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SOME GENETIC RELATIONS OF TIN DEPOSITS.

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Since the days of Werner, the different kinds of veins have been divided into groups according to their most prominent and characteristic features. To these groups, Werner applied the term *vein formation;* other authors have subsequently also used the term *vein type*. Even in Werner's time, it was difficult to fit all known veins into sharply defined groups. With the rapid increase in our knowledge of ore deposits in recent years, as more and more new mining districts have been discovered and described, the dividing lines between these groups have become less and less sharp, and in many cases complete transition exists from one group to another.

Among these groups, *tin veins* have stood out more distinct than probably any other type. They are almost always closely associated with granitic rocks; and are characterized by an abundance of fluorine and boron, and to a less extent lithium and phosphorus minerals, and the pneumatolytic metamorphism of the country rock. To one familiar only with the more common vein types, a more different group could hardly be pictured. Yet, notwithstanding the unusual characteristics of this group of veins, there are many transitional types which closely relate it to other groups. These transitions have been brought about by minerals, which in the type are accessory constituents of the vein filling, becoming the most prominent; and by the entrance into the vein filling of new minerals, and the disappearance of some of the characteristic features of the type.

No less distinct than the type itself, has the genesis of this group been considered. Moreover, our understanding of the genesis of this group dates back further and is considered more certain than in the case of any other. As early as 1841,[1]

[1] Daubrée: *Annales des Mines,* 3d Ser., Vol. XX., 1841, pp. 65–112.

Daubrée called attention to the fact that all tin veins are associated with granitic rocks, and that the tin and other characteristic elements of these veins were derived directly from the granitic magma. His synthetic experiments enabled him to arrive at conclusions as to the chemical processes involved. As the magma cooled, metalliferous gases and vapors were given off; and these, reaching the already solidified peripheral portions and the adjoining country rock, deposited their metallic contents, and at the same time, reacting chemically on those rocks, produced the profound metamorphism so constantly associated with these veins. Daubrée's theory was substantiated by the observations of his contemporary Elie de Beaumont[1] and is today accepted as the explanation of the origin of this type of veins. So radically different was this theory from the views held as to the genesis of veins in general, that the older French school drew a sharp line between *tin veins* and *sulphide veins,* and some went so far as to divide all veins into two main groups—*Filons stannifères* and *Filons sulphurés dites plombifères;* the former fumerolic products of granitic magmas, the latter hydrothermal deposits. Such a genetic isolation of this group is no longer tenable.

In the following paragraphs, I shall discuss briefly some transitional occurrences of tin deposits and point out their genetic significance.

PEGMATITIC DEPOSITS.

There are no magmatic segregations of cassiterite of economic importance; yet cassiterite is frequently found as a primary constituent of granite in tin districts. In pegmatite dikes, however, there are occurrences of sufficient richness to make a workable ore.

Most closely related to a normal granite is the rock in which occurs the tin deposit at Etta Knob in the Black Hills of South Dakota. The acid intrusive there is in the form of a stock with a nearly circular outcrop, measuring from 30 to 60 m. in diameter. This rock is an unusually coarse grained pegmatite,

[1] Elie de Beaumont: *Bull. de la Soc. Géol. de France,* 2d Ser., Vol. IV., 1847, pp. 1249–1333.

carrying feldspar crystals up to 50 cm. long and spodumene crystals as large as 12 m. in length and 1 m. in thickness. The tin ore occurs disseminated in the form of small granules and imperfect crystals making up about 2½ per cent. of the rock. This rock is characterized by an abundance of lithium and phosphorus minerals, and the lack of the usual fluorine and boron minerals of the tin veins. Though recognizing the pegmatitic character of the rock, Beck[1] and Bergeat[2] consider the occurrence so closely related to normal magmatic segregations that they have placed it in that category in their text books. Beyschlag, Krusch, and Vogt,[3] on the other hand, have placed it among the tin veins, because they hold that the tin, tantalum, lithium, and phosphoric acid have been introduced pneumatolytically. This difference in classification shows the transitional character of the deposit.

Very similar to the Black Hills occurrence is that of North and South Carolina, but here the pegmatitic character of the rock is more pronounced; and, besides many of the minerals of the Black Hills deposit, fluorspar also occurs. This deposit represents then a stage nearer to true veins, and all of the above mentioned authors agree in placing it among the tin veins in their classification. Yet both of these occurrences differ from typical tin veins in the almost complete absence of a greisen formation.

