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CANADA
DEPARTMENT OF MINES
HON. W. A. GORDON, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

GEOLOGICAL SURVEY
W. H. COLLINS, DIRECTOR

Summary Report 1932, Part A II

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OTTAWA
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THE MINING INDUSTRY OF YUKON, 1932

By H. S. Bostock

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INTRODUCTION

During the field season of 1932 three weeks in August were devoted to visiting Klondike and Mayo districts. The remainder of the season was occupied in the geological mapping of the Carmacks sheet to be published on a scale of 4 miles to 1 inch. In the course of this work a visit was paid to the locality of the lode gold strike made on Seymour Creek in 1930, previously visited in 1931.[1]

During the visit to Klondike and Mayo districts, the work was greatly enhanced by the gracious assistance of all those met among the Government officials, officials of the mining companies, and prospectors. The writer expresses his appreciation, in particular, to Mr. G. A. Jeckell, Comptroller of Yukon Territory, and also to the officials of the Yukon Consolidated Gold Corporation. Particular recognition is due to this corporation for the privilege of using in this report the information on the gravel reserves and operations in Klondike district. The writer is indebted to Mr. A. K. Schellinger of Keno for his kindness in escorting the writer over the properties on Keno and Galena Hills and for supplying a great part of the information relating to them. Without his assistance it would have been impossible to have collected so complete a record of the activities of this camp in the time available. The writer is also indebted to the officials of the Treadwell Yukon Company, Limited, for their kindness in showing him over the properties of their company.

In Yukon the mineral production of 1932 was slightly below that of 1931, but the activities of the main centres, Klondike and Mayo districts, were maintained. The gold production, which had been rising since 1926 and was $915,969 in 1931, fell to $842,925 in 1932. This drop is said to be due to two of the large dredges in Klondike district being closed down earlier than usual for reconditioning. Over three-fourths of the placer gold production came from Klondike district, the remainder from Sixty-mile area, Mayo, Livingstone, and Kluane districts. The only lode production is that from the mines in Mayo district. In 1931 this was $1,223,162, or 4,444,774 pounds of lead, 3,674,730 ounces of silver, and 245 ounces of gold. The tonnage shipped in 1932 is reported to be approximately the same as that of 1931.

[1] Bostock, H. S.: "Mining Industry of Yukon," 1931; Geol. Surv., Canada, Sum. Rept. 1931, pt. A, p. 7.

PLACER MINING

KLONDIKE DISTRICT

During 1931 and 1932 the Yukon Consolidated Gold Corporation has had five dredges in operation. Three of these dredges, all large boats with 17 cubic foot buckets, are on the Boyle Concession in Klondike Valley; Canadian No. 2, approximately a mile below Bear Creek, Canadian No. 3 approximately a mile above the mouth of Bonanza Creek, and Canadian No. 4 on the upper side of Bear Creek. The other two dredges are small boats with 7 cubic foot buckets and are on the Indian River tributaries. One of these, Northwest No. 1, is nearly a mile above the mouth of Caribou Creek on Upper Dominion Creek, and the other, Northwest No. 2, 2 miles below Granville on Granville Flat. In addition the corporation has been operating its hydraulic plants at Jackson Gulch in Klondike Valley and at Lovett Gulch in Bonanza Creek Valley. A number of individual miners were also working on Bonanza, Eldorado, and Hunker Creeks.

During the season of 1932 the Yukon Consolidated Gold Corporation, which with its subsiduary companies now holds almost the entire gravel reserves of Klondike district, employed Mr. E. H. Dawson, consulting engineer and placer expert, to examine their reserves and operations. Mr. Dawson's report was completed in December and it is probably the most comprehensive report ever compiled on the gravel reserves of Klondike district. The corporation has graciously permitted the publishing of the following information derived from this report.

In 1932 the operations of the corporation handled a total yardage of approximately 5,699,800 cubic yards of gravel yielding $685,000. This production was divided approximately as follows: Canadian No. 2, 1,720,488 cubic yards; Canadian No. 3, 842,358 cubic yards; Canadian No. 4, 1,450,665 cubic yards; Northwest No. 1, 562,979 cubic yards; Northwest No. 2, 534,810 cubic yards; and the hydraulic operations, 588,500 cubic yards. As already mentioned, two of the large dredges stopped work unusually early and the following figures are estimated to be the normal full capacity of the present plant: for the three large dredges in Klondike Valley, 1,800,000 cubic yards a year of 180 days each, or a total for the three of 5,400,000 cubic yards; for the Northwest No. 1, 600,000 cubic yards a year of 170 days; and for Northwest No. 2, 700,000 cubic yards a year of 180 days. It is also pointed out that the ditch supplying the hydraulic work is reported to be in a state of poor repair and has a capacity of only 1,000 miner's inches instead of 5,000 for which it was designed, and that this is limiting the hydraulic operations at the present time.

It is interesting to note the following estimated costs as given in the report for 1932: for Canadian No. 2 and No. 3, with thawing, 8·2 cents a cubic yard; and for Canadian No. 4, 6·7 cents a cubic yard without thawing (this dredge was digging naturally thawed ground); for Northwest No. 1, 16·2 cents a cubic yard with thawing; and for Northwest No. 2, 12·4 cents a cubic yard with thawing. Mr. Dawson points out that if the dredges can be kept running steadily for the full season these figures will be cut even lower.

Mr. Dawson points out that for the calculation of the gravel reserves the amount of data on the values of the ground over large areas is very scanty, and for this reason only a small percentage of the ground considered to contain gravel reserves can be classed as proved. A great deal of testing must be done before an exact working estimate can be made. The values that are available, however, are so distributed as to indicate very large reserves of partly tested ground.

A total of 9,740,000 cubic yards of proved and partly proved dredging reserves is given for the Klondike River side of the district on the Boyle Concession and Hunker Creek, and a total probable and possible dredging reserve of 117,296,000 cubic yards, making a total of approximately 127,000,000 cubic yards of dredging ground for the three big dredges on the Klondike side, or enough ground to keep them in operation for over twenty-three years at full capacity. In these figures, however, the large area of untouched ground on the right limit of Klondike River below the mouth of Foster Creek is not included and only a strip 1,500 feet in width along the southern edge of the valley flat between the Anderson Concession at the mouth of Hunker Creek Valley and that of Bonanza Creek is considered as dredgeable. Thus, very large areas of ground in Klondike Valley, which later may be proved to be of some value, have been left out. Another area that it would seem has some value but is omitted from the estimate is the upper part of Eldorado Creek above 27 Gulch, which has not been dredged or worked by modern methods.

Mr. Dawson points out in his report that Mr. McConnell's[1] estimate of the high-level gravels has proved dependable where it has been tested and that on a number of the high-level benches only a part of the gravel reserves estimated by Mr. McConnell have been exhausted by the hydraulic operations. From the available figures for those hills where sufficient volume is warranted for reopening operations, Mr. Dawson estimates that on Bonanza and Hunker Creeks there still remains a total of 60,247,000 cubic yards of these gravels which should contain a total value of $8,800,000. At 3,500,000 cubic yards a year, which he thinks could be managed with the restoration of the working equipment, this would mean a further life of approximately seventeen years.

The most promising areas of valued dredging reserves occur on the Indian River tributaries where Mr. Dawson reports over 15,811,000 cubic yards of proved and partly proved dredging ground. Most of this lies in Granville Flat and Cruger Concession. The probable yardage of dredging reserves on Granville Flat, Cruger Concession, Upper Dominion Creek, and lower Sulphur Creek is 34,500,000 cubic yards. Besides these areas, the report points out the enormous area of rather unknown territory in Indian River Valley from the Cruger Concession down stream to Ophir Creek, a portion of which is included in the estimates of possible dredging reserves and calculated to be nearly 24,000,000 cubic yards.

Large reserves of gravels are given for Quartz and Upper Sulphur Creeks which cannot be worked by dredging or the usual hydraulic methods and for which other methods are suggested. These reserves total over 4,500,000 cubic yards of proved, probable, and possible classes of reserves and have a total estimated value of $4,500,000.

[1] McConnell, R. G.: "Report on Gold Values in the Klondike High Level Gravels"; Geol. Surv., Canada, No. 979, 1907.

Summarizing the reserves, the report shows a total of all classes of reserves of 268,000,000 cubic yards of gravel containing a total value of $54,500,000 in gold.

The total of all the dredging reserves on the Indian River side amounts to 74,311,000 cubic yards. Over fifty years would be required to dig these reserves with the present two dredges with their combined capacity of 1,300,000 cubic yards a year. The question of fuller development of this large and promising area is now receiving attention. If, after thorough testing, these reserves approach the figures of the estimates it is not improbable that eventually the bulk of the dredging operations will become centred on the Indian River side.

It is apparent from Mr. Dawson's estimates that a very considerable increase in annual output of placer gold may be looked for from Klondike district after the next two or three years and that the production can be expected to be maintained for at least two decades.

OTHER DISTRICTS

Sixtymile District

Sixtymile district was not visited, but the following notes have been collected from those in touch with that locality. It is reported that in this district there is an increase in the activities of the placer prospectors and that creeks are again being prospected that have been practically deserted since the discovery of Klondike district.

The dredge installed on Miller Creek in the winter of 1912 by the Northern American Transportation and Trading Company,[1] and which had been closed down for over ten years, was put into operation by Messrs. Holbrook and Edmundson in 1929[2] and has been operating since that year. This is a steam-operated dredge of the Risden type with an open bucket line and bucket capacity of $5\frac{1}{3}$ cubic feet. Twenty-four men are said to be employed in the operation. The dredge is digging naturally thawed ground on the N.A.T. concession between the mouths of Miller and Glacier Creeks. The returns are said to be very satisfactory.

Placer work is being carried on by individual miners on a few claims above the N.A.T. Concession on Miller Creek. Two and a half to 3 miles of claims are being worked by individual miners on Glacier Creek. Individual miners are at work on Big Gold Creek from the bridge to the mouth and some of these are working deep ground. On Little Gold Creek a 5-mile prospect lease has been granted. Opposite the dredging concession on the left limit is a row of bench claims being held by individual miners, but only one or two were actually being worked during 1932. On Matson Creek one miner has been successfully operating since 1913.

Mayo District

In Mayo district some placer mining was being conducted on Duncan, Haggart, and Highet Creeks. On Duncan Creek Mr. Andrew Johnson has put in a ditch nearly a mile long above the first road house below Keno and a small hydraulic operation was in progress on Upper Duncan

[1] "The Yukon Territory, Its History and Resources"; Department of the Interior, Ottawa, 1916, p. 77.
[2] Cockfield, W. E.: Geol. Surv., Canada, Sum. Repts. 1929 and 1930, part A.

on the right limit just at the top of the canyon. Haggart Creek was not visited, but the following notes on the reported activities were collected. Three miles of placer leases are being worked on Haggart Creek and Dublin Gulch, the centre of the combined leases being about the junction of the two valleys. These leases were taken up during the autumn of 1931 and spring of 1932. All are being worked by hydraulicking. It is supposed that the values are coming from a pay-streak on the left limit, opposite the old workings. One or two miners are working on the lower parts of Highet Creek, but the chief operations are those of Mr. Elmer Middlecoff on a stretch of ground between Rudolph Gulch and McCreary Pup. The discovery of gold was made in this immediate locality in the autumn of 1903[1] and some mining has been in progress along this creek almost ever since. Mr. Middlecoff has operated in this vicinity over a period of more than twenty years[2]. The operation at the time of the writer's visit consisted in extending a cut down the left limit against the steep slope of the valley side. The face of the cut was approximately 30 feet high from the bedrock surface. Bedrock slopes diagonally from the right to the left limit and the rim on the left limit is not yet exposed, though it is evidently only a short distance away. The ground is being worked by an ingenious method developed by Mr. Middlecoff. Previously, various methods had been tried but with varied success. The water condition and the depth of gravel, together with a relatively slight gradient on the creek, made the more usual methods of operating difficult. Two of the chief problems were to dispose of the coarse gravel tailings and to so dispose of them as not to prevent future operations. One of the chief merits of Mr. Middlecoff's method is the solution of these problems. The face of the gravels is attacked with a monitor and the gravels are then blown by the jet of water into and up an inclined box having a suitable size and slope. The bottom of the box is a grating made of large, flat, iron bars set across the box and an inch or more apart. Under the box is a sheet iron tray several inches deep, the lower end of which empties into the sluice boxes. As the gravel is blown up along the length of the box, the finer material and gold fall through the grating into the inclined tray and are washed back along it into the sluice boxes, while the coarser material is blown out at the upper far end onto the tailings pile which is on the ground already worked. Fortunately a head of over 200 feet is available for the monitor and this gives sufficient force to blow everything up to 100 pounds weight up through the box. Heavier boulders are rolled to one side. The monitor is of $3\frac{1}{2}$-inch diameter and 10-inch pipe is used for it. The method disposes of the coarse tailings immediately and cuts down the gravel which goes through the sluice boxes to a minimum. It may result in a relatively low percentage of the total gold values being recovered as some are probably blown over onto the tailings pile, but as it enables this ground to be worked at a profit these losses are justified.

Other Districts

In Carmacks District three partnership groups of placer prospectors have been at work during the last two years on Stoddard and Seymour Creeks, tributaries of Big Creek. The two creeks drain the northeast and southwest sides, respectively, of Mount Freegold, upon which the recent

[1] Keele, J.: Geol. Surv., Canada, Sum. Rept. 1905, p. 34.
[2] Cairnes, D. D.: Geol. Surv., Canada, Sum. Rept. 1916, pp. 24, 25.

lode discoveries have been made. As yet the placer workings in this vicinity have not proved profitable, though enough gold has been recovered to keep the stakers interested. As far as can be told at present the geology of the neighbourhood appears favourable for placer mining possibilities. The area lies just within the limits of the unglaciated region and consequently any placers formed in the long period of erosion extending to the present, have not been disturbed. The rocks consist of a series of gneisses, schists, and quartzites similar to those of the Yukon group to which the rocks of the placer fields of the Klondike and the other important placer districts of the territory belong. These rocks have been intruded in this neighbourhood by a variety of granitic rocks and a large number of mineral showings have been discovered.

In Livingstone district no new developments have been reported. There are, however, a few placer miners working on Lake and Summit Creeks and it is reported that plans are being made to re-open operations on Cottoneva Creek next summer.

Four men are reported to have been working on Iron Creek, a tributary of Sydney Creek which enters Nisutlin River on the west or right limit. They are reported to have been examining some old placer hydraulic ground near the mouth of Iron Creek, about 12 miles southwest of the south end of Quiet Lake. In the past a quantity of equipment was installed there, but no work has been done during the last ten years.

A single miner is reported to have been working for several years on Geary Creek, a tributary of Teslin River which it enters from the west or left limit a little above the mouth of Boswell River.

A revival of activity is reported to have occurred on the placer claims on Squaw Creek, a tributary of Tatshenshini River.[1] Most of the mining is said to be taking place on the upper part of the creek on the south side of the provincial boundary.

LODE MINING

MAYO DISTRICT

In 1930, W. E. Cockfield visited and reported on the activities of this district.[2] The following notes record activities of the camp from that time to the present.

In 1931 and 1932 the bulk of the ore production was from the Lucky Queen and Sadie mines on Keno Hill and the remainder consisted of a small tonnage from the No Cash group on Galena Hill. Prospecting and development have been continued on one or other of the many properties and claims on the hills in the neighbourhood of Keno. This activity is supported by the feeling that if the price of silver were to rise to approximately 50 cents an ounce, it would be possible for these small, rich properties to be worked at a profit.

[1] Cockfield, W. E.: Geol. Surv., Canada, Sum. Repts. 1927 and 1929, pt. A.
[2] Cockfield, W. E.: Geol. Surv., Canada, Sum. Rept. 1930, pt. A.

Keno Hill

The Treadwell Yukon Company, Limited, in 1931 is reported to have treated 47,793 tons of ore in the mill at Wernecke, with a yield of 4,109 tons of concentrates. In addition to the concentrates some 154 tons of crude, high-grade ore was also shipped. All this ore came from the Lucky Queen. In 1932, 1,000 tons of ore were taken from the Sadie mine, the track was then taken out, and this mine abandoned. The rest of the production has come from the Lucky Queen. For the first few months this was from the 200 and 300-foot levels and for the later months of the year from the 100-foot level and above it where a body of ore was recently discovered. This ore contains argentiferous galena as the chief mineral of value; the gangue is quartzite. It was reported that over 4,000 tons of concentrates were to be shipped in 1932. It was expected that the ore in sight in the Lucky Queen would be exhausted in a few months, and as the margin of profit was not considered great enough to warrant any extensive exploration for more ore, the company planned to close the mine, transfer the necessary equipment, and start production from the Brefalt property on Galena Hill. It is reported that the Lucky Queen was closed down about the end of the year (1932).

On the Shamrock group no mining has been done since 1930, but the mine equipment and workings have been kept in good repair.

In the autumn of 1930 and in 1931 Keno Hill, Limited, carried out some development work on the Porcupine discovery made in 1929 and a body of mill ore was developed near the surface. A number of good surface showings have been discovered during the last year or so by tracing the veins across the property of the company.

On the Nabob claim a small amount of surface prospecting has been done each year and has resulted in exposing the continuation of the vein.

On the Stone claim, the long tunnel has been driven through the overburden into bedrock and is now over 400 feet long. It has intersected a vein that contains arsenopyrite, pyrite, and zinc blende, and some fair gold as well as silver assays have been obtained. It is intended to explore this vein further.

On the Peel claim some prospecting has been done resulting in exposing a vein, but the work has been discontinued.

On Mr. Andrew Johnson's Hope Gulch property a tunnel was driven a short distance in 1931 and showed up some galena ore.

Galena Hill

Mining operations on the Silver King and Webbfoot claims were continued by the Treadwell Yukon Company, Limited, until about January, 1931, when the option on these two properties was dropped. The bulk of the milling ore was raised and stacked on the dump on the adjoining fraction belonging to the company. At the time the property was visited in 1932 a warehouse had been erected, as it had been intended to build a mill or transfer that at Wernecke to the Silver King. A tramway grade had also been put in between the Brefalt property and the Silver King to transport the ore from the former to the mill on the latter. On the Silver

King, however, the ore carries an unusually high percentage of zinc and a penalty is charged for over 10 per cent; this with the low price of silver has prohibited the continuation of the developments on this property.

On the Brefalt property or Elsa group the underground development has been completed since 1930 by putting up raises between the levels. On the surface some buildings have been built including a small hand-sorting plant. The road to the property has been improved and a winter road has been built on a good grade from the Silver King to the Mayo road, which with the tramway grade between these properties will be used to haul out the production from the Brefalt property.

On the Settlemier property some surface development has been carried on and has resulted in the vein being picked up in two trenches 300 feet apart. By these trenches and float the vein has been traced a total distance of approximately 700 feet to the northeast into new territory. One of the trenches shows the vein to have a width of approximately 20 feet with a seam of 5 feet of solid ore in the middle.

On the Betty group the owner has sunk some prospect shafts and has found a lot of good mineral float on the bedrock below 20 feet of overburden. This is thought to come from a possible extension of the No Cash vein.

On the No Cash group the lessee, Mr. E. Bjonnes, continued operations on a small scale in 1931 and shipped somewhat less than 100 tons of ore running about 450 ounces of silver a ton. About 20 tons of ore were shipped in 1932.

On the Tyee claim a little surface prospecting has been going on since 1930.

On Bunker Hill a little development work was continued in 1930. On Sourdough Hill since 1930 nothing but surface prospecting has been done.

CARMACKS DISTRICT

During the season of 1931 a visit was paid to the gold strike northeast of Carmacks and an account is given in the Summary Report, part A, for that year. The strike was again visited in July, 1932, during the course of the field mapping of the Carmacks sheet, a reconnaissance sheet to be published on a scale of 4 miles to 1 inch and covering an area including the lower Pelly River, Selkirk, Carmacks, and Nansen Creek. The mapping was extended to take in the country in the immediate vicinity of the strike and a small sketch map (Figure 2) was made to show the geology in the immediate locality of the discoveries. The following notes are given to supplement those in the report of 1931.

The topographical mapping of the Carmacks sheet, under Mr. W. H. Miller, has accurately fixed the position and elevation of Mount Freegold (Figures 1 and 2) where the original lode discovery was made. The distance to Mount Freegold from where the trail leaves the road 11 miles from Carmacks is 26 miles. The distance by trail from McDade Hill (Figure 1) to the mouth of Williams Creek is 14 miles. Another route to McDade Hill leaves the Crossing Creek trail shortly above the ford across this creek and heads northwesterly, passing on the north side two lakes, crosses Merritt Creek, and follows the north side of this stream to its head. By this route it is 20 miles from the road to McDade Hill. There is also a route from Selkirk and Lewis River, by way of Big Creek and its tributary

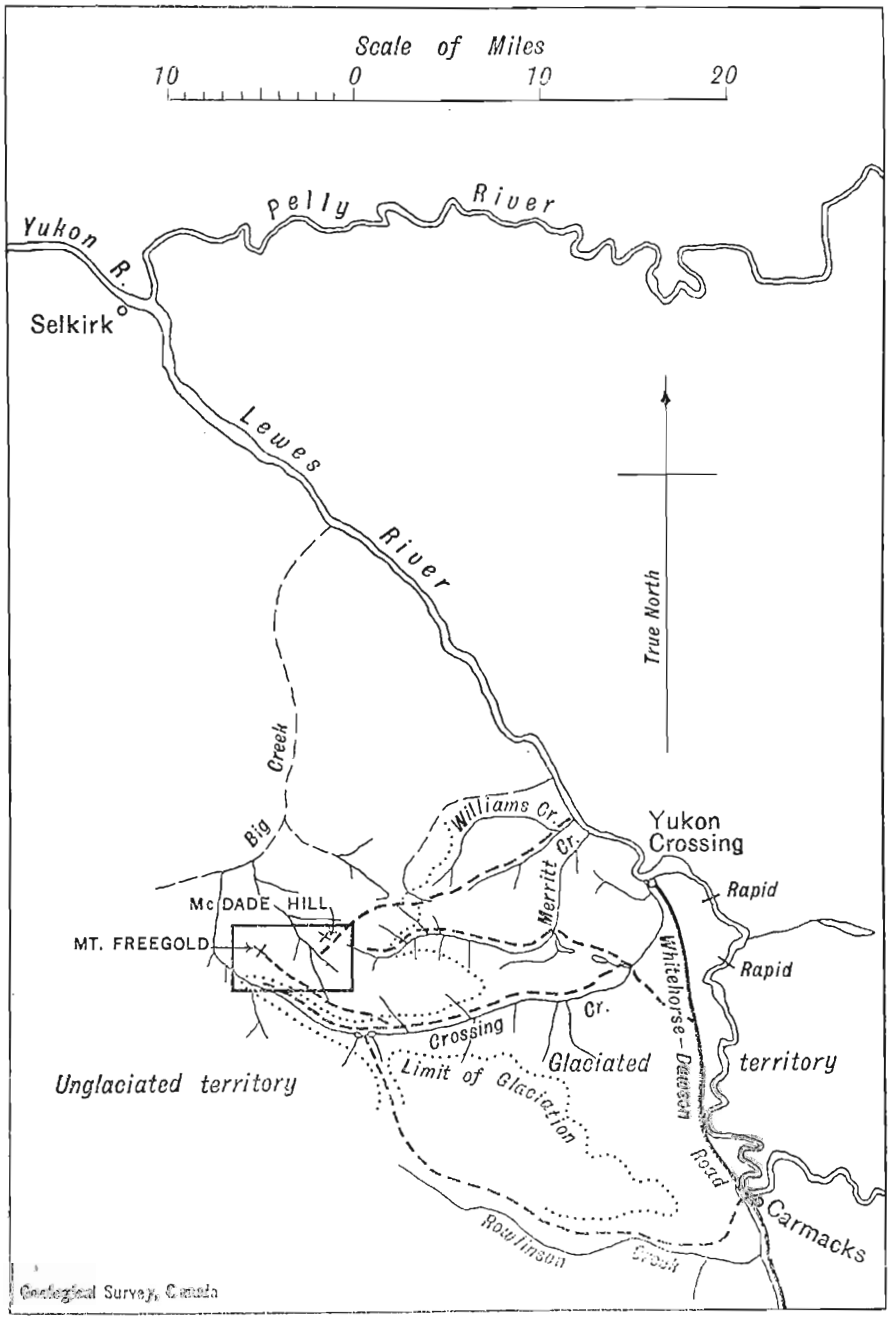

Figure 1. Index map showing location of Seymour Creek area, Yukon.

Stoddard Creek. Another route from Carmacks to Mount Freegold is by the Nansen Creek trail 34 miles long. No proper trail has been made along any of these routes. To reach the strike from Selkirk, or if coming up Lewis river, by boat, the best route is probably that by Williams Creek, whereas the best route from Carmacks and for horses is probably the Crossing Creek trail or that past the lakes and up Merritt Creek, depending upon which part of the locality it is intended to reach. The magnetic declination on Mount Freegold was found by Mr. Miller to be between 33 and 34 degrees east of true north and this is close to the average value for the parts of the Carmacks sheet so far covered. He also found that the compass varies widely from this figure locally in some parts of the map-area.

Many of the claims staked in the initial rush in the spring of 1931 have now been allowed to lapse. However, the assessment work has been done on a large number and some active prospecting was in progress in 1932. A good deal of trenching has been done and a large number of mineral showings have been found, but except those on McDade Hill, they are as yet merely discoveries.

General Geology

The rocks in the area represented by Figure 2 and its immediate vicinity form four divisions, a metamorphic series, a group of older volcanic rocks, granitic intrusives, and a group of younger volcanic rocks. The oldest of these is the metamorphic series referred to in the report of 1931. It consists in the main of gneiss, schist, and quartzite. On either side of Schist Creek these rocks show a persistent strike in a direction between north and northwest and a dip between 45 degrees east and vertical. On the northwest side of Mount Freegold the dips and strikes in those rocks vary very much more and indicate the presence of crumples and small folds. On Schist Creek the series is composed of interbedded gneiss and schist, the quartzites occurring on the west side of Mount Freegold and in the head of Guder Creek. The great part of the gneiss, as well as the schist and quartzite, is thinly bedded. The gneiss is composed of feldspar, quartz, mica, and hornblende. The schist is composed of quartz and mica with subordinate quantities of feldspar. Most of the schist occurs interbedded with the gneiss and smaller amounts with the quartzite. The quartzite is finely crystalline and in some places cherty in appearance. This series is cut off on three sides by bodies of younger granitic intrusives, but extends for an unknown distance to the northwest.

The older volcanics occur in the mountains southwest of Seymour Creek. Their extent here is unknown, but it is probable that they form a large part of the mountains to the south and southwest as similar rocks are recorded as occurring on Nansen Creek, 12 miles south.[1]

They are not well exposed here, but elsewhere are known to be composed of andesitic lavas and breccias with some small intrusive bodies of diorite and diabase that are intruded by the granitic bodies. Diorite and diabase dykes grouped with these rocks intrude the metamorphic series on Mount Freegold. The older volcanics are prevailingly green and may usually be distinguished by this colour. They are correlated with those bodies of

[1] Cairnes, D. D: Geol. Surv., Canada, Sum. Rept. 1914.

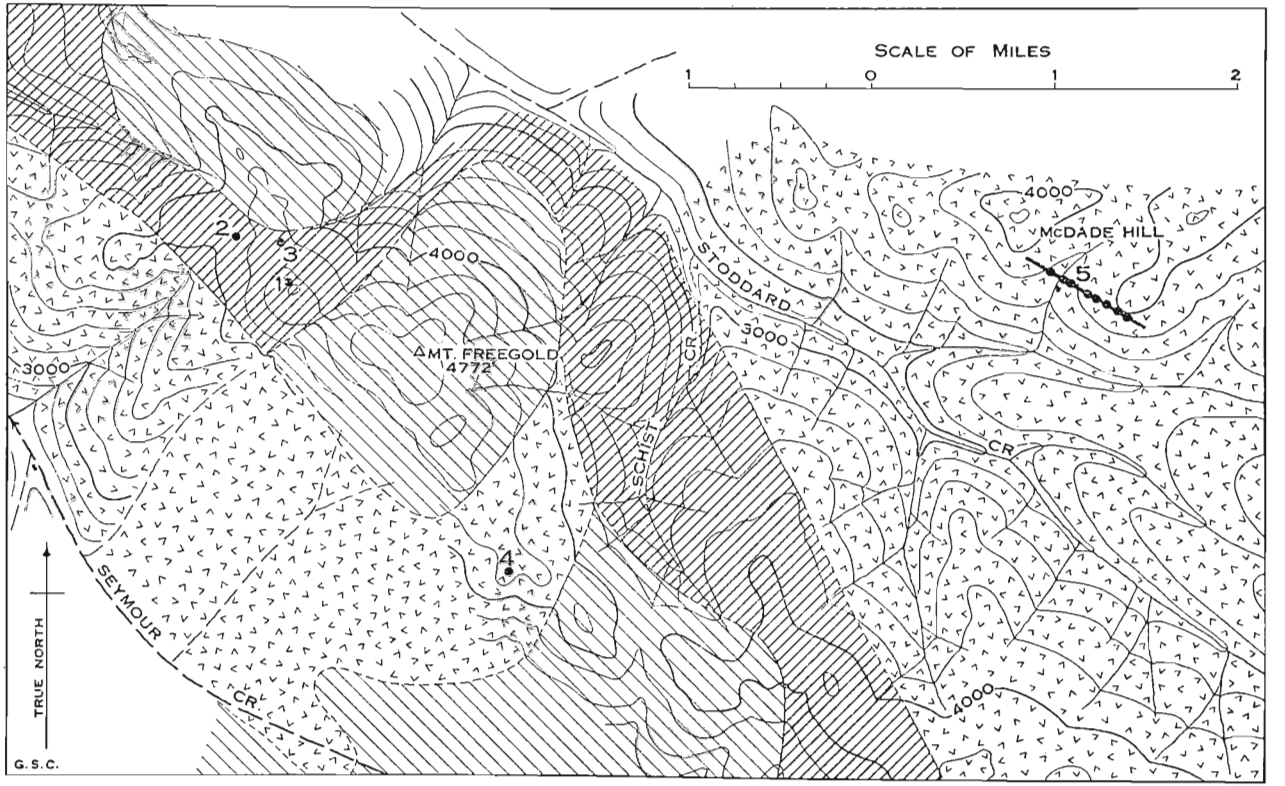

Figure 2. Seymour Creek area, northwest of Carmacks, Yukon. Areas of gneiss, quartzite, and schist shown by pattern of sloped, parallel, heavy lines; syenite porphyry by sloped, parallel, light lines; and granodiorite and granite by angles. Prospecting workings: 1, on Augusta claim; 2, on Margaret claim; 3, on Badger claim; 4, on Rambler claim; other workings on neighbouring claims lie south and westerly; 5, on vein on McDade Hill.

similar rocks found in other parts of Yukon, that have been grouped under the term Older Volcanics by D. D. Cairnes[1] and W. E. Cockfield.[2]

The metamorphic series and the Older Volcanics now form remnants of the roof into which large bodies of granitic rocks have been intruded. These granitic rocks include variations from hornblende syenites, syenite porphyry, granodiorite, granite porphyry, and granite. The syenites are the oldest and form two stocks on Mount Freegold ridge, and a third, larger body extending from the southeast end of the ridge across Seymour Creek and to the mountains directly south. Syenite porphyry is the chief rock of these bodies. It is typically very coarse grained and composed of large, pink orthoclase phenocrysts in a grey, coarse-grained groundmass of orthoclase, plagioclase, and hornblende. The rock varies from this to a hornblende syenite rich in hornblende and plagioclase and, on the other hand, to phases holding considerable quartz and very little hornblende. Where the two stocks have intruded quartzites on the west side of Mount Freegold, a considerable amount of contact metamorphism occurs, as evidenced by the presence of garnet, actinolite, and epidote, and with them, magnetite, specularite, pyrite, and chalcopyrite.

The intrusion of the syenite porphyry bodies was followed by the intrusion of a great, composite batholith of granites, granodiorites, and their porphyry phases. These rocks, besides occurring in the areas shown in Figure 2, stretch continuously 18 miles to the east, almost to Yukon Crossing. The many varieties of these rocks and the ways in which they are distributed, render it probable that the batholith is composed of a succession of intrusions closely related in composition and in age. Besides varying in composition it was noted that these granitic bodies near their contact with the metamorphic series, include numerous xenoliths of these rocks and in many places possess a foliated structure. Since these granitic rocks are younger than the older volcanics and in general resemble the Coast Range intrusives, it is probable that they and those granites near Selkirk mentioned by D. D. Cairnes[3] are correlatives of the Coast Range intrusives.

