurement of the temperature of formation of Cornish samples of cassiterite and wolfram has shown that whilst the former was deposited at 390°C. the latter was deposited at 265°C.

The author has carefully examined all the Cornish slides showing both cassiterite and wolframite in the collection of the School of Metalliferous Mining, Cornwall, and in no case has he found any evidence of wolfram being deposited before cassiterite. In one slide of ore from South Crofty, however, wolfram has clearly moulded itself around two sides of a cassiterite crystal.

In this connection it has been shown that at Castle-an-Dinas Mine cassiterite occurs in the walls adjoining the fissure lode whilst wolfram is found in the vein itself and in veinlets of the main vein. As far as the genesis of this ore-body is concerned the most reasonable assumption is that the cassiterite was deposited in the wall rock from mineralising agencies that travelled up a fissure which was later infilled largely with quartz and wolfram.

The author believes that cassiterite and wolfram were deposited during several phases of mineralisation : the cassiterite first, at a higher temperature than wolfram. If the concept of surges is correct, it is easy to understand why either mineral may appear earlier or later. He also agress that the relative concentration of the materials in solution, may reverse the order of deposition.

Specular Haematite.

The most conclusive evidence that Davison was correct in placing specular haematite in Zone 1, was found at Birch

Tor (Devon) where the mineral occurs intimately associated with cassiterite and tourmaline.

Specular haematite is not uncommon in the mines around the northern edge of Carn Brea, and specimens of the mineral sprinkled on quartz crystals in druses can be found without much difficulty. Cronshaw found similar material to be the latest component of portions of South Crofty No. 1 and No. 2 Lode. The latter lode consisted of fragments of quartz-cassiterite-tourmaline cemented by quartz, and in small cavities of the latter were crystals of siderite, fluorspar, haematite, pyrites and a "green coloured kaolin-like substance." It is clear therefore, that Cronshaw was correct in placing it in both Zone 1 and Zone 6.

Certain late N.—S. lodes of the St. Austell area contain considerable quantities of red haematite and limonite. These minerals have been derived in part from the oxidation of siderite and in other cases from haematite of the Davison Zone 6 period of formation.

Davison was in error in placing limonite amongst primary minerals in his table of zones : it is replaced by Göethite, which at Restormel, appears to be primary.

Wood Tin and Stannite.

The circumstances under which wood tin was found in a lode at the 200 fathom level near the Metal Shaft in Wheal Vor, clearly indicates that it is, at times a primary mineral. At Wheal Vor the "wood tin appeared as a cementing material binding together fragments of killas, and some of it was sprinkled over with brilliant crystals of tin oxide . . . " (13, p.177).

The mode of occurrence of wood tin in the Garth Mine (Penzance) and the close association of cassiterite with wood tin at Polberro (St. Agnes) strongly suggests that in both these places wood tin is also a primary mineral.

However, stannite is of not infrequent occurrence in the Cornish lodes, and at Cligga for example, it can often be found in a partial state of oxidation to malachite. It has been suggested that wood tin may develop from the breakdown of stannite, and though this has not been definitely proved, it is almost certainly correct. Thus, although much of the Cornish wood tin is probably primary, some may be secondary after stannite.

Stannite has been found by the author associated with arsenopyrite and chalcopyrite in the Cligga tin-wolfram lodes and it appears to be one of the earliest sulphides to be deposited. It should probably be placed in Zone 3.

Bismuth and Bismuthinite.

These minerals have been found in various parts of the world in pegmatites, pyrometasomatic deposits, hypo-, meso-, and epi-thermal deposits, and they appear therefore somewhat more independent of temperature, as far as deposition is concerned, than many other minerals. In Cornwall, however, the somewhat scanty evidence suggests that both minerals commonly occur together, accompanied by cobalt ores as at Wheal Sparnon, Wheal Herland, Wheal Beauchamp and Pengreep.

At Dolcoath the two minerals were associated with fluorite.

At Great Dowgas Mine native bismuth was associated with fluorite.

In Williams Lode at Fowey Consols bismuthinite was found in druses in the lode which contained chalcopyrite, siderite, and quartz.

At Botallack native bismuth was found in veins in jasper.

At Balleswidden Mine bismuth and bismuthinite were found associated with cassiterite, wolfram, quartz, tourmaline, and fluorite and they may therefore have been deposited earlier than in the localities mentioned above. This obviously does not follow necessarily but evidence is not available to enable a decision to be made.

The evidence available suggests that these minerals should be placed at the bottom of Zone 5.

Sphalerite, Galena, and Antimony minerals.

Examination of the literature shows that the following associations are fairly common:—Chalcopyrite and sphalerite: Sphalerite and galena : Galena, stibnite and jamesonite.

Many cases are known of lodes carrying chalcopyrite and sphalerite, associated with, and striking parallel to chalcopyrite-cassiterite lodes. Some lodes carry sphalerite, chalcopyrite and cassiterite in successively deeper zones. On the other hand, it is exceedingly rare to find galena in lodes carrying tin or in lodes parallel to, and near cassiterite lodes. Lodes carrying chalcopyrite, sphalerite and galena, or largely sphalerite and galena most commonly have strikes which vary by a large angle from those carrying cassiterite, and in some cases the copper-lead-zinc lodes can be shown by examination of intersections to be definitely later than the tin lodes. Literature is singularly barren of descriptions of such lodes from which the paragenesis can be definitely established.

Specimens obtained by the author from Wheal Rose, Porthleven, show that here the order of deposition was arsenopyrite, chalcopyrite, sphalerite, quartz, galena, siderite and dolomite. Specimens from Wheal Alfred (Hayle) and Lambriggan, show that in some cases chalcopyrite and sphalerite were deposited together, whilst in others, the chalcopyrite was earlier or later. The arguments advanced for tin-tungsten deposition apply here.

In East Cornwall many examples of stibnite and jamesonite bearing lodes which become galena bearing lodes in depth have been described,[27] for example at Wheal Boys (Endellion) jamesonite and stibnite are found in the upper part of the lode but the ore in depth changes to galena. Jamesonite itself was usually formed somewhat later than stibnite and at Poltreworgey Mine (Endellion) jamesonite was found in the top of the lode but in depth the ore changed to stibnite.

