CANADA

DEPARTMENT OF MINES

HON. CHARLES STEWART, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

Canada. GEOLOGICAL SURVEY

W. H. COLLINS, DIRECTOR

MEMOIR 158

Britannia Beach Map-area, British Columbia

BY

H. T. James

OTTAWA
F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1929

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Britannia Beach Map-Area, British Columbia

CHAPTER I

INTRODUCTION

GENERAL STATEMENT

The geology of Britannia Beach map-area is of interest because the area embraces a part of one of the numerous roof pendants remaining along the flanks and top of the Coast Range batholith; and affords an opportunity of studying in some detail the relation of the batholith to its ancient roof. The area is particularly interesting since within its boundaries is one of the largest copper mines of British Columbia, a mine that has been producing for a quarter of a century and whose rate of production has not yet reached its maximum.

FIELD WORK AND ACKNOWLEDGMENTS

The section of this report dealing with the areal geology and the description of some of the minor mineral occurrences, is based on work done by the writer during the field season of 1925 while in the employ of the Geological Survey. The geology of the important ore deposits—those of the Britannia shear zone—is entirely based upon work of geologists employed by the Britannia Mining and Smelting Company. In the spring of 1922 Dr. S. J. Schofield spent several weeks making the first maps of the underground geology of the Britannia mines. During the following two and a half years details were added by the writer while geologist of the Britannia Mining and Smelting Company. Since the autumn of 1924 the company's succeeding geologists, Messrs. H. A. Rose and F. Ebbitt, have added details from time to time. The larger and more important structural features were clearly outlined by Schofield in his preliminary work and his maps have been the basis of all the later work. A general summary of his results has been published recently.[1]

It would be difficult indeed to enter an area and receive more complete co-operation and general assistance than was accorded by the officials, and the technical and underground staffs of the Britannia Mining and Smelting Company. The writer wishes, particularly, to thank Mr. C. P. Browning, the General Manager, and Mr. J. I. Moore, jun., the Mine Superintendent, for their many courtesies, and for initiating a policy of co-operation that was most admirably carried out by the remainder of the organization. In addition, the company is to be very highly commended for opening to the Survey so much data that had been collected by their own technical staff.

During the field season Mr. Lees was a very enthusiastic assistant.

[1] Schofield, S. J.: "The Britannia Mines, B.C." Econ. Geol., vol. 21, p. 271 (1926).

To Dr. Schofield the writer owes a very great deal for both his advice and encouragement since being introduced to the Britannia area in 1922. The opportunity of spending a few days in the field with Mr. Dolmage and of discussing various phases of the geology was of distinct value and greatly appreciated. The writer is deeply indebted to the members of the Department of Geology at Harvard University for the very many things that professors can do for their students. An expression of appreciation is due especially to Prof. L. C. Graton and to Prof. E. S. Larsen under whose particular directions this report has been written.

PREVIOUS WORK

Very little geological investigation has been carried on in the immediate vicinity of the Britannia. In 1907, while preparing a report on "A Portion of the Main Coast of British Columbia and Adjacent Islands," LeRoy[8] visited the Britannia mines and has described briefly the rock formations and the ore deposits as they were then exposed. In 1913, R. G. McConnell[11] published a very brief description of the ore deposits. Dr. S. J. Schofield,[14] in 1918, was the first to undertake a more complete examination of the Britannia map-area, but he published his results only in summary form and without a map. He did, however, add materially to our knowledge of the mineral occurrences. Since then he has published a much more complete description of the ore-bodies, their general geological setting, and structural features.[15] Camsell[4] examined and described the mineral occurrences of the Indian River section of Britannia Beach map-area in 1917. In 1918 Burwash[3] published an interesting paper on "The Geology of Vancouver and Vicinity" in which he describes the geology and physiography of a relatively large area surrounding the Britannia Beach map-area.

A few other investigators have published articles having a direct bearing on the geology of Britannia area. Among these, McConnell's report[11] on Texada island is of importance because he found Lower Mesozoic fossils in rocks that LeRoy had regarded as being the same age as those in Britannia area. McCann's[9] description of Bridge River area, directly across the Coast Range batholith from Britannia area, is interesting because the base of the Triassic rocks is exposed. Johnston's[7] report on Fraser River delta has a direct bearing on the Tertiary and Recent history of the general coast region. Since the pre-batholithic rocks in Britannia area are tentatively correlated with the Vancouver group frequent references are made to Clapp's[5, 6] detailed description of this group as it occurs on Vancouver island.

In addition to these general descriptions, the Britannia mines and prospects within the area are described in more or less detail in the Annual Reports of the British Columbia Minister of Mines.[1] These are written chiefly by Mr. Brewer; and in the Annual Report for 1924 he has published a very excellent account of the history of Britannia mines. A similar account[16] appears in "Mining and Engineering Record" (Vancouver) for February, 1925. Within the last few years, Mr. Browning,[2] the general manager of the Britannia Mining and Smelting Company, has described the

[8] The numbers refer to the bibliography on p. 3.

general mining and milling methods; Mr. Monro,[12] the mill superintendent, has described the milling practice; and finally Mr. Moore,[13] the mine superintendent, has published an account of the mining methods that are in use at the Britannia mines.

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12. Monro, A. C.: "Milling Practice at the Britannia Mine"; Trans. C.I.M.M., vol. 26, p. 319 (1923).
13. Moore, J. I., jun.: "Operations at the Britannia Mines"; E. and M.J.P., vol. 122, p. 924 (1926).
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15. Schofield, S. J.: "The Britannia Mines—British Columbia"; Econ. Geol., vol. 21, p. 271 (1926).
16. Mining and Engineering Record—Vancouver, vol. 27, p. 81 (1923).

LOCATION AND ACCESSIBILITY

Britannia Beach map-area includes a small, rectangular strip in the Coast Range mountains about 20 miles due north of Vancouver. It embraces the watersheds of Britannia and Furry creeks, two small streams flowing west into Howe sound. It also includes the headwaters of Seymour creek, Indian river, and Stawamus river; the first two of these flow into Burrard inlet and the last flows north and west into Howe sound. The area is approximately 6 miles wide by 12 miles long.

The Union Steamship Company of Vancouver maintains a daily boat service between Vancouver and Squamish, the terminus of the Pacific Great Eastern railway. The boats on this service call at all way points on

Howe sound, and stop at the more important points, such as Britannia Beach, both going to and coming from Squamish. Boats leaving Vancouver at 9 a.m. arrive at Britannia Beach between 11 a.m. and noon and return to Vancouver between 6 and 7 p.m.

INHABITANTS

The principal town in the area is Britannia Beach, at the mouth of Britannia creek. It is owned by the Britannia Mining and Smelting Company and is the location of their mill and general offices. A larger town, known as Tunnel Camp, is maintained by the company higher up Britannia creek near the main portal of the mine, which is at 2,100 feet above sea-level. At Tunnel Camp are the necessary mine buildings and offices, ninety odd dwelling houses, bunk houses, and a variety of community buildings which go to make up a small town. Other small camps are situated in Furry creek, or South valley.

The small settlement at Porteau, on Howe sound near the extreme southwest corner of the map-area, is maintained by a company operating gravel pits at that point. Although the official name of the post office is Porteau, the camp is frequently referred to as Deek's gravel pits.

CLIMATE

The climate in Britannia area in general is moderate, and very similar to that in Vancouver. In detail the climate is quite varied because of the extreme difference of relief in the area. At Britannia Beach, on Howe sound, zero weather is seldom experienced and snow does not remain on the ground for more than a few days at a time during the winter. A few miles back from tide water at 3,000 or 4,000 feet elevation the actual snowfall may be measured in tens of feet and it covers the ground for several months of the year. At the higher elevations the temperatures are correspondingly lower.

The following table gives an indication of the climate at Britannia Beach:

—	Precipitation[1] six-year mean 1916–1922	Temperature—1925[2]		
		Mean	High	Low
January	9·50	38		
February	7·86	43		
March	11·14	43		
April	5·29	48		
May	3·09	56		
June	3·79	59		
July	2·15	66	88	23
August	2·30	64		
September	5·65	58		
October	8·46	48		
November	10·98	43		
December	10·52	43		
Total	67·40			

[1]From Records of Britannia Mining and Smelting Company.
[2]Climate of British Columbia, Department of Agriculture, B.C., Bull. 27.

GENERAL CHARACTER OF THE DISTRICT

Britannia Beach map-area is in a typically rugged section of the Coast range of British Columbia. It is situated near the head of the most southerly of numerous irregular fiords, or inlets, which penetrate to the very heart of the Coast range. The mountains rise abruptly from these fiords to elevations of 6,000 and 7,000 feet. In Britannia area steep, uninterrupted slopes rise from sea-level to elevations of 4,500 feet within a horizontal distance of 7,000 feet. The mountains are cut into a series of ridges by deeply incised streams. The topographic relief even near the heads of the streams is usually more than 2,000 feet. The ridges between the streams are rounded, and vary in elevation between 4,500 and 5,500 feet. The highest point in the area is one of the needle-like peaks in the Sawtooth range, situated in the centre of the extreme north edge of the map-area. The elevation of the point is 6,600 feet.

CHAPTER II

GENERAL GEOLOGY

OUTLINE OF REGIONAL GEOLOGY

Britannia Beach map-area is situated on the western flank of the Coast Range batholith, the huge mass of plutonic rocks that is exposed continuously for over 500 miles along the west coast of Canada, and again for another 500 miles north in both Alaska and British Columbia. Along the flanks of this complex of intrusives, and at intervals within the outlines of the main mass, thick series of volcanic rocks and variable amounts of normal sedimentary materials are found. These are earlier than the batholith and have been disturbed and metamorphosed during the batholithic intrusion. On the east side of the batholith, in the southern part of British Columbia, some of these rocks are definitely known to be of Palæozoic age[1] and rocks of similar age are believed to occur on the west side of the batholith.[2] The great bulk of these pre-batholithic volcanic rocks is, however, early Mesozoic in age. They are dominantly basic volcanic rocks consisting of flows, agglomerates, tuffs, and sills, but normal sedimentary rocks are represented in variable amounts.

Following this period of extensive volcanicity, is the period of the batholithic intrusion, which generally has been dated as Upper Jurassic. The history of the main Coast Range region has been chiefly one of erosion since the intrusion, and the core of the range has supplied great quantities of material to the basins on either side. By the end of Cretaceous time the range was probably reduced to a peneplain, only to be re-elevated during the Laramide revolution. Small granitic stocks along the east flank of the main batholith are generally assigned to this period of mountain building.

The character of the Tertiary deposits, in the immediate vicinity of the Coast range, is somewhat varied. On the east side, the Eocene deposits consist of local areas of sediments, occasionally coal-bearing, and locally overlain by flows which are probably Miocene in age. On the west side of the range forming the old Fraser River delta are 3,500 feet of Eocene and Lower Miocene strata; on Vancouver island, 40 miles west of Britannia area, the Eocene deposits are chiefly volcanics, consisting of flows, tuffs, and agglomerates. On Vancouver island the Cretaceous and Eocene beds were highly folded and faulted at the beginning of Oligocene time, and intruded by basic and granitic stocks. During all those periods of sedimentation, volcanic activity, and orogenic movements, the Coast range

[1] Dawson, G. M.: "Report on the Area of the Kamloops Map-sheet, B.C."; Geol. Surv., Canada, Ann. Rept., vol. VII, pt. B, pp. 373-393 (1896).

[2] Clapp, C. H.: "Sooke and Duncan Map Areas, Vancouver Island"; Geol. Surv., Canada, Mem. 96, p. 92 (1917).

proper quietly continued its work of filling the depressions on either side, and, as if to assure an unlimited supply of material for its task, it was re-elevated at intervals. The monotony of erosion was broken at the south end of the range by local volcanic activity. Approximately 20 miles north of Britannia area, and in the centre of the Coast range, is a volcanic centre known as Garibaldi district. This district was active in late Teritary time and has again been active since the recession of the main ice-sheet.

Following the Tertiary period the entire region has been covered at least once by a continental ice-sheet, and once by an ice cap which was sufficiently extensive to spread over the adjoining lowlands. Since the recession of the ice the coast region has been elevated as much as 800 feet in places.

Table of Formations

Era	Period	Formation			Lithological characters	Thickness
Quaternary	Recent and Pleistocene				Stream deltas and rock debris. Bedded sands and gravels, overlain in places by unassorted glacial material	
Tertiary (?)		Late dykes			Basalts	
Mesozoic	Possibly Upper Jurassic	Early dykes			Both acidic and basic	
	Upper Jurassic (?)	Coast Range batholith			Quartz diorite to granodiorite	
	Probably Upper Jurassic	Britannia sills			Albite dacites, dacites, and quartz latites	
	Probably Triassic or Jurassic	Britannia group	Goat Mountain formation	Upper	Andesitic aglomerates, tuffs, and flows	1,500±
				Middle	Chiefly basic sills with tuffs, flows, and shales	8,000±
				Lower	Greenstones, metamorphosed andesite, etc. Rhyolitic volcanics and greywacke	4,000±
			Britannia formation		Top not exposed Shales Fragmental and massive metabasites	5,300±
					Unknown interval	
					Arkose	700+
					Base unexposed	

DESCRIPTION OF FORMATIONS

BRITANNIA GROUP

LeRoy[1] originally described the Britannia group as the middle member of a series of volcanic and sedimentary rocks, occurring in various isolated areas along the western side of the Coast range. They were regarded as Palæozoic in age rather than early Mesozoic as they are now considered. LeRoy speaks of the Britannia group as a group of conglomerates, quartzites, slates, and quartz-mica schists, in which the slates are by far the most abundant rocks. The southern half of the roof pendant in Britannia area was mapped by him as the Britannia group. Since the northern half of the roof pendant does not outcrop along the coast, it was not seen by LeRoy and, therefore, was not described. Burwash later applied the term "Britannia formation" to parts of the same group occurring in the general vicinity of Britannia area,[2] and Schofield[3] has described the group of rocks in the southern half of the Britannia roof pendant under the heading "Britannia formation."

The original name, "Britannia group", is retained in this report to include the pre-batholithic sedimentary and volcanic rocks that constitute the roof pendant. It thus includes not only the group in the south half of the roof pendant, which LeRoy originally described as the Britannia group, but also the thick series of volcanic rocks in the north half of the roof pendant which he did not describe. Following Schofield, the term "Britannia formation" is used to designate the series of volcanic and sedimentary rocks occurring in the southern part of the area.[4] Included in the Britannia group, along with the Britannia formation, is a thick series of volcanic rocks which Schofield has recently described as the Goat Mountain formation.[5] It is described in this report under three main headings: the Lower, Middle, and Upper Goat Mountain formation. It should be mentioned at this point that Schofield believes the Britannia formation to be younger than the Goat Mountain formation[6]; but the present writer believes that the structural geology indicates the reverse order of the sequence, although the age relations are not definitely proved.

Britannia Formation

DISTRIBUTION

The Britannia formation forms the southwestern part of the roof pendant and underlies a long, narrow strip of country extending from Howe sound, on the west, to Seymour creek, on the east. At Howe sound, the width is approximately 6,000 feet. A small corner of this strip is on the north side of Britannia creek, but the southeast trend of the rocks soon carries them across the creek, over Britannia ridge into Furry creek, and on to the main branch of Seymour creek, a distance of about 8 miles. The width of the zone, in which the formation occurs in the Seymour Creek

[1] LeRoy, O. E.: "Preliminary Report on the Main Coast of British Columbia and Adjacent Islands"; Geol. Surv., Canada, 1908, p. 15.
[2] Burwash, E. M.: "The Geology of Vancouver and Vicinity", University of Chicago Press, 1918, p. 39.
[3] Schofield, S. J.: "Britannia Map Area"; Geol. Surv., Canada, Sum. Rept. 1918, pt. B, p. 56.
[4] Loc. cit.
[5] Schofield, S. J.: "The Britannia Mines, British Columbia"; Econ. Geol., vol. 21, p. 274 (1926).
[6] Loc. cit.

watershed, is about 9,000 feet exclusive of the isolated quartzites beneath mount Lomond. Of this 9,000 feet, less than half is underlain by Britannia formation. The remainder is occupied by later sill-like intrusives.

A series of arkoses, with some shale and metamorphosed basic volcanic at the base of mount Lomond, is included in the Britannia formation. They underlie an elliptical area immediately west of Seymour lake.

LITHOLOGICAL CHARACTERS

The formation contains by far the greater amount of true sedimentary rocks found in the area. They vary from medium-grained quartzites to dense, black, carbonaceous slates, including in this range, grey, siliceous slates as well as dense cherts and fine, green slates which may be of tuffaceous origin. Interstratified in the formation are fine-grained tuffs, for the most part included with the slates, and a considerable thickness of clastic volcanic material. Basic crystalline rocks also occur as sills, irregular intrusives, and, possibly, as flows. The rocks are all highly metamorphosed. Not only have they been sheared during the tilting into their present positions, but they have been greatly modified by the heat and the solutions emanating from the batholith and related intrusives. The main zones of sedimentary and volcanic rocks have been mapped separately. The greywackes beneath mount Lomond though represented on the map as part of the sedimentary division of the Britannia formation are an isolated series whose position in the group is not definitely known. Among the volcanic rocks, the fragmental and massive varieties have not been distinguished on the map, but their distribution will be mentioned in the following description.

Sedimentary Rocks

Mount Lomond Arkose. The isolated area of the Britannia formation partly surrounding mount Lomond contains an interesting series of sedimentary rocks not found elsewhere in the area. They are, essentially, impure sandstones resting on highly altered basic volcanics and thin layers of shale. Interstratified with the arkose are thin beds of shale and small amounts of fine, tuffaceous material, varying from a few inches to a few feet in thickness, and serving as parting planes between the thicker and more massive arkose members. Near the centre of the series the latter in many instances are unstratified beds of arkose from 10 to 30 feet thick. Towards the top of the series, the arkose is not divided into a succession of massive members as it is lower down, but is very distinctly bedded and presents the appearance of ordinary, well-bedded, impure sandstones; the individual beds varying from one to several inches in thickness.

A detailed petrographic study of the series has not been attempted, for the various beds are very similar in appearance. Only one thin section has been examined. It is from a specimen selected to represent the typical rock of the thick massive beds near the centre of the series. It is composed of very angular grains of quartz, plagioclase, and sericite schist, together with grains of chlorite, sericite, titanite, and a variety of fine-grained materials. About 50 per cent of the fragments are quartz and well over half of the remainder is a very fine-grained sericite and quartz-chlorite mixture, much of which is schistose. This is not a metamorphosed, and slightly sheared groundmass material, for it occurs as distinct grains, and the random orientation of the schistose fragments proves that they were metamorphosed before being incorporated in the arkose. The plagioclase is a fairly fresh oligoclase and is a conspicuous mineral. Orthoclase is quite subordinate in amount. The lack of rounding of the grains, the freshness of the plagioclase, and the thickness of unstratified beds proves that the material has accumulated rapidly, and has been transported only a very short distance from its source. It may very well represent a fan or deltaic deposit. The presence of oligoclase and orthoclase in relatively large grains, suggests then that an appreciable amount of the material was derived from plutonic rocks of the granitic family. Curiously enough, pebbles of granodiorite composed of quartz, oligoclase, and orthoclase are found in one of the flows of the Britannia formation, which will be described later. This would seem to be more than a coincidence. LeRoy[1] mentions conglomerates, found in the Britannia formation, as containing rounded fragments of granite in a quartz-feldspar matrix. Burwash[2] also describes granite pebbles in the conglomerate at the base of the Britannia formation, in the Garibaldi section, 20 miles north of Britannia Beach. The term " granite " is, of course, used to signify granitic rocks in general. These facts suggest that the lower part of the Britannia formation was deposited very close to a land mass, on which was exposed an appreciable amount of batholithic rocks of the granitic type. This must mean that the land mass had existed as such for a very considerable length of time in order that erosion might wear away the covering of the batholithic rocks.

Slates. Sheared argillites occur as a series of steeply dipping parallel bands within the main area of the Britannia formation. They are chiefly dense, black, sheared argillites, although nearly all types of sedimentary rocks are represented. Thinly bedded tuffs and fine, green slates, presumably of volcanic origin, are to be found in the two middle bands of " slate "; thin conglomerates, sandy layers, and fine chert occur in the two northerly bands; and limestone lenses have been observed in the most northerly band. As the name of the group (slates) signifies, most of the argillites and fine tuffs are sheared. All grades of fissility are represented, from very fine slates or schists, which may be split into paper-thin flakes, to massive, unsheared argillites. The average rock will split about as readily as ordinary roofing slate, but the cleavages are interrupted by numerous and very pronounced transverse joints. The impure shales outcropping along the incline railway are metamorphosed to grey and greenish grey sericite-schists that are very similar to many of the igneous schists. The very highly sheared and hydrothermally altered slates at points along the footwall of the ore zone, are distinguished only with the greatest difficulty from fine sericite schists derived from albite dacite. Unsheared phases are found chiefly along the contacts of the Britannia sills where they have been " baked " to hard, dense, brittle rocks, and rendered somewhat more immune to shearing than the unmetamorphosed argillites.

Included in the northerly band of " slates " are a number of sills and dykes of the albite dacite, too small and irregular to be mapped correctly. The bands of porphyry and volcanic rocks also include narrow lenses of slates.

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[1] LeRoy, O. E.: "Main Coast of British Columbia and Adjacent Islands"; Geol. Surv., Canada, No. 996, p. 15.
[2] Burwash, E. M.: "The Geology of Vancouver and Vicinity"; University of Chicago Press, 1918, p. 40.

Volcanic Rocks

Fragmental Types. Lower Group. The lowest group of rocks in the formation, with the exception of the Mount Lomond arkose and metabasite described above, contains a preponderance of clastic, crystalline rocks apparently of volcanic origin. They are to be found at intervals along the railroad grade near the head of Furry creek, in the upper part of the west fork of Seymour creek, and on the lower slopes of the hill south of the confluence of the west fork of Seymour creek and the main branch. In general these rocks have a fine-grained, light green groundmass in which chlorite is obviously an important constituent. In this groundmass are embedded fragments of various types and sizes. As a rule, very fine-grained rhyolitic fragments are conspicuous, although they are not necessarily more plentiful than the more basic fragments. Crystals of plagioclase are abundant in some beds and lend a porphyritic appearance to the rock; other beds are composed of fragments an inch or more in length. Occasionally well-rounded pebbles are to be found, but, as a rule, the fragments are distinctly angular. Bedding has not been observed except in a few places. Well-bedded crystalline tuffs are to be found on the hill south of the west fork of Seymour creek, and bedding is again suggested along the 3,000-foot contour, about 1,000 feet west of the divide between Furry and Seymour creeks.

Upper Group. Another horizon containing a great deal of fragmental material is the uppermost band of volcanics outcropping along Howe sound, immediately south of Britannia creek. Along the beach, just south of the mill, is a beautiful exposure of a slightly sheared, medium-grained, grey-green rock containing a large number of fragments, or inclusions, about the size of a man's head. The fragments have been drawn out into short lenses during the shearing. They appear to be andesitic rocks, not essentially different in composition from the matrix. The groundmass has a porphyritic appearance, but, on closer inspection with a hand lens, small grains of various textures and colours may be observed, suggesting that the matrix is fragmental. Numerous large fragments, such as are found at this point, are not typical of the series, for the fragments are generally less than an inch in diameter. They may be very numerous and constitute the whole rock, with the exception of just sufficient matrix to fill the opening between the fragments; or an ordinary hand specimen may contain only two or three recognizable fragments. Although the matrix is fragmental, it has the appearance of a slightly sheared andesitic porphyry containing feldspar phenocrysts 1 mm. or even 2 mm. in length.

Under the microscope the groundmass is found to consist of small fragments of different types of porphyry, and is evidently of tuffaceous origin. At one time it was suspected that the larger fragments were merely inclusions in a sill or a flow, but this cannot be maintained in the face of the microscopic evidence. The slight shearing and hydrothermal alteration have made the tiny fragments somewhat indistinct in the hand specimen, but they have not altered the texture of the individual fragments, so that a variety of rock types may be recognized in a single thin section even although the exact composition of the fragments cannot be determined. Some of the fragments are distinctly basic in composition and have the texture of basic porphyries. These are composed of feldspar, now more or less completely albitized, and contain variable amounts of chlorite, calcite, epidote, and occasionally, quartz, set in a groundmass of chlorite. Other fragments are, apparently, less basic and contain phenocrysts of albitized feldspar in a groundmass of fine-grained feldspar, chlorite, and other alteration products, which are too fine-grained to be determined. Many of the fragments possess a distinctly fluidal texture, due to the approximate parallel orientation of the tiny feldspar laths. Volcanic glass was not recognized in the thin section.

Non-Fragmental Types. It must not be assumed that this entire zone, outcropping immediately south of Britannia Beach, is composed of volcanic breccia, or that all rocks containing numerous fragments are necessarily clastic volcanics. It was discovered early in the study of the Britannia area, that intrusive sheets may be filled with fragments and beautifully banded. These phenomena appear, however, to be confined chiefly to later intrusions of albite dacite, but the recognition of intrusive breccia and banding makes one cautious in assigning rocks of fragmental appearance to the fragmental volcanic group. Massive porphyries are to be found at several places in this upper group of volcanic rock. Most of the porphyries are andesites or metabasalts, but, along the pipe-line between Britannia Beach and Furry creek, outcrops of rocks that resemble the mine porphyry series are to be found. They apparently have a very limited extent and have not been mapped separately. Along the south contact of this same upper group of volcanic rocks, on the south side of Britannia ridge, is an appreciable width of material that appears to be non-fragmental. The typical rock is an exceedingly hard, dense, light greyish green porphyry. It is found to contain scattered phenocrysts of plagioclase from 0·5 to 1 mm. in length, set in a fine-grained groundmass of feldspar, chlorite, and other fine-grained alteration products. The feldspars are completely albitized and exhibit most strikingly the irregular mottled appearance that is characteristic of albitized feldspars. Chlorite is abundant in the groundmass and also occurs in outlines that suggest that it is secondary after phenocrysts of some femic mineral. A brown biotite, associated with the chlorite, is plentiful. Calcite is found in tiny veinlets and is also present in small amounts as an alteration product, along with the chlorite and biotite. Titaniferous magnetite was, apparently, one of the accessory constituents, but it is now represented very largely by fine-grained aggregates of a highly birefracting mineral resembling leucoxene, and opaque particles that are probably iron oxide. Apatite is an accessory or rather a residual constituent. The rock is apparently a metamorphosed andesite. The proportion of fragmental to non-fragmental rocks in the upper band of volcanic rocks is not known, but the fragmental types are considerably more abundant than the massive types.

The next lower band of volcanic rocks, crossing the west end of Furry Creek ridge, seems to be composed entirely of non-fragmental types. Megascopically they exhibit the usual range of textures and colours expected in a series of metamorphosed andesite and basaltic porphyries. The phenocrysts, which may be recognized in the hand specimen, are usually plagioclases varying from 1 to 2 mm. in length. They are set in a dense groundmass composed of tiny plagioclase crystals and a great deal of chlorite, fine, dusty material resembling epidote, and other alteration products. The feldspar is the only mineral that has escaped complete alteration. What femic minerals may have been present originally, are completely altered to chlorite and epidote. These same two minerals are also developed in the feldspar, but less extensively. Epidote not only occurs as a replacement of the feldspar and of the groundmass in general, but also as a filling of small veinlets associated with quartz.

The metabasites along the foot-wall (north side) of the Britannia shear zone should probably be included with the band described above, for they are separated from it only by later intrusives. In any case they are undoubtedly metabasites of the volcanic series.

Above the lowermost horizon of dominantly clastic volcanics, and outcropping along the central part of Furry Creek ridge, is a crystalline rock containing a variety of pebbles, some of which are granodiorite not unlike certain phases of the Coast Range batholith. The rock in which these pebbles occur is distinctly older than the batholith and the fragments must, therefore, represent some older batholith. The original shape of the inclusion is not clearly shown, because the rock has been squeezed and the pebbles, or fragments, have been drawn out to short lenses. They appear to represent rounded pebbles up to 3 inches in diameter. The host rock is apparently a metabasalt flow which has picked up pebbles of granodiorite and other rocks.

On the south side of Furry Creek ridge, just east of the band of slates whose apparent trend is north-northeast rather than northwest, and extending to the next outcrop of slates 1,000 feet east, is an intrusion of diabase that is very similar to the diabase in the middle group of the Goat Mountain formation. Possibly it should not have been mapped with the Britannia formation, but as a later intrusive, but there is not sufficient data to warrant this at the present time. Throughout most of the distance between the two bands of slate, on the 4,000-foot contour, the rock is a dark, medium-grained, granular rock, similar in appearance to an ordinary diabase; but towards the eastern contact it becomes much darker and apparently much finer grained. The difference in texture is not altogether real, but is due to the extensive development of uralite, which tends to reduce the whole rock to a fine-grained and matted aggregate of uralite. The least altered specimen examined microscopically, consists of plagioclase and hornblende as the two most abundant constituents; magnetite and a very small amount of titanite are present as accessory constituents, and chlorite, biotite, and indeterminate, dust-like materials are plentiful as secondary minerals. The plagioclase occurs in euhedral, very distinctly zoned, tablets up to 2 mm. in length. The inner zone, in some grains, is a labradorite, but the outer zone is no more calcic than an andesine. This zoning is gradational in many instances, but numerous grains are found in which three distinct and sharply bounded zones are exhibited. The difference in the composition of the successive zones is not only revealed by the sharp breaks between their positions of extinction, but also by a decided difference in index. Each zone is not absolutely homogeneous, but is itself slightly zoned. Other examples are found in which the interior calcic zone is irregularly replaced by a more sodic plagioclase which extinguishes at the same time as the next outer zone. The feldspars are partly uralitized and the interior and more calcic zones are almost invariably more completely altered than the outer zones. The hornblende is a light green, slightly pleochroic variety filling in around the plagioclase, thereby producing the typical ophitic texture. It is partly uralitized and is also altered to a brownish biotite and to a chlorite which possesses a very strong dispersion. Magnetite occurs both as large independent grains filling in around the plagioclase and as finer grains in the hornblende. Epidote, which is such a prominent alteration product in all rocks of the Britannia series, has not been observed in this rock.

ATTITUDE AND THICKNESS

The general trend of the Britannia formation is northwest to southeast and the dip is rather steep to the southwest. Variations of the strike in the main band of the formation are not common; and although the angle of dip varies appreciably, it is almost always to the southwest. The band of slate, which crosses the lower part of the incline, is vertical in the central part of its course where it crosses Britannia ridge, but flattens at either end to about 45 degrees. The average dip in the mine zone is about 70 degrees; but farther to the east the prevailing dip is less steep, particularly in the lower part of the series. In places on the north side of Seymour creek the beds are horizontal, but more commonly the dips are about 45 degrees. The arkoses, at the base of mount Lomond, are folded into a broad anticline.

The Britannia formation, in this area, is approximately 6,000 feet thick. The thickness cannot be given with any degree of precision for a number of reasons. Neither the top nor the base is exposed; the Mount Lomond quartzites are separated from the rest of the formation by later intrusives and their position in the series is not known; the lower volcanic rocks are so poorly exposed that it is impossible to make more than a rough estimate of their thickness; and drag folds are so very common in the slates that their apparent thickness is undoubtedly much greater than their actual thickness. The quartzites near mount Lomond are about 700 feet thick; the volcanics, in the vicinity of the divide between Furry and Seymour creeks, are at least 1,000 feet thick; and the upper volcanics are as much as 2,500 feet thick. The remaining 1,800 feet is represented by slates.

INTERNAL STRUCTURAL RELATIONS

The general relation of the different members of the Britannia formation has been mentioned, but is more specifically stated below. The Mount Lomond arkoses are separated from the other members of the formation by intrusive rocks, and their true position in the series is not known definitely. Since they do not appear in the main part of the series they must represent either a lower or an upper horizon. The former alternative is believed to be the more probable, for the series is composed of angular quartz, oligoclase, and bits of schist—a mineral assemblage which could not be possible after the accumulation of 5,000 feet of shales and basic volcanic rocks such as is found in the main part of the series. The conclusion that the arkose is from the base of the series is supported by the structural relations as well, but faulting has been so pronounced in the area that structural evidence is of no particular value in itself.

Although shaly material and fine, greenish tuffs are found in a number of places throughout the series, the greater part of the argillites is confined to two horizons separated by about 2,000 feet of volcanic material. Each band is split into two bands by later sill-like intrusions. The lower band is split by the Britannia sills; and the upper, by a part of the batholith. Below the two main bands of slate is a series of volcanic rocks of unknown thickness, containing both clastic and massive members. It is apparent that the normal, quiet sedimentary processes were interrupted at intervals by volcanism. The periods of quiet sedimentation were relatively long, for each of the main bands is approximately 1,000 feet thick.

Goat Mountain Formation

LOWER GOAT MOUNTAIN FORMATION

Distribution

The rocks described in this report as the Lower Goat Mountain formation include all pre-batholithic rocks outcropping in Indian river, south of the diorite dyke that crosses the river near its source.

Lithological Characters

This group embraces a wide variety of rocks ranging from rhyolites to basalts, from intrusives to tuffs, and from shales to conglomerates. The general distribution of the principal types is fairly well known, but details of their occurrence, relations, and distribution are lacking. The walls of Indian river are not only very steep, but are also heavily timbered, and outcrops are confined very largely to the stream beds. These stream beds are not as favourable for geological study as might be imagined, for they occupy very steep-walled canyons, particularly on the east side of the river, and are interrupted by falls and other impassable obstructions. A second and perhaps the chief reason for the lack of detailed knowledge is the fact that a considerable part of the rocks is very highly altered. The formation occupies not only a topographic depression but also an actual depression in the granite; and, consequently, the rocks have been subjected to unusually intense metamorphic conditions. The very siliceous rocks are relatively fresh, but the andesitic and basaltic rocks are altered by dynamic, hydrothermal, and contact metamorphism.

Although the rocks of this series are referred to as one group, they can be described most easily under the following three headings: " greenstones, metamorphosed andesite, etc.," " rhyolitic volcanics," and " metamorphic rocks of unknown origin." The distribution of these three types is shown on the map.

Greenstones, Metamorphosed Andesite, Etc. These rocks underlie a long, narrow strip of territory paralleling the valley on the west side of Indian river, and an irregular area on the east side of Indian river southeast of Clarion lake. These two areas are apparently separated by a granodiorite dyke which outcrops just above the talus, at intervals along the west side of the valley. A large part of the southern half of the eastern area is underlain by schistose greenstones, containing a great deal of secondary quartz, chlorite, and some sericite. In places fragments of rhyolitic material are plentiful, suggesting that the rock may be tuffaceous.

The northern half of the eastern area and all the western area are underlain by unsheared andesites and basic porphyries in various stages of alteration. The freshest specimen examined is an andesite composed of oligoclase phenocrysts about 1 mm. long, in a groundmass of minute plagioclases and fine alteration products, chiefly chlorite and epidote. Two or three pyroxenes were also observed, and some of the larger chlorite aggregations appear to have replaced femic phenocrysts. The feldspars are fairly fresh and contain only small specks of chlorite, calcite, epidote, and sericitic material. A few of the phenocrysts enclose small patches of lower index feldspars, suggesting that albitization or decalcification of the feldspars has commenced. Fine-grained, light green porphyries are found to be composed very largely of chlorite and quartz with variable amounts of sericite, albite, and pyrite. In some types a reddish brown biotite is conspicuous. These rocks will be described in the section dealing with metamorphism.

Within the area of metamorphosed volcanics is a small, isolated exposure of conglomerate on Indian river. The outcrop consists of some 35 to 40 feet of coarse conglomerate containing boulders which measure as much as 30 inches across their greatest diameter and are of various light-coloured feldspar and quartz-feldspar porphyries. A few of the boulders are distinctly gneissic, the remainder are normal igneous rocks. The larger pieces are somewhat angular, but the smaller pebbles are well rounded. The entire outcrop is hard and resistant and forms a small canyon in the river. Immediately above it, is a band of bedded material apparently containing a few pebbles, but now metamorphosed to a quartz-chlorite schist. The strike of the banding is about north-northeast and the dip 40 degrees northwest. The lower contact is not exposed. On the upper side (north) the rock is cut by one of the late basic dykes, and is separated from the bedded rhyolitic series above by greenstones, and an irregular intrusion of quartz diorite. Attempts to trace the conglomerate, laterally, were unsuccessful. The conglomerate is undoubtedly significant, containing, as it does, blocks of metamorphosed igneous rocks which indicate the proximity of a deeply eroded land mass at the time of its formation. Blocks of this dimension could not have been transported far by water; and there is evidence that other agencies of transportation have been at work. At present, the conglomerate is not readily explained, for it appears to rest on the altered volcanics of the lower part of the series and these could not have produced this type of conglomerate. It is possible, however, that the greatest part of the volcanics are intrusive rocks, younger than the conglomerate, and have merely separated it from its original base.

Rhyolitic Volcanics. General Character and Distribution. The rhyolitic volcanics and associated rocks occupy more than half of the eastern slope of the part of Indian River valley included in the map-area. They outcrop more or less continuously along the crest of the ridge for about 3 miles from the northeast corner of the map-area to a short distance south of Clarion lake. From the crest of the ridge, they extend downward, towards the river, but, except at one or two places, do not outcrop in the stream bed.

The group, as a whole, can best be described as rhyolites, although amygdaloidal andesitic rocks are present in the central part of the series, and a considerable thickness of greywacke occurs at the top. The exposures most clearly demonstrating the nature of the lower part of the series are found in Clarion creek, and along the side-hill southeast of the creek; the upper part of the series is well exposed along the ridge towards the extreme northeast corner of the map-area. Weathering, in these areas, has very beautifully brought out the bedding and clastic nature of certain groups. The lower part of the series exposed in the Clarion Creek section is dominantly fragmental, and is composed of fine-grained, light grey and greenish grey porphyries of the rhyolitic series. The fragments vary in size from minute to those having a diameter of a quarter of an inch or more. The very slight differences in the colour of the fragments produce an irregular mottled appearance. A relatively few, small, angular fragments of more basic material are present. Interbedded in the tuffs, and overlain by a thin band of black carbonaceous shale, is a bed of conglomerate composed of well-rounded pebbles of the rhyolite. The shale and conglomerate are well exposed in Clarion creek, at an elevation of about 2,800 feet. The shale band may be traced, at intervals, along the north side of the creek up to the summit of the ridge where it is nearly vertical. If the shale band expresses the attitude of the underlying fragmental rhyolites, they are upwards of 1,000 feet in thickness. Above these beds are various exceedingly fine, light-coloured rhyolitic porphyries, amygdaloidal andesites, and some andesitic tuffs. The rhyolites form a conspicuous series of steep bluffs and cliffs along the upper part of Indian river. On the crest of the ridge, higher in the series, are coarser-grained porphyries, greywacke, and occasional bands of argillite. It is difficult to say how thick the greywacke may be, for it could not be distinguished with any degrees of certainty from some of the coarser porphyries. Both the greywacke and the porphyries are much sheared and are cut by numerous stringers and veinlets of quartz. Mr. Rose[1] informs me that the greywackes are well bedded just north of the map-area, but within the map-area bedding is not very distinct, although traces of it are found in different outcrops. A thin band of argillites outcrops along the ridge near the extreme northeast corner of the map-area.

Microscopic Description. Nearly all the rhyolites, whether fragmental or massive, are dense porphyries, containing minute phenocrysts of quartz and sodic plagioclase, and in many cases of orthoclase. All three minerals may be present as phenocrysts in the same rock; or the orthoclase may occur only in the groundmass as distinct minute grains, or in spherical aggregates associated with quartz. By a decrease in the amount of orthoclase, the rocks grade to quartz latites and albite dacites.[2] The latter apparently contained an occasional phenocryst of some femic mineral, but these are represented now by aggregates of chlorite.

Included with the rhyolitic volcanics, is a quartz latite characterized by the presence of well-developed phenocrysts of quartz and plagioclase, 5 mm. in length, in a dense, grey-green groundmass. The plagioclase is albite

[1] Geologist of Britannia Mining and Smelting Company.

[2] The plagioclase in this series is albite to albite oligoclase, as determined by the fact that its indices are appreciably lower than those of quartz or Canada balsam. The maximum extinction angles normal to 010, vary from 10 degrees to 15 degrees.

(about Ab_{95} An_5) and the groundmass contains tiny, tabular crystals of plagioclase and many small, spherical aggregates of quartz and, presumably, orthoclase. The microscopic appearance of the rock is distinctly different from the very fine, light-grey porphyries typical of the rhyolitic series, but the rock is very similar to them in composition and is included with the rhyolitic volcanics because it is confined to a very small section of the rhyolitic area along the extreme eastern edge of the map-area. This quartz latite may be much later than the rhyolitic volcanics and related to the batholithic period of intrusion.

Less siliceous rocks, found along the ridge, near the centre of the series, are amygdaloidal, feldspar porphyries containing phenocrysts of oligoclase in a fine-grained groundmass of plagioclase, secondary chlorite, and epidote. Crystals of femic material appear to have been plentiful, but they have been altered to chlorite.

Metamorphic Rocks of Unknown Origin. A series of light-coloured, highly metamorphosed rocks outcrop in the easterly flowing tributary of Indian river which meets the river at the 1,800-foot contour. The rocks are light grey to faintly buff-coloured, fine-grained, granular, and frequently possess a sugar appearance. The principal constituents are quartz, albite-oligoclase, orthoclase, brown biotite, sericite, and chlorite, and the less plentiful constituents are rutile, apatite, and zircon. Pyrite, chalcopyrite, and sphalerite are widely distributed in veinlets and irregular replacements. Camsell has described the rock as a mineralized granodiorite porphyry.[1] At the time of mapping the field geology it was thought to represent a metamorphosed contact phase of the batholith, but the microscopic evidence does not bear this out sufficiently well to warrant its being mapped as such. A more detailed field and laboratory investigation will be necessary before the origin of the rock can be determined satisfactorily.

