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THE ECONOMIC GEOLOGY OF THE MOUNT BISCHOFF TIN DEPOSITS, TASMANIA.

J. G. WESTON-DUNN.¹

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¹ Frecheville Fellow (1921), Royal School of Mines.

INTRODUCTION.

The tin deposits of Mount Bischoff offer an unusual opportunity for geological study, particularly with respect to the origin of the valuable deposits and to the character of the metasomatic changes in the rocks, preceding and accompanying the tin mineralization. The wealth of exposures disclosed in the numerous large open cuts (locally termed "faces") permits a detailed study of the structural features which influenced metallization, and also gives evidence tending to clarify the disputed point as to the lode, or alluvial character of these tin deposits.

The study of the Mount Bischoff tin deposits was undertaken at the suggestion of the Frecheville Research Fellowship Committee. Originally it was intended to form part of a more general investigation of "the relation between country rock and enclosed deposits," but the paucity of geological and petrological description made it rather more advisable to deal with the area separately.

Previous Literature.—At the present day the main tin-bearing material at Mount Bischoff is a loose, often incoherent pyritic (marcasitic) deposit. Until quite recently only the oxidized zone of this was exposed, and the true nature of the occurrence was not understood. This oxidized zone was represented in places by an extensive highly ferruginous gossan (as in the early Brown Face), and in other places by a loose sandy disintegrated material (typical of the North Alluvial Face and the White Face). These deposits were referred to first by Johnston,² Wintle,³ and Gould,⁴ and later by Kayser,⁵ Montgomery,⁶ Twelvetreets and

² R. M. Johnston, "Geology of Tasmania," 1888.

³ S. H. Wintle, "Stanniferous Deposits of Tasmania, Mount Bischoff," *Trans. Roy. Soc. N. S. W.*, 1875, p. 87.

⁴ C. Gould, *Quart. J. G. S.*, vol. XXXI., 1875, p. 109.

⁵ H. W. F. Kayser, "Geology of Mount Bischoff," *Aust. Assoc. Ad. Sc.*, Hobart, 1892, vol. IV., p. 352; and *Proc. Inst. Civil Eng.*, vol. CXXIII., pt. I, p. 377.

⁶ A. Montgomery, "The Mineral Resources of Tasmania," Dept. Mines, Tas., 1894.

Petterd,⁷ and Millen⁸ as of detrital or residual origin. Herman,⁹ however, was the first to show that this view was untenable, and to point out "that the detrital stanniferous material of Mount Bischoff is now, and probably has been throughout its existence, of quite minor importance, and that the great bulk of what apparently is and has been held, by the majority of observers, to have that character is (or was) truly lode material, of a peculiar character 'in situ.'"

The associated porphyry dikes at Bischoff were noted in the earliest papers of Wintle¹⁰ and Gould.¹¹ Von Groddeck¹² was the first to show that these porphyries were topazized quartz porphyries, comparable with the topaz-quartz porphyry in the Schneckenstein, Germany. Twelvetrees and Petterd¹³ have also described the petrographical characters of the topaz porphyries.

Apart from Herman's work no clear understanding of the true character of the actual tin deposits is recorded. The present writer, although agreeing with Herman that the greater part of the stanniferous deposit is a product of the alteration and replacement of the porphyries, also believes that the slate and sandstone country and some old basic igneous rocks have played a part in the tin deposition.

GENERAL DESCRIPTIONS.

Physiography.

The Waratah area is characterized by a precipitous and rugged topography of recent age. Mount Bischoff is a residual conical eminence rising some 500 feet above the level of a great dissected peneplain. The two main streams, the Arthur and Waratah Rivers, have scored deep gorges in the peneplaned sur-

⁷ Twelvetrees and Petterd, *Proc. Roy. Soc. Tas.*, 1897, p. 125; and W. N. Twelvetrees, *Rep. Sec. for Mines, Tas.*, 1899-1900, p. cxi.

⁸ J. D. Millen, *The Mining Journal*, London, 1910, p. 300.

⁹ H. Herman, "Australian Tin Lodes and Tin Mills," *Proc. Aust. Inst. Min. Eng.*, n. s., No. 14, 1914, p. 301.

¹⁰ S. H. Wintle, *op. cit.*, pp. 88-90.

¹¹ C. Gould, *op. cit.*, p. 109.

¹² A. von Groddeck, *Proc. Roy. Soc. Tas.*, 1865, p. 388 et seq.

¹³ Twelvetrees and Petterd, *op. cit.*

face so that the beds of the streams are now over 500 feet below the old peneplain. Mount Bischoff lies in that portion of the area situated in the angle formed by the junction of the two rivers.

South of the Mount the old peneplain has been covered by a late Tertiary basalt flow, so that here the country has a flatter surface. North and West, however, the rugged topography continues almost to the coast. The Mount, rising 2,598 feet above sea level, owes its elevation in large part to a series of porphyry dikes. In places these dikes stand out from the hill slope as steep precipitous cliffs.

On the Don Hill are the remains of an old river valley, evidently the pre-basaltic Waratah River. This old river bed is represented by alluvium; great boulders of porphyry shed from the Don and Southern Dikes, incorporated with tourmalinized porphyry, quartzite and slate pebbles, in a hard matrix of fine grit. This is overlain by a sandy clay which is rich in vegetable matter. Above this is the basalt. These alluvial beds were probably laid down on a valley slope, as they dip to the South at 30 degrees; this tilting may, however, have been produced by faulting. This old alluvium is probably of Upper Pliocene age; it has been worked for tin, and it appears probable that a deep tin lead may be continuous with it beneath the basalt to the South.

Rock Formations.

Stratified Rocks.—The dominant rock type of Mount Bischoff is a highly inclined, contorted, and faulted slate with beds of sandstone, quartzite, and pyroclastic breccia.¹⁴ These were originally correlated as Lower Silurian,¹⁵ but later as probably Cambro-Ordovician.¹⁶ Mr. Loftus Hills states¹⁷ that they are evidently members of the Dundas and Leven series of slates and breccias, porphyrites, and granite porphyries which constitute

¹⁴ W. H. Twelvetrees, *op. cit.*, p. cxliii.

¹⁵ W. H. Twelvetrees, *loc. cit.*

¹⁶ L. K. Ward, Geol. Surv. Rep. No. 2, Tas., 1911, p. 3.

¹⁷ Personal communication.

the base of the Tasmanian Cambro-Ordovician. These are largely of pyroclastic origin and formed under submarine volcanic conditions.

At Mount Bischoff, the slates, sandstones and quartzites are the important rock types of this period. So far as the writer is aware the only igneous representative is a rock evidently originally high in olivine (apparently a dunite), now serpentinized. It is not abundant, but occurs associated with the tin deposits. Its field relations are obscure, so that its position here is only tentative. It is older than the porphyries.

Porphyries.—Southwest of Mount Bischoff is the outcrop of a large granite intrusion of Devonian age.¹⁸ Between this point and the Mount the country is covered by the basalt, and it is quite probable that the granite approaches (beneath the basalt) close to the tin-bearing area. Twelvetrees and Petterd conclude¹⁹ “that the quartz porphyry is not a marginal portion of the main granite mass, but belongs to dikes running through the granite and having a slightly different composition from the latter”—that is, the porphyries belong to a later stage in the differentiation of the granitic magma, as is generally accepted elsewhere.

The great series of porphyry dikes forms perhaps the most striking feature of the Mount Bischoff area. Of these the Western Dike (see Fig. 14) is apparently the main one; it continues northeast to form first the Stanhope Dike, then the Northeastern Dike, and apparently dying out on the northern slope of the Waratah Valley. On the western side of the Mount, its outcrop cannot be traced, but it is again met with in the underground workings of the Mount Bischoff Extend Corp., on the Giblin Lode. Here the dike is nearly vertical.

The Northern Dike and its southern extension, the Ringtail Dike, appear to have a steep southwesternly dip, and the Radio Dike a steep northerly dip. These dikes consist of fine-grained porphyry, which carries few quartz phenocrysts, but much pyrite.

The Queen Dike strikes approximately northwest, but towards

¹⁸ W. H. Twelvetrees, *Rep. Sec. for Mines, Tas.*, 1899–1900, p. cxlviii.