Sometimes either sphalerite or galena is missing from the sequence of minerals deposited. Thus, at Trenute Mine, Lezant, the lode consisted of siderite, sphalerite, pyrite, calcite and stibnite, whilst at Treore Mine the lode contained siderite, mispickel, chalcopyrite, galena, gold, jamesonite and stibnite.

It appears then, that generally, the early tin-copper lodes were often re-opened, up to and including the time of the deposition of sphalerite, and towards the end of this phase, fissures, usually differing widely in strike from the earlier ones were initiated, and in them chalcopyrite, sphalerite, galena, stibnite, jamesonite and silver ores were deposited in that order. There was often some overlap as far as deposition was concerned, in time and space, of a given mineral by a succeeding one.

It is of course possible that some or all of these minerals may have been deposited in the upper horizons of the tin-copper lodes but that they have since been removed by erosion. The author, however, does not believe this to have happened often.

The following examples substantiate the above statements :—

(a) LODES CARRYING SPHALERITE AND STRIKING PARALLEL TO OR CLOSELY ASSOCIATED WITH TIN-COPPER LODES.[28]

Wheal Prudence (St. Agnes), N. Lode : quartz, slate, copper, and iron pyrites with some sphalerite and cassiterite.

Tresavean Mine (Lanner) : Some sphalerite was found in the upper levels, but in depth this gave place to chalcopyrite and this at still lower horizons to cassiterite.

Seton Mine (Camborne); S. Lode : quartz, iron and copper pyrites and sphalerite.

(b) EXAMPLES OF TYPE (a) LODES CARRYING ALSO GALENA (7, p.181).

Trevaskus Mine (Gwinear).

North Wheal Busy (Scorrier): tin and lead occurred together.

West Roskear (Camborne) : in a caunter lode, lead, zinc, copper, tin, and iron pyrites were present.

North Wheal Jane (Truro) : Tin, lead, and zinc occurred in the same lode.

(c) EXAMPLES OF LODES CARRYING SPHALERITE AND GALENA.

Lodes of zinc and lead far from tin lodes.

Wheal Rose (Porthleven).

Lambriggan Mine : pyrite, yellowish-green sphalerite and galena.

Wheal Chiverton[29]: quartz, galena and sphalerite.

Lodes of lead and zinc intersecting tin type lodes.

Wheal Metal.

Wheal Budnick.

New Consols (near Callington). Several small N.—S. lodes carrying galena, siderite and quartz intersect the E.—W. tin lode.

(d) EXAMPLES OF LODES CARRYING STIBNITE, JAMESONITE, AND/OR GALENA.

Pengenna Mine (St. Teath).

Wheal Boys (Endellion).

Argentite and other silver ores.

Argentiferous galena is a solid solution of argentite in galena and therefore it is probable that when free argentite or other primary silver mineral exists in a lode carrying galena that is not very argentiferous, that the silver mineral was formed after the galena had crystallised. Thus Old Treburgett was remarkable for its occasional oreshoots of rich antimonial silver, though the lead ore itself was usually poor in silver.

Much of the galena in Cornwall is argentiferous and the silver content varies from one horizon to another in the same lode in a manner which cannot be predicted. Thus galena from the shallower parts of the Tamar Mines contained about 145 ounces of silver to the ton, but from the deep levels, 35 to 40 ounces. On the other hand, the richest argentiferous galena at Wheal Trelawney obtained from a depth of 105 fathoms afforded 0.001376 its weight of silver and from 210 fathoms 0.001516. (Henwood). Furthermore, despite the common occurrence of argentiferous galena, free silver minerals are comparatively rare.

That argentite was formed fairly late, is indicated by its presence in some cross-courses intersecting copper lodes, as at Wheal Herland, where it is associated with arsenopyrite. At Wheal Ludcott, a considerable quantity of argentite, associated with native and ruby silver ore and siderite, was found at the 70 fm. level where the galena lode was intersected by a later fissure. In the more easterly N.—S. lode between the 93 and 110 fm. levels, single crystals of slightly argentiferous galena were embedded in large bunches of argentite.

The evidence, therefore, shows that both silver and lead were often deposited together as argentiferous galena, but that the silver lead ratio was very variable. Only rarely did silver continue to enter the lode after all the lead had been deposited and when this happened, the silver was most commonly deposited as argentite and this mineral should be placed therefore, immediately above galena in Zone 5.

In several areas silver-arsenic and silver-antimony sulphides are met with. At Wheal Ludcott, besides argentite, pyrargyrite, proustite and stephanite were also encountered. At Newton and Queen Mine a lode containing argentite, pyrargyrite was worked. At both mines the complex silver sulphides are closely associated with siderite and it is probable that they should be placed between argentite and stibnite in Zone 6. This is further substantiated by the occurrence of antimonial silver with galena low in silver at Old Treburgett. This association presumably resulted because the galena had largely been deposited before the silver and antimony solutions had entered the lode.

Probably tetrahedrite and bournonite should be bracketed with pyrargyrite and allied silver minerals in Zone 6. In this connection it is of interest to note that an analysis of tetrahedrite from Crinnis Mine made by Michell showed 1.8% silver.

That bournonite is a late deposited mineral, is suggested by the fact that at Rose Mine, Endellion, it was associated with jamesonite.

Argentiferous arsenopyrite occurred at Wheal Mary (Redruth), associated with cobalt ores and is probably replacement of an early sulpharsenide by a later sulphide.

The literature relating to Cornish geology is not useful in providing clear evidence of the relation of the silver minerals to each other and to other minerals, neither is it very helpful, as stated earlier, in providing clear evidence relating to problems in paragenesis generally.

There is little evidence to show whether or not any of the argentite or complex silver sulphides are supergene, but they are frequently associated with native silver and sometimes with cerargyrite both of which are unquestionably supergene.