Near Ober Graupen in Bohemia, at the southern end of the eastern belt of the Erzgebirge tin deposits, in the midst of an area of normal tin veins, is a vein of somewhat aberrant type known as the Luxer vein.[4] This vein differs from the other veins of the region in that it has not altered the country rock into greisen, and locally the quartz gangue gives place to coarsely crystallized orthoclase intergrown with albite. Violet blue fluorspar is also a prominent gangue mineral. It is thus apparent that this vein stands between the normal tin veins and the Carolina occurrence, a relation pointed out by Beck.

[1] Beck: "Die Lehre von den Erzlagerstätten," 3d ed., 1909, Vol. I., p. 65.

[2] Stelzner-Bergeat: "Die Erzlagerstätten," Vol. I., 1904, p. 23.

[3] Beyschlag-Krusch-Vogt: "Die Lagerstätten der nutzbaren Mineralien und Gesteine," 1910, Vol. I., pp. 343, 442.

[4] J. T. Singewald, Jr.: Econ. Geol., Vol. V., 1910, pp. 175–7.

These occurrences illustrate, therefore, a complete gradation from the *tin vein type* to cassiterite as a primary constituent in the consolidation of a molten magma.

CONTACT METAMORPHIC DEPOSITS.

Modern genetic classifications place contact metamorphic deposits intermediate between magmatic segregations and veins. The metal content of these deposits was derived directly from the magma. This transfer of material began before the consolidation of the igneous rock set in, and in many cases continued until after the consolidation of the crust of the igneous mass. Such a process must have been of pneumatolytic or at least pneumato-hydatogenetic character. In some cases ore deposition continued down to the hydrothermal stage, and ordinary veins are found intimately connected with some contact metamorphic deposits.

The physical-chemical principles involved in the formation of tin veins and contact metamorphic deposits are, therefore, similar; and operate contemporaneously with reference to the various stages in the cooling of the parent magma. But boron and fluorine, the elements so prominent in tin veins, are lacking in most contact metamorphic deposits. Hence, with respect to their mineral assemblage, two widely different types of ore deposits have resulted. Nevertheless it is clear that if a magma which is producing a contact metamorphic deposit contain tin, that tin can be deposited at the same time and a stanniferous deposit result. Further, when we consider that such minerals as fluorspar, tourmaline, and axinite, as well as other boron and fluorine minerals, as datolite, ludwigite,[1] etc., do occur sparingly in some contact metamorphic deposits, we would be surprised if there were no stanniferous contact metamorphic deposits.

In the third edition of his "Lehre von den Erzlagerstätten," 1909, Beck has introduced two new subdivisions into his group of contact metamorphic deposits which he calls the *Schwarzenberg type* and *tin deposits of contact metamorphic origin.* Equiv-

[1] Ludwigite occurs in large masses at one locality, near Dognacska, in Hungary.

alent to these is the group of *cassiterite bearing contact deposits* of Beyschlag, Krusch and Vogt's classification.

The deposit worked by the Bakerville mine[1] in the Herberton district Queensland, Australia, is the purest example of a contact metamorphic tin deposit. The ore occurs in the zone of contact metamorphism between a biotite granite and quartzitic schists, and forms a belt from 10 to 20 m. wide immediately at the granite contact. This ore belt consists of brown cassiterite in a gangue of quartz and minute radial aggregates of dark bluish gray tourmaline. Pyrite and pyrrhotite are present but in subordinate amounts.

At Pitkäranta[2] in Finland is a contact metamorphic deposit with a more complex association of ores, which yielded iron, copper, and tin. A batholith of Rappakiwi granite has contact metamorphosed the calcareous layers of pre-Cambrian hornblende schists. There are two principal ore beds called respectively the "lower" and "upper." The lower bed is characterized by a prominent development of skarn, which consists of salite and garnet. The district is divided into four fields, three of which yielded almost exclusively iron ore. The fourth, which is the most westerly and is situated close to Lake Lagoda, yielded almost all of the copper and tin ore. The ore beds are cut by pegmatite dikes which also carry cassiterite and chalcopyrite. The age sequence of the ores in the beds is (1) magnetite, (2) cassiterite, (3) chalcopyrite; but all were formed during the contact metamorphism. Scheelite, molybdenite, native bismuth, fluorite, and topaz (observed only microscopically) occur sparingly.