Attitude and Thickness

The rhyolitic volcanics of the Lower Goat Mountain formation appear to form a part of a northerly plunging anticline. The bedding in the upper members of the series, along the northwestern third of Indian River ridge, strikes north-northwest to northwest and dips, in general, at about 45 degrees to the southwest. Farther south on the ridge, the stratification appears to be nearly horizontal, and steepens farther south to a more nearly vertical position. On the basis of this interpretation of the structure the rhyolitic series of the group is about 4,000 feet thick.

The thickness of the metamorphosed volcanics forming the lower member of the group is not known.

MIDDLE GOAT MOUNTAIN FORMATION

Distribution

The middle member of the Goat Mountain formation is confined very largely to the eastern half of the northern border of the map-area, where it forms a strip 6,000 to 8,000 feet wide between Goat mountain and the diorite dyke, crossing the head of Indian River valley. The belt continues

[1] Camsell, C.: "Indian River Copper Deposits"; Geol. Surv., Canada, Sum. Rept. 1917, pt. B, p. 23.

westward, as a narrow band, along the north side of Britannia valley as far as the batholithic rocks; and an arm extends southeast alongside the west end of the central lobe of the batholith. The northern boundary of the map-area nearly coincides with the actual northern limits of the formation except at the extreme east end. Just north of the central part of the map-area and extending for many miles, is the main area of the Coast Range batholith.

Lithological Characters

The lower part of the formation, about 6,000 feet thick, is a series of massive, basic sills separated by narrow and irregular bands of "baked" carbonaceous shales. Towards the top of the formation, basic tuffs and flows become much more conspicuous. A series of tuffs, exposed on the east side of mount Sheer, are 2,000 feet thick, and other well-bedded groups are exposed higher in the series. A few flows have been recognized in Marmot creek, but these are quite subordinate to the intrusive type of rock.

Intrusive Types. The sills of the Middle Goat Mountain formation are best exposed on the slopes of Sawtooth range, a jagged group of peaks in the north centre of the map-area. Thick, dark grey masses of diabase alternate with thin and irregular bands of baked shale and tuffaceous material. The whole eastern flank of the range, down into Stawamus river, is, apparently, a thick series of westerly dipping sills with a few, irregular bands or partings of shale. The same rocks continue west and are exposed in Marmot Creek basin and on the east end of Goat mountain.

The upper sills are fresh-appearing, medium-grained diabase; but, lower down the slopes, the rocks are dense "greenstones." The primary textures are not essentially different, but the rocks are so highly altered that the textures are all but obliterated as far as megascopic examination is concerned. It is quite impossible to say how much of this section is intrusive rock, but very little of it has been identified as flows or pyroclastics. Approximately 2,000 feet of tuffs and general volcanic material are exposed a short distance south on the east side of mount Sheer, but they do not make their appearance in the section of Sawtooth range. Normally, they would be expected just where the sill-like character of the rocks in Sawtooth range is best revealed. They may have been lifted up above the section by the sills or have been faulted.

Although several thin sections of the rocks of the series were examined only two were sufficiently fresh to give a reliable indication of the composition of the plagioclase; and only one fresh enough to contain unaltered, primary femic minerals. The fresh rocks, as has been intimated, are in the upper part of the series, at the greatest distance from the batholith. The specimen selected to represent these rocks is a diabase, whose essential constituents are labradorite (Ab_{60-65}) and augite, in the ratio of about 2:1. Accessory constituents are inconspicuous. The individual plagioclase grains are small, well-developed tablets from 1 to 0·1 mm. in length, and are surrounded by the augite, producing the ophitic texture so commonly found in rocks of this composition. Although most of the augite is later than the plagioclase, some of it undoubtedly commenced crystallizing early, as occasional grains are contained in the plagioclase, and other grains, much larger than the average, may be recognized in the hand specimen as phenocrysts. The augite is very light in colour and slightly pleochroic. It is optically positive and has extinction angles up to 35 degrees. A small amount of green hornblende and chlorite is secondary after augite.

The other thin sections examined retain the texture of the basic rocks, but they are so completely uralitized that the original composition is not determinable. Radiating masses of uralite, small amounts of chlorite, and occasionally biotite, have completely replaced the primary femic minerals, and, in places, almost destroyed the feldspars.

Tuffs and Flows. In a few places, along the steep walls of Marmot creek, are bands of vesicular basalt which appear to be flows. Their number and distribution are not known.

Well-bedded, dark grey to almost black tuffs are exposed in the steep bluffs forming the east side of mount Sheer; and other beds, of coarser-grained fragmental material, are to be found in the divide between Goat mountain and Sawtooth range. Many of the bands are basic, crystalline tuffs resembling the " greenstone " phases of the intrusive rocks. Except in favourable places, where differential weathering has brought out the bedding, it is difficult to distinguish the tuffs from the non-fragmental rocks of the series. Some beds are fine grained and grade into black, cherty argillites.

Argillites. Narrow bands of argillites occur at a number of horizons throughout the series. The lowest exposure is near the base of the series, in the extreme northeast corner of the map-area, and, from here to the very top of the series, are numerous, irregular, thin bands of argillites. The largest area underlain by these rocks is along the lower slopes of Goat mountain, just below Tunnel Camp. Over an area of approximately 4,000 feet, the only outcrops to be found are dense black argillites, and these appear to belong to one relatively thin bed whose attitude is very nearly the same as the slope of the hillside. A short distance east of this, thin beds of tuffaceous sediments, none more than 20 feet thick, have an outcrop width of several hundred feet.

The most typical rocks are dense, black, unstratified argillites. They are usually hard, brittle rocks which break into small, regular blocks, and weather, on the cliff faces, to bright reds and yellows. The few bands of argillites that are well bedded are essentially tuffs containing variable amounts of fine rock fragments and carbonaceous material.

Attitude and Thickness

In the east, in the lower part of the series, the included bands of argillites have a general north-south strike, and dip to the west at angles varying from 15 to 30 degrees. Proceeding west towards the top of the series, the strikes swing to the west and the dips are to the south at angles of 15 to 45 degrees.

The thickness, as estimated along the north edge of the map-area, is approximately 8,000 feet. About 30 per cent of this thickness consists of bedded rocks; the remainder is, apparently, sills and intrusives.

UPPER GOAT MOUNTAIN FORMATION

Distribution

The Upper Goat Mountain formation is confined to two relatively small areas within Britannia Creek drainage basin, in the northwest section of the map-area. The most typical exposures are on the north side of the creek and underlie the upper part of Goat mountain where they rise abruptly in beautiful, colonnade-like cliffs, from the more gentle, timbered slopes of the lower part of the mountain. On the opposite side of the valley, the same rocks occupy a slightly smaller area extending from the crest of Britannia ridge to Britannia creek and, apparently, continuing under the talus for a few hundred feet up the north side of the valley.

Lithological Characters

The formation is a group of volcanic rocks, in which pyroclastics, ranging from thick, massive agglomerates to finely bedded tuffs, are the most prominent types. Amygdaloidal flows, flow-breccias, and sills are not uncommon, but are less conspicuous than the ejected types. Where best exposed—on Goat mountain—one finds thick beds of coarse agglomerates and poorly assorted, sandy tuffs, with occasional lenses of well-bedded material. The flows are apparently more common at the base of the series, but the condition is local, for one cannot expect thick beds of ejected material to have a very wide range of distribution.

The average rock is an andesite, whose principal constituents are plagioclase (varying from oligoclase to andesine), diopside, and hornblende. The only other primary mineral identified is iron oxide. Occasionally, magnetite is very plentiful, but, in many types it is quite inconspicuous. Chlorite, epidote, and hornblende are always present as secondary minerals, and calcite and kaolin are not infrequently developed.

Non-clastic Types. The flows and shallow intrusives are less metamorphosed than the clastic members of the series and afford a better opportunity for studying the primary composition of the group; none of them, however, is very fresh. They are usually fine-grained, olive-green porphyries, which have a dull, lifeless appearance as a result of their metamorphism. Small amygdules of chlorite or less frequently, calcite, are always present and in some cases are plentiful near the upper surface of the flows.

A specimen selected to represent the crystalline rocks near the base of the series, is an andesite composed of about 75 per cent andesine, 10 per cent augite, a few grains of interstitial quartz, and the remainder, secondary material such as chlorite and epidote. Magnetite is plentiful as an accessory constituent. An occasional phenocryst of plagioclase, 1 mm. or more in length, is present in a well-crystallized groundmass of tabular andesines less than 0·5 mm. long, and equidimensional augite grains, as well as an appreciable amount of chlorite. The feldspars exhibit a distinct tendency towards a parallel disposition, as a consequence of flow. A few of the augites are partly altered to hornblende and epidote. The feldspars are slightly clouded by the development of fine sericite, chlorite, and apparently kaolin, and, in the majority of phenocrysts, there may be detected the irregular, mottled appearance peculiar to albitized feldspar. The interstitial material of the groundmass is chiefly chlorite with epidote, a little hornblende, and titanite. Flow rocks, in which more than an occasional grain of primary femic minerals may be recognized, are the exception rather than the rule. It is probable, however, that they may have been present in the groundmass of many of the porphyries.

One of the fresher and more typical flows occurs as a pillow lava on the summit of Goat mountain, towards the east end. The centres of the pillows are medium-grained andesites, in which slightly zoned andesine phenocrysts constitute 20 to 25 per cent of the rock. A few augite phenocrysts partly altered to hornblende are also present. The groundmass is a dark, fine-grained, mottled aggregate of fibrous material, in which both hornblende and chlorite may be recognized. There are also numerous, fine-grained aggregations of opaque material resembling magnetite. The plagioclase phenocrysts are partly replaced by the material of the groundmass, as well as by small amounts of sericite and, apparently, albite. Amygdules are numerous and are composed of chlorite with a few radiating fibres of hornblende and stout crystals of epidote.

The individual pillows are beautifully distinct, almost spherical masses from 1 foot to 2 feet in diameter, and are surrounded by exceptionally well-bedded, bright green volcanic ash. Each pillow is composed of an outer shell of fine-grained, dark-coloured rock, about an inch thick, which grades to the normal, lighter coloured, medium-grained andesite described above. The ash surrounding the pillows has sifted through the openings between the pillows and is so very finely bedded that it must have been deposited under water. Without evidence to the contrary, it may be assumed that the flow was also subaqueous, a fact that according to many writers would explain the development of the pillow structure.

A different type of pillow structure is developed in a flow exposed on the short spur from Britannia ridge, immediately southwest of Park Lane dam. These pillows are indefinitely defined by dark, cherty material that appears to have oozed up between them, and to have been squeezed into cracks. This material in some cases appears as inclusions within the pillows, and seems to be a metamorphosed, fine-grained sediment. This type of pillow lava probably represents a subaqueous flow extruded among soft sediments. Petrographically, the lava is very similar to that described above, except that primary femic phenocrysts are not present.

Clastic Types. As stated above, the fragmental rocks are the dominant type in the group. On the south side of Goat mountain, one may find beds of agglomerate 100 feet thick, made of angular blocks from 1 to 2 feet in diameter, with scarcely enough fine material to fill in around the blocks. Within the coarser beds, stratification is not usually detected, but the unstratified beds grade into sandy tuffs, or may contain sharply defined lenses of conglomerate. The sandy tuffs may be more plentiful than was believed at the time of mapping, for, although in a few places they are exceptionally well bedded, in many outcrops bedding is very inconspicuous or entirely lacking. It is, then, somewhat difficult to recognize the tuffs unless thin sections are examined. Frequently, the tuffs possess a certain granular appearance which arrests one's attention and prompts a search for further evidence of their clastic nature.

The total amount of well-bedded material is small and, apparently, consists of a number of tuffaceous sands and conglomerates and small amounts of very fine ash. Ripple-marks are well preserved in one lens of sandy tuffs, which outcrops almost on the crest of Britannia ridge, towards the west end of the area underlain by the rocks of this series. The outcrop is particularly interesting because it contains a number of tubular and irregular openings, which suggest that fossils may have been present and leached out since consolidation of the tuffs. If the leaching is recent, it is possible that fossils might be found a few feet below the surface. Fossils are so rare in the volcanic series along the coast that all localities that may be fossiliferous are worth mentioning.

All the fragments, both in the agglomerates and sandy tuffs, appear to be of crystallized rocks. Glass has not been observed in any of the thin sections or in the field, but the rocks are so highly altered that its presence may have escaped detection. The fragments consist of a variety of medium-grained, feldspar porphyries, but this is about all that can be said in describing the original rocks. Many of the fragments resemble the andesitic flows and distinct fluidal textures are not uncommon. The groundmass is invariably altered to matted serpentine, or to fine-grained aggregates of chlorite, epidote, and indistinguishable dust-like particles. Calcite is present in some sections. The phenocrysts, which are usually plagioclase, are replaced to varying degrees by the fine chlorite aggregate of the groundmass, and, occasionally, by calcite. No matter how fresh the feldspars appear, they are usually albitized, so that the present range of the composition of the feldspars is from albite to andesine.

Attitude and Thickness

The Upper Goat Mountain formation forms a syncline. The beds, on the very top of Goat mouutain, dip west at low angles, but, on the south side, they dip to the south at an angle slightly steeper than the slope of the hill. On the south side of Britannia creek, the bedding is horizontal for 1,000 feet above the valley; but, on the crest of the ridge at the east end, the beds dip towards the north at an angle of 50 degrees. Farther east, along the ridge, they are more nearly horizontal.

The thickness of this series is at least 1,500 feet and may be much greater, for the top of the series is not exposed in the area.

INTERNAL STRUCTURAL RELATIONS

The Goat Mountain formation has been described under a number of major and minor subdivisions, and it might be well to summarize what is known or inferred regarding their relations to one another. The lowest group accumulated as a bedded deposit and is the rhyolitic volcanics of the Lower Goat Mountain formation. The lower part of this group consists chiefly of rhyolitic tuffs, with very small amounts of shale and conglomerate; the upper part is formed of bedded greywackes and an occasional thin bed of shale. Considering the stratified rocks as they occur upward in the series, and neglecting for a moment the intrusive sills, the sequence is as follows. Approximately 200 or 300 feet of dense, black shales are overlain by as much as 2,000 feet of basic tuffs and flows, and capping the series are 1,500 feet of agglomerates, tuffs, and flows comprising the Upper Goat Mountain formation. The shales and overlying 2,000 feet or more of basic volcanic rocks (Middle Goat Mountain formation in part) are intruded by basic sills, which constitute the greater part of the Middle Goat Mountain formation. The sills are younger than the shales and volcanic rocks of the Middle Goat Mountain formation, and the rhyolitic volcanics of the Lower Goat Mountain formation which they overlie. Some of the basic sills are also younger than some members of the Upper Goat Mountain formation, but it is not known whether the main period of sill intrusion accompanied, followed, or preceded the main development of the Upper Goat Mountain formation.

The relations of the altered basic volcanics which occupy the lowest position in the series, with the other groups, are not known. Some may have been intruded at the same time as the sills of the Middle Goat Mountain formation; but they may all be older. Although no definitely bedded volcanic rocks were recognized among the altered volcanics, some appear to be tuffaceous and would, of necessity, be older than the rhyolitic volcanics.

Age and Correlation

No recognizable fossils have been found within the Britannia Beach map-area and, therefore, the age of the Britannia group is not certainly known. It is probable that the assemblage is of the same age as the Vancouver group on Vancouver island which is known to be of Lower Mesozoic age—probably in large part Upper Triassic.

Contact and Thermal Metamorphism of the Britannia Group

In the foregoing description of the Britannia group, it has been impossible to avoid mention of the alteration products, for, in many instances, the only primary feature remaining is the texture. The purpose of this section is to give a more detailed account of certain prominent types of metamorphism found in the volcanic and sedimentary formations; to point out their extent, their relation to one another, and to the batholith.

The metamorphism not only varies with the physical conditions and the distance from the batholith, but also with the types of rock subjected to these conditions. Accordingly, the different types of metamorphism are described under the following headings: "Metamorphism of the Basic Rocks," "Metamorphism of the Acidic Rocks," and "Metamorphism of the Argillites." Following the section devoted to description is a discussion of the relations of the various types.

METAMORPHISM OF THE BASIC ROCKS

Chloritization

It is difficult to select a specimen from the pre-batholithic rocks that does not contain some of the minerals ordinarily regarded as secondary. Chlorite is almost always present, either as a replacement of the femic phenocrysts or of the fine-grained, femic constituents of the groundmass. Primary augite or hornblende phenocrysts are preserved in only three or four of the numerous, thin sections examined and in no instance are they entirely free from chloritization. The feeble stage of alteration is found at all distances from the batholith. If chlorite is the only secondary mineral present, it is more plentiful in the hornblende than in the plagioclase. In a few instances, where it is conspicuous in the plagioclase, a slight decalcification of the plagioclase may be detected by the occurrence of small, irregular zones of lower index feldspar within the larger grains.

Epidote-chlorite Rocks

Chlorite is usually accompanied by epidote and the plagioclase is frequently altered to a more sodic variety. This type of alteration is exceedingly common not only in this particular area, but in many areas of metamorphosed basic rocks; and the group of minerals characteristic of this type of alteration has been recognized by Eskola as comprising the *green-schist facies.* He describes the green-schist facies as "......metamorphic rocks containing some of the following minerals: albite, sericite, chlorite, talc, serpentine, epidote, calcite, dolomite."[1] This group of minerals, except for talc and dolomite, is characteristic of nearly all the fragmental volcanic rocks in the area, and is particularly prominent in the tuffs and agglomerates of the Upper Goat Mountain and the Britannia formations. The massive sills of the Middle Goat Mountain formation are uralitized rather than altered to the minerals of the green-schist facies. The first minerals to be replaced completely, under the conditions favourable to the development of the green-schist facies, are augite and hornblende; but so few of the thin sections examined contain these two minerals that it is not known which of the two is more readily altered. The basic plagioclase begins to alter almost as soon as the primary femic materials, but the rate of alteration is much slower. A large percentage of the original hornblende may still be present, when numerous fine flakes of chlorite make their appearance in the plagioclase. On the other hand, the hornblende is completely replaced long before the plagioclase is more than moderately altered. Even in the most advanced stages of alteration, the outlines of the plagioclase are relatively distinct. This is partly due to the fact that albite is frequently one of the products of alteration, and becomes fixed in the place of the original calcic feldspar, preserving its shape and much of its original transparency. Very frequently the amounts of the ordinary secondary minerals—chlorite, sericite, epidote, or calcite—may be very plentiful in an individual crystal of feldspar without effecting its decalcification, whereas other crystals containing a much smaller amount of these minerals may have the residual plagioclase completely altered to albite. The albite is recognized by the fact that its indices are decidedly lower than Canada balsam[2] and its extinction angles, normal to 010, are as high as 12 to 15 degrees. This indicates a relatively pure albite containing from 90 to 95 per cent of the albite molecule. Albitization of the plagioclase is pronounced in one section in which calcite occurs as a replacement of the feldspar. Epidote has the same decalcifying effect as the calcite, for Eskola[3] mentions epidote-albite as being an especially characteristic association of the green-schist facies.

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[1] Eskola, Pentti: "The Mineral Facies of Rocks"; Norsk Geologisk Tidskrift 1921, p. 155.
[2] The index of Canada balsam in this group of thin sections is approximately 1,540.
[3] Op. cit., p. 155.

Quartz is a stable primary constituent; it may also be one of the secondary minerals. The stability of magnetite is probably the same as quartz, for, in a few slides, it occurs as a released mineral and would, therefore, seem to be stable. The chlorite usually contains an appreciable amount of titanite, which has probably been released during the alteration of the femic minerals. In a few instances it has either been introduced or has been transported short distances, for it occurs in veinlets and in relatively large aggregates or grains.

Aside from the more common minerals of the green-schist facies such as epidote, chlorite, albite, and calcite, many fragments of the tuffs are composed of albitized feldspar and exceedingly fine, or amorphic, light green, serpentine-like material. The groundmass of some fragments may be composed very largely of this peculiar material, whereas adjoining fragments are altered in the more normal manner. The serpentine-like material occurs as a mass of elliptical blebs which appear to have been sufficiently mobile to be squeezed around fragments. Within this material, and within chloritic material in the same slide, are small, clear, colourless points resembling bubbles. Their index of refraction is decidedly higher than that of their host, and they are either amorphous or isotropic, probably the former. In the same slide are darker, bubble-like aggregations of a strongly birefracting material. A similar structure, on a larger scale, is beautifully displayed in a slide of another tuff. Here the bubble-like aggregations are larger, sometimes thicker than the section, and are found to be composed of an outer shell of small, titanite grains surrounding chloritic material. These aggregations occur chiefly in well-crystallized chlorite, but in some instances are surrounded by epidote and other minerals. Where the "bubble" is cut on both the upper and lower surfaces of the section, it is possible to follow the spherical outline very distinctly by changing the focus from the top to the bottom of the slide.

These large "bubbles," which may be identified as titanite and chlorite, are so similar in general appearance to the tiny bubbles first described, as to suggest that the latter may be amorphous or colloidal titanite, and that the fine, serpentine-like material surrounding them is amorphous or colloidal chlorite.

Albitization

Although the two phases of metamorphism described above are accompanied by a decalcification of the plagioclase, and although in a few instances the sodic plagioclase is a very conspicuous alteration product, the bulk composition of the rock is not necessarily changed. In a few sections examined, sodium has undoubtedly been added to the rock. The oligoclase of a dacite, collected on the trail about 1,500 feet east of the creek flowing due north from mount Lomond, is very largely replaced by a more sodic plagioclase. The rock also contains a small amount of chlorite, epidote, and, apparently, fibrous serpentine. Another specimen, from the greenstones crossing the head of Jane Creek basin, resembles, texturally, some of the andesites of the Britannia formation; but is composed almost entirely of very sodic plagioclase, with only a small amount of chlorite, epidote, and, possibly, very fine-grained quartz. If this rock has not been albitized, it is a most peculiar primary rock. A secondary addition of sodium seems the most probable explanation of its composition. At a third locality, southwest of Park Lane dam and about 1,000 feet from the contact of the batholith, albite is definitely introduced and occurs as lenses replacing the older minerals such as chlorite and epidote. These rocks all contain chlorite, epidote, and related alteration products and come under Eskola's definition of the green-schist facies. They differ, however, from the other members of the facies described, in that sodium has been introduced during the alteration process; and that, under the condition of its introduction, the remaining minerals of the green-schist facies are not necessarily stable.

Brown Hornblende-Andesine Rocks

The batholith-greenstone contact is best exposed in Britannia creek, between Tunnel Camp and the Park Lane dam. For 1,000 feet or more west of the batholith, the greenstones are uniform, fine-grained rocks, showing no recognizable variation in mineral composition as the contact is approached. Specimens for study, therefore, were not collected except near the batholith, assuming that the rocks were as homogeneous as they appeared in the field. This is probably an erroneous assumption. One of the specimens, selected to represent the main mass of the greenstone, is composed almost entirely of a brownish green hornblende and remnants of andesine. All the primary femic constituents, and a great deal of the plagioclase are replaced by distinct grains of hornblende, which are much stouter than the fine, fibrous, green hornblendes, characteristic of the uralitized rocks, described later. The unaltered part of the plagioclase is, apparently, not at all decalcified. Magnetite is plentifully developed and is, presumably, a released mineral.

Albite-clinopyroxene Rocks

Within a few feet of the contact, and apparently representing a higher grade of metamorphism, the brown hornblende-andesine rock is completely recrystallized to a fine-grained, even granular, aggregation of clinopyroxene and albite with an appreciable amount of epidote. The individual grains are about 0·02 mm. and less in diameter. The recrystallization has completely obliterated all traces of the original texture. Even the magnetite, which occurs in the hornblende-andesine as tiny, scattered grains, has been collected and recrystallized into larger grains. The pyroxene is a non-pleochroic and very faintly coloured variety, having an extinction angle of 45 degrees, a small axial angle, and positive sign. The albite is not twinned, but occurs in tiny, clear grains resembling quartz.

It is not clear whether or not epidote is one of the stable minerals developed during the recrystallization, or whether it is the product of a later alteration. Some of it, at least, has been introduced along joint planes with calcite, but the amount added in this manner cannot be determined.

Uralitization

Just as the fragmental volcanic rocks are characteristically altered to chlorite and epidote, the massive basic intrusives within the volcanic series are characteristically altered to the fibrous green hornblende, commonly known as uralite. This is a very broad generalization and does not necessarily mean that small sills, in the fragmental series, are uralitized rather than altered to chlorite and epidote. But it is a fact that the metamorphism of the Middle Goat Mountain formation, which is essentially a series of intrusives, is of the uralitic type and that the typical green-schist group of minerals is not developed in any of the thin sections examined from this series of rocks. It is also true that the only example of uralitization found within the zones of the two typically fragmental series (Britannia and Upper Goat Mountain) is that of a massive non-fragmental intrusive, outcropping on the south side of Furry Creek ridge, just west of the fault that bisects the ridge. Epidote, within the uralitized areas, is confined to fractures and to porous layers, such as fractured lava tops.

The least altered rocks in the Middle Goat Mountain formation are at the higher levels, at the greatest distance from the batholith, as on the higher parts of Sawtooth range. On the lower slopes of the range, nearer the batholith, the fresh, granular appearance of the rocks is lost, and in its place is found every gradation from unaltered rocks to dense, green rocks, in which no trace of the original texture remains. This change of appearance and masking of primary textures is not strictly gradational, and is, therefore, not entirely dependent upon the proximity of the batholith.

In thin section, even the freshest specimens contain appreciable amounts of fine, fibrous uralite, both in the primary hornblende and in the plagioclase. At this stage of alteration, the uralite in the hornblende may be accompanied by a small amount of brown biotite, and masses of chlorite penetrated by fine needles of green hornblende are not uncommon. Both chlorite and biotite persist in the more intensely altered phases, but, apparently, do not develop after the initial stage. It is possible that they have developed from some specific mineral, for in one specimen the outlines of chlorite-biotite areas are so regular that they are, apparently, pseudomorphs of definite crystals. The material surrounding these regular areas is the ordinary mottled aggregate of uralite with a small amount of chlorite.

The more advanced stage of uralitization is marked by an attack on both the plagioclase and the original hornblende. The plagioclase is, in some instances, uralitized along fracture planes; but more frequently, the uralite develops throughout the grains without any regard for fractures or cleavage. Apparently the only factor controlling the locus of replacement is the composition of the feldspar. Occasionally the outer sodic rims are decidedly fresh, whereas the hearts of the grains are more or less completely altered to uralite. Albite or a sodic-plagioclase was found in one thin section as a by-product of the alteration, occurring as small blebs and irregular veinlets in the plagioclase. The final product is a mass of fine, green hornblende needles, which are developed in the plagioclase and hornblende alike, completely destroying their original outlines.

Silicification

Superimposed on the more general and widespread types of metamorphism, is silicification which produces as an end phase, an exceedingly fine, dense, cherty rock, composed of quartz and a small amount of chlorite, sericite, leucoxene, and pyrite. The plagioclase is the first mineral to become unstable in the silicifying environment; it is readily replaced by fine-grained quartz, with variable amounts of chlorite and sericite. Occasionally quartz and albite pseudomorph the plagioclase, the albite occurring as a ragged and incomplete border outlining the original phenocryst. As the phenocrysts are being altered, the groundmass is recrystallized to the exceedingly fine aggregate of quartz with a little chlorite and these finally replace the whole rock and obliterate all structure.

The intensely silicified rock is found adjacent to the batholith in Indian river, particularly around the quartz diorite in the southwest corner of the map. In the same general area intense silicification occurs at some distance from the batholith, along narrow zones that were sufficiently fractured or permeable to localize the agencies of metamorphism. These are occasionally accompanied by sulphide mineralization.

METAMORPHISM OF RHYOLITIC VOLCANICS

The fine-grained, rhyolitic rocks have been particularly immune to thermal metamorphism, and dynamic metamorphism is not at all intense, except towards the upper part of the series, in the coarser grained porphyries and greywackes. Throughout the lower part of the series where the rocks are, chiefly, fine rhyolitic volcanics, the effects of shearing are noticeable only in the larger outcrops, and are not evident in hand specimens or thin sections. The principal effect of shearing is to develop quartz-sericite schists. The schists are cut by very numerous, small, quartz veinlets, usually less than an inch in width and a few feet long. The veinlets are both parallel with and transverse to the schistosity.

The lack of pronounced thermal metamorphism in the rhyolitic volcanics is to be explained by the fact that their principal constituents, albite and quartz, are stable minerals under a great variety of metamorphic conditions. Albite is one of the characteristic minerals in the green-schist facies, so there would be no reason why the primary albite of the rhyolites should decompose. The only secondary mineral present is a small amount of chlorite.

METAMORPHISM OF THE SHALES

Quartz-sericite Rocks

A study of the contact metamorphism of the shales has been attempted in only one small locality, and that along the contact of the quartz diorite which outcrops in the northwest corner of the map. This contact with the shales is well exposed in a few places along the lower part of Britannia creek, but only the immediate contact effect has been studied microscopically. In the field the variations in metamorphism, at distances from the contact, appeared so slight that a more careful study did not seem warranted.

The shales, within a foot of the contact and for at least 50 feet from it, are recrystallized to a very fine-grained, quartz-sericite rock containing numerous grains of magnetite, and flocculent aggregates of leucoxene. Variations from this type, at least along the immediate contact, are very local. In places the rock may take on a reddish tinge indicating a development of biotite. The reddish rocks also contain an appreciable amount of albite and quartz and should, therefore, be described as adinoles.

Adinoles

The few inclusions of shales, along this particular contact, are partly altered to adinoles and usually surrounded by a·narrow rim of granitic rock, which is distinctly finer grained than the average. The relation of the various phases is indicated by the accompanying sketch (Figure 1) of one occurrence. The sketch is numbered to indicate the positions from which specimens were taken for microscopic examination. The boundary between the inclusion and the granitic rock is very sharp and distinct, but the other boundaries are gradational.

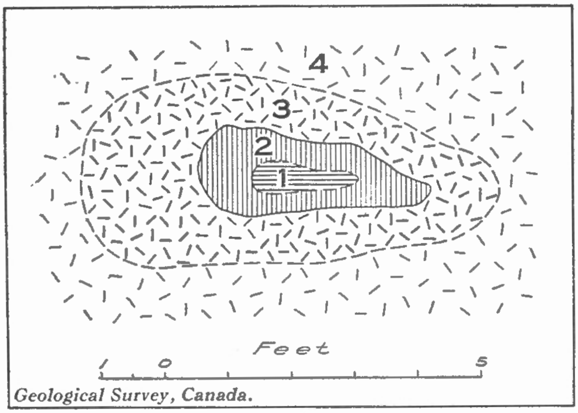

Figure 1. Sketch of a shale inclusion in quartz diorite: 1, quartz-sericite zone of the inclusion; 2, adinole zone of the inclusion; 3, fine-grained, quartz monzonite; 4, coarse-grained, quartz diorite.

The centre of the inclusion is a dense, dark grey shale apparently no more highly altered than the average shale along the contact. In thin section it is found to be essentially the same as the quartz-sericite rock described above, consisting of fine-grained quartz and sericite, with a great deal of magnetite, leucoxene, and fine-grained undeterminable material. This central phase grades gradually outwards into a more granular appearing, brittle, distinctly reddish rock. Although the sketch indicates but two specimens from the inclusions, three phases were studied. The hand specimen from point 1 was sufficiently large to include a section of the adinole zone as well as the central core of quartz-sericite rock. The adinole phase is composed of quartz and albite in about equal proportions, and of approximately 10 per cent of a deep reddish brown biotite. A few flakes of chlorite are present, and a little magnetite and leucoxene remain. The outer zone of the inclusion, as represented by specimen 2, contains over 60 per cent albite and, approximately, equal amounts of quartz and biotite. Ragged knots of hornblende are present and are apparently being replaced by the other minerals of the rock. Magnetite is not as conspicuous as it is in zone 1 and leucoxene is practically absent; both, apparently, having been incorporated in the biotite.

Without chemical analyses it is impossible to determine the chemical changes involved in the alteration of the shales to adinoles. The only obvious conclusion is that sodium has been added to the shales during the metamorphism—a very common result of the contact metamorphism of shales. Leith and Mead[1] have plotted twenty-three analyses showing the chemical changes in shales and slates at the contact of various intrusive rocks, ranging from granites to gabbros, and the most striking feature of their graph is the relative increase of sodium in the metamorphosed rocks. In only one instance is there a slight decrease in the amount of sodium. According to their analyses the introduction, or relative increase in the sodium content, is even more universal than the decrease in the water content.

The zone of fine-grained granitic rock around the inclusion (zone 3) is a quartz monzonite, composed of 35 to 40 per cent quartz, 10 to 15 per cent oligoclase, and the remainder, with the exception of a very small amount of altered biotite and green hornblende, is orthoclase. The average grain size is about 1 mm. The outer zone (No. 4) is the normal rock of this part of the batholith, a quartz diorite composed of the same minerals as the contact rim, but containing them in different proportions. The quartz content is approximately the same in both phases, but the relative amounts of orthoclase and plagioclase are reversed. The amount of femic minerals is very small.

The rim of fine-grained quartz monzonite is very definitely related to the inclusion, but the significance of the relation is not clear. The change in the composition of the inclusion may be the result of a simple reaction between the shale and the quartz diorite magma, and the rim of quartz monozonite may be the reciprocal alteration of the magma; or, sodium and potassium may have been introduced into the vicinity of the shales, accounting for the high albite content of the adinole and the relatively high orthoclase content of the quartz monzonite. If it is assumed that the original inclusion was essentially a quartz-sericite rock, and that the amount of sericite in the original rock was greater than the biotite in the adinole, the most obvious changes in composition may be explained, qualitatively, at least, by a reaction between the inclusion and the quartz diorite magma. Biotite and muscovite (sericite) contain approximately the same amount of potash, so that the second part of the assumption would imply that the adinole has lost potash during its development. It is obvious from the description of the rock that sodium has been added. The fine-grained rim of quartz monzonite contains less oligoclase and more orthoclase than the average rock of the batholith, and has, therefore, obviously lost sodium and gained potassium during its development. The

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[1]Leith and Mead: "Metamorphic Geology"; Henry Holt and Co., Pl. X ,1915.

assumption which is the basis of this suggestion is not entirely unreasonable, since the shales are essentially quartz-sericite rocks and the potash content of the average shale is 3·12 per cent,[1] which is the equivalent of 30 to 35 per cent sericite; this is greater than the biotite content of the adinole. Qualitatively, therefore, the reaction principle might apply.

The other explanation involves the movement of solutions towards inclusions, and a deposition of alkaline materials in and around the inclusions. Pegmatitic material is concentrated along the contact of the batholith, in the immediate vicinity of the inclusions studied, and occurs as pegmatitic knots and veinlets. The inclusions may, for some reason, have acted as a locus for the accumulation of materials and have reacted with them to produce the results observed.

RELATIONS OF METAMORPHIC TYPES

The least altered rocks are those in which the primary femic constituents are partly altered to chlorite. It is difficult to determine just how much of this alteration is due to metamorphic processes attendant upon the intrusion of the batholith and how much should be attributed to the final stages of consolidation of the basic rocks themselves. All gradations may be found, between the slightly chloritized rocks, and the most typical of the green-schist facies (epidote-chlorite rocks) on the one hand, and the uralites, on the other. The type of rock, which is here described as a "chloritized rock," is a relatively fresh rock in which the femic minerals are but slightly altered to chlorite. As the alteration increases in intensity, either epidote or uralite becomes conspicuous. The chloritization is, therefore, the feeblest phase of the two succeeding types of metamorphism.

The mineralogy of the rocks of the second type of metamorphism is characteristic of Eskola's *green-schist facies.* Albite is given particular prominence in the mineralogy of the facies, and is described as the characteristic companion product of epidote in the alteration of the plagioclase feldspar. In many of the sections studied from this area, albite is not conspicuous but is recognized in all the slides of the green-schist facies and may be more plentiful than is supposed. Albite is generally a recrystallization product, but in a few localities it has been added to the rock and replaces the earlier formed chlorite and epidote. Albite is, therefore, stable under a greater range of metamorphic conditions than either of its two companion products in the green-schist facies, and, in the cases cited, it is unquestionably a hydrothermal mineral.

Although practically all the rocks in the Upper Goat Mountain formation are more or less altered to chlorite and epidote, the tuffaceous layers are the most completely recrystallized. Non-fragmental flow rocks, within a few feet of highly altered tuffs, are relatively fresh and unaltered. The only essential difference between the two types of rock is that the flows are massive and impervious, whereas the tuffs are fragmental and permeable. It would seem that permeability has something to do with the intensity of the alteration. The most obvious and inevitable effect of higher permeability would be in controlling the movement of solutions. If solutions were partly responsible for the metamorphism, the most highly altered layers would be the fragmental layers; and this is actually the case.

[1] Clarke ,F. W.: "Date of Geochemistry"; U.S. Geol. Surv. Bull. 770, p. 631

A comparison of the uralitized rocks with the green-schist facies also suggests that solutions have played an important part in their metamorphism. The uralites and the chlorite-epidote rocks developed at similar distances from the batholith, and there is no reason to suspect that they were not developed under similar temperatures and pressure conditions. The range of stability of both is relatively great in terms of feet from the batholith, and if ordinary " dry " temperature and pressure are the controlling factors in metamorphism, the two types should be of the same metamorphic grade—or isogradic.[1] But it is doubtful if they are truly isogradic, because the parent rocks of both types are basic porphyries having the same general mineral assemblage, and should alter in a similar manner if other factors are equal. The alteration products, however, are radically different, therefore the metamorphic conditions were not equal. Since the fragmental series is more permeable than the group of dense sills, it would follow that the development of the green-schist facies (developed in the fragmental rocks) is more dependent on the movement of solutions than is uralitization. Another point, which has some bearing on the subject, is that epidote, one of the most common minerals in the green-schist facies, is entirely lacking in the uralites except where it occurs in veins or other channel ways. In these instances, at least, the epidote is undoubtedly hydrothermal, and it is significant that the epidote occurs in the uralites only as a hydrothermal deposit. These facts are not conclusive, but they suggest that moving solutions may play an important part in metamorphic processes, which are generally described as thermal processes.

The mineralogy of the brown hornblende-andesine and the albite-clinopyroxene rocks is totally different from that of the uralites and the green-schist facies, but it merely represents higher grades of metamorphism of the same group of basic rocks. The change from brown hornblende-andesine to the albite-clinopyroxene assemblage is effected by a complete recrystallization of the rock in the immediate vicinity of the batholith. One thin section contains not only the brown hornblende-andesite rock, but also a part of a narrow granitic veinlet along which the hornblende and plagioclase are recrystallized to clear oligoclase and clinopyroxene. The next higher stage in the alteration is to albite and clinopyroxene with a certain amount of epidote, some of which, at least, has been introduced along fractures and is possibly not a characteristic mineral.

In discussing the relation between a plagioclase-clinopyroxene rock (basic igneous rock) and an albite-clinopyroxene rock, such as described above, Eskola suggests that the clinopyroxene in the latter is in unstable equilibrium and that the albite-clinopyroxene assemblage should not be regarded as a special facies. His statement is as follows:

> "In such a series of assemblages some may represent true equilibria, or definite mineral facies, while others may be in a state of alteration from one to another facies, containing metastable relics from the earlier facies. This may be the case with assemblage 2 (albite-clinopyroxene) in which clinopyroxene is apparently metastable. It is not allowable to state that, in the change of conditions from those of clinopyroxene-albite, anorthite would become first unstable, while clinopyroxene still remains stable."[2]

[1] Tilley, C. E.: "The Facies Classification of Metamorphic Rocks", Geol. Mag., vol. 61, p. 168 (1924). "Rocks which belong to the same facies can be said to be in the same *metamorphic grade*, and can be referred to by the terms which I now suggest as *isofacial* or *isogradic*."

A metamorphic facies is defined by Eskola "to designate a group of rocks, characterized by a definite set of minerals which under the conditions obtaining during their metamorphism were at perfect equilibrium with each other." Eskola, P.: "The Mineral Facies of Rocks", Norsk Geol. Tidskr. VI, p. 145 (1920).

[2] Eskola, Pentti· "On the Petrology of Eastern Fennoscandia"; I. Helsinki, 1925, p. 74.

The rocks, which Eskola studied, altered directly from an ordinary basic rock to an albite-clinopyroxene rock, by a replacement of the plagioclase by albite. At Britannia, however, this is not the case. The albite-clinopyroxene is derived from a plagioclase-hornblende rock by a complete recrystallization of the whole rock, and would, therefore, seem to be an assemblage in true equilibrium. The fact that this assemblage has been developed, in one instance, from a plagioclase-clinopyroxene rock, and in another instance, from a plagioclase-hornblende rock, supports this contention, for, as Eskola says: "The criterion of true equilibrium would be, as general in physical chemistry, that it may be reached from different directions and in different ways."[1] The natural conclusion is that the albite-clinopyroxene rock is a special mineral facies, and it is the highest grade facies developed in Britannia area.

As compared with the basic volcanics, the rhyolitic rocks are only slightly modified by metamorphism, although both occur in the same area, at the same distance from the batholith, and, presumably, have been subjected to the same temperature conditions. Their primary mineral composition—quartz and albite with variable amounts of orthoclase—was stable under the conditions existing.

The shales near the batholithic contact are altered to quartz-sericite rocks. This mineral assemblage has, apparently, been developed and is stable under pressure and temperature conditions ("dry"), which are favourable for both the green-schist facies and the albite-clinopyroxene facies. This gives rise to a situation that appears to be anomalous, for one facies appears to be isogradic with two other facies that are not isogradic; but this merely means that one particular assemblage is much more stable than the others.

The adinole is a special type of metamorphic rock and cannot very well be correlated with the other types already described. The pressure and temperature conditions should be about the same as those that favoured the development of the albite-clinopyroxene rock in the basic series, but other conditions were not the same. The adinole was immersed in the magma, where it had every opportunity of reacting with the magma, and, therefore, its environment was not the same as that of the albite-clinopyroxene rock.

Silicification is also a special type of hydrothermal alteration, and it is in no way comparable with the general contact metamorphism, although it is possible that solutions may have been important in the latter process as well as in silicification.