Finally, it is possible that silver sulphantimonites/ sulpharsenites together with tetrahedrite, bournonite and jamesonite, may have been formed by ascending solutions, which partially dissolved earlier sulphides and re-deposited them in new combinations at higher horizons.

Cobalt, nickel and uranium.

In the St. Austell district a series of roughly N.—S. lodes intersect the tin lodes and not uncommonly carry nickel, cobalt, and uranium. At St. Austell Consols for example the main lode carried tin and copper ores, with a little cobalt and arsenic, while nickel, cobalt and uranium were found in the later N.—S. lodes.

It would therefore appear that the three elements should be placed above chalcopyrite in the primary zone table (where, indeed, Davison placed them). In the above example the indication is that cobalt is the earliest of the three metals to be deposited. Not infrequently, only one or two of the three elements in question were present in a given lode, as at Wheal Chance (nickel); at Holman's Quarry (cobalt); at Fowey Consols (nickel); at Dolcoath uranium was associated with cobalt, but nickel was absent. This failure of parts of a zone to be deposited in a given lode or area is a common phenomenon both in Cornwall and elsewhere.

Manganese.

Many of the late iron lodes in and near the southern portion of the St. Austell granite mass, carry oxides of manganese and iron. Pyrolusite is the commonest oxide encountered, but psilomelane and manganite have also been reported (e.g. at Restormel Mine). The source of the pyrolusite and psilomelane was probably siderite, as this mineral has been recorded from late N.—S. lodes and siderite generally carries a few per cent of manganese. The only analyses of siderite of Cornwall available to the author is that from Treamble and this carries, according to these analyses, sometimes 5% or more of the oxide of manganese. In this connection it is of interest to note that in the north of England the product of oxidation of both ankerite and chalybite is a mixture of hydrous ferric and manganese oxides.

Manganite may have contributed towards the secondary oxides of manganese, but it has not been found in quantity in any Cornish lode. Similarly also rhodonite and rhodochrosite could have been the parent manganese minerals. However, as these minerals are unknown in lodes in Cornwall connected with the granite intrusion, it is unlikely that the secondary oxides were derived from them.

If then manganese is included in the primary zone table it should be bracketed with siderite. Davison was certainly in error in placing pyrolusite in his primary zone table.

THE MINERAL PATTERN OF CORNISH LODES

In an earlier paper the overall lode pattern of Cornwall was dealt with together with the strike and dip patterns met with in the various mining districts. Also portions of pattern of individual lodes such as brecciation, slickensides, etc., which were due to physical causes, were described. These lode patterns have been made still more complex by the mineral pattern which has been superimposed over the physical one. As a result of the numerous physical and mineralogical combinations which were available during the period of metallisation, the lode patterns met with in Cornwall are extremely numerous, but on examination they are found to have been built up either in one of the following ways or by a combination of them :—

1. **By filling of a fissure in one or several operations** consisting of re-opening inside the initial fissure walls, and with or without displacement of the fissure walls, and with or without alteration of the wall rock. These processes result in a lode showing either a mosaic, banded, brecciated, conglomeroid or cockade pattern within the fissure which may or may not be bordered by a zone of altered country rock which may carry values.

Lodes which are essentially filled, unbranched fissures, and are comparatively simple, structurally and mineralogically, are found in the lowest horizons of the mineralised tract, usually in the granite, but always near emanative centres ;

also in regions far from emanative centres where they contain galena, siderite, stibnite and allied minerals ; or simply barren quartz.

Examples of the first type are the greisen-bordered veins of St. Michael's Mount and elsewhere, whilst an example of the latter type is the N.—S. striking Mary Ann Trelawney lode which carries siderite, galena, etc. The country rock near low temperature veins generally shows much less alteration than those of the high temperature type : the intense alteration of the slate associated with the lead lode of Red Moor is a notable exception.

In this category may also be included stockworks and other related bodies, for in these, the veins are small and extremely simple and values usually confined to the fissures. Examples of these types are as follows :—

Mulberry, Lanivet. This deposit has been worked by open-cast methods and consists of numerous veinlets varying in width from mere joints up to four or five inches, and which, though showing numerous intersections, strike generally in a direction N. 7° W. These veins are in ash grey slate and carry quartz, cassiterite, mispickel and wolfram.

The Wherry Mine, Penzance, was situated on a metallised porphyry just off the coast. The dyke was 18 feet wide and intersected by numerous, small, rich ramifying veinlets carrying chiefly cassiterite : the porphyry also contained very considerable quantities of this mineral. Whether a master vein supplied the cassiterite worked in the porphyry, or whether the intensely fractured porphyry was the channel for the ore solutions, is unknown.

Wheal Metal : the Metal Lode consisted of a quartz infilling in which cassiterite occurred chiefly at the junctions of this with other lodes. In some portions, however, the wall rock supplied considerable values for as much as 20 to 30 fathoms from the main fissure on account of small veinlets carrying cassiterite, branching out from the main fissure along joints and cleavage planes in the slate, so as to form in the words of Collins, "a veritable cassiterite schist."

Park of Mines : N.—S. striking master veins have "sent off" numerous parallel veins along the cleavage planes of the light coloured slate, which are roughly at right-angles to the master veins. These veins, varying in width from a mere knife-edge to one or two inches, usually consist only of quartz, but they are occasionally filled with cassiterite, tourmaline and quartz. The slate on each side of the veins has been locally hardened and tourmalinised.

The entire rock constituted the ore body, and was removed and sent to the mill.

2. **By the infilling of a series of closely spaced fissures** causing the development of a lode characterised by inclusions of parallel, country rock partings. The contents of the fissures of such a lode may show any of the patterns described under 1.

The standard example of a lode of this type occurred at Fowey Consols and is described fully below.

Partings of country rock have been found not infrequently in both hypothermal and mesothermal lodes in Cornwall, though no case is known to the author where it was as highly developed as in the Fowey Consols Mine.

Undoubtedly failure to recognise the possibility of lodes built up by this method have resulted in certain parts of lodes being overlooked during operations. The miner has mistaken a parting for the (true) wall of the lode.