The intrusion of the granitic rocks was followed in this region by a great period of erosion which was interrupted by the deposition of conglomerates and sandstones in some of the valleys and by the accumulation of a great thickness of volcanic rocks, chiefly basic lavas and breccias and tuffs. These lavas cover extensive areas between Mount Freegold and Carmacks and have been described by D. D. Cairnes under the name Carmacks volcanics.[4] They have also been grouped by Cairnes and Cockfield under the Newer Volcanics.[5] The areas covered by these rocks have few possibilities and are not recommended for prospecting, since little mineralization of value has ever been found in them in Yukon or in similar rocks in British Columbia, whereas mineralization has frequently been found associated with all the other formations mentioned here.

Mount Freegold and McDade Hill lie in unglaciated territory very close to the western limit of glaciation (*See* Figure 1). If the area has been

[1] Cairnes, D. D.: "Lewes and Nordenskiold Rivers Coal District"; Geol. Surv., Canada, Mem. 5 (1910).
[2] Cockfield, W. E.: "Whitehorse District, Yukon;" Geol. Surv., Canada, Mem. 150 (1926).
[3] Cairnes, D. D.: Geol. Surv., Canada, Guide Book No. 10, p. 90 (1913).
[4] Cairnes, D. D.: "Lewes and Nordenskiold Rivers Coal District"; Geol. Surv., Canada, Mem. 5 (1910).
[5] Cockfield, W. E.: "Whitehorse District, Yukon"; Geol. Surv., Canada, Men. 150, p. 33 (1926).

glaciated it was at a period so much earlier than that of the glaciation recognized that all ordinary traces of it have since been obliterated by normal erosion. The fact that Mount Freegold lies outside the limit of glaciation is an important consideration in prospecting. It means that fresh rock exposures are fewer than in the glaciated areas, but that float is much more easily traced to its origin by following upstream and up slope. It also means that the mineral showings at the immediate surface are likely to be leached of some of their original values in such metals as silver, copper, and zinc, whereas there is a possibility of a residual concentration of gold from the former parts of the mineralization now removed by erosion. This necessitates getting below the surface zone which in some places continues to considerable depths, before truly representative samples holding values likely to continue in depth can be obtained.

Mineral Deposits

The mineral showings worked upon during the last year may be divided into three groups: (1) the magnetite deposits of contact metamorphic type in the rocks of the metamorphic series on the northwest side of the summit of Mount Freegold; (2) the pyritiferous vein deposits in the granitic rocks on the south side of the mountain; and (3) the mixed sulphide vein deposit in the granitic rocks on McDade Hill.

Since 1931 a number of trenches have been put in on the claims containing the magnetite deposits. Mr. Guder has traced the line of float from the Augusta where the original showings are, across the Margaret and Gold Star claims, a total distance of over 4,000 feet. On the Augusta the trenches along the line of the float failed to find the magnetite in place beyond a point 200 to 300 feet northwesterly from the main showing at the upper end of the deposit. However, farther down hill, northward along the line of float on the Margaret, in the saddle at the head of King Gulch, a number of trenches and pits have revealed magnetite with hematite, quartz, pyrite, and chalcopyrite in place. Cubical cavities formed from the leaching of pyrite occur in the magnetite on the Augusta. A long trench not yet down to bedrock was being excavated on the Margaret and showed abundant magnetite float. On the adjoining Badger and Morning claims, Mr. W. Langham has started a number of long trenches, but bedrock had not been reached. In these trenches, however, some float carrying magnetite and pyrite in metamorphic silicates was found. No further work was done on the magnetite showings mentioned last year on these claims.

On the Rambler, and the neighbouring claims to the south and southwest being worked by Messrs. W. Langham, G. Fairclough, A. Brown, and others, a considerable amount of surface prospecting has been done. It has consisted of searching for float and trenching. This has disclosed some nine or more vein showings, all of the same general type as that referred to in the report of 1931 on the Rambler and Nabob claims, that is, quartz veins a few inches to a foot wide containing crystals of pyrite. At the time of the writer's visit the best exposed showing was on the Snowflake. Here Mr. Langham has exposed a quartz vein in two cuts on the steep slope of the mountain. In the lower cut, the vein is 5 feet 6 inches wide with stringers in the adjacent granite wall-rock, making a total width carrying vein matter of 10 feet. The vein quartz is very finely

crystalline and has a pale bluish grey colour. This colour is due to minute cubes of pyrite and some crystals of arsenopyrite disseminated through the quartz. The vein strikes north 34 degrees east and dips very steeply to the northwest. This was found to be the prevailing strike and dip for the veins of this immediate locality, with one or two exceptions that strike due north. In the upper cut, 30 feet above, the solid vein is 3 feet wide, but stringers occur on either side of it for a few feet. The granite wall-rock here, as well as in the cut below, is much sheared, weathered, and iron stained. Gold colours have frequently been obtained from fragments of the oxidized or partly oxidized vein matter by panning, but though a few spectacularly high assays in gold are reported the majority of the assays reported have been disappointing. Since, however, all these showings are in the most elementary stage of discovery and none of the trenches yet extends below the limit of weathering, considerable work must be done before they can be judged.

On McDade Hill a group of twelve claims have been staked along a single, large, persistent vein. This vein was discovered in 1931 by Mr. G. McDade and since then Messrs. G. McDade, T. Mackay, J. Walsh, and J. Coleman have put down a number of pits and shallow shafts at intervals of 200 to 400 feet along the vein, proving it to continue for at least 4,000 feet. The vein varies between 3 feet and 6 feet in width and has well-defined walls of granite, though in one place bodies of wall-rock are said to divide it into three close, parallel veins. The strike is approximately north 119 degrees east and the dip from vertical to 85 degrees north. One shaft 800 feet east of the creek (*See* Figure 2) has been put down 32 feet. This shows the vein to be 4 to 6 feet wide. Here, the vein is composed of quartz with patches of sulphides. The quartz is white, finely crystalline, and contains abundant small cavities which in places are so numerous that the quartz is in a loose, sandy condition. The wall-rock on either side is granite. The vein and wall-rock have everywhere been subjected to intense weathering even to the bottom of the deepest shaft. As a result, much of the original sulphides have probably been leached out and those remaining only occur where the quartz was solid and protected them. The wall-rock has been reduced to a crumbly state, particularly on the south or down hill side of the vein. In some of the pits on the vein the sulphides found are in different proportions. Thus in the shaft mentioned the sulphides seemed to be disseminated, but in the pits on either side they tend to be in large patches. The sulphides occurring in the vein are pyrite, galena, zinc blende, chalcopyrite, and tetrahedrite. Where the galena is found in solid masses it is coarsely crystalline and shows a sheared structure. The chalcopyrite occurs in small amounts associated with the galena. The zinc blende is a resinous variety. The pyrite forms small strings and patches of minute cubes. In places the quartz exhibits a comb structure and contains numerous small vugs amongst which the sulphides are scattered and a vague banding is apparent. Originally particular interest was drawn to the vein by the fact that fine colours of gold could be panned from almost any piece of rusty vein matter on the surface. A number of encouraging assays are reported, but unfortunately the values obtained to date from the majority, though consistently showing small amounts of gold, have not been high enough to class the matter as ore.

WHITEWATER GOLD BELT, TAKU RIVER DISTRICT, BRITISH COLUMBIA

By F. A. Kerr

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Figure 3. Whitewater gold belt, Taku River, B.C. 16

INTRODUCTION

During the summer of 1932 the geological survey of Taku River map-area was completed and a final report is in preparation. Preliminary reports on the area have already been issued in the Summary Reports for 1929 and 1930. The present report is merely a brief summary of some of the more important results obtained in the prospecting and development work and in the recent geological investigations in so far as they have a bearing on the gold deposits of Whitewater Mountain.

The Whitewater gold belt is the name given to an area along Talsekwe River that includes the Whitewater, Silver Queen, Silver Bird, and other groups of claims (*See* Figure 3). Gold prospects of a similar nature have been found on the first and last of the three named, which are, respectively, at the northern and southern limits of the area so far included in the belt. The claims are situated from 5 to 6 miles from the junction of Talsekwe and Taku Rivers on the west side of the former. The Whitewater prospects, the most northerly, are three-quarters of a mile from a warehouse that marks the landing on the main channel of the river and they can be reached readily by small boat to this point and thence by trail. The Silver Bird prospects are on the opposite or west side of the same mountain spur, on Wilms Creek about $1\frac{1}{2}$ miles direct from Talsekwe River. They can be reached from a boat landing above the mouth of Wilms Creek by a trail up this creek of about 3 miles in length. The Silver Queen group is reached by branch trail from Whitewater Landing and a further trail to the south along the east slope of the spur leads to a number of other claims and prospects in this vicinity.

The Whitewater group of claims was discovered in 1929, and is owned by Art. Headman, Ray Walker, and associates. The owners carried on some open-cut work in 1929 and 1930. In 1931 the property was bonded with a $5,000 cash payment by the N. A. Timmins Corporation of Montreal and development work was carried on during 1931 and 1932. In September, 1932, through inability to secure a year's extension of a $10,000 payment due then the option was dropped. The Silver Queen group of claims, owned by D. J. McDougal and associates, and the Silver Bird group, owned by R. G. Wilms, C. H. Smith, and George Bacon, staked in 1931, were explored under special ownership agreements by the Alaska Juneau Gold Mining Company of Juneau, Alaska, during the summer of 1932.

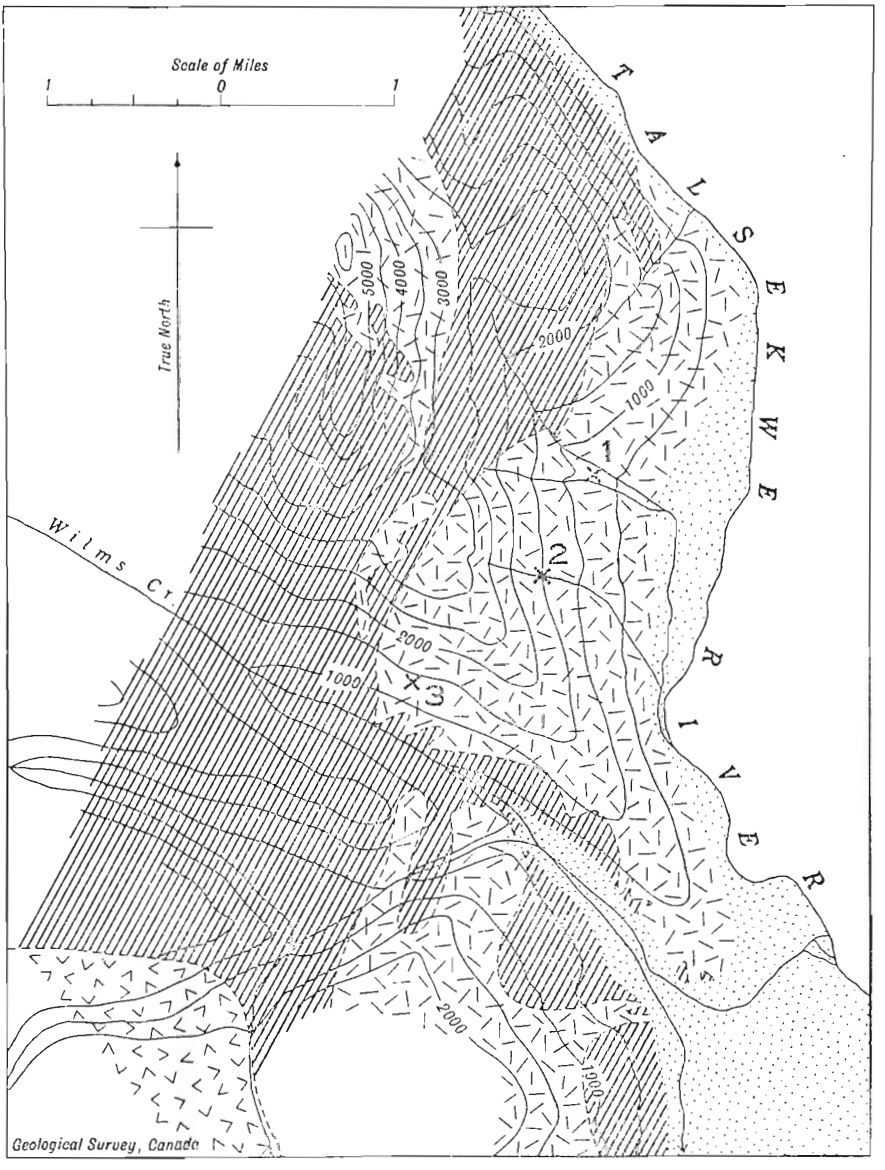

Figure 3. Whitewater gold belt, Taku River, British Columbia. Locations of main showings on the most important properties are indicated by crosses: 1, Whitewater; 2, Silver Queen; 3, Silver Bird. Areas of Recent alluvium are indicated by a stipple pattern, Coast Range intrusives by angles, Mesozoic volcanics by short dashes, and Palæozoic sediments and volcanics by sloped, parallel lines.

GENERAL GEOLOGY

The rocks of the Whitewater belt are in the main green volcanics, which include tuffs and flows probably in the main originally of andesitic composition. They are considerably altered everywhere, mainly to green chlorite and other secondary products. The bedding of the tuffs shows up very well in many places where the rock is exposed along creeks, but elsewhere it may not be apparent. As a rule the rocks present a fairly massive appearance and are hard. In some places, however, they are very much sheared and, as a rule, soft and may display a variety of shades from dark to light green and dark slaty grey to light silvery grey. In the localities where the grey colours occur the volcanics are not readily distinguishable from sediments. It is possible that some of the rocks of this character in the series are actually interbedded sediments, but at most the percentage of rocks that might fall into this category is very small. The volcanics are Mesozoic in age, probably Triassic, and they overlie unconformably Palæozoic rocks.

The Palæozoic rocks show a wide range in character and include crystalline limestone, quartzites, schists, slates, argillites, and some volcanics. The crystalline limestone, usually light grey in colour, occurs almost entirely in one group at the top of the series. Since an unconformity marks the boundary with the Mesozoic rocks, a considerable range of Palæozoic materials is found there. In the Whitewater section there are some isolated patches of the limestone which are usually small. In the main the rocks are schists with lesser quantities of interbedded quartzites, slates, and argillites. These rocks are, as a rule, readily distinguishable from the common, massive, green volcanics, but they may not always be separable from the more sheared and schistose parts.

The structure of the rocks is complex, as is fairly well shown by their distribution as indicated in Figure 3. In the main, the west side of Talsekwe Valley conforms to the same side of a synclinorium which has a general plunge to the south. The volcanics present, though fairly extensive, are more or less in the form of a shell on the valley wall. Owing to the innumerable small and complex folds the shell shows a wide range in thickness; in synclines it may be carried to a considerable depth, whereas over the crests of anticlines it may be entirely absent, as is the case at the base of the mountain on the east side not far south of Whitewater Creek and elsewhere. Wilms Creek to the southwest of the spur on which the properties are located has cut completely through the shell; it is not believed that there is any connecting band between the volcanics on either side of this creek. There is thus indicated a maximum possible thickness for the volcanic belt on Whitewater Mountain of about 2,700 feet. Over most of the area it is probably much less than this. As the contact along both sides of Wilms Valley is largely assumed, it is probably much more irregular and has greater heights to the anticlines than indicated. The plunge of minor folds shows a wide range in steepness and may be either to the north or the south, so that the attitude of beds in individual outcrops offers little criterion of general structure. The main trends along the northwest side of the area of volcanics are in general about parallel to the contact. On the Whitewater property the shear

zones near the contact show a trend of from north 20 degrees east to north 45 degrees east, whereas on the Silver Bird claims the strike is from north to somewhat east of north. Throughout the body of the volcanic mass the trends range from about north 45 degrees east to north 45 degrees west, in the main showing a direction near north-south.

Owing to the intensity of the folding the volcanics are sheared in many places along minor structures. The shear zones are, of course, concomitants of the main structures and their trends are in the main the same. However, owing to the irregularity of the structure and the massiveness and variability of the volcanics, shearing is very irregular. The trends are not constant and in places may swing as much as 90 degrees; a wide, well-sheared zone may narrow to a few inches of gouge, may split into many thin zones, or may vary in almost any way. Shear zones are usually not continuous for any great length. In the main the zones, which are numerous, are narrow, irregular, and discontinuous. However, well-defined zones up to 20 feet wide have been observed and it is not unlikely that some such zones display much greater regularity and continuity than the smaller ones.

ECONOMIC GEOLOGY

Mineralization in the Whitewater section consists of two types, one occurring in the Palæozoic sediments and the other in the volcanics. The latter is the main type of the Whitewater belt, but the former is associated and closely related. The main type, together with the deposits of this kind, will be considered first. All of the deposits of this group belong to the general replacement type common to the western part of Taku district and described in detail in the Summary Report for 1930. Briefly, they are generally marked by an alteration of the normal green volcanics to light grey materials made up mainly of combinations of the following minerals: quartz, white mica, carbonates, bleached chlorite, and albite. In places they have a sheared or banded structure. They may grade to the green volcanics or be sharply cut off from them. The weathered rock is usually rusty and in most places is somewhat softer—in some places being much softer or more friable than the enclosing rocks. Sections high in quartz on the other hand are correspondingly hard. The rustiness is due to a general impregnation of pyrite and to concentrations of this and other sulphides.

The altered zones are irregular in shape and in size and are usually small and more or less lenticular. The trend of the zones is, as a rule, irregular, but they generally tend to conform roughly to that of the main local structures, and the best developed zones are most likely to have a direction nearer north-south than east-west. The zones are commonly found near the contact of the volcanics with the underlying Palæozoic sediments. Such locations would appear to be the most favourable not only for finding the zones but for the finding of larger zones.

Many of the zones carry only one sulphide, pyrite, in important quantities. Some, however, carry important concentrations of mixed sulphides. In some of the narrower zones these occur throughout, but in many, especially the wider ones, the concentrations represent only a small

part of the total zone. The size or position of the concentrations has not yet been found to bear any systematic relationship to the size or shape of the containing zone. They are essentially lenses which tend to lie in one plane of the zone, though there may be subsidiary series. In the larger deposits the lenses may be intergrown and more or less continuous for considerable distances. Besides the concentrations of mixed sulphides there are in places, generally associated with these, some scattered impregnations. The sulphide content of the zones shows a considerable range from place to place within the district.

In some of the zones the more highly mineralized parts assume the form of veins and in a few places definite fissure veins occur. To some extent, therefore, the zones may be considered as veins with bordering bands of wall-rock alteration. In so far as true veins or other cavity fillings have occurred these deposits resemble those in the sediments of the Whitewater belt where alteration of the country rock by the mineralizing solutions is not apparent.

The general alteration in the zones is believed to be due to solutions in the main different from, but closely related to, and in part the same as, those responsible for the deposits of valuable minerals. The solutions probably showed a fairly wide range of compositions. It is believed that even in one locality there was a considerable variation over a period of time and also, partly because of changes in the routing of circulating solutions, that there were variations from place to place other than those that normally result from precipitation and solution during migration of the liquids. At times the material injected into the volcanics was of such a nature as to form dykes or dyke-like masses, mainly of quartz and albite. The metal content of the deposits naturally shows a considerable range even within a very limited district.

The deposits of the Whitewater belt are in the main replacements of the general type outlined, though veining characteristics are more pronounced than usual. The volcanics are altered to the usual grey rock and the altered zones follow sheared parts which are due in the main to the folding and, therefore, trend with the structures. They are, of course, located relatively near the contact with the older sediments, since this is not distant from any part of the volcanic mass on Whitewater Mountain. The altered zones exhibit an irregularity which conforms to that of the shear zones. On the Whitewater group most are less than 6 feet wide and only a few exceed 20 feet; on the Silver Queen one is over 200 feet wide, and on the Silver Bird there were observed over 200 feet of altered rock and the total width is reported to be in excess of 1,000 feet. On the Whitewater many narrow zones have been found, on the Silver Queen one wide zone and some narrow ones, and on the Silver Bird the alteration appears to be fairly continuous.

The minerals which in the main constitute the grey, altered rock are quartz, white mica, carbonate, and bleached chlorite. The rock is almost invariably rusty at the surface and in places is very friable and rotten to a considerable depth. Pyrite occurs throughout and is to a large extent responsible for the rustiness. Other sulphides noted in the deposits include stibnite, arsenopyrite, and chalcopyrite. Pyrite was probably the most abundant sulphide noted on all three groups of claims. It occurs mainly

as distinct crystals throughout the altered zones. In the parts of greater sulphide concentration it occurs in this form, as irregular grains of peculiar rounded or rosetted shape, as skeleton crystals, and as massive, irregular patches which in places with quartz have a vein-like form. Stibnite was observed abundantly in the main Whitewater showings and to a lesser extent in those of the Silver Queen and Silver Bird. It is usually fairly massive, with a somewhat irregular distribution, but with its gangue of quartz and other minerals forms vein-like masses which probably are irregular lenses. The stibnite replaces some of the massive pyrite and occurs as distinct veinlets cutting some of the quartz. Arsenopyrite has been observed only on the Whitewater and Silver Bird groups. It occurs only in certain sections of the altered zones. Some has been noted in all but a few of the parts where stibnite was found, but it does not bear any direct proportional relationship to the stibnite and has been observed abundantly in many places where no stibnite was seen. The arsenopyrite occurs entirely as disseminated crystals of unusual needle-shape which may be as much as one-half inch long. It occurs in the soft, altered, volcanic material, ranging in abundance from very sparse distribution to sufficiently close crystal groupings in very small areas to give the impression megascopically of massive veinlets or lenses. It also occurs in the quartzy parts. Here again with quartz, carbonate, and minor amounts of other non-metallic minerals, it is found in sufficient concentrations to give the aspect in the hand specimen of massive, tiny stringers or cement in shattered sections which are usually highly quartziferous and, consequently, brittle parts. Some of the arsenopyrite, notably that in the soft, altered volcanics, is clearly replacement in nature, whereas some, together with gangue minerals, filled fractures. It is probable, however, that much of that in the quartziferous sections is replacement also, for it is clear from the evidence of quartz traversing broken crystals of the arsenopyrite that some of the quartz was later, and it may very readily have replaced all the other minerals from around the arsenopyrite as it has quite evidently done in sections free of the sulphide. Chalcopyrite was noted only in one specimen, from the Silver Queen group. It seemed to have crystallized with the stibnite. Tiny quantities of unidentifiable grey minerals were noted in a few places within the stibnite and pyrite.

Neither native gold nor gold tellurides are observable under the microscope. There is nothing, other than perchance the odd crystal form[1] of the arsenopyrite, to suggest the presence of gold in ordinary mineralographic studies. Assay returns, however, have clearly shown the presence of the gold, and also that it does not occur with the pyrite or stibnite but with the arsenopyrite. Investigations by the Ore Dressing Division of the Mines Branch, Ottawa, show that the gold is not recoverable on ordinary amalgamation or cyanidation, but that practically all is obtainable by flotation with the arsenopyrite. Spectroscopic investigations further confirm the existence of the gold with the arsenopyrite. The gold, therefore, would seem to occur in solid solution or in some intimate relationship other than actual chemical combination, since the amount of gold present does not seem to bear a direct relationship to the amount of arsenopyrite. Assay returns lead to the belief that both the arsenopyrite

[1] It is significant that in sections of Manitoba and elsewhere prospectors have come to consider that the needles of arsenopyrite are a valuable indication of the presence of gold.

with quartz in stringer-like masses and that disseminated in the softer, altered, volcanic material carry gold. It is thought, however, that the arsenopyrite is not all of the same age and possibly some was gold bearing and some was not. As yet no suggestion as to the differentiation of two such types is forthcoming.

The extent of mixed sulphide mineralization relative to that of altered rock shows a wide range. On the Whitewater some of the zones show mixed sulphides across the whole width, whereas on the Silver Bird they are confined to narrow bands which represent a very limited part of the whole altered zone. Quartz is usually abundant in the sections of mixed sulphides. It appears to be of widely different ages. Some is pre-arsenopyrite mineralization, some is the same age as some of the arsenopyrite, and some is later. It occurs in a variety of forms, as fragments in a breccia, as irregular replacements of the volcanics, and as veinlets both regular and irregular. It ranges in colour from white or pink to dark grey.

It is clear that the solutions that were responsible for the alteration of the country rock and the formation of the sulphides and other new minerals showed a considerable range of composition over a period of time. Most of the pyrite was deposited at a different time from the stibnite and most of the arsenopyrite at a different time from both of these. All solutions, however, in the main followed about the same general courses. However, due to shearing and shattering during mineralization the details of circulation varied from time to time, so that the relative abundance of the various metallic minerals does not correspond. In later stages the brittleness of the quartzy sections, and a consequently greater shattering, may have considerably influenced the movement of solutions.

Out of all this data the important considerations are, of course, those that will lead to the location and identification of the sections likely to be high in gold. In the first place the gold mineralization so far as the volcanics are concerned is confined to the altered zones. It is not directly associated with either the pyrite or the stibnite, though high gold values may occur with these minerals. It is usually present where arsenopyrite occurs, though there is not always a direct relationship between the relative abundance of the two. Quartz in places is abundant in the sections of higher gold values. There is often much shattering in these sections. On the other hand some sections of high value are of softer materials, which are not susceptible to shattering and on weathering become very rotten. In these the arsenopyrite is distinctly a replacement and occurs in concentration bands parallel to the shearing. Thus in general there are quite definite criteria to aid in the search for the gold-bearing deposits.

The main type of deposit of the Whitewater gold belt is quite definitely limited to the mass of volcanics which it occupies, but similar altered zones occur on Mount Strong to the south and there is no reason why other similar gold deposits may not occur on this mountain or in still other sections of the western part of the map-area.

WHITEWATER

The discovery zones on the Whitewater occur along the southwest side of Whitewater Creek. The work done on these by the original owners and the information gained therefrom is described in the Summary Report

for 1930. The exposed zones appeared to have a trend of north 45 degrees east to north 20 degrees east and a dip of 60 to 80 degrees southeast. On the northeast side of the creek no counterpart of the zones was discovered and work to the southwest was discouraged in the early explorations and greatly hampered later by the lack of exposures and a heavy drift covering which occupies a depression extending toward the location point of the Silver Queen, shown on Figure 3.

During 1931 and 1932 much trenching, open-cutting, and diamond drilling were done over a considerable area on the hill-side between about 200 and 800 feet above the valley flat. The method of carrying on this work left a gap of unexplored ground in the upper part of this slope and thereby made a separation of the showings into two groups, which for convenience in description is maintained here. The upper group includes showings in the main between 620 and 720 feet above the base of the hill, lying between Whitewater Creek and the tributary to the southwest, and is indicated by the location point shown in Figure 3. The lower group, mainly between 200 and 600 feet above the flat, extends down the slope of the hill for about 1,000 feet and to the southwest of Whitewater Creek for about the same distance.

In the upper group, though a number of zones have been discovered beyond, the most important developments have been in the vicinity of the discovery zones and to the southwest along what is believed to be their extensions. Surface work has shown that within 125 feet along Whitewater Creek, between 640 and 680 feet above the valley flat, there are four zones, with widths from about 5 to 15 feet or more, which have returned assays from about $10 to $25 in gold a ton—being in the main near the lower figure.

Southwest of these showings (more especially of the two northwestern and wider ones) where there are practically no rock exposures five trenches have been dug. They have no very systematic arrangement; the most southwesterly is about 200 feet from the creek exposures. All show some mineralized rock. In most the full extent of the zone or zones is not defined, but demonstrated widths across the probable trend range from about 5 to 20 feet and values range from about $10 to $30 a ton in gold, with some narrow sections going much higher. A trench at 250 feet from the main showing did not strike bedrock, but showed rusty material as of the weathered part of a zone. Otherwise no trench in this section, and all were only 20 feet or less in length, failed to show zone material and good values. Some valueless rock was exposed in each, but the percentage was on the whole relatively small. Thus in a band 50 to 80 feet wide and 200 feet long, the trenches suggest at least that much of the rock is mineralized. It would be a most remarkable coincidence if the trenches had struck the only sections that are mineralized. Irregularity is clearly indicated, but it seems reasonable to expect some continuity and the maintenance of an average width of at least 10 feet for one zone for the 200 feet of length. The other zone (or others) so far as is demonstrated might have similar continuity and size. The surface work is far from sufficient to afford an adequate idea of the true nature of the showings.

Four holes were drilled below this section and a fifth cut below part of it. The depths at which the holes passed vertically below the showings ranged from 50 to 350 feet. Below the more important showings two holes at 50 and 350 feet are reported to have shown nothing of much value and the other two to have shown narrow zones with relatively low values. Vertically below somewhat less important showings, moderate widths and moderate values were indicated by two holes at about 100 and 130 feet below the surface. The results obtained were decidedly discouraging. However, they are hardly conclusive as to the true nature of the extensions below the surface since a tiny drill core penetrating a very irregular replacement zone may very well give an entirely erroneous impression. The complete results gained do not present a sufficiently reliable picture of the shape or size of the mineralized zones to make it justifiable to infer that they have no economic value.

In working out the shape of the zones it must be borne in mind that they may not have a great vertical extent. Though the general indications are for a northeast-southwest trend with steep dip, some may even follow the shearing of certain horizons in the volcanics and, therefore, may be saddle-shaped over the crests of minor anticlines or assume some other unusual form. Other irregularities due to similar irregularities in the structure and concomitant shearing may also be expected. In tracing any zone it is essential not to go too far afield from the known exposures unless its trend and shape are better known than has so far been indicated for any zone.

To the south of the Whitewater camp in the lower group area, between elevations of about 200 and 600 feet above the valley flat, conditions were favourable for ground-sluicing, so explorations were largely carried on there. A number of long trenches across the structure or down the slope were cut. Over a considerable area these exposed many altered zones. Most of these were indicated to be narrow, irregular, and discontinuous. Gold values in many were of no consequence. A number, however, gave values of $6 to $12 over widths of 2 to 5 feet and a few for widths of 10 to 20 feet. Drilling under one of the wider zones suggested a possible continuation to a depth of over 200 feet, with about the same width and values as at the surface. Drilling 200 feet lower showed very low values over a narrow width. On the whole the work throughout this section did not offer much encouragement.

In general the prospecting on the Whitewater has shown that there is a lot of gold in the mountain through a vertical range of at least 700 feet. Most of it is clearly scattered in zones that could have no economic value. It seems, however, to be a natural corollary of these features that, given a more favourable zone for mineralization, the solutions traversing the rocks were amply rich and abundant to have caused the formation of a deposit of economic worth. Further, a study of the available information whether it be the data on structures, shear zones, or other replacement deposits leads to the conclusion that such a zone is not an unreasonable expectation. At best, however, the zone is most likely to be irregular and even more or less discontinuous, and values are almost bound to be erratic. From structural and other considerations any mineral deposit of this type, at least in this section, is likely to have no very great depth.

Granting the possibility of a mineral deposit of economic worth, the question then arises as to where such is most likely to occur. From a purely geological viewpoint, taking into consideration structure and the location of other replacement deposits, the general vicinity of the upper group of showings on the Whitewater is probably a very favourable location. The topographical expression here, in view of the depression along the slope of the hill in the direction of the trend of the deposit, suggests the possibility of the continuation of the zone with its more readily eroded rocks. Of course, other similar depressions showing the same trend along the direction of ice movement, which have no readily apparent explanation, are to be observed elsewhere. Again, the actual showings and assay returns from the main zone of the upper group are the most encouraging found yet. Thus so far as present indications go the main zone of the upper group offers by far the greatest promise of being of economic worth. If further work on this should indicate that it has no value, the prospects of the property would become rather discouraging, though not entirely hopeless. It would be difficult to lose sight of the abundance of gold in the mountain. There is no very definite evidence that would point to any other showing being of economic value nor which would suggest favourable loci for other zones. It should be borne in mind, however, that the deposits do not have great vertical extent and that many zones may not reach the surface or may be comparatively poor there. It is of interest in this respect to note that one zone exposed on Whitewater Creek can be seen to pinch out upward from a width of 8 feet in a relatively short distance. Such features as these, however, cannot be used as offering much encouragement that the many small zones now exposed may become wider at depth. This is not likely to be the case and the possibility is not sufficient to warrant their testing without further inducement than has thus far been afforded.

SILVER QUEEN

The main showing on the Silver Queen is approximately at the location given on Figure 3. Here there are exposed 200 feet of altered volcanics highly impregnated with pyrite. In places the pyrite is quite massive. It is replaced by stibnite and chalcopyrite. No arsenopyrite needles have yet been observed nor have any important gold values been noted, though extensive assaying such as was carried on at the other two properties has not yet been done. The zone's chief merit so far lies in its position; it is at the southern end of the depression extending southwest of the main Whitewater showings; the projected strikes of the two deposits approximately correspond and the Silver Queen showing lies nearly on a line between the Whitewater and Silver Bird deposits; the mineralization is, of course, similar in all three except that the first, as stated, does not show the arsenopyrite and gold, the former of which, it should be noted, is not always readily detectable and the latter is apparent only on assay. Southeast of the main showing, along the creek, there are some other minor zones of altered volcanics which are of little consequence except to indicate the continuation to some extent of the mineralization on the eastern part of the Whitewater property.