BRITANNIA SILLS

A group of porphyritic intrusives varying in composition from albite dacite to quartz latite and occurring at a number of horizons in the Britannia formation have been referred to by Schofield[2] as the Britannia sills. In a later report he describes them as "quartz diorite porphyries which have more acid as well as more basic facies."[3] Inasmuch as the plagioclase is in very many cases sodic, containing no more than 10 per

[1] Eskola, Pentti: Loc. cit.
[2] Schofield, S. J.: Geol. Surv., Canada, Sum. Rept. 1918, pt. B, p. 57.
[3] Schofield, S. J.: "The Britannia Mines British Columbia" Econ. Geol., vol 21, p. 275 (1926).

cent or 12 per cent of the anorthite molecule, it seems best to select a name that will emphasize this point and not leave the impression that the feldspars are probably andesine. Accordingly the group could be described as a whole as sodic, or albite dacites. Quartz latites and dacite are also represented. Similar rocks have been described by Clapp[1] and Cooke[2] as quartz-feldspar porphyries.

Locally the Britannia sills are known as quartz porphyries owing to the fact that they are very siliceous, and quartz phenocrysts are visible in some of the coarser grained varieties.

Distribution

The Britannia sills have been intruded into the Britannia formation only and, therefore, they outcrop as a series of parallel bands in the southwestern half of the roof pendant. They vary from a few feet to a thousand feet in thickness. The most important band outcrops at the west end of the railway and may be traced northwesterly to the beach and southwesterly across Britannia ridge to Furry creek, and along the side hill of Furry Creek ridge to the fault that bisects the ridge. Smaller sills are numerous in the slates in the vicinity of the mine, but are too small, numerous, and broken to be mapped separately. The main band includes that part of the Britannia shear zone that contains all the commercial ore deposits of the area. North of this band in the Furry Creek section is another band of porphyries which is included with the Britannia sills; and their apparent easterly continuation is found along the side hill southwest of Seymour creek. A third band outcrops on the north side of Seymour creek below the arkose and metabasites of mount Lomond; and a fourth band, which is a massive sill at least 700 feet thick, forms the cone-like summit of mount Lomond.

Mode of Occurrence

The general concordance of the attitude of the intrusives with the sedimentary and volcanic series justifies the application of the term " sills " to the group, although in many instances the so-called sills cross the formation at relatively sharp angles. Where best exposed, along the beach north of Britannia creek, and at the west end of the railway, the intrusives are apparently true sills. In the drifts and raises between the beach and railway (part of the ore haulage system) it was found that the southern contact could be projected for several hundred feet with remarkable precision. Along the beach the contacts are beautifully exposed and are parallel to the bedding of the argillites for appreciable distances. In these same localities there is ample evidence that the rocks are sills and not flows. The sediments are baked on both the upper and lower contacts, and small, abrupt, crosscutting relations and apophyses may be observed in a number of places.

The main zone of the Britannia sills continues (as already described) across Britannia ridge to Furry creek, but the south contact, on crossing Furry creek, leaves the slates and crosses to a broad band of metabasalts.

Clapp, C. H.: " Geol. Surv., Canada, Mem. 13, p. 77.
Cooke, H. C. "Geol. Surv., Canada, Mem. 96, p. 167.

Although the contact was not observed for a considerable distance in this section, sufficient diamond drilling has been done from the surface to demonstrate that the distribution of the rocks is approximately as indicated on the map. Crosscutting relations are also found along the northern contact. Mining workings have penetrated the contact in a number of levels and at intervals for several thousand feet along the strike, and have shown that, on the lower levels at the west end of the mine, the porphyry is in contact with an appreciable thickness of tuffs, and that in going to the east the contact crosses to several hundred feet of slates and finally to a greenstone formation. It is evident, therefore, that the term "sills" is only a relative term and indicates merely that the trends of the Britannia sills and the Britannia formation are about the same.

So far this main band has been described as a simple intrusive, but as a matter of fact it contains a number of lenses of baked argillites and greenstones which are apparently partings between sills. A few of the larger and more important lenses have been separated at the east end of the band of sills, but as a rule they are too narrow, discontinuous, and poorly exposed to be separated in mapping. Mr. Rose,[1] Mr. Ebbitt,[2] and the writer have attempted on different occasions to construct a detailed map of a very small area west of Jane creek, but have never been successful in tracing an individual band more than a few score feet. Not only are the detailed structures complex, and the covering of vegetation heavy, but the lenses are probably irregular and discontinuous.

Detailed information is lacking regarding the mode of occurrence of the belts of porphyry on the north side of Furry-Seymour Creeks valley, but they are approximately parallel to the trend lines of the Britannia formation and are presumably sills. The lower contact of the thick mass of albite dacite forming the cap of mount Lomond is parallel to the bedding of the arkoses. The two zones of Britannia sills occupying an intermediate position in the Britannia formation and outcropping along the north side of Furry-Seymour Creeks valley are either bounded on the north side by faults, or they have been intruded into fault zones. Although the most accessible of the Britannia sills are clearly older than the folding and faulting it has not been established that all the rocks in the series were intruded at one period. As a matter of fact it is known definitely that albite-dacites, almost identical with the Britannia sills, have been intruded after the sills were sheared. It is probable, therefore, that at least a part of the sills in Furry-Seymour Creeks valley belong to this later stage of intrusion and have come up along fault planes. In general, however, they are believed to be older than the faulting, but since the mapping has been done entirely on the basis of petrographic similarity, a close correlation is quite out of the question.

The mapping of the Britannia sills in the east end of the area has been attended by a considerable amount of uncertainty, because rocks of a very similar type have been extruded before, and intruded after the main intrusion of the Britannia sills. No small part of the rhyolitic series of the Lower Goat Mountain formation is very similar to the Britannia sills,

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[1] Recent geologist of Britannia Mines.

[2] Present geologist of Britannia Mines.

both megascopically and microscopically, and albite dacites have been intruded after the tilting and shearing of the sills. Moreover, intrusion breccias are common in the sills, and, locally, foreign inclusions are very abundant, making it very difficult to distinguish the sills from tuffs or flow breccias, particularly after the rocks have been sheared and otherwise altered by metamorphism.

Lithological Characters

The principal variation in the different members of the Britannia sills is textural rather than mineralogical, although slightly different mineralogical types are developed. The dominant rock is an albite dacite in which quartz and sodic plagioclase (Ab_{80-90} An_{20-10}) represent well over 95 per cent of the rock. The remainder is chlorite, occurring as fine flakes in the groundmass or as aggregates replacing phenocrysts of some former femic mineral. Apatite is a conspicuous accessory mineral, whereas zircon and magnetite are plentiful in only a few thin sections. Quartz varies from about one-sixth to one-third of the rock and the remainder, except for the small amount of secondary and accessory constituents, is the sodic plagioclase. Another type less commonly developed contains an appreciable amount of orthoclase in the groundmass, and the plagioclase is andesine rather than albite oligoclase. In the great majority of slides, however, orthoclase was not recognized, although some potash is undoubtedly present in the rock.

The chief characteristic of the group as a whole is an exceedingly fine-grained, "cherty" groundmass composed of quartz and plagioclase with variable amounts of chlorite, epidote, and other alteration products. It varies in amount from 50 per cent to nearly 100 per cent of the rock. The phenocrysts in many of the rocks are exclusively plagioclase, but in some of the coarser grained types, or "bird's eye porphyries," severely corroded quartz grains may be present to the extent of one-quarter of the total phenocrysts. Occasionally one finds aggregates of chlorite which appear to have developed from some femic phenocryst, but no primary hornblende or pyroxene have been found in the Britannia sills.

Other variations in the sills are textural, or are the result of dynamic or hydrothermal alteration. The porphyry most frequently encountered in the vicinity of the mine, and between the mine and the beach, is grey, sometimes greenish or dark grey, in which blotchy plagioclase phenocrysts from 3 to 5 mm. in length are very conspicuous, and constitute from 10 per cent to 20 per cent of the rock. The groundmass is exceedingly dense ophitic material resembling chert. This coarse-grained porphyry, in which phenocrysts are large and numerous, usually contains a few quartz phenocrysts along with the feldspars. Among the finer grained varieties is to be found every gradation to exceedingly dense, homogeneous masses which have been mistaken for chert. Indeed the writer is uncertain as to whether some of the narrow beds now included in the sedimentary series and exposed at the very west end of the railway are not exceedingly fine-grained sills. As a rule an occasional phenocryst may be detected even in the finest grained varieties by turning a specimen in the sunlight and catching the reflection from the tiny cleavage faces.

A very interesting and suggestive variation in the texture is exhibited in some of the sills in Furry Creek valley. On examining the two most southerly sills on the north side of Furry Creek ridge, west of the fault, one finds himself describing the rocks in his field notebook as, " resembling fine-grained contact phases of the batholith." The porphyritic texture is retained, but the phenocrysts are quite inconspicuous owing to the distinctly granular appearance of the groundmass. Not only is the resemblance to the contact phase of the batholith very striking in the hand specimen, but the two rocks are practically identical in thin section. Each is composed of albite-oligoclase (Ab_{90} An_{10}) and quartz in proportion of about 7:3. Femic constituents are limited to 3 per cent or 4 per cent of the rock. The only difference between the two is that a few of the feldspars occur as phenocrysts in the sills, and fine-grained contact phases and the batholith have an even, granular texture. This variation is most strikingly exhibited at the east end of the most southerly of the two sills just mentioned, but it is well developed in other sills. The next sill north of this and the most northerly sill to outcrop in Britannia creek, are slightly finer-grained varieties of the same type. It is also represented in the sill, or group or sills on the north side of Furry creek opposite Furry Creek ridge.

Since all gradations may be traced from the finest grained porphyries to the finer grained phases of the batholithic rocks, it is suspected that the sills and batholith are very closely related to one another. This subject will be discussed in the section dealing with the age and correlations of the Britannia sill.

Brecciation and Banding

Intrusive breccias are very common in the Britannia sills and have been the cause of many misgivings in mapping certain areas, for rocks of similar composition occur as fragmental volcanics in the Indian River section of the area. Fortunately, striking examples of intrusive breccias are well exposed in members of the Britannia sills which are unquestionably intrusive. The matrix of these breccias is not fragmental, as in the tuffs, but this distinction is of no value for field determination, and it does not exclude the possibility that a rock, containing fragments surrounded by crystalline material, is a flow breccia. Excellent examples of intrusive breccias are found in some of the Britannia sills outcropping along Howe sound north of Britannia creek, and in a sill exposed along the railway about one-half mile east of its western terminal. Similar appearing breccias are numerous in the groups of sills north of the Furry-Seymour Creeks valley and are believed to be of the same origin, although direct proof is lacking. Very frequently the fragments can be detected on the weathered surface only. Fresh specimens from outcrops of distinct breccias may not show the slighest trace of brecciation, although on the weathered surface the fragments may be very conspicuous as a result of differential weathering.

Banding is also strikingly developed in a few sills, and at one locality it is related to brecciation in such a manner as to suggest that the two structures have a similar origin. One of the best examples of banding in the area is exposed in a rock cut towards the west end of the upper railway. Other examples are found along Howe sound. The banding is remarkably uniform and is due to the alternate arrangements of narrow bands of a lighter coloured porphyry and a darker coloured porphyry varying from 1 to about 4 inches in thickness. As a rule the individual bands retain their thickness with remarkable precision and all the bands in any one outcrop are inclined to be of about equal thickness. The contacts between the bands are reasonably sharp, but there is a certain blending, or welding, at the immediate contact which seems to be peculiar to primary banding, and is not readily duplicated along the ordinary intrusion contact. As far as could be determined the bands are approximately parallel to the surface of the sills. The maximum dimensions of the banded zones are not known, but some are at least 20 feet thick and 200 feet long.

The most interesting and instructive example of banding and the one studied in most detail is beautifully exposed in a railway cut at the point of intersection of the upper railway and aerial tram. Both banding and brecciation are exposed on one continuous face and may be studied in some detail. The bands which are at the west end of the outcrop are not straight as in most exposures, but are folded in a very open synclinal structure and terminate abruptly at the east in a peculiar jumbled zone. This zone in turn gives place within about 50 feet to a typical intrusive breccia. This variation of structure is along the strike of the banding. The fragments and matrix of the breccia are slightly different coloured quartz latite porphyries and are essentially the same as the alternating bands of the banded rock. The fragments in the breccia are darker-coloured than the matrix. The "jumbled zone" between the banding and brecciation is a confused type of breccia composed in general of masses of the darker porphyry surrounded by the lighter, as in the normal breccia, but locally the relations of the two rocks are so confused that it is impossible to determine which is the older. Both types are cut by lighter coloured and more siliceous appearing dykelets or veinlets. These are very irregular and discontinuous; at one point they may be quite sharply defined and within a few inches fade into the matrix in a most elusive manner.

The colour difference between the two types is reasonably distinct and it was fully expected that the difference in primary composition would be appreciable; but this is not the case. Both are quartz latites containing phenocrysts of andesine and of resorbed quartz in a fine-grained groundmass of quartz and orthoclase. Apatite, magnetite, and zircon are accessory constituents common to both types, although they are present in different proportions—apatite being more plentiful in the darker coloured rock. The phenocrysts are also more numerous in the darker bands (and fragments) and since the plagioclase is apparently present only as phenocrysts the darker rocks are presumably a little more calcic than the lighter. The only other primary difference noted is that the groundmass of the darker rock is slightly finer grained than the groundmass of the lighter coloured rock. Although the primary compositions are very similar to one another, effects of late magmatic or hydrothermal alteration have been totally different. The groundmass of the finer grained rock is extensively replaced by chlorite and fine needles of hornblende, whereas these two minerals are practically lacking in the coarser grained, or lighter coloured rock. In their place are found calcite and a mineral of the epidote group. These occur, however, as knots rather than as finely denominated material as the chlorite and hornblende are inclined to occur. Fine sericitic material is common in the plagioclase phenocrysts of the chloritized rock, but similar phenocrysts in the other rock are altered to epidote, calcite, and quartz. An explanation for this secondary and principal difference between the bands is not easily discovered.

Since the breccia grades into the banding and the rocks of the breccia and the bands are the same, it is not unreasonable to suppose that they were developed at the same time and by similar processes. The presence of fragments in a crystalline matrix means that the fragments were once a part of a more or less solid rock that was fractured, and invaded by the magma that crystallized to form the matrix. The fracturing might be the result of a bending of the sill or the welling along of more magma. Is it not possible that the same movement that fractured the rock might open up sheeting joints into which the incoming magmas could be injected? It is admittedly difficult to understand why the resulting bands should be so very uniform in thickness and so evenly spaced, but how else may the facts be explained? The later of the two rocks is coarser grained than the earlier, presumably because it was injected into rocks that were hot and possibly had not completed their crystallization. Wilson[1] explains the banding of the Laurentian gneisses by a similar process, assuming some differentiation to account for the slight difference in the composition of the various bands. Since the primary composition of the different bands in the Britannia sills is so similar many of the older explanations of banding are not applicable. It is not possible to assume, for example, a heterogeneous magma as suggested by Geikie and Teal[2] or convection currents to carry and deposit crystals;[3] or a differentiation in place. Even granting a difference in composition of the bands, and thereby admitting a certain amount of differentiation, it is difficult to see how *differentiation in place* is competent to develop the repeated alteration of two types of rock.

Even if the suggested explanation is accepted and it is assumed that sheet jointing would develop in this very remarkably uniform manner, it does not explain completely the most noticeable differences in the bands, namely, the difference in the relative amounts of the secondary minerals; although on the assumption outlined above we might have predicted a tendency to develop the conditions actually found. If the movements that resulted in brecciation and banding took place just before the final consolidation, the small amount of interstitial liquid would tend to flow from the fragments or bands into the openings before these openings were filled by the incoming magma. As a matter of fact the liquid in the fragments and the " solid " bands would actually be sucked into the openings, because it is assumed that brecciation took place under an impervious cover where open spaces would approach the conditions of a vacuum at the instant of their development.[4] The forcing of the small amounts of

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[1] Wilson, M. E.: "Banded Gneisses of the Laurentian Highlands of Canada"; Am. Jour. Sci., vol. 36, p. 122.

[2] Geikie, Sir A., and Teal, J. J.: "Banded Structures of Tertiary Gabbros in the Isle of Skye"; Quart. Jour. Geol. Soc. of London, vol. 50, p 645.

[3] Grout, F. F.: "Internal Structures of Igneous Rocks"; Jour. Geol., vol. 26, p. 439 (1918).

[4] This involves the conception of dilatency, which has been discussed from a geological point of view by W. J. Mead, in Jour. Geol., vol. 33, p. 685 (1925).

residual magma from the broken rock might leave a porosity which would control the circulation of later magmatic or hydrothermal solutions, and pave the way to the selective alteration of the fragments and earlier bands. The fact that calcite and epidote are more abundant in the later bands is not readily explained on these assumptions. They may be related to a later alteration that has affected all the rocks in the south half of the roof pendant, for calcite, epidote, and quartz are developed in fractures cutting the specimen examined and they are common alteration products of the Britannia sills in general.

The suggested explanation of the banding and brecciation is that the sill was bent and fractured just before the final consolidation of the magma which was already in place. The movement fractured the partly consolidated rock in one place and developed sheeting joints in another. The fragments were surrounded by a magma which also injected itself along the sheeting joints, but before this could take place the small amount of residual magma in the fragments and solid bands would tend to be sucked into the fractures and leave the fragments and bands slightly porous. This porosity would control the movement of solutions and induce differential alteration.

Metamorphism

The Britannia sills have suffered a certain amount of hydrothermal alteration and locally have been subjected to intense dynamic metamorphism. The groundmass of the porphyries invariably contains tiny flakes of chlorite and a dusting of small knots of epidote, and both the minerals are very frequently found in the feldspar phenocrysts. Where epidote occurs as well-developed and distinct grains in the feldspar the latter usually possesses a slightly mottled appearance commonly observed in the albitized rocks. Such hornblende or augite as may have been present has been completely altered to chlorite. Calcite, sericite, and quartz are not uncommon and pyrite is widespread in the finer grained varieties toward the east end of the area.

The extent and uniformity of distribution of the small amount of chlorite and epidote would suggest that they have been developed during the final crystallization of the magma. Locally, however, one finds a concentration of pyrite, chlorite, or calcite, as the case may be, and the presumption is that these materials have been transported by solutions to their place of concentration. Hydrothermal solutions are, therefore, appealed to for at least a part of the alteration, and since pyritization and silicification are intense in sills due south of the Furry-Seymour Creeks divide it is evident that these solutions have had an extensive circulation. Just at present there seems to be no satisfactory way of distinguishing between hydrothermal and late magmatic alteration.

Locally, as in the Britannia shear zone, the sills have been sheared to chlorite and to sericite schists which are known locally as " green-mottled" and " silver " schists respectively. The typical green-mottled schist is a decidedly schistose, chlorite-sericite schist which grades on the one hand into unsheared porphyry, and on the other, into the silver schist. The chlorite and sericite in the green-mottled schist are confined very largely to thin, lenticular aggregates a few centimetres long and a millimetre or so thick, lying in the plane of the cleavage, and appearing on the cleavage faces as evenly distributed blotches of greenish material surrounded by the light grey of the porphyry. Locally the mottled appearance is due to the presence of inclusions of slate and greenstone, but they are the exception rather than the rule.

In thin section it is found that the blotches in the green-mottled schist are essentially the sheared and recrystallized part of the rock. The original texture of the material between the blotches is remarkably well preserved, but the blotches themselves are exceedingly fine aggregates of sericite and chlorite in which no trace of the original texture is preserved. There are, of course, all gradations between fracturing and the development of the blotches, but the shearing is much more concentrated in the blotches than elsewhere. It is interesting to note that they are composed of a very fine intergrowth of chlorite and sericite and that they have been developed from a rock that is made up predominantly of very sodic plagioclase and quartz. The change in composition as a result of the shearing must be considerable.

The silver schist is a more intensely sheared phase of the green-mottled schist. An increase in the shearing has not only developed a more fissile and finer textured schist, but has also developed a sericite schist from a chlorite-sericite schist. The number of blotches at first increase and the rock becomes a more cleavable chlorite schist, but finally the green of the blotches begins to fade and to give place to the beautiful silvery colour of the sericite. In some places within the mine the blanching of the chloritic schist is due to hydrothermal alteration and is not the result of more intense shearing. There are, however, a number of places where the transition is undoubtedly due to shearing. All stages may be found between fairly massive chloritic schists, through fissile schists in which " ghosts " of the chloritic blotches are still visible, to exceedingly fine sericite schists in which no trace of green remains. As a rule the sericite, or silver schists, are so fissile that it is impossible to prepare a chip for a thin section at right angles to the cleavage, but this difficulty is seldom experienced with the chlorite-sericite or green-mottled schist.

Although no chemical analyses are available it is almost inevitable that the composition of the two types of schist is different, even although they are phases of the same rock. This illustrates a principle in schist formation that has been emphasized by Leith and Mead.[1] They maintain that the platy minerals are stable in schist-forming environments and that a long continuation of shearing will favour their development to such an extent that the composition of the rock will change towards the composition of those particular platy minerals that happen to be stable under given conditions. This means that important amounts of material must be carried out of the rock. It is difficult to believe that the movement of solutions is sufficiently great to effect this transfer of material during shearing, but the fact remains that a change in composition may be one of the results of shearing.

[1] Leith and Mead: "Metamorphic Geology"; New York, 1915, pp. 127, 137, 157.

Age and Correlation

It has been pointed out above that certain phases of the Britannia sills are almost identical with one of the contact phases of the batholithic rocks and it was suggested that the sills were genetically related to the batholith. Although correlation of igneous rocks on the basis of similarity of composition and texture is undoubtedly dangerous, it is supported in this instance by one other bit of evidence which is very suggestive. Mr. Dolmage, who has studied both flanks of the Coast Range batholith, at intervals, throughout the length of British Columbia, informs the writer that rocks resembling the Britannia sills are everywhere encountered as the batholith is approached. Their locus, therefore, is the zone of the batholith, and since they are so similar to it in composition one cannot but assume that they are directly related to it in origin. The sills are, therefore, regarded as vanguards which the batholith sent far ahead into the overlying strata as it commenced its ponderous march upward. Many sills were injected into flat-lying strata that were later tilted and partly engulfed by the magma as it continued its way to the surface. A few may possibly have been injected after the folding, although the evidence for this is not clear. The sills are, therefore, believed to be Upper Jurassic in age.

Similar rocks have been described elsewhere along the coast in the vicinity of batholithic rocks generally related to the Coast Range batholith. Clapp describes feldspar porphyries of the Sicker series in the following terms.

> "Intrusive into the Sicker series, very abundant in many instances, and usually conformable to the bedding or schistosity, are quartz-feldspar porphyrites which are associated with the plutonic rocks all along their contacts.. ..The groundmass is very fine, and is composed essentially of angular grains of feldspar and quartz. The feldspar predominates and is entirely plagioclase. The feldspar phenocrysts are also plagioclase, apparently in most cases albite-oligoclase, although at times they are replaced by epidote and calcite, suggesting that more basic plagioclase is sometimes present."[1]

This description could be used for the Britannia sills, and a later, more detailed petrographic description of the same porphyrites by Cooke[2] makes the similarity still more striking. Both authors mention that the sills are older than the batholith and have been sheared by later Jurassic folding movements which attended the batholithic intrusion.

O'Neill in describing certain granodiorite porphyries in Portland Canal district says "The main granodiorite intrusion was preceded by granodiorite porphyry which worked its way into the overlying rocks and cooled before the main intrusion reached its climax and the porphyry is actually cut by the granodiorite, although it was a part of the same magma and has suffered a general regional shearing in consequence."[3] Schofield and Hanson[4] in describing the same rocks under the heading "Premier Sills," add that they are probably sill-like intrusives, and that their composition is similar to that of the Coast Range batholith.

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[1] Clapp, C. H.: "Southern Vancouver Island"; Geol. Surv., Canada, Mem. 13, p. 77.
[2] Clapp, C. H., and Cooke, H. C.: "Sooke and Duncan Map Area"; Geol. Surv., Canada, Mem. 96, p. 167 (1917)
[3] O'Neill, J. J.: Geol. Surv., Canada, Sum. Rept. 1919, p. 83.
[4] Schofield, S. J., and Hanson, G.: "Geology and Ore Deposits of Salmon River District, B.C."; Geol. Surv., Canada, Mem. 132, p. 21.

From the foregoing it is evident that there is nothing novel in the conception that sills and dykes, of the same general composition as the batholith, may be intruded sufficiently early in the sequence of batholithic events to be folded and severely metamorphosed as a result of the intrusion of the main mass. Although it may not be a new idea it has a significant bearing on batholithic intrusion which has not been discussed. This topic, however, must be left for later consideration (*See* page 56).

BATHOLITHIC ROCKS

General Statement

The rocks that are referred to the main period of batholithic intrusion may be described most conveniently under five separate headings. First: in the Indian River section of the area are a number of small, irregular intrusions of diorite and quartz diorite which, in general, are more metamorphosed than the normal quartz diorites and granodiorites of the main batholith and, on the average, contain a little more of the femic constituents. Secondly: the foliated or "gneissic" group of rocks that occur along the southwestern side of the roof pendant, and are represented by quartz diorites; in places, sodic quartz diorites and granodiorites. The more highly sheared rocks are at the west end near the contact and it is here that the orthoclase content also increases. The third group is the main central lobe of the batholith, which is composed of the ordinary, even-grained granodiorites and quartz diorites of the Coast Range batholith. Some large blocks of diorite are found in one locality sharply separated from the granodiorites, but, as a rule, the contacts are gradational. The most basic phases are quartz diorites. Where fine-grained contact phases are present the plagioclase is more sodic than usual, quartz is more plentiful, and orthoclase is absent. The fourth type, outcropping in the northwest corner of the area, is a coarse-grained, siliceous granodiorite or orthoclase-bearing quartz diorite. The fifth type is a porphyritic rock of similar composition outcropping near the southwest corner of the map. It is of interest because it is later than the shearing and is, therefore, presumably later than the gneissic types, although the two have not been observed in contact.

Indian River Intrusives

The batholithic rocks which are grouped as the Indian River intrusives occur as four distinct bodies in the Indian River section. The two northerly occur in the form of broad, north-south dykes up to 1,000 feet wide, which cross the valley at an oblique angle and are exposed for variable distances on both sides of the valley. The first of the two southerly areas is more irregular than its neighbours to the north, but is similar to them in that it crosses the river and is exposed for short distances up each side of the valley. The most southerly area is confined to an irregular area on the east side of the valley, about midway between the stream and the crest of the hill. It is more irregular than any of the others and contains a number of large inclusions of the earlier Volcanic series, a few of which are indicated on the map. Their number is greater than indicated, for these are only a few that were encountered in the traverses.

The average, or typical rock of the group is a dark grey, medium-grained, plutonic rock containing dull greenish feldspars, chloritized femic minerals, and a small amount of quartz. Microscopically, it is found to contain oligoclase, quartz, orthoclase, and chlorite. The latter is probably a hydrothermal alteration product of some one of the usual femic minerals. Apatite and magnetite are necessary constituents. With the chlorite there is usually associated variable amounts of leucoxene and epidote, the latter frequently being very plentiful and conspicuous even in the hand specimen. Other common secondary minerals are uralite, calcite, sericite, metallic sulphides, and kaolin. The principal constituent is plagioclase representing approximately 75 per cent of the rock and occurring in slightly modified, euhedral grains surrounded by the other constituents of the rock; of these, quartz is slightly more plentiful than either the femic minerals or the orthoclase.

Variations from the typical phase are common. As a matter of fact each of the four masses, included in the group, grade in one place or another to the more typical granodiorites of the main batholith. This gradation, of course, is very slight, for it is marked only by a small increase in the amounts of orthoclase and quartz at the expense of the plagioclase. The femic constituents in the Indian River quartz diorites are slightly greater than in the typical granodiorites, but the difference in colour between the two rocks is due to the general chloritization of the Indian River rocks rather than to variations in the content of primary femic materials. Another phase, not infrequently encountered, is granodiorite containing an appreciable amount of pink orthoclase and a very small amount of femic constituents. This type of rock is found in the most northerly area, where it is exposed on the west side of Indian river, and at the north end of the most southerly intrusive of the group.

None of the rocks of this group has been observed in actual contact with the main mass of the batholith and their age relations, therefore, are not known. They possess, however, certain group characteristics that seem to warrant their being described as a distinct group, and that suggest that they may be slightly earlier than the main intrusion. They are much more metamorphosed than the main rocks of the batholith, and the metamorphism is of a slightly different type, resembling more the metamorphism of the greenstones than that of the quartz diorites of the main intrusion. Epidotization is conspicuous; crushing and shearing are common; and one mass (the third going south) is well mineralized in places. Although these facts are no more than suggestive, they do seem to indicate that the Indian River intrusives are slightly earlier than the main intrusion of the batholith.

Southwestern Area of Batholithic Rocks

The southwestern area of batholithic rocks is probably continuous with the central area and is part of the same general period of batholithic intrusion; but within the area studied, they possess distinctive features and are, therefore, described separately. The rocks of the southwestern area, which include all the batholithic rocks southwest of the roof pendant, and the dyke-like intrusions in the Britannia formation near the southwest contact, are foliated or " gneissic "; whereas the rocks of the central area are quite homogeneous and unsheared. The foliation, as LeRoy has pointed out in describing these same rocks, is of two types ". . . .the first is caused by an alignment of the minerals during the cooling stages of the magma, while the second is the result of dynamic action subsequent to final or partial solidification"[1]

GENERAL TYPES

The most common rock type in the area, and the one that is apparently the most typical in this section of the Coast Range batholith, is a quartz diorite,[2] although the variations, particularly along the contact, are quite marked and very significant. Aside from the normal quartz diorite, gradations to gneissic granites and also gradations to sodic quartz diorites are found. The specimen, selected to represent the normal rock of the southwestern area, was collected on the 500-foot contour at the extreme west end of the map-area and approximately 3,000 feet south of the main contact. The rocks, from here to the south border of the map-area, appear to be essentially the same in the field, but they have not been studied in thin section. They are medium-grained, granitic rocks containing, approximately, 20 per cent combined hornblende and biotite in very dark, clear-cut grains, which stand in marked contrast to the very white plagioclase and quartz surrounding them (*See* Plate II C). The femic constituents, and, less noticeably, the feldspars, are crudely oriented in a plane approximately parallel to the main contact of the batholith. This is not very clearly seen in a small hand specimen, but is a conspicuous feature in outcrops that are normal to the plane of foliation. Not only are the crystals oriented, but also the inclusions, which are very numerous in places, are oriented with their major axes in the plane of foliation (*See* Plate IIIB).

In thin section, the foliated rock is found to be a quartz diorite containing andesine, quartz, hornblende, biotite, as essential constituents; orthoclase, as a minor constituent; and apatite, magnetite, and zircon as accessory minerals. The femic minerals represent 20 to 30 per cent of the rock; quartz is about half as plentiful; orthoclase makes up no more than 1 or 2 per cent; and the remainder, with the exception of the very small amount of accessory constituents, is andesine. One large phenocryst-like plagioclase is zoned. The central part of the crystal is a confused mass of slightly different types of plagioclase which grade into one another and extinguish at different positions. This is surrounded by seven or eight relatively broad zones, of which each alternate zone becomes dark at about the same position; these in turn are divided into a number of narrower zones whose extinction angles are very nearly the same. This multiple zoning indicates, as Fenner[3] has recently pointed out, that the crystals have remained suspended in the magma for a long time, and that they have not remained in a uniform magma, nor in a magma that changed in a uniform manner. The alternate deposition of sodic and more calcic layers must have been accompanied by a parallel change in composition of the surrounding magma.

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[1] LeRoy, O. E.: "Portions of the Main Coast of British Columbia and Adjacent Islands"; Geol. Surv., Canada No. 99 (1908), p. 22.

[2] *See* Burwash, E. M.: "Geology of Vancouver and Vicinity"; University of Chicago Press.

[3] Fenner, C. H.: "The Katmai Magmatic Province"; Jour. Geol., vol. 34, p. 703 (1926).

Zoning is not confined to the large, phenocryst-like plagioclase, but is well developed in the normal phenocrysts of rock. In this case, however, the zoning is not oscillatory or multiple, but is the ordinary type produced by the gradual increase of sodium in the outer part of the crystal. Occasionally, two or three sharply defined bands are found, but each successive band is more sodic than the one preceding.

MARGINAL PHASES

Another specimen collected at about the same elevation (500 feet), but within about 700 feet of the main contact, is very similar to the one just described. The femic constituents are not quite as plentiful as in the rocks farther from the contact and the shearing is more pronounced. In thin sections of this rock, as in the other, multiple zoning of the plagioclase is conspicuous. From eight to twelve zones of alternating calcic and sodic layers may be observed in certain of the crystals.

Two other specimens were taken still nearer the contact; one within a few feet of the main contact and the other at about 300 feet from it. These specimens are from localities separated from that of the above described specimen by a narrow band of metamorphosed slates which is practically continuous with a broader band higher up the hillside, giving the impression that the zone of the specimens is a separate, sill-like intrusion. There is no reason, however, to believe that it was not intruded at the same time as the main intrusive and has merely wedged off a very large slab of slate.

The specimen selected at about 300 feet from the main contact is a sheared granodiorite containing highly fractured and bent crystals of oligoclase surrounded by crushed and recrystallized quartz and orthoclase. The femic constituents are limited to small amounts of chlorite, biotite, and epidote along the shear planes. The rock nearer the contact is a gneissic granite composed essentially of quartz and orthoclase, in approximately equal proportions. In addition to these minerals it contains only small amounts of kaolinized plagioclase, a few shreds of chlorite, and an occasional small grain of black iron ore.

The four specimens show that the nature of the granitic rocks varies as the contact is approached, and that the variations are of a uniform and progressive type. Within the line of section, all the rocks are foliated; but at 3,000 feet from the contact, the parallel orientation of the grains was brought about during the crystallization period of the magma and is, essentially, a primary structure. As the contact is approached, this primary foliation is obliterated by a later shearing, which is parallel to the primary structure, and which becomes more intense until the rock, at the very contact, is completely recrystallized. This is paralleled by a decrease in the proportion of femic constituents and a decrease in the amount of calcium in the feldspars. This last change is noted first by the appearance of oligoclase in place of andesine and is followed, nearer the contact, by a very remarkable increase in the relative amount of orthoclase as compared with the amount of plagioclase.

Before attempting to inquire into the possible significance of these variations in texture and composition it would be well to examine a few other localities along this contact. At a point on the 4,000-foot contour, about 8,000 feet east and within about 100 feet of the contact, the rock is a well-sheared quartz diorite, apparently porphyritic, containing broken oligoclase phenocrysts in a granulated groundmass of quartz, plagioclase, and a very small amount of orthoclase. A little epidote is present, but the ordinary coloured constituents are practically absent. This specimen is more calcic than the specimen selected at 300 feet from the contact, for orthoclase is present in only very small amounts. Otherwise the two rocks are similar, in that the plagioclase is oligoclase and the femic constituents are very inconspicuous.

Continuing along the contact another 1,000 feet to just west of the confluence of Furry creek proper and Lynn fork, is a series of exposures grading from the normal appearing quartz diorite to an exceedingly fine-grained phase towards the contact. The actual contact was not observed. A relatively fine-grained specimen composed of grains averaging 0·5 mm. in length, was selected for microscopic examination. It is a sodic quartz diorite containing, approximately, 25 per cent quartz, 2 per cent biotite and hornblende, and a very sodic plagioclase making up the remainder except for small amounts of secondary minerals such as chlorite, epidote, sericite, biotite, and kaolin. Orthoclase is apparently absent and the rock is not sheared. The feldspar was recognized as a sodic variety by the fact that the high index is less than that of Canada balsam and that extinction angles in the zone normal to 010 are as high as 15 degrees. This means that the plagioclase contains[1] about 95 per cent Ab—an unusually sodic plagioclase to occur in this manner; and yet this is practically the same composition as was found in some of the Britannia sills. This contact modification of the batholith agrees with the modification farther west, in having a more sodic plagioclase than the normal rock, but differs in that orthoclase was not found. Orthoclase, however, is probably present to a considerable extent as a solid solution in the plagioclase. Quartz is also much more plentiful than usual; and it is intergrown with the plagioclase in vermicular fashion and appears to represent a replacement of the plagioclase by quartz.

A type of rock, which is almost identical with the sodic quartz diorite of the last locality, reappears in one of the two dykes that have been included in the batholithic rocks of the southwestern area. The first dyke (7), from north of the head of Lynn fork, is a sheared quartz diorite not unlike the main rock in this part of the batholith, although the plagioclase is a little more sodic than usual. The next dyke, north of this and outcropping just over the crest of Furry Creek ridge, is a sodic quartz diorite essentially the same as the contact phase described above. The only sensible difference is that the plagioclase is slightly less sodic, containing more nearly 90 per cent than 95 per cent Ab. It has already been suggested that this dyke may possibly be a continuation of one of the Britannia sills; but, owing to the lack of detailed knowledge of its line of outcrops along the cliffs west of its present mapped extent, the correlation cannot be made with any degree of certainty. Petrographically, however, the two rocks are very similar or practically identical. It is evident, also,

[1] Goranson, R. W.: "The Determination of Plagioclase Feldspars"; Am. Min., vol. 11 (1926).

from the foregoing descriptions, that the dyke may be equally well included with the main batholithic rocks, for not only has it the same composition as the contact phase, but its mode of occurrence is identical with that of the dyke to the south, which is more certainly a phase of the batholith.

Central Area of Batholithic Rocks

The central area of batholithic rocks underlies a large part of the southeast section of the map-area and extends into the centre of the map-area as an irregular, blunt lobe. Erosion has uncovered a small area of these same rocks in the upper part of Marmot creek, the north branch of Britannia creek, and similar rocks are found in the stream bed of Indian river at the southeast corner of the map-area.

GENERAL TYPE

Although this section of the batholithic rocks varies from diorites to sodic diorites and to granodiorites, the variations from the normal type are apparently much less than 1 per cent of the total mass. The average rock is a light coloured plutonic rock of the usual granitic texture, in which plagioclase and quartz are readily recognized in the hand specimen as the most important constituents. The coloured minerals, biotite and hornblende, invariably constitute less than 10 per cent of the rock. In thin section, orthoclase is recognized and is even more plentiful than the combined amounts of biotite and hornblende. It represents approximately 10 per cent of the rock and occurs with the quartz as a filling around the earlier, and, more or less, idiomorphic, plagioclase. The amount of quartz varies from 10 per cent to 20 per cent. The plagioclase is an average oligoclase, as the index is $1 \cdot 544 \pm 0 \cdot 003$ and the extinction angles are very small. Accessory constituents are magnetite and apatite. Aside from these, of course, there is the usual quota of alteration products such as chlorite, leucoxene, sericite, and kaolin. From the above, it is apparent that the average rock is midway between an orthoclase-bearing quartz-diorite and a granodiorite. (A typical hand specimen is illustrated in Plate II B.)

BASIC PHASES

The only locality where basic phases were examined in detail is on the east side of Seymour creek, a short distance above the west fork of the creek. At this point one of the tunnels in an old prospect started in the normal phase of the batholith and encountered two masses of diorite that are sharply defined and appear to be huge inclusions in the batholith. One is about 25 feet thick and the other is exposed for about 100 feet, and the end of it has not been reached. The inclusions are dark grey plutonic rocks having the usual granitic texture, and are referred to, by the miners, as "black granite." Approximately two-thirds of the rock is andesine; the remainder is diopside, hornblende, quartz, a very small amount of orthoclase, and magnetite as an accessory constituent. Some grains of diopside occur as phenocrysts or larger grains than the average, and are surrounded by a fringe of magnetite and hornblende; the magnetite being segregated or deposited on the outside of the fringe next to the diopside. The two femic constituents are present in about equal amounts and represent about one-third of the rock. Quartz, magnetite, and orthoclase combined do not make up more than 2 or 3 per cent of the total volume. The plagioclases are zoned, and, occasionally, the successive zones are so different in composition, and so sharply defined, that the difference in indices is noticeable. The zoning, however, is not the oscillatory type, but each successive layer is more sodic than the preceding layer.

The usual method of explaining the presence of large blocks of more basic rock is to assume that they represent a part of the batholith that crystallized earlier than the main mass, and that they were later engulfed by the remaining magma as it continued to advance towards the surface. This explanation is probably correct, but there is no particularly good evidence to support it in this area. Here the contact phases of the batholith are either the same as the rest of the rock, or more siliceous.

Another area of diorite, or more nearly a quartz diorite, is to be found directly northeast, on the opposite side of the ridge. It is several hundred feet in diameter and is apparently gradational into normal batholithic rocks. The reason for its occurrence here is not apparent, for it is at least 1,500 feet from the top of the batholith and a few thousand feet from the lateral boundaries. The occurrence has not been studied in detail and cannot be discussed intelligently. At other points on the hillside are numerous occurrences of dark-coloured rock, but they resemble the highly metamorphosed phases of the earlier volcanics more than basic phases of the batholith.

CONTACT PHASES

At a number of places where the contact of the batholith with the underlying volcanics or sediments is clearly exposed, the appearance of the rock at the contact is exactly the same as anywhere else in the batholith. Crystals, which are touching the greenstone, are just as large as those at some distance from the contact; the percentage of femic constituents is unchanged; and the mineral assemblage is identical. Occasionally, however, finer grained contact phases are encountered, and one is very much surprised to find that they are more siliceous and even more sodic than the average. Thin sections of this type have been examined from two localities; one is from the east contact on the Indian River side of the ridge about 7,500 feet from the northeast corner of the batholith and the other is from the west contact due south of Park Lane dam. The rock from the first-mentioned locality is a porphyritic quartz diorite composed of rounded phenocrysts of sodic oligoclase, averaging about 0·5 mm. in diameter set in a matrix of fine-grained quartz, biotite, and pleochroic chlorite. Apatite, magnetite, and titanite are accessory constituents, the apatite being particularly abundant. The plagioclase is full of tiny blebs of crystalline material that resembles quartz, but could not be identified with any degree of certainty. The biotite resembles the type found in adinoles from the northwestern area of the batholith, and the pleochroic chlorite appears to be just as much a primary mineral as the biotite or quartz. All these unusual features suggest that the rock may not be a true type, but a hybrid rock.