A similar structure was described from King Edward Mine where partings of fault clay occurred in the lode.[31]

The presence of horses in Cornish lodes is a further related structure.

Fowey Consols example : a portion of a vein consisted of numerous veins of quartz each separated by partings of the slate country. The lode was developed parallel to the cleavage planes in the slate and was the result of successive fissuring and infilling ; the fissuring in each case taking place in the country rock.

3. **By the development of one or more fissures along which mineralising agents move and alter the country rock** adjoining the fissures, bringing about the development there of economically valuable minerals. The fissures themselves, may, in the

completely developed lode, either be insignificant and barren, or of reasonable size and ore bearing.

This mode of formation in which values were deposited partially or entirely in the wall rock was the most important one in the development of the majority of the great tin and copper lodes of Cornwall.

Whilst lodes thus formed are of common occurrence in the tin and copper horizons, they are very rare and probably entirely absent from the lead-iron-antimony horizons.

Sometimes the master fissure or fissures of such lodes are of considerable width and highly mineralised, but frequently they are barely visible, a fact which led Collins to believe that certain deposits of this class found in the granite were quite unassociated with any master fissures, and indeed were true magmatic segregations.

Replacement deposits reach their maximum development in the St. Ives area where great ore-bodies called carbonas were developed in the granite.

The ore-pipes of E. Wheal Lovell are further examples of ore-bodies having this method of formation.

Many of the important tin lodes of the Camborne-Redruth area belong essentially to this type, and replacement characteristics are usually most marked near the granite-slate contact. Often the replaced country rock portion of the lode is rich, not so much because of the cassiterite deposited within the rock, but rather because considerable quantities of that mineral have acted as a cement for the country rock which had become highly fractured as a result of wall rock movement.

Such lodes in the vicinity of the granite contact often show a most complicated pattern and frequently all three methods of formation have contributed towards their development. Cronshaw's sections[8] illustrate this clearly, and he has shown that such lodes become simpler in structure and minerals, when traced away into slate or granite : at different horizons, a lode may show very different patterns, e.g. the shallow parts of Dolcoath Main Lode were of distinct combs of quartz and copper ore . . . the deep tin-portions composed of irregular, numerous bands of tin ore separated by siliceous capel.

The following examples are representative of Method 3 :—

(a) Carbonas :—These irregularly shaped deposits are exceptional developments of ordinary lodes, and always associated with cracks or joints. They are pipe-like or irregularly shaped bodies of tin-ore, schorl, chlorite, quartz, etc., and owe their origin to alterations and mineralisation of country rock (granite) near the vein, which is frequently at right-angles to the ordinary lodes of the county.

Providence Mines (St. Ives) : showed a vertical carbona of quartz, felspar, schorl and tin-ore 30 x 15 x 4-36 ft., connected to the Comfort Lode at 105 fms. by strings and pipes.

St. Ives Consols : a great carbona occurred at the junction of a cross-course (Kemp's Lode) with E.—W. veins; a pipe-like mass, with a general N.—S. bearing, consisting of schorl, tin-ore, chlorite, fluor, and copper and iron pyrites ; the change in the character of the rock in passing from the carbona to the country rock was gradual.

(b) Pipes and bunches are essentially the same as carbonas and are ore-bodies formed by mineralising agencies moving along certain channels and bringing about replacement of the wall rock.

In Cornwall they have only been found well developed at E. Wheal Lovell.[30] These pipes, of which the largest was followed from the 40 to 110 fm. levels, consisted of a central fissure from a quarter to a half inch wide filled with quartz and ferruginous clay. This was surrounded by metallised, altered granite, consisting of quartz, gilbertite, and cassiterite, with some fluorspar, iron and copper pyrites, bornite, chalcocite, and siderite, which gradually faded away into the parent granite.

(c) Complex tin lodes consisting largely of replaced country **rock.** One of the outstanding examples of this type is the Great Flat Lode striking roughly parallel to the long axis of

Carn Brea, in the Troon-Carnkie Valley. Its distinctive features have been summarised thus, by Le Neve Foster :—

"i. The invariable presence of a small leader generally only a few inches wide, apparently occupying the spaces due to the shifting of the two sides of a comparatively flattish fissure, and filled partly mechanically, partly chemically.

ii. A lode or mass of stanniferous schorl rock containing 1 to 3 % of cassiterite, from 4 to 15 feet in width, either above, below, or on both sides of the leader. The tin is distributed in little grains of the rock, or in strings.

iii. Schorl rock, poor in tin-ore (locally called capel, greyblack, black granite), separating the lode from the granite, and schorl rock with its constituent minerals arranged in layers, also called capel, separating the lode from the killas.

iv. Gradual passage of the schorl rock (capel) into lode on one side and into granite or killas on the other ; in other words, absence of any wall between the capel and the lode."

NATURE OF WALL ROCK ALTERATION

The importance of wall rock alteration in lode development, especially of the high temperature type, has been already indicated, and now the nature of the alteration, which has been brought about by one or more of the five processes below, will be described.

It has been shown earlier that the order of arrival of the gangue minerals is as follows :—

Tourmaline, chlorite, fluorspar, carbonates, with quartz appearing in conjunction with all of them.

This is indicated by the fact that the earliest lodes are bordered by greisen (a process akin to silicification) and these are followed by lodes carrying tourmaline and associated with tourmalinised country rock : at higher horizons, the tourmaline gives place in both lode and country rock to chlorite. Associated with tourmalinisation and chloritisation is silicification, but this latter process also extends beyond that horizon where chlorite is most developed.

Wholesale development of fluorite alone in country rock adjoining lodes has never been found, but occasionally it occurs in wall rock altered largely by other processes, in notable quantities, e.g. the fluor-bearing greisen of Parc-an-Chy Mine.

1. **Greisening** is a hypothermal process of wall rock alteration associated with the earliest tin-wolfram lodes in granite, where the felspars and micas of the granite walls are broken down and converted into quartz and secondary micas. Cassiterite may be introduced as at Cligga Head, or topaz as at St. Michael's Mount, or zinnwaldite, as at Great Work Mine, or tourmaline, as at Carn Brea, or fluorite, as at Parc-an-Chy. It is probable that the last two minerals were introduced after the development of the greisen proper.