SILVER BIRD

The main showing of the Silver Bird group of claims consists of an extensive, altered zone which was observed over a width of 200 feet and is said to be in all about 1,000 feet wide. It is, of course, unlikely that the highly altered grey rock is continuous across this whole width; in the part examined there were noted some sections comparatively little altered. The general trend of the zone according to limited exposures appears to be nearly north and south. The main showings examined occur between 1,200 and 1,500 feet in elevation. The altered zone extends 300 to 500 feet higher and then passes into the usual green volcanics, apparently unaltered by the mineralizing solutions. Down hill there are no exposures until near the creek, at 500 to 700 feet elevation, where the underlying sediments are found, so that the zone probably does not extend down the hill as low as this. Pyrite occurs throughout and according to assays the zone is reported to show about $1 in gold over considerable widths. To the west some smaller zones are exposed. To the east not a great deal is known of the rocks because of very limited exposures.

The most important prospect is located along what is known as Sulphide Creek. This stream, which is very small, follows along a fracture that roughly trends north-south and in places shows a dip as low as 30 degrees east. There has been considerable shattering and shearing along it and in places there is gouge-like material. In others it is filled with what appears to be a vein, but actually is a series of veinlets or quartz-cemented breccia. This is highly mineralized with arsenopyrite occurring entirely in disseminated crystals which, however, in places are concentrated in streaks suggestive of veinlets or of breccia cement. Some pyrite and stibnite are present. Values of $8 to $24 in gold to the ton are reported. The material constituting the vein or vein-like section has a maximum width of not much more than a foot and maintains something near this amount for only a relatively short distance, though the fracture with associated mineralization, or others similar to it, are to be found along the creek for about 200 feet. On either side of the fracture are zones up to 4 feet wide which have impregnations of arsenopyrite and carry up to about $2 in gold—probably in places somewhat more. The zones are very irregular. The arsenopyrite in places is in exceptionally large needles. This mineral is more abundant in the vein material than noted elsewhere, but here as in other places the gold content does not appear to vary directly with the arsenopyrite. This band of mineralization as exposed does not appear to have any economic worth. Some similar mineralization has been found nearby, but nothing of greater consequence has so far been found in the main altered zone. However, a large part of it is not at all exposed and is unprospected.

It would appear that the Silver Bird display of the altered rock represents a vertical cross-section of the altered zone and that the altered zone probably continues into the mountain in the direction of the Silver Queen and the Whitewater zones, though the line-up and projections of strikes do not correspond exactly. The fact that it is not continuous to the crest of the spur is more or less of a normal expectation in that the altered zones do not appear to have great vertical extent. There are considerable unaltered volcanics on the spur overlying what might normally be expected to be

the extension of either the Silver Queen or the Silver Bird. So far as is known it is quite reasonable to expect that the main altered zones on all three properties are more or less continuous; that is, throughout a belt about 8,000 feet long between locations 1, 2, and 3 as shown on Figure 3, at elevations from 700 to 2,000 feet to the south and up to 800 feet to the north, there is a belt of the volcanics likely to show much alteration. In this belt it is also reasonable to expect zones of high gold values such as occur at either end. The abundance of gold in the mountain in seemingly less favourable sections would suggest that in this part there might be expected something better than found elsewhere. It would, therefore, seem that starting with the Whitewater showings this section deserves somewhat more attention than it has previously received. A relatively small amount of work should afford a much clearer picture of the possibilities of success.

OTHER PROPERTIES IN THE VOLCANICS OF WHITEWATER MOUNTAIN

Most of the spur of Whitewater Mountain has been covered by claims. Some alteration of the volcanics has been noted at various points as far south as the tip of the spur, and zones that in general appearance are like those on the Whitewater have been noted. None of those observed, however, seem to offer any promise, but they serve to indicate the widespread character of this type of mineralization. Since the present work was completed it has been reported that similar mineralized showings have been found north of Whitewater Creek Valley which previously had seemed to mark a boundary between the volcanics with mineral zones and those without.

GOLD DEPOSITS IN THE PALÆOZOIC METAMORPHOSED SEDIMENTS

The Palæozoic sediments, apparently being unfavourable for replacement by the more common types of mineralizing solutions, have naturally been considered less favourable for the occurrence of mineral deposits. Certainly they are not suitable for the occurrence of deposits of the type most commonly found in the district, and the presence of these in volcanics near the sediments in so many places further emphasizes the unsuitability of the sediments as a host. However, on the Silver Bird group intensive assaying of the rock has brought to light a new type of gold deposits.

In a small stream ("Middle Creek") valley just beyond the volcanics considerable prospecting has revealed, over an area possibly 75 feet wide across the strike, erratic gold values said on assay results to range up to $30 a ton with much of it between $1 and $2. The rocks are mainly dark grey schists and argillitic quartzites. They carry many veins and irregular masses of quartz and considerable impregnated pyrite, and in these and other respects are typical of the series—in fact even to fairly careful observation there would be revealed nothing that would suggest that any part of the rock here differed from elsewhere, certainly nothing to suggest the gold values reported. The operators have been very much bewildered by the assay results and though they can spot, more or less, some of the higher grade material they have been unable to define any

zones according to values. Assay results on some of the lower grade material taken in the present work confirmed the results reported; no assays were made on the higher grade materials.

Careful observation reveals the fact that the rocks are cut by two types of quartz—one common to the formation and another not readily distinguishable from it. The former seems to be more of a creamy, massive, and dense material, whereas the latter is darker grey, crystalline with vugs, and more vitreous. This quartz occurs in irregular masses, in definite tiny stringers, and as breccia cement. In the hand specimen it appears to carry smears of light bronzy white mineral which because of tarnish is somewhat more suggestive of an unusual pyrite than anything else. On a polished surface it can be seen to be thin streaks up to $\frac{1}{2}$ inch long of arsenopyrite. These occur mainly in groups, in and along the edge of the quartz, and are very similar to some of the arsenopyrite occurrences in the gold deposits of the volcanics, and it is believed that the quartz-arsenopyrite combination here is responsible for the gold values also, and that it is due to the same mineralizing solutions and is, therefore, closely related. This material was noted to be most abundant in the parts where the highest values are reported. Here there is a definite brecciated zone which, however, shows no very great regularity. In the rocks in which the moderate values were noted neither similar quartz nor arsenopyrite was recognized in most places. The field identification of the rock with the moderate and the higher gold values at best will be found to be difficult, but it is likely that if the gold does occur with this quartz-arsenopyrite combination, as seems probable, a little practice coupled with a few assays of the various quartzes found will enable the prospector to distinguish at least the sections of higher values.

The deposit as so far disclosed shows very erratic values, but according to the reports there is considerable rock with interesting quantities of gold in it and there is thus indicated a possibility of deposits of economic worth. It is likely that such deposits in the sediments will have structural trends conforming to those in the volcanics, that is, northeast-southwest. The best zones are likely to occur in the more brittle and, therefore, more readily fractured parts of the formation, but as there are some brittle rocks throughout, sufficient fracturing may occur anywhere. Such deposits in the sediments may, however, be merely in the nature of overflows or extensions of those in the volcanics, but the fact that the latter overlie the former stratigraphically, and usually in their present positions also, would tend to the belief that the mineralizing solutions would pass through the sediments first and that although these may be less favourable for deposition they may under some conditions have caused precipitation before the solutions reached the volcanics.

CONCLUSIONS

The widespread occurrence of gold on Whitewater Mountain and the abundance indicated, even though it is scattered, offers great encouragement that deposits of economic worth may exist. Only one favourable factor has so far not been demonstrated to exist, that is, the presence of a sufficiently well-defined and large zone to have captured enough of the mineralization to be of value. There seems to be no reason why such a

zone should not have existed. There is a large area of volcanics that are definitely in the gold belt. The deposits likely to occur in these in the main are probably small without very great vertical extent. There is already indicated, however, at least one part of the volcanics that may contain deposits of economic worth.

The discovery of gold mineralization in the Palæozoic sediments greatly extends the indicated potential gold-producing areas. The possibility of gold occurring in the sediments below the volcanics of the Whitewater belt is an interesting consideration which, however, should not carry too much hope since it appears that the volcanics are the more favoured host. The deposits in general suggest that the whole of Whitewater Mountain is favourable for the occurrence of gold deposits. Similar mineralization on Mount Strong extends the favourable zone to include this. Geological conditions throughout a belt lying between the Talsekwe-Stoohini (South Fork) Valley and the main axial core of the Coast Range composite batholith are similar and are worthy of consideration in a search for gold deposits. Of course it must be recognized that so far the Palæozoic sediments, which are the most abundant rocks of this area, have not been demonstrated to be very favourable for mineralization. The chief hope there lies in the occurrence of not readily identifiable deposits such as have been described. The absence of placer deposits has, of course, no significance in an area such as this where any that had existed would most probably have been completely destroyed by glaciation. So far as the rest of Taku district is concerned the history of mineralization is probably so complex that gold deposits may be found anywhere in the general zone most favourable for mineralization, which can tentatively be considered as lying between a northwest-southeast line along King Salmon Valley and the main axial core of the batholith.

ZEBALLOS RIVER AREA, VANCOUVER ISLAND, BRITISH COLUMBIA

By H. C. Gunning

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Figure 4. Zeballos River Area, Vancouver Island, B.C. 36

INTRODUCTION

During the summer of 1932 work on the Nimpkish Lake quadrangle, lying between latitudes 50° 00′ and 50° 30′ and longitudes 126° 00′ and 127° 00′ on Vancouver Island, was continued[1] and about 400 square miles in the southwest part of the area were studied. As at least one more year of field work is necessary to complete the whole quadrangle and as a final report cannot be written before that time, summary reports, covering, in brief fashion, the more important geological and economic results of the season's work, are published each year. This is the second such report. It so happens that most of the interesting geology and practically all mineralization were found, this year, in the vicinity of Zeballos River on the west coast drainage. Consequently, most of this report is devoted to a discussion of that part of the area.

The summer's work was greatly facilitated by the cheerful and efficient assistance, under most trying climatic conditions, of Messrs. A. P. Beavan, C. H. Donaldson, and C. E. Cleveland. Invaluable air transportation and many courtesies were given by members of the Royal Canadian Air Force from Jericho Airport, Vancouver, under Squadron-leader A. B. Shearer. Hospitality and valuable information were freely given by residents of the district and in this respect the writer is particularly indebted to Alfred Bird and T. J. Marks of Zeballos River and to officials of Nelson Bros.' reduction plant at Ceepeecee. As in 1931, vertical aerial photographs taken by the Royal Canadian Air Force were used as a base map in the field.

During the summer sufficient field work was completed to afford a correlation between the formations exposed near Nimpkish Lake on the northeast side of the island and those outcropping on the southwest side in the vicinity of Esperanza and Kyuquot Sounds. It is now apparent that the same succession of rocks is exposed in these two areas and that the structure from Nimpkish Lake southwest towards the coast is anticlinal. Thus, when adequate base maps are available, a geological section across the northern interior of Vancouver Island can be constructed for the

[1] *See* Geol. Surv., Canada, Sum. Rept. 1931, pt. A, pp. 22-35.

first time. Additional information was also obtained regarding the age of the rocks of the Vancouver group and further data were secured on the nature and form of the Coast Range intrusives.

The economic results are of more immediate interest. The large area in the vicinity of Woss and Vernon Lakes was not found to contain signs of any important mineralization. Volcanic rocks and interbedded limestone are, it is true, intruded by many large and small bodies of granodiorite, but there is a remarkable scarcity of metallization in the vicinity of these intrusives. As a result, this large and formerly little known area cannot be recommended to the prospector. A different condition exists, however, towards the western part of the area, for there is widespread and diversified mineralization in the region drained by Zeballos and Artlish Rivers. It includes contact metamorphic copper and magnetite deposits, replacements of chalcopyrite and of zinc blende, and small veins of quartz and sulphides that carry important gold values. Much of the gold occurs as native metal in a finely divided state throughout the veins, but particularly in association with zinc blende and chalcopyrite. Although the known veins are small, varying in width from an inch or less to about one foot, and none has as yet been traced for any very great distance, yet gold values are sufficiently high to encourage development towards small scale mining operations.

To date prospecting has been restricted to the valley of Zeballos River and the lower reaches of its north fork. This territory has been fairly carefully investigated during the past few years, but it is so difficult to prospect, on account of heavy timber and drift and its rugged nature, that further attention might well be paid to it. Geological work this season, however, was extended into the area northwest of Zeballos River that is drained by Artlish River. This region is very little known and is believed to be entirely unprospected. It is rugged and possesses no trails, but the same succession of rocks that cross Zeballos River and contain the known mineral deposits there—namely, limestone, other sediments, and volcanics intruded by a large, continuous body of granodiorite—extend northwesterly across it. A broad belt adjoining the granodiorite on the northeast, where the rocks dip southwest or towards the intrusion, is extensively mineralized with pyrite, pyrrhotite, and, more rarely, magnetite, and other minerals. It should prove attractive to the prospector, particularly if any placer gold were found in any of the streams draining it.

PHYSICAL FEATURES

The whole area covered in 1932 is mountainous. Further than that, a large proportion of it is extremely rugged, so that locomotion away from a very few main routes is not only exceptionally difficult but in places downright dangerous. The mountains, although not much over 6,000 feet in elevation at any place and, over large areas, well below that figure, are steep and rough, and so broken by bluffs and deep valleys that to travel on foot more than 3 or 4 miles a day is frequently impossible. The principal range extends southeasterly from Atluck Lake to the south end of Woss Lake and then easterly to Vernon Lake. At the northwest is the sharp and precipitous Pinder Peak, a little over 5,000 feet in elevation. On the southeast, immediately west of the south end of Woss Lake, is the extensive

Rugged Mountain, on which are the highest peaks in the area. Between these two, and separated from them by the deep valleys of the north fork of Zeballos River on the north and of Zeballos Lake on the south, is Zeballos Mountain, 5,171 feet high. Between the south end of Woss Lake and Vernon Lake is a broad stretch of moderately high but very rough mountainous country which passes, northwards, into lower and less rugged territory near Nimpkish Valley. West of the Pinder-Rugged Range the mountains again become lower, but the valleys, as the west coast is approached, are correspondingly deeper, so that the difficulties of travelling are not greatly reduced. Nimpkish Valley, on the north and east of the area covered, is broad and low and heavily timbered. Woss Lake, one source of the Nimpkish, is 491 feet above sea-level and Vernon Lake, another source, is about 700 or 800 feet above sea-level. Nimpkish Valley connects on the south with the valley of Gold River which flows into Muchalat Arm on the west coast and the broad, heavily timbered divide between the two streams cannot be over 1,000 feet above sea-level. There is a second low route through the area, following Zeballos River and its north fork, and so to Wolfe Creek and past Wolfe and Hustan Lakes to the south end of Nimpkish Lake. The summit on this route, at the head of Wolfe and Zeballos Rivers, is slightly over 1,200 feet above sea-level. Two miles south of this summit there is a low pass, just over 1,500 feet in elevation, between the north fork of Zeballos River and Artlish River on the west. There is no easy route between Woss Lake and Zeballos River, although the divide, east of Zeballos Lake, is only slightly over 2,000 feet above sea-level. Zeballos Lake is 1,046 feet above sea-level. In addition there is a pass about 1,600 feet in elevation between the south end of Woss Lake and Tasis River which flows into Tasis Canal on the west coast. The whole area is densely timbered with hemlock, cedar, fir, balsam, etc., to an elevation of about 3,000 feet. Above this the timber thins and many of the summits and ridges are bare and rocky. This dense vegetation makes for relatively few and scattered outcrops in the lower ground, except in rough places or in stream bottoms. Contrary to general belief, the underbrush throughout much of the area is not excessively dense. Indeed, many of the steep mountain slopes and broader valleys are remarkably free from bad bush. In these places the thick stands of large timber make beautiful park-like country in which one may travel in comparative ease without a trail. The upper Nimpkish Valley is exceptionally open in large part and contains, the writer believes, one of the largest stands of good Douglas fir remaining on the island. Nevertheless, areas that are poorly drained and many of the flatter summits do support a dense growth of brush, and where this is mixed with much fallen timber or where it occurs in old burned areas, which fortunately are rather scarce, progress on foot may become practically negligible. In a general way the worst bush is encountered within 1 or 2 miles of salt water.

There are very few trails in the area. One leads up the east side of Nimpkish River from Nimpkish Lake, and it is good for about 10 miles or a little more. Beyond that it continues as a well-blazed and partly cut-out line to and up the south side of Davie River at least as far as Klaklakama Creek. A branch line is blazed from the Nimpkish, about 1½ miles above Woss River junction, to Martin Lake and south to Davie river. The main trail continues south up the east side of Nimpkish River to Maquilla Creek

and circles back to Klaklakama Lake as well as continuing up Nimpkish Valley, but beyond Maquilla Creek it is very difficult to follow. A poorly defined branch leads to Vernon Lake. None of these lines, with the exception of the first 10 miles above Nimpkish Lake, is really worthy of the name trail—they have been blazed and cut out at one time or another by trappers and timber cruisers, but within recent years they have had very little use. On the west side the trail situation is also lamentable. A good foot trail extends from the mouth of Zeballos River to the forks, a little less than 7 miles up. Beyond that a poor trail has been blazed out for a few miles up the north fork and there is a moderately good game trail up the southeast fork. In 1931, A. J. Campbell of the British Columbia Department of Lands cut out a trail from Hustan Lake past Wolfe Lake and over the summit to the headwaters of the north fork of Zeballos River. There is, too, a fair foot trail up Tasis River and over the pass to Woss Lake, but the northerly mile or two of this one can only be recommended as a last resort. No trail, except the 10-mile stretch above Nimpkish Lake, is suitable for pack horses. The climate is wet and mild. As the interior part is uninhabited no records are available for it, but it is probably somewhat dryer, or less wet, than the part adjacent to the west coast where the rainfall must average in the neighbourhood of 100 inches per annum or over. Most of the rainfall occurs between September and May and not infrequently the summers are moderately dry and pleasantly warm. However, exceptions are common. During the writer's experience the record for the summers has been as follows: 1929—a wet, stormy June, July, and August, with possibly three weeks of sunshine, but a fine, dry September; 1930—good weather during most of July and August and the first half of September, June and the latter part of September very wet; 1931—a wet June and September but practically no rain in July and August; 1932—intermittent heavy rains all summer, with twenty-four rainy days in July and no more than five consecutive days of sunshine from mid-June until late September. If the law of averages applies the summer of 1933 should be fairly pleasant. In the lower areas, within a few hundred feet of sea-level, 2 or 3 feet of snow is considered excessive and many winters are entirely open. At higher elevations the snowfall must be tremendous and snow remains in large quantity well on into June and July in the loftier peaks. The only permanent ice field of any size is on the northeast slope of Rugged Mountain. The climate is similar to that of Vancouver with the rainfall about doubled.

The Canadian Pacific Railway maintains a tri-monthly service up the west coast of the island, the north-bound boats leaving Victoria on the first, eleventh, and twenty-first of each month. The nearest port of call to Zeballos River is Ceepeecee, from which a launch or rowboat must be used to go the 12 miles to the mouth of Zeballos River. Ceepeecee is likewise the nearest port of call to the mouth of Tasis River. Artlish and Tahsish Rivers are reached from one of the ports in Kyuquot Sound. The upper part of Nimpkish Valley is most easily accessible from Englewood on the east coast of the island.

Within comparatively recent days there has been a tremendous rock-slide at the head of the north fork of Kaouk River. A large part of the diorite mountain immediately north of the source broke away and slid down and across the valley, forming a small lake on the south side in a

tributary valley. The trees are still standing in the lake in a comparatively good state of preservation. The bulk of the broken rock, however, turned west and rode down the main Kaouk Valley about 2½ miles, sweeping everything before it and, in the bends, rushed considerable distances up the mountain slopes, cleaning off all the timber. The present stream is meandering in the broad, open, boulder-strewn valley. There has been another great rock-slide, older than the above, at the outlet of Zeballos Lake. A large portion of the volcanic mountain lying east of the valley, a shoulder of Rugged Range, slid down and across the stream, damming up the lake with a mass of broken rock. Consequently the lake drains out underground except at periods of extreme highwater and the maximum rise and fall of the lake-level is well over 30 feet. The size of the lake today must greatly exceed that which existed before the landslide.

Some of the stream valleys are underlain for considerable distances by the Quatsino limestone, for example, all the upper reaches of Artlish River and several miles of the southeast fork of Zeballos River. The soluble nature of the limestone permits the water to form underground channels, so that, except at periods of high water, long stretches of these rivers have dry beds. The water of a whole stream may suddenly disappear from sight in a cave or a gravel-filled depression and, some distance below, as unexpectedly boil up from below. Such valleys generally abound in excellent exposures of smooth, water-worn, crystalline limestone with associated dykes and flows, and the whole Artlish Valley above a point some 8½ miles from salt water is particularly interesting in this respect. Sink-holes, caves, canyons, underground channels, and an occasional natural bridge are all there and at one place the whole south fork passes, underground, through a small mountain for about ¼ mile, appearing again on the downstream side in a deep and inaccessible canyon.

GENERAL GEOLOGY

The same general succession of rocks is found in Zeballos River area as in Nimpkish Lake region.[1] Early Mesozoic volcanics and sediments of the Vancouver group are intruded by batholiths, irregular bodies, and dykes of granitic rock, known collectively as Coast Range intrusives. As in Nimpkish area the Vancouver group rocks fall readily into a threefold subdivision. The central division is the important Quatsino limestone, a prominent calcareous horizon consisting of at least several hundred feet of fine-grained or coarsely crystalline, dark grey to white limestone with minor intercalations of green flows and fine-grained, grey, green, or brown tuffs, the tuffs becoming particularly abundant towards the top of the formation.

Conformably beneath the limestone is a great assemblage of volcanic rocks, predominantly andesitic to basaltic flows, but containing considerable quantities of coarse volcanic breccias and some tuffs. The flows are dark green to almost black and include a large proportion of amygdaloid and pillow lava. The fragmentals (breccias and tuffs) are green, grey, and reddish. Interbedded with these volcanics are very minor amounts of fairly pure, white to impure, dark grey limestone in the form, generally, of quite limited lenticular beds. The contact between the Quatsino limestone and the underlying Karmutsen volcanics is always sharp and frequently exhibits evidence of faulting along it.

[1] *See* Geol. Surv., Canada, Sum. Rept. 1931, pt. A, p. 22.

The Bonanza group overlies the Quatsino limestone conformably and consists of a great variety of volcanic flows and fragmental rocks with interbedded sediments. The distinctive pillow lavas and amygdaloids of the Karmutsen volcanics are absent and their place is taken by green and grey andesitic and more acidic, lighter-coloured types with a minor proportion of black, basaltic rocks and very few fine-grained amygdaloids. Fragmentals including green, purplish to red, and grey breccias and the corresponding finer-grained tuffs or beds of consolidated volcanic ash are very abundant. Crystal tuffs, resembling porphyries, are widely developed and there are a few coarse-grained porphyritic flows. Interbedded with all these, but most abundant near the base of the group, are the sediments. These include well-bedded, pure to impure limestone in thin beds, and argillites and quartzites. The latter two are not nearly as abundant as in the vicinity of Nimpkish Lake, but thin-bedded quartzitic to calcareous and argillaceous tuffs or tuffaceous sediments of this type are of common occurrence. As a general rule the top of the Quatsino formation must be taken at the horizon where tuffs or argillaceous to quartzitic sediments become so abundantly interbedded as to form the bulk of the formation, so that, towards the top of the Quatsino limestone up to 50 per cent of the formation may be tuffs and other sediments, nearly always in very thin, sharply defined beds. Green to grey dykes, believed to be part of the volcanic series, are quite abundantly developed in all the rocks of the Vancouver group.

A few collections of poorly preserved fossils were made from the rocks of the Vancouver group, but they have not as yet been studied by a palæontologist. Accordingly, no direct evidence of the age of these rocks was obtained, but on structural evidence and lithological similarity it is fairly safe to conclude that the same age as determined near Nimpkish Lake applies to the rocks in Zeballos River area. On these grounds, then, it may be assumed that a lower part of the Bonanza group is definitely Upper Triassic. Presumably all the Vancouver group strata fall within the Triassic and, possibly, the earlier part of the Jurassic.

All the above-mentioned rocks are invaded by the Coast Range intrusives. These are brown to grey and greenish grey, crystalline, plutonic rocks that vary in composition from quartz gabbro to quartz monzonite. They form dykes, sills, irregular bodies, and batholiths in the other rocks. Apart from the bodies shown in Figure 4 there are large masses of these granitic rocks in the neighbourhood of Nimpkish Valley and Woss and Vernon Lakes. The small belt near the mouth of Zeballos River, indicated on Figure 4, consists of a multitude of dykes and small bodies of intrusive rocks that vary from a very dark quartz gabbro to quartz monzonite and micropegmatite, cutting the volcanics and sediments of the Bonanza group in such an irregular manner that it is impossible to definitely separate the intrusive material from the rest on a map of the scale used. Within the belt, the acidic intrusives are more abundant on the southwest, whereas the darker, more basic phases predominate on the northeast. The large body that trends northwesterly across Zeballos area (Figure 4) may be termed the Zeballos batholith. It exhibits an interesting variation in composition and appearance. Where it crosses Zeballos Valley, below the forks, and southeast therefrom, it is predominantly of a light grey colour and the average com-

position would approximate granodiorite, although light grey diorite is quite common. Northwest of Zeballos River, however, the body is much more complex. In a general way the northeast side of the mass is much more basic, and darker coloured, than the southwest part. The more basic phases, too, including much diorite and some gabbro, are invaded by dykes and irregular bodies of aplite, granodiorite, and quartz monzonite and these same rocks constitute most of the southwest part of the main body. But the field relations indicate that all these varieties, from gabbro to quartz monzonite, were formed during a single extended period of intrusion; during this period differentiation proceeded within the magma, however, so that a variety of rock types were formed, beginning with the early gabbro and diorite and ending with the much lighter more acidic, granodiorite, quartz monzonite, and associated dyke rocks. Around the peripheries of the major intrusive bodies there are many dykes. They have not yet been studied microscopically, but they vary from dark grey or green diorite to light grey aplite and white alaskite or albitite. Some of the earlier ones are very rusty on the surface due to disseminated pyrite or pyrrhotite and the latest phase is probably represented by dense green to greyish green lamprophyres. These are generally quite barren of sulphides and do not weather to brown or rusty shades.

Regarding the age of the Coast Range intrusives, the only evidence obtained within the area under discussion is that they intrude, and are, therefore, later than, rocks of upper Triassic age. Above the fossiliferous Triassic horizons, however, there is a great thickness of volcanic and sedimentary rocks which are also invaded by the same intrusives. In all probability the invasions did not commence until late Jurassic days at least and the field evidence indicates that they must have continued throughout a very considerable period of time.

STRUCTURE

The predominant structure of the rocks of the Vancouver group within Zeballos area is monoclinal, the beds striking northwest and dipping at moderate angles, not generally over 45 degrees to the southwest. In the vicinity of the large Coast Range intrusive bodies, however, this simplicity disappears and the rocks are frequently greatly contorted and somewhat faulted. This condition obtains all along the southeast fork of Zeballos River, and over most of the area contiguous to the lower reaches of Zeballos River. In all these places vertical or very steep dips and, less frequently, sudden, radical changes in strike, are exceedingly common. In some places the strata are overturned.

In addition, the regional monoclinal structure is complicated by a tightly folded syncline whose axis approximately parallels and lies close to the north fork of Zeballos River and continues northwards along the valley of Wolfe Creek towards Nimpkish Lake. This structure is in many places practically isoclinal and the beds are overturned towards both the west and east. As a result of this folding narrow remnants of Quatsino limestone are preserved, along the north fork, in the underlying Karmutsen volcanics (*See* Figure 4). To complicate matters, the folding has been accompanied or followed by faulting. The most pronounced fault trends a

little west of north along the north fork and dips vertical or steeply east where observed. It forms the western boundary of the infolded masses of limestone and the east side of the fault has moved down, and possibly northward, relative to the west side. Apparently this fault is later than a number of cross faults, striking east to east-northeast and dipping nearly vertical or moderately steeply to the south. It will be noted that these faults trend approximately at right angles to the contact of the Zeballos batholith; three that have been observed are shown on Figure 4. The folding and faulting along the north fork are of considerable economic importance, as will be pointed out below. Although along faults and some bedding planes the rocks of the area are locally crushed and sheared, no large masses of schistose or brecciated strata were encountered.

MINERAL DEPOSITS

The only mineralization of any importance that has been found within the area lies in a comparatively narrow belt that trends northwest from Zeballos River on the southeast to Artlish River on the northwest, and only that part of this belt that is drained by Zeballos River has been prospected. The more important, known mineral deposits are indicated on the accompanying map (Figure 4).

They, and others that will be mentioned, are considerably diversified both in mineral content and mode of origin. All are believed to be related in origin to the Coast Range intrusives which are abundantly developed in the region, and of these the Zeballos batholith is the largest and most important. The deposits include:

(1) Pyrometasomatic or contact metamorphic replacement deposits. These occur most commonly in limestone or calcareous sediments, less commonly in flows or fragmental volcanics, and are always closely associated with Coast Range intrusives. They contain values in copper, generally in the form of chalcopyrite, or, less frequently, in zinc in the form of sphalerite, and very commonly include large quantities of magnetite, either relatively pure or mixed with sulphides. Generally they do not carry important values in gold.

(2) Certain replacement deposits in volcanics or calcareous sediments containing chalcopyrite as the principal metallic constituent. They formed at a lower temperature than the contact metamorphic deposits to which, however, they appear to be closely related in origin.

(3) Veins, of quartz or quartz and calcite mixed, that contain important gold values and such minerals as pyrrhotite, pyrite, arsenopyrite, zinc blende, chalcopyrite, and galena. The gold is in large part free, but very finely divided, and the veins, at least those found to date, are small. They occur in flows, tuffaceous sediments, or limestone and are a distinctly later and lower-temperature phase of mineralization than the contact metamorphic deposits. On account of the depressed condition of the base metal market, and the consequent increased activity in gold deposits, they are of greater interest at the moment than any of the other mineralization.

In addition to the above principal types of mineralization, some of the gravels along Zeballos River contain placer gold. No great success

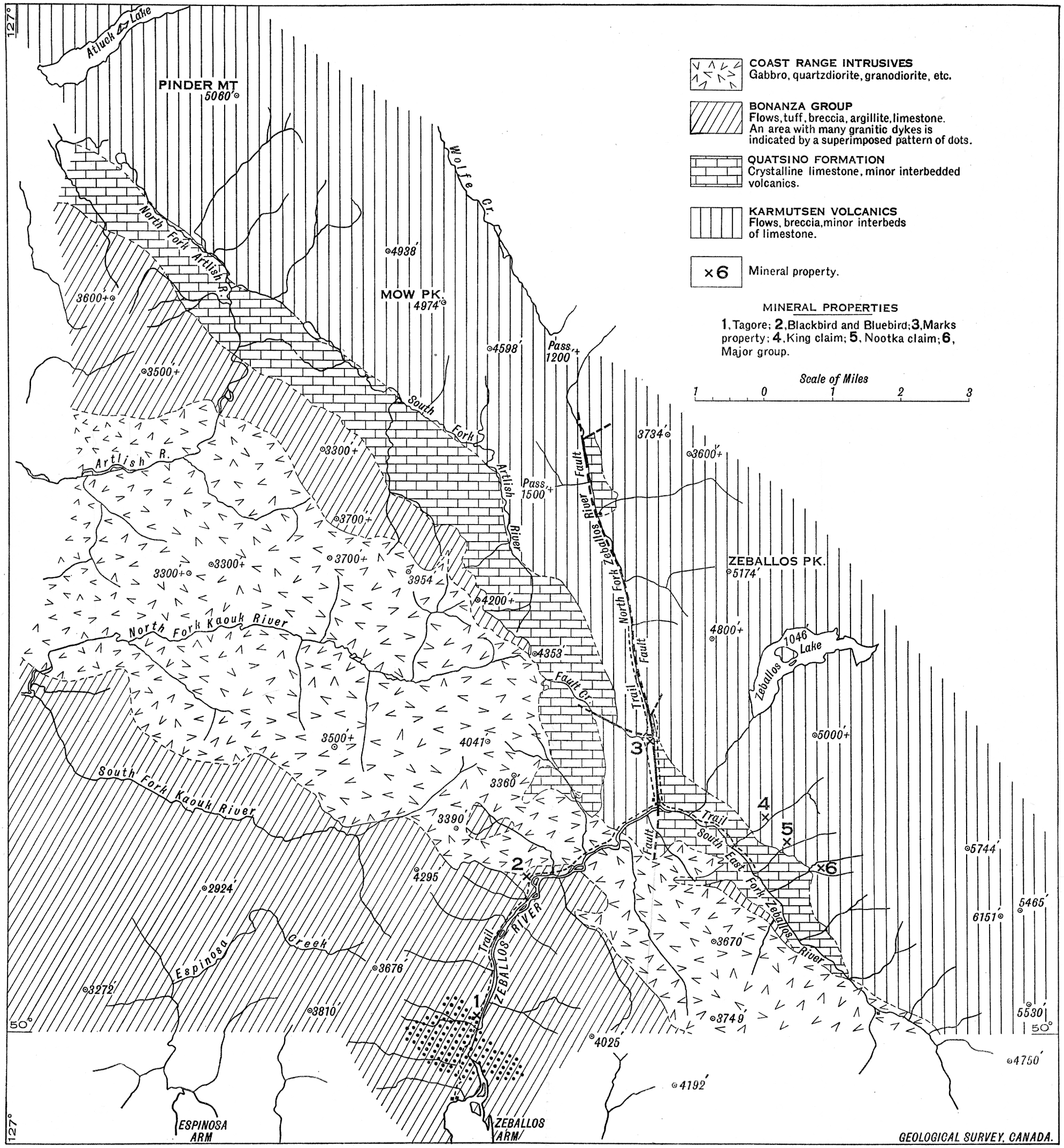

Figure 4. Zeballos River area, Vancouver Island, British Columbia.

has accompanied one or two attempts that have been made to extract the precious metal.