¹⁹ Twelvetrees and Petterd, *op. cit.*, p. 125.

its western end trends nearly due west. Westward, the dike dips 70 to 80 degrees into the hill, but eastward it flattens to 30 degrees. The Queen Dike has been worked in places for tin.

FIG. 14. Mount Bischoff. Plan of workings and dikes. (Compiled from plans by H. Sommerville, H. B. Schell, and A. D. Mackey, and from author's notes.)

The Southern Dike and White Face Dike are huge porphyry masses, sill-like in character. The Wheal Dike and North Alluvial Dike are both sills, their northern extensions taking on the character of dikes; possibly they are both tongues from the Queen Dike.

The Little Wheal Dike is practically vertical. In its southern extension isolated patches and splashes of porphyry may be noted in the fault rock, giving the impression that the porphyry

also has been faulted, but as the outcrop is traced farther south the dike tails out, the patches of porphyry become less and finally give out, and the line of strike is then represented by a fault rock. The apparently isolated splashes of porphyry are evidently due to the squeezing of the molten magma into the fault rock; often a thin connecting thread of porphyry may be traced between the patches. The fault rock is a hard breccia of quartzite and slate in a fine silicified matrix.

The contention that the Western Dike, and its northeastern continuation, is the main dike of the area seems to be upheld, then, by a comparison with the structural characteristics of the other dikes of the area. Its continuation in depth is proved as well as its persistence in strike. The writer believes that this Western Dike in depth was connected with the granite magma below, that it was the channel up which first the porphyries of the area and then the ore solutions ascended.

In addition to these main dikes occupying fault fissures and those occurring as sills, there are numerous irregular and tongue-like masses distributed throughout the tin-bearing area, and often apparently isolated from other porphyry masses. For the most part these irregular porphyries—they may be compared with an irregular *lit-par-lit* injection into a highly fractured zone—have been subjected to extreme alteration. The Brown Face, White Face, Slaughter Yard Face and Gossan Face, the principal tin-bearing areas of the Mount, are practically made up of these highly altered porphyries, with the inclusion of large and occasionally highly replaced “horses” of slate, and the association of altered basic igneous rocks. The slate is generally replaced by marcasite; the basic igneous rock is often completely altered to talc, with often the formation of tremolite (showing alteration to asbestos), or the alteration is less complete—merely serpentinization, or part replacement by calcite. The altered basic igneous rock is not tin-bearing as a rule.

In the Mount Bischoff Extended underground workings a large “boss” of porphyry is met with, but does not outcrop. It

is apparently a bulge in the Western Dike, as in depth it appears to decrease where cut through.

Faulting.

The Cambro-Ordovician series have been disturbed to such an extent within the area of the Mount that there does not appear to be any regular strike of the country. Still, a northeasterly strike predominates, particularly in areas of least disturbance on the east side of the Mount, while on the west side a northwesterly strike is the rule. These variations of the strike in different parts of the area are the result of great thrust faults, some of which have played perhaps the most important part in the subsequent localization of the tin deposits. The main direction of thrust movement was apparently almost east and west, as indicated by the three most important faults—the North and South Walls of the Brown Face, and the irregular south dipping “wall” on which the Gossan Faces rest.

Subsequent normal faulting just prior to, or contemporaneous with, the period of igneous intrusion has still further disturbed the country. These normal faults have been the main passages of ascent of the porphyries. As shown by the often almost microscopic injection of porphyry, the fault rock was still in a soft and easily permeable state at the period of intrusion, so that the porphyries are closely related in time to the faulting.

A still later series of faults formed the original lode channels; these cut the earlier faults.

At Mount Bischoff, then, the important series of faults may be summarized as follows:

- (1) Thrust faults, probably associated with the folding and crushing of the Cambro-Ordovician,
- (2) Normal faults occupied by the porphyries and probably contemporaneous with the earlier stage of igneous intrusions, and
- (3) A regular series of southwesterly to westerly dipping faults forming the lode channels, and evidently associated with the later stage of igneous activity, later even than the formation of the main tin deposits.

Irregular Tin Deposits.

The Brown Face and Gossan Benches are the main deposits now being worked at Mount Bischoff²⁰ (Plate III a). Their structural relations may be noted from Figs. 15 and 16. A little

FIG. 15. Sketch section across Brown and Gossan faces to show approximate structural features. (F = probable fault wall.)

rock is still won from the bottom of the White Face; the North Alluvial and Summit Faces are now abandoned.

The Brown Face.—This deposit is confined north and south between two strong fault walls which converge west to form the apex or end of the deposit. The South Wall (or fault) apparently extends downward with little change in dip, whereas the North Wall flattens in depth and apparently becomes horizontal beneath the deposit before abutting against the South Wall; this change in dip may be noted on the "50 ft. level," just below the Open Cut, and is shown in Fig. 15. The floor of the deposit is generally a vuggy crystalline quartz-tin "make," up to 2 feet

²⁰ At the time of the writer's visit, prior to the temporary closing down of work in October last.

in width. Above this is generally a dense marcasite which passes into a soft decomposed porphyry above. Both the marcasite and porphyry may carry tin. Large horses of slate occur throughout, and these often show replacement by sulphides and may be impregnated with tin.

The slate country immediately beneath the "floor" on No. 2 level is, for the most part, practically horizontal. The level is driven on a "flat make" running almost parallel with the true floor, and this flat "make" carries good tin in places. The slate country here is so saturated with water that it is quite soft and clay-like in places. It is noticeable that the South Wall acts as a watercourse, the slates in its vicinity also being soft and saturated.

Along the South Wall, and to a lesser extent the North Wall, excellent slickensided surfaces may be met with, as well as much fault rock. The striations vary greatly in direction. On the whole the movement was along the fault, and was essentially a thrust movement.

The North Wall is much more irregular than the South Wall and appears to have been only a minor plane of movement—probably merely a kind of relief fracture. Between these two walls the ground is severely crushed and shattered.

The eastern boundary is irregular; it may be a fault wall, but it appears more likely that the boundary is a more gradual one, and formed by the diminution in crushing and fracturing of the country farther from the fault junctions.

Into the crushed area enclosed between the North and South Walls came the porphyry, as tongues, dikes and irregular masses. These have, for the most part, been much altered subsequent to being impregnated and veined by tin, and they have in places been severely sheared and crushed. The alteration of the porphyries is a replacement by sulphides, sericite, pyrophyllite or talc, and these replacements are of such an extent that all signs of the original porphyry may be (and generally are) quite lost. Other alterations are to a coarse sharp gritty sand, or to a soft mass of clay or sericite in which secondary sulphides (as mar-

casite and chalcocite) and sulphates (as cyanosite and copperas) may be abundant. Impure secondary copper sulphides, black, and of a pitchy lustre, may abound in the clay and sericite, or when in the white decomposed porphyry they often produce a black or brown stain against which patches of the white porphyry stand out sharply. This is particularly striking along No. 2 level.

Isolated in the sulphide, numerous round and lenticular pockets of white coarse sharp sand are met with, often rich in tin.

The sulphides oxidize irregularly to gossan, the oxidation in different places apparently being governed by the presence of lines of water percolation, joint faces, and the junction of dissimilar rocks, such as slate and sulphide. It is only within the last few years that the pyritic zone has been reached. Above, the Brown Face was entirely of gossan, highly ferruginous, mainly of limonite, but in part of siderite. In the early days the "cap" formed a small subsidiary eminence as represented by the surface profile in Fig. 16. Locally, it is said that the tin

FIG. 16. Sketch section C-D, E-W. (See Plan, Fig. 14.)

ore in this upper zone often occurred in huge masses of pure cassiterite, and the ground was often so rich that it could be shovelled into bags and sent to the smelters without dressing. In those days the tin ore is said to have been so abundant that it was stacked on the spot more quickly than it could be removed to the smelters. The exceptional richness and coarseness of the

tin in that upper zone, now removed, can only be accounted for by secondary downward enrichment by leaching probably keeping pace with denudation.

The best values at the present day are generally within a ten-foot zone around the walls of the deposit. The fault breccia along the walls, where silicified, often carries tin, while small lenticular tin veins occasionally penetrate the country; for this reason the wall is in many places removed for a few feet back.

On the eastern side of the South Wall, fresh unaltered porphyry intersects it, showing that the porphyry is definitely later than the formation of the walls. Below the Brown Face a dike is met with in No. 2 Level West, and continuing down below the Western Crosscut. This dike may be one of the channels up which the porphyries forming the deposit ascended.