The conditions at the second locality are quite different, however. The rocks can be followed step by step up Britannia creek to Park Lane dam, and then up the creek that flows north into the west end of the reservoir. The lower contact in Britannia creek is well down on the side of the batholith, and the rocks are coarse grained of the average type containing oligoclase, orthoclase, quartz, hornblende, and biotite as the important constituents. On nearing the top of the batholith in the branch creek, the texture gradually becomes finer grained until, on the flat near the small lake, it is decidedly finer than the average. The small flat is not only a topographical bench, but is also a flat part of the batholith. The thickness of the transition zone is approximately 100 feet. Judging from a macroscopic examination, there is no essential difference in composition between the finer and coarser grained types. This superficial examination is, however, entirely misleading, for the finer grained rock is a sodic quartz diorite, composed of albite (about 93 per cent Ab), quartz, and a femic mineral that is now altered to chlorite, leucoxene, and fine opaque particles, probably magnetite. If orthoclase is present, it is in very small amounts. Quartz is more plentiful than in the average rock and some of it occurs in a vermicular intergrowth with the albite. The average grain size is approximately 0·3 mm.

It will be recognized immediately that this rock is almost identical with the fine-grained contact phase of the southwestern area of batholithic rocks described on page 48 and this, in turn, has been shown to be very similar to one of the dykes that is included with the southwestern area of batholithic rocks, and to certain of the Britannia sills.

DYKES

Ordinary small dykes radiating from the main mass of the batholith are extremely uncommon, much more uncommon than one would expect if the magma were as fluid as is generally believed. One or two very small dykes are found in Britannia creek within a short distance of the contact. They are very narrow; and from the appearance in the field, or in hand specimens, are essentially the same as the main part of the batholith.

One dyke, only, is sufficiently large to be indicated on the map. It is the dyke in the vertical fault that crosses the ridge immediately south of mount Sheer and isolates a large block of argillite from the main mass of volcanic rocks to the north. Presumably the dyke was intruded along a fault at the time of batholithic intrusion. At the west end, just above the trail, the dyke is 100 feet wide and is a medium-grained, granular rock composed of oligoclase, with small amounts of quartz, orthoclase, and femic constituents. The quartz content is lower than that of the normal batholithic rock and orthoclase is not very conspicuous. The rock is really a diorite, but this term is misleading, unless it is pointed out that the femic constituents are even less plentiful than in the normal rock of the batholith and that the plagioclase is the same (*i.e.* oligoclase) in both rocks. The only essential difference is that quartz and orthoclase are slighly less plentiful. Following the dyke upward and to the east, it narrows to a few feet and becomes a fine-grained quartz porphyry, containing phenocrysts of quartz and oligoclase in a very fine matrix of quartz and, apparently, orthoclase.

Another very interesting type of dyke is found in the Bank of Vancouver group. It outcrops, at an elevation of about 3,000 feet, in the small tributary of Seymour creek, on the east side of the valley, midway between the outlet of Seymour lake and the junction of the west branch of Seymour creek with the main creek. It stands vertically, strikes about north 30 degrees east, and is approximately 200 feet wide. The actual contact with the granitic rocks was not seen, for the contact was covered with drift on the upper side, and, on the lower side, it is separated from the batholithic rocks by a very narrow inclusion of sedimentary rocks. It is thought to be a dyke, since it contains inclusions resembling the surrounding granodiorite. Attempts to follow the dyke to the north were not successful as the number of exposures are very limited; towards the south, it is soon lost in cliffs and talus.

The dyke is a medium to fine-grained, granular rock, slightly darker in appearance than the surrounding batholithic rocks, but apparently of the same general composition. The most striking feature in the outcrop is the presence of numerous small kernels of chalcopyrite 3 or 4 mm. in diameter. On closer inspection, small grains of pyrite and magnetite, knots of quartz, and biotite are also found; as well as miarolitic cavities lined with calcite, quartz, mica, and the ore minerals.

Two thin sections were examined; one showed miarolitic cavities, the other did not show them. The first of these is found to be a quartz diorite, composed of andesine, quartz, and biotite, as essential constituents, with apatite and a great deal of magnetite as accessory constituents. Orthoclase may be present to a small extent, but the potash of the rock is contained chiefly in the biotite. Many of the plagioclases are replaced by albite and others contain several zones of sodic plagioclase alternating with the normal andesine. The biotite is partly altered to a green pleochroic chlorite and to titanite, particularly in the vicinity of the miarolitic cavities. Sections of two cavities were shown in this particular slide. They are filled with biotite, quartz, pyrite, chalcopyrite, magnetite, and apatite. The order of deposition of the first four minerals is in the order named. The relative age of the other two minerals is not clear. The second thin section is a quartz diorite porphyry containing phenocrysts of oligoclase-andesine and, occasionally, quartz surrounded by a groundmass of quartz plagioclase, biotite, pleochroic chlorite, and a small amount of orthoclase. Accessory constituents are magnetite and apatite.

This is very much like the fine-grained contact phase described from the eastern side of the central area of the batholithic rocks and would lead one to suppose that the dyke might be a contact phase engulfed in the magma. The only evidence against this interpretation is that certain inclusions resemble the surrounding batholithic rocks.

The difference between the two thin sections of the dyke is not very great; but it is probably significant that that part of the rock body in which the miarolitic cavities are most numerous is the most highly altered and is coarser grained than the other. These cavities are believed to be due to the accumulation of gases, or possibly fluids, during the later stages of crystallization, and it is to be expected that they would assist in the growth of crystals and would react with the crystals as the temperature decreased. The calcic plagioclases would be replaced by albite, the biotite by chlorite and titanite, and residual materials would be deposited in the cavities.[1] The most conspicuous fillings and linings of the cavities are the ore minerals and their origin is presumably the same as that of the rock minerals in the same cavities. This implies that they were part of the dyke as it was intruded. Since there is some question as to whether or not this body is a dyke it is not possible to discuss its significance as a phase of the batholith or its possible relation to the ore deposits of the Bank of Vancouver group.

Northwest Area of Batholithic Rocks

Very little need be said about the distribution of the rocks included under the above heading, for they are confined to one small area in the northwest corner of the map-area. No attempt has been made to trace them to the north and east to see whether or not they grade into the normal batholithic rock, as typified by the rocks of the central area. Within this map-area they are a distinctive type of coarse-grained plutonic rocks and are, therefore, described separately.

GENERAL TYPE

The typical rock, which is illustrated in Plate II A, is a light-coloured, coarse-grained, granitic rock containing quartz, plagioclase, biotite, and hornblende as minerals easily recognized in the hand specimen. The quartz, which represents, approximately, 25 per cent of the rock, occurs in spherical or other regular-shaped grains up to 1·5 cm. in length, and is surrounded by well-developed crystals of plagioclase having about the same dimensions. The plagioclase is very easily recognized as such by the fact that the albite twinning lamellæ are very distinctly seen without the aid of a hand lens. The femic minerals occur in smaller grains and together make up less than 5 per cent of the rock. Finer material found between the quartz and large plagioclase grains, cannot be recognized in the hand specimen, but, upon examination in immersion liquids, it is found to contain no small amount of orthoclase. The total amount of orthoclase, however, would not represent more than 10 per cent of the rock. The plagioclase, as determined by the immersion method, is oligoclase. It is apparent, from the above description, that this rock is a very siliceous quartz diorite grading towards a granodiorite and is not very different from the average rock of the central area. Quartz has increased a little and the femic constituents are not quite as plentiful, so that the change is towards a more siliceous type. It is doubtful if it would have been singled out as a special type if the texture had not been decidedly coarse grained.

CONTACT PHASES

At a few places along the contact the texture is more nearly the ordinary granitic texture found in other parts of the batholith; and occasionally one finds a concentration of orthoclase and quartz in small, irregular pegmatite dykelets near the contact. These are always small

[1] For a complete discussion of this type of alteration *See* Colony, R. J.: "The Final Consolidation Phenomena in the Crystallisation of Igneous Rocks"; Jour. Geol., vol. 31, p. 169 (1923).

and occur either as knots a few inches in diameter, which grade into the normal rock, or as dykelets an inch or so wide standing at right angles to the contact. Locally this pegmatitic material takes the form of a fine-grained contact phase almost identical, in appearance and composition, with the fine-grained rims surrounding the adinoles inclusions (*See* page 30). The fine-grained contact phases are composed of quartz and orthoclase, intergrown in a crude graphic pattern, as well as small grains of sodic plagioclase, and thin lenses of albite in the orthoclase. They are very narrow local phases quite different from the gradual transition of the other fine-grained contact phases described, which are scores of feet wide. These quartz orthoclase segregations resemble ordinary pegmatitic accumulations more than anything else. While dealing with the subject of pegmatites, it might be well to mention that pegmatites and pegmatitic material, in general, are surprisingly scarce within Britannia map-area. As a matter of fact, to the writer's knowledge, they are confined to this one small locality.

Although these pegmatitic phases are encountered along the contact, the general experience is to find the rock, at the contact, essentially the same in texture and composition as that at a distance from the contact.

Porphyritic " Quartz Diorites "

A small area of porphyritic " quartz diorite " outcrops on the extreme eastern slope of Furry Creek ridge at a short distance southwest of the confluence of Seymour creek and the west fork. It is of particular interest, in that it crosses the east end of the Britannia shear zone, but is itself quite massive and unsheared, showing not the slightest signs of differential movement. In this respect it is quite different from the southern area of batholithic rocks, particularly the two dykes of the southern area which occur immediately west and south of this porphyritic quartz diorite. Both the dykes and the southern area of the batholith are sheared and must, therefore, have been intruded before strong differential stresses ceased. The porphyritic " quartz diorite," however, although lying directly on the line of the main shear zone, is not affected by shearing, and was, presumably, intruded after the shearing. It is believed that this phase of the batholith is at least younger than the rocks of the southern area.

The porphyritic " quartz diorite " is a porphyry containing phenocrysts of oligoclase a little less than 1 cm. long, and smaller phenocrysts of quartz in a groundmass of quartz, oligoclase, and a very small amount of altered femic minerals. The amount of orthoclase is rather difficult to estimate, for it occurs as a fine-grained and irregular intergrowth with quartz. In addition, both the orthoclase and the oligoclase have lower indices than the quartz, and both are extensively kaolinized, making it difficult to distinguish one from the other. The orthoclase does not, however, represent more than 10 per cent of the rock, so that it is really a " quartz diorite " grading to a granodiorite. In many ways, it is more like the granodiorites than the quartz diorites, for the plagioclase is an average oligoclase containing about 80 per cent Ab; the femic constituents form only 2 or 3 per cent and quartz is plentiful, representing up to 15 per cent of the rock. It is not very different, in composition, from the last two groups described, but is distinctly different from the quartz diorites of the southern area of batholithic rocks. The term "quartz diorite" is, therefore, placed in inverted commas to indicate that it does not apply to a normal quartz diorite.

Summary of Rock Types

Before entering into a discussion of the relationship of the various types and masses of batholithic rocks, which have been described, it might be well to reduce the foregoing description to a brief tabulated statement.

The batholithic rocks have been described under five main headings under each of which is a description of the predominate rock type in the group, as well as descriptions and locations of variations from the normal type. These are as follows:

(1) *The Indian River Intrusives* represented by four irregular and dyke-like bodies occurring in Indian River valley and consisting of dark to light-coloured quartz diorites containing oligoclase, quartz, orthoclase, and variable amounts of femic constituents. In general, they are more highly metamorphosed, and are, therefore, believed to be earlier than the main areas of the batholith. Positive evidence of the relative ages is lacking.

(2) *The Southwestern Area of Batholithic Rocks* are those which occur along the southwest side of the roof pendant and include two broad dykes exposed near the east end of Furry Creek ridge. The normal rock type is a foliated quartz diorite composed of andesine, quartz, hornblende, biotite, and orthoclase. The foliation is about parallel to the main contact and is due, in part, to the parallel orientation of the tabular minerals before final consolidation. A section along Howe sound, north from the normal rock to the main contact, shows the following variations.

(*a*) At a point 3,000 feet from the contact, is the normal quartz diorite, foliated but not sheared. The larger plagioclase crystals exhibit striking examples of multiple zoning and the others show progressive zoning from calcic, on the inside, to more sodic on the outside of each grain.

(*b*) At a point 700 feet from the contact is a quartz diorite similar to the last described, but containing a smaller percentage of femic minerals. The rock is sheared.

(*c*) At a point 300 feet from the contact, the rock is a sheared granodiorite, composed of oligoclase, quartz, and orthoclase, with only a very small amount of femic minerals.

(*d*) At a point within a few feet of the contact, the rock is a highly sheared and completely recrystallized quartz-orthoclase rock containing only very small amounts of kaolinized plagioclase and a few shreds of femic minerals.

Although this series shows a gradual change as the contact is approached, it cannot be regarded as a typical contact variation; for, at a point 8,000 feet east, and within 100 feet of the contact, the rock is a well-sheared quartz diorite composed of oligoclase and quartz with a little orthoclase. Femic constituents are notably lacking. At another point 1,000 feet farther east the contact phase is a fine-grained, sodic quartz diorite, the principal constituents of which are albite (Ab 95 per cent) and quartz, in a proportion of about 3 to 1. This phase is practically identical with the more northerly of the two dykes belonging to this section of the batholith. The other dyke, south of this, is a quartz diorite. Both are sheared.

(3) *The Central Area of Batholithic Rocks* is represented predominantly by an even-grained granitic rock, intermediate in composition between a quartz diorite and a granodiorite. In places, large blocks of diorite are found within the granodiorite and probably represent an early crystallized phase of the batholith. In other places are areas of dioritic material grading into the normal rock. At two localities, only, have fine-grained contact phases been found, the rocks generally retaining their texture and composition up to the contact. At a point near the west contact, the contact phase is a sodic quartz diorite almost identical with the one described above. A locality on the east side of the batholith shows a quartz diorite containing oligoclase and quartz with a small amount of brown biotite and pleochroic chlorite. This appears to be a metamorphosed, or at least a contaminated, type. A large dyke from the batholith is similar to the average rock in composition, but contains a smaller amount of both quartz and femic minerals.

(4) *The Northwest Area of Batholithic Rocks* differs from the average type, described above, in that it is much coarser grained and contains a little more quartz. Where contact phases are present, they are pegmatitic materials, that is quartz and orthoclase, occurring as small dykelets, knots, or as a fine-grained border.

(5) *The Porphyritic "Quartz Diorite"* occurring in a small area at the east end of Furry Creek ridge has about the same composition as the rock described above, that is between a granodiorite and a quartz diorite. It is mentioned separately because it is disinctly later than the shearing and is, therefore, apparently later than the batholithic rocks of the southern area at least.

Relations of the Batholithic Rocks including the Britannia Sills

Although the average rock, in four out of the five main rock groups, is intermediate between a quartz diorite and a granodiorite, there are sensible and characteristic differences between some of the groups. The coarse-grained rocks of the northwest area are more siliceous than the others and the Indian River intrusives are generally more basic. The differences are not so much in the relative amounts of orthoclase and plagioclase, which is the general basis of rock classification, but in the greater amount of quartz in one instance and of femic minerals in the other. The average type, in the central area, is very similar to the porphyritic "quartz diorite," although the coloured minerals are slightly less plentiful in the latter. Of the larger masses of the batholith, the foliated quartz diorite is the most basic. It would, therefore, be possible to arrange the rocks in order of their decreasing basicity, commencing with the foliated quartz diorites of the southwestern area, or possibly some of the Indian River intrusives, and proceeding to the central area, thence to the porphyritic "quartz diorite," and, finally, to the coarse-grained group of the northwestern area. Having established such a gradation, it might be urged that the order of intrusion was the same as the order of decreasing basicity. Other evidence, in support of this, is very fragmentary and is really no more than suggestive. It has already been stated that the Indian River intrusives are much more crushed, sheared, mineralized, and generally metamorphosed than the other areas; therefore, they are probably older than the main part of the batholith. Another point indicating a sequence in the order of intrusion is that the porphyritic "quartz diorite" is not at all sheared, although it occurs in the same zone as sheared members of the southwestern area of the batholith, a fact that suggests very strongly that the porphyry is later than the quartz diorite of the southwestern area. The above-mentioned facts indicate that the order of intrusion is as follows: Indian River intrusives, batholithic rocks of the southwestern area, and porphyritic "quartz diorite," leaving the relative ages of the central and northwest masses unknown, except that they are possibly later than the very earliest of the series. This order agrees with the order deduced from the decreasing basicity of the series, and supports the contention that the batholithic rocks have probably been intruded in some such order as outlined.

A very striking exception to this sequence is that the Britannia sills, which are regarded as the earliest phase of the batholith, are not the most basic in the series, but are, in general, the most acidic. A study of the fine-grained and acidic contact phases of the batholith suggests a method of explaining the situation and leads to other important inferences.

The fine-grained contact phases are apparently the more rapidly crystallized parts of the magma and their composition is generally regarded as an approximation to the composition of the magma, as intruded. This, of course, is not strictly true if the rock is crystalline and not a glass and, what is more important, if the magma is not homogeneous. If the magma is not homogeneous, it is obvious that a fine-grained contact phase cannot represent the magma, except at the immediate contact, and can tell us nothing of the bulk composition of the magma. From what is now known of the order of crystallization of rock minerals, and particularly of the plagioclase series, the first plagioclase to crystallize is more calcic than the magma as a whole, and more calcic than the later plagioclase. Since the contact phases, which are being discussed, are composed of albite (Ab 95-85 per cent) and quartz, and the main granitic bodies are composed, essentially, of oligoclase or andesine (Ab 80-65 per cent) and quartz, we must conclude that the magma was either not homogeneous, or that the contact phases are not what they appear to be. They may, for example, have been altered by late magmatic solution. This alternative does not seem to be the case, for there is not the slightest evidence of decalcification of the plagioclase; there are no remnants of more calcic types; and the albite does not possess the mottled appearance so characteristic of albitized feldspars. It is true that the vermicular intergrowth of quartz and plagioclase appears to be a replacement of the plagioclase by quartz, which probably indicates a late magmatic alteration. The plagioclase, however, has been replaced, and, apparently, not decalcified. It is quite possible, of course, that decalcification might have taken place without leaving the slightest indication of the process, but it is strange that the *coarse-grained* contact phases have not been altered as well as the *fine-grained* contact phases. It is quite impossible to maintain that the alteration has not only produced a decalcification of the plagioclase but also a complete recrystallization of the rock to fine-grained type. The writer thinks it is more reasonable to believe that the original magma was not homogeneous and that the fine-grained contact phases crystallized from a more " acidic " part of the magma. In other words, the fluid part of the magma was differentiated.

The conception of differentiation of the fluid part of a magma is nearly as old as the recognition of differentiation as an important process in petrogenesis; but, within recent years, Bowen[1] has so skilfully and convincingly presented the case of differentiation by fractional crystallization, that other possible causes are not always considered. There can be no question but that fractional crystallization is an important factor in differentiation and as a matter of fact a certain amount of liquid differentiation seems to be a natural corollary to the settling of crystals. Consider, for example, two strata in a crystallizing magma and assume that calcic plagioclase is crystallizing. The plagioclase, upon sinking into the lower layer, will enrich that layer in calcium; and, to the extent that equilibrium is maintained between the crystals and the immediately adjacent liquid, the liquid of that layer will be richer in calcium than the one above. It might be added that, to the extent that equilibrium is maintained between the crystals and the adjacent liquid, the liquid of the lower layer will be used up more quickly than that of the upper layer, because the resolution of the excess plagioclase, which has settled into it from above, will cause the precipitation of additional plagioclase lower in the series. It seems, therefore, that the settling of crystals would not only produce a gradational change in the solid, but also in the liquid, part of the crystallizing mass; and the more alkaline magma would be at the top.

Although liquid differentiation is an old hypothesis it is by no means obsolete. In a recent detailed paper on Katmai district, Fenner suggests that the upward movement of volatile material would, at least, assist in producing the straight-line type of differentiation which he describes in that area.[2] In summing up a discussion of differentiation from a number of localities he says, further, " Gaseous transfer, crystallization differentiation, assimilation of foreign material, and mingling of magma have apparently each played an important part in one or another described instance, but it is impossible to say what is the quantitative importance of any one of these in volcanism as a whole or whether there may not be still other important processes."[3] Daly maintains that water was one of the important factors in the differentiation of the Pigeon Point sill of Minnesota.[4] Grout's studies of the Duluth Lapolith led him to a similar conclusion.[5] Although in the opinion of these authors, the volatiles bring

[1] Bowen, N. L.: Am. Jour. Sci., vol. 39, p. 175 (1915).
Jour. Geol., vol. 25, p. 209 (1917).
Jour. Geol., vol. 27, p. 393 (1919).
[2] Fenner, C. H.: "The Katmai Magmatic Province"; Jour. Geol., vol. 34, p. 770 (1926).
[3] Loc. cit., p. 771.
[4] Daly, R. A.: Am. Jour. Sci., vol. 43, p. 423 (1917).
[5] Grout, F. F. :"A Type of Igneous Differentiation" Jour. Geol., vol. 26, p. 657 1918).

about, or assist in, differentiation in different manners, each recognizes the necessity of appealing to something, other than straight crystal settling, to explain the phenomena that are observed. Some process of liquid differentiation is demanded. It is not radical, therefore, to believe that an upper layer of progressively more alkaline magma may be developed in a magma chamber.

The reason for inquring into the possible origin of the small masses of unusual contact rocks is not so much to determine their particular origin, as to arrive at some conception of a possible method of development of the magma which was injected as the Britannia sills. They are decidedly earlier than the main batholith, and yet they are generally more acidic. The sequence of eruption of plutonic rock has been shown to be the more basic followed by the more acid, in accordance with the well-established sequence produced by fractional crystallization, and any other sequence must be explained or looked upon with suspicion. One way out of the difficulty in this particular instance would be to assume that the magma of the Britannia sills was developed in the earth's crust, early and quite independent of the main batholithic magma, and that the similarity of types was accidental and of no significance. It might be well to recall the fact that sills and dykes of this type are not confined to the Britannia area, but apparently are co-extensive with the Coast Range batholith. We are not considering, therefore, a local intrusion, but a type of intrusion that is localized to the Coast Range batholith. A reasonable explanation of these facts seems to be that the liquid of the batholith differentiated, as outlined above, and that the first small part of the batholith to be injected was the upper "acidic" differentiate, which is now preserved as the Britannia sills.

This interpretation of the Britannia sills cannot be reconciled with Bowen's suggestion that granitic batholiths have probably developed by differentiation *in place* from a basaltic magma.[1]

The conception that the Britannia sills, and similar sills elsewhere, are a part of the batholith, can lead to no other conclusion than that differentiation was well advanced before the major batholithic invasion began. This conclusion is supported by another observation. The primary foliation, or orientation of crystals, in the rocks of the southwestern area, indicates that crystallization was well advanced at the time of injection. It also indicates, either that the remaining magma was sufficiently viscous to hold the crystals (and the inclusions) in their given orientation, or that the upward flow was maintained until complete solidification was almost attained. In either case, there would be no opportunity for the settling of crystals and we must assume that the rock, which we see, represents the magma as it was intruded.

In the description of the foliated quartz diorite, the occurrence of large crystals of multiple zoned plagioclase was mentioned, in which the succession of sodic and calcic zones was repeated a score of times and more. These crystals are much larger than the average and apparently have been in the magma a (relatively) great length of time in order to account for both their size and the great number of successive layers. The layering indicates that the conditions in the magma (either its composition or physical

[1]Bowen, N. L.: Jour. Geol. Sup., vol. 27, p. 70 (1915).

conditions) have changed back and forth a great number of times; but the outermost calcic layer is just as calcic as the core, so the net change in the composition of the magma has not been great. If these crystals have settled, or risen in the magma, they have settled or risen to a place that had essentially the same composition as the magma from which it started to crystallize. Other types of differentiation have produced no apparent change in the composition in the vicinity of the crystals at least. All the evidence seems to point again to the conclusion that the magma has remained relatively uniform in composition for a considerable length of time. Although none of these arguments is at all conclusive they do support the conclusion that the foliated quartz diorites of the southwestern area crystallized from a magma of essentially the same composition. In other words, the batholith was intruded as a quartz diorite magma, and did not differentiate in place from a much more basic magma.

The relation of the structure of the roof rocks to various groups of the batholith is of assistance in interpreting the history of their intrusion, and in explaining some of the features that have been described above. The question of the origin of the parent magma cannot be discussed at this time. It may be considered as a basic magma which has differentiated to form the various granitic products that have been described. At one period of its development, according to the evidence presented, the magma had differentiated to such an extent that a layer of the composition of the Britannia sills had accumulated in the upper part of the reservoir, and was injected into the Britannia formation while the latter was in an undisturbed horizontal position. The injection was probably at a time immediately preceding the main intrusion of the batholith. This last was attended by, or possibly brought about by, the yielding of the overlying strata to tangential stresses, which folded the rocks into northwesterly striking structures parallel to the Coast range and thrust them to the southeast along steeply inclined thrust planes. The folding, and particularly the thrust faulting, would demand an active flowing of the magma towards the surface; for not only is the magma a fluid, but it is probably a fluid of less specific gravity than its covering of basic volcanic rocks, and would, therefore, be urged towards the surface by hydrostatic pressure alone. Such other forces as may be acting on the magma, in this zone of compression, would drive the magma towards the surface. Active bodily flow is suggested by the primary foliation in the southwestern area of batholith rocks. It will be recalled that these rocks are foliated quartz diorites in which the foliation is due, in part, to a primary orientation of the tabular minerals in planes approximately parallel to the contact of the batholith, and that the main contact is with very steeply dipping rocks, which apparently have been thrust into their present position. The structural conditions for the flowing of the magma are right, and the primary foliation and orientation of inclusions indicates that flowing of the partly crystallized magma has taken place. The magmas of the other areas must flow upward as they work their way to the surface by stoping, or some other quiet method of advance, but their rate of flow must be relatively slow. They have intruded themselves into relatively undisturbed rocks and the outline of the intrusion frequently bears no relation to the attitude of the bedding. The western lobe of the central area may be examined in a number of places, and it appears to have worked its way up by a quiet displacement of its roof. The dips are towards the batholith rather than away from it, as would be the case if it were forced into place.

This peaceful method of advance almost certainly indicates a slower rate of advance, or a longer time for the intrusion period, and permits differentiation processes to continue relatively undisturbed. Would this not very well explain the reason why the central and northwestern parts of the batholith are slightly more alkaline than the foliated quartz diorites of the southwestern mass? All would be a part of the same magma, but the foliated quartz diorites would, on this conception, have been forced towards the surface along a structural break, and other parts of the magma would quietly work their way towards the surface, taking a longer time to go a similar distance and giving a greater opportunity for differentiation.

It is fully realized that the Britannia area embraces a very small part of a tremendously large and complex unit, the Coast range batholith, and that conclusions based on observations within this area may be quite out of keeping with more comprehensive data. Although the Britannia area is small, it is very suitable for a study of batholithic events. It includes a part of the covering of the batholith—the rocks that were actually invaded by the batholith—and that would reflect some of the vicissitudes experienced during the invasion.

Age and Correlation

Since evidence is completely lacking in the Britannia map-area concerning the age of the Coast Range batholith, the writer can do no better than quote Schofield and Hanson's conclusions on this subject. They say:

"To sum up the evidence, it is clear that the Coast Range batholith intrudes the agglomerates of the Yakoun formation of Middle Jurassic age on Graham island, and pebbles of granite derived from the Coast Range batholith are present in conglomerates of Lower Cretaceous age (Knoxville) on Skagit river, which overlie the granite unconformably. The granite batholith must have been intruded and unroofed before the deposition of the Knoxville which is lowermost Cretaceous. Hence the Coast Range batholith must have been intruded during Upper Jurassic time."[1]

DYKES

Three different types of dykes are recognized within the area. An early group of basic dykes cut the batholithic rocks and similar dykes are found in the Britannia shear zone. These latter are earlier than the shearing, and although the individual dykes have not been traced from the shear zone into the batholith, their general appearances are so similar that they are probably the same age. Early siliceous dykes occur under the same conditions; they are found in both the shear zone and in the batholithic rocks, and those in the shear zone are pre-shearing. The third group is a group of basaltic dykes that are distinctly later than the shearing.

[1] Schofield, S. J., and Hanson, G.: "Geology and Ore Deposits of Salmon River District, British Columbia"; Geol. Surv., Canada, Mem. 132, p. 25.

Early Basic Dykes

The earlier groups of basic dykes are medium grained and highly altered "greenstones." They have not been studied in detail, only one thin section having been examined of those occurring in the granitic rocks and one from those in the shear zone. The specimen selected from the shear zone was taken from one of the largest, most massive, and apparently least altered dykes in the mine, and yet the only primary minerals present are a small amount of quartz and the accessory magnetite. The rock was presumably an andesitic porphyry. The phenocrysts are now altered to albite[1] with variable amounts of epidote and chlorite, and they are surrounded by these same two minerals. As a rule decalcification of the plagioclase can be detected by a slightly mottled appearance of the new feldspar, but the albite in this specimen seems to be perfectly homogeneous, and, as far as the appearance is concerned, could be taken for the primary plagioclase. It seems more probable, however, that it is a product of decalcification of some more calcic variety. Chlorite, epidote, and albite are very commonly associated as the alteration products of andesitic and similar rocks.

The specimen selected to represent the early basic dykes cutting the granitic rocks is altered in a similar manner. Primary quartz is conspicuous, but the plagioclase is so highly altered to calcite and chlorite that their original composition cannot be determined. The plagioclase which is not altered to calcite and chlorite has indices lower than Canada balsam and is probably more sodic than the original plagioclase. The groundmass is composed chiefly of chlorite with a very liberal sprinkling of leucoxene.

Both of these groups of dykes appear to have been quartz-bearing andesites, but whether or not they are of the same age is not known definitely. The presumption is that they are the same age. Those in the shear zone are, as has been mentioned, highly sheared and contorted and have, therefore, been intruded before the development of the shear zone.

Early Siliceous Dykes

The early siliceous dykes occurring in the shear zone have been recognized only in the west end of the shear zone where they are confined to a narrow strip along the south, or hanging-wall, side of the Britannia ore zone. They are exposed most frequently in a sheared porphyry, but are also found cutting the sedimentary rocks at the west end of the ore zone. The dykes are very similar in appearance and composition to the Britannia sills. They are light grey, medium to fine-grained porphyries, which at times may be distinguished from the Britannia sills by a light sprinkling of small, dark phenocrysts, giving a "salt and pepper" appearance to the dykes. Phenocrysts of femic minerals are quite uncommon in the Britannia sills, but they do occur, and it is not always possible to tell the dykes from the sills by an examination of individual specimens. In thin section they are found to be more "granular" than the porphyry. The

[1] All the indices are below those of quartz and the extinction angles are up to 12° so that the composition is about $Ab_{90}\ An_{10}$.

principal constituents are albite-oligoclase and quartz, and a small amount of some femic mineral is represented by aggregates of chlorite. Apatite occurs as an accessory constituent. The phenocrysts are chiefly plagioclase, although the femic minerals—which were present and are now represented by chlorite—occurred almost entirely as phenocrysts. The groundmass is a well-crystallized, granular aggregate of quartz and plagioclase in the ratio of approximately 1:5. The dykes are albite dacites.

Although these dykes were intruded before the final period of shearing the larger members are readily recognized in mine workings by the "blotchy" nature of their fracture as contrasted with the "schisty" fracture of the sheared porphyry. The smaller dykes are usually as highly sheared as the surrounding sheared porphyry, and may not be distinguished from it with any degree of certainty. The larger "blotchy" dykes are found to be massive and "blotchy" only in their centre and are quite schistose along their contacts. It is evident that the dykes were intruded before the final shearing movements took place and it seems to be equally evident that they were intruded after shearing had been fairly well advanced, for they have essentially the same composition and texture as the sill which they intrude, and yet they are not as well sheared as it is. This difference in the amount of shearing in the two rocks may be explained by the fact that the sills had been through a period of mountain building, and intense folding, before the dykes were intruded, so that even before the shear zone was developed the sill would be more sheared than the dyke.

In a few places outside the shear zone very narrow, fine-grained quartz feldspar porphyries are found cutting the granitic and earlier rocks. The phenocrysts are oligoclase and quartz, and the groundmass is an exceedingly fine-grained aggregate, presumably of quartz and plagioclase with possibly some orthoclase. The relation of these dykes to the albite dacites in the shear zone is not known.

It is believed that all the early dykes, both basic and siliceous, are related to the main period of batholith intrusion.

Late Basic Dykes

Fine-grained, dense, and almost black basaltic dykes occur in a number of places throughout the area. They are porphyritic rocks containing a very few clear grains of bytownite up to 1 mm. in length, set in a groundmass of plagioclase, diopside, dark brown hornblende, and brown glass. Magnetite is very plentiful and one corroded grain of quartz was observed in the thin section examined.

The dykes cut the batholith, the early volcanic and sedimentary rocks, and have been encountered recently in the shear zone, crossing the schistosity at a sharp angle.[1] At no point are they found in, or cutting the ore-bodies, so the relative age of the ore and dykes is not known. For the time being they may be regarded as Tertiary in age.

[1] The writer is indebted to Mr. Ebbitt, geologist for the Britannia Mining and Smelting Company, for this information and for the specimen of the dyke that is described. Prior to this, basalt dykes had not been known in the mine workings, but were known only from diamond drilling.

QUATERNARY GEOLOGY

During the Ice age Britannia map-area was completely covered by a mantle of ice up to an elevation of 5,500 feet at least, for beautiful striæ, deep glacial grooves, and large erratic boulders are found along the summit of Goat mountain at this elevation. The Sawtooth peaks, due east of Goat mountain, are a group of needle-like peaks rising to elevations of 6,700 feet, and it is possible that they projected above the ice cap and are now sharp peaks because they were not smoothed off by the ice. Their serrated outline, however, has probably developed by cirque cutting and may not be a residual feature of preglacial development. As a matter of fact a small glacier is active even yet on the northeast side of the peaks. The continental ice-sheet moved southerly, parallel to Howe sound and directly across Goat mountain and Britannia ridge. The erratic blocks left on Goat mountain are granitic, and since Goat mountain is underlain by volcanic rocks it is evident they must have been transported by ice. Similar blocks are relatively numerous along the ridges and the upper part of the gentler valley slopes.

The Quaternary deposits were laid down after the retreat of the main ice-sheet and are preserved in the valleys, at the mouths of the streams, and in a few places along Howe sound. Coarse, glacial material fills Furry Creek valley to a depth of about 150 feet at the point where the main creek swings to the south away from the Britannia shear zone. The depth of gravel and boulders is well established at this point by underground workings. Farther down Furry Creek valley, just east of the first large tributary coming in from the right, and at an elevation of 1,500 feet, the upper level of the old stream bed is beautifully preserved on the south side of the stream. One can walk from the relatively bare "granite" out onto the edge of the old boulder-strewn stream bed. At various places below this upper level are small exposures of well-bedded sands and gravels. Although the sands and gravels are not exposed on the north side of the valley their presence is clearly indicated by the occurrence of very numerous, sharp little gulleys which are never found where solid rock is but a few feet below the surface.

Britannia Creek valley is likewise filled with coarse glacial material, poorly assorted fluvioglacial deposits, and well assorted sands and gravels. The first two types are well exposed about half-way between Tunnel Camp and Howe sound where they must be 150 feet thick. Mixed with the material and overlain by it are great quantities of talus which has rolled down from the steep side hills. The well-bedded sands and gravels are exposed at an elevation of 2,100 feet, which is just the upper end of Tunnel Camp directly opposite the main adit of the mine. At the mouth of Britannia creek is a platform, or terrace, of steeply dipping gravels at an elevation of 150 to 200 feet above sea-level.

Along Howe sound are other gravel deposits. Immediately south of Britannia creek is a basin of gravels which have been built up to an elevation of 500 feet. South of Furry creek, at the extreme southwest corner of the map-area, are well-bedded gravels reaching an elevation of several hundred feet above sea-level. Time did not permit an examination of the upper gravels. One of the lower gravel benches, standing at about 50 feet above sea-level, is overlain by several feet of unassorted glacial material (Plate IV). Since it is improbable that the lower, well-bedded gravels would remain undisturbed throughout the entire glacial period it is suspected that the layer of glacial material was deposited during the second feeble ice advance.[1]

During recent time the whole area has been subjected to uplift and erosion. The amount of uplift in this area is at least 500 feet and Burwash[2] claims the amount of uplift has been as much as 800 feet.

The bedded gravels referred to as occurring in the southwest corner of the map-area supply Vancouver with no small amount of its sand and gravel. The deposits are owned and worked by Mr. Deek of Vancouver.

STRUCTURAL GEOLOGY

A detailed investigation of mining districts usually reveals the fact that the structural geology is far from being simple—the Britannia map-area is no exception to this rule. Although it is believed that the general structure of the roof pendant is fairly well understood, the solution of the structure is at best qualitative, and many important and very striking structural features are not understood at all. One reason for the lack of precision, even in the more obvious structures, is that the normal stratigraphic succession of the bedded rocks is not known, and, therefore, the amount of movement of isolated series, such as the Mount Lomond arkose, cannot be determined at all, and the direction of movement may be inferred only from indirect or inconclusive evidence. The main structural problem in the area, the relations of the Goat Mountain and Britannia formations, is a problem of this nature. At no point are the relations of Goat Mountain and Britannia formations revealed, and lacking this definite knowledge, Schofield[3] is inclined to believe that the latter is the younger formation and that the roof pendant forms the southwest limb of a syncline. The writer believes, however, the evidence warrants a different conclusion, and that the Britannia formation is the older of the two and has been thrust up against the Goat Mountain formation.

MAJOR FAULTING

Relations of the Goat Mountain and Britannia Formations

The structural relationships of the Goat Mountain and Britannia formations are shown and the interpretation indicated in sections AC and DE (*See* Map 199A). The reasons for believing that the latter formation is older than the former and has been thrust into its present position will become apparent on briefly investigating the sections. The upper part of Goat mountain is underlain by upper volcanics of the Goat Mountain formation, which in general dip southerly into Britannia Creek valley although locally reverse dips are encountered. The dip of the beds lower down the mountain side corresponds very closely to the slope of the mountain. Thin beds of shale and thin flows are exposed for 200 to 300

[1] For more detail on the two ice advances *See* E. M. Burwash, "The Geology of Vancouver and Vicinity"; University of Chicago Press, 1918; and Johnston, W. A., Geol. Surv., Canada, Mem. 135.
[2] Loc. cit., p. 100.
[3] Schofield, S. J.: "The Britannia Mines, British Columbia"; Econ. Geol., vol. 21, p. 274 (1926).

feet in elevation along the hillside, and just above the talus the hill slope becomes flatter than the bedding and the upper volcanics are once again exposed on the surface. On the south side of Britannia creek, well-bedded agglomerates, typical of the upper volcanics, are found to be flat lying, and a short distance above this, vertically, is a broad band of black slates. These are the foot-wall slates of the ore zone, which are well exposed in the crosscut tunnel.

They are highly sheared, and where bedding is preserved it invariably stands at steep angles. It is evident that there is a sharp break of some kind near the contact. An abrupt steepening of the dip to the south might possibly explain the situation at this particular section (AB) and the Britannia formation would then be younger than the Goat Mountain formation as suggested by Schofield.

This interpretation, however, does not agree at all well with the facts presented in section DE. There the volcanics are found to swing into a syncline dipping to the north, and not into a monocline dipping to the south, as would be expected on Schofield's assumption. The up-turning of the Upper Goat Mountain volcanics is more easily reconciled with the conception that the Britannia formation has been thrust into its present position and is actually a much lower formation than the Goat Mountain formation. If this is not the case it is difficult to explain why the Britannia sills, which were intruded in part at least before folding and faulting, are confined to the Britannia formation. If this formation is the upper formation we would expect to find dykes, and at least a few sills, in the Goat Mountain formation through which the magmas of the sills would have to pass on their way to the upper formation. On the other hand, if the Britannia is the lower formation, as believed, the lack of sills in higher formations is readily explained.

Another point that must be raised in favour of the thrust hypothesis is that the arkoses on mount Lomond have evidently been derived from a granitic land mass and most certainly not from basic volcanic rocks. The only way that they can be explained satisfactorily is to assume that they were deposited near an old land mass before volcanism commenced, for it is unlikely that after 10,000 or 12,000 feet of volcanic rocks have been built up, batholithic rocks would not be exposed to erosion, and the deposition of several hundred feet of arkose containing granular grains of quartz and oligoclase would not be possible.

A fact which at first seems to discredit the thrust hypothesis is that topographic expression of the main fault plane is completely lacking. It must be pointed out, however, that profound faulting is demanded on the alternate assumption, for the slates of the Britannia formation, which are in contact with the Goat Mountain formation on the line of section AC, are well over 1,000 feet above the base of the formation. Sufficient faulting must, therefore, be assumed to explain the elimination of the lower part of the series at the west end of the fault zone. The reason for lack of topographic expression of the break along the crest of Britannia ridge may be due to the fact that the fault zone is occupied by one of the late albite dacite intrusives, which are identical with the Britannia sills.

Although difficulties are recognized, the most satisfactory explanation of the main structure of the roof pendant is that the Britannia formation is older than the Goat Mountain formation and has been thrust at least several thousand feet into its present position along a steeply inclined fault zone which strikes northwest-southeast and dips southwest.

Faulting of Britannia Sills

Aside from this major faulting an appreciable amount of faulting must be assumed to explain the fact that the large body of Britannia sills on the south side of Britannia ridge (shown in section DE) does not continue to the west along the foot-wall of the shear zone. These rocks, where exposed, are characteristically dense, siliceous porphyries and as far as the writer knows, they are not exposed along their strike west of Empress creek. If they do cross the creek they must cross it as a very narrow band in no way comparable with the width of the band on the east side of the creek. The present interpretation of the situation is that a branch of the main fault comes down Empress creek. The movement along this branch fault is not known.