None of the properties has been very extensively developed. The Tagore, which first attracted attention to the district in 1924, has been prospected by numerous open-cuts and by a deep cut and shallow shaft on the main vein. Numerous surface cuts and a short adit have been driven on the Marks property on the north fork. For the rest, a few open-cuts and surface stripping constitute the total, in addition to small-scale placer operations at two places. About 5 or 6 ounces of gold have been won from the latter. About 5 tons of ore has been shipped from the Tagore, yielding possibly 50 ounces of gold.

DESCRIPTIONS OF PROPERTIES

The *Tagore* group of claims straddles Zeballos River about 1½ miles above its mouth. The vein is on the west bank of the river and was discovered in 1924 by J. West and A. Ostman. Known as the Eldorado at that time, it was systematically prospected and abandoned by an English syndicate in 1925. In 1929 it was optioned as the Tagore, by A. B. Trites, from Messrs. Malmberg and Nordstrom of Quatsino. About 2 tons of ore, unofficially reported to have assayed about 20 ounces in gold to the ton, was shipped, but apparently results were not satisfactory, for the property lay idle until 1932 when Malmberg, Nordstrom, and four associates commenced mining on a small scale, under an agreement with A. B. Trites. By September a shipment of 4,500 pounds had been made and the smelter returns indicated an assay value of 2·63 ounces of gold and 2·52 ounces of silver a ton; a gross value at that time of $50·50 a ton. The property is on the main Zeballos River trail and accommodation consists of two small cabins and a blacksmith shed.

The vein consists of quartz or quartz and calcite with a small to very large proportion of pyrrhotite, zinc blende, chalcopyrite, galena, pyrite, and native gold. Pyrrhotite and zinc blende are most abundant, and pyrite and galena are very minor constituents. Native gold was seen only during microscopic examination of polished surfaces of the ores and then as small, scattered grains in sulphide or gangue. A very small amount of an unidentified grey mineral was also noted. The quartz is white and finely crystalline to coarse and vuggy. It is much more abundant than calcite which is quite locally, but in some places abundantly, developed. The vein has been followed for a total distance of about 50 feet and varies from a barren, tight fissure to an exceptional maximum width of about 15 inches. It trends northeast, along a well-defined fissure, and the dip is vertical. The rocks in the vicinity are Triassic flows, tuffs, limestone, and other sediments of the Bonanza group cut by a multitude of dykes and irregular bodies which vary from a very dark quartz gabbro containing abundant magnetite to light grey and white micropegmatite. These Coast Range intrusives are very abundant for about one mile south of the property, but do not continue far to the north. The Triassic rocks are much contorted and somewhat faulted and generally have very steep dips.

The vein fissure cuts fine-grained, green, banded tuffs and crystalline limestone which strike 10 degrees north of east and dip very steeply north.

Towards the northeast end of the vein these rocks are cut by a northerly-trending diorite dyke, about 7 feet wide, which, on the west side, is partly replaced by white to light grey quartz-augite-albitite. Within the limits of this dyke there is practically no ore in the fissure. The whole productive part of the vein is in the dense, brittle tuffs which have been extensively altered, in large part before the vein was formed, to garnet, epidote, and chlorite. Immediately northeast of the dyke the vein has been developed by a shaft to a depth of 15 feet. Just north of the dyke the vein was found to split into two parts; one continued northeast but died out within 8 feet, the other turned to 10 degrees north of east, approximately along the bedding, and had been followed for 14 feet at the time of examination. The vein pinched and swelled along this part, sometimes forming a narrow network of small veins in the volcanics, but, at the junction of the two parts, widths up to about 15 inches of good ore were encountered for a few feet. The vein continued 15 feet southwest of the dyke, in an open-cut, and then encountered altered crystalline limestone in which the ore soon ceased although the fissure continued. The limestone member is probably about 6 feet thick and dips steeply north; it was extensively altered to a mixture of garnet, diopside, quartz, calcite, and zinc blende, with some albite and apatite, before the vein was introduced, and, in heavily weathered portions, exhibits casts of fossils. No search has been made for the vein immediately south of the limestone, this part of the surface being drift covered, but the writer understands that some ore was encountered in the limestone immediately beneath a narrow lamprophyre dyke that strikes 13 degrees north of east and dips 36 degrees south, above the south end of the vein. Unfortunately the collar of the shaft is at the edge of the high water-level of Zeballos River, so that further development to the east would have to be well underground in order to avoid excessive inflow of water.

For several hundred feet to the southeast of this vein the ground was prospected by pits and open-cuts in 1925. Some low-grade, contact metamorphic mineralization, including considerable zinc blende, was found in the same types of rocks that are exposed near the vein, but no similar vein was encountered.

Examination of the ores under the microscope showed that the gold varied considerably in colour, probably because of a variable amount of silver alloyed with it, and that the tiny grains occur either in quartz, or in galena, or in sphalerite, or along the boundaries between different sulphides. It is definitely later than zinc blende which it sometimes veins, and in all probability was one of the last minerals introduced. No gold was observed in the pure pyrrhotite which forms a considerable part of the ore. Some surfaces suggest, but do not definitely prove, that the precious metal formed at about the same time as chalcopyrite.

It is noteworthy that the vein cuts and is definitely later than the contact metamorphic zinc mineralization in the adjoining rocks.

The *Marks property* consists of thirteen claims, staked two abreast along the north fork of Zeballos River, immediately above the forks. Control is held by Thomsen and Clarke Timber Company, Limited, of Vancouver, but T. J. Marks, the original owner and discoverer, still retains an interest in the property. The claims include two principal types of

mineralization—certain replacements of chalcopyrite and pyrite which do not carry important gold values and several small but rich, gold-bearing veins. A trail leads up both sides of the north fork from Marks' cabin at the forks, on the main Zeballos River trail about 250 feet above sea-level. It is nearly 7 miles from salt water to this cabin. The principal showings are from $\frac{3}{4}$ to $1\frac{1}{2}$ miles up the north fork.

Some mention has already been made of the geology along the north fork. For $1\frac{1}{3}$ miles above the forks the east side of the river is underlain by massive crystalline limestone of the Quatsino formation. This formation is tightly folded so that dips are nearly vertical or overturned toward the east and it narrows towards its north end to about 150 feet before it is terminated, in that direction, by a fault striking about north 25 degrees east and dipping from 50 to 60 degrees southeast. On the west, along the bed of the north fork, the limestone contacts with flows and fragmentals of the Karmutsen volcanics along a fault plane which, where observed, dips steeply east; and it continues for at least several miles to the north. Thus, volcanic rocks, cut by dykes that also occur in the limestone, are exposed all the way up the west side of the north fork and on the east side for 3 miles north of the Quatsino limestone. The east wall of the fault has evidently moved down relative to the west wall, but the actual amount of displacement was not determinable. A second fault of major importance trending approximately east-southeast and dipping steeply north, lies along or near the bed of Fault Creek on the west side of the north fork. A little over $\frac{1}{2}$ mile up the creek the fault is visible and has offset the westerly dipping contact between Quatsino limestone and Karmutsen volcanics about 2,000 feet to the west on the south side of the fault.

Several small gold veins on the property had not received a great deal of development at the time of examination, but the most promising, on the west side of the north fork a short distance below Fault Creek, had been opened up on the surface by several cuts and an adit had been started towards it from the bank of the river. The vein occupies a fissure in dense, green, volcanic rocks and strikes 5 degrees east of south, dipping steeply east or vertical. It maintains its southerly trend for about 100 feet, being exposed throughout most of this distance by open-cuts. At the south end it makes an abrupt swing, along an intersecting fissure, to a south 30 degrees west course and is exposed in this direction for about 10 feet past the turn. In two small cuts 75 and 125 feet horizontally to the southwest narrow widths of similar vein material have been found and these may represent a continuation of the vein. If so, the vein may be said to have been found on the surface at intervals for a total distance of about 235 feet. Where exposed it varies in width from a maximum of about 6 inches to $\frac{1}{2}$ inch or less and consists of fairly coarsely crystalline, and in places crustified or banded, quartz with zinc blende, arsenopyrite, pyrrhotite, chalcopyrite, and pyrite. The sulphides constitute from less than half to the bulk of the vein. In addition, arsenopyrite is sometimes disseminated abundantly through the wall-rock, particularly in the west wall, for an inch or more from the edge of the vein. Ninety feet below and 80 feet east of the central part of the best exposed part of the vein an adit has been started from the edge of the north fork of Zeballos River. It had been driven 50 feet in September, 1932, encountering andesitic flows and some dykes. Since then it is reported that at about 75 feet from the portal,

almost vertically below the outcrop, a vein system nearly 6 feet wide was encountered, and that the vein system consisted of five, nearly parallel, small veins, varying from 2 to 5 inches in width, mineralized with sulphides similar to those in the surface exposures. Also, that the country rock in the vein system was mineralized with small veinlets and disseminated sulphides. Gold values across the 6 feet were sufficiently good to encourage further development along the vein and this work, the report indicates, is being proceeded with.

The vein does not outcrop in the bed of Fault Creek some 200 or 300 feet north of the surface exposures and, indeed, apparently dies out, on the surface, within 40 or 50 feet north of the point under which the adit has been driven. Irregular replacements of low-grade copper mineralization appear immediately north of the end of the vein, but exposures were not sufficiently good to disclose the relation of this material to the gold-bearing vein.

A small sample of a complete section of the vein from the surface was collected by the writer and submitted for assay.[1] It consisted of about 50 per cent quartz with zinc blende, arsenopyrite, pyrite, and a little chalcopyrite and pyrrhotite and assayed 2·84 ounces of gold and 0·82 ounce of silver a ton. Much higher values have been reported from the vein and undoubtedly could still be obtained, but it was thought that the small sample might represent something near an average of the material in the vein.

Polished specimens were examined under the microscope and tiny, scattered specks of free gold were noted in most of them, generally closely associated with zinc blende and (or) chalcopyrite, but occasionally isolated in quartz. No free gold was noted in arsenopyrite either in the vein or in the wall-rock, although that mineral is somewhat crushed and in part veined by chalcopyrite. A small amount of a very soft and sectile bronze-coloured mineral was noted in two surfaces but could not be identified. Also, a little galena was observed.

About 1,400 feet north of the adit and on the opposite or east side of the north fork a second vein has been found, but has received practically no development. It is exposed for 35 feet across a small ravine known as the "Glory Hole" some 100 feet east of the river and about 80 feet above it. It follows the contact between Quatsino limestone on the west and altered, andesitic flows of the Karmutsen volcanics on the east and strikes north 8 degrees west, dipping 66 degrees east. The vein varies from 6 to 8 inches in width and consists of white, fine-grained, banded to coarsely crystalline, cavernous quartz sparsely mineralized with pyrrhotite, chalcopyrite, and pyrite. The limestone on the foot-wall contains irregular bodies of volcanic rocks and is cut by a few dykes; also it is irregularly mineralized with pockets and streaks of pyrrhotite and chalcopyrite. Near the vein the hanging-wall volcanics are somewhat sheared and finely divided biotite and pyrite have been introduced. A chip sample taken across the 8 inches of vein at the south side of the exposure assayed 0·28 ounce of gold and 0·13 ounce of silver a ton. It should be noted, however, that Mr. Marks believes, on the basis of assays made for him, that the vein would average better than $20 a ton in gold.

[1] All new assays reported were made by A. Sadler, Mines Branch, Dept. of Mines, Ottawa.

Several hundred feet farther north, half-way up some bad bluffs about 150 feet east of the river, a similar vein is exposed for a few feet along the same limestone-volcanic contact. It is about 2 inches wide and is fairly heavily mineralized with pyrrhotite, chalcopyrite, and a little zinc blende. Mr. Marks reports good gold values from this place and also informs the writer that he has succeeded in finding the "Glory Hole" vein about 250 feet south of the main showing. It is questionable whether gold values warrant further work on the vein, but if they do prospecting for it along the strike should be fairly simple. It may be reasonably expected to continue to follow the limestone-volcanic contact as long as mineralization persists and this contact is a pronounced structural feature trending east of south and swinging farther to the east of the north fork as it goes south. It crosses a large sink-hole over one-half mile south of the "Glory Hole" and could be found easily at several places in the intervening distance by moderately shallow trenches.

A few hundred feet below the adit, in the bed of the north fork, there is an area of possibly 7,500 square feet on the west side of the stream, over which very rough, pyritic, green to brownish, volcanic breccia is cut by dark grey to greenish feldspar-porphyry dykes and is mineralized sparsely with a number of small, lenticular veins carrying quartz, pyrrhotite, pyrite, chalcopyrite, and zinc blende. The largest of these veins exposed is only 2½ inches wide and about 12 feet long and the veins are not very abundant. Previous samples, taken across the stream bed for a width of nearly 100 feet, were reported to have averaged close to $9 in gold a ton. The writer collected samples of the pyritic, altered volcanic, being careful to avoid all mineralized quartz stringers. They assayed: gold, none, and silver, 0·18 ounce a ton. A specimen of the largest and most heavily mineralized quartz stringer was polished and examined under the microscope; in about one square inch of surface there were seven, visible, tiny specks of free gold, either alone in quartz or with zinc blende and (or) chalcopyrite in veinlets in the quartz. Also, a little arsenopyrite was identified.

On the opposite bank of the stream a small area is underlain by contorted grey to white, crystalline limestone with interbedded, fine-grained, brown tuff. The brown material is very pyritic and near or in it are one or two, small, discontinuous stringers of quartz and calcite carrying sulphides. The pyritic material was again sampled and it assayed no gold and 0·1 ounce of silver a ton. A specimen of one of the richer stringers containing considerable arsenopyrite and some zinc blende assayed: gold, 0·41 ounce, and silver, 0·19 ounce a ton. Judging by these results it would seem that the pyritic, altered rocks of this area contain very little or no gold, whereas the small quartz veinlets contain fair values in that metal. No individual stringer is sufficiently large or continuous to encourage development and it seemed unlikely that there is sufficient high-grade material of this sort scattered through the rock to produce any important quantity of commercial ore. As the few samples obtained can hardly be taken to definitely prove this point, however, it might be advisable to channel sample more promising sections across definite minable widths.

There are several other places on the Marks property where small quartz stringers carrying gold values have been found, but none has showed sufficient promise to encourage development.

The copper mineralization on the property is on the west side of the north fork and north of Fault Creek. For about 2,500 feet north of this creek andesitic flows and fragmentals are intruded by many grey to green, feldspar porphyry dykes and are considerably fractured and locally sheared. They have been extensively chloritized and mineralized, either very irregularly or along bedding or shear planes, by mixtures of quartz, epidote, pyrite, chalcopyrite, and pyrrhotite. Development has been concentrated in an area about 200 feet long, north and south, and from 100 to 125 feet wide, west of the river bed, some 800 feet north of Fault Creek. Here several open-cuts have been made on the steep hillside and they reveal some fine copper ore. Exposures between the scattered cuts are poor, however, so that it is difficult to form an accurate picture of the occurrence. But it seemed to the writer that the principal mineralization trends about parallel to the north fork and that well-mineralized material forms from 15 to 20 per cent of the total width of about 125 feet partly developed by cuts, the remainder being altered and pyritic volcanic. The volcanic rocks near the upper showings appear to strike about north 15 degrees west (nearly parallel to the river) and dip at 45 degrees or less to the west. Both north and south of this principal section the mineralization is less promising. To the north, large bodies of quartz are exposed along the bank of the stream, but they generally contain only a meagre amount of chalcopyrite and pyrite. To the south there is much less quartz and what little copper there is occurs in chloritic volcanics with pyrite. In the Quatsino limestone on the east side of the river there are many pockets and small, irregular bodies of pyrrhotite with some chalcopyrite, but nothing sufficiently persistent to encourage development. One or two of the porphyry dykes along the creek bed are themselves mineralized along joints and cracks with narrow seams of quartz, pyrrhotite, and chalcopyrite.

South of Fault Creek there are one or two showings of similar, irregular copper mineralization in the volcanics, but none has as yet received any extensive development.

On the whole, it seems that there is an extensive, low-grade copper mineralization on the claims which, under favourable market conditions, would merit some further development. At present, with copper around 6 cents a pound and no appreciable precious metal content reported from the deposits, they are naturally receiving no attention.

In connexion with all the mineralization along the north fork of Zeballos River there are a few general considerations that may be stressed. The faulting is of prime importance. The major fault running north along the bed of the river has undoubtedly been accompanied by minor sub-parallel or branching faults, particularly in the volcanic rocks on the west side of the stream. This fault zone, with the adjoining deep and narrow infold of limestone on the east, is truncated on the south by the Zeballos batholith from which the mineralizing solutions of the area are believed to have been derived. The fault zone and the infold have in all probability provided an excellent channel along which the mineralizing

solutions from depth to the south could rise to form veins in fault fissures and cracks, or along prominent contacts and replacement bodies in favourable areas. Gold values were evidently very largely restricted to that period of mineralization that formed the quartz-sulphide veins. The distribution of these veins has apparently been affected by the faulting along approximately east-west planes which, in conjunction with the main north-south faulting, divided the area into a number of fault blocks. Thus, no important gold values have as yet been found in the block lying north of Fault Creek and west of the north fork, nor on the east side of the north fork north of the fault at the north end of the Quatsino limestone.

Mineralization Along the Southeast Fork

The southeast fork of Zeballos River has been prospected principally by Mr. T. J. Marks and by Alfred Bird and associates. On the east side of Blind River (the outlet of Zeballos Lake) about 1,600 feet up from its confluence with the southeast fork, crystalline Quatsino limestone is cut by a number of dykes varying from dark, basic porphyries to light-coloured aplites. Near these dykes there are several small showings of mineralization in the limestone. The largest seen consists of a triangular-shaped body, about 7 feet wide, of pyrrohtite with some magnetite and chalcopyrite between two dykes. The other showings are smaller and contain much pyrite.

More interesting discoveries have been made farther up the southeast fork by Alfred Bird and associates. The *King claim*, (*See* Figure 4, location 4) is 850 feet above the southeast fork. On it a narrow band of impure, grey limestone and green, calcareous tuff strikes north 55 degrees west and dips from 50 to 65 degrees southwest. It is underlain by basaltic and amygdaloidal flows and overlain by tuff, breccia, and andesitic flows, the whole being part of the Karmutsen volcanic assemblage and lying several hundred feet stratigraphically below the Quatsino limestone. One or two porphyritic granodiorite dykes cut these rocks, their most general trend being northeast. On the north bank of the small stream a shallow cut shows a 5-foot width of tuff and limestone quite heavily but irregularly mineralized with chalcopyrite, quartz, calcite, and epidote. Across the small stream a little pyrite was all that was noticed on the continuation of the lead. To the northwest of the cut the same calcareous horizon follows up a steep and narrow draw for at least 200 feet vertically. In this draw there is a zone of low-grade, bunchy mineralization with a maximum width of about 20 feet. Along the foot-wall, against the basic flows and below the impure limestone, there is in places a regular band about 2 inches wide of magnetite, pyrite, and quartz. Some pyrrhotite and quartz occur along the calcareous horizon, and above it, in the tuffs, magnetite, pyrite, pyrrhotite, chalcopyrite, epidote, and some garnet are irregularly developed along cracks or in small bunches. It would seem that the mineralization entered along or close to the calcareous horizon and spread out into the hanging-wall rocks where they are extensively fractured. It was in such an area of extensive fracturing that the maximum width of about 20 feet across the mineralized zone was measured.

As a straight copper proposition the deposit does not seem very promising, but it is possible by panning to obtain colours of gold from

some of the rusty, decomposed material well up the draw and Mr. Bird states that good copper ore from the creek level will run from $6 to $8 in gold. A specimen collected there by the writer assayed: copper, 5·14 per cent, gold 0·08 ounce, and silver 0·92 ounce a ton.

On the *Nootka claim* about 2,000 feet to the south and a little over 100 feet higher than the showings on the King claim, on the north side of the next small creek to the south, a pronounced shear zone strikes north 40 degrees east and dips about 80 degrees southeast in altered, green, basic volcanics. To the southeast of a well-defined fault wall there is about 3 feet of white crystalline quartz, partly cavernous, and heavily mineralized with chalcopyrite and pyrrhotite. For about 2 feet southeast of this the sheared rock is seamed with quartz veins and contains epidote and a little garnet, but very little sulphide. A specimen of slightly oxidized material from the richest part of the vein assayed: copper, 17·07 per cent, gold 0·40 ounce, and silver 3·64 ounces a ton. Sixty feet below, in the creek bed, the lead appears on the north side as a 6 to 18-inch band of quartz, chalcopyrite, and pyrrhotite on the foot-wall side of the shear zone and even this poor showing is not visible on the south side of the creek. There is some additional low-grade copper mineralization several hundred feet farther up the creek.

About ½ mile farther south, at the forks of the next stream of any size, on the *Major group* of claims, the contact of the Quatsino limestone with the underlying volcanics on the east is poorly exposed, but can be seen in one place to be mineralized for a width of 5 feet or more with garnet, epidote, magnetite, pyrite, and a little chalcopyrite. The probable dip of the formations is 60 degrees to the west. One hundred feet above the contact, on the south fork of the small stream (*See* location 6 on Figure 4) basic volcanics are much sheared and in part converted to serpentine and chlorite schist along a narrow zone striking north 18 degrees west and dipping 60 degrees northeast. For a width of as much as 80 feet east of the shear zone the altered rocks are sparingly mineralized with pyrite, quartz, and a little chalcopyrite. On the east they are intruded by a large dyke of greyish green feldspar porphyry which appears to be from 20 to 40 feet wide and trends about parallel to the shearing. The dyke is strongly fractured and jointed and contains many small and large veins of white to watery, coarsely crystalline quartz, the strongest development of which appears to lie along the east side of the dyke. Much of the quartz is quite barren, but some contains a small quantity of pyrite and chalcopyrite, particularly where the quartz surrounds angular inclusions of altered dyke rock. The maximum width of fairly pure quartz observed was about 5 feet, but exposures are poor and no development has been done. Mr. Alfred Bird, the discoverer, reports that some of the richest copper-bearing material assayed about $4 in gold a ton.

About 4 miles up the southeast fork from the main forks of Zeballos River the Quatsino limestone and Karmutsen volcanics are cut off on the south and west by the Zeballos batholith. This body, near the contact, consists of black-speckled grey granodiorite and quartz diorite of medium grain with scattered inclusions of the older rocks. The first outcrops of the granodiorite in the creek bed are cut by numerous, small, irregular, and lenticular veins of white to watery, coarsely crystalline and cavernous

quartz and some of the veins carry an appreciable quantity of pyrite, pyrrhotite, and chalcopyrite and an occasional speck of zinc blende. The two largest veins observed were from 6 to 10 inches wide, but merged at one place to a thickness of about 16 inches. The granodiorite is quite fresh alongside the veins which in no place exhibit any great continuity. Mr. Bird, one of the discoverers, states that gold values were too low to encourage development. The showings deserve mention because they serve to emphasize the fact that the granitic intrusives of the district do contain appreciable mineralization; consequently they should not be passed over too carelessly by prospectors.

The *Blackbird and Bluebird claims*, belonging to Alfred Bird and C. W. Smith, are on the west side of Zeballos Valley 2½ miles south of the forks. The showings are at the base of the steep mountains which form the west side of the valley and lie along the south contact of the Zeballos batholith. The granodiorite intrudes grey, crystalline limestone and some interbedded tuffs and the limestone is extensively altered to garnet, epidote, wollastonite, actinolite, and other minerals. The main contact trends from east to northeast, but several open-cuts indicate that irregular dykes of granodiorite extend out from it into the sediments. One cut, across 12 feet from east to west, shows a mixture of garnetite, including much magnetite, with irregular bunches and streaks of chalcopyrite and some pyrite and pyrrhotite. A second cut 50 feet southeast shows about the same width of similar mineralization. In addition, there are several undeveloped outcrops of apparently barren garnetite within a radius of about 100 feet from the first cut. And, about 100 feet east of it, silicified and otherwise altered limestone contains a lenticular mass of rich chalcopyrite in magnetite and silicates. It is exposed for a maximum width of 3 feet and for a length of about 7 feet. A few feet below this there is some disseminated bornite in green garnetite. Microscopic examination of the chalcopyrite from this place revealed the interesting fact that intergrown with it there is a small proportion of cubanite ($CuFe_2S_3$). About 75 feet northeast of this, and probably very close to the main contact of the granodiorite, pyrrhotite with considerable chalcopyrite is exposed for 7 feet across a width of about 18 inches.

In addition to the above showings there are a few, small, barren or sparsely mineralized quartz veins in the granodiorite.

The showings indicate a typical contact metamorphic copper deposit and in all probability the mineralization will be found, if developed farther, to follow the contact of granodiorite and limestone quite closely. Mr. Bird reports that one assay of rich copper ore ran $4 a ton in gold and 8 ounces in silver. But it is a matter of common knowledge that similar copper deposits on the island generally average well under $2 a ton in gold and that any appreciably higher values are very erratically distributed in the ore.

Placer Gold

Placer gold has been known to occur in the gravel of Zeballos River and its north fork for a number of years. In 1907 or 1908 T. J. Marks attempted a small operation on the northwest bank of the main river just below the forks, immediately above where volcanic rocks outcrop in the river bed. He and his associates moved a large amount of gravel and

small boulders and laid bare the water-worn bedrock in several places, using hand methods and sluice-boxes. Mr. Marks reports that they recovered about 5 ounces of gold, much of it small, chunky particles, some square, about the size of the end of a match, but that the cost of operations was considerably in excess of the value of the gold recovered. Later, he sank two small shafts to depths of 10 or 15 feet on the small flat immediately north of the workings, but did not reach bedrock. The shafts exposed a mixture of gravel and rounded to angular boulders up to 2 or 3 feet in diameter. Mr. Marks reports that gold colours are contained throughout the gravels and sands and that he encountered no important concentrations on bedrock—indeed, that frequently the best values lie in the upper part of the gravels.

In 1932 Alfred Bird made a search for placer gold along the north fork. About one-third mile above the forks, on the east bank, he succeeded in panning fairly good colours from sands and gravel. About 6 feet above water-level he encountered a diorite dyke in the massive crystalline limestone and cleared off the surface, exposing the east wall of the dyke for about 25 feet in one place. The wall strikes north 4 degrees west and dips 58 degrees east, and the limestone on that side is worn away to a depth of several feet at least, the depression being filled with gravel and boulders. He cleared out the gravel to a depth of 6 feet, exposing the wall of the dyke which was covered with a thin film of goudge, clay, and rust. Adhering to this material near the top of the wall he found, by panning, several quite coarse gold nuggets, the largest being worth about $1.25. In all, from this and an adjoining hole 15 feet south along the same wall, he extracted possibly $10 of gold. The nuggets are rounded to subangular or almost square and do not appear to have been transported a great distance. Small particles of quartz and rock are embedded in them and pannings of gold-bearing material always reveal the presence of more or less black sand. The bottoms of the holes were filled at the time of examination, but Mr. Bird reports that very rough and irregular limestone was encountered within 7 or 8 feet of the top of the wall and that there were many large pot-holes or sink-holes in the limestones, some of which he could not bottom. Also, that no important amount of gold was found on the limestone surface, but that a considerable quantity of coarse, angular to subangular magnetite was recovered from depressions in it. The best gold nuggets were found towards the top of the wall of the dyke. A short distance south of the workings the writer and his assistants panned some of the recently deposited surface sands from a small pocket in bedrock and secured a number of small colours of gold.

It seems most probable that the placer gold in Zeballos River has been derived from the gold-bearing quartz sulphide veins on the north fork. No appreciable quantity of placer gold has been found in the southeast fork, on which no gold-bearing deposits are known approaching those of the north fork in values. The gold in the gravel near the forks and on the north fork does not appear to have been transported any great distance, and the fact that it is not particularly concentrated near bedrock and that the most recent sands in the stream bed contain appreciable colours indicates the recent origin of the precious metal. The veins on the Marks property within a mile or so up the north fork are known to contain free gold and they are being actively eroded at present, and the debris from them

can only find its way down the north fork. It hardly seems necessary to search further for a source. True, no gold as coarse as the nuggets found by Mr. Bird has been observed in the veins, but rich pockets containing coarse gold might easily occur in them and indeed, might explain some of the exceptionally high assays that have been reported from the veins. The presence of much black sand and considerable coarse magnetite with and near the gold led to some speculation as to whether this mineral was associated with the gold in its primary occurrence. No good reason for assuming that such is the case is apparent. No magnetite except one small particle that might have become accidentally attached during transportation was found adhering to gold nuggets or colours. And no magnetite has as yet been observed in any of the gold veins, although there are small amounts of the finely divided mineral in some of the basic volcanics in which the veins lie. It is not at all impossible that there may be some small bodies of magnetite in the Quatsino limestone along the north fork, but as a matter of fact no magnetite occurrences are known anywhere along the river. The only known probable source of the placer magnetite in the north fork is a large deposit of that mineral which was discovered by the writer during field work at the extreme head of Fault Creek and at present, and probably for some time past, no very great amount of this could find its way down to the main north fork.

Gold colours can be panned from the gravels of Zeballos River from the forks to salt water, but they are generally very fine and no important concentrations have been encountered. No doubt additional contributions to the gold in the river have been made during erosion of the rich Tagore vein. But on the whole there does not seem to be any very great probability of important placer production from the area. The valleys have been glaciated and the known primary deposits that carry gold are hardly sufficiently large or numerous to lead to much hope of large recent accumulations of the precious metal. The small flat at the forks, underlain by gravel and boulders, certainly contains a considerable quantity of gold, but it is very doubtful if the values are sufficiently rich or evenly distributed to warrant attempts at extraction. Unfortunately the bedrock in the vicinity consists most largely either of hard, massive volcanics that wear to smooth, slippery surfaces, or of limestone that when eroded leaves an irregular, fairly smooth surface that frequently abounds in pot-holes or solution cavities. Neither type is well adpated to collecting placer gold. Perhaps the best that can be said for the area is that an experienced placer miner, with a good "nose" for gold, might find small, rich concentrations that would repay the effort expended in prospecting.

Additional Mineralization

A number of other showings of mineralization were either reported or discovered during the summer. About one mile southwest of the Blackbird claim Mr. Bird has discovered a number of showings of zinc blende, but has not as yet done any work on them. A series of flows, tuff, argillite, and limestone of the Bonanza group, striking on the average north 25 degrees west and dipping steeply west are considerably sheared and intruded by grey or green feldspar porphyry dykes. Several of the beds of tuff, some of it much altered, are veined and replaced by zinc blende.

These low-grade showings are scattered over a considerable area on a heavily timbered mountain side, rather, it appeared, at several different horizons than in a large, continuous body.

Mr. Bird also reports having found mineralization near the head of the first small stream north of the Blackbird claim, including some molybdenite and a small quartz-sulphide vein similar in appearance to the gold-bearing veins of the valley. The locality is underlain by greatly crushed and sheared sediments and volcanics of the Bonanza group, intruded and completely surrounded, on the surface, by granitic rocks. Bird's showings were not visited, but there is widespread development of pyrite, calcite, and other minerals in the Bonanza rocks.

Two-thirds of a mile south of the forks the main valley trail crosses some showings of garnetite in limestone. They follow along the north contact of the Zeballos batholith for several hundred feet west of the trail. Magnetite is fairly abundant in places and there are a few traces of chalcopyrite, but nothing of much economic interest is exposed. Several very small showings, including some chalcopyrite in contact metamorphic silicates and a small quartz vein carrying pyrite, galena, and chalcopyrite, were encountered in the rough, mountainous ground south of the north fork, either near or in the Zeballos batholith.

There is considerable scattered mineralization from 1 to 2 miles up the first creek that flows into Zeballos River west of the north fork. It includes much magnetite and small showings of contact metamorphic copper mineralization and all lie in the Quatsino limestone fairly close to the batholithic contact.