Greisen bands are best developed at St. Michael's Mount and Cligga, and in both cases, they appear as grey bands a few inches wide on both sides of the lode.

2. **Tourmalinisation** has affected the major and minor acid intrusives and also the sedimentaries. In the former case, when the process has been carried to the extreme, it has converted the felspars and micas into tourmaline, at the same time liberating silica, some of which developed as secondary quartz. The resulting rock therefore consists essentially of quartz and tourmaline (schorl rock), with which may be associated notable quantities of cassiterite.

The stages of tourmalinisation of granite associated with a lode can be clearly followed by examination of the mine waste at the Providence Mines, St. Just, and elsewhere. As the lode is approached the felspar phenocrysts take on a pink tinge and the felspars of the ground mass and the micas, become progressively obliterated and replaced by tourmaline and quartz. Near the lode, deep pink felspars may be found in a matrix of quartz and tourmaline ; on other occasions all signs of felspars are obliterated. Some of the tourmaline is black in the hand specimen and brown in thin section, but the tourmaline found within the lode either as a replacement of the country rock or as a true fissure filling is frequently pale blue, or zoned blue and brown, and occurs as small acicular crystals.

Obviously the element boron plays a dominant role : the manner, however, in which it was introduced is unknown ; perhaps in the form of boric acid, or, if cassiterite was also deposited, in the form of a borate of tin.

Slates adjoining fissures carrying cassiterite and quartz are frequently locally tourmalinised and this results in the production of a banded rock of various shades of grey known as tourmaline-slate hornfels. The banding is due to the selective attack of the more aluminous layers, the siliceous layers remaining more or less unaltered. An excellent example of this was encountered at Belowda.

Closely associated with the above is the development of axinite (calcium boro-silicate). This mineral has been developed locally in greenstones and impure limestones. In greenstones it is always associated with high temperature fissure veins traversing the rock and was obviously formed as a result of boron solutions emanating from the fissures and attacking the lime felspars : at the same time epidote and lime garnet may develop. An excellent example of this type of alteration is to be seen at Carrick Dhu quarry, St. Ives, in altered greenstone. Here a vein carrying chalcopyrite represents the original channel along which the boron solutions moved which attacked the felspars and brought about local development of axinite, epidote and calcite.

Axinite, epidote and lime garnet are also found together with quartz and calcite in the calc-flintas of central Cornwall. This rock is an impure limestone which has been altered by hydrothermal solutions. It would appear that here the boron solutions travelled directly from the granite through fissures in the limestone from which they soaked into the whole rock and altered it. That such fissures existed, is seen at Rosevanion Quarry, St. Columb, where they are occasionally found filled with coarsely crystallised axinite, calcite and garnet, in marked contrast to the fine-grained texture of the rock as a whole. No minerals of economic value have been found within the calc-flintas.

3. Chloritisation. Chloritised country rock is found in association with lodes (largely high temperature types) occurring in the granite and associated minor intrusives, and also in the slate.

In the case of granite the rock may be converted into a mass of chlorite and quartz, the latter being primary and secondary.

The process of chloritisation of granite can be clearly traced by examination of the rocks on many dumps, e.g. the base of Carn Brea. There is at first a progressive obliteration of biotite and the felspars of the ground mass by chlorite, and the felspar phenocrysts at the same time frequently take on a pinkish tinge. As one approaches the lode the larger felspars are seen to become progressively chloritised and the processes of rim and centrifugal replacement are observed : the latter method is well seen at Beacon Quarry, St. Agnes.

Quartz-chlorite country rock bordering the lode-fissure may carry notable quantities of cassiterite.

In the case of slate, chloritisation results in the conversion of all silicates to chlorite so that a fine-grained essentially quartz-chlorite rock is produced.

Lodes, both in granite and allied rocks, and in slate, in zones of chloritisation, very frequently have a selvedge of chlorite which is probably due to the reaction between lode solutions and the country rock, but many veins have also a great deal of chlorite scattered throughout the fissure, and it is held by some, that the whole of the constituents necessary for its formation were derived from the mineralising solutions themselves.

Chlorite is the commonest gangue mineral (excluding quartz) in the copper-tin lodes of the Camborne-Redruth area, yet little has been written about its occurrence either in this area or in other Cornish areas and many writers indeed, have ignored the mineral completely.

The chlorite mineral associated with the lodes is prochlorite ($H_4Mg_3Si_2O_9$ —— $H_4Mg_2Al_2SiO_9$), and much of it may have developed by the action of hot water on biotite mica, though as stated above, it is possible that some of it may have been due to the interaction between substances in the mineralising solutions.

4. Kaolinisation involves the conversion of felspar to kaolinite and allied clay minerals directly or through an intermediate hydro-mica stage. It is now generally agreed that kaolinite is a low temperature mineral produced by ascending carbonic acid acting on felspar or secondary mica at the very end of mineralisation ; possibly boric and hydrofluoric acids may act similarly.

5. Silicification. Associated with all the above processes is the development of a good deal of secondary quartz, often formed as a by-product, but undoubtedly much of it has also been deposited independently. The process of silicification is best seen associated with certain lodes in the slate as at the Boiling Well Mine (Phillack) where slatey inclusions, and locally the country rock, have been noticeably hardened as a result of silica solutions soaking in and depositing quartz.

RICH PARTS IN THE CORNISH LODES, (excluding rich parts due to oxidation and secondary sulphide enrichment).

It is well known that only portions of any given lode are sufficiently large, or contain a sufficient concentration of ore to be worth working.

As far as Cornwall is concerned the chief factors which determine the rich parts of lodes are :—

1. Temperature.

From what has been written earlier about primary zoning it will be apparent that the limiting dimensions of a deposit of any given mineral is controlled by temperature.