In the northeast corner of the Brown Face masses of talc are met with, associated with a highly altered basic igneous rock, from which probably most of it was altered. Veins of tremolite (altering to asbestos) are also associated and are evidently derived from the basic igneous rock. This appears to have been an olivine rich rock, much serpentized, but pyroxene was evidently abundant in places as bastite may be noted altering to talc. This section of the Brown Face carries little or no tin.

The Gossan Benches.—These occupy part of the southern slope of the Mount. At intervals along and up the slope an irregular North Wall is met with along the benches, often with horizontal striæ—evidently another line of fault movement. The structure here is still obscure. Possibly it may be as indicated in Section *A-B*, Fig. 15.

The crushed material evidently associated with the faulting in the Gossan Faces has been injected with porphyry dikes, masses, and tongues in the same way as the Brown Face. There have been similar alterations, but the main one has been to a pyritic material, weathering to ferruginous sands and clays (originally thought to be detrital), and to gossan. Along the walls the country is so crushed and decomposed that it cannot be

determined if the pyrite was originally contained in porphyry or in slate (Plate III b).

Occasionally, apparently isolated masses of comparatively fresh porphyry may be found throughout the benches. Only in rare instances do they penetrate the wall, as in No. 6 bench.

Siderite is a common mineral in the Gossan Faces, and is often associated with galena and sphalerite. Occasionally it is concretionary, a shell of siderite enclosing crystals of galena, sphalerite and pyrites; these were regarded as water-worn pebbles in the early days.

Talcose rocks similar to those in the northeasterly part of the Brown Face are met with, but are quite rare. Beneath the No. 5 Bench, in the Main Tunnel, is a hard massive dolomite carrying a little green talc (apparently residual) or serpentine, and often "making" into almost pure sulphide. It may have resulted from the total replacement of some basic intrusive. If this is correct the presence of the magnesia is explained, but it may be pointed out that the ore solutions at Mount Bischoff were quite high in magnesia. Throughout the West Coast of Tasmania the association of magnesia with ore solutions is noticeable.

In the Gossan Faces the best values occur in a 20-ft. zone along the wall. Within this zone veins of tin penetrate the deposit in all directions. Veins of coarse fluorite (carrying no tin) are common also, as well as much secondary vuggy quartz. The Gossan Faces are, on the whole, low grade. As in the Brown Face, the more siliceous parts are higher grade than the clayey or talcose.

The White Face.—This deposit lies to the east of the Gossan Faces, and differs from the ones previously discussed. As will be noted from Fig. 14, it is in part intimately associated with the junction of the White Face Dike, Stanhope Dike and Little Stanhope Dike. Evidently the deposit was originally a huge bulge or "boss" of porphyry resting on a slate floor. As practically the whole deposit is now removed, whatever evidence there was as to any structural similarity to the Brown Face or Gossan Faces can no longer be observed. The only part of the deposit remain-

ing is a fine marcasite at the bottom of the open cut, and this evidently goes down for at least another 20 feet. In the past the pyrite was never worked. According to Herman,²¹ the materials worked at the White Face were friable sands and clays, often overlain by slates and sandstones, and were apparently the complete decomposition and disintegration product of porphyry *in situ*. The clays are really a white decomposition product of topaz and tourmaline. Herman, by watching the workings closely for some months, noted the gradations of the clays and sands "through all stages of friability to an adhesive granular quartz rock, then to a hard stanniferous porphyry." In Nos. 1 and 2 benches of the White Face East, Herman watched an open cut which "was in rounded and sub-angular boulders of gray porphyry in a matrix principally of sand. The whole presented a striking appearance of fluvatile origin; but at intervals, as the work progressed from week to week, this loose aggregation occasionally merged into and from undoubted more or less decomposed porphyry *in situ*. The steep dip of the slate and sandstone wall terminating the material was strong corroborative evidence that it was really a wall of a lode and not the 'bottom' of an alluvial or any detrital deposit."²² In places, a fine impalpable powder mixed with fine gray tin was met with, and carried 30 to 40 per cent. tin. Herman points out in addition that the "sedimentary rocks also, in places, have a tendency, when stanniferous, to assume a loose granular character, but not nearly to the same extent as the porphyry dikes."²³

It appears, then, that the White Face possessed practically none of the characteristics of a gossan, it consisted mainly of a peculiar white, loose sand and clay, and appears to have carried very little ferric oxide. This is peculiar in view of the pyrite lying at the bottom of the deposit. Either the replacement of the original porphyry by sulphides has only taken place at the lower limits of the deposit, or leaching has gone on to such an extent as to totally remove all iron.

²¹ *Op. cit.*, p. 294.

²² Herman, *op. cit.*, p. 297.

²³ Herman, *op. cit.*, p. 295.

a

b

c

a. Brown face "Glory Hole" looking west to the apex at convergence of the two walls.

b. Oxidation and leached zones in porphyry; central pyritic zone surrounded by brown oxidized zone, and by leached zone.

c. Radial topaz (pycnite) being replaced by prosopite (showing cleavage) and replaced and veined by pyrrhotite. $\times 20$.

Perhaps one of the most persistently rich parts of the whole mine was worked in the White Face where a 15-inch seam of tin-bearing sand was met with, traversing decomposed porphyry, and along the walls of which was radial topaz or pycnite-rock. This seam was remarkably rich, the values constant throughout, and maintained the mine returns at a high level for some years.

In the tunnel beneath the White Face lenticular patches of a cellular, sintery quartz are met with in the sulphide—evidently a product of leaching. At the mouth of the tunnel, south of the open cut, is an extremely fine-grained porphyry in which phenocrysts are so few that the rock may at first sight be erroneously regarded as a fine-grained sandstone.

The North Alluvial Face.—This deposit, on the north side of the Mount, is now abandoned. Originally it consisted of tongues and irregular masses of partly decomposed and disintegrated porphyry, in slate country. Herman records that "it had the character of the 'wash' of the White and Brown Faces, with perhaps an unusually large proportion of clay."²⁴ Much of the porphyry still remains practically unaltered, so that the undoubted derivation of the sands and clays from the alteration of the porphyry "in situ" may be traced out. Herman states that the erroneous idea held at the time, as to the origin of these sands and clays, was responsible for the misleading name North Alluvial. This Face proved a prolific source of tin for some years.

The Slaughter Yard Face.—This deposit, situated between the Brown and Gossan Faces, is identical in origin with them. Very little pyrite has been met with as it has been mainly worked in the oxidized zone. Although now abandoned, the deposit still goes down below the bottom of the open cut, except in places (as in the north part of the cut), where slate forms the floor.

The structure is obscure; no records have been kept, and the faces of the open cut are irregular and broken, so that nothing definite can be made out. To the writer, it appears that the structure resembles the character of the Gossan Faces, as shown

²⁴ Herman, *op. cit.*, p. 299.

in Section *A-B*, Fig. 15, the deposit occupying what was originally a broken and shattered zone.

The best values were in the upper gossan, downward leaching evidently having brought about secondary enrichment.

The Stanhope Face.—This face, now abandoned, shows a rather fresh porphyry which originally carried considerable tin, disseminated and crystallized along joint planes. The porphyry is well jointed, large blocks of it carry good tin towards their boundaries, the tin content becoming poorer inwards so that generally the center is barren. This often coincides with a bleached outer shell of white porphyry, and an inner kernel of hard, dark fresh porphyry. Within the outer shell of bleached porphyry is often a concentric zone of oxidized, ferruginous porphyry, generally with tin content intermediate between the outer bleached porphyry and the barren central pyritic porphyry. The ferruginous band represents the zone of oxidation of the porphyry working inwards from the joint planes, the bleached outer band represents the zone of leaching following oxidation.

The coincidence of values with these zones may perhaps be due to lateral enrichment caused by surface waters leaching and concentrating the tin towards the joint planes. On the other hand, it seems more probable that the concentration of the best tin content towards the bounding joint faces was essentially primary—the ascending tin vapors or solutions traversed the rock along the joint planes, then permeated inwards from each joint, so that the best values would be closer to the joint faces; in those cases where the tin was unable to reach the center, the inner zone would be barren. This seems to be in some measure confirmed by the tin selvage often found along joint planes, associated generally with quartz, pyrites, sphalerite, galena, bismuthinite, arsenopyrite, chalcopyrite and sometimes tourmaline. The secondary oxidation and bleached zones are therefore superposed on the primary zonal distribution of tin.