In a small basin at the south side of the head of Fault Creek the Quatsino limestone is cut off on the south by the Zeballos batholith which here varies from diorite to gabbro and is cut by later aplite and lamprophyre. Along the contact, over an area at least about 200 feet by 200 feet, there are many exposures of massive to partly decomposed magnetite, accompanied by little pyrite. The croppings were discovered during field work by the writer and are at an elevation of 3,500 feet. The magnetite has formed largely by replacement of limestone and irregular remnants of that rock lie in it. In addition, however, there are streaks and vein-like masses of magnetite in the adjoining intrusive, accompanied by garnet and other silicates. From this point northwest to Artlish River numerous signs of mineralization were noted along the batholithic contact, as will be discussed in the following paragraphs.

ECONOMIC POSSIBILITIES

It will be seen from the foregoing account that the more accessible parts of Zeballos Valley have been fairly carefully prospected. The possibility of any production in the near future depends largely upon developments on two properties containing small but rich gold deposits. If any considerable production is attained, prospecting in the area will be encouraged. The main possibility of new discoveries being made lies in more intensive prospecting of favourable ground already staked, or in more careful search of the more inaccessible, rugged parts of the area drained by Zeballos River, particularly those parts not too far removed from the

major Coast Range intrusives. In addition, however, there is a broad belt which is as yet unprospected, but is now known to be mineralized, extending northwest from Zeballos River and crossing Artlish River within about 8 miles above its mouth. This belt lies principally along the northeast side of the Zeballos batholith, although there are also some possibilities along parts of the southeast side. On the northwest the Quatsino limestone and sediments and volcanics of the Bonanza group dip southwest and are cut off, in that direction, by the batholith. In a wide belt along the contact the sediments and volcanics are crushed, contorted, and intruded by a multitude of dykes that vary greatly in composition and appearance, and over considerable areas these rocks, and particularly the argillaceous sediments, are heavily mineralized with pyrite or pyrrhotite. Weathering of this material has produced large areas of outcrops that are heavily stained with brown or yellow iron oxides. Where the Quatsino limestone abuts directly against the intrusive, the mineralization takes rather the form of lenses and irregular bodies of magnetite, in some cases accompanied by contact metamorphic silicates and small amounts of chalcopyrite or iron sulphides. In only one or two places, particularly in Artlish Valley within about 7 miles of its mouth, was any extensive silicification observed. Particularly extensive, rust-stained areas were observed in the sediments of the Bonanza group around the heads of the south fork of Artlish River.

The widespread evidence of mineralization and the favourable geological setting indicate clearly that the belt should be prospected. However, there are no trails, the area is rugged and heavily timbered, and in addition the climate does not make for very agreeable prospecting conditions. Consequently, any extensive search for mineral will be accompanied by considerable labour and hardship and should only be undertaken with a full understanding of the whole situation. In this connexion the following considerations are of importance.

Great interest would attach to the belt if it were definitely known to contain, or if it could be reasonably assumed to contain, gold mineralization similar to that already found in Zeballos Valley immediately to the southeast. But no such mineralization is known in the belt, and, although it might be assumed, on the basis of the similar geological conditions existing in the two places, that similar mineralization should occur, yet definite proof for such an assumption is lacking. Furthermore, the geology along the belt differs in certain important details from that along Zeballos River. In the latter place, the gold-bearing veins are believed, with good reason, to represent a late stage of the mineralization produced by the Coast Range intrusives, distinctly later than the contact metamorphic copper and iron deposits which also occur there. The latest stages of Coast Range intrusion, the more acidic phases including much granodiorite and quartz monzonite and even some micropegmatite, are abundantly developed in the vicinity of Zeballos River. The occurrence of gold-bearing quartz veins may well depend upon the existence of these more acidic phases of intrusion. But, although similar acidic types are present in the Zeballos batholith to the northwest, yet the earlier and more basic phases, including much quartz diorite and some gabbro, are more abundantly developed, particularly along the northeast side of the batholith, than they are in Zeballos Valley. It may be that the mineralization in the unprospected belt to the northwest has been derived largely or entirely from these early,

basic phases of the intrusion and that conditions were not favourable to the production of gold-bearing quartz veins in that area. At least prospecting should be undertaken with such a possibility clearly in mind. The first logical step in an examination of the area would then seem to be an attempt to discover if there be any direct reason to suspect the presence of gold in the area, practically all of which is drained by Artlish River. So far as the writer knows there are no records of any discovery of, or of any search for, gold in Artlish River. If gold-bearing deposits occur in the rocks drained by this stream, placer gold should occur in some of the gravels. If even a very small quantity of placer gold could be discovered in the gravels of the main river, its south fork, or their tributary streams, added encouragement would be lent to any endeavour to prospect the area under discussion for lode-gold deposits.

AN OCCURRENCE OF VANADIUM-BEARING ROCK ON QUADRA ISLAND, BRITISH COLUMBIA

By

H. V. Ellsworth and H. C. Gunning

Vanadium is a metallic element that has been found to impart very valuable properties to steel when added in amounts from 0·2 to 1 per cent, and alloy steels containing vanadium are standard products. The effect of the vanadium is to render the steel tougher and less subject to loss of strength caused by vibration or repeated shocks or strains. The vanadium is added in the form of an iron alloy, ferrovanadium, recent United States quotations for which have been around $3 a pound of contained vanadium, though the price in the past has been as high as $6 or $7 a pound of contained vanadium. There is also a considerable use of vanadium as a catalyzer in the chemical industry, and minor uses are: in inks, dyes, brass, bronze, paint, medicine.

Vanadium in minute amounts is widely distributed in rocks, plants, and animals, but workable deposits are comparatively rare. Of the igneous rocks, the more basic kinds carry the most vanadium, but rarely more than a few hundredths of a per cent. Ferromagnesian minerals such as biotites, hornblendes, and pyroxenes may contain as much as $\frac{1}{10}$ of 1 per cent. Many iron ores, including probably most magnetites, and ilmenites carry a little vanadium, usually not more than a few tenths of a per cent, as V_2O_5. Only a few Canadian iron ores have been found to carry as much as, or slightly more than, $\frac{1}{2}$ of 1 per cent V_2O_5.[1] It appears that the primary iron ores probably represent the greatest concentration of vanadium possible by magmatic processes, so that it is not probable that a primary deposit containing much more than $\frac{1}{2}$ per cent V_2O_5 will be found. Secondary vanadate minerals, however, are sometimes found in metalliferous deposits in sufficient quantity to be used as ores, as in Rhodesia and Southwest Africa.

Vanadium also occurs in small amounts in sedimentary rocks and more especially in carbonaceous, bituminous, or oil-bearing shales, slates, or sandstones. The ashes of some coals, lignites, asphalts, and petroleums carry high percentages of vanadium. Thus, vanadium is concentrated not only by igneous action in primary minerals, but also and in some cases to a greater degree by secondary, organic and sedimentary processes. In its chemical associations vanadium is related to phosphorus and it has been supposed that it perhaps can be used by certain plants and animals to replace or supplement the phosphorus which is so necessary to the higher organisms. Vanadium is also a good catalyzer and oxygen

[1] Robinson, A. H. A.: "Titanium"; Mines Branch No. 579.

carrier and it has been thought that it may replace iron or copper in the blood of those marine animals in which it is present in some quantity. It would not be surprising if it should be found eventually that minute amounts of vanadium are actually necessary to the proper functioning of plant and animal life in general.

The association of vanadium with organic material in sediments thus may have resulted either from the burial of vanadium-bearing organisms as the sediments were laid down, or the precipitation of vanadium from solutions circulating through sediments may have been favourably influenced by the presence of organic matter that itself did not originally contain a noticeable amount of vanadium. Such vanadium-bearing solutions might have resulted in the first place from the decay of igneous rocks. In the case of sediments originally only slightly vanadiferous certain parts might be enriched by deposition of vanadium from other parts subject to leaching. The carnotite deposits of the United States furnish a good example of such local enrichment of vanadiferous sandstone.

The occurrence described here is the first discovery of vanadiferous rock of this grade in Canada and is important because it shows that suitable conditions for the deposition of vanadium existed at the time of formation of this deposit in the area where it occurs, and though the deposit itself is probably too small to be of commercial interest, the possibility of the occurrence of larger bodies of the same, or approximately the same, age and stratigraphic relationships is indicated. The carnotite discoveries of Mr. Crowe-Swords, in conjunction with this discovery, may also indicate the possible existence of another vanadiferous (and uraniferous) horizon above that described here.

Last September, 1932, one of the writers (Mr. Gunning) made a brief examination of a property situated at the north end of Gowland Harbour, Quadra Island, where Mr. R. Crowe-Swords had previously found and extracted some small pockets of a carnotite-like mineral[1] occurring in crevices of the volcanic rocks. No more than traces of these carnotite pockets remained, but specimens of the rocks were taken and were subsequently tested for radioactivity by means of the alpha ray electroscope. None of the specimens showed appreciable radioactivity, but one lot of samples attracted attention because of their peculiar character. These consisted of a finely banded, siliceous, carbonaceous material 1 to 4 inches thick, embedded between two lava flows and carrying some thin, greenish copper stains. It was suspected that this carbonaceous streak might carry vanadium and chemical tests showed that in fact it did. A sample for analysis was obtained by taking chips across the carbonaceous zone from several specimens and was believed to represent a rough average of the larger specimens collected. This was ground and on analysis yielded the results under column I. Another sample tested for vanadium only, yielded over 3 per cent V_2O_5.

[1] Geol. Surv., Canada, Ec. Geol. Series No. 11, p. 139.

—	I	II	III	IV
	Per cent	Per cent	Per cent	Per cent
SiO_2	75·31 (1)	Cu.....2·28	Cu.....0·06	Cu.....4·99
FeO	2·29	V_2O_5....1·60	V_2O_5....0·29	V_2O_5.....0·30
Al_2O_3	3·70	SO_3.....0·48	SO_3.....0·03	
TiO_2	0·15			
MnO	0·10			
CaO	4·08			
MgO	0·53			
Cu	2·88 (2)			
V_2O_5	2·16			
S	0·72 (3)			
P_2O_5	Trace			
U, Cr	Not detected			
H_2O	2·61			
C, CO_2	Present (4)			

I. Average sample of siliceous-carbonaceous zone.

(1) Microscopic examination and chemical tests indicate that most of the silica is present in the rock as quartz.

(2) Copper is present as chalcocite (Cu_2S), also as basic carbonate (malachite) and probably also in small amount as sulphate and silicate.

(3) Some of the sulphur is apparently present as SO_3.

(4) Carbon about 5 per cent by calculation. No hydrocarbons detected.

II. Shows the amounts of Cu, V_2O_5, and SO_3 that passed into solution when 1 gramme of the material of I was digested for an hour on the hot water bath with 100 cc. 1 per cent hydrochloric acid solution.

III. Shows the amounts of Cu, V_2O_5, and SO_3 recovered from the insoluble of II by a repetition of the treatment with 100 cc. of 1 per cent hydrochloric acid.

IV. Copper and V_2O_5 determinations on a sample of the lower lava, comprising material about 2 inches below the contact with the vanadiferous zone.

It may be noted that as the greater part of the silica of analysis I represents quartz in the rock, vanadium must be present to the extent of about 6 per cent in, say, the third of the material that is not quartz, and most of it could be very easily and economically extracted, together with the greater part of the copper, by simple leaching with mineral acid, as no acid would be consumed by the quartz.

CHARACTER AND ORIGIN OF THE VANADIFEROUS HORIZON

In a hand specimen the material of the vanadiferous zone appears to be made up largely of more or less wavy, very thin, dark-coloured, siliceous bands, mostly no thicker than paper, along with some thicker bands and lenses of black carbon, the whole cut in places by minute veinlets of later quartz. In thin section the structure appears very complex and confused, and in part at least is somewhat suggestive of a colloform precipitate. The quartzose bands are seen to be composed very largely of tiny, irregularly spherical bodies, which vary in diameter between about one-fifth and one-seventy-fifth of a millimetre. There is much black, carbonaceous matter with the quartz, either as particles or cores in it, or as layers between the

quartz bands. The quartz is crystalline and many of the grains exhibit radial structure. In addition, irregularly distributed quartz bodies, circular in section and presumably spherical, make up a considerable part of the rock. These commonly contain a core of carbon and in polarized light the quartz is seen to have a radial arrangement of crystalline segments. Streaks of translucent, brownish material, and some grains of chalcocite are present. There appears to be present, also, a small amount of finely divided biotite, augite?, and epidote?

It does not appear possible that this rock could have been originally a sandstone or normal clastic sediment. It is suggested that it may have been formed of the remains of vanadium-bearing plants or animals, or both, having siliceous skeletons, which were gradually deposited on the submerged lower lava. When the upper lava flow occurred, covering and heating this thin-bedded mixture of silica and organic matter, the silica may have been more or less recrystallized and the volatile organic matter driven off, leaving fixed carbon behind. There is also the possibility that some of the material may have been originally a chemical precipitate.

GEOLOGY OF THE OCCURRENCE

The claims examined are 1½ miles north of the north end of Gowland Harbour, which is 5 miles north of Campbell River, a settlement on the Vancouver Island highway and a port of call for coast boats. They are the property of Radium Explorers, Incorporated. The claims staked are about 500 feet above sea-level, in a fairly rough but relatively low-lying tract that is underlain by a series of dark green to grey, andesitic, and basaltic lava flows which Bancroft[1] has placed in the Valdes group and tentatively assigned to the Triassic. Much of the area has been logged and burned, so that exposures are good. The flow rocks are commonly amygdaloidal and dip gently south and southwest at angles not often exceeding 15 degrees. Rolls in the flow bedding are not uncommon. however, and numerous fractures and joints along which the rocks are sometimes slickensided and sheared, indicate that there has been some faulting. Within a radius of a few miles there are several showings of copper mineralization that have received, in the past. considerable development, and on the claims examined there are a number of old open-cuts on showings of chalcocite, both disseminated in flows and also along shear zones, accompanied by sparingly mineralized, small gash veins of quartz and calcite.

The vanadium-bearing specimens were collected from an old open-cut at the extreme north end of the company's showings. The cut had been made on croppings of chalcocite in gently dipping lava flows on the west side of a small ridge, and is about 75 feet long north and south with a maximum width near the north end of 25 feet. The cut is about 6 feet deep and shows on the west wall the base of a greenish grey, amygdaloidal flow of augite andesite. The many amygdules are filled with chlorite, quartz, calcite, and a greenish blue to straw-coloured amphibole. A very small percentage of chalcocite occurs disseminated in the rock and in some of the amygdules. Beneath this flow, which dips gently to the south, is a second flow of dark grey, amygdaloidal augite andesite which contains,

[1] Bancroft, J. A.: Geol. Surv., Canada, Mem. 23 (1913).

particularly in its upper parts, considerable disseminated chalcocite. This flow contains less augite than the upper one and is more altered, but both are considerably chloritized. Between these two flows, at the base of the east wall of the cut, is the layer of thin-banded, fine-grained, and very hard, black rock that carries the vanadium. This varies in width from about 1 to 4 inches and is exposed for a length of 30 feet. As exposed it shows green and yellow to brownish stains.

All these rocks are broken by joints and fractures, the most pronounced of which trend close to north 70 degrees west magnetic.

ECONOMIC POSSIBILITIES

As stated above, the occurrence is probably too small to be of much economic importance, but indicates that conditions suitable to the deposition of vanadium existed when the volcanic rocks of the Valdes Group were formed. It is possible, therefore, that other vanadium-bearing strata, similar to the one described here, may occur in these rocks. A search for such strata might best be commenced in the vicinity of the known occurrence, and an attempt be made to ascertain if additional deposits of the same nature exist at about the same horizon in the volcanic rocks. It is also possible that similar vanadium-bearing material may have been deposited at any horizon in the volcanic series, so that any similar strata found in the series might well be tested for vanadium. Further than this it may be noted that beneath the Valdes Group there is a series of argillites and thinly bedded quartzites that might merit some investigation. Of these rocks, which outcrop on Open Bay on the east side of Quadra Island, Bancroft says[1] "Some of the argillites are compact, fine grained, and siliceous to such a degree that they may appropriately be called chert. Individual strata of this group are seldom more than a few inches in thickness and since these occupy steeply inclined or vertical positions, weathered surfaces present a striking, ribboned appearance because of differential weathering." The fine bedding and siliceous nature suggest a possible similarity to the vanadium-bearing horizon farther west.

The occurrences of carnotite that have been found in crevices of the lavas overlying the vanadium-bearing horizon are not yet proved to be of commercial importance. The source of the carnotite is not known, but it indicates the presence of vanadium (and uranium) at some horizon above the vanadium-bearing one. Although that horizon may have been within the lavas of the Valdes Group there is another possibility that should be considered. On Vancouver Island, within about 6 miles south of the claims, volcanic rocks similar to, and almost surely a direct continuation of, those of the Valdes Group exposed on Quadra Island are unconformably overlain by Upper Cretaceous sediments. These include a basal member of sandstone and conglomerate with some shale and coal, that farther south is known as the Comox sandstone and contains the Cumberland coal deposits. It is distinctly possible that a continuation of this member may have overlain the rocks now exposed on Quadra Island, although no remannts of it have been found there. Carnotite and other vanadium-bearing minerals occur in commercial deposits in Jurassic sand-

[1] Op. cit., p. 145.

stone in the southwestern states and the sandstone, like that on Vancouver Island, contains abundant carbonaceous material. The vanadium-bearing minerals are particularly associated with the carbon in the sandstone. If the Comox sandstone or similar strata overlay the flows on Quadra Island at some time in the past, they may have contained vanadium-bearing minerals, and during erosion of the sandstone these minerals might well have been accumulated in crevices in the underlying volcanic rocks, to form deposits the remnants of which have now been discovered. This possibility at least suggests that some of the more favourable carbonaceous horizons in the sandstones exposed on Vancouver Island may contain vanadium.

In order to help prospectors who may wish to have tests on rocks suspected to contain vanadium, the Geological Survey will examine specimens sent in and will make qualitative or quantitative analyses for vanadium free of charge when it is considered that the character of the specimens justifies such tests. Prospectors desiring examinations or tests should co-operate by giving full details as to the locality and nature of the occurrence of specimens submitted. All specimens should be numbered, wrapped separately, and described by number, and should be selected to represent as nearly as possible an average of the material examined. Specimens submitted for examination or tests may be addressed to the Director, Geological Survey, Ottawa, Canada.

CADWALLADER CREEK GOLD MINING AREA, BRIDGE RIVER DISTRICT, BRITISH COLUMBIA

By W. E. Cockfield and J. F. Walker

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INTRODUCTION

Towards the close of the 1931 field season the senior author spent several weeks in the detailed study and mapping of the augite diorite stock in the vicinity of the Lorne mine (1).[1] This work was continued in 1932 jointly by the authors and extended to cover the entire Cadwallader Creek gold belt from the Wayside mine, north of Bridge River, to the Plutus group, 4 miles south of the Pioneer mine. Owing to the lack of an adequate base map, work of a less detailed nature was done between the Plutus group and the Royal group, on the east side of McGillivray Creek. Previous work was done in the area by Camsell (2), Drysdale (3), and McCann (4), and the reader is referred to the report and maps by McCann for a description of the petrology and mineral deposits of this particular area as well as the surrounding country. The properties are described in the annual reports of the British Columbia Minister of Mines (5). As the object of the work was the mapping of the augite diorite intrusions the reader is referred to McCann's (4) report for a more extensive examination and study of the other formations which are poorly exposed in the area examined.

Efficient assistance in the field was rendered by N. McKechnie, H. Sargent, and H. K. Long in 1931 and by H. Sargent, J. C. Hall, and V. J. Dalton in 1932. Field work was facilitated through the courtesy of the mine managers and owners of the several properties.

The base map on which the geology was laid down is from compilations of Crown-granted claim surveys by Underhill, Underhill, and Fraser and by Noel Humphreys and Company, land surveyors and civil engineers. The geology from the Wayside group to the Plutus group was laid down in relation to Crown grant surveys; south of the Plutus group surveys had not been completed at the time of examination and the geology has

[1]Numbers such as this will enable the reader to find the complete bibliographic reference in the list of papers at the end of this report.

been adjusted to these later surveys, and, therefore, some error in the actual location of outcrops may be expected. Work was continued in some instances beyond the Crown grant surveys.

The Cadwallader Creek gold belt is reached by road from Bridge River or Shalalth stations on the Pacific Great Eastern Railway, the distance being 57 miles to the Pioneer mine. A trail extends southerly from the Pioneer mine over McGillivray Pass and branch trails lead to the various prospects in this area. Motor stages connect with the trains and all points along the road to the Pioneer mine.

GENERAL GEOLOGY

Bridge River area lies on the eastern flank of the Coast Range, in the transition belt between the Coast Mountains and the plateaux of the central interior system. Taken as a whole the region is rugged, with a relief of from 6,000 to 7,000 feet.

The area examined lies along the valley of Cadwallader Creek, the lower reaches of Hurley River, and about the junction of this stream with Bridge River. The relief in the area from the Wayside group to the Pioneer mine averages about 1,000 to 1,200 feet; southerly from the Pioneer mine the augite diorite was traced on to the sharp ridges on the southeast side of Cadwallader Creek Valley, at elevations of 3,500 feet above the valley bottom.

Outcrops are fairly plentiful along the west side of Bridge River on the Wayside group and southerly to the road bridge. On the side east of Bridge River and east along Hurley River for a distance of over 4,000 feet bedrock is heavily covered with unconsolidated materials and outcrops in only a few instances. Southeast from this point along Hurley River outcrops are sufficiently numerous to give a clear conception of the bedrock geology for 12,000 feet, where for a distance of about 2,000 feet bedrock is obscured by a belt of heavy overburden running easterly from the river, being again exposed at intervals to the Pioneer mine, where another belt of overburden obscures the bedrock for 3,000 to 4,000 feet southerly. From this point to Crazy Creek bedrock is well exposed on the higher ground to the southwest of the creek. Outcrops are sparsely scattered along the east side of McGillivray Creek except on the summits.

The oldest rocks described by McCann (4) in Cadwallader Creek area belong to the Bridge River series and occur along Hurley River and Cadwallader Creek, about the junction of these streams, and along Cadwallader Creek Valley east and south of the Pioneer mine (*See* Figure 5). The Bridge River series, according to McCann, is composed of metamorphosed sedimentary rocks with interbedded volcanic rocks. The chief sedimentary member of this series is a bluish grey chert that grades into a banded, cherty quartzite in which the bands, one-half inch or more thick, are separated by thin layers of argillite. The series also includes thin-bedded, dark, argillaceous strata, highly siliceous in places with a tendency to pass into chert. A red-weathering, arenaceous member occurs in places and a number of lenses of crystalline limestone occur throughout the area of the Bridge River series. The volcanic rocks included in the series are almost entirely dense, altered, dark basalts grading into andesites.

No fossils have been found in the Bridge River series, but on the basis of lithological and structural similarities, McCann correlated the strata with the Cache Creek series, considered by him to be Pennsylvanian to Permian in age.

Dark grey siliceous phyllites, graphitic on shearing planes grading into dark, siliceous to cherty argillites of McCann's Bridge River series, outcrop along the easterly side of Cadwallader Creek and Hurley River, immediately above and below the junction of these two streams. The foliation in these rocks strikes about 15 degrees and dips about 85 degrees to the west. Slates and cherty rocks of the Bridge River series, intruded by greenstone, outcrop up the hill from the Eagle claims immediately northeast of the Pioneer ground. These rocks strike 330 to 340 degrees and the dip is variable, but generally steep, to the northeast. Siliceous argillites, slates, and cherty sediments, striking northwesterly and dipping southwesterly, outcrop on the Pioneer Extension ground at intervals from the McKinley claim to the Besance claim, at distances of 1,500 to 3,000 feet south of Cadwallader Creek. Similar rocks outcrop on Chism Creek, about half-way between the trail crossing and Cadwallader Creek, at the Dan Tucker workings, and on Red Hawk ground, about half-way between the trail crossing and Cadwallader Creek, as well as on the ridge between Agnes and Copp Creeks near the head of the former. These rocks are evidently all part of McCann's Bridge River series. Cherty quartzite of the same formation outcrops up the hillside from the trail on the Royal group. Cherty sediments similar to those of the Bridge River series outcrop on the Wayside group and are interbedded (?) with and intruded by greenstones. These rocks outcrop in an area mapped by McCann as Cadwallader series, but strongly resemble the rocks of the Bridge River series, and for the purposes of this report will be considered as part of that series.

According to McCann, the rocks next in age to the Bridge River series are a group of serpentine rocks, described as the Shulaps volcanics, which have apparently two different phases, a porphyritic phase and a dense phase. The former appears to have been derived from such rocks as olivine gabbro porphyry, or the porphyritic equivalent of a peridotite. These rocks when weathered are greyish brown with the more resistant pyroxene phenocrysts standing out in relief. The freshly broken surface, however, is dull, bluish black. The dense serpentine rocks are more altered than the porphyritic, and were probably originally olivine basalts. The weathered surfaces are reddish brown to brownish yellow, except where the rocks have been crushed, in which cases the rock has been minutely sheared, the slip planes being covered with fine films of serpentine, which gives the rock a greasy feel (1).

With regard to age, McCann concludes that the serpentine rocks were extruded over the eroded surface of the Bridge River series before the rocks of the Cadwallader series were deposited. He points to the possibility, however, of the intrusion of the serpentine rocks as sills along the contact of the Bridge River series and the later formations, which would make the serpentines later than the Cadwallader series (1). Within the area covered by the present examination serpentine rocks which can be definitely assigned to the Shulaps volcanics were found on the ridges

bordering Crazy Creek, and also the ridges bordering Agnes Creek southeast from the Red Hawk group. Serpentine rocks of doubtful origin cross Hurley River at the Berta claim of the Bridge River Consolidated Company's holdings; also outcrops on the Mauser claim of the Taylor holdings; along Cadwallader Creek below the Pioneer holdings, and at the Coronation mine; on the Bess and Besance claims of the Pioneer Extension group; and along the trail on the Dan Tucker group. These exposures of serpentine rocks may represent intrusive phases of the Shulaps volcanics; the alteration of basic greenstones of the Bridge River or Cadwallader series, or even alteration phases of basic marginal phases of the augite diorite. On Crazy Creek, at the little lake, beds of massive, light grey, siliceous tuff occur in the Shulaps volcanics.

The rocks of the Cadwallader series, next younger than the Shulaps volcanics, consist of conglomerates, sandstone, and shales, with subordinate, thinly bedded limestone and dolomite, and in the lower part of the series, great thicknesses of greenstones. The pebbles of the conglomerate vary in size from $\frac{1}{4}$ inch to 4 inches and are principally quartzite, but some are limestone and others are serpentine. The conglomerates are succeeded upwards by shale. Fossils collected by McCann from the upper part of the series indicate that the Cadwallader series is referable to the Upper Triassic (1). Within the area examined rocks mapped as Cadwallader series by McCann (4) are very largely greenstones. Outcrops of these rocks are fairly abundant on the Wayside group and west of the diorite mass between the Wayside group and the road across Bridge River; also from the Peach claim of the Bridge River Exploration Company to the Pioneer mine along the east side of Hurley River and Cadwallader Creek. In the vicinity of the Lorne mine are certain shaly rocks which were mapped by McCann as part of this series. Outcrops are not as plentiful between the Pioneer mine and Crazy Creek along the southwesterly side of Cadwallader Creek, but the greenstones are again well exposed on the ridges from Crazy Creek to Agnes Creek, a small creek flowing into Cadwallader Creek just north of Copp Creek. The greenstones are very fine-grained, greenish to dense greenish grey rocks and are sometimes porphyritic. The rocks are highly altered and examination under the microscope throws little light on their character. Such information as could be obtained, however, suggests that they were originally about the composition of andesite. The greenstone appears to be largely of volcanic origin, but intrusive phases are also present. Actual relationships to formations other than the augite diorite were seldom found within the area examined.

The augite diorite, which should, from the specimens examined by the writers, perhaps be more correctly classed as hornblende diorite or greenstone, is intrusive into the three rock series mentioned above. The importance of this formation in relation to the gold quartz veins of the Cadwallader Creek gold camp was the principal reason for remapping that part of Bridge River map-area in greater detail. Greater attention was, therefore, paid to the mapping of this formation than to a study of the other rock formations. Although the specimens selected by the writers for examination showed that this rock should be more properly classed as hornblende diorite, the usage of the term augite diorite is so well established that it has been retained. The average augite

diorite is a medium-grained, speckled grey and white rock, in which hornblende, chlorite, and feldspar can generally be seen with the naked eye. It grades, in marginal phases and in small tongues, to a fine-grained, dark grey rock, which should be more correctly called an andesite, and which, lacking field evidence, cannot be distinguished from the andesitic members of the Cadwallader series. In places in contact with the greenstones, the marginal phase is a coarse-grained, dark greenish grey rock, with large crystals of hornblende developed in it. This phase may really be a contact metamorphic phase of the greenstone rather than a marginal phase of the diorite, and the writers incline to this explanation. Under the microscope the diorite shows intense alteration, and the feldspar is rarely determinable, but appears to be of the composition of andesine-labradorite. Pyroxene was found to be seldom present in the specimens selected by the writers, although McCann reports this as an essential constituent in places. The common dark mineral is found to be colourless to pale green or brown amphibole. The feldspars are largely altered to kaolin, sericite, and zoisite. The dark minerals are largely altered to chlorite and calcite. Leucoxene is generally present and occasionally epidote. One section from a specimen on the Wayside claim, somewhat fresher than the average, shows a considerable amount of alkali feldspar and here the rock appears to be closer to a ferromagnesian rich syenite than to a diorite.

The diorite outcrops (*See* Figure 5) in a number of stock-like masses and as injection tongues in the older rocks at intervals throughout the area examined from the Wayside group to the Royal group. The most northerly mass on the Wayside group outcrops chiefly on the Wayside and Newport claims, and is exposed for a greatest length of 2,400 feet and width of 1,500 feet. Numerous tongues project into the greenstones on the westerly contact. An isolated area of small size outcrops on the Beta-Alpha line and may be part of a larger area extending from the Cabinet claim, paralleling the road to the bridge across Bridge river. This mass has a length of 6,500 feet and an exposed width of 1,000 feet. A zone of diorite dykes in greenstone extends along the east side of Hurley River from the Arizona claim to the Oregon claim, a distance of 11,000 feet, and has a width of 750 to 1,500 feet. This zone of dykes probably represents the offshoots of a larger and more massive body of diorite which has not been exposed by erosion. An irregular body of diorite outcrops on the Cosmopolitan, Noelton, and Star claims, and has a length of about 3,500 feet. Over a considerable part of this area the bedrock is covered with drift, so that only occasional outcrops are available. The area as outlined is deduced from these outcrops, and may be subject to correction as mining work makes further information available. The largest mass of diorite examined extends from the Lorne mine to the Pioneer mine, a distance of 11,000 feet and has a width of about 1,500 feet. This area has been mapped with a considerable degree of accuracy on the north end, where outcrops are fairly numerous, and where the Lorne workings throw much light on it; the southerly extension is mapped on rather scattered outcrops and in part on physiographic evidence and may not prove to be a homogeneous mass of diorite. This mass tails out on the southerly extension into a number of tongues of diorite intrusive into greenstone, as found on the Pioneer ground. A zone of diorite dykes or tongues com-

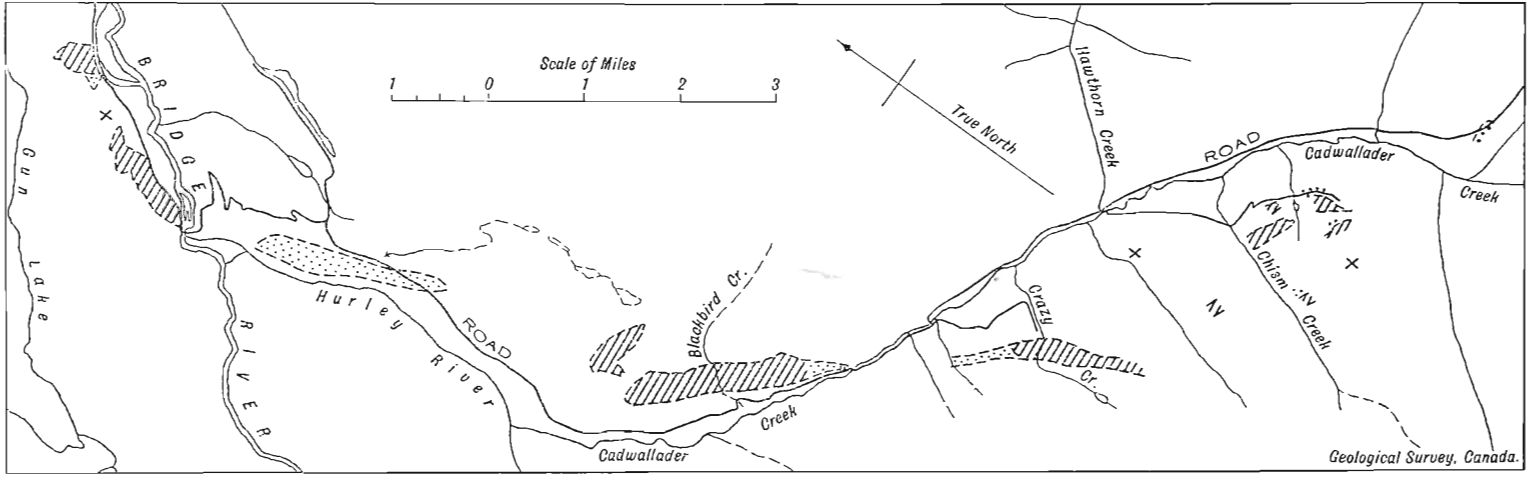

Figure 5. Cadwallader Creek gold mining area, showing positions of bodies of augite diorite (pattern of sloped, parallel lines), of areas of numerous tongues and small masses of augite diorite (pattern of dots), and of outcrops (shown by crosses) of augite diorite.

mences on the Bess claim and extends to the east side of the Besance claim, where massive diorite is exposed for over 7,000 feet crossing Crazy Creek, and has a width of from 500 to 1,300 feet.