Possible Faulting Along Indian River

The structure and thickness of the rhyolitic volcanics in Indian river are not sufficiently well known to permit a definite statement, but it is suspected that faulting has been very pronounced in Indian River valley. According to the present data regarding the attitude of the rhyolitic volcanics, they should be exposed on the west side of Indian river as well as on the east. This apparently is not the case and a fault is, therefore, indicated. If a fault is present it is in the floor of the valley and approximately parallel to the valley.

Minor Faulting

Faulting is probably much more common than is indicated on the map, because faults would not be detected in the volcanic series unless an attempt was being made to follow some particular bed. Only two have been noted that deserve special mention. One of these is the vertical fault occupied by a fine-grained "batholithic dyke" immediately south of mount Sheer. A series of argillites 400 feet thick, with interbedded, fine green tuffs, and capped by a sill, is surrounded on three sides by batholithic rocks and on the fourth by the fault and dyke. On the north side of the dyke are tuffs and crystalline volcanic rocks with small amounts of argillites, but at no point is there a series of argillites that would correspond to this isolated section. It is possible that these rocks were faulted during the batholithic intrusion, but the direction and amount of movement are not known. Southwest from them, across the narrow stretch of plutonic rocks, is another small area of crumpled sedimentary and volcanic rock which may be a part of the same series. A fault is suspected on the west side of this second area of argillites, but definite evidence has not been obtained to prove its existence. If one is present it is earlier than the batholith.

The other fault of sufficient size and importance to be mentioned is a thrust fault which bisects Furry Creek ridge. The strike is about northeast and the dip is approximately 55 degrees southwest. The drag of the cleavage, and the direction of the grooves and striæ on the fault plane, which is beautifully exposed at one point, indicate that the block on the upper or southwest side of the fault moved up and to the north. The line of movement was approximately due north. The strata on either side of the fault have not been correlated accurately enough to determine the amount of movement. It is suspected, however, that the two northerly bands of slate shown on either side of the fault are the same band, in which case another band of slate should be found in the small area left unmapped on the east side of the fault.

The age of the fault is not known definitely except that it is later than the folding. It is possible that it is also later than the development of the Britannia shear zone—but the limits of the shear zone are too indefinite to be mapped sufficiently close to prove this.

Britannia Shear Zone

The most important structure in the area from an economic standpoint is the Britannia shear zone, for within the shear zone, or closely related to it, are found all the commercial ore deposits of Britannia area. The outline of the shear zone is indicated on the geological map. Although the greater part of it is covered by talus and glacial gravels, its general outline is reasonably well established by prospect tunnels, diamond drill holes, and by outcrops along the steeper parts of the valley walls. Occurring as it does in the southern half of the roof pendant it is confined entirely to the steeply dipping rocks of the Britannia formation and the included Britannia sills.

Since the shear zone, with all its major and minor structural features, has been so important in localizing the commercial ore deposits of the area the details of its structure will be described in the chapter on economic geology. The following brief description is all that is necessary in this place.

The shear zone is a tapering strip of sheared rock about 5 miles long extending in a northwesterly direction from the granitic rocks in the main fork of Seymour creek to the lower cirque basin in Jane creek, due south of Tunnel Camp. The strata on either side of the shear zone were slightly sheared during the regional folding, but the shear zone proper includes only those rocks that have been more highly sheared than the surrounding rocks. The east end of the shear zone is not very well defined, for it grades into the regional shearing and seems to die out along the strike in a series of smaller shear zones. The section in Furry Creek valley is reasonably well defined and is approximately 2,000 feet wide. The west end of the shear zone leaves Furry Creek valley where the stream turns sharply to the south, and, after crossing Britannia ridge, continues down into Jane Creek basin where it is practically lost beneath gravels and other debris. Within this distance, which is about 7,500 feet, the shear zone narrows to a point from a width that is a little less than 2,000 feet. To say that the shear zone narrows is not strictly correct, but the zone of sheared crystalline rocks narrows at the west end as the band of slates along the north side of the shear zone (as mapped) widens. The differential movement has been absorbed by and distributed through the slates so that west of Jane Creek basin the crystalline rocks along the strike of the shear zone are not at all schistose and even the slates are not unduly sheared. This westerly tapering wedge of the shear zone is confined almost entirely to one member of the Britannia sills, which will be referred to hereafter by the more specific and convenient term " the mine porphyry." Since the ore deposits are situated within this westerly part of the shear zone the details of its structure can be considered to better advantage in the section of the report dealing with the ore occurrences.

The main part of the shear zone, or that part occurring entirely within the Furry-Seymour Creeks valley, is not confined to one type of rock, but crosses the grain of the country at a small angle. Within the shear zone, therefore, are found fine, green chloritic schists derived from the basic tuffs and flows, and very fissile and soft "slates", as well as sheared phases of the mine porphyry and other members of the Britannia sills. The shear zone strikes about northwest-southeast and dips at an angle of about 70 degrees southwest, whereas the stratified rocks which it crosses have a more northerly strike, and dip at angles of 45 to 70 degrees southwest. The flatter dips are found towards the east end of the shear zone. A glance at the map will show that this section of the shear zone is more nearly parallel to the southern contact of the roof pendant than to the strike of the Britannia formation.

The shear zone was apparently developed after the main intrusion of the batholith, for sheared dykes in the shear zone are very similar to dykes found cutting the batholith (*See* page 61). If this is true, and it appears to be a reasonable conclusion, the shear zone was probably developed at the same time that the southwestern area of quartz diorites was sheared. The dating of the shear zone as post-batholith brings up a very important question regarding the age of the porphyritic "quartz diorite" which has been described previously as a late phase of the batholith, and later than the Britannia shear zone. Not only is the shear zone presumably post-batholithic, but it apparently is later than the basic dykes that generally close a period of batholithic intrusion. This suggests that the porphyritic "quartz diorite" is very much later than the main mass of batholith. The evidence for this involves so many assumptions and presumptions that the possibility cannot be given more than passing mention.

CHAPTER III

ECONOMIC GEOLOGY

HISTORY AND PRODUCTION

The history of mining in Britannia area is very similar to that of many of the mining camps in America—a chance discovery, followed by a rapid change of hands, and a period of prospecting and development before the district finally entered upon its longer and prosperous period of production. It is said that the Britannia deposits were discovered in 1888 by Dr. Forbes while deer hunting, but not being able to interest anyone in his discovery they were abandoned. Ten years later Oliver Furry, a trapper in the mountains north of Vancouver, rediscovered the mineralized zone and staked seven claims for himself and Mr. Clark, a storekeeper in Vancouver, who had aroused Furry's interest in prospecting and had furnished supplies for his trapping and prospecting excursions into the mountain.[1] The seven claims staked by Furry represented the original Britannia group, and were the nucleus around which was built the property now known as the Britannia mines. Since the discovery of the Britannia ore zone, other discoveries of less importance have been made in the Seymour Creek and Indian River sections of the area, but up to the present time the Britannia ore zone is the only one that has been productive.

The earliest description of the Britannia ore zone was written in 1900 by Wm. M. Brewer,[2] Resident Provincial Mining Engineer of the district including Britannia area. Mr. Brewer has followed the development of the Britannia deposit for twenty-five years in his capacity as Resident Mining Engineer, so one can do no better than quote his account of the history and development of the Britannia mines. The following paragraphs are, therefore, taken directly from his most recent article on this subject.[3]

"It rarely occurs that a mining engineer is called upon to examine a prospect in the very earliest stages of development and twenty-five years later to examine the same property after nearly 50 miles of underground development work has been done, and when an annual production of about 800,000 tons of ore is being made. This did happen to the writer on the last day of 1924, when he made an examination of the latest development work done in the Britannia to obtain information for this report. . . . In the late fall of 1898 the writer's attention was first called to the mineralized zone, now known as the "Britannia Mineral Belt," and the group of claims that had been staked by Oliver Furry and associates, but it was not until

[1] Haggen, E. A.: "The Britannia Mine"; Eng. and Min. Rec., vol. 27, p. 81 (1923).

[2] Brewer, Wm. M.: "British Columbia, Howe Sound Division"; Eng. and Min. Jour., vol. 70, p. 189 (1900). Also in Ann. Rept., Minister of Mines, B.C., 1899.

[3] Brewer, Wm. M.: "Britannia Mining and Smelting Company"; Ann. Rept., Minister of Mines, B.C., 1924, pt. B, p. 229.

January, 1900, that he was called upon to examine the prospects. At this time the total development amounted to about 220 feet of cross-cut adit and drift on the Jane, one of the seven original claims of the Britannia group. This work was done on what is now known as the 1,000-foot level, and where the first mining camp was established, consisting at that time of two cabins for the 5 or 6 miners employed. Today the company employs between 600 and 700 in and around the mines exclusive of those employed in and around the concentration plant at Britannia Beach.

The early history of the Britannia mine illustrates unique conditions with regard to financial management. The original group of mineral claims was first sold in 1898 by Oliver Furry and associates to Leo Boscowitz, of the fur-buying firm of Boscowitz and Sons, of Victoria, for $10,000, when the development work on the Jane claim was begun. In 1899 a syndicate headed by the late Howard Walters, of Libby, Montana, purchased seven-tenths of the property for $35,000. The development work was continued with a small force of miners; at the same time, under an agreement with Boscowitz, Walters endeavoured to secure a purchaser of the entire property, for the reason that as the development work progressed it became quite apparent that large capital investment would be necessary to successfully develop the mine. In a word, the work indicated an enormous body of low-grade ore, such as would necessitate plants for both mining and treatment of much more than ordinary capacity, and consequently an outlay of capital far beyond the ability of the average mining operators to secure. The original syndicate had first been organized on the basis of ten men furnishing $1,250 each, in shares or units of $125 par value. Later, before a sale could be consummated, some of the same men, together with some friends, invested a similar amount of cash as further capital was needed. During 1900 the property was examined by several leading mining engineers representing some of the largest operators of copper-mines in the world, but the price asked by the syndicate, $1,000,000 with a very heavy cash payment on a short-term bond, was generally considered too great for an undeveloped prospect. However, the shares subscribed for by the members of the original syndicate were so eagerly sought after that in the autumn of 1900 some were sold on the basis of $1,500 for an original $125 unit.

....It is not necessary to follow the various reorganizations of the original syndicate. About 1902, when the late George Robinson, of Butte, Montana, associated with the late Henry Stern, of New York, secured the controlling interest in the property, as well as the three-tenths interest retained by Boscowitz, it was incorporated as the Britannia Copper Syndicate, Limited. In 1908 the present company known as the Britannia Mining and Smelting Company, Limited, was organized after the control of the property passed into the hands of Moore and Schley of New York. The Britannia Mining and Smelting Company, Limited—capitalization 2,500,000 shares $25 par—is organized under the laws of British Columbia, but is controlled by the Howe Sound Company of New York.

In November, 1911, J. W. D. Moodie, who had been formerly in charge of the Tintic properties in Utah, succeeded R. H. Leach as manager, the latter having resigned on account of failing health after having been in charge of development work for about two years. It was during the same year that the Britannia mine was brought into the ranks of important shippers following the extensive development work on the Fairview claim, which had demonstrated the advisability of opening up that section of the property on a much more extensive scale.

It was during the latter end of 1911 that serious experiments were undertaken with the oil flotation method of concentration. The result was that this method was adopted for the treatment of all the ore mined, and has been responsible for the present entirely modern and extensive milling and concentrating plant at Britannia Beach today, with a capacity to treat 2,500 to 3,000 tons of ore a day, which was erected to replace the mill destroyed by fire in 1921."

At the present time C. P. Browning is general manager of the company, with headquarters at Britannia Beach. James I. Moore, jun., is mine superintendent, A. C. Monro is mill superintendent, and W. A. Matheson is secretary-treasurer.

The performance of the Britannia mines during their period of production is well illustrated in the accompanying chart, Figure 2. Since first shipping ore in 1905 the rate of production shows a general but very decided increase until in 1925 annual production was 29,000,000 pounds of copper, approximately 8,250 ounces of gold, and 132,000 ounces of silver.[1]

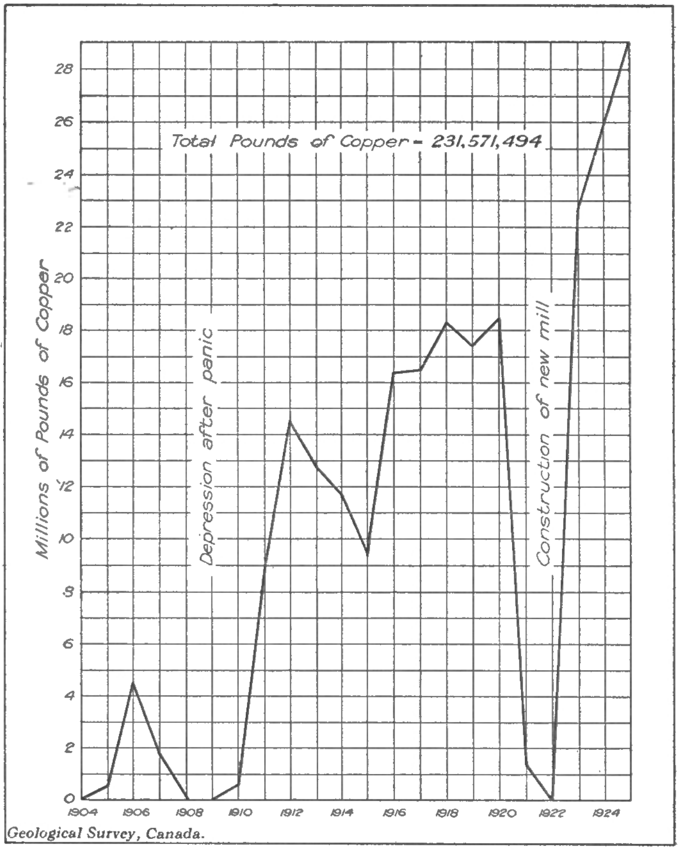

Figure 2. Chart showing annual production of Britannia mines from 1905 to 1925 (after Moore in E. and M. J. P., vol. 122).

The presence of a large producing mine in this district, operated by a company which has always been willing to increase its holdings, has maintained the interest of prospectors in the general Howe Sound district, and has resulted in the discovery of a number of showings which at least warranted serious testing. The Indian River section of the district has received more or less attention from prospectors and mining men since 1912, when Habrich and Herres, two prospectors from Squamish, located

[1] The gold and silver figures represent the total gold and silver from Vancouver Mining district, in which the only producer is the Britannia. Ann. Rept., Minister of Mines, B.C., 1925.

the Belle Group of claims near the head of the river. The publication of the Minister of Mines report in the following year containing the statement that the showing was 50 feet wide and that a sample, representing the material that could be sorted readily from the showing, assayed 5·3 per cent copper and 2 ounces silver, undoubtedly stimulated prospecting in the area. During the next few years the London, Bulliondale, A.B.C., and Roy groups were located and prospected with tunnels and open-cuts, and many other groups were staked in the district. New discoveries are still being made in the Britannia roof pendant northeast of the map-area.

MINERAL DEPOSITS

GENERAL CLASSIFICATION

The mineral deposits of Britannia map-area occur in the metallogenetic province, which Schofield has named the "Pacific mineral belt" of British Columbia.[1] It is "the belt which follows along the Pacific coast, including the island fringe on the western side of the Coast Range batholith" and is characterized by the fact that it contains copper deposits, in contrast with the gold, silver, and lead deposits occurring along the eastern side of the batholith. In conformity with this broad generalization, the principal mineral occurrences in Britannia area are those in which copper is the most important metal present. It occurs almost exclusively as chalcopyrite, but in a variety of associations and under conditions that illustrate, in a general way, the regional zoning of ore deposits. In detail, the deposits are not all copper, for zinc deposits are found in which the copper content is very low, and is present as tetrahedrite rather than chalcopyrite. Important amounts of anhydrite belong to the general mineralization, and occur in distinct bodies that must be classified as a separate type. These last specialized types are only variations of one of the most important groups described below, and do not vitiate the generalization that the important deposits are those in which copper is the most valuable constituent.

For purposes of general description, it is convenient to divide the mineral deposits of the area into the following three groups.

(1) *Deposits Within the Britannia Shear Zone.* At the present time, these are the only economically important deposits in the area. The principal minerals are pyrite, chalcopyrite, and quartz. Locally, sphalerite, barite, and anhydrite are plentiful, and galena is not infrequently found. The commercial deposits of this group are about 4,000 feet from the nearest exposure of the batholith, but mineralization, in the shear zone, occurs within 2,000 feet of the batholith.

(2) *Deposits Near the Batholith.* Two or three small properties in the Indian River section are in massive, unsheared rocks, within a few hundred feet of the batholith. Pyrite, chalcopyrite, and quartz are again the most plentiful minerals, but barite, anhydrite, tetrahedrite, and galena do not occur. The sphalerite in these deposits contains more iron than the sphalerite in the shear zone.

[1] Schofield, S. J.: "Geology and Ore Deposits of Salmon River District, British Columbia"; Geol. Surv., Canada, Mem. 132, p. 63.

(3) *Deposits Within the Batholith.* In addition to pyrite, chalcopyrite, and quartz, variable but small amounts of hematite, magnetite, molybdenite, and pyrrhotite appear within the batholith.

GENERAL MINERALOGY

The mineralogy of the ore deposits in Britannia map-area is relatively simple. The first two of the following three columns include all those minerals that have been recognized as forming a part of the primary mineralization. The third column, the list of supergene minerals, is not complete because secondary processes have not been important within the area and the secondary products have not been studied.

Hypergene minerals	Hypergene minerals	Supergene minerals
Non-metallic—	*Metallic—*	
Sulphur[1]	Gold	Gypsum
Quartz	Magnetite	Copper
Octahedrite (?)	Hematite	Cuprite
Calcite	Pyrite	Chalcocite
Undetermined carbonate	Pyrrhotite	Covellite
Barite	Chalcopyrite	Marcasite
Anhydrite	Bornite	
Sericite	Sphalerite	
Aphrosiderite	Wurtzite (?)	
Chlorite	Galena	
Titanite and leucoxene	Tetrahedrite	
Albite		
Apatite		
Undetermined phosphate		

Non-Metallic Hypergene Minerals

SULPHUR

Dr. Schofield[2] is the only one who reports native sulphur from Britannia area and he describes the occurrence as follows:

"The sulphur occurs in the same shear zone, but widely removed from the locality of the gypsum. It occurs in well-defined veins and impregnations in the schist. The veins vary in width from thin, almost microscopic, stringers to veins 4 inches wide. The sulphur is bright yellow in colour and when it impregnates the schists it gives them a yellowish green colour. The flakes of the schist close to the veinlets are separated by sulphur. Small, colourless crystals of gypsum were found associated with the sulphur.

Origin

Since the sulphur and the gypsum are intimately associated in the shear zone it is concluded that they are associated in origin. Gypsum in any large quantity has usually a sedimentary origin. At Britannia it is found in a shear zone in porphyry and since the gypsum is not sheared it must be of later age than the shear zone. This fact, that the gypsum is unsheared though it occurs in a strongly sheared zone, makes the theory impossible that it is a sedimentary remnant included in the porphyry. From the above facts it is concluded that the gypsum and the sulphur are of igneous origin. The large masses of gypsum, as far as known, do not show traces of sulphur and the veins of sulphur show only small crystals of gypsum; and since the sulphur and gypsum are far apart, it is concluded that the sulphur was not derived from the gypsum."

[1] Described by Schofield as hypergene.
[2] Schofield, S. J.: "Britannia Map-area"; Geol. Surv., Canada, Sum. Rept. 1918, pt. B, p. 59.

Since Schofield is the only one who has examined the sulphur occurrence his statement should probably be quoted without comment, but, since the time of his writing, more information is available regarding the origin of the gypsum, which Schofield believes to be the same age as the sulphur. The bulk of the gypsum, as shown below, is undoubtedly a surface alteration of anhydrite, and a small amount of gypsum is transported, and redeposited along the walls of the tunnels in clear, colourless crystals. These are apparently similar to those Schofield describes as occurring with the sulphur, and the inference is that both are supergene minerals.

QUARTZ

Quartz is the most plentiful gangue mineral in the deposits, and it occurs in a variety of forms. It is most conspicuous as the essential constituent in the masses of silicified rock, such as the Bluff deposit at the west end of the shear zone, and the silicified zones of the Roy Group in Indian river. The quartz, which replaces the groundmass and the chloritic areas of the porphyries, is usually clouded with numerous, fine, dusty particles, but the quartz replacing the phenocrysts is invariably clear, and not infrequently contains from one to several small crystals of apatite. This type of quartz corrodes pyrite and is, therefore, later than some of the pyrite.

A second generation of quartz occurs as fine, clear, fibrous grains radiating from pyrite, and, less frequently, from chalcopyrite and sphalerite. The striking feature of this quartz is that it replaces not only chlorite, sericite, and the general material of shale, but also the earlier silicified mass. As a rule, a small amount of chlorite and sericite recrystallizes and accommodates itself to the shape of the quartz fibres, but the dust-like particles in the silicified rock are eliminated completely, and the quartz of the silicified rock becomes oriented with the fibres. This quartz is later than pyrite and, part of it at least, is later than chalcopyrite and sphalerite. Quartz is plentiful as vein fillings. It is usualy coarse grained and milky white to slightly pinkish in colour, although quartz crystals, projecting into vugs, are invariably colourless and glassy.

OCTAHEDRITE

This mineral has not been identified definitely, but in a few thin sections minute crystals resembling octahedrite were observed. It occurs in chloritic schists that have been very highly silicified, and probably represents a recrystallization of fine-grained titanite which is so common in the unaltered schist.

CALCITE

Calcite is not at all plentiful. It has been observed as veinlets cutting quartz, pyrite, and chalcopyrite in the shear zone deposits, and specimens have been secured from vugs in the Fairview and Victoria mines.

UNDETERMINED CARBONATE

A more widely distributed carbonate, having a higher index than calcite, and occurring as small rhombs and irregular grains, was recognized in a number of thin sections from the shear zone deposits.

BARITE

Barite is confined to the deposits of the Britannia shear zone. It is most plentiful as a gangue mineral in sphalerite ores at the west end of the shear zone, but small amounts of barite also occur in the very siliceous ores of the Bluff mine, and in the transition zone between the Bluff and Fairview mines. The barite is almost invariably corroded by quartz.

ANHYDRITE

This is one of the most abundant and widespread of the non-metallic minerals within the Britannia shear zone. It does not occur, however, as a gangue mineral in the sulphide veins, but in a separate and distinct group of veins, in which anhydrite, and the residual minerals of the rock, are the only materials present. The veins vary in width from a fraction of an inch to a score of feet. One vein in the Victoria mine is about 5 feet wide, and is essentially pure anhydrite, as far as one can determine from a macroscopic examination. A larger mass, on the 1,050-foot level of the Fairview mine, has been altered to gypsum. The anhydrite is not confined to the shear zone proper, for blocks of it were found on the dumps of small prospects in Mineral creek, a few hundred feet above the western terminus of the upper railway.

SERICITE

Although sericite is common in the ores, very little of it has developed as a direct result of the mineralizing process. A certain amount of the original sericite in the schists of the Britannia shear zone has recrystallized in the immediate vicinity of the vein, and, occasionally, small shreds of sericite are found in quartz veinlets where it is obviously a transported mineral.

APHROSIDERITE

A chlorite, having the optical properties of aphrosiderite, is widely distributed in the ore deposits of the Britannia shear zone. It occurs in vugs with clear colourless quartz in a number of places within the Fairview mine. The normal chlorite of the schist, in the immediate vicinity of the vein, is recrystallized to a mineral having optical properties similar to those of the aphrosiderite. At least a part of the aphrosiderite is later than the pyrite, for it is found radiating from the pyrite in the same manner as the fibrous quartz.

CHLORITE

A chlorite of slightly higher index than aphrosiderite, occurs in veinlets with quartz in one of the deposits near the batholith.

TITANITE AND LEUCOXENE

Slightly silicified chloritic rocks contain fine aggregates of leucoxene-like material. Occasionally these become crystallized into larger individuals resembling titanite, and a small amount of titanite occurs in quartz veinlets, evidently as a transported mineral.

ALBITE

Two different types of albite have been developed within the Britannia mineral deposits. Albite replaces the plagioclase feldspar in one of the basic dykes of the Empress mine, and occurs in a similar manner in the greenstones surrounding the Roy deposit in Indian river. A very small amount of albite occurs in tiny veinlets cutting the albite dacite, where the latter forms the hanging-wall of the third vein on the 1,050-foot level of the Fairview mine. It is associated with quartz, carbonate, chlorite, and apatite.

APATITE

Although apatite is not a plentiful mineral in the ore deposits of Britannia area, it is widely distributed in the shear zone deposits. Minute crystals of apatite are frequently found with the quartz aggregates replacing the feldspar phenocrysts of the sheared mine porphyry, and grains of apatite are found in small quartz veinlets. On first discovering that apatite was one of the minerals introduced during mineralization, it was thought to be an unusual occurrence, for the Britannia shear zone deposits are not the high temperature type of deposits in which apatite is most characteristically found. Apatite is common in pegmatites, in magnetite deposits, such as those at Kiruna and in the Bushveld, as well as in other high-temperature deposits, as the gold veins of the Appalachians,[1] and the Broken Hill deposits of New South Wales.[2] Apatite is also associated with low-temperature mineralization. Burton mentions it as one of the metasomatic minerals in the Premier mine;[3] a deposit containing such primary minerals as sphalerite, galena, tetrahedrite, polybasite, and pyrargyrite; and Lindgren describes it as one of the metasomatic minerals developed in the basic dykes of Cripple creek.[4] From these few examples, cited from the literature, and from the occurrence at Britannia, it is evident that apatite may develop throughout the entire temperature range of ore deposits—from magmatic segregation deposits to veins formed near the surface.

Undetermined Phosphate

A mineral having the appearance of apatite, but differing from it in optical sign, was observed in a few thin sections from the shear zone deposits. A micro-chemical test for phosphorus was decidedly positive, but the mineral does not occur in sufficient quantity to be segregated for chemical analysis, or even for determination of the optical properties. It occurs in the soft slates along the hanging-wall of the barite-sphalerite deposits of the Jane mine, and one small crystal was observed with the anhydrite.

Metallic Hypergene Minerals

GOLD

Small amounts of gold are recovered from all the deposits in the shear zone, but it is most plentiful in the two westerly deposits. Probably all of it is present as the native metal, for a fair proportion is recovered on the nap of woollen blankets in the mill tailings sluice.

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[1] Graton, L. C.: "Gold and Tin Deposits of the Southern Appalachians"; U.S. Geol. Surv. Bull. 293.
[2] Andrews, E. C.: "The Geology of the Broken Hill District"; Mem. Geol. Surv. of N.S.W., Geol. 8, 1922.
[3] Burton, W. D.: "Ore Deposition at Premier Mine, B.C.: Econ. Geol., vol. 21, p. 595 (1926).
[4] Lindgren, W.: "Geology and Gold Deposits of the Cripple Creek District"; U.S. Geol. Surv., Prof. Paper 54

MAGNETITE

The only deposits in which magnetite is present as an introduced mineral are those within the batholith. It occurs both as a pseudomorph after hematite, and as an original precipitate.

HEMATITE

Hematite is confined to one deposit in the batholith, and is preserved as minute residues in the magnetite.

PYRITE

This is the most abundant and widespread of the metallic minerals, and is the only one of the sulphides that occurs in all the deposits. It occurs both as a vein mineral, and as a metasomatic mineral in the wall-rocks of the veins. The chloritic blotches in the green-schist of the shear zone in many cases contain very numerous small grains of pyrite at some distance from the vein. The pyrite is invariably corroded by quartz and, occasionally, is completely replaced by it.

PYRRHOTITE

This mineral is not found in the shear zone deposits nor in any of the other common types, but is apparently confined to a few narrow stringers in and near the batholith.

CHALCOPYRITE

The mineral of greatest economic importance is chalcopyrite, and it is plentiful in all types of sulphide deposits, except the barite-sphalerite type. Pyrite and chalcopyrite are practically the only sulphides in the Fairview and Victoria mines of the Britannia shear zone. Chalcopyrite is later than the quartz and pyrite, and some of it is probably later than the sphalerite. Minute blebs of chalcopyrite are numerous in the sphalerite, and not infrequently small gashes of sphalerite, making angles of 120 degrees with one another, are found in the chalcopyrite.

BORNITE

Bornite is rare in Britannia area and is apparently confined to the west end of the shear zone deposits. Bornite was not observed in the numerous polished specimens examined, but it has been reported from one of the stopes above the 1,600-foot level of the Bluff mine, and LeRoy[1] mentions it as occurring in the upper levels of the Bluff.

SPHALERITE

Although sphalerite is widely distributed in the area, it is not a conspicuous mineral, except in the west end of the Britannia shear zone. On the 1,050-foot level of the Jane mine, sphalerite and barite form replacement deposits in the sedimentary rocks, and similar material is found in

[1] LeRoy, O. E.: "Main Coast of British Columbia and Adjacent Islands"; Geol. Surv., Canada, No. 996, p. 83.

the hanging- and foot-wall slates of the Bluff mine. Sphalerite is conspicuous in the siliceous ores of the Bluff mine, particularly on the upper levels, and is present in one of the Indian River deposits—the Belle group—near the batholith. The sphalerite of the shear zone deposits appears in thin section as colourless grains frequently containing a dark, opaque core. A possible explanation of the opacity of parts of the sphalerite is that these areas contain a very great number of small inclusions. This was suggested by the finding of a crystal of sphalerite which contained all gradations between small spherical inclusions, sufficiently large to be recognized as individual grains, and the opaque areas. The sphalerite, which is transparent and colourless in thin section, is relatively pure, for the index of refraction is approximately 2·34 (lithia light) which is the index of pure sphalerite according to Merwin.[1] Sphalerite from four different places in the shear zone was examined, and although the colour in the hand specimen varied from amber to colourless, the index in each case was essentially the same. The sphalerite from the deposit near the batholith appears very dark in the hand specimen and brownish in thin section, and is found to have an index of 2·35+, which would indicate an iron content of 4 or 5 per cent.[2]

WURTZITE

One thin section of the barite-sphalerite ores of the Jane mine contains a small prism which resembles sphalerite, except that it is birefracting. It may possibly be wurtzite.

GALENA

Galena is apparently confined to the shear zone deposits. It is fairly plentiful on the upper levels of the Bluff mine, and in the barite-sphalerite ores of the Bluff and Jane mines. It is later than all the other sulphides, having been found replacing chalcopyrite, sphalerite, and tetrahedrite, and in veinlets cutting sphalerite and pyrite.

TETRAHEDRITE

This mineral is confined to the Jane and Bluff mines of the shear zone deposits. It is most plentiful in the barite-sphalerite ores, but is occasionally found in the siliceous ores of the Bluff mine, and in the siliceous zone between the Bluff and Fairview mines. It is later than chalcopyrite and sphalerite, but earlier than galena. A spectroscopical analysis of a specimen of tetrahedrite from the Bluff mine shows that small amounts of silver and arsenic are present.[3]

Supergene Minerals

GYPSUM

Anhydrite is almost invariably accompanied by gypsum, the hydrous form of calcium sulphate. Near water channels, on the lower levels of the mine, the gypsum occurs as very narrow replacement veinlets in the anhydrite, and as a coating on nearby joint planes. On the upper levels, within 200 or 300 feet of the surface, the anhydrite is completely replaced

[1] Allen and Crenshaw, microscopic study by Merwin: "The Sulphides of Zinc, Cadmium, and Mercury"; Am. Jour. Sci., vol. 34, p. 384 (1912).
[2] Loc. cit., p. 386.
[3] For this analysis, the writer is indebted to G. V. Douglas, an instructor of geology at Harvard.

by gypsum, and still nearer the surface, both the anhydrite and gypsum have been removed by circulating groundwater. Small crystals of gypsum are deposited from water which seeps through the backs of the drifts near some of the anhydrite-gypsum veins. It is evident that the gypsum is related to the present surface of erosion, and is a supergene, and not a hypergene, mineral, as suggested by Schofield.[1]

COPPER

Native copper is a fairly common mineral in the upper levels of the shear zone deposits.

CUPRITE

Small cubes of cuprite have been reported from the upper levels of the Fairview mine.

CHALCOCITE

Chalcocite is the most plentiful of the secondary sulphides, but it is confined very largely to one deposit in the shear zone, the Empress mine. It is a very fine, soft, " sooty " chalcocite which could not be polished at all satisfactorily, and, therefore, its relations to the other minerals are not well known. Both sphalerite and chalcopyrite are, however, replaced by chalcocite.

COVELLITE

This mineral is found in the same deposit as the chalcocite, occurring as distinct replacement veinlets in the sphalerite, and to a lesser extent in the chalcopyrite. Since the covellite is apparently confined to veinlets, and the larger areas of secondary copper sulphides are chalcocite, it is probable that the covellite represents the first stage of alteration and is replaced by the chalcocite as the alteration continues.

MARCASITE

Marcasite has been found in only one small vein in the granite, where it replaces the pyrrhotite in rounded forms.

DESCRIPTION OF DEPOSITS

ORE DEPOSITS OF THE BRITANNIA SHEAR ZONE

The group of five deposits occurring within the westerly 7,500 feet of the Britannia shear zone and known, collectively, as the Britannia mines, are generally referred to as the deposits of the Britannia shear zone, although the most westerly of the five deposits, the Jane mine, is really not in the shear zone as defined in this report. It is, however, so very directly related to the shear zone, and to the shear zone deposits, that it is quite properly described at this time.

From west to east the ore-bodies are known as the Jane, Bluff, Fairview, Empress, and Victoria mines. The last four are within the shear zone proper and are distributed at fairly regular intervals along the foot-

[1] Schofield, S. J.: "The Britannia Mines, British Columbia"; Econ. Geol., vol. 21, p. 280 (1926).

wall (north) side of the shear zone. The Jane mine is a little south of the general strike of the foot-wall, and is separated from the actual shear zone deposits by several hundred feet of soft and highly metamorphosed argilites. The distribution, form, and to a certain extent, the mineralogy, of the ore deposits are controlled by major and minor structures of the shear zone, and, therefore, these structures, their origin, and influence on ore deposition will be described in some detail.

Structures of the Shear Zone, Their Origin and Influence on the Form and Position of the Ore Deposits

One of the most comprehensive generalizations to be made regarding the distribution of ore in the shear zone, is that green-mottled schist is the host rock for all the important veins, and that the silver schist is invariably barren.[1] Both schists are sheared phases of one of the Britannia sills, which will be referred to as the mine porphyry. The silver schist is a very fine, fissile sericite schist; the green-mottled schist is a chlorite-sericite schist representing a less sheared phase of the mine porphyry. Another generalization that has been established is that the Bluff ore-body on the 1,050-foot and 1,200-foot levels is overlain by a capping of slates that plunges to the west, and that the Empress and Victoria deposits are related to similar structures.[2] The Fairview veins are definitely related to minor, but important structures in the shear zone, and the veins grade into the Bluff mineralization at certain points. The Jane is a shallow deposit, whereas the others extend to a considerable depth. The purpose of this section of the report is to show that all these modes of occurrence, as well as a few minor irregularities in the veins, are dependent, very largely, on either the major structures of the shear zone and the surrounding rocks, or on the minor structural features developed in the shear zone, as a result of the differential movement. The influence of dykes, and pre-mineral faults, on the distribution of the ore, has been important in several instances and will also be described in this section.

MAJOR STRUCTURES OF THE BLUFF AND JANE DEFOSITS

In order to explain certain structural features of the ore deposits, it is necessary to understand some of the structures that existed before the shear zone was developed. It may be recalled that the Britannia sills were intruded into the Britannia formation before the latter was folded and thrust into its present position; that the sills are not all true sills, but that some cross the formations at appreciable angles; and that one of these crosscutting sills, the mine porphyry, forms the western part of the shear zone and contains most of the commercial ore deposits. It is the structure and structural relations of the mine porphyry, therefore, that are of importance in ore deposition. The general attitude of the mine porphyry before the development of the shear zone was presumably about the same as it is now, the strike was northwest and the dip southwest at about 70 degrees. At the east end of the ore zone, within the Victoria section, the porphyry was apparently 2,000 feet wide and was bounded,

[1] Schofield, S. J.: Loc. cit., p. 276.
[2] Schofield, S. J.: Loc. cit., p. 281.

on the south side, by a band of black slates, and on the north, by a very narrow lens of slates. For a considerable distance west of this, the southern boundary of the porphyry has not been determined accurately, but the porphyry gradually narrows until, within the Fairview mine at an elevation 2,000 feet above the Victoria, it is approximately 700 feet wide. It is bounded on the south, at this point, by a narrow band of highly sheared slate, which is probably a fault zone. Along the north side of the porphyry, throughout this distance, are massive greenstones, with the exception of an occasional lens of slate. Farther east, the slates, on both the north and south sides, become wider and finally unite, forming an anticlinal structure that plunges northwest at about 35 degrees.

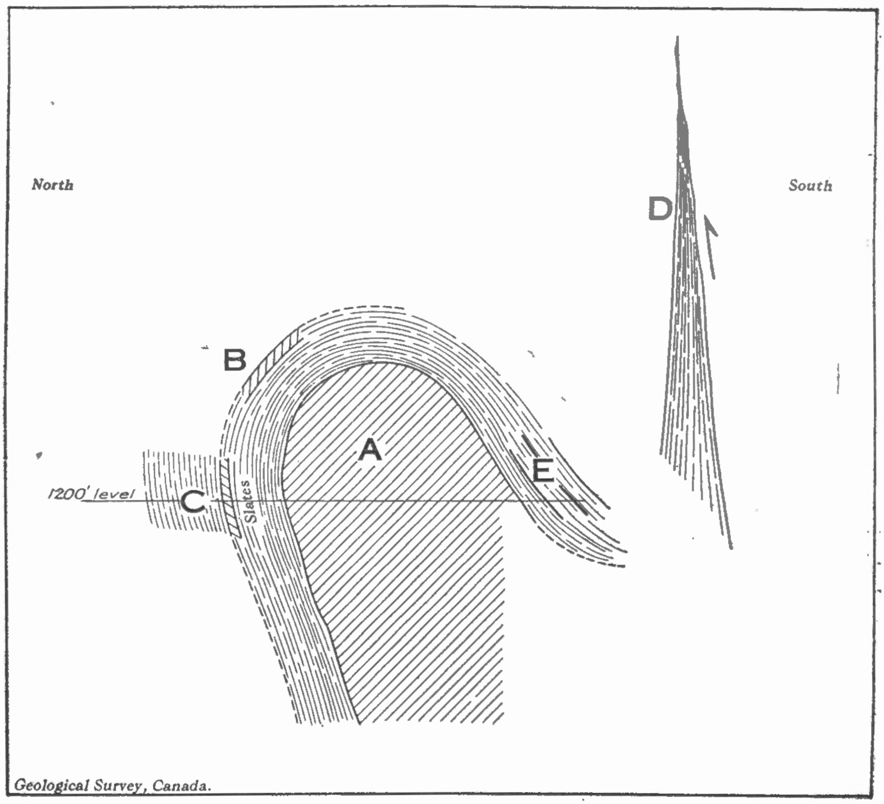

Figure 3. Vertical section illustrating apparent structure at west end of Britannia shear zone.

The details of the anticlinal structure at the west end of the mine porphyry have not been unravelled, but, by piecing together a few discreet facts, one arrives at the conclusion that the structure is possibly a faulted anticline as indicated in Figure 3. It is definitely known from underground workings on the 1,050 and 1,200-foot levels of the Bluff mine that the slates overlie the mine porphyry as indicated in Figure 3, and diamond drilling has shown that the slates, on the south side of the structure, do not continue to the 1,600-foot level in the zone of the Bluff mine. On the east wall of Jane Creek basin, somewhat west of the Bluff mine, is a thin band of well-bedded slates which dip north at about 45 degrees, and, judging from the relation of the cleavage to the bedding, the slates are right side up. A similar band is exposed in a crosscut on the 1,200-foot level of the Bluff mine, but it dips south at about 80 degrees and the beds are apparently overturned. The relative positions of these two exposures are represented by points B and C in Figure 3. On the south side of the general structure, and exposed on the east wall of Jane Creek basin, is a narrow wedge of highly sheared slates which terminates upwards in a fault zone, as represented at D in the diagram. The Jane mine occupies the position E in the diagram, and although the structure in the Jane is not at all simple, the beds dip south and the dips are at lower angles on the lower levels. The major structure is by no means as simple as indicated on the diagram; and points A, B, C, D, and E do not fall along any one section, but their relative positions are approximately as shown, and they suggest that the structure is a faulted anticline. This diagram, however, is a generalization and must be regarded merely as one interpretation of the structure. It is suggested because it assists in explaining the peculiar distribution of the slates in Jane Creek basin, and, what is more to the point at the present time, it helps to explain the attitude and shallowness of the Jane ore-bodies. These ore-bodies are replacements of definite horizons in the bedded rocks and, being on the short limb of the faulted drag-fold-like structure, they do not extend far below the crest of the anticline. The detailed structures in the Jane mine are very complex and are not known in detail, since the upper levels are flooded and caved, and the openings on the lower levels (1,100 and 1,200 feet) are but single crosscut tunnels. The general structure, however, is apparently as outlined above, but is modified by minor folding and faulting.

The thick mantle of slate enveloping the west end of the mine porphyry has been very important in controlling the manner in which the mine porphyry has responded to the stresses that developed the shear zone, and later, during the period of mineralization, the mantle influenced the movement of the solutions, and, therefore, affected the shape of the mineralized zone to a very marked degree. The reason for the localization of the shear zone is not known, but, knowing that the shear zone developed along the strike of the mine porphyry, and knowing the relation of the porphyry to the surrounding rocks, it is possible to deduce the general nature of the influence of the slates on the shearing and ore distribution.