In the earlier days, the outer shells of huge porphyry blocks were spalled off, the fragments sent to the battery, the hard pyritic barren kernel picked up by crane and dumped.

The Summit Face (or Wheel Face).—This is an open cut on a sill-like mass of porphyry (continuous with the porphyry at the pinnacle of the Mount, just above). The porphyry is irregular, but on the whole lies practically horizontal; at the edge of the cut on the east side, however, the porphyry turns and lies nearly vertical, then apparently continuing down the hillside as a more normal dike.

Both the porphyry and associated slate country carried tin. Often fine facings of tin and quartz are met with in the joint faces of porphyry and slate. Pyrite is absent. The slate is rather indurated and silicified in parts, often producing a banded slate by selective silicification. Silicification and banding is not associated particularly with the tin; it often occurs in quite barren parts of the Mount. Neither is it associated exclusively with the presence of porphyries.

This face is now abandoned; at one time it was an excellent tin producer.

THE LODES.

Apart from the Queen and Giblin Lodes, veins have not been worked extensively at Mount Bischoff, up to the present. The Queen Lode is now abandoned, and practically no records have been kept. It lies to the north of the Brown Face; a plan of some of the levels is shown in Fig. 14. The strike is approximately northwest and it cuts across the Queen Dike, in places following along the walls of the dike. The dip is southwest and much flatter than that of the dike so that the lode and dike intersect in both dip and strike. In the past, the Queen Lode was an important feature in the ore reserves.

The Brown Face Lode evidently lies almost parallel to the Queen Lode in both dip and strike. A short level from the Main Tunnel beneath the Brown Face has been developed. It carries good values, but is merely in the prospecting stage as yet. The levels on the North East Lode (S. E. corner), the South West Lode (S. of pinnacle), and the winzes on the Thompson's Lode (S. of Gossan Faces) are shown in Fig. 14.

These generally show a good tin content, but have as yet been only prospected. Their dip is always westerly.

From Fig. 14 it will be noted that the lodes appear to radiate from some point in the northwest of the Mount, the variation in strike being quite regular. The dip is always in the same relative direction, varying of course with the strike, the lodes with northwesterly strike dipping southwest, those with almost due northerly strike dipping west.

The Giblin Lode is worked by the Mount Bischoff Extended Tin Mining Company. A short description of this lode will serve for all the lodes of the area.

The Giblin Lode has been excellently described by C. W. Gudgeon.²⁵ It is a typical tin lode, "making" and "pinching" in strike and dip. The average width is about 2 feet, occasionally widening to 15 feet or pinching to a mere film. On the whole, the widest parts are in slate, the pinching generally occurring in quartzite. Associated with the wider parts of the lode, there is almost universally a large amount of gouge, while the thinner and more average parts are of dense and vuggy quartz often highly stanniferous throughout the width. The lode walls are occasionally polished and slickensided.

Generally along either the footwall or hanging wall, but more often the former, the lode is highly pyritic, containing pyrite, arsenopyrite, marcasite, pyrrhotite, galena, stibnite, sphalerite, and bismuthinite. In depth the galene-sphalerite content increases, the tin diminishes, the sphalerite becomes the dominant mineral, until the lode is characteristically a lead-zinc one. These sulphides also are sometimes scattered throughout the lode, and often in what appear to be transverse fissures across it. Still, although a large part of the sulphides seem undoubtedly later than the great bulk of the lode filling, much was definitely contemporaneous with the main veinstone. The tin, in places, is intimately associated with the sulphides both mechanically and chemically (probably as stannite).

²⁵ C. W. Gudgeon, "The Giblin Lode of Tasmania," *Bull. Inst. Min. and Met.*, January, 1919.

Wolfram was occasionally found in small pockets in the upper parts of the lode, generally along the hanging wall and apparently only in the wider "makes." Its relation to the other minerals remains obscure.

Below level No. 5 there are two large "droppers," or subsidiary lodes, and dipping at a much steeper angle than the main lode. The walls of these "droppers" are also slickensided. These "droppers" are similar in structure to the main lode, but the tin content is unpayable and they carry more sulphides. There was an enrichment of tin where they junction with the main lode. These "droppers" apparently go up the footwall, and as Gudgeon pointed out,²⁶ introduced the lead-zinc minerals.

First "makes" of quartz containing a little tin often occur in the footwall between the lode and "droppers." In the lode, horses of large dimensions often occur. Between levels No. 5 and 6 a large one of slate, quartzite and porphyry occurs, the hanging wall carrying the payable ore.

The ore solutions in places appear to have altered the slate walls, generally the hanging wall. This alteration is mainly a slight silicification. The walls are often impregnated with tin for a few feet on either side of the lode. In the neighborhood of small veins and fractures running off from the lode, there is often a slight replacement of the country by fluorite.

The mineral sequence appears to be tin and quartz, pyritic sulphides and fluorite, lead-zinc.

The lower limit of the oxidized zone is irregular, and the tin appears to have migrated, enriching the upper zone and often forming coarse masses of cassiterite.²⁷

REPLACEMENT AND ORE GENESIS.

The Porphyries.

Mechanics of Intrusion.—It has been shown that the intrusion of the porphyries was preceded by much faulting. The magma

²⁶ Gudgeon, *loc. cit.*, p. 6.

²⁷ Gudgeon, *loc. cit.*, p. 9.

was intruded under great pressure as is shown by the forcing of "splashes" of the porphyry into the fault rock. This great pressure was probably the means by which the dike walls were forced apart, and it was also evidently the cause of the irregular tongue-like masses which formed the various faces.

It would appear that while the dikes were still molten, and probably even accompanying the ascension of the magma, the fluorite and other vapors commenced to ascend. The quartz phenocrysts, which in the deep-seated magma had grown to clear idiomorphic crystals, continued their growth after intrusion. But with this later growth was included much fine topaz in the quartz, the inner border of the inclusions still retaining the sharp outline of the original deep-seated phenocryst. Where magmatic resorption had corroded and embayed part of the phenocryst, the inner border of the topaz inclusions follows the corroded outline. Under ordinary light this outer zone of inclusions is confused with the quartz topaz groundmass, except that the topaz is rather finer grained, but with crossed nicols the outer border of quartz is in optical continuity with the original quartz phenocryst. Every quartz phenocryst examined in the topaz-quartz porphyries of Bischoff shows this peculiarity. The writer accepts it as evidence that the fluoride vapors ascended while the dikes were still molten so that topaz was included in the quartz which grew around the phenocrysts when they reached their present position in the dike.

An alternative explanation may be that the fluoride vapours ascended subsequent to the consolidation of the dike, and replacing feldspars by topaz, threw out excess quartz, which crystallized around the quartz phenocrysts. If this were so, it could hardly be expected that the whole of this border of later quartz would show such optical continuity with the older magmatic phenocryst. Also, in this case, the topaz enclosed in the border would be expected to be similar to that in the groundmass, whereas it is actually much finer. Also, it would be necessary to postulate that the phenocryst, once it was intruded with the magma, did not grow further, that is, there was no more free quartz available.

But the abundance of quartz in the groundmass shows that much free quartz was still present, and some of this would certainly have still further enlarged the phenocryst. Again, if the topaz replaced the feldspars subsequent to the consolidation of the magma, it would be expected that the topaz replacing the feldspar phenocrysts would be precisely similar to that replacing the feldspar of the groundmass. But the topaz replacing the feldspars is often an aggregate of topaz laths, that replacing the groundmass is generally either very fine-grained and felted, or more definitely crystalline. That little or no quartz was thrown down during topazization is indicated by the almost total absence of quartz with the topaz replacing feldspar phenocrysts; all excess quartz is apparently removed.

The evidence, then, favors the opinion that the fluoride (topaz) vapors ascended while the dikes were still molten, replaced the feldspar phenocrysts as aggregates of laths, replaced all feldspar in the groundmass coincident with its crystallization, and topaz was enclosed in some of the quartz which enlarged the older deep-seated phenocrysts.