2. Variations in dip and strike of the lode fracture.

A fissure developed by normal faulting from a fracture whose dip varied, has its widest portions in those parts which dip most steeply. It is clear also, that, because of the mechanism involved, a series of parallel lodes would tend to have their steepest, and therefore richest parts in roughly the same horizon, a fact long ago appreciated by the miner and which was the source of the saying "ore against ore."

A given lode generally has also a variable strike and if lateral displacement of the walls takes place during fissure development, a series of opened and closed portions would be developed. Most normal lodes have been subjected to a certain amount of lateral displacement and Thomas was able to correlate the rich parts of the Main Lode of Dolcoath and other mines, with variations in the strikes of each of the individual lodes.

Lateral displacement associated with variable strike, was, according to Le Neve Foster, the determining factor in the development of the rich ore-pipes of E. Wheal Lovell.

3. Intersection of fissures.

Numerous examples have been met with in Cornwall of rich bodies of ore at the intersection of two or more lodes. When enrichment at intersections took place, the lodes in question were of approximately the same age, but intersected at acute angles.

Enrichment under such circumstances may have been due to chemical action between two slightly different solutions and/or the development of stagnant conditions due to the considerable break up of the wall rock which often occurred at the point of intersection.

The following are typical examples of rich parts developed at low intersections :—

Wheal Vottle (St. Agnes) : at the "point" where a vertical lode was displaced by a flat lode a rich bunch of cassiterite was found. "This rich part averaged perhaps four feet in thickness and gave about 15,000 tons of ore which assayed close on 50 lbs. of black tin to the ton, while in the ground beyond the shoot, which has been pretty well explored, the lode did not average more than ten inches wide and assayed only 9 lbs. to the ton."

Wheal Basset : pipe-like deposits carrying tin and copper ore were found in the granite and they were considered by James to have been formed at the intersection of branches from the nine or ten roughly vertical lodes which traversed the mine.

Other examples of rich parts at intersections are described elsewhere.

4. Drag and related phenomena due to descent of the hanging wall.

Drag produced by descent of the hanging wall may produce structures which on mineralisation constitute rich parts. It may result in brecciation of the hanging wall which may become a stockwork as at the Towanrath Lode, Wheal Coates, or it may cause the opening of cleavage planes in the slate giving rise to rich parts such as occurred at Wheal Metal, or it may cause the development of branch veins which often seem to carry ore of a higher tenor than the major fissure with which they are associated. The reason for this latter case may be the development of stagnant conditions in a "dead end."

5. Variations in physical properties of the rocks traversed by the lode.

The nature of the country rock combined with intensity of the "shock" which initiated the fissure seems to have determined whether or not a single clean cut fissure was evolved, or a fissure which branched and re-united, etc.

A lode intersecting a porphyry dyke sometimes passes through it more or less undisturbed and sometimes was broken into numerous fissures which did or did not re-unite on the other side. When lodes split in a dyke, rich ore was sometimes developed there ; sometimes, the lode was impoverished.

Intensely shattered country rock may be converted into valuable ore-bodies provided sufficient mineralising solution is available, as seems to have been the case for example, during the development of the Mulberry ore-body. On the other hand, intense shattering associated with inadequate quantities of mineralising solutions leads to the development of irregularly distributed patches of ore which usually are not of great economic value ; the tin lodes of Trevaskis Mine are a case in point.

It appears that really valuable ore-bodies are only found in intensely shattered rock when they are directly above an emanative centre, or on a smaller scale when they are associated with a strong master fissure.

6. Variations in chemical properties of the rocks traversed by the lode.

Though vein intersections have in some cases helped in the development of carbonas, a much more important factor is the chemical reactivity of the granite, and it appears, that whenever high temperature mineralising solutions were caused to stagnate within granite, that they attacked the rock with comparative ease. On the other hand, slate is a much more inert rock, and consequently high temperature solutions usually caused it to be altered but slightly, and so, whilst rich ore in granite may be found either within the fissure, or in the country rock, in the slate it is almost entirely confined to the fissures.

Whilst the above is the case, it is possible that some varieties of slate, by reacting with mineralising solutions, were able to bring about the precipitation of minerals within the fissure. Several of the earlier Cornish investigators have made remarks suggesting this, and have supported their argument by comparing the appearance of slates adjoining ore-rich portions of fissures with those adjoining more or less unmineralised portions. Obviously some or all of these differences may have been due to variations in the amount of alteration during mineralisation and may not have been the cause of ore deposition. In this connection it is of interest to note that Schnellmann showed conclusively that in the north of England and in Wales, galena was deposited at certain horizons, not because a particular bed happened to be favourable, but because it was directly overlain by an impervious bed ; whether this sort of thing controlled deposition of ore in Cornwall is doubtful.

An example which is supposed to support the "favourable bed theory" has been given by de la Beche who recorded that the most productive copper lodes in the Gwennap district are in certain "argillaceous slates which accompanied the red or varigated slates of the district, and which have a fine grain and a blue-grey colour."

The altered dolerites for some reason, possibly chemical, seem to be generally unfavourable to the deposition of ores of tin, copper and lead, although occasionally the ores are more highly developed in them than in adjoining rocks. At Wheal Seton (135 fathom) a greenstone was encountered in which, contrary to the normal character, the lode became greatly enriched.

De la Beche has recorded that fissures in greenstone are often large and that the greenstones are often favourably situated in relation to the granite contact, and yet despite these things, the lode which is associated with them is often poor. It would seem then, that the only possible explanation for the general poverty of lodes whilst in these rocks, is a chemical one.

7. Precipitating power of some minerals.

In Cornwall no work has been done on the possible precipitating action of an early mineral on the components of a hypogene solution entering later. That earlier minerals can bring about precipitation of material from later hypogene solutions is indicated by the hypogene alteration of wolfram to scheelite with accompanying local precipitation of calcite. Further partial evidence is obtained from the following mines :

Herland Mine : the silver cross-course . . . yielded at one time considerable quantities of silver near its intersection of the (copper) lodes.

Wheal Ludcott : yielded some fine specimens of ruby silver . . . almost invariably accompanied by a considerable proportion of white iron (chalybite), with which it seems to have some distinct relationship.