At Schwarzenberg[3] in Saxony, the geology is similar to that at Pitkäranta. Calcareous layers in a metamorphic series have been contact metamorphosed with the formation of skarn minerals. According to Beck, the ore minerals are not strictly contemporaneous with the contact minerals. Magnetite is again the

[1] Beck: *loc. cit.,* Vol. I., p. 144.

[2] O. Trüstedt: *Bull. de la Com. Géol. de Finlande,* No. 19, 1907.

[3] R. Beck: "Jahrb. fur das Berg- und Hüttenwesen im Königreich Sachsen," 1902, pp. 51–87; 1904, pp. 56–96.

most important ore, but copper, zinc, and lead-silver ores are also abundant. Tin is not everywhere present, and occurred most abundantly in the mines at Breitenbrunn, in association with fluorspar, apatite, and tourmaline. The ores seem to have been introduced by impregnation from fissures which cut the ore beds, as the richest ore shoots occur along the fissures. At Breitenbrunn the ore bed is cut by tin veins[1] which were probably the source of the tin and its accompanying minerals in the beds. The entire mineralization is, however, closely connected with the contact metamorphism.

A step further removed from the contact metamorphic deposits are the tin ores in limestone in Campiglia Marittima, Tuscany, and in the province of Perak in the Malay Peninsula.

At Campiglia[2] tin occurs in association with limonite, either as a vein filling in schists or as metasomatic replacement of limestone in connection with recognizable fissures. Malachite and pyrite with cassiterite inclusions also occur, and it is probable that the limonite has been derived from the pyrite by the decomposition of the latter. In the present form of the deposit, both contact minerals and the characteristic minerals of the tin group are lacking. Nearby are lead, zinc, and copper sulphide ores in association with contact minerals and fluorspar. Less than two miles from the tin mines is a tourmaline granite, the extension of which below the surface as far as the mines is possible. Bergeat looks upon the deposit in its present form as the gossan of a primary stanniferous sulphide deposit of hydrothermal origin. Certainly to place it among the contact metamorphic deposits, as Beyschlag, Krusch, and Vogt[3] have done, is to give it a rather conjectural position.

At Chongkat Pari[4] in Perak, Malay Peninsula, in addition to the placer tin deposits, which are by far the most important, tin occurs in situ in granite and in limestone. In the granite, the

[1] *Idem.*, 1904, pp. 63–64.

[2] A. Bergeat: *Neues Jahrb. für Min., Geol., und Paleon.*, 1901, Vol. I., pp. 135–156.

[3] Beyschlag-Krusch-Vogt: *loc. cit.*, Vol. I., p. 405.

[4] R. A. F. Penrose, Jr.: *Jour. of Geol.*, Vol. XI., 1903, pp. 146–7, 149–150.

cassiterite occurs in pockets, small veins, and networks of intersecting stringers, associated with quartz, tourmaline, fluorite, pyrite, and arsenopyrite. Less frequent are occurrences in limestone. These consist of impregnations along fissures in the limestone, and carry in addition to the cassiterite, pyrite and arsenopyrite, smaller quantities of chalcopyrite and bornite, and some rhodocrocite. These occurrences in limestone are, therefore, closely associated with characteristic tin veins in granite; but the lack of fluorite and tourmaline, which are present in the veins in the granite, hardly admit of a closer genetic association with the granite than the hydrothermal stage.

The group of occurrences just described show then a gradation from a typical contact metamorphic deposit most intimately related to the parent magma to deposits certainly as far removed as the hydrothermal stage.

In the light of the gradations that have just been traced from one major division of a genetic classification to another, gradations of the *tin vein formation* into other *vein formations* are not remarkable; nevertheless, these gradations are extremely interesting and well worth tracing out.

In one direction, the tin veins grade over into the *tourmaline bearing copper formation*. Though copper sulphides, especially chalcopyrite, are seldom absent from tin veins, in their most typical development, as in the case of most of the Erzgebirge deposits, the veins carry only minute quantities of the copper minerals. But even in some of the Erzgebirge deposits, as for example in the so-called "Kupfergrube bei Sadisdorf" the copper ores become more abundant.