The porphyries in general consist of quartz phenocrysts and topaz pseudomorphs after feldspar phenocrysts, in a groundmass of quartz and topaz. The groundmass may vary from extremely cryptocrystalline to coarse grained. Occasionally muscovite is met with, and generally shows alteration to a sericitic aggregate. Pseudomorphs of tourmaline after feldspar (blue and green) are often met with; occasionally the whole rock may show tourmalinization close to joint planes. A little cassiterite is generally present. Practically all the porphyries of Bischoff are pyritic, the pyritic minerals being secondary.

The replacement of the porphyries has gone on in a definite sequence, apparently commencing, as indicated above, while the dikes were still molten. This replacement sequence is probably governed by temperature considerations, and may be taken under two general headings—Pneumatolytic Replacement and Hydrothermal Replacement.

Pneumatolysis.

The pneumatolytic stage at Mount Bischoff is represented by topazization, tourmalinization and cassiteritization. It is possible that some sericitization commenced during this period, but the main bulk of sericite came in early in the hydrothermal stage.

An extreme result of pneumatolytic action subsequent to consolidation is the removal of all alkalies and evidently alumina as soluble fluorides, leaving the silica as an insoluble residue. In the White Face, a 15-inch seam of tin-bearing sand was evidently formed in this way. The excess fluorides liberated by the deposition of much tin along a master joint plane converted the porphyry to angular sand particles, the excess fluorides evidently removing all alkalies and alumina. Either side of this, where the action of the liberated fluorides was not quite so severe, the porphyry was converted into a pycnite rock; the presence of tourmaline in this indicates also the accompaniment of boron vapors. Still further from the wall of the seam of tin-bearing sand, the porphyry was the more normal topaz porphyry, but rather weathered. This same action of the pneumatolytic vapors has also taken place on the slate and sandstone at Bischoff, all feldspathic and other minerals being removed, leaving a clear, sharp, angular, "etched" quartz sand. The lenticular tin-bearing sand pockets in the deposits at Bischoff appear to owe their origin to this acute phase of pneumatolysis.

In Cornwall a similar phenomenon has been observed. J. H. Collins has recorded²⁸ that in places the stanniferous solutions have carried away the feldspathic ingredients of the granite "leaving the quartz in loose grains so producing the sand lodes," as at Wheal Coates and the Great Beam Mine.

Topazization.—Topazization of the porphyries is practically universal throughout the area, unreplaced feldspars occurring only on the north side of the Mount away from the tin deposits, as recorded by Twelvetrees and Petterd.²⁹

²⁸ J. H. Collins, "On Some Cornish Tin-Stones and Tin Caxels," 1888, p. 38.

²⁹ Twelvetrees and Petterd, *op. cit.*, p. 120.

Topazization was the first alteration of the porphyries to take place and apparently commenced while the porphyries were still molten and continued after the consolidation of the dikes. For the most part, only the feldspars are replaced, but occasionally (as along the wall of the previously mentioned tin-sand seam of the White Face) the whole of the quartz is also replaced, and a topaz (or pycnite) rock results. In such cases the topaz occurs as spherulitic aggregates; the central portion of each spherulite is generally fine-grained to granular, and surrounded by radiating prisms and needles of topaz (or pycnite). Apparently the central granular aggregate represents the replaced phenocryst, the radiating prisms and needles the recrystallized groundmass. Pycnite rock is particularly abundant where tin is also abundant. (At the present day there is none to be found at Bischoff, all of it having been put through the battery long since; only specimens in museums can now be examined.) The pycnite rock has generally associated with it some radial blue tourmaline, and is often stanniferous. Contrary to the usual stability of topaz, the pycnite variety easily weathers and alters either to sericite or a clayey material. It is also easily replaced by later minerals, particularly sericite (or damourite) and iron sulphides. It may be here noted that the whole of the topaz of Mount Bischoff is the pycnite variety; pycnite embraces the spherulitic, radial, columnar and compact varieties of topaz.

Tourmalinization.—Tourmalinization commenced rather later than topazization. There is no evidence that boron vapors were active during the crystallization of the porphyries. It is possible that boron was associated with the early fluoride vapors, but the temperature was still too high for stable boron minerals to form. Spherulitic tourmaline aggregates are intimately associated with the radial pycnite rock; the two minerals, pycnite and tourmaline, appear to be simultaneous in growth. In some cases the whole of the porphyry is replaced by radial aggregates of tourmaline with which is often associated much tin. These radial aggregates of tourmaline are somewhat similar to those of topaz—a granular to fine-grained central aggregate (often with a brownish

tint) surrounded by radiating blue or green prisms or needles. In places where only the feldspar phenocrysts have been replaced, the tourmaline is a fine-grained prismatic or lath-shaped aggregate. Tourmalinization is always confined to the neighborhood of joint planes or contacts of porphyry and country, and never replaces the whole rock mass in bulk.

Tourmalinization apparently continued long after topazization. It evidently continued (but with very diminished activity) to the crystallization of pyrrhotite, as one thin vein of blue tourmaline was noted in pyrrhotite. The mineral is rather common at Bischoff, but it is by no means as extensively distributed as topaz.

Cassiterization.—The replacement of the porphyries by cassiterite is, of course, slight compared with topazization and tourmalinization, and is in fact almost confined to the occasional replacement of feldspar phenocrysts by tin. Topaz and tourmaline also show occasional replacement by cassiterite. From the fact that all of the porphyry always carries at least .005 per cent. Sn, it would appear that at least a little tin accompanied the early vapors and crystallized while the rock was still molten. Most of the tin deposition commenced with the topaz and tourmaline. The stanniferous vapors moved up and along joints and fissures in the porphyry, impregnating the rock mass from the joints inward, with resulting zonal distribution already indicated. In the Brown and Gossan Faces, the walls of the deposits formed the easiest passage or line of weakness along which stanniferous vapors (and later solutions) could ascend, so that in these deposits the best values are in the neighborhood of the walls.

The extreme result of pneumatolytic activity noted under "Pneumatolysis" as the total removal of all alkalies and alumina from the porphyry, leaving only an angular "etched" sand, is evidently a result of cassiterite replacement. It is always associated with remarkably high tin (gray) values (often as much as 40 or 50 per cent. Sn), and appears to be the result of the excess fluorine liberated during the deposition of cassiterite.

The association of cassiterite with pycnite rock has already

been noted. Occasionally the tin appears to have accompanied excess boron vapors, converting the porphyry into a tourmaline-tin rock, in the immediate vicinity of joint planes or other lines of weakness.

The ascension of tin appears to have been prolonged to the hydrothermal stage as in the quartz lodes of the area. The cassiterite occurs as both the gray and very dark amber or black varieties, the dark colored being by far the most common.

Hydrothermal Replacement.

The alteration of the topaz-quartz porphyries by hydrothermal replacement is not so widely distributed as topazization. It is practically confined to the main tin zone, and here the original character of the porphyries has, in the main, been lost. In fact, hydrothermal replacement is a more distinctly special feature of the crushed zones forming the tin deposits, than is pneumatolysis, in that whereas pneumatolytic replacement of the porphyries may extend throughout the area traversed by the dikes, total hydrothermal replacement is confined to the actual tin deposits.

There appear to be certain temperature stages in the hydrothermal period, producing an apparent mineral succession:

- (1) Sericite, gilbertite, and damourite; with probably talc and pyrophyllite.
- (2) Quartz, tin and chlorite (?).
- (3) Prosopite, pyrrhotite, calcite, fluorite (?).
- (4) Arsenopyrite, marcasite (?), pyrite (?), chalcopyrite.
- (5) Galena, sphalerite; fluorite continuing with dolomite and siderite.

The minerals of each stage are more closely associated with one another than with those of later stages, but within each stage there appears to be a mineral sequence. The minerals of an earlier stage may transcend those of a later stage. Quartz evidently continued to the early part of stage 5; fluorite continued through to 5; probably sericite continued to the stage 4. It may

be pointed out that these stages are not intermittent, they overlap to a large extent, and appear wholly governed by gradual lowering of temperature. The stages will only represent, then, the temperature at which each mineral *commenced* to crystallize.

FIG. 17. Apparent sequence of important minerals at Bischoff.

The sequential positions of talc and pyrophyllite are doubtful, it can only be said that they are earlier than all the sulphides. The age of chlorite is also doubtful—it is earlier than the sulphides, but apparently rather intimately associated with the tin in quartz veins. Chlorite is by no means a common mineral in this area.