If the rocks along the line of the shear zone were uniform in character, the size and general features of the shear zone would be relatively uniform throughout its length, but if soft plastic rocks, such as slates, occur along the line of the shear zone, the shearing will tend to be concentrated in the slates, leaving the hard, resistant rocks, such as the mine porphyry, less sheared. As the thickness of slate increased, the amount of shearing in the more solid rocks would correspondingly decrease. This would mean that the zone of shearing in the porphyry would become narrower, or the intensity of the shearing would decrease. Both effects are noted at Britannia. As the mine porphyry is followed westerly towards the mantle of slates, the width of the shear zone decreases appreciably and is actually confined to the zone between the hanging- and foot-wall bands of slates, and, as the thickness of the slates increases, the porphyry becomes less sheared until, at the very west end of the Bluff mine (on the 1,050-foot level) the differential movement has been absorbed by the slates to such an extent that the porphyry is fractured rather than sheared.

This fractured condition of the mine porphyry has permitted a free circulation of the ore solutions throughout the fractured mass, and has exposed tremendous areas to the influence of the solutions, with the result that the " nose " of porphyry, surrounded by the slates, has been intensely silicified, and mineralized with variable amounts of the sulphide minerals. The solutions were not confined to narrow channels as they were farther east in the Fairview, Empress, and Victoria mines, but were distributed by numerous channels throughout a large mass of rock. This not only produced a large, irregular ore deposit, in which the ore-shoots are very poorly defined, but is responsible for the intense alteration of the porphyry. By the time silicification penetrated the individual fragments to a depth of 2 or 3 inches, the fractured mass was more or less completely silicified; but a silicified zone a few inches wide along the Fairview or Empress veins is very inconspicuous, and the amount of wall-rock alteration is apparently slight. Therefore, the fracturing is, to a certain extent, responsible for the type of mineralization within the " nose " of the mine porphyry—which is the Bluff mine.[1]

The prevalence of fracturing at the west end of the mine porphyry is clearly indicated in the Bluff glory-hole on the 1,050-foot level, for the face of the cut is seamed by numerous quartz and sulphide veinlets. Clear-cut, sharply defined, and intersecting veinlets of filling are very numerous and beautifully developed in an exceedingly fine-grained cherty rock, lying along the foot-wall of the Bluff ore zone on the 1,050 and 1,200-foot levels. The Foot-wall stope, in places, between the 1,050 and 1,200-foot levels, is composed of this cherty material cut by the very small but numerous veinlets carrying the ore minerals. The blocks, bounded by these veinlets, are highly angular, but more commonly the veining is an irregular, indefinite type which tends to segregate subangular to spherical blocks of porphyry. The larger blocks are silicified and impregnated to a variable extent with pyrite, and the intervening zones, containing most of the sulphides, are replacements of smaller fragments. In other places the veins, or really the sulphide zones, simulate crude sheeted zones parallel to the foot-wall of the shear zone. This type of structure is more commonly developed on the lower levels of the Bluff mine at an appreciable distance from the actual " nose " of mine porphyry.

The Bluff ore-body, occurring directly under the slate hood on the 1,050-foot level, plunges at a much steeper angle than the slate structure, and is, therefore, a considerable distance from the nose of the porphyry on the lower level, and in rocks that are distinctly more schistose. The prevalence of fracturing over shearing is due to the proximity of the protecting mantle of slate, and since this plunges to the west, the general fracture zone plunges to the west, and the porphyry vertically below the slate hood is progressively more schistose. Steeply plunging ore-bodies, therefore, go

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[1] One other possible influence of fracturing on the type of mineralization in the Bluff mine is suggested on page 122.

downward into normal schist. The attempt to differentiate fracturing from shearing is liable to lead to a misconception of the conditions in the Bluff mine unless the statements are qualified slightly. All the rocks in the Bluff mine have been sheared to a certain extent, except possibly at the very apex of the mine porphyry, but at specific points, which have been indicated, fracturing has played an important part in rock deformation, whereas in other sections, shearing has been relatively more important.

The west end of the mine porphyry, or the actual position of the slate hood, has not been located below the 1,200-foot level and its projection beyond this level is purely conjectural. For the time being we cannot assume that it has influenced the distribution of the Bluff ore except on the upper levels of the mine, but the apparent form of the newly developed westerly ore-body makes one suspect that its influence may possibly have been more extensive (*See* Figure 7). The upper levels, however, afford ample evidence of the importance of the structure. Aside from having been responsible for the fracturing, and, therefore, the permeability of the rock immediately under the slates, they have intercepted the solutions rising through the Bluff ore zones, and confined them to this fractured and permeable section of the porphyry. The same structure apparently extended over the present Fairview ore zone, a short distance to the east, and effected a junction between the Bluff and Fairview ore-bodies. On the lower levels of the mine, the two ore-bodies are separated by several hundred feet of barren schist, but on the upper levels, a short distance below the slate hood, they are united by a zone of intensely silicified rock. On the 1,050-foot level the Bluff ore-body and the west end of the Fairview veins are surrounded by the silicified rock, but above this level the Bluff ores have been removed by erosion. The gradation between the Fairview and the Bluff mines is indicated on the plan of the 1,050-foot level (in map pocket), and by Figures 7 and 11. The mineralogical aspect of the gradation is described on page 104.

LOCALIZATION OF THE FAIRVIEW VEINS

Three different types of Fairview veins are recognized; the foot-wall veins, the anhydrite veins, and the hanging-wall veins. The foot-wall veins are very regular sulphide veins, from 2 to 40 feet wide and as much as 1,200 feet long, whose attitude and position in the shear zone were controlled, apparently, by fracture zones developed in the porphyry during shearing. The anhydrite veins are similar to the foot-wall veins, in form, but they are later than the sulphide mineralization, and occur, in part, in such highly sheared rocks that the openings for the mineralizing solutions were probably formed subsequent to the shearing. The hanging-wall veins are zones in which small mineralized fractures are sufficiently numerous to form large, commercial ore-bodies.

The structure which is responsible for the position of the foot-wall veins would not have been suspected but for the presence of several basic dykes that are earlier than the shearing and serve as horizon markers, tracing in detail the internal structure of the schist. It is safe to assume that the dykes were straight and regular at the time of their intrusion.

They have since been contorted into a series of drag folds, whose loci indicate the position of the brecciated zone which later became the Fairview foot-wall veins.

The accompanying diagram, Figure 4, is a generalization of the relations of the basic dykes to the shear zone, to the schistosity, and to other features developed during shearing. At the west end of the shear

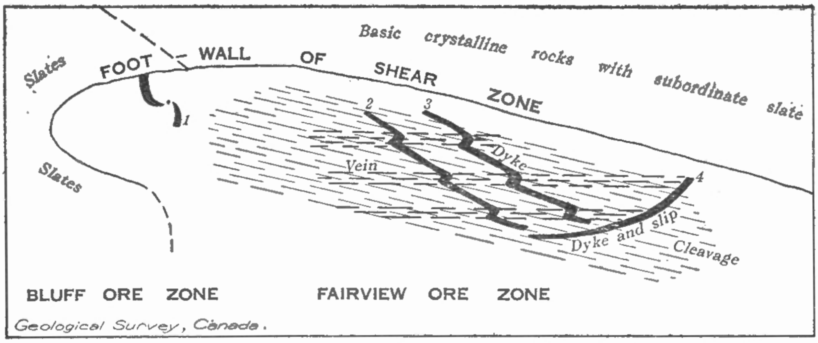

Figure 4. Diagram illustrating relation of Fairview foot-wall veins to structure within the Britannia shear zone.

zone, where the shearing is not pronounced, a few of the dykes are nearly vertical, and about normal to the foot-wall of the shear zone. Although the dykes are not generally schistose, they are occasionally broken by narrow shear zones, which are essentially fault zones,[1] such as indicated at point 1, Figure 4. Farther west in the main part of the shear zone, where schistosity is well developed, two sets of basic dykes cross the shear zone. One set of dykes, represented at points 2 and 3 (Figure 4), cross the shear zone in a general northwesterly direction and have been crumpled into a series of small drag folds. The other set of dykes crosses the shear zone in a northeasterly direction and is represented by one dyke, at point 4 (Figure 4).[2] The sections of the northwesterly dykes between the drag folds are sheared to a fine, green, chloritic schist, whereas the drag-folded sections are generally much more massive, although occasionally they are quite schistose. The axes of the drag folds lie in the plane of the cleavage, which dips about 70 degrees south, and the plunge of the axial line is nearly 90 degrees. This vertical plunge of the drag folds indicates that the direction of greatest relief from the shearing stresses was lateral and not upward. If one side of the shear zone had moved up with respect to the other, the axes of the drag folds would be inclined to the vertical, at an angle depending upon the relative importance of the upward, and lateral components of relief.

The actual direction of the horizontal movement is shown by the offset in dyke No. 1 (Figure 4), in which the north side has moved west relative to the east; but the apparent direction of movement, as indicated by the drag-folded dykes, is opposite to this. From the attitude of the drag folds,

[1] This particular type of structure is developed in one of the dykes on the 1,600-foot level of the Bluff mine.
[2] The actual distribution of these dykes is shown on the plan of the 1,050-foot level.

it might be suspected that the shearing was produced by rotational stresses, acting in such a manner as to move the north side, east, relative to the south side. The direction of the deforming stresses is very difficult to determine, because the direction of schistosity, jointing, and relative movement is dependent on the direction of relief, as much as on the actual direction of the deforming stresses. The effective stress, in this case, may be considered normal to the direction of relief, or elongation, and according to Leith and Mead[1] this is parallel to the cleavage direction.

The crumpled zones, indicated by the drag folds in the dykes, would be inclined to the effective stress when first developed, but as the squeezing continued and the rocks " flowed " laterally, parallel to the schistosity, the crumpled zones would be rotated into a position more nearly parallel to the direction of elongation, or the schistosity. The amount of rotation is dependent upon the amount of lateral movement. Now we find the crumpled zones inclined to the schistosity at 5 to 15 degrees, and since the Fairview foot-wall veins are confined to the crumpled zones, they, likewise, cross the schistosity at a small angle.

The Fairview foot-wall veins follow the crumpled zones, or the loci of the drag folds, because these zones were more pervious than the surrounding schist. The dykes very clearly indicate the physical condition of the porphyry along the crumpled zones. They are much more massive and blocky at the crests of the folds than they are along the limbs; and since the dykes are massive where they are sharply folded, it follows that fracturing must have been relatively important at these points. The frequently illustrated saddle reefs occurring along the crests of sharply folded sediments have made us familiar with the fact that such places are favourable for mineralization; and this is true merely because actual openings are formed along the crests of the folds at the same time that the limbs of the folds are tightly compressed and sheared. The same principle holds in the case of crumpling in the massive mine porphyry, but instead of the crescentic shaped openings, which are typical of the saddle reefs, the openings are small joints and fractures. The shape of the openings in the saddle reefs is due to the flexibility of the slates, but since the mine porphyry is a siliceous and brittle type of crystalline rock, the crescentic openings are resolved into two sets of joints. Theoretically, one set of joints would be short-tension joints, tangent to the crest of the fold, or normal to the elongation; and the other set would be at about 45 degrees to the deforming stresses. As a matter of fact, the second set of joints would be actually the planes along which there was lateral movement while the tension cracks were being opened, and might be normal to the tension cracks. Such a combination of tension points and "slipping" planes, if that term may be used, is well preserved in the lower part of the fifth vein (2,200-foot level), and is illustrated in Plate III A. The short, stout, transverse gash veins represent the tension cracks, and the narrower, long veins, the "slipping planes". As a rule the vein structure is not nearly so regular as in this illustration, but is merely a network of interlocking stringers and irregular replacements.

[1] Leith and Mead: "Structural Geology"; New York, 1923, p. 124.

One of the veins is about 1,200 feet long and has a vertical extent of 2,200 feet. The actual relation of the dykes to the veins is shown on the plan of the 1,050-foot level. It may be observed that the fifth vein on this level is intercepted by three dykes and each of the dykes is intercepted at a drag fold.

Schistosity is the result of the recrystallization of a rock under the influence of very intense compressional stresses, and, therefore, it is a process that tends to eliminate all openings. The ore solutions could penetrate only along those zones that were fracture zones originally, and if shearing became more intense it would reduce the zones to an ordinary schist and destroy the channel ways. This is probably the reason why sulphide veins have never been found in the silver schist, which is a very highly sheared phase of the mine porphyry, and why the green-mottled schist, or the normal sheared phase of the porphyry, is the ore horizon. The band of green-mottled schist is favourable for ore deposition merely because shearing has not been sufficiently intense to obliterate the fractures zones, and not because of any material difference between the chemical or physical conditions of the two types of schist.

That an increase in the amount of shearing would close the channel ways and practically inhibit the circulation of ore solutions, seems to be a logical conclusion from general considerations, but it may be viewed with some suspicion until the occurrence of the anhydrite veins in the silver schist along the hanging-wall of the Fairview mine can be reconciled with this conclusion. Although it is perfectly true that none of the metallic ores is found in the silver schist, anhydrite is rather extensively developed in the silver schist of the Fairview mine; and since the anhydrite is a hypergene mineral, deposited from circulating magmatic solutions, its localization should be controlled by the same structures that determined the position of the sulphide veins. Its occurrence in the silver schist, therefore, must be explained.

The silver schist in the zone containing the anhydrite is mapped as such because it is a very light-coloured schist, similar in appearance to the very fissile silver schist, but some of it is no more highly sheared than the green-mottled schist, and the whole zone changes between the 850-foot and the 500-foot levels from silver schist, so-called, to the very massive schist containing the Fairview hanging-wall veins (*See* Figure 10). A wide zone of intense shearing would not be expected to die out in such a short distance. It is not implied that all the silver schist in this particular zone is not the very fissile variety, but merely that a part of it, at least, is no more highly sheared than much of the green-mottled schist; and, therefore, the preservation of channel ways is to be expected. This explanation, however, is not entirely satisfactory, because anhydrite occurs in the very highly sheared and soft foot-wall rocks of the Victoria mine. The anhydrite apparently belongs to a very late stage of mineralization (*See* page 123) and may have been introduced after all the more favourable channels were sealed by quartz and sulphides, and forced to seek less favourable places for deposition, or the anhydrite mineralization may have been preceded by a slight development of tensional stresses. Under conditions of tension the first openings produced in the shear zone would be in the soft slates and fissile silver schist, and these would then become the most favourable places for mineralization. The only reason for assuming tensional stresses is that some method of explaining the localization of the anhydrite veins is necessary.

The Fairview hanging-wall veins are a group of veins occurring above the 600-foot level, along the hanging-wall of the shear zone. On the 500-foot and 600-foot levels, which mark the bottom of the ore, the veins are fairly distinct, but above the 250-foot level the whole hanging-wall section of the mine is one ore-body, containing rich zones up to 70 feet wide, which are the so-called veins. These veins are zones in which narrow stringers of sulphide are more numerous than in the sections between the veins. The stringers are both parallel with and transverse to the schistosity, which is not pronounced, and average less than 2 inches in width. Most of the ore in the eighth and ninth veins is carried in stringers that are essentially parallel with the schistosity, but in many places along the tenth and eleventh veins the values are largely in the transverse stringers.

The accompanying diagram, Figure 5, shows the attitudes of the mineralized fractures in the tenth vein above the 250-foot level. The schist, as mentioned, is relatively massive, and the fracturing is probably

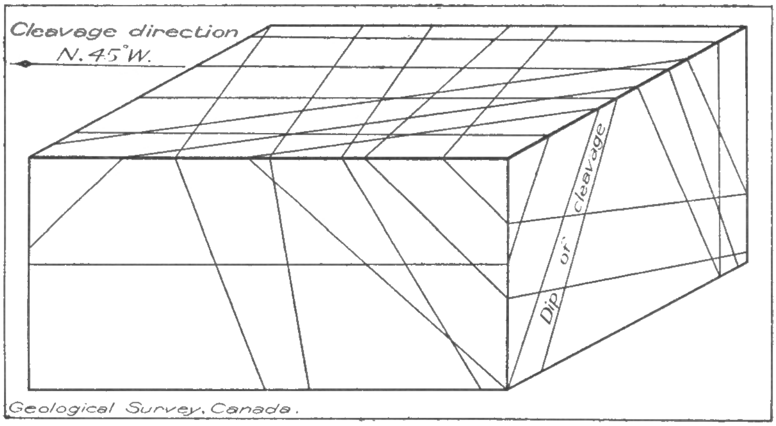

Figure 5. Diagram illustrating the fracture system of the Fairview hanging-wall veins.

an expression of the same differential stress that tended to develop the schistosity. In this respect these zones would be analogous to the fracture zones at the " nose " of the mine porphyry, where the upper Bluff ore-body is situated; and the prevalence of fracturing in both instances is responsible for the extent of the ore-bodies. The reason for the porphyry being fractured in the upper hanging-wall section of the Fairview mine is not as apparent as it was in the case of the Bluff porphyry. It is possible, however, that the band of slates along the hanging-wall of the Fairview mine, on the upper levels (*See* Figure 10), may have absorbed a great deal of the shearing and favoured the development of fractures.

EMPRESS STRUCTURE

The west end of the Empress ore-body, above the 1,050-foot level, is encased in a small hood of slate which is very similar to the larger slate hood that partly surrounds the Bluff ore-body on the same level.[1] The origins of the two structures, however, are apparently different. The accompanying sketch (Figure 6) is a generalization of the structure at the west end of the Empress ore-body on the 1,050-foot level. The foot-wall slates form a re-entrant into the sheared porphyry, and, continuing from the re-entrant wedge of slate, is a band of very highly sheared silver schist. The slate re-entrant, and the silver schist, together form the hanging-wall of the Empress ore-body; and the foot-wall is the main foot-wall of the shear zone. The ore zone is divided into two veins by a narrow band of silver schist which branches from the foot-wall, at some little distance from the crest of the drag-fold-like structure. The main structure has been developed, apparently, by the dragging back of a part of the foot-wall slates into the sheared porphyry, along a local zone of intense shearing, represented by the main band of silver schist. Both the slate re-entrant and the silver schist pinch out on lower levels and seem to be related structures.

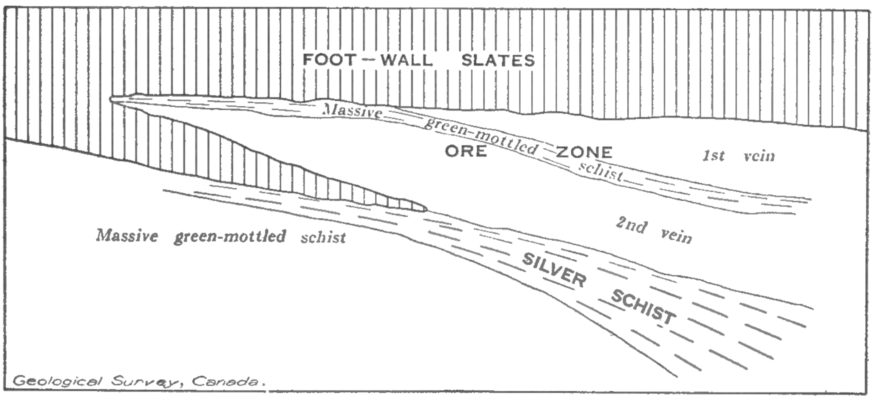

Figure 6. Generalized diagram of structure at west end of Empress ore-body.

The Empress structure is known on the 850-foot and 1,050-foot levels (high levels are caved), but it does not extend to the 1,200-foot level, although the ore continues to the 1,600-foot level at least. In view of these facts, it is difficult to see how the Empress structure could have influenced the position of the Empress ore-body, although it has played an important part, undoubtedly, in controlling the movement of the ore solutions above the 1,050-foot level.

A structure very similar to the Empress structure is found on the two upper levels (1,800 feet and 1,900 feet) of the Victoria mine, but is lacking on the lower levels. The slate re-entrant in this case, however, is not accompanied by silver schist. The origin of the structure is not known.

[1] *See* plan of 1,050-foot level. These structures are also figured by Schofield in Econ. Geol., vol. 21, p. 274 (1926).

INFLUENCE OF DYKES ON ORE DISTRIBUTION

The basic dykes have been mentioned above in the description of the fracture zones that controlled the position of the Fairview foot-wall veins. Aside from the basic dykes is a group of albite-dacite dykes, occurring along the hanging-wall of the Fairview, which have influenced ore distribution to a variable degree. All the dykes are essentially barren and in several instances they have acted as barriers to the ore solutions, and have interrupted the continuity of the veins.

The drag-folded dykes have played a variable role in the ore distribution. Generally speaking they are not ore bearing, although occasionally they may be pyritized and contain low-grade copper ore. In one particular instance which came under observation during the development and mining of the third vein on the 1,200 and 1,600-foot levels, the vein widened appreciably on the west side of the dyke—which was in the direction of the main ore-body—and was narrow, short, and valueless on the east side of the dyke. For a short distance above the 1,600-foot level the ore immediately west of the dyke was higher grade than the average, but above the 1,400-foot level the ore spread into the dyke and was lower grade than the average; on both levels the dyke marked the end of the commercial ore. It is apparent the ore solutions were trapped by the dyke and were prevented from spreading farther along the vein. Between the same two levels the fifth vein is intercepted by one of the basic dykes, but the dyke had no effect on the distribution of the ore, except that it itself was not mineralized.

The basic dyke which crosses the shear zone in a northeasterly direction—No. 4 of Figure 4—has been much more important than the drag-folded dykes in controlling the distribution of the ore along the vein zones. The west end of the dyke is nearly parallel to the schistosity, but, towards the east, it gradually swings across the shear zone, and marks the eastern limit of the Fairview foot-wall veins. The dyke is very highly sheared and is essentially a soft, shear zone which is mapped on the more accurate plans and sections as the "Fairview slip". On the 1,050-foot level the dyke is not as continuous as the slip, but on the upper levels they are usually co-extensive, and can be described together. The dyke not only forms the eastern boundary of the foot-wall veins, but is the dividing line between the hanging and foot-wall veins (*See* Figure 10).

The dyke has not played an important part in the distribution of the ore below the 850-foot level, except possibly for the seventh vein, because none of the veins is strongly mineralized as far east as the dyke. But above the 850-foot level some of the veins do reach the dyke as strong veins. On the east side of it, however, they are invariably reduced in size and continue as short, non-commercial lenses. The fine, chloritic schist and gouge in the slip, associated with the dyke, have apparently been sufficiently impervious to prevent a free circulation of the ore solutions along the vein zone. In section, the dyke, or Fairview slip, is slightly steeper than the veins, as shown in Figure 10, but its effect on the downward continuation of the ore has not been determined.

The fine, green, chloritic schist of a sheared basic dyke in the Bluff mine, apparently has been as important in controlling the position of one of the Bluff ore-shoots as the foot-wall of the shear zone. The foot-wall section of the easterly ore-shoot follows the foot-wall of the shear zone from the 1,000-foot to the 1,600-foot levels, but above the 1,600-foot level it rises vertically for 300 feet along a shear zone localized in a narrow, basic dyke. The shear zone and dyke pinched out somewhere below the 1,200-foot level and the ore solutions were permitted to extend over to the foot-wall again, developing a very wide ore-shoot (*See* Figure 8).

A number of dense albite dacite dykes are found along the hanging-wall of the four most westerly mines (*See* plan 1,050-foot level in map-pocket). On the 1,050-foot level they form the boundary between the green-mottled and the silver schist, but this is really a fortuitous section, for the dykes are entirely within the green-mottled schist in the upper levels. The dykes are very broad and massive at the west end of the mine, but they split into three or four narrower dykes towards the east. In a general way they are about parallel to the schistosity, but in tracing a dyke to the west, or upward, it is found to cross toward the foot-wall of the shear zone. Since the Fairview veins cut the schistosity in the opposite direction in plan, and are parallel to the schistosity in section, the veins are intercepted by the dykes. This is shown in the plan of the 1,050-foot level and in the transverse section of the Fairview mine, Figure 10. The dykes, being very dense, massive rocks dipping at a flatter angle than the veins, have tended to deflect the veins, and concentrate ore along their foot-wall side.[1] This is illustrated by the crowding of the stopes above the 500-foot level in Figure 10. The concentration of ore in this manner is important where the mineralization is scattered and not particularly strong. The larger, well-defined veins are deflected but slightly, and cut right through the dykes. The main ore channels were formed after the dykes were injected and they apparently did not affect the continuity of the principal fracture zones, but only interrupted the minor fractures. One clear example of a vein cutting one of the dykes is the fifth vein on the 1,050-foot level (*See* plan in pocket). In this example the vein continues only a few feet beyond the dyke. The break in the dyke, however, is clearly shown.

INFLUENCE OF PRE-ORE FAULTS ON ORE DISTRIBUTION

After the development of the shear zone, and before the introduction of the ore, the shear zone was broken by a number of thrust faults which strike approximately parallel to the schistosity and dip south at angles varying from 45 to 70 degrees. The faults are not continuous down the dip, but steepen, and swing into the cleavage direction. Individual faults persist along the strike for 600 or 700 feet at least. The offset along the fault plane is as much as 50 feet. In various instances the veins are deflected upward along the fault plane and narrowed, in some cases, to a bare inch of quartz and sulphides. The offset of the veins apparently represents the actual offset of the original brecciated zone, for dykes are found to be offset the same amount as the veins. The faulting has dragged, or bent, the schist along the fault plane and occasionally has developed small tension cracks which are now long, slender vugs partly filled with

[1] *See* Schofield, S. J.: Loc. cit., p. 278.

the common vein minerals such as quartz, chlorite, calcite, and chalcopyrite. One of these vugs, about 3 square inches in cross-section, was nearly 30 feet long. Since the vugs are lined with the ordinary vein minerals, it is obvious that they were developed before the final mineralization at least. The quartz and sulphides along the faults do not represent crushed ore, but are solid materials such as are found in other parts of the vein.

These faults are not always single breaks, but are frequently represented by a zone of branching slips. One such fault zone is shown in the transverse section of the Victoria mine (Figure 12). In this particular instance a 20-foot vein is narrowed to a few stringers and the horizontal offset is about 30 feet.

INFLUENCE OF POST-ORE FAULTS ON ORE DISTRIBUTION

One of the unusual features of the Britannia shear zone is that post-ore faulting occurs very rarely. The ore zone on the 2,200-foot level is more than 7,000 feet long, and within this distance only two or three post-ore faults have been noted. All save one are small, unimportant, vertical faults striking a little east of north (or west of north, magnetic), along which the west side has been moved north a few inches. One is a low angle fault and was encountered in one of the stopes between the 1,050 and 1,200-foot levels. The fault plane was rolling and irregular, but in general the strike was normal to the vein, and the dip a few degrees to the west. The movement was practically down the dip of the fault, or parallel to the strike of the vein. The actual amount of movement could not be determined, but the offset, at right angles to the vein, was about 4 feet to the south.

Jane Mine

The Jane is the most westerly of the five mines related to the Britannia shear zone. The other four mines are confined to one continuous zone of schist which is essentially a sheared phase of the mine porphyry, one of the Britannia sills, but the Jane mine occupies an isolated position about 1,200 feet beyond the west end of the sheared mine porphyry, and separated from it by several hundred feet of soft and highly altered argillites. Since the Jane was the discovery claim, and has proved to be a very shallow deposit, it was worked out some time ago, and as a result very little detailed information is available regarding the character and distribution of the ore. The Jane mine is particularly interesting, however, because both the siliceous copper ores and the barite-sphalerite ores are represented.

The siliceous copper ores occur in two bands, striking northwest and dipping southwest at angles which are steep on the 1,050-foot level and apparently flatter on the lower levels. A small amount of development work below the 1,050-foot level seems to indicate that the ore zones flatten appreciably, but owing to the complication of the structure and the intensity of metamorphism it has not been possible to correlate horizons on different levels. The most easterly ore zone has been followed by a raise to the 1,100-foot level, but it fails to make its appearance on the 1,200-foot level. The one level above the 1,050-foot has been worked out and allowed to cave, so that our information on the Jane is practically limited to a geological plan of the 1,050-foot level. And even here the copper ore-bodies have been mined out and the workings are partly flooded. The siliceous copper deposits are intensely silicified masses of igneous and sedimentary rocks in which the ore occurs as large, irregular masses. The ore-bodies are merely zones in which chalcopyrite is more concentrated than in the main silicified mass.

The barite-sphalerite type of mineralization is most typically developed in the sedimentary rocks of the Jane mine. The ore occurs as a replacement of the sediments, and although the bedding is perfectly preserved, the replacement has been so complete that the original composition of the sediment is not known. The essential minerals in the ore are barite and sphalerite, and, in addition to these, pyrite and tetrahedrite are common. Galena is present in small amounts, and chalcopyrite is very inconspicuous, being confined to small blebs in the sphalerite. The ore is bounded on the south side by fine-grained, argillaceous sediments composed of exceedingly fine quartz, sericite, and other materials that could not be determined. The only distinctly metasomatic mineral recognized is a phosphate, resembling apatite in crystal outline and general appearance, but having a positive, rather than a negative, optical character.

The barite-sphalerite ore grades on the north side into a highly silicified rock which is similar to the silicified zone containing one of the siliceous copper ore deposits. Although chalcopyrite is not at all important at this point, the silicification is undoubtedly a part of the same mineralization that was responsible for the siliceous copper ores, and the gradation, therefore, may be regarded as a gradation between two contrasted types of ore deposit. The siliceous ores are composed, essentially, of quartz, pyrite, and chalcopyrite; whereas the zinc ores are composed of barite and sphalerite dominantly, with pyrite, tetrahedrite, and galena occurring as less important constituents. The zinc ores represent a distinctly lower temperature type of mineralization than the former, and, normally, we would expect them to be later than the copper ores. This, however, is not the case, for the quartz is later than the barite, sphalerite, and pyrite, and the transition from the one type of mineralization to the other is accomplished by a substitution of quartz for barite and sphalerite. The transition zone is very narrow. Of two specimens collected within 2 feet of one another, one of them contains less than 1 per cent of quartz and the other contains as much as 75 per cent of quartz. The possible significance of this reverse in the normal sequence will be discussed in a following section.

Bluff Mine

The Bluff mine is situated at the west end of the mine porphyry, and the ore-bodies, on the upper levels, are directly associated with the plunging anticline of slate, which has been described on a previous page. The Bluff ore deposits are huge siliceous replacements along the foot-wall of the sheared and fractured mine porphyry. Two distinct ore-shoots are recognized, which, for convenience in this report, will be referred to as, respectively, the westerly and easterly ore-shoots.

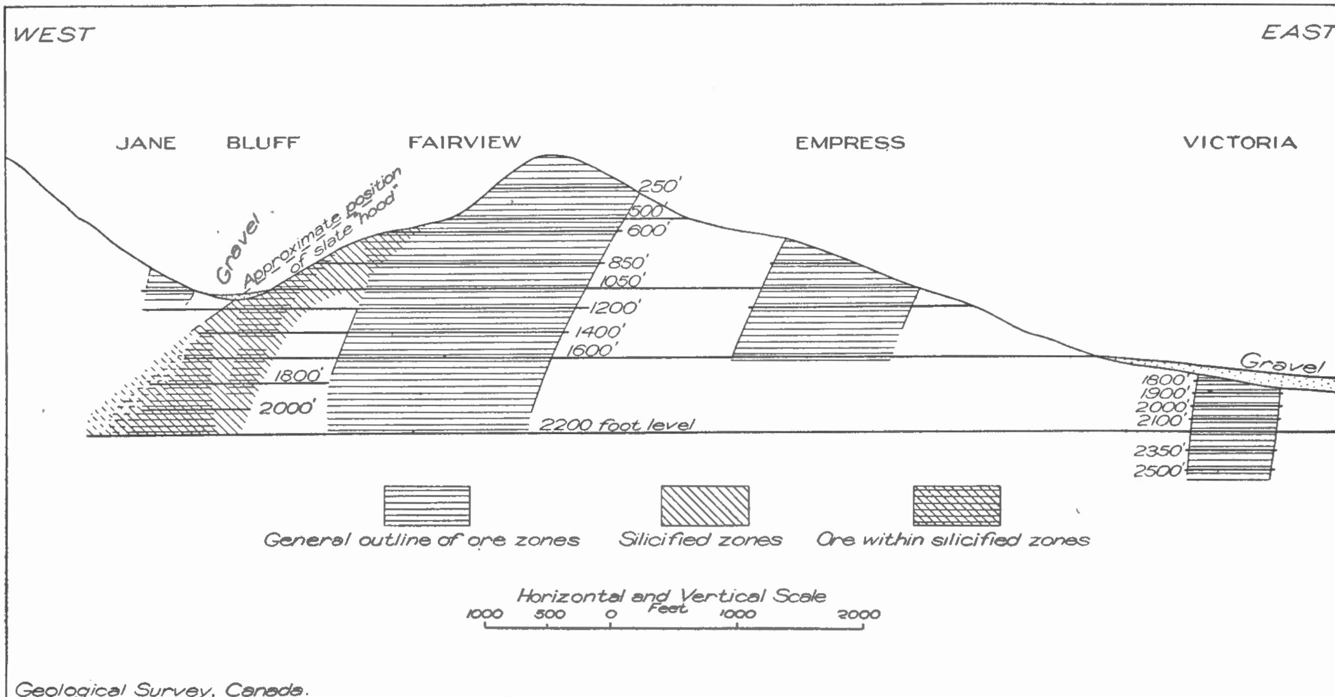

Figure 7. Generalized longitudinal section of Britannia mine.

The westerly ore-shoot is a blind ore-body, terminating below the 1,200-foot level in an intensely silicified mass of the mine porphyry, and extending downward to the 2,200-foot level at least. The details of the ore distribution are not known, because the ore-body has not been completely developed, but sufficient work has been done to indicate its general dimensions. The area of the ore-shoot on the 2,200-foot level is about 100,000 square feet, but upward it narrows rapidly and dies out between the 1,200 and 1,400-foot levels in the intensely silicified porphyry immediately beneath the slate hood (*See* Figure 7). On the 1,400-foot level, the ore-shoot is a very distinct high-grade body of ore, but, within its projection on the 1,200-foot level, nothing is found but the low-grade and non-commercial silicified porphyry which is the typical country rock of the Bluff ore-bodies. Although silicification is pronounced on the 2,200-foot level, it is not nearly so intense as on the upper levels. Apparently, the slate hood[1] has effected an increase in the intensity of mineralization by confining the solutions to the fractured "nose" of mine porphyry which it overlies. Unfortunately the increased mineralization is not attended by a concentration of valuable constituents, but by the worthless silica.

The easterly ore-shoot extends from the 1,800 to the 1,050-foot level, where it outcropped as a very conspicuous iron-stained bluff, standing vertically for about 100 feet. It was known as the "Mammoth bluff" and has given its name to one of the original claims of the Britannia group, and to the Bluff mine. The easterly ore-shoot is actually represented by two ore-bodies, which coalesce above the 1,200-foot level to form an irregular pipe-like body contained within the slate hood on the 1,050-foot level. The individual ore-bodies are very poorly defined zones in the intensely silicified porphyry. As a rule, either the hanging- or foot-wall side of the ore-bodies is bounded by slates or soft, chlorite schist, but the limits in the other three directions are entirely commercial, and very difficult to determine, particularly in the upper levels where silicification is most intense.

The two parts of the easterly ore-shoot are known as the Hanging and Foot-wall ore-bodies. They plunge to the west, in the same direction as the slate hood, but at a much steeper angle (Figure 7). A typical cross-section of the Foot-wall ore-body is shown in Figure 8. Between the 1,800 and 1,600 foot levels it rests directly on the foot-wall of the shear zone, but for 300 feet above the 1,600-foot level it is deflected from the foot-wall by a narrow, shear zone in one of the basic dykes. Both the shear zone and the dyke die out between the 1,200 and 1,400-foot levels, and the ore-body spreads out again to the foot-wall of the shear zone. The fine, chlorite schist of the dyke obviously has been an effective barrier to the ore solutions just as it has been in the Fairview mine, but on the first opportunity, the ore solutions worked their way out to the foot-wall along numerous fractures and joint planes. The mere fact that the solutions have spread out in this manner indicates that the porphyry was extensively fractured and that the solutions were sufficiently mobile to work their way along minute fracture planes.

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[1] Described in some detail on page 81.

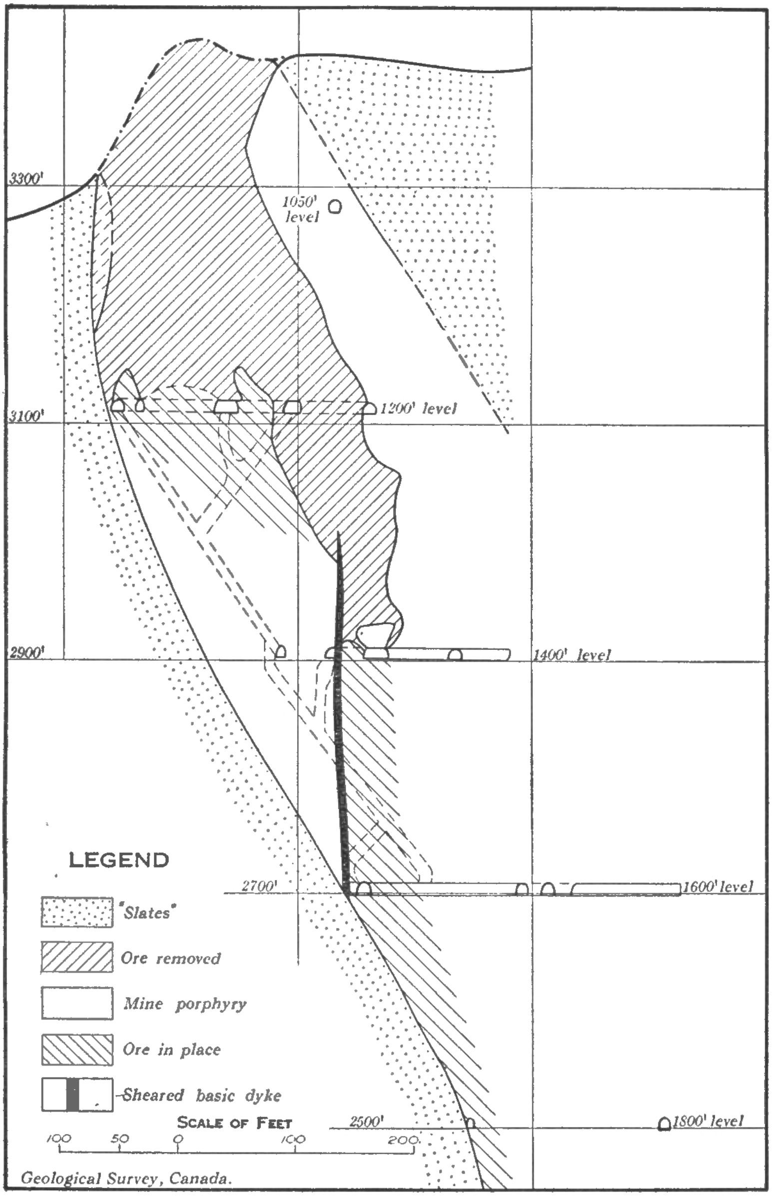


Figure 8. Vertical section of Bluff ore-shoot.

The general relations of the Hanging-wall ore-body to the slate hood, and to the Foot-wall ore are shown in Figure 9. Although it has not been proved that the Foot-wall and Hanging-wall ore-bodies unite at this particular section, the continuity of the two is definitely known from mine workings a very short distance east of the section. Stopes, between the two, have broken into both Hanging and Foot-wall stopes 100 feet or so above the 1,200-foot level. The influence of the slate hood in controlling the form of the ore-body is fairly obvious from this section.

The Bluff ore-shoot on the 1,050-foot level represents the combination Foot and Hanging ore-bodies. It is roughly elliptical in outline and occupies the full width of the mine porphyry from foot- to hanging-wall slates, but curiously enough commercial ore does not extend into the very apex of the structure (*See* 1,050-foot level plan in map-pocket). The sulphide minerals, apparently, have been crowded out of the most favourable localities by quartz. The ore zone is actually 150 feet shorter on the 1,050-foot than on the 1,200-foot level, illustrating again the fact that the concentration of ore solutions at any one point is not necessarily paralleled by an increase in the economic value of deposits at that point, but merely by an increase in the general mineralization, which may be the non-metallic minerals. The silicified zone on the 1,050-foot level is much more extensive than the ore-shoot, extending along the foot-wall for about 800 feet from the apex of the shear zone, and having a width of about 600 feet at the west end of the Fairview veins. The Bluff and Fairview mineralization forms one continuous zone on and above the 1,050-foot level, but below this level they are quite separate. The gradation between the two deposits is described and illustrated, following the description of the Fairview mine.

The Bluff ore deposits are the typical, and only important, examples of the siliceous copper ores in the shear zone. They represent extensive replacements in the sheared and fractured mine porphyry, and the most abundant metasomatic mineral is quartz. In the upper levels in particular, silicification has been very complete and the whole ore-body is composed of silicified rock containing variable amounts of chlorite, sericite, and the sulphides. Of the latter, pyrite is the most plentiful and chalcopyrite is the one mineral of economic importance. Sphalerite is distributed from the 2,200-foot level to the surface, but it is not an abundant mineral except on the upper levels. Some of the old records of diamond drilling on the 1,050-foot level show that, locally, sphalerite was even more plentiful than chalcopyrite. Galena is not a conspicuous mineral; it is frequently observed in the stopes above the 1,400-foot level. Individual specimens of bornite and tetrahedrite have been found, but these minerals are very rare.

In addition to the siliceous chalcopyrite ore, small deposits of the barite-sphalerite type are found on the 1,050-foot level, in the hanging- and foot-wall slates of Bluff mine. The occurrence in the hanging-wall slates is nearly 200 feet south of the slate contact, but the foot-wall band is in contact with the siliceous ores. There is, however, no transition between the two types of mineralization as in the Jane mine. The barite and sphalerite are confined strictly to the slaty foot-wall rock, and the siliceous ores to the porphyry. Since the two types of ore are in contact, and each is confined to a specific type of rock, it would seem that the composition of the rock influenced the type of mineralization.