The intermediate position of the Cornwall[1] ores is still more apparent. Briefly stated, the Cornwall deposits differ from the Erzgebirge deposits in their abundance of copper and in the prominence assumed by tourmaline as a gangue mineral at the expense of topaz. The Cornwall veins show a difference in depth due to both secondary enrichment and primary deposition.

[1] Phillips-Louis: "A Treatise on Ore Deposits," 2d ed., 1896, pp. 191–229.

Where the outcrops have been weathered and the gossan thoroughly leached, a vein yielding only tin at the surface will at greater depth yield rich copper ores. It is, however, the primary difference that concerns us here. In many of the mines copper veins became in depth tin veins.[1] Thus the Dolcoath mine, the most important of the region, had in its upper levels copper ores almost exclusively. With increasing depth, the ores carried both copper and tin, and finally passed over into tin ores carrying but little copper. This change took place approximately where the workings passed through the schists into the underlying granite. Though this closer relation of the tin to the granite is not always brought out as sharply as in the Dolcoath vein, it is an unmistakable characteristic of the district.

In this connection may also be mentioned the copper bearing veins of the Dry River Valley in the Herberton district, Queensland. These veins are distinguished from the other veins of the district by the presence of copper ores in considerable amount and by certain aberrant features from the tin vein type. The most important of these is the Lancelot vein, and it will be described as representative of the group.[2] In contrast to the occurrence of the copper in the Cornwall veins, the copper ores in the Lancelot vein occur in irregularly distributed masses of rich ore several meters long and deep and taking up the whole width of the vein. The ore minerals in these masses consist of chalcopyrite, bornite, and chalcocite; and the ore itself may run as high as 20 per cent. Cu and 0.1 per cent. Ag. At a depth of 100 m. the vein takes on in part a banded structure, and the hanging wall portion consists of sphalerite, galena, and arsenopyrite, while the rest of the vein filling consists of cassiterite, pyrite, and quartz. In this respect the vein shows some analogy to the *pyritic lead ore formation.* The characteristic fluorine and boron minerals are lacking, as well as the pneumatolytic alteration of the country rock. These veins, therefore, represent a gradation to hydrothermal veins; and their tin and copper content alone suggest a relationship to the *tin vein-tourmaline bearing copper vein* series.

[1] D. A. Macalister: Econ. Geol., Vol. III., 1908, pp. 371–2.

[2] Edlinger: *Zeit. für prak. Geol.*, 1908, pp. 276–277.

The best illustration of the end member at the copper end of the series is the Thelemark district[1] in southern Norway. The veins here occur in granite, in schists which the granite has intruded, and in granitic dikes which cut the schists. Pneumatolytic minerals as fluorspar, tourmaline, and apatite are present in the gangue; and the country rock has undergone a greisen-like metamorphism which differs from typical greisen in the scarcity of topaz and lithia mica. The Svartdal veins in this district differ from the rest in that they do not occur in granite, but in quartz mica diorite, and besides copper carry gold. They have, however, also caused a greisen-like alteration of the country rock.

The gold bearing copper veins of Chili[2] show a great similarity to the Svartdal veins and might be briefly mentioned here. They carry in addition to the auriferous copper ores small amounts of molybdenite and scheelite, and as gangue minerals quartz and tourmaline. They are closely related to acidic or moderately acidic eruptives which have undergone tourmalinization along the veins.

The similarity of the various members of this *tin vein-tourmaline copper* series has been concretely stated by Vogt[3] in that he calls the tourmaline bearing copper ore veins, tin veins in which copper takes the place of tin. The whole series is characterized by the presence of pneumatolytic minerals and by pneumatolytic alteration of the wall rock. The transition is purely a chemical one. Copper has gradually replaced tin and tourmaline has become prominent at the expense of topaz.

STANNITE VEINS.