Sericite, Gilbertite or Damourite; Talc and Pyrophyllite (?).—The secondary muscovites appear to be the earliest of the hydrothermal minerals. There can be made out no definite line of demarcation between sericite and gilbertite, fairly coarse-grained gilbertite merging into extremely cryptocrystalline sericite, which when compact and dense becomes rather of the nature of damourite.

It appears evident that some of these secondary micas are es-

entially pneumatolytic in origin, and may even have existed prior to topaz. Occasionally the porphyry shows no sign whatever of topazization, in which case the feldspar is altered to sericite or gilbertite. It is known that sometimes the action of fluoride vapors on feldspar results in the formation of muscovites. In the Brown and Gossan Faces where this type of alteration occurs, the porphyries concerned are isolated tongues. They are generally rather low grade, and would appear to be away from the main path of ascension of pneumatolytic vapors. On the Don Hill numerous nodules of sericite-gilbertite-quartz porphyry occur in the more normal topaz porphyry. These nodules would appear to be segregation nodules formed before the consolidation of the main bulk of the porphyry, so that fluorine vapors would not have as great an action on them as on the still molten porphyry.

It would appear, then, that where the fluoride vapors were not sufficiently in excess at Bischoff to form topaz, the feldspars were merely altered to muscovite. Where the porphyries show only sericitization, first the feldspar phenocrysts are replaced by sericite, then the groundmass is replaced until almost the whole rock, including much of the quartz, may be altered to a mass of sericite; the outline of the original phenocrysts is quite lost. During this process of replacement, the fine sericite may be recrystallized into a coarser gilbertite. In cases where the sericitized porphyry has been silicified, the secondary muscovites are left in the secondary quartz as ghosts of the original sericitized phenocrysts.

Much of the secondary micas, therefore, may be pneumatolytic, and may precede or accompany topazization as representing a stage of only partial pneumatolytic activity. More abundant fluorine would form topaz, while subsequent to consolidation, excess vapors would remove all feldspathic constituents, leaving only a sharp angular "etched" sand.

Compact and occasionally banded masses of cryptocrystalline muscovite (damourite) are occasionally met with, closely associated with a massive topaz-pyrrhotite-prosopite rock after

porphyry, the damourite apparently being a product left after the leaching of practically all sulphides. The damourite is the result of alteration of the topaz—a type of alteration also recorded by Clarke,³⁰ who shows that it may be brought about by the action of percolating alkaline waters on topaz. Within this compact fine damourite, unaltered patches of prosopite may still be noted. This variety of muscovite is formed at least at a later date than the prosopite; it is probably due in part to weathering, as many large massive boulders show this surface alteration.

Within the Brown Face, large masses of saturated, clay-like, pyritic, brownish muscovite are met with, which on breaking possess the radial structure reminiscent of pycnite rock. This muscovite is so decomposed and saturated with groundwater that it is quite soft, unctuous and clay-like. It is possible that it may have resulted from the alteration of pycnite rock whose structure it retained—an alteration due to percolating alkaline groundwaters. On the other hand, it may be due to the alteration of porphyry by the solutions accompanying the sulphides which also replaced the porphyry. It is highly pyritic, often merging into pure marcasite. It is quite saturated with surface waters and besides carrying secondary sulphides, as chalcocite, often contains much ferrous and copper sulphates from the breakdown of marcasite and chalcopyrite. These clay-like masses of secondary muscovite do not carry good tin, except close to the walls of the deposit.

Talc appears to have been derived by the action of magnesia-bearing solutions. It is met with in the northeast portion of the Brown Face and along the Gossan Benches. No definite gradation in the alteration of porphyry by talc is met with, as the mineral is not generally associated with other minerals. However, some of the talc is so closely associated with masses of porphyry that there would appear no doubt of the replacement of porphyry by talc through the action of magnesia-bearing solutions.

³⁰ F. W. Clarke, "Data of Geochemistry," p. 388. Also, U. S. G. S. Bull. 27, 1886, p. 9.

Occasionally, tourmaline spherulites may be seen to have been replaced by talc and this in turn by fluorite. The talc replaces the tourmaline from the edge of the spherulite inwards, at the same time assuming the radial habit of the tourmaline.

In the Brown Face, the talc occurs close to a basic olivine-bearing igneous rock. It is possible that the magnesia has been derived from the igneous rock by percolating waters which then replaced the neighboring porphyry. Much of the igneous rock has been converted into talc *in situ*. On the other hand, the abundance of magnesia has been recognized in the ore solutions of other areas on the West Coast of Tasmania, and talc, dolomite and other magnesia-bearing minerals are common associates of ore bodies in this mineral belt.³¹

Pyrophyllite, the aluminous talc, was originally recorded by Twelvetrees and Petterd,³² as an alteration product of muscovite and also of feldspar. McIntosh Reid³³ believes it to be formed by the action of carbonic acid on feldspars, and shows that it often accompanies sulphides. It may therefore be formed at the same time as some of the secondary muscovites at Bischoff.

The age of both talc and pyrophyllite is very doubtful. They are occasionally replaced by sulphides, but apart from that nothing definite can be said as to their age. Although probably accompanying the sulphide solutions, they appear to have separated out before the pyritic minerals.

The secondary muscovites are of widely varying ages, some probably pneumatolytic, others hydrothermal, and others again possibly products of weathering. The greater quantity formed prior to the sulphides, and before silicification.

Quartz, Tin, Chlorite.—The period of silicification was evidently coincident with the commencement of formation of the lodes. The tin indicated at this stage is that accompanying the quartz, and represents the last of the tin deposition; the ascen-

³¹ A. McIntosh Reid, Geol. Surv. Bull., No. 28, Dept. Mines Tasmania, 1918, p. 59.

³² Twelvetrees and Petterd, *op. cit.*, p. 122.

³³ A. McIntosh Reid, *op. cit.*, pp. 39 and 59.

sion of stanniferous vapors and solutions had been practically continuous down to this period.

Quartz occasionally replaces the porphyries, sometimes replacing the whole of the topaz and leaving only an apparent quartzite in which not even any sign of the phenocrysts can be detected. In cases where the porphyry has been previously sericitized, unreplaced sericite in the quartz may represent the "ghost" of original phenocrysts. The quartz is generally immediately followed by the crystallization of sulphides, and if these were abundant, but later removed, the rock becomes quite cellular.

The silicification of the country evidently took place at this period. Around the walls of the Brown Face, tin often accompanied the silicification, forming a tin "make" similar to the "make" forming the floor of the Brown Face, and the "flat make" immediately below that again.

The chlorite is found accompanying the tin in the lodes, as is occasionally a little blue tourmaline—tourmaline was still slightly active at this phase. In some of the tourmaline porphyries, chlorite may be noted replacing both tourmaline and muscovite. Chlorite is not an abundant mineral in the area.

This group is quite well-defined. It represents the last stage of the deposition of cassiterite, and the commencement of quartz crystallization; quartz continues down through the next group. Tourmaline becomes more scarce, but continues into the next group to just later than pyrrhotite. Chlorite possibly represents the cooler stages of tourmaline, with absence of boron.

Prosopite, Pyrrhotite, Fluorite, Calcite.—The occurrence of prosopite [$\text{Ca}(\text{FOH})_2\text{Al}(\text{FOH})_3$] in the porphyries at Mount Bischoff had been noted by von Groddeck. Twelvetrees and Petterd³⁴ referred to the conversion of topaz to prosopite and pointed out that this pseudomorphous alteration product had been mistaken for kaolin. Crystalline prosopite, however, may be found definitely replacing the radial pycnite. It is nearly always ac-

³⁴ Twelvetrees and Petterd, *op. cit.*, p. 123.

accompanied by pyrrhotite, fluorite, and calcite, but these latter appear to have crystallized a little later (Plate III c).

The prosopite replacing the topaz at Bischoff has a very small axial angle and is almost pseudo-uniaxial. Dana records axial angles for prosopite up to $2E = 104^{\circ} 14'$, so that it is variable. Its constant association with fluorite at Bischoff would lead to the inference that it was the result of the reaction of CaF_2 on topaz. The curious combination in prosopite of fluorite with the cleavage, birefringence colors, and positive sign of topaz is striking; the mineral is, however, monoclinic. It is a hydrothermal replacement of topaz, and not the result of surface waters, as was supposed by Twelvetrees and Petterd.