Trugo (St. Columb) : cobalt was obtained from a vein four to six inches wide where it crossed a copper lode.

Wheal Rose, Porthleven : the author has found specimens of "islands" of chalcopyrite surrounded by sphalerite but not apparently replacing it. This suggests that the chalcopyrite brought about the precipitation of the sphalerite.

The ability of sulphides to replace each other in accordance with Schuermann's series is well known and it seems that this ability plus the apparent ability which some minerals have for precipitating others, may be amongst the prime movers in the development of rich parts in a lode.

8. The number of times a given lode was re-opened.

Repeated re-opening of a lode accompanied by deposition in each fissure developed, may either increase or decrease the value of a lode. If the re-openings take place within a short space of time, then a given portion of the lode is likely to be enriched as far as any given mineral is concerned. On the other hand, a lode which has suffered repeated re-openings, between each of which there was a considerable period of time, is likely to become mineralogically complex due to the deposition of minerals of different zones within the same lode horizon. This may decrease its commercial value.

NATURE AND MODE OF TRANSPORTATION OF THE SUBSTANCES FROM WHICH THE ORE MINERALS WERE DEPOSITED.

A. The physical state of these substances.

For many years the question as to whether cassiterite and allied minerals were deposited as a result of interaction between gases (or liquids above their critical temperatures) or were deposited from the solution, has occupied the minds of economic geologists and others, and both ideas have been ardently supported.

Had this dissertation been written a year ago it would have been necessary to consider the merits and demerits of each theory, but recently Smith has conclusively shown that the Cornish cassiterite and related minerals have definitely been deposited from solution.

Smith's proof was obtained by measuring the degree of filling of the liquid inclusions in quartz crystals which he was able to show by the decrepitation method, were formed at approximately the same temperatures as associated wolfram, chalcopyrite and cassiterite crystals. The interpretation of his results was based on the fact that if the "small trapped sample of the solvent fluid" is of low density then the mineral was formed by pneumatolytic action, and if it was of high density then the mineral was deposited from solution.

The following are the results obtained by Smith[26] as a result of examination of three Cornish specimens :—

1. A vuggy intergrowth of tourmaline, cassiterite **and quartz from St. Austell.**

Mineral	Temp. of filling of the liquid inclusions.	Corrected temp. assuming minerals formed at a depth of 2 miles.
Tourmaline	345° C.	390° C.
Cassiterite	345° C.	390° C.
Quartz	329° C.	370° C.

2. A coarse intergrowth of quartz, wolfram and chalcopyrite from South Crofty.

Quartz	293° C.	345° C.
Wolfram	242° C.	265° C.

Chalcopyrite not recorded.

3. An intergrowth of coarse chalcopyrite and quartz from Tincroft Mine.

Chalcopyrite	261° C.	280° C.

Quartz not recorded.

"Under the microscope, the liquid inclusions in the quartz from the three localities were found to be of the normal type, consisting of a gas bubble in a larger amount of solution. Therefore the deposits were not formed by pneumatolysis, but by the usual hydrothermal methods."

The fact that large crystals of wolfram, cassiterite and other minerals are frequently found "suspended" in quartz, suggests that either both must have crystallised very quickly together or that the suspended mineral developed in a silica gel which subsequently crystallised. The author is inclined to think that the latter was the case, and is quite certain that during the time of deposition of minerals in lodes generally, that rapid movement of solution was not taking place. If rapid movement were taking place it is very unlikely that crystals would be developed, for example, with their long axes at right-angles to their fissure walls (as wolfram crystals often are in the Cligga veins), and it seems impossible that the crystal pattern found in a cassiterite-quartz pebble from Nanpusker, and described by Davison, could have been developed other than in a silica gel.[32]

B. The chemical state of these substances.

The chemical compounds from which cassiterite and other minerals were deposited are unknown. The following have been suggested as "carriers" :—

1. Fluorine. As a result of Daubrée's classical experiment in which he produced stannic oxide by hydrolysis of stannic chloride :

$$SnCl_4 + 2H_2O = SnO_2 + 4HCl$$

it has been suggested that cassiterite was deposited by hydrolysis of stannic fluoride and that the hydrofluoric acid liberated reacted with available calcium compounds to form fluorite.

In Williams' opinion, tin is carried up to the granite margin as stannic fluoride at which place the Daubrée reaction takes place, but from there, further transportation of the stannic oxide takes place in a manner discussed below.

Edwards and Gaskin hold that tin and wolfram are transported as halides and say that it is "likely that strongly polarizing cations like Sn^{4+} and W^{4+} would link with highly polarized halide ions, to form strongly bonded molecules in which the anions would be so distorted that the bonding would become homopolar, rather than ionic in character. Such molecules, with strong internal coherence, and little excess or external bonding force, would tend to remain as isolated units — that is, as a highly stable gas phase at the prevailing temperatures. In a magma, they could be pictured as floating up into the upper crystallising mass, where so long as the cation had its insulating sheath of halide ions, they would accumulate, and condense. Subsequent hydrolysis at relatively low temperatures would be inevitable." (3, p.237).

2. Boron : The frequent occurrence of tourmaline with cassiterite has led to the suggestion that tin and possibly other metals were transported as borates.

If tin has been transported as a borate on some occasions, it certainly has not been generally, as many occurrences of cassiterite are known in which tourmaline is not found associated with it. At Uganda, for example, quartz-cassiterite veins occupy previously tourmalinised rock : had boron been a carrier the tourmaline would have been intimately associated with the cassiterite. In the Camborne-Redruth area also, many portions of lodes consist of quartz, chlorite and cassiterite without a trace of boron containing minerals.

3. Silicon : Campbell is of the opinion that all the ore minerals found in lodes have been deposited from silicic acid solutions and that the metals involved were combined with, rather than dissolved in silicic acid. He believes for example that lead, zinc, copper and antimony were possibly transported as silicate-sulphide molecules and that tungsten might have been transported as silico-tungstic acid. His argument is largely based on the fact that quartz is the only mineral found in association with all the ore minerals.