I wish next to take up a very unusual type of tin deposit, namely, that in which stannite, a sulphide of tin, occurs as an ore. In all the deposits considered up to this point the tin ore occurs solely in the form of the oxide, cassiterite (SnO_2). For the sake of simplicity, stannite may be looked upon as chalcopyrite in which one half of the iron is replaced by tin and the formula may

[1] J. H. L. Vogt: *Zeit. für prak. Geol.*, 1895, pp. 149–153.
[2] Stelzner: *Idem.*, 1897, pp. 41–53.
[3] Vogt: *Idem.*, 1895, p. 149.

be written $CuFeS_2 \cdot CuSnS_2$. Though found in many tin deposits as a mineralogical curiosity, it is thus far known in sufficient amount to be considered one of the ore minerals in only two districts in the world. These are the Cerro de Potosi district in Bolivia and the Mt. Zeehan district in Tasmania.

In the decade preceding his death, Stelzner became especially interested in the rich silver veins of Bolivia which also carried a large amount of tin. Though he never visited the district he thoroughly worked up the literature on that portion of South America, and supplemented this information with an extensive correspondence and a careful study of specimens sent to him by his correspondents in Bolivia. In 1892 he made a preliminary statement before the German Geological Society; but it was not until 1897, soon after Stelzner's death, that Bergeat published the detailed discussion of his results in the shape of a partially unfinished manuscript.[1] The lack of personal acquaintance with the field makes some imperfections in this work inevitable, nevertheless it stands today as the most valuable description that we have of these extremely interesting deposits. Stelzner starts out by calling attention to the prevalent idea that tin veins occur over the whole earth not only under uniform geological conditions, but also show uniform mineralogical properties. The Bolivian veins he says are characterized, however, by the simultaneous occurrence of tin ore with silver and lead ores, and by the complete absence of the boron and fluorine silicates. (Since Stelzner's time these minerals have been found in small quantity in the deposits described by him.)[2] These veins presented, consequently, such a departure from the normal tin veins that he emphasized the statement that the most, *but by no means all,* tin deposits over the whole earth show uniform geological and mineralogical features. These Bolivian veins he designated the *Typus Potosi,* and in "Die Erzlagerstätten" of Stelzner-Bergeat this type appears as a separate group under the name *Silberzinnerzgänge.*

This *Typus Potosi* occurs over an extensive area on the high

[1] Stelzner: *Zeit. der deut. Geol. Gesell.,* Vol. XLIX., 1897, pp. 51–142.

[2] W. R. Rumbold: Econ. Geol., Vol. IV., 1909, pp. 321–364.

plateau of Bolivia, extending from latitude 15° S. to 21° S. The characteristics emphasized by Stelzner are that the veins are connected with dacites and quartz trachites which were erupted in early Cenozoic time and not with granites. The nearest granites are from 170 to 520 km. from the deposits, with the exception of a small occurrence of tourmaline granite of much greater age than the veins. The usual pneumatolytic minerals, tourmaline. topaz, fluorspar, and apatite, are absent. The tin occurs as both oxide and sulphide, that is, as cassiterite and stannite. As cassiterite it is enclosed in the form of microlites in the other sulphides, and occurs also in massive form in association with much pyrite. The veins are remarkably rich in silver especially in the enriched zones. The silver occurs chiefly in association with tetrahedrite. In the oxidized zone enormous masses of secondary cassiterite, called from its appearance "wood tin," occurred together with great masses of secondary silver ores. The latter were mined long ago and gave Bolivia its great renown as a silver producing country. Besides the tin and silver ores, lead, zinc, copper, bismuth, and antimony ores are prominent in different parts of the region. The presence of rare germanium minerals, as argyrodite and franckeite, also adds renown to the region. The silver and tin ores are so intimately intergrown, that it is impossible to separate them by hand sorting, and the tin is obtained from the residue after the silver has been extracted by roasting and amalgamation. Stelzner concluded from his study of the ores that the tin minerals and the silver-bearing minerals were deposited simultaneously, and that it was not possible to hold the view that tin veins were formed first, and subsequently reopened and the silver minerals deposited. Hence the tin ores of these veins must have been formed under hydrothermal conditions and not pneumatolytic. The features just described seemed to him to sever completely these veins from the tin vein type.