Pyrrhotite veins and replaces the earlier minerals (topaz, prosopite, quartz, tourmaline and sericite), and is quite a common mineral at Bischoff. If its alteration product, marcasite, is included, it is one of the commonest minerals of the area. Occasionally it entirely replaces the porphyry, when a massive pyrrhotite results. Pyrrhotite elsewhere is often a magmatic mineral, segregating or liquating out while the parent rock is still molten; such deposits are typically associated with basic rocks.³⁵ At Bischoff, however, the mineral is much later than the consolidation of the porphyries and is essentially a hydrothermal mineral. At Bischoff pyrrhotite was earlier than pyrite and marcasite and its separation out from the ore solutions was apparently so rapid as to inhibit the formation of pyrite. The mineral is found throughout the majority of lodes in the West Coast of Tasmania.

The fluorite is included in this period only because of its association with the pyrrhotite and prosopite. In other parts of the deposit, the fluorite is later than the sulphides, but where it was noted in the thin sections associated with prosopite and pyrrhotite, none of the later sulphides occurred. The fluorite replaces calcite in part.

Arsenopyrite, Marcasite, Pyrite, Chalcopyrite.—Of this group, arsenopyrite is undoubtedly the earliest; the later minerals are oc-

³⁵ Tolman and Rogers, "Characteristics of Magmatic Sulphide Ores," *Min. and Sci. Press*, 114, 1917, p. 550.

casionally moulded around it or vein it. The mineral may conceivably be of the same age as the pyrrhotite, but no definite relation between these two could be made out. It is rather a common mineral and as in the case of pyrrhotite, replaces quartz, topaz, tourmaline and muscovite. Often marcasite is intimately associated with arsenopyrite, although the latter would appear to be usually earlier. Both arsenopyrite and marcasite are quite definitely earlier than pyrite, but marcasite is commonly moulded on pyrrhotite.

Although some marcasite is apparently primary and crystalline, the greater bulk of it at Bischoff is secondary, botryoidal, and due to the alteration of pyrrhotite. This alteration may always be noted as a series of irregular "shells" of marcasite, concentrically arranged around a nucleus of pyrrhotite. The alteration of pyrrhotite to marcasite is always from the outside inwards, and the action is apparently perfectly pseudomorphic. Later minerals to pyrrhotite, therefore, appear later than the marcasite, with the result that it is difficult to estimate the true age of the botryoidal marcasite—whether it is due essentially to the action of surface water, or to the action of sulphide solutions on the pyrrhotite.

At the bottom of the Brown Face, the deposit is in places practically of pure marcasite, from the often botryoidal character of which it would appear to be after pyrrhotite. This part of the deposit is quite saturated with surface waters—in fact the upper limit of this dense marcasite zone seems rather to coincide with the top of the saturated zone. The association of maximum marcasite with surface waters would perhaps tend to point to the secondary character of the mineral as being due to the action of surface waters on pyrrhotite.

On the other hand, Allen³⁶ has shown that pyrite or marcasite may be formed by the action of sulphuretted hydrogen or alkaline polysulphides on pyrrhotite at a temperature above 575°. The ore solutions carrying the metallic sulphides very probably carry

³⁶ E. T. Allen, "Genesis of Iron Sulphides—General Principles," *Journ. Chem. Met. Min. Soc. South Africa*, 12, 1911-12, p. 287 et seq.

dissolved alkaline polysulphides which reacting on the pyrrhotite give up their sulphur, forming marcasite and probable pyrite. Allen has also demonstrated the laboratory conditions under which pyrite or marcasite will form, indicating that marcasite cannot be formed in nature at a temperature above 450° C. In the presence of H_2SO_4 marcasite shows greater tendency to form than pyrite.

The formation of marcasite by the action of alkaline polysulphides on pyrrhotite would also provide an explanation of the massive and occasionally compact sericite with which these sulphides are often associated. Clark³⁷ has shown that secondary muscovites may be formed by the action of alkaline waters on topaz. The alkalis liberated from the alkaline polysulphides subsequent to their giving up sulphur to pyrrhotite may react on the topaz, with the formation of sericite.

Pyrite is generally found in the porphyry dikes replacing first topaz, then muscovites, tourmaline and quartz in order of preference. It is met with in the porphyries, slates and sandstones over a mile from the Brown Face. Its position in this group is not clear, the writer has seen sections in which chalcopyrite veins, and is moulded on the pyrite, but its position in regard to the other minerals of the group remains doubtful. Although the greater part of the sulphide in the tin deposits is marcasite, there is evidently much pyrite present also. The general soft loose character of the material prevents a decisive determination of relative ages.

Chalcopyrite has been occasionally noted moulded on marcasite and less often on pyrite. As a general rule, it is in small quantities throughout the whole deposit, generally altering to chalcocite or other secondary sulphides, and to sulphate.

The formation of these sulphide deposits may be said to be the main feature of the hydrothermal phase in the replacement of the porphyries. Although at the present day the maximum replacement by these sulphides is to be found at the bottom of the several faces, it is quite probable that actual replacement

³⁷ F. W. Clarke, U. S. G. S. Bull. 27, 1886, p. 9 et seq.

reached a considerable higher level, oxidation and leaching having removed them. The gossans of the Brown Face, Slaughter Yard Face and Gossan Face are evidently the oxidized zones of these pyritic replaced porphyries.

Galena, Sphalerite, Fluorite, Dolomite, Siderite.—These form the last group of the hydrothermal stage. Galena and sphalerite may be said to form the end phase of the pyritic sulphide group, and accompanied the last of those minerals.

Fluorite, dolomite and siderite are occasionally notable as important replacements of porphyry. Fluorite replaces topaz, tourmaline, talc and perhaps sericite, and occasionally replaces pyritic sulphides. It also accompanied galena and sphalerite and occasionally replaced them. Fluorite is often accompanied by carbonates (dolomite) and is often veined by them. Dolomite is not a common replacement of porphyry. Siderite, however, may be noted replacing large masses of porphyry as a jointed crystalline siderite in which the only sign of earlier minerals is the occasional outline of replaced sulphides or a few plates of muscovite. This siderite often carries unreplaced cassiterite.

Carbonates may be sometimes noted replacing pseudomorphic topaz aggregates.

Weathering and Denudation.

One effect of the weathering of the porphyry has been described—the zoning of blocks of porphyry, producing an outer white bleached and often cellular porphyry, beneath which is an iron-stained oxidized band surrounding an unaltered kernel of hard pyritic porphyry. A normal pyritic topaz-porphyry shows, then, first oxidation of the pyrite which may then be removed, leaving a slightly cellular and somewhat soft white porphyry. Further alteration of this by weathering is to a crumbly disintegrating material of sand and clay. In one instance, the alteration of the porphyry to a shale-like clay was noted along joint planes, the laminæ of the pseudo-shale lying parallel to the joint plane; this was in the White Face, close to where there had been a considerable amount of pycnite rock and

where the porphyry was fairly high in sulphide. The unaltered porphyry was mainly topaz carrying very few quartz phenocrysts, and these phenocrysts were removed during the alteration along the joints. The only explanation of the occurrence appears to be that the reaction of H_2SO_4 (resulting from the oxidation of pyrites) on the topaz liberated hydrofluoric, leaving kaolin; the hydrofluoric reacting on the little quartz present forms a hydrofluosilic acid which may be either removed or perhaps further dissociated with deposition of cryptocrystalline quartz. The "shale" is very fine grained, the laminæ faces quite smooth and almost polished.

Where the porphyry has been replaced in part by considerable quantities of sulphide without any other alteration, the sulphide on removal may leave a coarse sandy residue or a cellular quartz, depending on the extent of the original sulphide replacement (in general there will be little or no residual topaz, as during replacement sulphides show a preference for topaz before quartz so that the rock would become a sulphide-quartz rock). This is evidently the origin of much of the coarse sand deposits of Bischoff, but these are quite distinct from the sands formed by the pneumatolytic action of fluoride vapors on the porphyry.