Williams believes that cassiterite and wolfram, having been deposited from fluorides at the granite-slate contact, are further transported in "aqueo-siliceous" solutions from which they "finally crystallise in accordance with the principles of eutectic crystallisation." In favour of this theory he states that the "peripheral resorption and redeposition of wolfram embedded in quartz were observed in Stewart Island," which suggests that siliceous solutions can dissolve wolfram. He also suggests that the common presence of ore minerals entirely surrounded by siliceous gangue is another indication of deposition from solution.

The evidence afforded by the Nanpusker pebble described earlier, strongly suggests that silica may have been closely associated with the transportation of tin in this instance.

4. Sulphur and/or arsenic : Pyrite and arsenopyrite are frequently found associated with cassiterite, and the frequency of this association combined with the infrequency of the occurrence of topaz caused Jones[33] to suggest that the tin may have been transported in the form of arsenide or sulphide.

In connection with 3 and 4 it is of interest to note that Smith has synthesised cassiterite by the hydrolysis of sodium stannate in accordance with the following equation :—

$$Na_2SnO_3 + H_2O = 2NaOH + SnO_2$$

He also carried out this hydrolysis in the presence of sulphide ion and obtained then crystals of amber cassiterite. He suggests that the brown colour of natural cassiterite may be due to a solid solution of sulphur in oxygen positions since the synthetic cassiterite when deposited from solutions free of sulphide ion was white and fluorescent, whereas when deposited from solutions containing sulphide ion, it was amber and not fluorescent.

If tin is deposited naturally from this type of solution it probably exists (in solution) as stannate and thiostannate ions which are in dynamic equilibrium.

He has also shown that tourmaline is unstable in strongly acid solutions and in doing so has further established the theory that cassiterite may have been deposited naturally in the manner in which he synthesised it.

Sullivan has suggested that the frequent occurrence of tourmaline and fluorite with cassiterite may be due, not to the fact that any relationship existed between them but simply because the ionic radii of boron, fluorine and tin was such that these elements could not be incorporated into the crystal lattices of the granite minerals and so were concentrated together in the residuum.

References :

1. Sullivan, J. C. : "Ore and Granitisation" ; Econ. Geol., Vol. 48, p.471.
2. Garretty, M. D. : do do. Econ. Geol., Vol. 44, p.626.
3. Edwards & Gaskin : do. Econ. Geol., Vol. 44, p.236.
4. Dines, H.G. : "Lateral Extent of Ore-Shoots in Primary Depth Zones of Cornwall" : Tr. R.G.S.C., Vol. 16, p.279.
5. Davison, E. H. : "Estimation of Cornish Mineral Areas" : Mining Mag., Vol. 32, p.179.
6. Schneiderholn, H. : "Time and Temperature Curves in relation to Mineral Associations in Cooling Intrusions" : Econ. Geol., Vol. 29, p.471.
7. Geology of Falmouth and Camborne : Mem. Geol. Sur., 1906.
8. Cronshaw, H. B. : "Structure and Genesis of Tin Lodes in Camborne District" : Tr. Inst. Min. Met., Vol. 30, p.408.
9. Davison, E. H. : Handbook of Cornish Geology ; p.70.
10. Dewey, H. : South-West England : H.M. Stat. Office, p.50.
11. Rastall, R. H. : "Geology of the Metalliferous Deposits" (Cambridge), p.192.

12. Davison, E. H. : "Primary Zones of Cornish Lodes" : Geol. Mag., Vol. 58, p.505.

13. Collins, J. H. : "Observations on W. England Mining Region": Tr. R.G.S.C., Vol. 14.

14. Henwood, W. J. : Tr. R.G.S.C., Vol. 5 (Tables).

15. Thomas & MacAllister : "Geology of Ore Deposits" (Arnold), p.87.

16. Jones, W. R. : "Tinfields of the World" (Mining Mag.).

17. See "Notes on New Exposures" : Tr. R.G.S.C., Vol. 17, p.346.

18. "Geology of Land's End" : Mem. Geol. Sur., pp.102-3.

19. Kutina, J. (1949): "Occurrence of Albite in Cassiterite Deposit of Krupka" : (Charles Univ. Pub., Prague).

20. Smith, G. F. : "Transport and Deposition of Non-sulphide Vein Minerals" : Econ. Geol., Vol. 3, p.188.

21. Davison, E. H. in Report of Tin-Tungsten Research Board (H.M.S.O.), in which good illustrations of veinstones are shown.

22. Jones, W. R. : "Tin and Tungsten Deposits : economic significance of their relative temperatures of formation" : Tr. I.M.M., Vol. 29, p.346.

23. McLaren, M. : "Geology of E. Pool Mine, Camborne": Mining Mag. 1917, p.249.

24. Campbell, J. M. : "The Origin of Primary Ore Deposits" : Tr. I.M.M., Vol. 30, p.91.

25. Williams, G. : "Genetic Significance of some Tin-Tungsten Lodes in Stewart Island, N.Z." : Econ. Geol., Vol. 29, p.430.

26. Smith, G. F. : "Lab. Testing of Pneumatolytic Deposits" : Econ. Geol., Vol. 44, p.625.

27. Dewey, H. : "Arsenic and Antimony Ores" : Mem. Geol. Sur.

28. Dewey, H. : "Copper Ores of Devon and Cornwall" : Mem. Geol. Sur.

29. Collins, J. H. : "Leading bearing lodes of W. England" : Tr. R.G.S.C., Vol. 12, p.703.

30. Foster, Le N. : "Tin Deposits of E. Wheal Lovell" : Tr. R.G.S.C., Vol. 9, p.167.

31. Lees, P. B. : "Geological History of Williams Lode in King Edward Mine, Camborne" : Tr. R.G.S.C., Vol. 13, p.611.

32. Davison, E. H. : "Alluvial Pebble from Nanpusker" : Tr. R.G.S.C., Vol. 15, p.367.

33. Jones, W. R. : "Origin of Topaz and Cassiterite at Gunong Bakau, Malaya" : Geol. Mag., Vol. 52, p.255.