This mass lies 4,000 to 8,000 feet south of Cadwallader Creek and the southerly end on the slope toward Nameless (Plutus) Creek was not located. A small mass of diorite, of unknown extent, outcrops just above the intersection of the Plutus 1, 2, 3, and 4 claims. A 700-foot band of diorite is exposed high up on the south side of Nameless (Plutus) Creek, some 8,000 feet south of Cadwallader Creek. It is known to die out before Chism Creek is reached, and does not extend far westerly unless it bends to join the Crazy Creek mass.

Three areas of diorite outcrop immediately east of Chism Creek, two on the Dan Tucker group and one 3,500 feet south. The extent of these exposures is not known, except that those on the Dan Tucker are not over 1,500 feet by 500 feet and 3,500 by 800 feet, respectively, the smaller mass being the one just above the trail. A lens-shaped mass of diorite, not over 2,500 feet by 1,000 feet greatest dimensions, is exposed on the Red Hawk, and what may be a larger mass south of this one on the summit of the ridge. A small zone of diorite tongues in greenstone is exposed along the trail for about 1,000 feet, easterly from the workings of the Royal group and also at the workings just below the trail.

Dykes of albitite, aplite, and quartz diorite are fairly numerous within the area examined. Tongues of rock closely resembling the quartz diorite of the Bendor batholith (4) cut the augite diorite on the Wayside claim, and this is taken as direct evidence in placing the age of the augite diorite as greater than that of the rocks of the Bendor batholith. The aplite dykes are probably differentiates of the Bendor batholith. Under the microscope these rocks are seen to consist of a somewhat granular intergrowth of plagioclase and orthoclase feldspar with quartz; a little brown mica is present. The albitite dykes vary in grain from finely granular to dense, and in colour from white to pale brown. Albitite, which in the Lorne mine is an alteration of the diorite and on the Pioneer Extension appears to be an alteration of greenstone, resembles the albitite of the dyke rocks. The brownish albitites, which are evidently alterations of greenstone, are almost identical in appearance with the ankeritic carbonate rocks so frequently found as alterations of greenstone. Regarding the origin of albite-rich rocks Bowen (6) states:

"The absence of any glassy rocks corresponding with granite very rich in albite is important in connexion with the tendency of recent investigators to refer albite-rich rocks to a replacement process. One would expect glassy rocks of such composition if these were magmas of corresponding composition. On the other hand, if the richness in albite is the result of a secondary process of impregnation of a solid rock with albite by circulating aqueous solutions, we should not expect glassy rocks rich in the albite molecule. Such solutions would be incapable of consolidation in toto, a process which is necessary for the formation of a glassy rock. The absence of glassy rocks rich in the albite molecule is thus to be taken as confirmatory of the concept that albite-rich rocks are formed by a process of replacement, probably in all cases. Rocks consisting of albite and calcite belong here. There is nothing in the manner of their occurrence to warrant belief in their formation by simple consolidation of a magma, nor is there in 'carbonate dykes'."

This statement fits the case of the albite-rich rocks of Cadwallader Creek area. The albite-rich rock referred to on the Pioneer Extension is an irregular intrusion into sediments. It is a finely granular, grey to light

brown rock, and the latter phase, examined under the microscope, is seen to consist of kaolinized albite, ankeritic (?) carbonate, some brown mica, limonite, apatite, chlorite, and quartz. It is typical of the alteration of greenstone. The albite-rich rocks have a distinct argillaceous odour from the kaolinization of the feldspar, and in the case of the dense varieties this can be used as a means of differentiating them from the aplites.

Pleistocene and Recent unconsolidated deposits, including glacial and stream deposits, cover a large part of the area, particularly at the lower elevations, so that bedrock outcrops in many places are relatively scarce. White pumice, ranging in size from dust to fragments nearly an inch across, occurs on the surface throughout the northern part of the area.

ECONOMIC GEOLOGY

Three principal factors appear to have had an influence on mineralization in the Cadwallader Creek Gold mining area. These are: (1) the manner in which the diorite intrusions are strung out along a comparatively narrow zone in this area suggests that it was one of structural weakness. At a later date when mineralization occurred it was still apparently a zone of weakness, though strengthened to some extent by the diorite intrusions. The later fissuring was along the same general line of weakness, the fissures striking rather closely with the longer axes of the diorite intrusions. Locally, as on the Lorne, where a larger and more resistant mass of the diorite is exposed, the fissuring has been controlled by the more resistant rock, and tends to parallel its contacts (1). Apart from this local control of the fissuring on the Lorne mine, no quartz-filled fissures are known to strike across the general direction of the diorite intrusions along the zone of weakness. In a few instances, as at the upper working on the Red Hawk, mineralization has followed dykes which have filled older transverse fissures. (2) The augite diorite and more massive andesitic greenstones are physically more competent to maintain fissures than the rocks of the Bridge River series, due to their more massive character and their relative brittleness. (3) It is possible that the augite diorite and immediately surrounding rocks had retained some of the heat from the intrusive and that temperature conditions at the horizons now exposed by erosion were more favourable than at greater distances away from the intrusive in this local area.

The veins of proved economic worth are quartz-filled fissures either in the diorite or in zones of greenstone, intruded by tongues of diorite, immediately adjacent to exposures of massive diorite or presumed to overlie larger bodies of that rock.

Quartz forms by far the predominant vein filling material, and is in nearly all cases white. In some veins it is massive, whereas in others a pronounced ribbon structure is present. Subordinate gangue minerals are calcite, sericite, dolomite, mariposite, and scheelite.

Calcite is not very common in the veins, but is found in some, and also in stringers in the altered wall-rocks.

Sericite occurs in the partings of the ribboned quartz and also in the altered wall-rock. Siderite and dolomite are reported by McCann from some localities.

Mariposite (chrome mica) is found sparingly in a number of the veins and only locally is abundant. It was noted in the underground workings of both the Lorne and Pioneer mines and, according to information received, usually accompanies high-grade ore. The identification of the mineral was verified by E. Poitevin of the Mineralogical Division, Geological Survey.

Specimens of a pale orange-coloured mineral, occurring with calcite in the Pioneer mine, were forwarded to the writers during the past winter and were identified as scheelite. This mineral is reported (7) to occur not infrequently through the mine. This mineral, which has not been previously reported from the veins of the area, is believed to strengthen materially the conclusions reached with regard to the temperature at which the veins were formed.

The main metallic minerals are gold, arsenopyrite, pyrite, chalcopyrite, galena, sphalerite, stibnite, tetrahedrite, and a telluride, sylvanite or possibly calaverite. The gold apparently occurs distributed in the quartz, but locally it is concentrated into shoots of ore in which the particles of gold are readily visible to the naked eye. Spectacular values have been reported from points in both the Lorne and Pioneer mines.

Specimens of very high-grade ore from the Pioneer mine showed on examination the gold occurring as irregular blebs in the quartz, but chiefly associated with arsenopyrite and to a less extent with sphalerite and galena. No visible gold was found with the pyrite in the specimens examined. The appearance of the gold associated with the arsenopyrite suggested contemporaneous and slightly later deposition of the gold than the arsenopyrite.

Arsenopyrite is common both in the quartz veins and in the altered wall-rock of the veins. It is usually quite abundant in the thin black seams that give the quartz its ribbon structure, and which are partly gouge and partly sulphides.

Pyrite is the most abundant metallic mineral in the veins and in the altered wall-rock.

Chalcopyrite is rare; galena and sphalerite occur only sparingly.

Stibnite and tetrahedrite are reported by McCann, the former from the Ida May and Coronation mines, and the latter from the Wedge vein of the Lorne mine and on the Forty Thieves claim.

Tellurides were noted in small quantities in polished specimens of high-grade ore from the Lorne mine, but exact identification of the mineral could not be made. McCann reports tellurides from the Ida May and Shaft veins of the Lorne mines. An analysis of the mineral showed that it was apparently sylvanite, but it seemed to carry more silver than would be expected in that mineral.

The mineral assemblage suggests that mineralization occurred under moderate, approaching high, temperature conditions. If such is the case, there is no reason why mineralization should not continue to considerable depths provided the fissures are maintained.

The veins, which average under rather than over 3 feet but sometimes reach 12 feet in thickness, have been proved for lengths of 800 to 2,000 feet. There is no reason to believe that these fissures do not persist to considerable depths, for in no place has a mass of diorite been exposed of

such great extent that it would not lend itself readily to fissuring. It is possible that if the diorite should increase very rapidly in size with depth, and expand into a mass of very considerable proportions, it would not lend itself so readily to fissuring, but there is no evidence to suggest that this is the case.

There is a definite concentration of the ore into shoots, with low-grade material lying between the shoots, but the factors governing their occurrence have not been ascertained. Where the fissures pass from diorite or greenstone into serpentine or other softer rocks, the fissures are tight and filled with gouge which is more or less impervious and acted as a dam, holding back the mineralizing solutions within the more brittle rock. This, however, does not account for the lean sections in the veins within the favourable rock formations, and the explanation is not always evident, though in the case of the Lorne it may be accounted for by movement along a somewhat sinuous fissure tending to produce open and tight areas along it. Locally at least there can be but little doubt that there are small enrichments at the intersection of stringers or branch veins with the main veins, but the main ore-shoots in the Pioneer and on the King vein of the Lorne mine do not appear to be accounted for by these causes. On the other hand, a small shoot of extremely high-grade ore on the Shaft vein of the Lorne mine occurs at such an intersection.

The veins are repeatedly faulted, but in most cases the horizontal displacement of such faults is not large, measuring from 2 to 4 feet. A major fault on the King vein of the Lorne mine has displaced this vein somewhat over 200 feet.

DESCRIPTIONS OF PROPERTIES

As the object of the work was largely the mapping of the areas of augite diorite, no attempt was made to study the individual deposits or to describe them in detail. The following descriptions are intended to supplement data already published, and for more complete descriptions the reader is referred to previous reports and more particularly to the Annual Reports of the British Columbia Minister of Mines.

PIONEER MINE

The relationship of the Pioneer mine to the augite diorite has already been discussed. The difficulty of separating what have been referred to as marginal phases of the diorite from the greenstone has led to the conception that the workings of this property lie in the augite diorite stock. Specimens examined from the workings, however, and the few outcrops on the surface lead the writers to the belief that the workings lie in the greenstone, which is intruded by tongues of the augite diorite. The main body of diorite outcrops on the surface on the Countless claim. The massive greenstone may be considered physically competent to maintain a fissure, equally so with the diorite, and it is believed that there is as much reason to expect this fissure to carry to depth under the geological conditions outlined as under the former conception of the geology of this property.

The developments at the mine during the year have proved very interesting. A new shaft has been raised from the former lowest level, and sunk below that level to a depth of 1,625 feet below the surface. This shaft is vertical. At the time the writers visited the property crosscutting from this shaft to the vein was in progress on the different levels below those already established. The vein is inclined at a steep angle, so that short crosscuts are necessary from the vertical shaft. Information has since been received that the vein has been encountered in all of the crosscuts. The vein has thus been proved to a depth of 1,625 feet below the surface. During the progress of this work, two new veins were encountered, one at 150 feet from the surface, and the other a short distance above the bottom of the shaft. This second vein was also encountered in the crosscut driven from the bottom of the shaft towards the main vein. It is a comparatively flat-lying vein, inclined towards the main vein. Development work on these veins had not been carried out.

Recent reports from the mine have related the finding of a pocket of spectacular ore. No details as to the manner of its occurrence are available.

A new unit added to the mill has brought the capacity to 300 tons daily. The mine is thus in a position to very materially increase its production this year.

BRALORNE MINES, LIMITED

This company has acquired the properties of the former Lorne Mines, which extend from the Lorne mine to the Pioneer holdings. These holdings cover most of the largest known belt of augite diorite, and include a number of properties along it where the mineral deposits have formerly been worked, such as the Blackbird, Ida May, and Coronation. Recent work has, however, been confined to the King vein of the old Lorne mine. This mine is opened by a long adit level (the 8th level) from which the King, Wedge, and Shaft veins have been crosscut on the one side, and the Alhambra vein on the other. During the year a winze has been sunk on the King vein from the 8th level and two new levels opened up below. Four levels have been opened above the 8th level. Two shoots of ore have been partly developed, one of which rakes in a westerly direction. This shoot was found on the 9th level, but was considerably shorter than where found on the 8th, being apparently cut off by a major fault. On the 10th level this ore-shoot was not found. This level was, accordingly, continued through the fault and crosscutting is reported to have picked up the vein. The fault is reported to have a horizontal displacement of over 200 feet. A considerable block of ore is believed to lie beyond this fault.

The second shoot of ore was found by the continuation of the old 4th level. The rake of this shoot had not been determined, but it is quite possible that it rakes in the opposite direction to the first shoot.

The 100-ton mill was completed and started operations early in the year. It is reported to have worked at capacity.

BRIDGE RIVER EXPLORATION COMPANY

This company did considerable work on the California vein, and alsc on the holdings of the Bridge River Consolidated Company, the Why Not, Arizona, and Forty Thieves. On the California vein an adit was

run in some 500 feet. This vein is in reality a shear zone with masses of quartz cementing fractured country rock. Quartz veins appear in places in the shear. A large number of samples taken by the company are reported to show low values in gold over very considerable widths. The width of the zone is stated to vary from 12 feet to 27 feet, with values throughout. The California vein is believed to be traceable from the Why Not across the California and Oregon claims, although not continuously exposed over this distance. The assay results reported, combined with the width of the zone, render the property worthy of consideration from the standpoint of a low-grade body of possibly considerable extent. Further work on this property appears justified.

The adit lies on the slope of the hill above the bench that marks the top of Hurley River Canyon at this point. The country rock is greenstone with a great many tongues of diorite. One tongue of diorite is exposed at the mouth of the adit. Passing northward from the workings, greenstone outcrops in a series of hills overlooking a small creek several claim lengths north of the California. Here there are undoubted surface flow structures in the greenstone, and no tongues of diorite were noted.

The geological feature of the property that merits attention is the numerous tongues of diorite in the greenstone. These are believed to be the surface manifestations of a larger and more continuous body of diorite below. There is no evidence on which to base a statement as to the depth at which such a body, if it exists, may be expected. It is believed, however, that this large shear, if it descends in the greenstone in the vicinity of a body of diorite of considerable size, is liable to repeat to some extent the general temperature conditions that prevailed in the formation of the Lorne and Pioneer veins. This does not in itself necessarily promise a repetition of similar ore-shoots; nevertheless somewhat deeper development than has taken place would probably be justified.

This company also prospected the Why Not, Arizona, and Forty Thieves claims of the Bridge River Consolidated Company. The results were stated to be somewhat disappointing in so far as values were concerned. These properties were not examined in sufficient detail to permit of giving an adequate description of them.

RED HAWK GROUP

The Red Hawk group extends southwesterly from Cadwallader Creek to the summit of the ridge between Agnes and Chism Creeks and occupies somewhat more than half the ground between these creeks adjacent to the latter.

Prospecting had not been advanced very far on the group and the workings consisted of two small adits and a surface cut of three separate showings of quartz. On Red Hawk claim No. 8 a surface cut exposes a 4-foot vein of quartz, striking 325 degrees, and dipping 67 degrees to the southeast, following an aplitic dyke. The quartz has penetrated the crushed country rock along the sides of the fissure for 1 foot to 1½ feet, giving a total width of vein matter and country rock of 6 to 7 feet. The vein has been exposed for only a few feet along its strike and passes under overburden in both directions. Mr. Ker, who was on the property, reported low values in gold from this vein. The most interesting feature

about this vein is that its strike, if projected northwesterly, would appear to follow along the westerly contact of a mass of augite diorite exposed immediately above the Red Hawk trail, and which pinches out on the easterly side of the basin in which the camp is situated about 1,000 feet from the surface cut. A continuation of the vein was not discovered on the steep wall of the basin, but the fact that the fissuring is along the direction of the diorite mass suggests that it is related to the intrusion of the diorite, which, though considerably older than the period of the mineralization, may later have formed a suitable channel for ascending mineral solutions. Again, this fissuring may be younger than the intrusion of the diorite and has been controlled by the resistance of the more massive rock.

The upper adit, west of the Red Hawk basin, has exposed considerable quartz in the face, which appears to have followed a white albitite (?) dyke, strike 70 degrees, dip about vertical. In several places in Cadwallader Creek area mineral solutions have followed fissures filled with dykes, now altered to albitite, replacing to a certain extent the albitite. This type of mineralization is very erratic, the albitite being replaced by sporadic bunches of quartz. The quartz in this type of deposit would have to carry very high values to permit of mining the barren dyke rock in which it occurs and such deposits do not appear to hold a great deal of promise for profitable development.

The adit just above the camp has been driven to explore a showing of quartz and albitite (?) exposed by surface stripping. The nature of this occurrence is not clear and it is not certain if the albitite (?) is an altered dyke or is the alteration of the greenstone country rock.

A number of open-cuts on the Red Hawk claim No. 4 along the trail, close to the northeasterly contact of diorite, expose small gash veins in greenstone cut by tongues of diorite. These little gash veins of quartz strike more or less along the contact of the diorite and dip from high angles southwesterly to about 50 degrees northeasterly. They are reported to carry values in gold, but are very small and discontinuous.

ROYAL GROUP

The Royal group lies easterly from the junction of McGillivray Creek with Cadwallader Creek.

Ground-sluicing along a small creek on the Royal A Fraction, below the trail, has exposed tongues of diorite in greenstone, outcrops of which continue southerly for about 1,000 feet along the trail. A $4\frac{1}{2}$-foot quartz vein with 1 foot of gouge and altered wall-rock on either side was exposed in this little creek. The vein strikes 306 degrees and the dip is about vertical. The quartz is clean and milky in appearance and is fractured transverse to the direction of the vein. A little iron stain is present, but no sulphides were observed. Some have apparently existed in the vein quartz and apparently more along the walls of the vein in the now altered material. The vein had been exposed for about 20 feet, maintaining its width to the south end where it pinches rapidly to a couple of inches. Mr. Pederson who was working on the property reports that the gouge and altered material along the sides of the vein carry the best values.

DAN TUCKER GROUP

The Dan Tucker group lies up the hill-side southwesterly from Cadwallader Creek between Chism Creek and the Red Hawk group. A shaft was down about 56 feet on a shear in sediments of the Bridge River series, strike approximately 295 degrees, average dip 70 degrees southwesterly, between serpentine rocks immediately to the northeast, or down the hill-side, and a small mass of diorite, immediately to the southwest, or up the hill. The shear follows closely the direction of the diorite contact and dips towards it. Stringers and lenses of quartz appear in the shear and Mr. Hall Carpenter, who was working on the property, reports that they carry good values in gold. The dip of the diorite contact is not known, but it is possible that if the shear should dip into the diorite more favourable conditions for the formation of ore-shoots will be found. Several open-cuts between the shaft and the creek on which the camp is situated to the south expose small, gently to steeply southwesterly dipping lenses of quartz.

On the Chism Creek slope about 350 feet lower in elevation than the shaft and at some distance from it a silicified and heavily pyritized shear zone in greenstone has been exposed across a width of 12 feet in a surface pit. The strike of the shear zone as closely as it could be ascertained is 300 degrees and the dip is high to the southwest. Mr. Carpenter states that a little gold, which is spongy in appearance, can be panned from crushed material out of parts of this zone. This silicified zone may line up with the shear at the shaft, and if it should average only a few dollars in gold would seem from its considerable width to merit further attention.

PAYMASTER GOLD QUARTZ GROUP

This group of claims extends easterly across Crazy Creek and lies southwesterly from the Pioneer Extension ground. The principal showing on this group is on the easterly side of Crazy Creek. A 6-foot albitite dyke, striking northerly and dipping vertically, cuts greenstones close to a contact with slates to the northeast and with diorite to the southwest. The dyke is well exposed on the bluffs overlooking the creek. Fine grains of pyrrhotite occur at intervals throughout the dyke. The dyke is silicified in places and stringers and masses of quartz are irregularly distributed in it. The future of this type of deposit depends on whether the quartz carries sufficient gold values to permit of mining the full width of the dyke. Systematic sampling would quickly determine the value of this dyke, which is well exposed for some distance up the steep slope of the hill-side.

WAYSIDE GROUP

The Wayside group is situated on the west side of Bridge River a short distance below the mouth of Hurley River.

Two well-defined shears in augite diorite are exposed in a number of workings on the Wayside claim close to the westerly contact of the augite diorite. The easterly shear—strike average 345 degrees, dip 50 degrees to 65 degrees to the northeast—is well exposed in a long adit at trail level just above the road. This shear is quartz-filled for about 180 feet with an average width of about 3 feet in the adit, and low average values on gold

are reported from this section. The other shear is 75 feet westerly from the first at trail level and is opened up by four short adits at intervals up the hill-side for a horizontal distance of 1,500 feet. This shear strikes slightly more to the north than the first and the dip is not quite so steep to the northeast. In the third adit up the hill-side 14 to 16 inches of quartz is exposed in it. An adit situated between the third and fourth on this shear and slightly east of them is probably on the first-mentioned shear. The long adit on the first shear was turned westerly, evidently with the object of intersecting the second shear, but does not appear to have been driven quite far enough to reach it. It is apparent that the shears should intersect some distance below the lowest workings. Whether they will unite to form a single shear is problematical, and whether conditions will improve if they do is also uncertain. The presence of quartz filling in the first-mentioned shear suggests the possibility of finding other shoots of quartz in both shears, but whether values may be expected to improve either with depth or by tracing the shears northerly out of the diorite is a matter of speculation. The shears are in a favourable rock formation close to the diorite contact, and the work done to date may give a fair idea of what is to be expected from them.

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AN OCCURRENCE OF MAGNESITE NEAR CLINTON, BRITISH COLUMBIA

By W. E. Cockfield and J. F. Walker

In the course of field work in Cariboo District the writers were instructed to examine a deposit of magnesite near Clinton, samples of which had been sent in to the department by D. B. Hutchison of Seventy-mile House, and which appeared to be high-grade magnesite. The writers express their thanks to Mr. Hutchison for the time given in guiding them to the property.

The deposit is readily accessible, being situated near the valley of Bonaparte River about a mile east of Mond ranch and approximately 6 miles by road from Clinton, which is situated on the Pacific Great Eastern Railway. A road from Clinton to Bonaparte Valley passes within half to three-quarters of a mile of the property, and the construction of a road to the property itself offers no difficulties, as the valley is the sparsely timbered country typical of the dry belt.

The deposit occurs at a change of slope on the hill-side overlooking Bonaparte Valley. Below, the slope is somewhat steep, but above it flattens out to a gentle slope covered with superficial deposits, no outcrops being seen over a considerable area. A washout or rockslide has broken away part of the unconsolidated material and bedrock for about 150 feet along the top of the steep slope, and the rock debris, including much magnesite, is scattered as talus below. Magnesite is exposed in places up to 65 feet apart along the top of the slope. An open-cut has been made at one point showing the nature of the occurrence.

The bedrock of the vicinity is a badly altered, basic rock, now consisting largely of serpentine. The main mass of the rock consists of pale greenish grey serpentine with crystals of an olivine colour. These crystals are, however, soft, and although they may have originally been olivine, are probably now highly serpentinized.

The magnesite is apparently formed by surface alteration of this rock and various stages in the alteration may be noted. As far as could be seen the alteration to magnesite is confined to within 4 or 5 feet of the surface of the bedrock.

The altered serpentine rock in one stage shows further alteration to more highly serpentinized green material with yellowish brown, ankeritic carbonates and possibly some hydrous iron oxide, with grains of magnetite and black streaks that are possibly manganese.

A further stage in the alteration shows grains and small masses of magnesite in the serpentinized rock. Further alteration changes the rock largely to magnesite and ankeritic carbonates, and the final alteration, to magnesite. The magnesite replaces both the serpentine and the ankeritic carbonates, and in the early stages occurs as small, pale brownish white grains and replacement masses. The complete alteration produces a china-white, dense magnesite of good quality. The better quality of the material

is confined to within 3 or 4 feet of the surface of bedrock and then decreases rapidly to the coloured variety occurring in the serpentinized rock. Mr. Poitevin of the Geological Survey reports "The samples submitted by Mr. Hutchison consist of compact cryptocrystalline magnesite showing no cleavage and breaking with a conchoidal fracture. In appearance it resembles the magnesite occurring in Tulare, Santa Clara, and San Benito, California, and it also resembles the magnesite from the old typical Grecian locality."

As the deposit appears to be the result of surface alteration it is considered that it is less likely to extend over the steep slope of the hill-side than it is up the gentle slope above the exposures. This slope is covered with unconsolidated materials that are probably fairly thin and development work should in the first instance be confined to trenching this slope to see if the magnesite extends in this direction. The deposit does not appear to have any depth, but it may extend over a considerable area, and since the size of the deposit bears such a close relation to the area over which it can be demonstrated that alteration has taken place, the development outlined would appear to be the quickest and cheapest method of testing the commercial possibilities of the property. Although perhaps only half of the material recovered to a depth of 3 to 4 feet from the surface of bedrock would be of commercial grade, nevertheless it appears to be very pure material, and warrants a limited amount of exploration.

It should be borne in mind, however, that even if a body of commercial size and grade be demonstrated, the question of securing markets for the product must also be considered as one of the problems to be solved in the utilization of this material. The chief use for magnesite is in the lining of steel furnaces, but it is also used to some extent in the building industry and in the manufacture of artificial periclase. The local or British Columbia market would probably be very limited. Hitherto magnesite of this quality has not been readily obtainable in close proximity to a railway, but C. E. Cairnes of the Geological Survey has recently announced the discovery of good grade magnesite of considerable extent, occurring in the vicinity of Marysville, Cranbrook area, B.C. This deposit is also conveniently situated with regard to transportation, but is much farther from tide water than the Clinton deposit.

Magnesite is produced from a number of countries, but the chief producers are Austria, United States of America, Greece, Czechoslovakia, and Russia.

SOME MINERAL OCCURRENCES IN THE VICINITY OF CRANBROOK, BRITISH COLUMBIA

By C. E. Cairnes

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INTRODUCTION

This report calls attention to interesting features connected principally with mineral deposition in an area west of Kootenay River and within a 25-mile radius of Cranbrook. It follows four months field work and is not presented as a final statement on the many problems encountered. It may, however, afford some help to those engaged in mining in the area. Field work was greatly facilitated by the cordial co-operation of residents of the district and by the capable assistance of Messrs. H. M. A. Rice and N. D. McKechnie.

The area examined lies mostly within Purcell Range and is drained by the southerly flowing Kootenay River. The great, longitudinal depression containing this stream is sharply defined on the east by the abrupt and impressive western wall of the Rocky Mountains. West of the river, however, the depression merges with wooded foothills which, in turn, give way to the main eastern slopes of Purcell Range. Relief ranges from about 2,500 feet at Kootenay River to 8,550 feet at the summit of Evans Mountain.

Within Purcell Range proper St. Mary and Moyie Rivers and their principal tributaries occupy prominent valleys which have an extended history in later geological time. Where, however, these valleys emerge upon the broad, low-lying country flanking Kootenay River there has been much disorganization in drainage, a feature of special significance in its relation to placer accumulations in the district.

GEOLOGY

The consolidated rock formations (1, 2)[1] are mainly sediments and mostly of Precambrian age. The oldest, or Aldridge formation, is host rock for the important silver-lead-zinc deposits in the district. Others, again, contain or consist of valuable deposits of non-metallic materials such as gypsum, limestone, magnesite, etc., of which, it is anticipated, an increasing use will be made.

[1] These numbers will enable the reader to find the complete bibliographic reference in the list of papers at the end of this report.

A variety of igneous formations is also represented. These include both volcanic and intrusive types, the latter being of particular interest because of their definite genetic relationships to some mineral deposits and probable or possible relations to others. The most important and interesting of these intrusives are the Purcell sills in which a great number of mineral discoveries have been made and to which much of the mineralization in the associated intruded formations may be related.

Much of the investigated area is drift covered, especially the low-lying country between Kootenay River and the main Purcell Range. The drift occurs as: (1) sorted sands and gravels of preglacial age; (2) boulder clays, morainal deposits and silts, sands, gravels, and other less well-sorted materials of glacial age and, principally, glacial and fluvioglacial origin; and (3) recently formed stream gravels, valley alluvium, and delta deposits. The recent stream gravels have hitherto provided most of the placer gold in this district, but operations have been extended to explore older gravel deposits or other types of drift for placer occurrences.

All formations, with the probable exception of the granitic intrusives, have participated in all the structural disturbances of the district. These disturbances have developed broadly folded structures trending north to northeasterly and plunging, in general, towards the north. The continuity of the folds is interrupted by prominent faults of which two sets have been recognized, one with a general northeasterly strike and the other, and apparently later, set trending nearly east and west. The displacements effected are not known, but the relative horizontal shifts have, in a number of instances, been approximately determined and vary from a few hundred feet or yards to a matter of miles.

The economic significance of these faults, as of other structural features, is largely dependent on the assumption that much of the mineralization in this investigated area is either directly or indirectly related to the Purcell sills and allied intrusives. If this is so and if, as structural conditions appear to indicate, these sills have been involved in all the major disturbances affecting this area to a like degree with the formations in which they occur, it follows that the mineral deposits related to the sills have been similarly affected by the deformative processes.

ECONOMIC GEOLOGY

Cranbrook district has attracted attention principally as a result of the huge production won from its silver-lead-zinc deposits, as exemplified at the Sullivan, St. Eugene, and North Star mines. Its mining history began, however, with the discovery in 1863 of placer gold on Wild Horse Creek near Fort Steele, and until about the mid-nineties production was entirely from such deposits, and amounted altogether to a sum variously estimated at from half a million to several million dollars. Since that time placer mining, though continuing to attract attention, has been carried on more spasmodically, and the average annual output has been comparatively small. The recent slump in metal prices has turned attention more particularly to the placer possibilities of the district, with the result that unusual activity has been experienced in this direction and some further discoveries made. Lode properties in which gold values occur have acquired a fresh significance, though no important developments are

recorded. Some active interest is also being taken in the non-metallic field and the recent discovery of a large and conveniently situated deposit of rock magnesite may serve to further stimulate this interest.

The mineral deposits of the area may be classified as follows:

Metalliferous deposits
- Placer gold
- Lode deposits
  - Gold-quartz
  - Silver, lead, and zinc
  - Copper-gold, etc.

Non-metallic deposits
- Magnesite
- Ornamental stone

Metalliferous Deposits

PLACER GOLD

Placer gold has been obtained from different types of material and under a variety of conditions that have led to much speculation as to its origin, the value of the deposits in which it occurs, and the methods best adapted to their exploration. Unfortunately there is little available authentic information on either the values obtained from any particular deposit, or class of deposits, or the character of the gold discovered in them. On the one hand, Government statistics from 1874 indicate that total production west of Kootenay River has been small as compared with recoveries east of the river and may, in fact, amount to only a few thousand or, at the most, a few tens of thousands of dollars; also that the expenses involved in this production have probably exceeded returns. On the other hand, it is equally apparent from official reports that placer gold in paying quantities has been found at several places, though it is less certain to what extent such occurrences have been exploited or whether in any instance any considerable body of pay dirt was developed. It is also quite probable that important gold recoveries may have been made prior to 1874 and it is the contention of some of the residents of the district that it was during this earlier period that most of the production was won. Be that as it may the fact remains that the status of placer mining in the area investigated is, at present, largely prospective and though the industry has undoubtedly yielded encouraging indications and has suggestive possibilities much exploratory work remains to be done before operations on any extensive scale can be confidently recommended.

Principal operations in the past have been conducted in the valleys of Perry Creek, Moyie River, and Weaver and Palmer Bar Creeks. Recent discoveries in Fish Creek Valley have attracted attention. The following notes present some of the more interesting facts relative to these operations and to the conditions encountered.