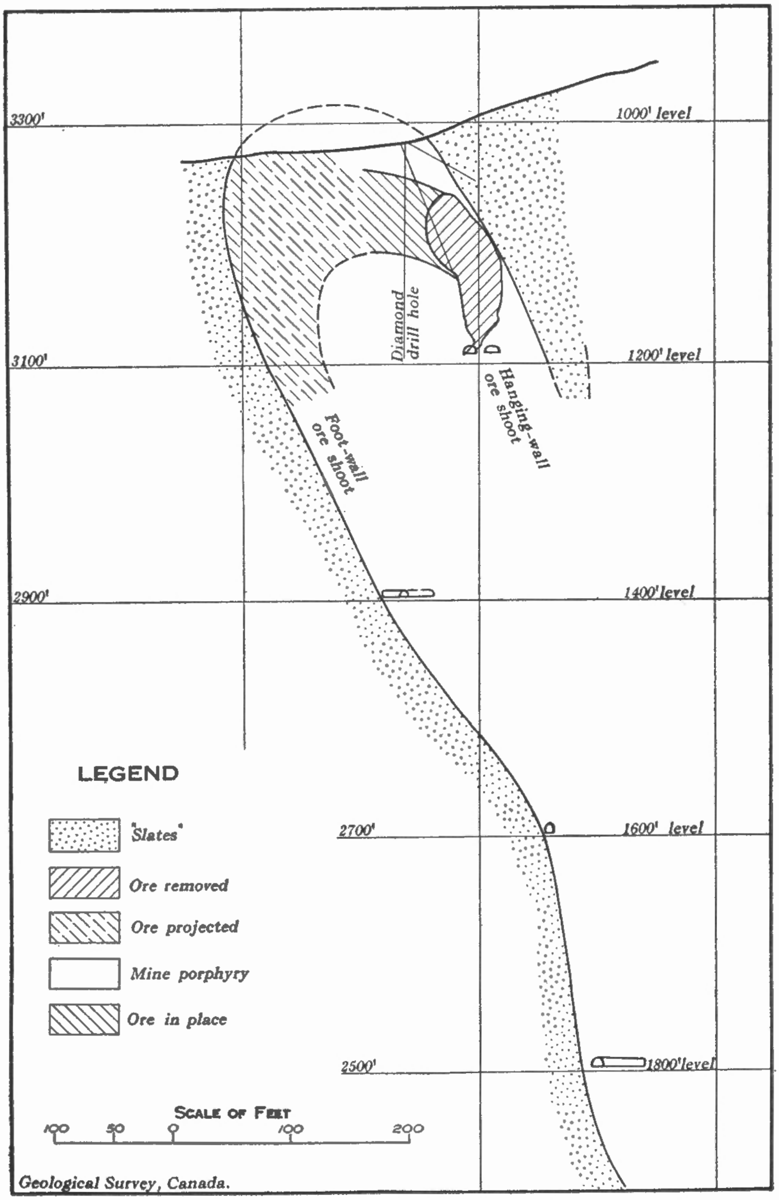


Figure 9. Vertical section of Bluff ore-shoots.

Fairview Mine

Two very different types of mineralization are extensively developed in the Fairview mine. Aside from the copper ores, anhydrite is widely distributed as replacement veins in both the hanging- and foot-wall sections of the mine, and occurring from the 850 to the 2,200-foot level at least. Although anhydrite has not been observed above the 850-foot level, it undoubtedly extended to the surface. The chalcopyrite veins are twelve in number and occupy about 1,700 feet of the shear zone immediately west of the Bluff mine. Eight of the veins, numbered from 0 to 7, and known as the Foot-wall veins, are fairly regular, tabular deposits occupying the foot-wall section of the shear zone. The remaining four veins, Nos. 8 to 11, are broad zones, in the hanging-wall section of the shear zone, which are irregularly mineralized along fractures, and are known as the Hanging-wall veins.

The general relation of the Fairview Foot-wall veins to the other deposits, and their attitude and distribution in the shear zone are clearly shown in the general plan of the 1,050-foot level. Although all the veins are not represented on this level it illustrates the character and relation of the veins better than any other. The favourable ore horizon, or the belt of green-mottled schist, is a belt about 400 feet wide and 1,700 feet long, striking northwest, essentially parallel to the main foot-wall of the shear zone, but separated from it by a zone of barren green-mottled and silver schist of variable width, up to 300 feet. The hanging-wall of the belt of green-mottled schist is defined on the 1,050-foot level by a series of albite dacite dykes, and south of the dykes is a broad band of silver schist. These different belts of rock are essentially parallel to one another and to the schistosity, striking northwest, and dipping southwest at about 70 degrees, but in detail the structures are not strictly parallel. The west end of the ore zone is nearer the foot-wall of the shear zone than is the east end. And, although the albite dacite dykes are nearly parallel to the schistosity in plan, the northerly dykes are distinctly inclined to it in section (*See* Figure 10). The band of soft, silver schist, carrying the anhydrite veins on the south side of the dykes, changes its character a few hundred feet above the 1,050-foot level, and is represented on the upper level by very massive schist and the Hanging-wall veins. The east end of the Foot-wall veins is defined by a very soft, shear zone, designated as the Fairview slip. It is a very persistent zone of fine chlorite schist, developed from one of the pre-shearing basic dykes, which crosses the east end of the ore zone at a small angle, and marks the easterly limit of commercial ore. The west end of the slip is about parallel to the veins, and is a natural boundary between the Foot and the Hanging-wall veins (*See* Figure 10). The west end of the Foot-wall ore zone on the 1,050-foot level grades into the general Bluff silicification, but below the 1,050-foot level, the Fairview and Bluff ore zones diverge at a small angle, although both plunge steeply to the west.

The veins are distributed in the ore horizon in a very orderly manner, but unlike the other general features of the zone they are oblique to all the structures in plan, although conformable to them in section. The strike of the major structures is north 45 degrees west, but the strike of the veins varies from north 55 to 65 degrees west. In any short section of a vein the schistosity and the veins are apparently parallel, but in following a vein along a drift for some distance a "breaking over" to the left is quite noticeable. As a result of this the veins approach the foot-wall of the shear zone as they go east. The most northerly veins (near the foot-wall) are the first to be intercepted by the foot-wall, and since the west end of the northerly five veins (Nos. 0 to 4) are in approximately the same longitude, the veins become progressively longer the farther they are from the foot-wall. The west end of the fifth to seventh veins is cut off by the hanging-wall of the green schist zone, and the east end by the Fairview slip, so that the length of the veins does not increase indefinitely. The longest vein is the third-fourth vein system which has been mined continuously for 1,200 feet. It is represented by two distinct veins above the 1,050-foot level, but, on and below the 1,050-foot level, they unite to form one continuous ore-body extending to the 2,200-foot level. The fifth vein is only 200 feet shorter than the third-fourth vein system, and has the same vertical range. The veins vary in width from 5 to 40 feet and are invariably wider on the upper levels.

The Foot-wall veins are essentially replacement deposits along fracture zones which were developed at the time the mine porphyry was sheared. They consist of reticulating masses of quartz and sulphides enclosing variable amounts of schist. Filling of open spaces undoubtedly has been of some importance and is clearly recognized in a number of places, but the replacement process is believed to have been the most important. Masses of vein material, from a few inches to several feet in width, may be composed essentially of quartz and sulphides, containing only a few thin flakes of schist, which usually retain their normal orientation. These may be traced from large blocks to narrow, discontinuous streaks, which are very difficult to explain unless they are replacement residuals. If filling of brecciated zones had been the principal method of ore replacement a very clear and distinctive pattern would have been developed somewhat similar to the vein pattern in Plate III A, but such patterns are seldom preserved and the inference is that they have been modified by replacement.

The Hanging-wall veins consist of four broad zones of commercial ore separated by bands of mineralized schist. After having mined the richer streaks, or the veins, by underground methods, the remainder has been mined successfully from the surface. They differ from the Foot-wall veins in that the mineralization is carried in a great number of narrow individual veinlets, rather than in relatively narrow zones of interlocking veinlets and massive replacements. All gradations are found, of course, between the typical Hanging-wall vein and the typical Foot-wall vein, but each is a distinct type of vein, and is well represented. The stringers in the two northerly veins of the Hanging-wall group (Nos. 8 and 9) are chiefly parallel to the schistosity, but in the two southerly veins (Nos. 10 and 11) transverse stringers are very numerous and carry a large proportion of the ore. The attitude of the mineralized fractures and stringers in the tenth vein is shown in Figure 5.

Another difference between the Hanging and Foot-wall veins is that an important amount of the sulphides in the former has been deposited in

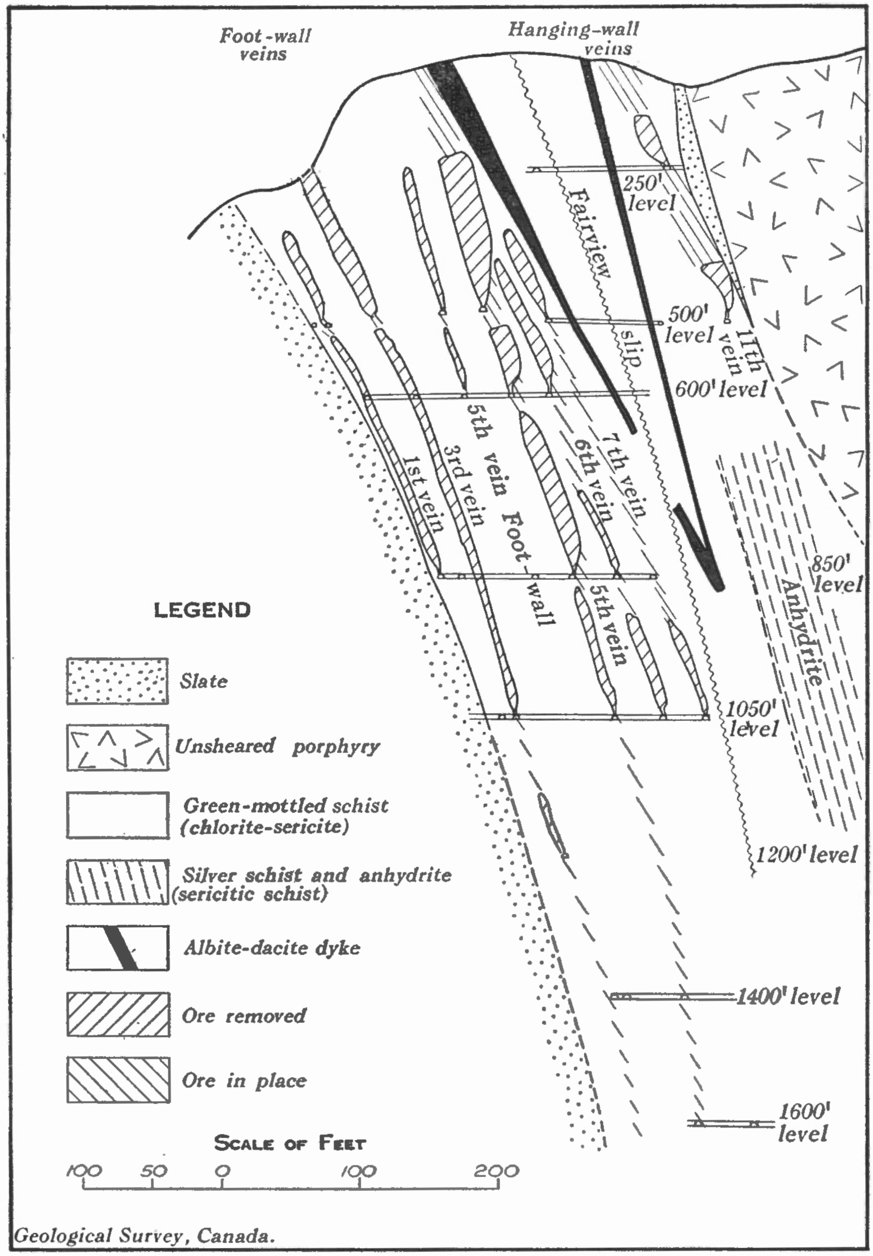


Figure 10. Transverse section of Fairview mine.

open spaces, rather than by a replacement of the wall-rock. The relative importance of the two processes cannot be determined, but open space filling is indicated in a great number of the veinlets by the development of banding and a comb structure. The walls of the veinlets are frequently lined with quartz crystals, projecting inward, and the centres are filled with pyrite and chalcopyrite. More commonly, the banding is not developed, but the veins have all the appearances of fractures that have been filled with the sulphides. They are as regular and uniform in width as those veinlets in which comb structure is developed and presumably have been formed in the same manner. Silicification is pronounced in the vein immediately under the hanging-wall of the shear zone and it contains irregular bunches of replacement ore.

The mineralogy of the Hanging and Foot-wall veins is essentially the same. Aside from quartz, which is the dominant mineral, pyrite and chalcopyrite are the only two minerals that are at all conspicuous. Sphalerite, tetrahedrite, galena, calcite, barite, and chlorite occur sparingly as vein minerals. Unlike the Bluff ores, sphalerite is an uncommon mineral in the Fairview veins, having been found only in the transition zone between the Fairview and Bluff and in one small bunch on the 2,200-foot level. As far as the writer's experience goes sphalerite is found only around the fringe of the commercial veins. It is accompanied by barite, galena, and at one point, by tetrahedrite. The latter, however, is very rare in the Fairview mine and is apparently confined to the transition zone between the Fairview and Bluff mines.

Anhydrite is widely distributed in the Fairview mine, occurring on both the hanging and foot-wall side of the main sulphide ore zone, but not directly related to the sulphide ores. Much of it, on the 1,050-foot level, is replaced by gypsum, as a supergene alteration product. The largest mass of gypsum is a vein 15 or 20 feet wide occurring in the foot-wall slates near the west end of the Fairview mine, and smaller stringers are found in the soft schist farther east along the foot-wall. The band of silver schist forming the hanging-wall of the ore zone on the 1,050-foot level contains very numerous stringers of anhydrite, partly altered to gypsum. The anhydrite frequently possesses a pinkish tinge, and the gypsum which is replacing it is white translucent material.

The anhydrite occurs unquestionably as a replacement of the schist, for all gradations are found between schist containing a few specks, and anhydrite in which nothing of the schist remains but ghosts of the chlorite blotches, and this in turn grades to pure anhydrite. The solutions depositing the anhydrite have been capable of removing all the material of the schist and of depositing anhydrite only. The chlorite of the schist was first altered to a very light-coloured variety, and this, apparently, was resistant to the solutions, for it was the last mineral to be replaced. As a result of the blanching of the chlorite, the schist is lighter coloured than the average, and is represented on the plans as silver schist, although, by definition, the latter is really a sericitic schist, representing a very highly sheared phase of the mine porphyry. Much of the schist included in the hanging-wall band of silver schist is the highly sheared, sericitic variety, but some of it, at least, is the bleached green-mottled, or chlorite-sericite schist.

The hanging-wall zone of silver schist and gypsum represents the downward extension of the massive schist, and sulphide mineralization of the Hanging-wall veins, but unfortunately mine workings do not connect these two highly contrasted types of rock and mineralization and their detailed relations are not known.

FAIRVIEW BLUFF GRADATION

The Bluff and Fairview mineralizations grade into one another on and above the 1,050-foot level, and the Bluff type of ore changes towards the Fairview type on the lower levels. Both of these gradations are partly attributable to the influence of the slate hood on ore deposition.

The most conspicuous difference between the siliceous copper ores of the Bluff, and the chalcopyrite veins is that the former occur as indefinitely defined ore-shoots in a silicified body of rock, whereas the latter are clearly defined veins in relatively unaltered rock. It has been suggested above that the reason for this difference is that the Bluff ore-body has been developed in a section of the mine porphyry that has been extensively fractured, thus permitting the ore solutions to pervade large masses of rock, and exposing it as relatively small, discrete blocks, to the influence of the solutions; whereas the solutions forming the vein deposits were confined to definite channels bounded by impervious schist. Assisting in the silicification of the Bluff ore zone, is the slate hood which has intercepted the solutions rising in the entire Bluff zone and directed them upward along the fractured nose of porphyry. In this way, sections higher up in the structure are exposed to a much greater volume of solutions than sections lower down, and are more highly altered. In conformity with this we find that the most intensely altered zones in the Bluff mine are on the 1,050 and 1,200-foot levels immediately beneath the slate hood. The Bluff ore zone below the 1,200-foot level is not nearly so siliceous as above that level, and on the lower levels of the westerly ore-shoot the lack of Bluff silicification, and irregularity of the ore, are still more noticeable. Breasts of ore on the 2,000-foot level of the Bluff are almost identical with breasts of ore in the Fairview veins. The gradation towards the Fairview type of mineralization is not limited to a decrease in the intensity of the wall-rock alteration, but is accompanied by a parallel change in the mineralogy. Sphalerite is an abundant mineral on the upper levels of the Bluff, but it is distinctly less plentiful on the lower levels. Galena is also more rare on the lower levels, and since both these minerals are found only locally in the Fairview, it seems that the Bluff ore deposits, on the lower levels, are approaching the Fairview type.

The slate hood has intercepted the solutions rising in the Bluff channels, and has directed them to the east across the zone that normally separates the Fairview and Bluff ore zones. Presumably the Bluff solutions alone are responsible for the mineralization between the Bluff and Fairview, but the general silicification at the west end of the Fairview veins would be the result of the combined action of the two streams of solutions. Normally the wall-rock alteration accompanying the Fairview veins is an inconspicuous type, limited to a pyritization of the chloritic blotches, a replacement of the feldspars by quartz, and a slight silicification, but on the upper levels, as the west end of the Foot-wall veins is approached, the silicification becomes more intense, and the zones of silicification become wider, finally uniting to form the transition zone between the Bluff and the Fairview. This is illustrated in the plan of the 1,050-foot level, which is the only level containing the Bluff ores, the transition zone, and the Fairview veins. Below this level the Bluff and Fairview ore zones are separated by barren schist, and above it, parts of the Bluff, and of the transition zone, have been destroyed by the glacier that cut Jane Creek basin. The gradation on the 1,050-foot level, however, is really not complete or typical because it catches only the lower fringe of the transition zone (*See* Figure 7). It is true that the veins (Nos. 0 to 4) are embedded in a silicified mass of rock, but still they are distinct veins and not the large, irregular deposits typical of the Bluff ores.

A more complete picture of the transition may be obtained by combining the plan of the 1,050-foot level with a vertical section through the west end of the Fairview veins. This plan and section are assembled in Figure 11, which indicates also the approximate position of the slate hood. It so happens that the hanging-wall of the Fairview veins is defined at this section by one of the larger albite dacite dykes, which has acted as a barrier to the ore solutions, and has assisted the slate hood in confining them to a restricted channel way. Although the dyke has assisted in developing the transition zone at this point, it is not an essential feature, for veins on the hanging-wall side of the dyke, farther east on the upper level, show the same tendency to widen out into silicified masses of schist. The dominating influence, therefore, seems to have been the slate hood; except for it the Bluff and Fairview solutions would have continued upward along their respective channel ways, the Bluff solutions would not have been deflected into the Fairview zone, and there would have been no Fairview-Bluff transition zone.

According to Figure 11, it will be observed that the Fairview ore along the third-fourth vein does not extend far into the silicified wedges that project from the Bluff. Along the continuation of the vein, the chalcopyrite decreases in amount, sphalerite makes its appearance, barite becomes conspicuous, and small amounts of galena and tetrahedrite are found. The increase in sphalerite indicates a tendency to change towards the Bluff type of mineralization, but the association of sphalerite with barite, tetrahedrite, and galena is more characteristic of the barite-sphalerite mineralization, typically developed in the Jane mine. The possible significance of this mineral association will be discussed in a later section. The gradation of the Fairview veins into the Bluff type of ore-body is better illustrated in the vertical section part of the diagram. The silicification around the third-fourth vein begins to widen around the 1,200-foot level and continues to widen as it approaches the slate hood. The vein between the 1,200 and 1,050-foot levels is fairly uniform and well defined, but above the 1,050-foot level both the ore and the silicified zone widen rapidly, and the regularity of the Fairview veins is lost completely. On the 850-foot level the silicification and the general character of the ore are very similar, indeed, to the Bluff ores, and the Fairview veins actually grade from relatively narrow, distinct veins to very broad, irregular, siliceous masses which are characteristic of the Bluff mine.

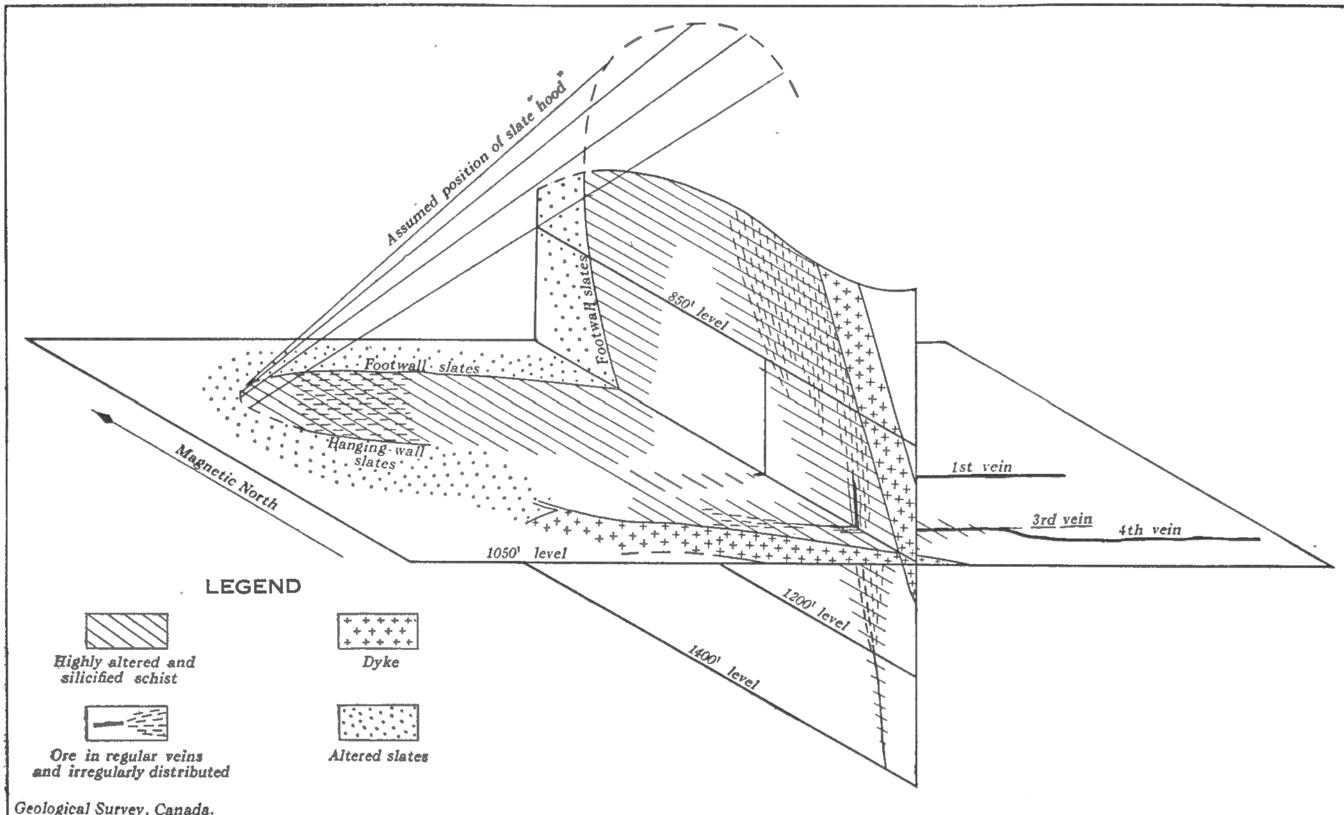


Figure 11. Illustrating the grading of the Fairview veins into the Bluff type of mineralization.

Empress Mine

The Empress mine occupies a position on the foot-wall of the shear zone about 800 feet east of the Fairview. It is confined to a wedge-like mass of schist, embedded in the foot-wall slates,[1] in somewhat the same manner as the Bluff-Fairview ore zone is surrounded by the main slate hood.[2] The Empress structure, however, is much smaller, and has been formed in a different manner. The small wedge of slate forming the hanging-wall (south) side of the structure, is believed to have been dragged into the main shear zone along the local zone of intense shearing which is mapped as silver schist. Just at the west end of the small wedge of hanging slate, the silver schist is narrow and very highly sheared, but farther east it widens considerably, although retaining much of its very fissile character. The Empress structure is developed only above the 1,050-foot level; below this level neither the narrow hanging-wall wedge of slate, nor the narrow band of very highly sheared schist have been found. The ore zone extends from the surface, between the 600 and 700-foot levels, to the 1,600-foot level at least.

The Empress ore zone is divided into two ore-bodies, known as the first and second veins, by a second band of silver schist which meets the foot-wall of the shear zone at a small angle about 100 feet east of the apex of the main Empress structure. Each vein, therefore, is a wedge-shaped body, whose hanging-wall is a soft, intensely sheared schist, and whose foot-wall is either the foot-wall of the shear zone or the silver schist. These walls are all soft and have added considerably to the difficulties of mining. Two basic dykes are found in the hanging-wall section of the mine. The larger of these, striking about parallel to the foot-wall, apparently has been offset by the narrow band of silver schist which, of course, is essentially a fault zone if the Empress structure has been developed in the manner suggested. The reason for the abrupt termination of the other dyke is not known.

Although the walls of the veins are soft, the rock within the vein zones is distinctly massive and less sheared than much of the green-mottled schist of the Fairview mine. The ore occurs as very numerous, irregular, and discontinuous stringers, forming an ore zone rather than a distinctly defined vein. The Empress ores contain appreciable amounts of sphalerite in addition to the quartz, pyrite, and chalcopyrite that are present in all the deposits, and in this respect they resemble the Bluff ores. Silicification, however, is not pronounced except locally, at the west ends of the veins on the upper levels.

Victoria Mine

The Victoria mine is the most easterly of the Britannia mines and is situated directly on the foot-wall of the shear zone, about 1,000 feet east of the Empress. None of the veins outcrops on the surface, but all are covered by about 100 feet of glacial till which conceals so much of the shear zone in South valley. The Victoria is the last of the Britannia mines to have been discovered, and was located by diamond drilling along the strike of the shear zone. The early prospectors had recognized the general trend

[1] *See* plan 1,050-foot level.
[2] *See* Schofield, S. J.: Loc. cit., p. 284.

of the Britannia ore zone, and had started small shafts almost over the Victoria deposit, but the unusually thick mantle of drift was too great an obstacle to be overcome by individual prospectors with their limited equipment. The red rock, at the west end of the Victoria ore zone, is a short distance above the 1,800-foot level, and is below this level at the east end of the mine. The mine has been developed to the 2,500-foot level without any indication of a decrease in the values or the size of the veins. This is the lowest level that has been developed in the Britannia mines, but a tunnel is being driven on the 2,700-foot level to tap the west end of the shear zone.

The commercial veins of the Victoria mine are confined to a zone 900 feet long by 200 feet wide, along the foot-wall of the shear zone. The northern boundary is indicated by two wedges of slate, and the hanging-wall is defined by a broad band of silver schist which is apparently continuous with one of the silver schist bands of the Empress mine. The Victoria ore zone differs from the Bluff, Fairview, and Empress ore zones, in that sheared members of the Britannia formation are represented, and mineralized, as well as the mine porphyry. In the other mines of the shear zone, except the Jane, the sulphide veins are strictly confined to sheared phases of the mine porphyry, although barite-sphalerite ores and anhydrite veins are found in the foot-wall rocks, which belong to the Britannia formation. In the Victoria mine the sulphide veins not only occur in rocks of the Britannia formation, but cross, indiscriminately from one formation, or one type of schist, to the other. They are not found, however, in the slates or the silver schist, and the anhydrite veins are, apparently, confined to the slates. Aside from the slates, the green-mottled and the silver schists, which are common to all the mines, a "Victoria" and a "light green" schist are recognized in the Victoria mine. The latter is a typical chloritic schist developed from an andesitic rock and is readily distinguished from the other schists in most parts of the mine. The boundaries are obscured by shearing, but the typical rock is quite distinct from the typical green-mottled schist. Usually the cleavage planes contain very sharply defined, dark green, elliptical blotches of chlorite, which are apparently flattened amygdules. The Victoria schist is a difficult rock to describe. It resembles the green-mottled schist, and frequently the two rocks cannot be distinguished, but in general it has a much more irregular, blotchy appearance as though developed from a breccia containing fragments of slightly different composition. It is believed to be a member of the Britannia formation. Owing to the uncertainty of the distribution of the green-mottled and Victoria schists in certain parts of the mine, both types are indicated as green-mottled schists on the accompanying plan of the Victoria mine, except for one band of Victoria schist along the foot-wall of the ore zone.

Within the Victoria ore zone are five distinct veins, as well as small lenses of commercial ore. They strike northwest, parallel to the foot-wall of the shear zone, and dip at 80 to 90 degrees to the southwest. The two northerly veins are from 25 to 30 feet apart throughout the greater part of their length, but coalesce towards the west end in a single, broad, siliceous ore zone. The west end of the two veins, above the 2,000-foot level, is restricted to a wedge of schist embedded in slates, but the slates

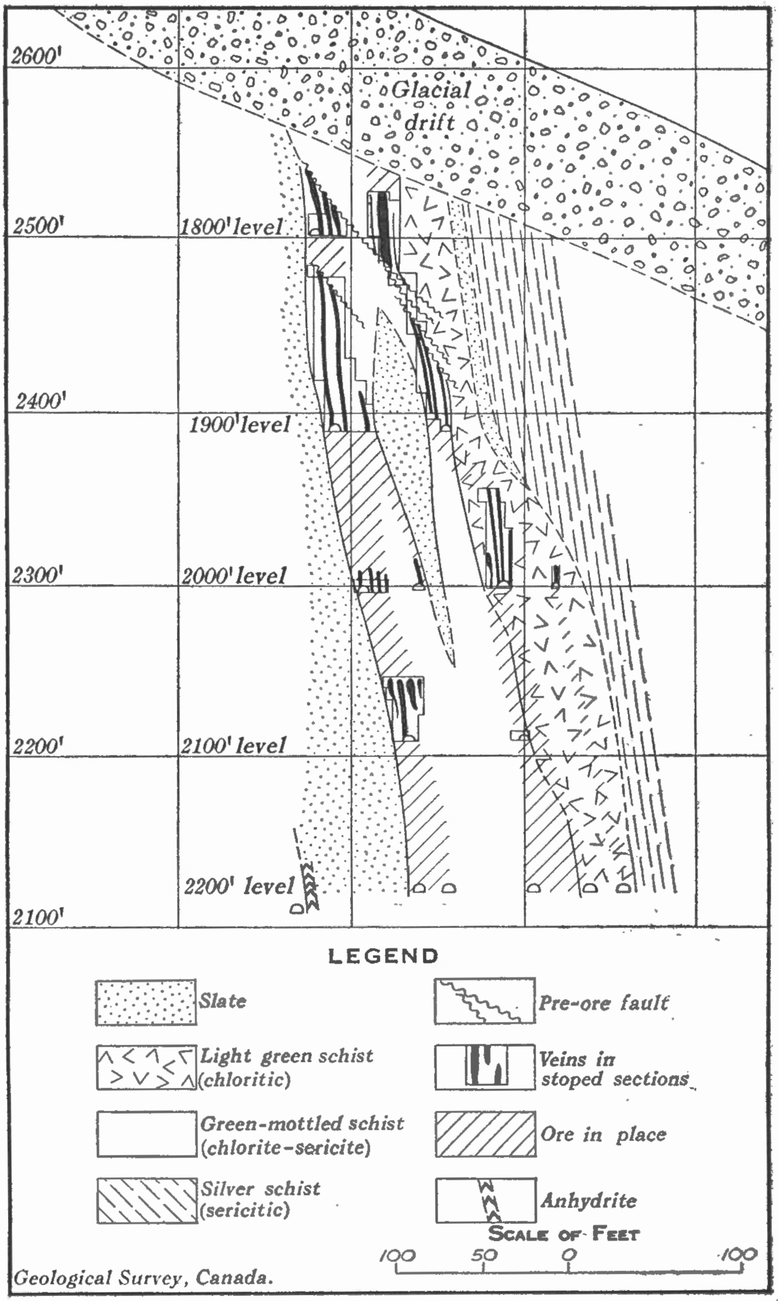


Figure 12. Transverse section of Victoria mine.

that form the hanging-wall part of the wedge do not continue to the 2,100-foot level (*See* Figure 12). The ore, in the eastern half of the northerly vein, occurs in a series of distinct lenses arranged *en échellon* along the general trend of the foot-wall. Each lens is 1 or 2 feet to the left of its neighbour. On one of the upper levels, the ore occurs along the contact of the light green and Victoria schists, and the lenses seem to be related to irregularities of the contact, resembling drag folds, but the schists in the vein zone are so difficult to distinguish, that the exact nature of the irregularities and their relation to the lenses could not be determined. In the wider, silicified section of the veins, the ore occurs in a number of parallel zones, each consisting of massive to reticulating stringers of quartz and sulphides.

The remaining three principal veins of the Victoria mine constitute a hanging-wall group of veins, and consist of two short lenses on either side of a long, persistent vein known as the "E" vein. It is about 900 feet long and throughout the greater part of its length it follows the contact of the light green and the green-mottled schist, very closely. The ore, however, is not confined to the contact nor to either one of the schists, and the relation of the vein zone to the contact seems to be a coincidence, and of no particular significance. The unimportance of the contact zones in influencing the position of the Victoria veins is well demonstrated by the manner in which the two foot-wall veins cross from one rock to the other without a break in the mineralization (*See* plan in pocket). The central vein of the hanging-wall group is relatively narrow at the east end and consists of the usual interlocking stringers and lenses of sulphides and quartz. Towards the west, the vein widens to 20 feet and more, and is made up of a number of narrow, parallel stringers. It is in this section that the two shorter veins of the hanging-wall group make their appearance, one on either side of the main vein.

The mineralogy of the Victoria ores is extremely simple. Quartz and pyrite are essentially the only gangue minerals, and chalcopyrite the only ore mineral present. A specimen of galena was found in one of the foot-wall veins and calcite occurs sparingly.

A description of the Victoria ore zone is not complete without mentioning the beautiful vein of anhydrite which is developed in the foot-wall slates, and exposed in the haulage tunnel on the 2,200-foot level. The vein is 4 or 5 feet wide and is pure, massive anhydrite, except for occasional slivers of unreplaced slate or stringers of secondary gypsum. On the 2,000-foot level the anhydrite vein is completely altered to gypsum, and on the 1,900-foot level, 100 feet below the glacial till, the gpysum has been carried away by the circulating ground waters, leaving a soft mass of residual slate saturated with water. The gypsum is directly related to the surface and is undoubtedly a supergene mineral.

Wall-rock Alteration Accompanying the Shear Zone Deposits

The host rock of nearly all the ore deposits in the Britannia shear zone is a sheared or fractured phase of the mine porphyry, and only small amounts of ore are found in metamorphosed igneous and sedimentary rocks in the Jane mine, and in sheared basic rocks in the Victoria mine. The mine porphyry is an albite dacite, containing phenocrysts of sodic plagioclase in a fine-grained groundmass of quartz, plagioclase, and chloritized femic minerals. By shearing, the porphyry is converted into a chloritic schist, which is known as the green-mottled schist, owing to the development of irregular chloritic blotches along the cleavage planes. Phases of this rock contain all the commercial ore in the Bluff, Fairview, and Empress mines, and a good proportion of the ore in the Victoria mine.

The only materials that have been added to the wall-rock in any appreciable amounts are quartz and pyrite, and of these, quartz is by far the more abundant. Other minerals appearing as metasomatic products are chlorite, sericite, calcite, apatite, leucoxene, and locally barite, but all of these materials are only intermediate transitory products, developed during the early stages of alteration. The ultimate product of wall-rock alteration in the shear zone deposits is a completely silicified rock. It is true the final stage is never reached, except in tiny areas, frequently microscopic, but the tendency towards complete silicification is very clear. Pyrite is more resistant than the other minerals, but it is invariably corroded by quartz, and is not stable, therefore, under the conditions of intense silicification.

The most feeble expression of hydrothermal alteration is a partial replacement of the plagioclase phenocrysts by quartz, accompanied by small and variable amounts of chlorite, sericite, calcite, and apatite. Some of the chlorite and sericite occurring along the fractures in the phenocrysts, may have been developed during shearing, but the quartz, calcite, and apatite are undoubtedly hydrothermal minerals, introduced during the ore-forming period. Usually the phenocrysts are replaced by aggregates of clear quartz, but, occasionally, calcite represents a considerable proportion of the original crystal, and not infrequently the quartz contains from one to several small crystals of apatite. This feeble stage of the alteration is usually accompanied by the development of tiny pyrite crystals in the chloritic blotches, and is very extensive. It is found on the upper levels, 300 or 400 feet from the nearest known ore-body, and within 50 feet of the highly altered rock at the west end of the third vein on the 1,505 foot level.

More advanced stages of alteration are marked by a complete silicification of the phenocrysts, the removal of calcite, and a more pronounced development of pyrite in the blotches. The amount of pyrite not only increases, but the former pyrite apparently recrystallizes to larger grains. This is followed very closely by a silicification of the chloritic blotches. In nearly every slide that contains pyrite, slender fibres of quartz are found radiating from the pyrite cubes, and replacing either the blotches or the finer groundmass material. The early stages of silicification are accompanied by a slight recrystallization of the chlorite and sericite of the blotches into coarser grained aggregates of the same minerals. The original chlorite has positive elongation, but all the recrystallized chlorite has negative elongation, and resembles the aphrosiderite which occurs in cavities within some of the Fairview veins.

Intense silicification is associated with the copper ores of the Jane and Bluff mines particularly, and is developed to a less extent at the west end of the Fairview veins on the upper levels, and at the west end of the

Victoria foot-wall veins. However, the amount of silicification accompanying the average vein is remarkably slight, and usually cannot be detected in a macroscopic examination of the rock. Silicification seems to be of two different types; first, there is a general silicification which alters the rock to an aggregate of very cloudy quartz containing residuals of the former rock constituents, and the sulphide minerals; and second, there is a development of fine fibrous quartz, which usually radiates from the sulphides, and replaces everything in front of it. Even the first generation of cloudy quartz is replaced by, or recrystallized to, the fibrous variety, and the dust-like particles are removed. The fibrous quartz is not necessarily a late product, for it formed during all stages of alteration, but the point is that it continues to develop even after silicification is, apparently, complete, and does not cease until the older, cloudy, and impure quartz is replaced by clear, pure material.

Sufficient work has not been done to determine the extent of this secondary recrystallization of the quartz, but it may have an important bearing on the distribution of the ore in the Bluff mine, which contains the most typical example of the siliceous ores. It has been shown previously that the most favourable place for mineralization would be in the very apex of the mine porphyry, immediately beneath the slate hood, but that the highest grade ore is not located at this point. The very apex, however, is the most highly silicified zone in the mine, and it would be interesting to find whether or not the sulphides were concentrated there originally, and were displaced later by the quartz, or whether the quartz was there first and simply excluded the sulphides. The first alternative is not at all improbable, for the pyrite is invariably corroded by quartz, and the fibrous quartz is found radiating from chalcopyrite and sphalerite, and is, therefore, later than these minerals. The actual reason for the exclusion of the sulphides from the very apex of the shear zone is not known and cannot be determined without further study.

The Jane mine affords an excellent example of later silicification destroying a good commercial ore. The barite sphalerite ores of the sedimentary rocks are very definitely earlier than silicification, and have been replaced by a fine, dense mass of cherty appearing quartz. The original extent of the barite sphalerite is not known, but the zone was at least a few feet wider than the present zone. The silicification is on the foot-wall, or north side of the ore zone; on the south side, the only metasomatic mineral recognizable in the wall-rock, which is a very fine-grained argillite, is a phosphate, resembling apatite (*See* page 77).

DEPOSITS NEAR THE BATHOLITH

A number of prospects have been located in the highly metamorphosed rocks of the Lower Goat Mountain formation exposed in Indian river. The formation is in a favourable position for general mineralization, for it occupies a depression in the batholith corresponding closely to the topographic depression of Indian River valley. Except at the north end of the valley on the east side, the batholithic rocks form the upper valley walls and the ridges, and the pre-batholithic rocks are restricted to the lower slopes and the valley floor. In addition to being partly surrounded by the batholith they are intruded by numerous irregular and dyke-like apophyses from the batholith, with the result that metamorphism is pronounced, particularly in the greenstone members, and at intervals sulphide mineralization is concentrated. The same band of greenstones continues north beyond the limits of the map-area and should be a favourable district for prospecting. Several discoveries have been made in this section, and there is no reason why other mineral occurrences should not be located. The districts around the upper part of Indian and Stawamus rivers have been made accessible by a good pack trail from Squamish, situated at the head of Howe sound.

Chalcopyrite is the one mineral of economic importance, and apparently the only sulphide minerals associated with it are pyrite, sphalerite, and pyrrhotite, the latter occurring very rarely and only in isolated stringers. The sphalerite is a very dark-coloured variety, containing more iron than the amber-coloured and colourless varieties found in the shear zone deposits. The difference in the iron content is apparently 4 or 5 per cent, for the difference in refractive indices is about 0·01. The occurrence of an iron rich sphalerite in this type of deposit suggests that it has been formed at a higher temperature than the shear zone deposits, and this suggestion is supported by the fact that barite, anhydrite, tetrahedrite, and galena are confined to the latter group. This is to be expected on the zonal theory of ore distribution, provided the batholith was the source of the ore solutions, for the shear zone deposits are 4,000 feet from the batholith, whereas the near batholith deposits of this group are within a few hundred feet of it.

Belle Group

The Belle group of claims is situated on the west side of Indian river about three-quarters of a mile south of the divide between Indian and Stawamus rivers. A good pack trail leads from Squamish to an excellent cabin on the group, which has been constructed near the principal showings, at an elevation of about 2,250 feet above sea-level, or 400 feet above Indian river. The group is owned by J. Habrich and P. Herres, and consists of five Crown-granted claims, known as the Ethel, Rose, Irish Molly, Lucky Jack, and Jenny. The workings consist of two tunnels and a number of open-cuts.