In 1907, Steinmann,[1] who personally visited the deposits, called attention to the fact that just northeast or east of the veins described by Stelzner, are veins in lower Silurian schists which

[1] Steinmann: *Zeit. der deut. Geol. Gesell.*, Vol. LIX., 1907, pp. 7–9.

show a simpler composition—quartz with cassiterite and pyrite, and complete absence of the complex silver ores. Steinmann still clung close to Stelzner's view in interpreting their relation to the *Potosi type.* He considered an original differentiation of the mineral bearing solutions to have taken place. The one phase, which was the more closely connected with the liparites and dacites, deposited the ores of the *Potosi type;* the other deposited at a greater distance from the eruptives the pure tin veins which he called the *Araca type,* from their occurrence at Araca. Beck[1] agrees with this interpretation.

Rumbold,[2] in his article on the origin of Bolivian tin deposits, brings out points of similarity between these deposits and normal tin veins and concludes that their origin was the same. The only distinguishing characteristic he finds in these veins is the presence of silver.

In a recent number of the *Annales des Mines,*[3] M. Armas discusses at some length the Bolivian tin deposits. He strongly attacks Stelzner's position and comes back to the pneumatolytic origin of the tin deposits as the only tenable explanation.

He brings out the fact that there are two zones of tin deposits in Bolivia, having a northwest direction and lying about 60 km. apart. The southwesterly zone includes the most important deposits, Oruro, Potosi, Chorolque, etc., and is associated with young eruptives. The northeasterly zone, within which Araca is situated, lies in great part in ancient schists and quartzites. The tin veins Armas says have all derived their tin from the same source, that is, from a deep lying acid magma of great extent with apophyses which show here and there in the mineralized region as dikes and intrusive masses. To substantiate his views Armas describes in detail many of the deposits, but principally those of the northeastern zone with which he is better acquainted. In this belt he describes stanniferous pegmatite dikes and veins closely associated with pegmatite dikes carrying pneumatolytic minerals. The mention of the southwesterly zone, in which

[1] Beck: "Die Lehre von den Erzlagerstätten," 3d ed., 1909, Vol. I., p. 310.

[2] W. R. Rumbold: *loc. cit.*

[3] M. Armas: *Annales des Mines,* 10th Ser., Vol. XX., 1911, pp. 149–213.

the principal silver bearing veins occur, is very brief; but he regards the introduction of all the other ores to have taken place by means of hydrothermal solutions, subsequent to the formation of the tin ores, as a result of a reopening of the veins.

Although Armas strongly attacks Stelzner's view, he excuses him on the ground that most of the veins he describes were not known in Stelzner's time, and that had Stelzner been familiar with them he would have modified his views.

Though still not as reliable or as thorough as one might wish, the information we have in regard to this district indicates that neither Rumbold and Armas on the one hand, nor Stelzner on the other, are wholly right. In one portion of the field it seems that pneumatolytic tin veins with the normal associations of such veins exist; in other portions, we have tin bearing veins of hydrothermal origin in which the tin has in part been deposited in the unusual form of stannite. Further exploration in this little known region will doubtless bring out the relation of these two types more clearly, and show that the gradational steps away from an igneous source are from *Typus Araca* to *Typus Potosi*. Such a relation is far more probable than the gradation from *Typus Potosi* to *Typus Araca,* suggested by Steinmann and endorsed by Beck, which is entirely at variance with the accepted views as to the origin of tin veins. This view is also rendered the more probable in the light of recent investigation in the Zeehan district.

In a bulletin on The Ore Bodies of the Zeehan Field, Twelvetrees and Ward[1] have given a comprehensive discussion of the genetic interrelationships of the Zeehan field and surrounding territory. In the Zeehan field proper is a Silurian complex of slates, sandstones, and conglomerates with intruded dikes and beds of malaphyre and malaphyre tuffs, and some gabbro and serpentine. To the west lies the Devonian Mt. Heemskirk granite massive. This brief geological sketch is all that is necessary for the present purpose.

Within this region, several different types of ore deposits

[1] W. H. Twelvetrees and L. K. Ward: Bull. 8, Depart. of Mines, Tasmania, 1910.

occur, which are arranged areally in three zones, termed respectively, the Granite Zone, the Contact-Metamorphic Zone, and the Transmetamorphic Zone.

Within the borders of the Mt. Heemskirk granite are a number of ore bodies carrying chiefly cassiterite, and less abundantly wolframite, native bismuth and molybdenite. Associated with these are tourmaline and pyrite. Isolated occurrences of similar veins extend out into the transmetamorphic zone.