Perry Creek

Placer mining west of Kootenay River has been largely identified with operations on Perry Creek (2A; 3, page 1014; 4, pages 76-79; 5, page 114), a principal tributary of St. Mary River. The creek is about

21 miles long and at 8 miles or so from its mouth enters the foothills of Purcell Range. Above this point Perry Creek Valley is broadly flaring down to 1,000 feet or so above creek-level, but below this level the walls steepen and the valley is distinctly trough-shaped. Both upper and lower slopes are glaciated and both are intersected by a series of narrow, tributary valleys of youthful appearance. Interstream divides are proportionately broad and are in alinement down the main valley. The suggestion of powerful, glacial erosion, particularly in the lower, more trough-shaped, valley slopes would seem to preclude the preservation of preglacial placer deposits. In spite, however, of this unfavourable circumstance some attractive values are reported to have been found a number of years ago in operations conducted about 6 miles above Old Town. The locality was not visited by the writer, but is referred to at some length by Fleet Robertson (4, pages 78-79) from whose report the following extracts are taken:

"The East Kootenay Placer Mining Company has secured leases about 4½ miles above the falls, and has established a steam shovel for lifting the gravel into the sluice-boxes. At the point selected for operations the creek bed has a grade of about 2 to 3 per cent, and at a depth varying from 3 to 10 feet there occurs a "false bedrock", consisting of a sandy clay, on and above which gold in considerable quantities has been found. The true bedrock is believed to be at a depth of approximately 50 feet lower, since at this depth it was struck in both the old Ridgeway and Baker shafts, a short distance away. From the former of these shafts drifts were made, so it is reported, down stream for 150 feet and up for 25 feet. In the shaft $90 was said to have been found, and the drifts were stated to have paid $7 per day to the man for a time. The Baker shaft was also drifted from for some 100 feet, but was not profitable.

The original intention at the installation of the plant was to work the gravel on and above the false bedrock, and of this a patch 64 yards long, 8 yards wide, and 2 yards deep, equal to about 1,000 cubic yards, has been taken and dumped into the rough sluice-boxes. From this small patch gold amounting to $260, as reported by the management, was obtained, being equivalent to 26 cents per cubic yard.

If the ground worked may be taken as a sample of the values to be found above the false bedrock, and there is no reason why it should not be, there is on the lease a large tonnage of material which, with the plant modified as proposed to suit the conditions, can be handled to a good profit. The plant, as it stands at present, is realized to have too small a range to be effective, and operations had been suspended until the requisite alterations were made. It is expected that, as work proceeds upstream, true bedrock will rise nearer the surface, and that towards the upper part of the leases it may be possible to reach it from the level."

In this report there are no references to the size, shape, or character of the gold, nor, with the exception of the false bedrock of sandy clay, no comments upon the character of the materials composing these detrital deposits. The project proved unsuccessful, as a result, apparently, of mechanical difficulties which at the time (1903) did not seem to be insuperable. In view of the reported values it is rather surprising that no further action has been taken to investigate these deposits. It would be interesting to know something more about the character of the bedrock across the bottom of the valley in this section. Has it, as would seem likely, been entirely glaciated? Or is it possible that some deep-cut stream channel may have escaped, or partly escaped ice erosion? In the latter event the ground might well repay careful exploration. Otherwise the gold present must be regarded as representing a reconcentration from, principally, glacial deposits. The possibilities of the ground would, in such circumstances, be materially reduced and the reported values should be carefully checked before any ambitious development scheme is undertaken.

Below the point where, as noted above, Perry Creek enters the foothill country of Purcell Range (about 2½ miles above Old Town) there is evidence of a disorganization of drainage suggesting that Perry Creek has, in the past, occupied other channels than the present. On the one hand this consideration has complicated the search for placer deposits, but, on the other, has lent some encouragement to the hope that along one or other of these channels significant deposits may have escaped or partly escaped glacial erosion. Looking down Perry Creek Valley from any high point of vantage on the northwestern slopes of the main range one is impressed by the delusion that Perry Creek flows along the steep and narrow valley occupied by Valley Lake and the upper valley of Valley Creek. Instead, however, of pursuing this course, Perry Creek swings rather sharply to the opposite or north side of its valley and then follows for a mile or so along a rocky gorge ending in a deep, box canyon from which the creek emerges over a 100-foot falls. The canyon and much, at least, of the gorge above, are quite evidently recent topographic developments in the valley of Perry Creek; and the impression is that prior to their development Perry Creek did for a time flow through the pass that now contains Valley Lake and upper Valley Creek. An examination of this pass reveals that it was once much deeper and that it has been filled to its present level by accumulated debris including no inconsiderable proportion of slide material from the steep slopes of the mountain to the south. Following the pass through to the east it is seen to swing to the right (or southeast) and to join in this direction with the remarkable through valley containing Fish Lake and Fish Creek, to which further references will subsequently be made. Nothing, so far as the writer is aware, has yet been learned of conditions at or near bedrock in Valley Creek Pass and although the pass presents interesting placer possibilities an adequate investigation would, owing to the heavy drift accumulations, be doubtless expensive, and unless unusually rich gravels were encountered the operative costs might well be prohibitive.

At the foot of Perry Creek Falls (mentioned above) and situated 1½ miles above Old Town, some energetic attempts have been made to explore and work what appears to be an old channel deposit on the right or south side of the creek (*See* Plate I A). The "channel" joins Perry Creek at grade and at the bottom is only a few yards wide, but apparently widens higher up, though in this direction the rim rocks are not well exposed. The channel is, presumably, a short one, connecting Valley Creek Pass with the present valley of Perry Creek. It is filled to a height of about 400 feet above Perry Creek or to the top of the narrow divide separating the two valleys. The lower part of the deposits filling this channel consists mainly of fine gravel and sands and the upper part, principally of clay and silt, probably of glacial origin. According to early reports (3, page 1014; 4, page 77) an adit (the old Montezuma tunnel) was driven in on this channel from near the level of Perry Creek for a distance of from 1,000 to 2,000 feet and certain workings developed therefrom. It is, further, reported that these workings were not on bedrock or even rim rock, but followed a pay-streak in the gravels. Other pay-streaks were subsequently discovered above the first and, as a result, an attempt was made, 1904–06, by the Perry Creek Hydraulic Mining Company, to hydraulic the whole bank. The project was never completed, and it seems doubtful if any considerable quantity of gold was recovered.

Curiously enough nothing yet seems to be known of bedrock conditions in this channel and yet it would appear that this should have been one of the first features to be investigated.

For 1½ miles below the falls, Perry Creek has an average gradient, as determined from barometric readings, of 2·8 per cent and is confined between steep, mostly rocky, walls. Towards the falls the stream gravels are shallow, but farther down stream they reach depths of from 40 or 50 to 100 feet or more. To what extent these gravels were worked in the early years is not known, but it seems probable that considerable gold was won from the shallower deposits. Later efforts included some attempts to investigate the deeper gravels and, also, certain bench remnants clinging to the lower, steep, valley slopes. About half a mile below the falls is a shaft 48 feet deep; 700 feet farther downstream is another 60 to 65 feet deep. Both shafts are reported to have reached bedrock and to have encountered good values and some coarse gold. The property belongs to M. P. Johnston, Lancaster Building, Calgary. Below this claim a series of creek leases have been taken out by the Perry Creek Syndicate, consisting of G. M. Bell and associates, of Calgary. Operations in 1932 were being concentrated at a point in Perry Creek Valley about 1½ miles below the falls. Here rim rock (Creston formation) is exposed 25 feet north and 225 feet south of the creek and dips steeply below the valley deposits. An attempt to sink a shaft to bedrock in these deposits, about midway between rim rock exposures, was frustrated by the occurrence of a thick deposit of quicksand. The shaft was accordingly abandoned at about 35 feet, and another commenced, in the rim rocks themselves, about 50 feet north of the creek, the idea being to sink to about the level of bedrock in the channel and then crosscut to the channel bottom. Concomitant with this work a drill was installed and, first of all, a hole sunk below the abandoned shaft to bedrock, a total depth below the surface of about 90 feet. At bedrock and for a distance of 4 feet into it encouraging detrital gold values are reported to have been found. Subsequently, two more drill holes, at distances of 25 and 50 feet, respectively, north of the first, were sunk to bedrock, reaching it at exactly the same depth as the first but encountering very little gold. The material encountered in the drill holes included, from top to bottom, 60 feet or so of irregularly sorted sands, gravel, and clay (including the quicksand mentioned above) underlain by 25 feet of more regularly bedded, loose sand and fine gravel, underlain, in turn, by about 15 feet of clay, gravel, and sand. The bedrock is composed of a decomposed, greenish rock of uncertain origin, but most resembling a highly altered, basic dyke rock. The flattish bottom of the channel; the, apparently, very steep walls; and the decomposed bedrock are features that as a whole are more suggestive of stream than glacial erosion. The lower 40 feet of gravels, etc., have, too, more the characteristics of stream gravels than glacial deposits, whereas the overlying materials are, in the main, more likely of glacial origin. If an opinion may be hazarded from the available data at this locality and from a comparison with the section of gravels, etc., exposed along St. Mary River below the mouth of Perry Creek (*See* later reference), the lowermost gravels encountered in the drill holes would correspond best with the, presumably, Tertiary deposits of St. Mary River; the upper 60 feet or so of materials penetrated by the drill are, in turn, analagous to the glacial deposits from

the river sections; and the intervening band of "loose sand and gravel" finds its counterpart along St. Mary River in a band of dark, clean gravel resting, unconformably, on the Tertiary deposits. A confirmatory test as to the possible Tertiary age of the lowermost gravels in the drill holes would be the discovery therein of plant remains or thin seams of lignite or partly coalized, carbonaceous material. Should this suggested correlation be correct it would lend much encouragement to exploratory work in this lower section of Perry Creek. Even as it stands the project should, with a reasonable amount of underground exploration, go far towards proving, once and for all, the possibilities of this section of Perry Creek Valley below the falls.

St. Mary River

Comparatively little placer mining has been attempted along St. Mary River. Possibilities here seem limited to one group of deposits, to which some reference may be made. These deposits are exposed in a number of high, cut banks along the river below the mouth of Perry Creek. At Wycliffe they consist mainly of coarse to fairly coarse gravels (*See* Plate I B), but farther down stream consist of finer gravels interbedded with much sandy and clayey materials. They have a thickness of over 100 feet; overlie an irregular, unglaciated rock surface; and are distinguished from overlying materials by, in part, a rusty appearance, by partial decomposition of the constituent cobbles, pebbles, etc., by a certain amount of deformation indicated by gentle folds, and by faults—one fault with a throw of 10 feet being observed—by an unconformable relation with overlying horizontally bedded formations, by the occurrence of blocks and narrow, irregular seams of partly lignitized wood, and by the presence of plant remains diagnostic of a semi-tropical climate.

Schofield (1, pages 86-91) regarded these deposits as of either early Pleistocene or interglacial age; Hollick (6) considered them as, more probably, late Tertiary; and Berry (7) has subsequently proved to his satisfaction that they are of Tertiary, Miocene age. On the basis that they are preglacial, these deposits at once assume a significance in respect to placer possibilities that they might not otherwise possess. Not that it may be inferred from this that these gravels do contain important placers nor, even if they do, that such deposits could be profitably worked. The gravels may, for example, be of deltaic origin rather than stream-channel deposits and would not in that case be expected to contain sufficiently concentrated values to warrant exploration; or, again, even if they are normal stream deposits and even if it be assumed that good values occur along the old stream channel, it might be that mining costs would be too great to afford a profitable production. In this connexion too, it might be pointed out that as much of these gravels, etc., are rather firmly cemented, their gold content, if any, might not (probably would not) separate easily from the sandy matrix about the boulders or pebbles, but would tend to adhere to the boulders along with much of the cementing material. An adequate test would, therefore, require that the boulders in the sample tested be well scoured and the cementing material thoroughly pulverized before concentration is attempted. It might, indeed, be found that even though good values were thereby obtained a process of this sort would in practice be found too costly to warrant the development

of these deposits. On the other hand, and in spite of the uncertainties involved, these Tertiary deposits undoubtedly have possibilities and would seem to be worth a little preliminary exploration. No effort, so far as the writer is aware, has yet been made to investigate bedrock at the base of these gravels, although bedrock is exposed at a number of places along and in the vicinity of St. Mary River. If, too, they are stream-channel gravels, values would be concentrated towards or at the centre of the old channel and its position would have to be determined.

Overlying these deposits unconformably and elsewhere exposed in cut banks along the lower St. Mary River and Perry Creek is a succession of well-stratified, creamy silts and unstratified, compact, grey boulder clays associated with minor proportions of gravelly and sandy materials. Collectively they have a maximum thickness of probably 400 feet or more, the proportions of the individual constituents varying greatly in the different sections examined. A little work has been done here and there on some of these deposits and though a few colours have been obtained there seems little chance of discovering substantial deposits in these materials which are, mainly at least, of glacial or fluvioglacial origin.

Palmer Bar and Vicinity (2A)

Palmer Bar is a name generally applied to the low-lying area on either side of Palmer Bar Creek in the vicinity of Lumberton. Considerable work has been done in this vicinity, but opinions vary widely as to how much gold has been produced and where it was found. A visit to the locality revealed a number of parties working at intervals along the west side of the creek from about a mile below to one-half mile or so above Lumberton. At the latter point a number of both old and comparatively recent workings were observed on the North Star bench lease owned by G. A. Ness of Cranbrook. These workings, including a number of large and small pits and open-cuts, two shafts, and an adit 350 feet long, have investigated an irregular assortment of drift deposits occurring at an average elevation of about 80 feet above and 100 yards or more west of the creek. Along the upper or west side of these workings bedrock is exposed in places, but was not seen in the diggings themselves. The surface workings occur in poorly sorted drift containing occasional, conspicuous boulders up to several feet in diameter. The shafts, one of which was 38 feet deep, were not examined on account of water, but are reported not to have reached bedrock. The adit exposes a series of irregularly bedded clays, sands, and fine gravels with lenses of what appeared to be boulder clay. Considerable fine gold and some fair-sized nuggets are reported to have been found in streaks and in small quantities at different horizons in these deposits. Most of this gold, as well as that obtained at other workings on the property, is a somewhat rusty or bronzy yellow, though some of it is distinctly brighter. Samples shown the writer included coarser and more nuggety material than that being found farther down the creek. The deposits are also reported to carry a lot of black sand, assays of which were shown to carry 6 to 12 ounces gold a ton.

Below Ness's property a succession of prospects was observed. At each of these efforts were being concentrated on investigating ill-sorted surface deposits occurring at or near the base of a steep pitch leading

down to a flat near the level of, but some distance to the west of, Palmer Bar Creek. At most of these placers there was very little evidence of bedding in the deposits and such bedding as was noted was very irregular and of local occurrence. Only the upper 2 or 3 feet of such material was being worked and the few attempts made to investigate the deposits at greater depth had yielded no results. In general the gold obtained became increasingly finer down stream. Nearly all of it occurred as small flakes or disks varying in size from mere colours to flattened pieces up to one-fourth inch or so in diameter and rarely exceeding 50 cents in value. Most of the gold, too, is quite bright and is stated to run between $18 and $19 to the ounce. Black sand, including both magnetite and hematite, is locally plentiful.

In general, depositional conditions at Palmer Bar are of such a chaotic nature and work has been done in such a desultory fashion that it is extremely difficult to form an opinion of the prospects of this section. The broadly developed, low-lying area about Palmer Bar has been a favoured dumping-ground for enormous amounts of glacial materials obtained from both Kootenay and upper Moyie Valleys. It is an area, too, of glacial deposition rather than glacial erosion. No doubt quite a lot of gold, in the aggregate, was distributed through these glacial deposits and has since been gradually concentrated within the remaining, and still great, quantities of drift. There is little doubt, either, that the old preglacial channel of Moyie River once extended somewhere across this area and that important placer deposits occurred along it. Further contributions were also, probably, made from Fish Creek Valley in interglacial (?) times. Whether portions of the old channel deposits still exist is quite problematical and, so far as the writer knows, no attempt has been made to locate them. It is, however, quite within the realm of probability that important auriferous deposits are present. The writer's suggestion is that bedrock conditions should be more fully investigated and less attention paid to the numerous anomalous occurrences of, mostly fine, gold found here and there on false, clayey bedrocks.

Fish Creek Valley

Fish Creek is a tributary of Palmer Bar Creek and occupies the southern part of a through valley connecting with Valley Creek and Perry Creek Valleys near Old Town. This steep, narrow, through valley cuts deeply into the underlying formations. Its alinement, as previously mentioned, with the valley of Valley Creek, has suggested that, for a time, Perry Creek may have drained southerly into Moyie River. The upper slopes of the through valley are trough-shaped, suggesting modification by glacial erosion, but the lower slopes, up to a maximum elevation of about 800 feet above the valley bottom, are more distinctly V-shaped and expose steep bluffs of ragged rocks. Fish Creek itself is about 4 miles long and heads at Fish Lake, a narrow body of water about a mile long and up to 100 feet or more deep. The recent discovery of placer gold along Fish Creek Valley has attracted much attention. Most of this gold has been found within half a mile or so south of Fish Lake, on the east side of the valley towards the bottom and for upwards of a hundred feet or so above creek-level. It occurs erratically distributed in cracks and crevices in

ragged rim rocks underlying a poorly sorted, bouldery drift. Quite a little of this gold has been fairly coarse, nuggets worth from 50 cents to over $2.50 being not uncommon. Some gold has also been found beneath remnants of an old bench or benches situated about 800 feet above the creek. At the time visited, however, explorations in this direction had only just begun. The bench remnants occur at intervals on one or other or both sides of Fish Creek and doubtless represent portions of once much more extensive deposits. That some gold is being found in them and at bedrock under them is significant in the sense that it suggests where the erratic gold hitherto picked up at lower elevations has come from. It also suggests that, as much of the bench materials have been worn away, including probably the bulk of such placer deposits as may have been associated with them, much of this contained placer gold may have gravitated to or near bedrock in the present valley bottom.

Moyie River and Weaver Creek (2A)

Judging from brief visits to these localities placer operations have been and are chiefly concerned with investigating filled-in channels along which, presumably, these streams once flowed. In the case of Moyie River such a channel occurs on the right bank of the present stream a short distance above the mouth of Nigger Creek. At this point Moyie River has cut a deep box canyon through low-dipping Aldridge quartzites and drops over a considerable falls. The old channel lies immediately to the south of the falls and is filled, to a depth of 100 feet or so, with what appeared to be poorly-sorted drift comprised of sandy and bouldery materials. When visited (June 21) James Ewen and Dave Oscarson were driving a rock tunnel westerly from the foot of the falls towards the eastern rim of the old channel and were in 200 feet. Where the old channel joins the present valley below the falls some drifting had been done years ago on the channel materials and it is reported that encouraging gold values were encountered. These old workings are now quite inaccessible. Some effort, however, was being made by S. A. Nogalski and W. Nystrand to hydraulic the channel deposits at this point, but difficulties were encountered in disposing of the tailings, which included much large bouldery material. Partly to overcome these difficulties these two men had nearly completed construction of a boom-gate across Moyie River at the top of the falls. It was purposed to lay a series of sluice-boxes across and for some distance down the river bottom below the falls and with the aid of this gate to flush out the accumulated debris about the face of the old workings, after which hydraulic operations might be more effectively resumed. This method had been employed to advantage at an earlier date by Nogalski and E. Keller on Weaver Creek.

It is reported that considerable gold, some of it notably coarse, was obtained in earlier years from Weaver Creek, a tributary of Moyie River. The pioneer operator on this creek was George Weaver, for whom the creek received its name. His and later workings are situated about 3 miles up Weaver Creek and are accessible by road from Lumberton. They have been principally concerned with investigating a presumably old channel of Weaver Creek situated to the left, or north, of the present creek and at a distance varying up to 100 yards or so from it. This channel has

been explored over a length of about 1,200 feet by a series of six, or possibly more, shafts from which, in the aggregate, several hundred feet of drifting has been done. None of these workings is now accessible. The uppermost, or old Roberts, shaft is situated only a few yards from, and a few feet above, the present level of the creek. The writer was informed that this shaft is 110 feet deep; that, from the bottom, a total of about 400 feet of drifts have been run upstream and down along the old channel bottom; and that considerable coarse gold was, thereby, obtained. Between this point and the main cabin, a distance of about 400 feet to the east or downstream, are three other shafts all sunk to bedrock along the south rim of the channel which is reported to be very smooth. The north rim has not yet been found. About 800 feet farther downstream the old channel joins Weaver Creek and is about in line with the lower valley of this creek. Upstream from this point Weaver Creek swings abruptly to the south for 200 to 250 feet before resuming its more general northwesterly to westerly course. Near its junction with Weaver Creek the old channel has been investigated by a couple of shafts, one of which is reported to have reached bedrock at 38 feet. Some drifting was done from this shaft, but very little gold found. In the gravelly material, however, a large number of hematite boulders were encountered, a feature characteristic of both the present stream gravels of Weaver Creek and the old channel deposits.

Below the cabin, Weaver Creek follows for several hundred feet along a deep canyon cut into rocks of the Aldridge formation, which are intersected, along the creek bottom, by a narrow, basic dyke. The canyon has been flushed clear of gravels by the operation of an ingeniously constructed automatic boom-gate of a type similar to that being built across Moyie River at the falls. On the south side of Weaver Creek, near this gate, some coarse gold nuggets are reported to have been found resting on bedrock or caught in crevices in the bedrock on the top of a bench 50 feet or more above the level of the creek. This bedrock, where exposed, has a smooth, probably water-worn, surface, but is mostly covered by shallow, poorly sorted, drift deposits. One nugget, shown the writer as having come from this locality, was nearly one-half inch in diameter, was smooth, bright yellow, and included some quartz. Most of Weaver Creek gold, however, has a bronzy shade more resembling the Fish Creek gold and the darker gold on Palmer Bar.

In addition to these principal workings some attempts at placer mining have been made elsewhere in the valley of Weaver Creek. On the North Fork, or Dream Creek, over half a mile from the main camp and about 200 feet above it, is an old shaft, now inaccessible, which is reported to be down 74 feet without reaching bedrock, and in which some gold values are said to have been obtained from near the bottom.

Old, filled-in channels of the type observed along Moyie River and Weaver Creek are probably fairly common in the district. Their prospective value depends on a number of things, as, for example, their locality, their origin, and time of formation; bedrock conditions; and the source of the filled-in materials. Essential requirements are that the channels occur in valleys which elsewhere are known to carry placer deposits; that the bedrocks be not too steep or too smooth to prevent the accumulation of gold; and that the deposits overlying bedrock should be stream and not glacial deposits. When testing such materials, too, investigations should, in each case, be extended to and along bedrock.

LODE DEPOSITS

Gold-Quartz

Gold values are obtained from different types of deposits in the district, and, in some, are the only values of interest. In general they seem to favour veins rather than replacement deposits, and, in other respects, to be associated with pyrite and chalcopyrite rather than with galena, sphalerite, or pyrrhotite. Most of the prospected deposits of this type occur in the valley of Perry Creek and in the Creston formation. A few, however, have been found in other localities and in different rocks.

The gold-quartz deposits of Perry Creek have been referred to and described individually and at some length in a number of Government reports of which those by Fleet Robertson (3, pages 1014–1017) and Galloway (5, pages 108–110) are the most comprehensive. Many of the deposits were discovered in the mid-nineties and were regarded at the time as the probable source of Perry Creek placers. Subsequent exploratory work has, on the whole, been disappointing in that not only have rich ledges failed to materialize, not only is free gold of appreciable size a distinctly rare constituent of the lodes, but the quartz bodies themselves are, with possible exceptions, so low grade as to be of very doubtful economic importance.

Perry Creek has a general northeasterly course coincident with or close to a strongly developed fault or fault-zone, against which a wide belt of, principally, Creston quartzites, to the southeast of the creek, is faulted against a succession of formations from Creston to Perry Creek (Cambrian) on the opposite side. For at least half a mile from the fault the less competent rocks have been greatly sheared, and individual faults and fractures, presumably related to the same disturbance, occur at still greater distances from the main rupture.

Within that part of Perry Creek basin in which most of the gold-bearing lodes occur, an area extending roughly from the headwaters of the creek to the vicinity of Sawmill Creek, the general strike of the formations is about parallel with the main fault zone and with the general course of Perry Creek. Northwest of the creek the formations dip to the northwest at angles varying from about 20 to 60 degrees and probably averaging about 40 degrees. On the opposite side of the valley, however, the dips, so far as observed, appear to be mainly to the east or southeast and at a somewhat steeper average angle.

Intruding the sedimentary formations and involved in the deformations attendant upon the Perry Creek fault, are a number of dark green, basic dykes which, as observed, vary from a few inches to at least 40 feet wide. The dykes have a general northeasterly strike and, mostly, steep to vertical dips.

The lodes occur on both sides of Perry Creek Valley, but have been more extensively explored on the northwesterly slopes. They are found within the more massive rocks as well as in the less competent, intensely sheared members. In the former the lodes are, principally, massive quartz ledges with very little evidence of mineralization on either side, but in the more sheared members the lodes may either include important widths of partly silicified, mineralized country rock on one or both sides of a main quartz ledge, or the country rock may be the predominating constituent of the lode.

The lodes vary from a few inches to 40 feet or more wide, those of principal interest averaging several feet in width. These lodes are, apparently, continuous, in some instances, for several thousand feet and, perhaps, for as much as several miles. Presumably, also, they persist to great depths. The more persistent lodes strike about in line with the formations, but generally have a steep dip to the east. Towards the head and on the northern slopes of Perry Creek Valley, in the vicinity of Gold Run Creek, two sets of quartz vein-lodes were observed, one striking a few degrees east of north, about parallel with or angling slightly across the Creston formation, and the other trending more nearly east and west. The former seemed the better mineralized, though it seemed likely that they were all related to the same period of formation. Farther northeast, down the valley of Perry Creek, the lodes strike mainly to the north or northeast, though occasional, small, transverse, quartz veins were observed. Actually the number of prospected lodes did not appear to be great, probably not more than half a dozen or so of consequence being observed, that is, presuming they were as continuous as supposed.

Examined in detail the lodes were observed to possess certain distinctive characters. The main quartz ledges are composed of white to, in some cases, distinctly pinkish, vitreous quartz which is generally so massive in its general appearance as to suggest that it had been intruded, dyke-like, along some line of fracture in the enclosing rocks. At places along these ledges, however, the country rock was observed to have been replaced by silica across, in some instances, as much as the full width of the ledge, and that in such places the original rock structures were still preserved. Both the larger quartz ledges and such smaller quartz veins as may occur on either side were generally found to be severely fractured and in some cases badly sheared. Strong faults were seen cutting across these veins and displacing them and, in general, it appeared that considerable deformation had followed their deposition. On the other hand, it was noted that in some cases even small quartz veins an inch or two wide might persist in length and depth for as much as 50 or 100 feet in spite of the fact that the adjoining wall-rocks were sheared and schistose. Such veins, it appeared, had followed the period of deformation that had involved others. It was evident, too, that all the quartz veins had followed fractures of some sort and that, therefore, some deformation had occurred prior to the introduction of any quartz. Further, there was little in the character or mineralization of the lodes to suggest more than one period of vein formation. In short, it appeared likely that the quartz content of the Perry Creek lodes had formed at intervals during the one prolonged period of mineralization, a period coincident with that of the deformation of the associated country rocks and of the disturbance that produced the great fault up the valley of Perry Creek.

The principal and generally abundant gangue mineral is quartz, but a little carbonate, principally calcite, is generally present. A little scheelite is also reported to occur, but has not yet been identified in the material collected. Commonly the quartz carries disseminated pyrite which, locally, may be abundant. Chalcopyrite and galena are less common sulphides. Weathered surfaces and oxidized portions of the mineralized quartz bodies are cellular as a result of leaching of the sulphides, and the cavities may be partly filled with reddish iron oxide and with other

sooty, decomposition products. This oxidized ledge matter commonly shows good colours on panning. Mineralization may also extend into the wall-rocks of the quartz veins in the lode, particularly where these rocks are sheared and partly replaced by quartz. Such lode matter is commonly stained with iron oxides and, less commonly, with copper carbonates. Some samples of it have also been observed to pan well and are reported to have yielded high values in gold on assay.

The Perry Creek lodes are not confined to any particular formation. Towards the head of the creek and along most of the southeastern slopes of the valley the lodes occur mainly in the Creston, for the obvious reason that this formation is here the most widely exposed. Elsewhere on the northeastern slopes, however, the lodes are found in sediments transitional from Creston into and including the Kitchener formation, and in the Old Town and Perry Creek formations, the latter, at least, being of Cambrian age. A possibly significant geological feature is the intimate association of the lodes, at several places, with basic dykes. These dykes become larger and more numerous towards the headwaters of Perry Creek and at Nogalski Peak seem to be connected with more irregular, stock-shaped intrusives of similar composition. The discovery, years ago, of some high-grade gold-quartz ore on the Swenson group of claims about this peak suggests that perhaps more prospecting might be done to advantage in that vicinity.

Opinions vary as to the economic importance of these gold-quartz lodes. Judging, in part, from the large proportion of officially recorded assay returns and, in part, from the appearance of the lodes themselves, most, at least, of the large quartz ledges that form the principal parts of the lodes are too low grade to be of possible value. On the other hand, there is no lack of records of samples running from $4 or $5 to $10 or $15 to the ton and occasionally much higher. These more encouraging values appear, however, to represent selected rather than average material and to have been obtained mostly from either narrow quartz veins situated on one side or other of the main quartz bodies, or from less certain widths of the associated, sheared and mineralized country rocks. In each case the higher values were obtained from oxidized lode matter which, on panning, and particularly after roasting, would show an impressive tail of fine gold. Assays of fresh, or comparatively unoxidized, lode matter appear, on the other hand, to have given much lower returns and this in spite of the amount of sulphide minerals present. The inference seems to be that the primary gold values are contained in the sulphides; that these primary values are low, but that oxidation processes have, in places, effected a considerable enrichment by leaching the sulphides of their values and redepositing the contained gold within the oxidized zone in the free form. Some mill tests were made in 1897 on small tonnages of ore from several of the Perry Creek properties (3, pages 1916-1917). The results obtained were not commercially satisfactory, but were inconclusive to the degree that much, probably most, of the values had escaped in the tailings. Since that time no further mill tests have been run and though numerous, small samples have been taken from the workings on a few properties there appears to have been no concerted attempt to either prove or disprove the existence of commercial bodies of ore. In the writier's present opinion the possibilities of these Perry Creek lodes are extremely

limited. The main quartz ledges seem to be very low grade and such comparatively rich, narrow veins as may occur within the lodes are too small to warrant their development. Less, however, seems to be known of those mineralized widths of sheared and oxidized country rock that form variable and, commonly, considerable parts of the lodes, and from which good values have been obtained. Perhaps a more careful sampling of this type of material would result in outlining ore-bodies of sufficient size to permit mining on a moderate scale. Values in such material must be assumed to be profitable only within the zone of oxidation and, therefore, not to depths of probably more than a hundred feet or so below the surface. Depending, however, on the other dimensions such depths might not be inadequate for mining purposes.

It seems rather astonishing that after so many years of prospecting and development work so little is really known about average values, either as regards the veins as a whole or workable portions of the veins. After all, the veins are, in most cases, well exposed and easily accessible and, therefore, open to ready and thorough sampling. Such a program would be well advised and should determine once and for all whether a vein might pay to mine, either as a whole or in part, and on what scale operations should be conducted. Perhaps, on a basis of such a program, some co-operative scheme of development and production would be suggested.

The following pages include a detailed description of the Homestake property on Perry Creek. This property is chosen for discussion for several reasons. In the first place it is the best known and one of the most extensively worked of the Perry Creek properties. When visited it was under option to Calgary interests and the workings had been mostly opened up for inspection and for careful sampling by their engineer,Dr. W. V. Smitheringale. The writer had the privilege of examining these workings in company with Dr. Smitheringale, and, subsequently, of becoming acquainted with the contents of his report. In other respects the Homestake property illustrates most of the features characteristic of the Perry Creek gold-quartz deposits and though the values found on it are not necessarily representative of other properties, the failure, to date, to discover workable bodies of pay ore on it, is naturally a source of some discouragement to further operations on these other properties.

The succeeding report on the Wellington group is added to illustrate a somewhat different type of gold-quartz deposit occurring outside of Perry Creek basin and in a somewhat different geological environment.

Homestake (3, page 1016; 5, page 109; 8, page 297; 9). The Homestake property, consisting of sixteen claims, held by location, is owned by the Cranbrook Gold Mining Company, Limited, of Cranbrook. The property is situated on the northwest slope of Perry Creek Valley between Liverpool and Manchester Creeks and is accessible by road to within a mile of the workings and by pack trail the rest of the way. The principal workings lie between elevations of 700 and 1,100 feet above Perry Creek, or between 5,200 and 5,600 feet (barometric) above sea-level. These workings form two main groups known as the Columbia, and Homestake workings, respectively. the former situated near Liverpool Creek and the latter about midway between Liverpool and Manchester Creeks, less than half a mile northeast of the Columbia workings and between 200 and 400 feet below them.