The action of surface waters on pyrrhotite may have been in part the cause of its alteration to marcasite. Chalcopyrite is altered to secondary copper sulphides, some of which have a black pitch-like appearance and occur in pockets and streaks in the brown sericite masses. These black copper sulphides may also stain irregularly the soft saturated white decomposed porphyries beneath the Brown Face. In warm weather the decomposition of the marcasite provides in places a sticky plastic mass of sulphur on the surface of the cut. Impure arsenic salts also often form on the exposed surface of pyritic masses. In dry weather, ferrous sulphate is quite abundant in the sulphide. Often in opening up the marcasite it fires, igniting the timbers, in which case it has to be quickly sealed up again.

The oxidation of the sulphides has been the cause of the huge gossan deposits. The denudation of the upper limits of these

with the concurrent downward enrichment of the tin resulted in the huge masses of tin found in the early days.

To the east of the Brown Face and within the semicircle formed by the Queen and Stanhope Dikes a depression was formed during denudation, with an outlet to the south down the side of the Mount. Within this drainage area a thin detrital deposit accumulated, and was sluiced off by the old Stanhope Company. This, with the workings on the Don Hill, formed the only detrital deposit at Bischoff.

Other Replacements.

Slate and Sandstone.—The alteration of the country rock is for the most part confined to silicification, impregnation, by tin, and replacement by sulphides.

Silicification and impregnation by tin take place mainly in the vicinity of dikes, or along the walls of the deposits. During silicification, the slate or sandstone is converted into a quartzite, and may become quite vuggy. Sometimes minute topaz may form in the quartzite along the walls.

Occasionally slight tourmalinization of the slate and sandstone may take place close to the walls, with formation of brown tourmaline. At other times the sandstone is altered to a biotite hornfels with considerable silicification.

Within the Brown and Gossan Faces, the crushed masses of slate and sandstone country often show entire replacement by pyritic sulphides and where this takes place, it cannot be distinguished from the pyritic replacement of porphyries. It is quite conceivable that much of the sericite may be a result of the action of hydrothermal solutions on slate.

Herman³⁸ has noted that the country rock may show an alteration to coarse sands similar to the porphyries. This may be a result of pneumatolysis as in the porphyries, or the sands may represent the residue after the removal of sulphides from replaced slate and sandstone country.

In rare cases, the replacement of slate by fluorite may be noted,

³⁸ Herman, *op. cit.*, p. 295.

both in the various faces, and along the walls of the Giblin Lode.

Basic Igneous Rocks.—Very little is known about these rocks; outcrops are small and difficult to distinguish from the altered porphyry. Their determination rests mainly on microscopical evidence. Specimens showing least alteration are fine-grained, in part greenish, in part brownish in color, and carry a little magnetite. Thin sections show a variable grained rock, mainly of rather fine-grained olivine, altering to, and in a base of, green to brownish serpentine, and containing secondary fibrous amphibole and talc. Carbonate (probably dolomite) appears to have filled vugs into which well-developed crystals of olivine project. The carbonate also replaces serpentine and is in places traversed by veins of secondary talc. Magnetite occurs in fine dust in the serpentine. These specimens evidently represent a serpentinized olivine-rich rock, probably dunite.

In the northeast part of the Brown Face, specimens of fibrous amphibole (tremolite) altering to asbestos and talc are met with in large massive pieces and evidently representing alteration of the olivine-rock along joint planes. Occasionally thin sections of talc show an alteration from fibrous amphibole of short stumpy habit—probably bastite.

The dolomite containing a little residual serpentine that occurs in the main tunnel beneath the Gossan Benches may be a replaced basic igneous rock. This dolomite contains a good deal of sulphide, which appears to replace the carbonate.

The relation of the period of alteration of these basic igneous rocks to that of the mineralization of the porphyries is doubtful. If the talc is associated with the same period as the formation of the Brown Face deposit, then the alteration of the rock by calcite and serpentine is prior to the tin deposits. This supposition would be confirmed if the dolomite beneath the Gossan Faces represents a replaced basic igneous rock, as the dolomite in its turn is replaced by sulphides. On the other hand, the alteration of the olivine-rich rock in the northeast of the Brown Face is quite conceivably due to the action of surface waters. These rocks carry little tin.

CONCLUSIONS.

The direct association of the deposits with the porphyries indicates that the mineralization period represents the end phase of magmatic intrusion and differentiation. Subsequent to the intrusion of the granite batholith to the south of Waratah, progressive differentiation gave first the porphyry dikes and later the mineral deposits.

The concentration of such mineralizers as fluorine and boron by abstraction from the granite magma continued down to the stage of the differentiation of the porphyries from the metallic minerals. Relief of pressure during the intrusion of the porphyry dikes was probably responsible for the release of the fluorine and boron mineralizers, so the pneumatolytic phase immediately followed the intrusion by the dikes while the latter were still molten.

The commencement of topazization, cassiteritization, and tourmalinization took place in that order, and was probably governed by lowering of temperature rather than progressive alteration in the pneumatolytic vapors. At the commencement when fluoride vapors were not abundant, secondary micas would appear to have preceded some topaz, and were incorporated in segregation nodules as on Don Hill. The pneumatolytic phase continued after the consolidation of the porphyries. Where pneumatolytic activity was excessively severe, feldspathic constituents were removed, leaving a coarse etched sand, while where the pneumatolytic vapors were a little less active pycnite-rock was formed. Excessive pneumatolytic activity accompanied high tin values, and was probably the result of fluorine liberated during the deposition of SnO_2 .

Topazization was the first of the pneumatolytic replacements to be completed; cassiterite and tourmaline continued into the hydrothermal stage.

In the hydrothermal phase, it is difficult to separate the mineral periods; they evidently succeeded each other in rapid succession with much overlapping.

Sericitization to some extent probably belongs to the pneumatolytic phase. But a large part is evidently directly associated with the pyritic sulphides, and represents the action of alkaline polysulphides on the replaced rock.

Perhaps the first definite stage in the hydrothermal phase is the formation of the lodes. In these, cassiterite appears to have been the first mineral to crystallize, often forming seams of practically pure tin oxide along the walls. This was followed by quartz and cassiterite, which in turn were followed by the pyritic sulphides, then galena, sphalerite and fluorite—each of these stages being coincident with its equivalent replacements in the deposits.

The formation of the quartz lodes was of the same period as the silicification of some of the porphyry and of the country. Silicification was followed in places by alteration of the topaz to prosopite accompanied by pyrrhotite, calcite and perhaps fluorite. Alteration of topaz to prosopite appears to be due to the action of CaF_2 on topaz, but in general the free CaF_2 did not crystallize out till later at a slightly lower temperature.

Pyrrhotite replaced large masses of the porphyry in the crushed zone, and probably also the slate and sandstone country. This pyrrhotite was apparently later altered by alkaline polysulphide solutions to marcasite. This preferential alteration to marcasite instead of to pyrite may indicate a low temperature of alteration (below 450°) with perhaps the presence of free H_2SO_4 . Away from the tin deposits where probably no free H_2SO_4 was present, disseminated pyrite crystallized in the dikes and country.

The pyritic sulphides were succeeded by galena-sphalerite, and the final phase of mineralization was the replacement by fluorite and carbonates.

A graphic attempt at depicting the mineral sequence is made in Fig. 17.

Mineralogically, little of practical use can be said of the localization of tin values. The sharp "etched" quartz sands, representing severe pneumatolytic activity, carry high tin; and in the early days when pycnite rock was abundant, this was also as-

sociated with tin. As practically the whole of the porphyry at Bischoff is topazized, there appears to be no other relation between topaz and tin. Where diminished pneumatolysis resulted only in the formation of secondary micas, the tin content is always low.

Structurally, the best tin is in the neighborhood of the walls of the several deposits; the tin bearing vapors and solutions evidently followed the line of least resistance along the fault walls and joint planes.

The tin content in the lodes show a depth limit. In the Giblin Lode this limit is about the No. 9 level. The tin of the dikes is mainly of an earlier period than in the lodes, so that owing to the higher temperature tin values in the dikes are not likely to continue down to the same depth as in the lodes. For this reason, there is little possibility that any similar crushed zones that may occur in depth are likely to carry tin.

The large masses of tin and the exceptional richness of the upper part of the huge gossans would suggest that there has been secondary enrichment by leaching by surface waters, keeping pace with denudation.

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GEOLOGICAL SURVEY OF INDIA,
CHOWRINGHEE ROAD, CALCUTTA.