The contact metamorphic zone is the most well defined, simple, and narrow of the three principal zones. The most prominent ore of this zone is magnetite. Some magnetite occurrences are practically free from sulphides; in others the sulphides of lead, zinc and copper are very prominent. The point of chief interest to us in this zone is the occurrence, in one instance at least, of an admixture of cassiterite and magnetite.

In the transmetamorphic zone, the prominence of the oxide ores disappears, and with few exceptions the primary metallic minerals occur as sulphides. In this zone, the authors have distinguished two main divisions. In one of these, the predominant gangue mineral is pyrite; in the other siderite. In areal distribution, the pyritic veins form an inner belt, the sideritic an outer belt, with reference to the granite massive. The dividing line is naturally not sharp and transitional types occur. The principal sideritic veins carry galena, though a few nickel-silver veins are known.

The pyritic group is further subdivided into the galena type and the stannite type. The galena type, in addition to the pyrite may or may not carry sphalerite. Some of the veins of the stannite type carry chalcopyrite, in addition to pyrite, in association with the stannite; others carry galena. Small quantities of wolframite and bismuthinite occur in these veins. The cupriferous stannite veins are also argentiferous, and were for a long time worked chiefly for their silver and copper, no payment being made for the tin. Since 1901, a contract has been in force providing for payments for the tin in the stannite when the ore ran above 8 per cent. Sn. The average content of the stannite ores since then has been 9 per cent. Sn. At the principal occurrence of the stannite veins, one of the pyrite cassiterite veins of the granite zone type has been discovered.

The foregoing description suffices to bring out the genetic relationships of the ore deposits of this region. The gradation passes successively from cassiterite veins in granite, to contact metamorphic deposits in which cassiterite has been found, to sulphide veins, some of which carry tin sulphide, to sulphide veins with a carbonate gangue. Expressed genetically, the gradation is from pneumatolytic in a solidified portion of the parent magma, to pneumatolytic at the contact with the parent magma, to pneumatohydato-genetic or hydrothermal, to more pronouncedly hydrothermal. Since this transition, which has been traced horizontally, is not essentially a horizontal function, but rather a function of absolute distance from the parent magma, and since the Mt. Heemskirk granite probably continues across the Zeehan field at an unknown depth below the surface, the authors suggest that the same gradation would probably be found if one could go down vertically from the outer belt of the transmetamorphic zone until the granite was encountered.

The Zeehan field, and less perfectly the Bolivian tin region, the only known occurrences of stannite in relatively large quantities, bring out admirably, therefore, the transition from the magmatic phase to the pure hydrothermal phase in the formation of ore deposits.

In the foregoing discussion, little or no emphasis has been laid upon the almost constant association of tungsten with tin, and the very frequent association of bismuth ores in considerable amount with tin. In the case of both of these metals, transitions can be traced from pure tin types to pure types of either of them. Also taking up each of these metals separately, similar transitions from one genetic type to another can be traced as have been traced in the case of tin. To have done so would have been beyond the scope of the present paper, in which it was intended to deal primarily with tin ore occurrences.

The genetic relations of tin deposits brought out in the pre-

Phases.	Via Pegmatitic.	Via Contact Metamorphic.	Via Tin Vein-Tourmaline Copper Vein.	Via Stannite Veins.	
				Bolivia	*Mt. Zeehan*
Magmatic ↓	Cassiterite in granite	Cassiterite in granite			
Pneumatolytic ↓	Etta Knob Carolinas Luxer Vein Erzgebirge	Bakerville Pitkäranta Schwarzenberg	Erzgebirge Sadisdorf Cornwall (Dry River Valley) Thelemark Chili	Typus Araca	Tin veins in granite Contact metamorphic
Hydato-pneumatolytic ↓				Typus Potosi	Pyritic veins with stannite
Hydrothermal		Campiglia Perak			Sideritic

ceding pages are compactly summarized in the accompanying table. In the first column are placed the phases under which the deposits have been formed, starting with the magmatic phase and passing down to the hydrothermal. Transitions have been traced along four main lines, and each of these is represented by a column parallel to the first column. These four columns may be regarded as the routes by which the transitions have taken place. The examples in each column are then placed as nearly as possible opposite to that phase in the first column to which they correspond. This arrangement shows at a glance the inter-relationships of the deposits which have been discussed.