The mineralization occurs in a light-coloured, fine-grained, granular rock composed chiefly of oligoclase, quartz, and orthoclase, in variable proportions, and containing in addition small amounts of brown biotite, chlorite, rutile, apatite, zircon, and magnetite. Although rutile and apatite represent only a very small proportion of the rock they are very abundant for accessory constituents, particularly the former. Mineralogically the rock resembles the batholithic rocks of the area, but the microscopic texture is that of a recrystallized rock rather than of an ordinary igneous rock. The original texture is so completely destroyed that the origin of the rock could not be determined. Camsell[1] refers to it as "granodiorite porphyry" and it appears to grade into the batholith on the north side. Exposures, however, were not sufficiently good to prove this conclusively, and since the two thin sections examined obviously

[1] Camsell, C.: "Indian River Copper Deposits"; Geol. Surv., Canada, Sum. Rept. 1917, pt. B, p. 24.

represent a highly metamorphosed rock, it seemed advisable to refer to them, for the present at least, as "metamorphic rocks of unknown origin." The width of the outcrop in Canyon creek—a small stream, well named, just south of the cabin—is about 2,000 feet, and consists of two zones separated by an irregular band of greenstone. In Canyon creek the greenstones are quite narrow, but they widen rapidly on either side of the creek. The sulphides occur in lenses and bunches throughout the siliceous rock, but the greenstones are barren.

Several open-cuts have been made in the upper of the two bands of siliceous metamorphic rocks and have exposed variable amounts of mineralization. One showing about 200 feet above the cabin, and lower tunnel, is well mineralized over a width of about 25 feet, but apparently no concerted attempt has been made to determine the actual dimensions of the mineralized area. It is one of the early discoveries, and has been described by Brewer[1] as follows: "The most important of these outcroppings is one which the writer sampled in 1913. The sample was taken across 25 feet in width, and while it is not considered an average of the showing, it represented such ore as could be roughly sorted from the ore-body, and assayed: gold, trace; silver, 2 ounces; copper, 5·3 per cent. . . . . The length of the outcropping exposed by stripping is about 50 feet." The tunnel near the cabin was driven to cut this and lower exposures, but was started in the greenstones and has not been driven far enough to reach the siliceous metamorphic rock. The length of the tunnel is approximately 120 feet. A second tunnel about 110 feet long is a few hundred feet east of the cabin and about 150 feet above it in elevation. It also is in the greenstones and, therefore, barren.

Bulliondale Group

The Bulliondale group, consisting of six claims, Lady of the Lake and Bulliondale Nos. 1 to 5, adjoins the Belle group on the south, and is owned by Robert Mungall of Vancouver. Nothing has been done on the property for a number of years and the showings and tunnels could not be located. The following description, therefore, is taken directly from other sources.

After mentioning that the Bulliondale group is on the same side of the river as the Belle, but lower down the valley, Camsell[2] describes the mineral occurrence as follows.

"It is on the same ore zone and the ore occurs under similar geological conditions. A tunnel about 100 feet in length was driven to crosscut the lead at a point about 1,000 feet above the river, but the entrance was caved by a slide and could not be examined. The ore occurs in a fine-grained acid porphyry dyke, mineralized by pyrite and chalcopyrite, and also in a reddish, knotted, silicified limestone along the contact of the dyke."

The showings in the tunnel are described by Brewer[3] in the following terms.

"At the head of a gulch, a tributary to Mungall creek on the north side of the creek and about 800 feet elevation above the trail, on the Lady of the Lake mineral claim, there is an adit 100 feet in length, driven in a south 75 degrees west (magnetic) direction, which crosses three bodies of low-grade copper minerals. The

[1] Brewer, W. M.: Ann. Rept., Minister of Mines, B.C., 1917, pt. F, p. 276.
[2] Camsell, C.: "Indian River Copper Deposits"; Geol. Surv., Canada, Sum. Rept. 1917, pt. B, p. 24.
[3] Brewer, W. M.: Ann. Rept., Minister of Mines, B.C., 1917, pt. F, p. 277.

first ore is exposed near the portal of the adit and apparently is crosscut along the top. This body dips into the mountain about 30 feet from the portal of the adit. The second body of ore exposed in the adit is about 60 feet from the portal; it shows for 10 feet in width, and is drifted on to the southeasterly a short distance. A sample taken across 3 feet at the face assayed: gold, trace; silver, trace; copper, 0·5 per cent. A third body of low-grade copper mineral is exposed near the face of the adit, where the indications show that the ore is continuing beyond the face and that the full width is not exposed."

Roy Group

The Roy group is situated on the east side of the river about 3½ miles south of the divide between Indian and Stawamus rivers. It consists of eight Crown-granted claims known as the Roy Nos. 1 to 8, and is owned by the Britannia Mining and Smelting Company. Formerly a good trail connected the workings with the main Indian River trail which followed Indian river down to tidewater, at the head of North arm, a part of Burrard inlet, but the lower part of the Indian River trail is now in disrepair. The section of the Indian River trail connecting the Roy group with the Squamish trail, at the head of Indian river, is in very poor condition, particularly where it crosses some of the wide snow slides. The principal workings, and the site of the old camp, which have been broken down by the weight of snow, are about 800 feet above the river, at an elevation of 1,900 feet above sea-level.

The principal showing is a massive sulphide vein, striking about northwest, parallel to the hillside, and dipping to the southwest at a slightly flatter angle than the hill. The hanging-wall of the ore-body, and an appreciable amount of the ore itself, have been removed by erosion, leaving the vein exposed as a blanket on the surface. It is several feet thick in places, and, according to Camsell[1], the surface area of the high-grade ore is about 2,300 square feet. The sulphide minerals are chiefly chalcopyrite and pyrite with a very small amount of sphalerite. Lower down the hill a considerable amount of work has been done in very highly silicified zones in the greenstone, but the sulphide mineralization in these is very weak and occurs chiefly along joint planes. An early set of joints, or fractured planes, are occupied by fine jasperoid, and are cut by later fractures containing quartz, chlorite, pyrite, and occasionally chalcopyrite.

The massive sulphide vein and the silicified zones are developed in dull green porphyries, which are schistose in places, although the shearing is not pronounced except at some distance from the mineralization. The porphyries were apparently andesitic in composition, but near the ore-bodies they are so highly altered that their original composition could not be determined. At several feet, vertically, from the massive sulphide vein, the feldspar phenocrysts of the porphyry are replaced by aggregates of chlorite, sericite, quartz, and albite in variable proportions. The femic phenocrysts are altered to chlorite with some leucoxene. There is a tendency for all the platy minerals and albite to be replaced by quartz, suggesting that this is merely an early stage in the development of the intensely silicified zones with which the second type of mineralization is associated. By an increase in the silicification, the greenstone porphyry is altered to a quartz-sericite-chlorite rock, from which the albite has

[1] Camsell, C.: "Indian River Copper Deposits"; Geol. Surv., Canada, Sum. Rept. 1917, pt. B, p. 24.

been removed completely, and the outlines of chloritized femic phenocrysts are largely destroyed by the development of fine-grained quartz. The groundmass of the most highly altered phase is composed of exceedingly fine quartz and sericite with scattered crystals of pyrite. The porphyritic texture is beautifully preserved, for the feldspar phenocrysts have been replaced by quartz aggregates, whose grain size is much larger than the groundmass material, and which are relatively free from sericite. Practically all the chlorite has been replaced by the quartz and sericite. Tiny veinlets are very numerous and traverse the rock in all directions. The larger veinlets, above 0·1 mm. in width, are composed of quartz and usually are bounded by a narrow selvage of sericite. Along one of the veinlets, the sericite rim is separated from the fine quartz-sericite groundmass by a zone of chlorite. The exceedingly fine fractures, or veinlets, are chiefly sericite and probably represent the beginning of the alteration, and it (the alteration) is followed by complete silicification which pushes the narrow sericite zone ahead of it into the rock. Although in many instances the veins are sharply defined and simulate veins of filling, in other places the gradual replacement of the fine-grained quartz-sericite mass by larger, clear grains of quartz and sericite, and the elimination of the dusty material, may be traced in all its detail, and there is no question but that a great deal of the vein material has been formed by replacement. Some of the sericite along the margins of the veins is probably the sericite that has recrystallized from the fine-grained quartz-sericite rock, and was rejected from the central part of the coarsely crystallized quartz veinlet. The end product of this type of alteration is apparently clear quartz, just as it was in the shear zone deposits (*See* page 110).

DEPOSITS WITHIN THE BATHOLITHIC ROCKS

None of the deposits within the batholithic rocks as yet has proved to be of economic importance, but they are interesting from a mineralogical standpoint, forming another link in the chain of mineralogical types within the area. The mineral of economic importance is again chalcopyrite, but it is associated with an entirely new set of minerals which indicate a higher temperature of deposition. Hematite, magnetite, and molybdenite make their appearance for the first time, and with pyrite are principal associates of the chalcopyrite. The occurrence of the iron oxides and molybdenite in the deposits within the batholith not only suggests that these deposits have been formed at higher temperatures than the others, but also suggests that all the deposits in Britannia area are genetically related to the batholith. If they had been formed at some distinctly later stage of igneous activity there would be no reason why the highest temperature types of deposit should be within the batholith, and the lowest temperature type at the greatest distance from it.

Three deposits belong to this group. Two of them are in the Indian River section of the area, and one is situated in Seymour Creek valley, a short distance below Seymour lake.

London Group

The London group is situated on the east side of Indian river, adjoining the Roy group on the northwest. The mineralization occurs in an irregular body of quartz diorite belonging to the Indian River intrusives. The outcrop of the mineralized zone is a very conspicuous, bare, iron-stained area, outcropping along a heavily timbered side hill, at about 200 to 400 feet above the stream. The quartz diorite is seamed with numerous small veinlets of quartz, and the sulphide minerals, which are pyrite, chalcopyrite, sphalerite, and molybdenite. Pyrite is disseminated throughout the rock and contains small blebs of both sphalerite and chalcopyrite, although these two minerals occur chiefly as individual grains within the quartz veins. Molybdenite is apparently restricted to the veins and is found usually as a very thin plating along their walls. The veins range from joint cracks, coated with a thin film of quartz or sulphides, to narrow lenses, 2 or 3 inches wide and several feet long. A tunnel, about 110 feet long, has been driven under the most highly stained part of the outcrop and contains low-grade mineralization throughout its length.

About 1,000 feet northwest of the tunnel, the quartz diorite outcrops in a creek bed and is mineralized in the same manner as the principal showing. The mineralized zone on the London group is large, but the copper content is apparently small.

A.B.C. Group

The A.B.C. group, consisting of the A.B.C. Nos. 1, 2, 3, and 4, is situated at the head of Indian river on the east side of the stream. A 30-foot tunnel has been driven into the east bank of the most northerly tributary of Indian river, but the tunnel is barren unless the mineralization is concealed behind the 15 feet of lagging at the portal. In the stream bed, a small amount of pyrite and chalcopyrite is to be found in a crushed and metamorphosed dioritic rock.

Bank of Vancouver Group

The Bank of Vancouver group, owned by the Britannia Mining and Smelting Company, is situated on the east side of Seymour creek, about three-quarters of a mile below Seymour lake. One or two large blocks of brecciated "granite," containing appreciable amounts of chalcopyrite and other metallic minerals, were found in the lower part of a long talus slope, and have encouraged a careful search for their source. A similar type of mineralization was found in place on the south side of the talus, but the actual ore-body from which the blocks were derived has not been located. The ore that has been found occurs in the brecciated granodiorite, and in a large block of quartz diorite, which is apparently an inclusion in the granodiorite. Most of the ore occurs in narrow and irregular stringers within a zone 10 or 15 feet wide, but in places a typical breccia is developed, cemented by hematite, magnetite, chalcopyrite, pyrite, chlorite, carbonate, and quartz, with small amounts of molybdenite and sphalerite. In one large specimen the first mineral to develop around the fragments was hematite, as plates standing normal to the side of the fragment. This was later reduced to magnetite, and rosettes and irregular bunches of the magnetitic oxide are deposited between, and at the ends of, the hematite plates. On the outside of the magnetite again, towards the centre of the original cavity, is an incomplete zone of chlorite, having an average index of about 1·646, and the remainder of the space is occupied by chalcopyrite and a high index carbonate. In other specimens, quartz is earlier than the magnetite and pyrite is at least earlier than the chalcopyrite.

In the creek immediately north of the talus slope containing the large blocks of ore, is a very interesting occurrence of an entirely different type. Small, spherical specks of chalcopyrite occur in a medium fine-grained granitic rock, which is apparently a dyke (*See* page 52), containing numerous small miarolitic cavities, 3 or 4 mm. in diameter. Some of these are filled with the rock and ore minerals. One of them, contained in a thin section, is filled with biotite, magnetite, pyrite, and chalcopyrite, deposited in the order named. The biotite is partly replaced by a chlorite, which has a very strong dispersion, and by titanite. The presence of the very numerous, although small, miarolitic cavities suggests that the rock contained an unusual amount of volatile material, and it is not unreasonable to suppose that a great deal of the materials deposited in the cavities was concentrated and transported by those volatiles, and was actually a part of the rock magma as it was intruded. If this is the case it is possible that the dyke is the immediate source of Bank of Vancouver ore deposits. However, there is no way of proving that the ore minerals were a part of the magma, and it is possible that later ore solutions, forming the Bank of Vancouver deposits, found and filled some of the cavities in the dyke.

SUMMARY CLASSIFICATION OF THE MINERAL DEPOSITS AND THEORETICAL DISCUSSION OF THEIR RELATIONS

SUMMARY CLASSIFICATION OF MINERAL DEPOSITS

Deposits Within the Britannia Shear Zone

Distance from known batholithic rocks about 4,000 feet.

Sulphate Mineralization

Anhydrite. Replacement veins and stringers in silver schist (sericite schist) and foot-wall slates. The veins are found on all levels of the mines. Anhydrite does not occur in the sulphide veins, but appreciable amounts are found in the lower projection of the Hanging-wall vein zone.

Sulphide-sulphate Mineralization

Zinc Ores. These are found only as replacement of sedimentary rocks in Bluff and Jane mines, and are composed essentially of barite and sphalerite. Pyrite, tetrahedrite, galena, and a very small amount of chalcopyrite are present. In the Jane mine this type of ore is earlier than the general silicification accompanying the siliceous copper ores, and the contact between the two is gradational. In the Bluff mine the contact is sharp, the zinc ores being confined to the foot-wall rocks and the siliceous ores to the mine porphyry.

Sulphide Mineralization

Siliceous Copper Ores. The siliceous copper ores, typically developed in the Bluff mine, are fairly regular but indefinitely defined ore-shoots in a zone of intensely silicified material, situated at the extreme west end of the mine porphyry. The most siliceous ores, representing the extreme development of the type, are found immediately beneath the mantle of slate that surrounds the west end of the mine porphyry. On the lower levels, vertically below the mantle of slate, which plunges to the west, silicification is less intense and the ores approach the chalcopyrite vein type. Characteristic minerals are quartz, pyrite, chalcopyrite, and sphalerite, with some galena, and barite.

Chalcopyrite Veins. These are tabular deposits in chloritic schist and as represented by the Fairview, Empress, and Victoria ore-bodies. The prominent minerals are chalcopyrite, pyrite, and quartz. Sphalerite is plentiful in the Empress mine.

At the west end, and on the upper level of the Fairview mine, where the veins approach the slate hood, the silicification around the veins becomes intense, and the zone of silicification becomes wider, merging into the Bluff ore zone. This junction is effected immediately below the slate hood, and as a direct result of its influence in controlling the movement of the mineralizing solutions.

Deposits Near the Batholith

Developed in Indian river at less than 1,000 feet from the batholith.

Sulphide Mineralization

Copper Ores. Copper ore deposits near the batholith are found in greenstones and siliceous metamorphic rocks, and are represented by the Belle, Bulliondale, and Roy properties. The characteristic minerals are pyrite, chalcopyrite, sphalerite, and quartz, which is the same group of minerals found in the shear zone copper deposits. In this case, however, anhydrite and barite are not associated minerals and their absence suggests that the deposits near the batholith were formed at a higher temperature than those within the shear zone.

Deposits Within the Batholith

Sulphide-oxide Mineralization

Copper Ores. Represented by the London, A.B.C., and Bank of Vancouver properties. Aside from quartz, pyrite, and chalcopyrite, which are present in all the copper ores, hematite, magnetite, and molybdenite are characteristically developed. This mineral assemblage is the highest temperature type in the area. Most of the ore has been deposited in open spaces.

The range of mineralogical types of deposit within the area is fairly great and, in general, the deposits are arranged in accordance with the zonal theory of ore deposition, which postulates that the lower temperature types of mineralization should be farther from the source of the solutions than the higher temperature types. It is generally agreed that the type of mineralization represented by the shear zone deposits as a whole would be formed at a lower temperature than those within the batholith; and the batholith is presumably the source of the solutions. The detailed relations of the deposits within the shear zone, however, show variations in distribution and sequence that are not normally expected on the zonal theory, although perfectly in accordance with its doctrine.

The anhydrite veins, for example, are believed to have been formed at a lower temperature than the sulphide veins, and would be expected on the upper levels of the mine, but actually they are found on all levels, and in one particular instance the anhydrite veins occupy the lower part of a sulphide vein zone, to the exclusion of the sulphides. Again the zinc ores, or the sulphide-sulphate mineralization, are a lower temperature type of mineralization than the copper ores, and not only would be expected above the latter, but they would normally be later than the copper ores. Instead of this, both types occur on the same levels, 1,000 feet below the known top of the copper ores, and the zinc ores are earlier than the silicification that accompanies the copper mineralization. These variations from the normal expectation based on the zonal theory are recognized in other districts. Spurr[1] devotes a chapter to telescoped ore-bodies, which are those ore-bodies exhibiting a wide range of mineralogical types within a very limited vertical extent. And he[2] describes reverse zoning, or the reverse of the normal sequence of deposition, at Aspen, Colorado.

Before discussing the relations of the deposits within Britannia area it might be well to review briefly the factors which seem to be the most important in controlling the zonal distribution of ore deposit, and the sequence of the various types. It is so generally agreed by geologists at the present time that sulphide ore deposits are genetically related to igneous rocks, that this phase of the subject need not be developed.[3] Molten magmas are known to be very complex solutions of silicates containing small amounts of water, gases, and the general materials of ore deposits. As the magmas solidify, by the crystallization of the silicates, the less plentiful elements and compounds are concentrated in the residual liquids. When crystallization has advanced to such a stage that the ordinary metallic minerals begin to precipitate, the residual liquids may be regarded as ore solutions. Very little is known about the composition of these solutions, except that they contain quartz, the alkalis, and the various materials that are found in mineral deposits. Most geologists believe they are essentially mobile aqueous solutions and although Spurr[4] regards much of the vein-forming solutions as thick, viscous substances containing but very little water, he does recognize that aqueous solutions are responsible for certain replacement deposits. Since much of the Britannia ores have been formed by replacement, all would agree on the general nature of the solutions responsible for their development.

The crystallization of a magma and concentration of the ore solution are due, primarily, to a loss of heat. As any solution is cooled, crystallization proceeds in a regular manner, each succeeding mineral, or group of minerals, precipitating as their solubility product reaches the critical value for that particular solution. Some of the earlier substances may be resorbed and their constituents reprecipitated later in other compounds, but the net result of the loss of heat in a saturated system is an increase in the amount of crystalline material. The temperature range within which any

[1] Spurr, J. E.: "The Ore Magmas", New York, p. 292.
[2] Spurr, J. E.: "Ore-deposition at Aspen, Colorado"; Econ. Geol., vol. 4, p. 319 (1909).
[3] There is some doubt in the minds of many, as to the direct igneous origin of the lead zinc ores in Mississippi valley, and of certain bedded deposits such as the copper ores of Mansfield, Germany, but no one questions the igneous origin of the ordinary sulphide deposits.
[4] Spurr, J. E.: "The Ore Magmas", New York.

one substance will precipitate is dependent on the relative amount of that material in solution. The same principle holds true in the crystallization of more complex solution; certain minerals (or groups of minerals) will crystallize over a range of temperature that is determined by the composition of the solution; and at specific temperatures, which are again determined by composition of the solutions, other substances will begin to crystallize, and will continue to do so over a definite temperature range. This, of course, is assuming equilibrium conditions at all times. The composition of the solution not only influences the temperature range during which a mineral will crystallize from a solution, but also the order in which it will crystallize.

The lowest temperature ores in the Britannia shear zone are the barite-sphalerite ores of the Jane mine at the extreme west end of the shear zone at some distance from all the larger sulphide deposits. They are associated with relatively small bodies of siliceous copper ores and, as emphasized above, they are earlier than the silicification that accompanies the copper ores. As a result of the replacement of the barite and sphalerite by quartz, the barite-sphalerite ores grade into intensely silicified zones. Although the particular body of siliceous rock adjoining barite-sphalerite ore does not happen to contain commercial copper ore, it does contain the same group of minerals that the copper ores contain, and it is apparently correct to say that the barite-sphalerite mineralization is replaced by the siliceous-chalcopyrite mineralization. Since the former is represented by barite, sphalerite, pyrite, tetrahedrite, and galena, and the latter by quartz, chalcopyrite, pyrite, sphalerite, and locally, galena, it would seem that a low temperature mineralization had been replaced by a high temperature mineralization. In other words we have reverse zoning. Spurr[1] explains the reverse zoning at Aspen, Colorado, by assuming that mineralization and igneous intrusion were contemporaneous; the first ores being deposited while the magma was at a distance from the surface, and the last minerals after the magma had risen nearer the surface, or nearer the point of deposition. This explanation is not applicable to the Britannia area, for the batholith, which is presumably responsible for the mineralization, is mineralized along fracture zones, and must, therefore, have been solid before the period of mineralization.

The relation of the barite-sphalerite to the siliceous copper mineralization can be explained on the assumption that the first ore solutions were cooled by the rock, and forced to precipitate low-temperature minerals within the Jane mine, but as hot solutions continued to ascend, they heated the rock, and higher temperature minerals were carried into the same section of the mine, and replaced the earlier, low-temperature minerals. We would expect to find this type of reverse zoning only at the outskirts of an ore zone; it is essentially a marginal feature, for within the main zone all traces of the first low-temperature minerals would have been removed. We find the reverse zoning just where it would be expected—at the extremity of the shear zone, even beyond the shear zone proper and beyond all the important ore deposits.

Although it is possible that the barite-sphalerite mineralization is best preserved at the end of the shear zone because the solutions depositing

[1] Spurr, J. E.: "The Ore Magmas", New York, 1828, p. 288.

these minerals had been cooled by the surrounding rock, and the volume of later solutions had not been sufficiently large to elevate the temperature and deposit higher temperature minerals in their place, one other possible explanation of its occurrence in this position must not be overlooked. That possibility is that the host rocks may have exerted a selective precipitating effect and induced barite and sphalerite to precipitate in one place, and quartz, pyrite, and chalcopyrite in another. All the conspicuous occurrences of the barite-sphalerite mineralization are found in the sedimentary rocks at the west end of the shear zone, and all the important copper deposits are found in modified crystalline rocks. One of the copper deposits in the Jane mine is in crystalline rocks and the other replaces a part of the barite and sphalerite. The influence of the composition of the rocks is rather strikingly shown at one point along the foot-wall of the Bluff mine on the 1,050-foot level where a narrow band of the typical barite-sphalerite rock occurs in sharp contact with the typical Bluff ores. The baritic material is confined to the slates and the Bluff ores to the fractured porphyry. The only reason for not stressing this explanation of the development of the barite-sphalerite ores is that the typical minerals of this group occur in the sheared porphyry, and because the alternative explanation will suffice for both this occurrence and the more important occurrences in the slates. It also assists in explaining the different types of ore in the Bluff and Fairview mines.

The occurrence of the barite and sphalerite in the sheared mine porphyry is in the Fairview mine, at the west end of the third-fourth vein system on the 1,050-foot level. The typical copper ore mineralization changes along the strike of the vein to a type in which barite and sphalerite are prominent and chalcopyrite is inconspicuous. It is true that the mineralization occurs in silicified rocks, but it is at the very lower fringe of the transition zone between the Bluff and the Fairview mines, just where remnants of low-temperature mineralization would be expected. The solutions moving out to the borders of the fracture systems would be cooled by the rocks and deposit low-temperature minerals. The cooler rocks merely hasten the course of crystallization of the lower temperature minerals. If the solutions are sufficiently plentiful they will heat the rock and carry the low-temperature minerals farther along their way.

This same principle may be used to explain the difference between the Fairview and the Bluff ores. The Fairview ores consist essentially of quartz, pyrite, and chalcopyrite. The Bluff ores contain the same essential minerals, but in addition they also contain considerable amounts of sphalerite and some galena, particularly on the upper levels, and are apparently lower temperature ores than the Fairview. The difference in mineralogy may be due to the fact that the solutions forming the Fairview ores were confined to very definite channels, whereas the solutions forming the Bluff ores were distributed throughout a large mass of fractured rock. In the latter case the solutions have worked along all the fracture planes and have come in contact with a much greater area of rock than the solutions rising in the simple veins, and would be cooled much more quickly than the vein solutions. At any given level above the sources of the solutions, those in the fracture zones would be at a lower temperature, and depositing lower temperature minerals than those in the veins. Thus we have on the 1,050-foot level, both the typical Bluff ores, developed in the fractured porphyry and containing large amounts of sphalerite and some galena, and the typical Fairview veins in which neither of these two minerals appears.

The relation of the anhydrite mineralization to the sulphide ores presents a different problem. Although the anhydrite is very abundant, occurring in all the mines of the shear zone proper, it has not been found as a gangue mineral in the sulphide ores, and the only sulphides that have been found in the anhydrite are a few corroded grains of pyrite and chalcopyrite. This is true even where the anhydrite is found in the downward projection of the Fairview veins. Above the 600-foot level the Hanging-wall vein zone is extensively mineralized with pyrite and chalcopyrite, but on the 850 and 1,050-foot levels these minerals are essentially absent and replacement veinlets of anhydrite are very numerous. The anhydrite, presumably, represents a lower temperature mineralization than the copper ores, and, if this assumption is correct, it must have been deposited later than the copper ores, for otherwise it would have been destroyed by the rising copper solutions.

The sulphide and the sulphate (anhydrite) mineralizations have probably been developed during the one major period of hydrothermal activity, but a distinct break is indicated between the development of the sulphide and the sulphate deposits. If the mineralization had been a continuous process one would expect to find some anhydrite in the sulphide ores, and some sulphides in the anhydrite. But this is not the case, the two types are decidedly separate and distinct. They are not only separate types mineralogically, but, with the exception of the Hanging-wall zone just mentioned, the position of the anhydrite veins is not related to the position of the sulphide veins. Large masses of anhydrite are found in the foot-wall slates at the west end of the Fairview mine, and veins have been found near the foot-wall of the shear zone from one end of the ore zone to the other. Since there is no very direct relation between the distribution of the anhydrite and the sulphide, and there is no mineralogical gradation between the two types of mineralization, it is probable they have been separated by a distinct time interval; and, as suggested above, the anhydrite is probably later than the sulphides. Although a distinct break is indicated between the anhydrite and the sulphides there is no reason to believe that both are not related to the one major period of mineralization.

AGE OF MINERALIZATION

After having shown that the deposits in Britannia area are distinctly zoned with respect to the batholith it hardly seems necessary to discuss the age of the mineral deposits. The highest temperature mineralization occurs within the batholith, and the lowest temperature mineralization at the greatest distance from the batholith, and it seems obvious, therefore, that the mineral deposits were formed at least before a normal temperature gradient had been re-established in the area. How long this may have been after the intrusion of the batholith is a difficult question to decide, but presumably it would be only a short time geologically, and the ore deposits may be regarded as of the same age as the batholith. This conclusion may suffice for a broad generalization, but it has been shown that all the batholith rocks were not intruded at one time, and a more specific correlation of the age of the deposits is, therefore, desirable.

Although there has been some movement in the shear zone since the period of mineralization commenced, it has been of a very slight and incidental nature. Evidently differential stresses have not been pronounced in the area since the deposits were formed. This means that they are distinctly later than the southwestern area of batholith rocks, for these are strongly sheared in places. It has also been shown that the ores are later than acidic and basic dykes which are similar to dykes found cutting the Indian River intrusives, and batholithic rocks of the southwestern and central areas. As a matter of fact the shear zone is later than these dykes, and the ore deposits are later than the sections of the batholith enumerated. However, the higher temperature deposits are found in the Indian River intrusives and in the rocks of the central area, so the normal heat gradient apparently had not been re-established around these particular bodies at the time of mineralization. The only rock definitely known to be later than the shear zone is the small area of porphyritic "quartz diorite" occurring at the east end of the shear zone; but the writer does not care to insist that it is particularly later than the rocks of the central or western area. The only conclusions that may be arrived at, safely, are that the ores are distinctly later than the foliated quartz diorites of the southern area, but may not be much later than the other masses of the batholith.

SUMMARY OF ECONOMIC GEOLOGY

Three major groups of mineral deposits are recognized in the Britannia area.

(1) A few deposits are found within the batholithic rocks and characteristically contain a moderately high temperature assemblage of minerals, such as magnetite, hematite, molybdenite, as well as chalcopyrite, pyrite, and sphalerite.

(2) A few deposits are found in the metamorphic rocks within a few hundred feet of the batholith, and although they do not contain typically high-temperature minerals all of the low-temperature minerals occurring in the following group are lacking.

(3) Five distinct ore deposits are found within the Britannia shear zone. Aside from pyrite, chalcopyrite, and sphalerite, which are common to all three groups, important amounts of barite and anhydrite are found in the shear zone deposits, and galena and tetrahedrite are fairly plentiful in certain parts of the shear zone.

Up to the present time the only deposits of economic importance are those occurring in the shear zone. The other two groups, indicating progressively higher temperature conditions near the batholith, serve to correlate all the deposits of the batholithic rocks.

The Britannia shear zone is a belt of highly sheared rocks, about 5 miles long by 2,000 feet wide, within the southern half of the roof pendant. It strikes about northwest and dips 70 degrees to the south. Throughout the greater part of its length the shear zone crosses the strike of the steeply dipping members of the Britannia formation at a small angle, but the westerly 7,500 feet is confined to one member of the Britannia sills, the mine porphyry. Within this section, which contains the commercial deposits of the area, the shear zone and the mine porphyry narrow from 2,000 feet to a blunt point, or really to a blunt edge, which is surrounded by slates and plunges to the west at about 35 degrees. At the time the shear zone was developed the slates apparently absorbed a great deal of the differential movement, so that at the very west end of the mine porphyry, immediately beneath the mantle of slate, the porphyry was fractured rather than sheared.

The deposits in the Britannia shear zone, enumerated from west to east, are: the Jane, Bluff, Fairview, Empress, and Victoria. The Jane mine is really not in the shear zone as defined, but is a small deposit in the sedimentary series that surrounds the west end of the mine porphyry. It contains two types of mineralization. Zinc ores, consisting chiefly of barite and sphalerite, with small amounts of galena tetrahedrite and pyrite, replace bedded sedimentary rocks, and these ores in turn are replaced by quartz which grades into the siliceous type of copper deposit. Since the latter consists essentially of quartz, pyrite, chalcopyrite, and variable amounts of sphalerite, it would seem that the low-temperature mineralization (barite and sphalerite) is earlier than the higher temperature mineralization. A suggested explanation for this is that the first ore solutions were cooled by the country rock and low-temperature minerals were precipitated, but as the flow of solutions continued, the rocks were heated and higher temperature ores were deposited, replacing the earlier and lower temperature minerals.

The Bluff ore deposits are the most westerly deposits in the shear zone proper and occupy the apex of the mine porphyry. The ore-shoots are fairly continuous, but poorly defined zones lie along the foot-wall of the shear zone, within the intensely silicified mine porphyry. The ore-shoots are steeper than the slate hood, and are, therefore, intercepted by it on the upper levels. As they approach the hood the silicification becomes more intense, and sphalerite and galena become more conspicuous. The commercial ore does not extend into the very apex of the mine porphyry where one would expect the greatest concentration of the solution. This place, however, is the most highly mineralized locality in the mine, but fortunately the mineralization is chiefly quartz. It is not known whether the quartz replaced the sulphides, or was there first and prevented the sulphides from entering.

East of the Bluff are the Fairview, Empress, and Victoria deposits located at fairly regular intervals along the foot-wall of the shear zone. These are all very similar, consisting of two to several veins of pyrite, chalcopyrite, and quartz in chloritic schists. With the exception of one or two veins in the Victoria mine, all the veins are within sheared phases of the mine porphyry.

The position of the Fairview veins has apparently been controlled by fracture zones which were developed in the mine porphyry at the time of shearing, for many of them occur along the loci of drag folds in small basic dykes. The veins are very regular, tabular bodies varying from 1 or 2 to 40 feet in width and are as much as 1,200 feet long. The upper part of the vein zone is intercepted on the upper levels by the slate hood in the same manner that the Bluff ore-shoots are intercepted. Above the 1,050-foot level the two ore zones blend into one another as a direct result of the influence of the slate hood on the circulation of the ore solutions.

The Bluff ores contain appreciable amounts of sphalerite, and galena is fairly conspicuous on the upper levels. Since these minerals are very rarely found in the Fairview ores, the latter is apparently a higher temperature type than the former. It is suggested that the difference in the mineralization is due to the fact that the Bluff ore solutions have risen through a fracture zone where they would come in contact with tremendous areas of rock and would become cooled more quickly than the Fairview solutions, which ascended through well-defined veins exposing only a limited area of rock to the solutions.

Within the Fairview, Empress, and Victoria ore zones, are numerous veins of anhydrite. In general this distribution bears no direct relation to the sulphide ores, but in the hanging-wall section of the Fairview mine, anhydrite is very abundant along the downward projection of a group of irregular sulphide veins. Anhydrite, however, is not found in the sulphide ores, nor are the sulphide minerals found in the anhydrite. Since there is no mineralogical gradation between the two types, and in general there is no particular space relation between them except that they both occur in the shear zone, it is believed that the anhydrite is distinctly later than the sulphides, although probably belonging to the same general period of mineralization.

The Britannia ore deposits have been mined to a depth of 2,500 feet and the Bluff and Victoria deposits are known to continue at least another 200 feet. The barite-sphalerite mineralization has not been recognized below the 1,050-foot level, but the anhydrite apparently has the same vertical range as the copper ores.

PLATE I

A. View west down Britannia creek; Howe sound in the distance, Goat mountain in foreground on right, Britannia ridge in middle distance on left.

B. View northeast across west fork of Seymour creek to mount Lomond in foreground on left, and into Seymour Creek valley in foreground on right.

PLATE II

A. Coarse-grained phase of batholith rocks, typical of northwest area. (Page 53.)

B. Normal granitic texture of batholithic rocks, typical of central area. (Page 49.)

C. Foliated quartz diorite, typical of southwestern area; foliation parallels longer straight edge on left side. (Page 46.)

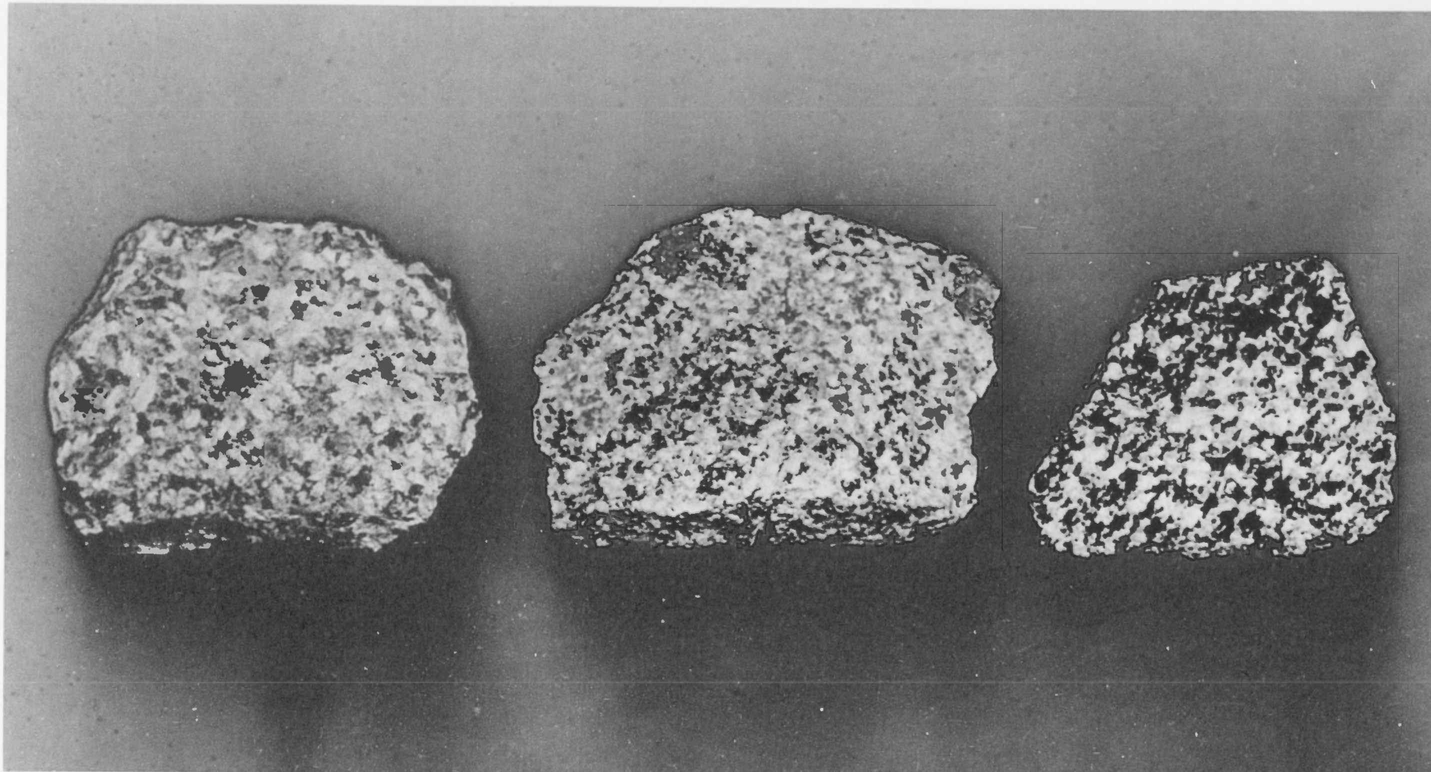
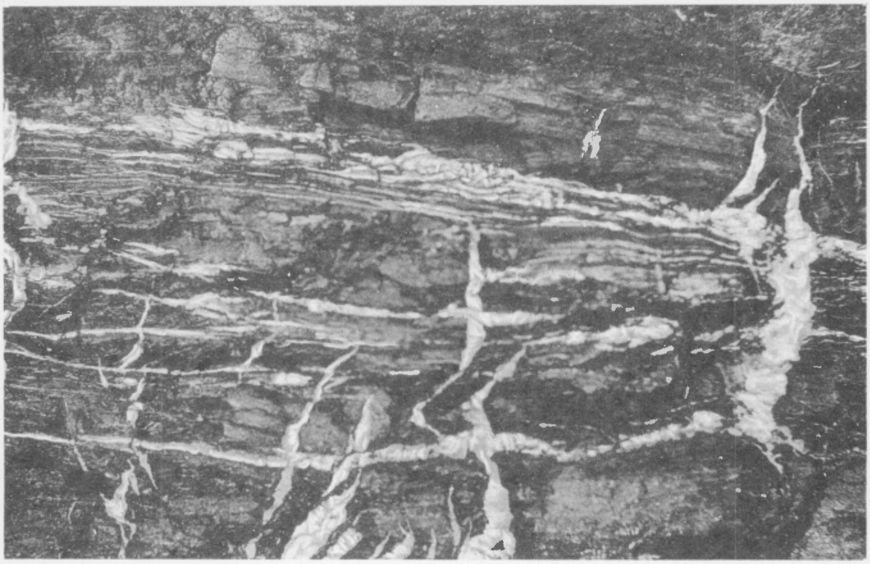


PLATE III

A. Fracture pattern in Fairview foot-wall vein. (Pages 87, 101.)

B. Oriented inclusions in foliated quartz diorite; note also glacial grooves; picture taken at tidewater, Howe sound. (Page 46.)



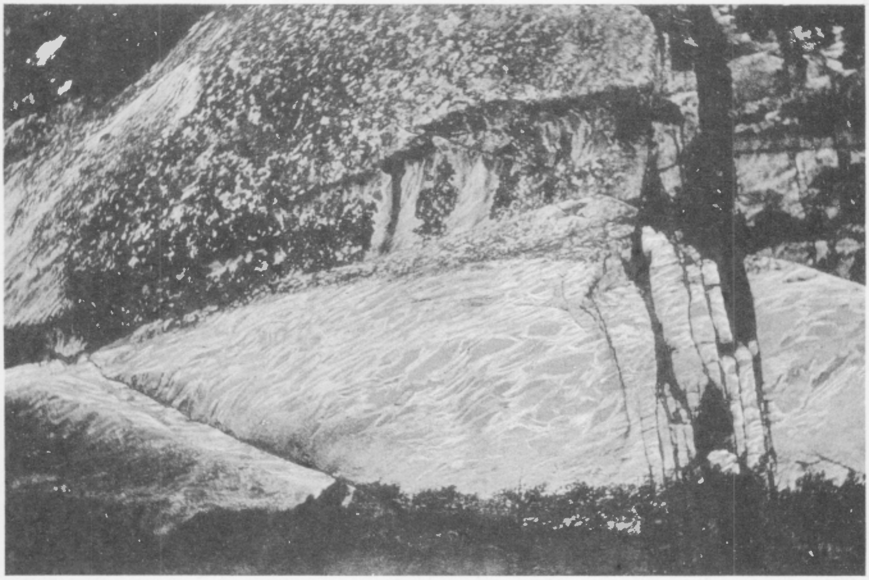


PLATE IV

Bedded gravels overlain by glacial material, Porteau, Howe sound. (Page 65.)

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