The country rocks at the Homestake workings are principally upper members of the Creston formation. They are intruded by dark green, basic dykes varying up to at least 15 or 20 feet wide and having the composition of diorite. From the upper (Columbia) workings to near the heads of Liverpool and Manchester Creeks the sediments are mainly massive, purplish, greenish, and grey Creston quartzites. These have a general north–northeast to northeast strike and dip northwesterly at an average angle of about 35 degrees. From the upper workings down the hill to, and perhaps for some distance on the opposite side of, Perry Creek the formations are, on the whole, more thinly bedded, argillaceous types; are predominantly greenish, and, particularly in the vicinity of and below the Homestake workings, include numerous, narrow, buff-weathering, limy beds. This association suggests a transition from typical Creston rocks to sediments more characteristic of the Kitchener formation. The same belt of relatively incompetent rocks has also been the medium for a great deal of shearing which, in places, is more pronounced than in others. The shearing runs parallel with the formational trend and, where observed, dips steeply to the northwest.

The Columbia workings consist of an adit, a shaft, and several surface or near-surface workings. The adit known as the "Scorgie tunnel" is driven northwesterly from the Liverpool Creek Valley slope, is over 500 feet long, and has certain workings therefrom. The Columbia shaft is 50 feet deep and is sunk vertically from the surface at a point 200 feet above and 465 feet northeast of the portal of the adit. Other workings consist of a number of open-cuts, pits, trenches, and (?) short adits (now caved) representing an aggregate of 200 to 300 feet or more of lineal work. They are situated between the adit portal and a point 100 feet or so northeast of the shaft.

These workings investigate a quartz-vein lode of uncertain width and with indefinite walls, known as the "Columbia vein." The lode occurs in sheared and faulted rocks including both sediments and one or more dykes. It consists, in part, of a quartz ledge 15 to 20 feet wide, striking north-northeasterly approximately in line with the schistosity of the enclosing rocks, but standing nearly vertically or dipping steeply southeast. Along, particularly, the hanging-wall side of this ledge, and across an average width of from 5 to 10 feet, the wall-rocks have been partly silicified and are intersected by narrow quartz veins. The main ledge is well exposed at the surface for a length of 250 feet, mostly southwest of the shaft. Its extensions to the northeast and southwest are obscured by drift, but its continuity to or near the portal of the adit is inferred by one or two small outcrops in this direction and by developments underground. It was also observed that the ledge was directly in line with a wide exposure of similar ledge matter on the Theis group of claims south of Liverpool Creek about 2,000 feet from the Columbia workings. In the opposite direction claim surveys indicate that the "Columbia vein" has been picked up at intervals over an aggregate length of a mile or more from the Columbia shaft. As exposed the quartz ledge is fractured, sheared, and faulted. It consists of white to slightly pinkish, vitreous quartz mineralized by disseminated pyrite. In places the quartz is cellular and stained with iron oxides as a result of leaching processes. The adjoining silicified wall-rocks are sparingly mineralized. The smaller quartz veins within the lode vary

individually, as well as along their strike, from an inch or two to several inches wide. They tend to follow the schistosity of the enclosing rocks, but may cut across it. Developments on these small quartz veins and the adjoining schistose wall-rocks have revealed better gold values than in the main quartz ledge.

The Columbia shaft is sunk on a narrow quartz vein situated about 7 feet southeast of the main ledge. The vein splits into two stringers half-way down the shaft and these persist to the bottom through highly sheared and schistose rocks. A short crosscut from the bottom of the shaft picks up the main quartz ledge after passing through several feet of a sheared and partly silicified greenish rock much resembling an altered dyke.

The "Scorgie tunnel" follows, mainly, along the hanging-wall section of the lode, but for the first 200 feet or so angles slightly to the northeast across it. Between 50 and 100 feet from the portal the wall-rocks are noticeably sheared and silicified, though there is little evidence of mineralization. At the latter point a fault angles north-northeasterly across the adit. It is marked by a foot of gouge, dips steeply to the east, and, apparently, forms the foot-wall of the main quartz ledge, which is well exposed in short crosscuts to the east and west within the next 50 feet or so of the adit. The first (No. 1) crosscut, to the east, is 15 feet long and is in quartz to the face where the vein matter is cut off by a fault striking about north and dipping steeply west. In this crosscut the quartz is heavily mineralized with pyrite and partly oxidized pyrite. The second crosscut (No. 2), to the west, is about the same length as the other and is in quartz to within 3 or 4 feet of the face, where it is cut off by another fault striking northeasterly and dipping steeply to the west. In both crosscuts the ledge matter is badly crushed and in the second crosscut is intersected by two or more faults about parallel with the one near the face. The east wall of the adit opposite No. 2 crosscut is marked by grooves dipping about 50 degrees north, indicating the probable, relative direction of movement on either side of the fault at this point. Beyond the second crosscut the adit follows, to its face, a zone of sheared and partly silicified rocks, which forms the hanging-wall, or southeast, section of the lode. At the face, 400 feet past No. 2 crosscut, there is several feet of quartzose material, probably mainly vein quartz, the west wall of which is marked by a strong shear dipping steeply southeast. At 23 feet from the face a shallow winze has been sunk on two narrow quartz stringers occurring in highly sheared and altered wall-rocks. At 45 feet from the face crosscuts extend in both directions: No. 3 to the southeast for 20 feet; and No. 4 to the northwest for 80 feet or more. At the mouth of No. 3 is a narrow quartz vein dipping steeply southeast and occurring between sheared and slickensided walls. This vein may be a continuation of one of the stringers from the shaft and is apparently continuous for upwards of 100 feet to the southwest along the adit. In this direction it splits into two stringers and is investigated by a winze at about 45 feet southwest of the crosscuts. As developed by the winze the vein was well mineralized by pyrite, chalcopyrite, and galena. The other crosscut, No. 4, intersects the main quartz ledge a few feet from the main drift. The ledge is here about 18 feet thick and is composed of massive, completely silicified rock rather than normal vein quartz. It is very sparsely mineralized. At 10 feet west of

the ledge the crosscut encounters a mineralized quartz vein, a few inches wide, along which drifts have been run to the northeast and southwest, exposing the vein for a total length of 25 feet. West of this vein the crosscut is entirely in country rock and the same seemed true of No. 3 crosscut beyond the small vein at its mouth. The "Columbia vein" or lode has, therefore, at this point, a total width of about 40 feet. Between No. 2 and Nos. 3 and 4 crosscuts the main ledge would appear to lie entirely to the west of the adit, a conclusion supported by its position at the surface. Owing, however, to the abundant shearing and faulting in evidence in these workings, the position and continuity of the main ledge as of the smaller quartz veins on either side can only be established by close development work.

Values obtained from the Columbia workings have on the whole been disappointing, as far, at least, as quantity averages are concerned. The best values seem to have been obtained from or close to the narrow vein or veins encountered in the shaft and in the hanging-wall section of the Columbia lode as exposed in the Scorgie adit. Samples across narrow widths of such material have not uncommonly assayed up to $10 or $15 and, in some cases, up to $50 or more. Other samples, again, have shown only traces of gold or values of less than a dollar to the ton. Samples from the main quartz ledge have afforded but little encouragement, assays rarely exceeding and mostly being less than a dollar to the ton across any important width of ledge matter including even such heavily mineralized quartz as that occurring in the No. 1 crosscut of the Scorgie adit. Occasional samples have been reported to run from $4 to $6 in gold, but it seems doubtful if such values are representative of any considerable body of ledge matter. Less seems to be known of the values in the sheared and partly silicified rocks bordering this ledge, particularly on the hanging-wall side, and here, perhaps, some further sampling might be done.

The Homestake workings consist mainly of an adit and a shaft. The former is a crosscut for 130 feet from the portal. The crosscut is driven northwesterly and from it, at 100 feet from the portal, drifts have been run for 50 feet to the southwest and for 175 feet to the northeast. At 25 feet from the face of the longer drift is a 25-foot crosscut to the northwest and at the face of the drift another crosscut is driven 25 feet to the southeast to reach the bottom of the Homestake shaft. The latter is 70 feet deep and is sunk vertically from the surface. About half-way down it a crosscut has been driven for 30 feet to the northwest to intersect the Homestake lode.

The Homestake "vein" or lode is a mineralized shear zone of uncertain but considerable width, involving, chiefly, a dark green, basic dyke. The dyke appears to be at least 10 or 15 feet wide. It strikes northeasterly, dips to the northwest at about 70 degrees, and intersects thinly bedded, greenish and grey, argillaceous, and limy sediments and minor quartzitic beds representing the upper Creston formation. These sediments strike north-northeasterly and dip northwest at about 50 degrees.

Mineralization is represented by numerous, irregular, quartz veins and lenses, associated with a little carbonate and carrying, chiefly, disseminated pyrite. The latter occurs in less amount in the adjoining rocks. A little galena and chalcopyrite may also be present. The quartz forms

a network of lens-like bodies through the dyke and occurs also as veins along either wall and, to some extent, extending into the adjoining sediments. Most of the quartz bodies do not seem to be more than a few inches wide and a few feet long. In places, however, they widen to as much as several feet and are exposed in the drift for lengths of 20 feet or more. These quartz bodies are fractured, but are not sheared to the extent of the enclosing rocks. Alteration of the rocks and oxidation of the sulphide minerals has tended to obscure the identity of the formations and the character of the primary mineralization. The lode is poorly exposed at the surface and its continuity not well established. Presumably, however, the same dyke was picked up by open-cuts as far as the north side of Manchester Creek about 2,000 feet northeast of the main workings. Also, what appeared to be the same dyke was observed nearly 300 feet below the Scorgie adit of the Columbia workings about 2,000 feet southeast of the Homestake adit.

Gold values have been obtained both in the mineralized quartz and associated mineralized rocks. Colours may be panned from some at least of the oxidized lode matter and it is reported (3) that free gold has been detected in selected material. The free gold is believed to be of secondary origin and to have formed as a result of oxidation of, principally, pyrite. Below the zone of oxidation the primary ore cannot be expected to carry better values than the oxidized material and probably carries less. It is interesting in this connexion to note that an exposure of quartz heavily mineralized with pyrite and but slightly oxidized occurs on the northeast wall of the Homestake adit about 70 feet from the main crosscut. Samples of this material are reported (9) to have shown only low values in gold. A number of other samples have been taken from time to time and the assay returns recorded in official Government reports. Occasional assays have run up to several dollars in gold and up to 1 ounce in silver to the ton. The majority, however, have yielded from a trace to 0·10 ounce in gold and would probably not average more than 0·03 or 0·04 ounce and such values seem more representative of the lode matter in quantity than the higher assay returns. On the whole, the shaft workings have provided the most encouraging values, a feature that may be related to the greater oxidation of the lode matter in these workings.

In addition to the vein-lodes developed by the Columbia and Homestake workings at least two others have received some attention on this property. One of these has been opened up below the Columbia workings and about on a level with the Homestake shaft by an adit known as the "Wallinger tunnel". This working is caved and the nature of the lode is not readily discernible from the surface. Apparently, however, some vein quartz was encountered from which values up to $4 in gold are reported to have been obtained. Some old workings were also observed about 1,000 feet, vertically, above the Homestake shaft. Here, an old shaft and some surface cuts expose a quartz vein in altered Creston quartzites. Where exposed the vein is 2 feet wide. Quartz obtained from it is vuggy and cellular and is mineralized with pyrite which is partly oxidized. The vein seemed to be striking northwesterly. Values are not known.

Wellington Group (1, pages 135-136; 5, page 113). The Wellington group of four claims is owned by James Angus of Marysville. The property is located on the eastern slopes of the valley of Angus (East Fork

of Hellroaring) Creek several hundred feet above the creek. The cabin, near the workings, is accessible by trail $6\frac{1}{4}$ miles long (paced) from the end of a road about a mile from St. Mary Lake and stands at an elevation of about 2,575 feet (barometric) above the lake or 5,700 feet above sea-level.

The workings consist of a dozen or more open-cuts, a shaft 55 feet deep with short drifts from the bottom, and an adit 127 feet long. The latter is driven northerly at about the elevation of the cabin and is located 850 feet south of, and 135 feet below, the most northerly and highest workings and 650 feet south of the shaft.

The workings investigate the continuity of a mineralized quartz vein, or veins, which follow a strong fault-fissure. The fissure has a curving strike varying from nearly north and south at the more northerly workings to about north 30 or 35 degrees east at the adit. Its dip varies in the same direction and in the same distance from about 65 to 80 degrees east. South of the adit the hill-side drops away more steeply and the fissure and contained vein are less well exposed and less certainly continuous to the most southerly and lowest workings several hundred feet away. North of the adit, however, the fissure is, apparently, occupied by a continuous quartz vein varying from about 1 foot to 2 feet wide and averaging about $1\frac{1}{2}$ feet.

This vein is, as exposed, composed of white, banded quartz conspicuously mineralized with cube galena, pyrite, and, more locally, chalcopyrite. At the surface these minerals are partly oxidized to iron oxides and copper and lead carbonates. Some manganese stains were also observed. Numerous samples of this vein matter (1, page 136; 5, page 113; and 12) have indicated values in gold ranging from 0·02 ounce to 4·80 ounces a ton; silver, from 0·30 ounce to 57·5 ounces; lead, from 1·5 to 69·6 per cent; and copper, from 0·8 to 10 per cent. Average values probably do not exceed $8 in gold and would be about 5 per cent lead. At the time visited the shaft was inaccessible, but Schofield reports that at the bottom the vein "is somewhat broken, but still in evidence". At the face of the adit the vein is about 22 inches wide. Gold values are stated to improve with increase in chalcopyrite.

The hanging-wall of the vein is marked in places by as much as a foot of gouge and above this is a width of several feet of a sheared, brownish-weathering, quartz-carbonate rock, probably a sediment. O'Grady reports (12) that this rock, as sampled, carries no values. The foot-wall rocks are, on the whole, more massive, grey to greenish grey, quartzitic sediments. In places they are banded and this banding is about parallel with the strike of the vein-fissure. Both dip and strike of the latter are, however, principally controlled by the schistosity developed in the enclosing rocks. In general these rocks are so altered by deformation, thermal metamorphism, and weathering processes that their identity is not easily established. Their metamorphism is attributed to a stock-shaped body of granite outcropping 200 feet or more below the vein exposures. Probably, also, their deformation, resulting in the development of the fault-fissure now occupied by vein-matter, is connected with the period of granitic intrusion. Presumably, too, the vein mineralization may be a related phenomenon, though this is by no means certain.

The encouraging average values and proved, lateral persistence of the vein matter on the Wellington property are offset, to some extent, by the narrowness of the deposit. On the other hand, the strength of the fissuring along which the vein deposits have formed supports the view that the vein matter should persist at depth. Whether it will widen out appreciably in this direction or contain better average values cannot be foretold from developments to date, but at least the chances are equally as good that it may as that it may not. In view of such possibilities and in view of the character of its mineralization the property would appear to be well worthy of further exploration.

Silver, Lead, and Zinc

The phenomenal production credited to lode mining in Cranbrook district and vicinity has been won, almost entirely, from properties producing silver-lead and silver-lead-zinc ore. Most of the properties have carried an important content of all three metals, though it is only within the last fifteen years or so that zinc values have assumed an importance at all comparable with those for silver and lead.

Among the productive properties the Sullivan mine is outstanding, being credited, to June 30, 1928, with total shipments of all classes of ore amounting to 7,714,599 tons (10, page 201). The St. Eugene mine, for many years the largest producer of lead in the province, had, up to September, 1913, produced 1,017,106 tons of silver-lead ore, valued at $10,626,608 (1, page 119). Other important producers of this class of ore include the North Star mine near Kimberley and the Society Girl near Moyie, on neither of which any active work has been done for many years. The Stemwinder mine at Kimberley and Aurora mine at Moyie have also shipped considerable silver-lead-zinc ore. Less productive properties include the Guindon at Moyie and Park group near Marysville, the former producing silver-lead-zinc and the latter silver-lead ore. At present none of these properties, with the exception of the Sullivan, is operating, but they have closed down for various reasons, principally the exhaustion of developed reserves.

Except for the Park group, which occurs in a Purcell sill, the ore-bodies on these properties are in the Aldridge formation and have formed there by processes of which replacement is of chief importance. At the Sullivan and Stemwinder mines, for example, replacement has been easily the most significant factor in mineral deposition. At others, such as the St. Eugene mine and adjoining Moyie Lake properties, the positions of the lodes have been largely determined by a system of fractures (1, page 118), and it is probable that on all of them structural features of one sort or another have exerted an important influence, both in a regional and local sense, on the positions, size, and shape of the ore-bodies; their significance may, however, be only apparent as development proceeds.

Interesting features connected with the mineralization in these properties relate, on the one hand, to an occurrence and association of ore and gangue minerals characteristic of high, or fairly high, temperature conditions, and, on the other, to a surprising lack of granitic intrusive, other than the Purcell sills, such as might be supposed to account for these conditions. The ore minerals include varying proportions and combinations of, principally, pyrrhotite, pyrite, sphalerite, galena, chalcopyrite, arseno-

pyrite, and magnetite. Secondary minerals, such as cerussite and pyromorphite, are locally important, as at the Society Girl and North Star mines. The gangue consists of mineralized wall-rock and of quartz with one or more of such silicates as garnet, biotite, muscovite, amphibole, pyroxene, chlorite, and, probably, others not yet identified. Generally a little calcite is present. Gangue minerals as a whole occur in relatively small amounts and are commonly disseminated through the ore and mineralized country rock rather than segregated from them.

It is, perhaps, noteworthy that these silver-lead and silver-lead-zinc deposits occur only in the oldest, or Aldridge, formation of the Precambrian, sedimentary succession, for it is in this formation that the Purcell sills are best developed. It is also in one of these sills that the Park group silver-lead deposit was found. This association of Aldridge formation, Purcell sills, and mineral deposits is strongly suggestive of some genetic relationship between the sills and the mineral deposits as, aside from the presence of these sills, there seems no particular reason why the Aldridge should be more favoured by ore-deposition than some, in particular, of the succeeding Precambrian formations. The sills are regarded by Schofield as of Precambrian, late-Siyeh age and if so, and if the mineral deposits are connected with the period of intrusion of these sills, their occurrence in the deep-seated Aldridge formation might readily account for the high-temperature character of the mineralization referred to above. In any case, and pending further more particular information regarding the age of the Purcell sills and their relationship to the silver-lead and silver-lead-zinc deposits of this district, it would appear that further prospecting for such deposits might best be confined to areas in which sills are known to occur and, preferably, within a reasonable distance of such sills.

The following account of the B and V property is introduced to illustrate conditions and the character of mineralization within a considerable area of outcropping Aldridge formation in the vicinity of large, basic intrusions of the Purcell sill type and one, younger, stock-like mass of quartz-syenite. On the one hand, the mineralization on this property shows many points in common with that occurring on important silver-lead and silver-lead-zinc deposits in the district and the section is evidently one where mineralizing solutions have been active; on the other hand, the smallness of the individual discoveries in this section suggests either the lack of those co-operative structural conditions necessary for the development of large ore-bodies or failure to date in locating the place or places where such conditions exist.

B and V Group. The B and V group of eight claims, held by location, is owned by W. Van Arsdalen and Umbert (Bert) Frisini, Cranbrook, B.C. The property occupies a round-topped, wooded ridge situated southwest of Cranbrook and east of Fish Creek Valley and is accessible by road, via Smith Lake, 7 miles from Cranbrook. The western slopes of the ridge drop off steeply into Fish Creek Valley, 550 to 900 feet below. The eastern slopes are, however, more gentle. The difference in elevation between the summit of the ridge and Cranbrook varies, for different points on the summit, from about 1,000 to 1,400 feet.

The ridge is composed, chiefly, of massive, grey quartzites and dark grey to black, pyritized, rusty weathering, argillaceous quartzites of the

Aldridge formation. These have a general northwesterly strike and a low, northeasterly dip averaging about 15 degrees. In detail the structure is rolling and shearing has occurred along some of the less competent, more argillaceous beds.

Towards the base of the ridge, on the Fish Creek slopes, the Aldridge sediments are intruded by a large, sill-like mass or masses of a dioritic rock probably related to the Purcell sills. Towards the east, again, the same sediments dip beneath a widely exposed, intrusive sill of similar character and over 200 feet thick. To the north and northeast of the property and within a half mile or so of it the Aldridge formation is in contact with a stock of coarse-grained, porphyritic, grey to pinkish grey quartz-syenite about a mile in diameter. The stock is conspicuously exposed about the shores of Fish Lake at the head of Fish Creek. In addition to these major intrusive bodies, a light-coloured, feldspar-porphyry dyke, 1 to 2 feet wide, cuts across the Aldridge quartzites about midway of the B and V property.

The workings on this property consist of three shafts, sunk from the surface to depths of 30, 15, and 38 feet, respectively, one drift adit 80 feet long communicating, at 18 feet from its face, with the bottom of the 30-foot shaft, and several shallow surface workings in the form of pits, open-cuts, and trenches.

These workings investigate mineralization connected with a series of narrow quartz veins occurring at irregular intervals along or near the summit of the ridge over a distance of about a mile in a north-south direction. The veins have a general east-west strike, varying, as observed, from 5 degrees south to 15 degrees north of west. They stand vertically or dip steeply at angles to the south and their positions are apparently controlled by a system of joint fractures in the Aldridge formation. Most of the work has been done on three veins which may be referred to, from south to north, as the Nos. 1, 2, and 3 veins, respectively. No. 1 vein has been explored by the 38-foot shaft which was inaccessible at the time visited. As exposed, the vein is a foot wide and is composed of a vitreous quartz carrying appreciable cube galena as well as pyrrhotite, pyrite, arsenopyrite, sphalerite, and (?) stibnite. The adjoining wall-rocks are bleached and sparsely impregnated with pyrite and arsenopyrite. The continuity of the vein was not determined. A selected sample of mineralized vein matter is reported by the owners to have assayed: 1·7 per cent zinc; 20·0 per cent lead; and 3 ounces in silver and 0·02 ounce gold to the ton. No. 2 vein lies about 150 yards north of No. 1 vein. This vein is a foot, or less, wide and is about parallel with, and of the same character as, No. 1 vein. A 15-foot shaft has been recently sunk on this vein at a point where the sediments on either side have been heavily impregnated with sulphides and quartz for a distance of at least several feet from the vein and across a width of from 2 to 3 feet. The sulphides include galena, pyrite, marcasite (?), arsenopyrite, and chalcopyrite. The quartzitic rocks are bleached and biotitized. Samples from the shaft are reported to have shown values in gold, one sample assaying $16 and another $3 in gold to the ton. No. 3 vein is the one opened up by the 30-foot shaft and drift adit mentioned above. The vein is drifted on from the portal to a few feet beyond the shaft where it seems to be cut off by

a slip angling across the adit. The vein is of variable width, averaging probably several inches wide, and mineralization has extended into the wall-rocks on either side for upwards of a foot or more. The principal gangue is quartz and this, in places, carries abundant pyrrhotite, chalcopyrite, galena, and pyrite. Secondary minerals include white iron sulphate, iron oxides, and sooty oxidation products of the copper sulphide. Selected material would, of course, assay high in lead and one sample is reported to have given $2 in gold to the ton. A sample of lead ore obtained by the owners from the upper 10 feet of the shaft assayed 0·02 ounce gold and 18·7 ounces silver to the ton and 40·3 per cent lead; another sample from the lower 20 feet of the same shaft assayed 0·03 ounce gold and 38·8 ounces silver to the ton and 40·6 per cent lead.

In addition to these veins several others were observed and have had a little work done on them. Most of these are mere stringers of quartz, commonly associated with coarse, black mica. Two or three others were observed to carry some sulphide minerals. They vary from 2 to 8 inches wide and are composed of cellular quartz associated with some coarsely crystalline calcite and carrying local concentrations and disseminations of galena, pyrrhotite, pyrite, and chalcopyrite. An assay of clear pyrrhotite from one of these veins is stated to have given 0·2 ounce gold and 1·1 ounces silver to the ton and 0·22 per cent copper.

Mineralization at the B and V property is of interest as regards its character, its origin, and its economic significance. The glassy, vitreous vein quartz, the common association of coarse, to finely crystalline, black mica with the quartz, the bleached and otherwise altered appearance of the sediments alongside the veins, and the relative abundance of, particularly, pyrrhotite among the sulphide minerals, are features which, collectively at least, suggest the formation of the vein deposits at high or fairly high temperatures and are characteristic of the silver-lead-zinc deposits of the district in general. The origin or source of mineralization, too, seems more easily correlated with the basic, sill-like intrusions underlying and overlying the Aldridge sediments, as exposed on this ridge, than with the adjacent, stock-like intrusion of quartz syenite. The sill rocks are themselves hosts to mixed sulphide vein deposits, on some of which quite a little work has been done. Little evidence of mineralization was, however, observed either in or about the contacts of the quartz-syenite. Also, though no contacts between the syenitic stock and the basic intrusive bodies were observed, it seemed fairly evident that the former was the later intrusive for it definitely cuts across structures with which the more basic intrusives tend to conform. As to the economic possibilities of the B and V property, the showings, except possibly the one at the new shaft, seem entirly too small and too scattered to be of economic value even with metal prices appreciably higher than they are today. On the other hand, the numerous vein deposits, the encouraging mineralization found in some of them, the apparently favourable geological situation of the property, and the similarities shown between the mineralization here and on other, important properties in the district, suggest that further exploratory work in this vicinity should be done, though the question as to what form this work should take is, perhaps, a little more difficult to decide and would depend to some extent on the means available. A little further work at

the new shaft would seem to be in order and concurrent with this a careful survey of the property by some approved geophysical method might be attempted, particularly over the drift-covered areas.

Copper-Gold, Etc.

With this group is included a large number of deposits on which, in the aggregate, much prospecting has been done and a great deal of money expended. The deposits are mostly valued for their copper content and these copper properties generally carry from traces to low values in gold. On others, gold values are of more importance. The principal values may, however, be in silver, or in silver and lead, and other metals present may include one or more of arsenic, antimony, cobalt, and nickel.

The deposits occur in the so-called Purcell sills, or allied intrusive bodies, and, therefore, within areas underlain largely by the Aldridge formation. The majority of them are situated in the basin of St. Mary River and are accessible by road and trail within a radius of 15 or 20 miles of Marysville.

According to their mode of formation the deposits are of two types; one occurring as masses of sill rock more or less heavily impregnated with sulphides and the other as fissure-vein deposits cutting steeply across the sills and terminating at or close to the sill contacts. Both types seem definitely related to the sill intrusions, but it is less certain whether individual deposits are derived from the particular sill only in which they occur.

The sills vary from a few feet to at least several hundred feet thick and are prominently and widely exposed in the St. Mary and Upper Moyie River basins. They are medium to moderately coarse-grained, massive, green rocks of a general dioritic appearance in which dark green amphibole and light-coloured plagioclase feldspar are commonly the abundant constituents, the former generally preponderating and accounting for the colour of the rock. Variations in composition may be noticeable within individual sills, the bottom portions, in such cases, being somewhat darker and more basic than upper portions. The lighter-coloured and most acid phases may not, however, occur at the top and may be the result of more than one geological process. The sills may occur either singly or in groups of two or more (multiple sills) closely spaced and roughly parallel bodies. Single sills may split into two or more components. Though generally sill-shaped, that is, structurally conformable with the formations on either side, they may show distinct crosscutting relationships, or may be connected one with another by stock-shaped masses of the sill-rock intrusive.

The sills invariably carry visible disseminated sulphides and magnetite as accessory minerals. The common sulphide is pyrrhotite, but pyrite and, less commonly, chalcopyrite may also be present and abundant. Where, as locally, these sulphides become conspicuous constituents and, especially where chalcopyrite is one of them, the sill rock becomes economically interesting. It is, in the writer's opinion, however, less certain to what extent such concentrations of sulphides may be regarded as magmatic, that is, as deposited with or from the molten sills during consolidation or as post-magmatic and derived from hot mineralizing gases and solutions

referable to either the cooling sills or to the source of these sills. It appeared, in fact, that two processes might be important. By the one a gravitative adjustment resulting in the settling of much of the magnetite and probably also the pyrrhotite towards the bottom of the cooling sill would effect a concentration of these high-temperature minerals in the lower part of the sills. By the other process much of the chalcopyrite, as well as other ore minerals, would be more likely retained in the magmatic solutions until towards or at the close of the consolidation of the sills. They would then form, in part, as impregnations through the last portions of the sills to consolidate and, in part, as vein and replacement deposits along shear zones and fractures developed, principally, in the sill rocks after their consolidation and, to a less certain but possibly important extent, in the adjoining sediments or included bodies of sediments. Of these various possible types the impregnation deposits would be truly magmatic and would correspond with Schofield's "differentiates" in that they would tend to occur in the more acid, lighter, and, therefore, upper portions of the sills and might also show a similarity in sulphide mineralization with deposits of gaseous or of hydrothermal origin formed either in the sediments during the consolidation of the sills or in the sills themselves after their consolidation. Bodies of sill rock carrying disseminated chalcopyrite were observed both on Evans Mountain and on Alki Creek. In these instances the chalcopyrite was, in places, definitely the result of replacement and in others less certainly due to the same process. For example, it was noted that the wall-rocks of the Kokanee vein on Evans Mountain were, in places, heavily impregnated with iron and copper sulphides and that specimens of such wall-rocks might of themselves be easily mistaken for differentiate ore; also that whereas large talus blocks from steep, copper-stained cliffs overlooking Kelly basin on Evans Mountain contained an important copper content, the appearance of the outcrops, viewed from a distance, and the occurrence of considerable quartz in the float specimens suggested the presence of veins and, therefore, the replacement of the sill rocks along fracture zones, by vein solutions and gases rather than a magmatic deposition of the sulphides. On Alki (John) Creek, again, an adit on the Mystery claim (Levecque workings), follows northwesterly for over 150 feet along a shear zone in a Purcell sill. For this distance and across an average width of apparently several feet the sill rock is impregnated with iron and copper sulphides and is intersected by narrow, mineralized quartz veins and stringers. The shearing seems to be in part, at least, post-mineral. Specimens of the wall-rock might readily be taken to represent magmatic mineralization, but the presence of vein quartz and the disposition of the mineral body along the shear zone are suggestive of replacement by vein-forming solutions and gases. Towards the face of the adit the mineral body seems to narrow and at the face is represented by a sparsely mineralized quartz vein less than a foot wide. No cross-cutting has, however, been attempted and it is possible that the adit may have swung to one side of the ore-body. From a large pile of ore at the portal, reported to contain 250 tons of high-grade, it is stated that a 250-pound sample gave an assay return of 19½ per cent copper and $10 in gold to the ton. Judging from the appearance of the ore and the amount and reported values obtained from this one small working, the deposit is worth further exploration.

Much prospecting work has been done on vein deposits in these sills. Such deposits are very common and occur in at least most of the sills in the area. They vary from mere stringers a few feet long to well-developed fissure veins continuous, in some cases, for at least several hundred feet and perhaps half a mile or more. These larger veins would probably average between 5 and 10 feet in width. They tend to stand about perpendicular with the plane of the sills in which they occur and in most such cases have been guided in their formations by shrinkage fractures developed in the cooling sills. There also seems to be a distinct tendency for them to develop best in the upper portions of the sills and to spread out, sometimes splitting into a number of components, below the top of the sills. Rarely do they persist for more than a few feet into the overlying sediments.

The abundant vein mineral is, generally, quartz. It may be milky white to nearly colourless and, particularly in the latter case, is extremely vitreous. The quartz is commonly associated with more or less carbonate, principally calcite, but including also varieties carrying iron and magnesia. These carbonate minerals are generally coarsely crystalline. They may be either intimately mixed with the quartz or occur as separate bands within or along the walls of the vein-lodes. In the aggregate the veins contain a variety of ore minerals of which pyrite and chalcopyrite are most common. One or more others, including magnetite, pyrrhotite, galena, grey copper, and, less commonly, sphalerite, arsenopyrite, and nickel and cobalt minerals, may, however, be present and, in certain veins, may be of principal importance. These ore minerals occur streaked or disseminated through, mainly, the quartz gangue and, in some cases, form veins or lens-like masses of considerable dimensions. The wall-rocks of the quartz veins may be impregnated with sulphides for distances of from a few inches to a foot or more. Outcrops of the vein are commonly stained with copper carbonates, iron oxides, and, more rarely, by cobalt bloom. Films of native copper have also been observed.

The only productive property, to the writer's knowledge, is the Park group situated near Marysville. Many of the veins on other properties are evidently too small and values too low to warrant further development. Some of the larger veins, however, carry showings of more promise. These showings take the form of shoots occupying restricted portions of the veins and are not sufficiently developed to indicate either their behaviour with depth or the available tonnage. Over widths of from a few inches to several feet, and for lengths varying from a few feet to 50 feet or more, values of from 1 or 2 to, perhaps, 15 per cent or more copper have been reported and small tonnages of high-grade ore are piled up at some of the workings. A trial shipment of 2,200 pounds from the Pollen vein on Evans Mountain is, for example, reported to have assayed 6 per cent copper and to have carried low values in gold and silver.

The vein-bearing properties may be grouped geographically to include: (1) numerous, mostly small prospects on St. Mary Prairie, a low tract of land lying north of St. Mary River and east of Marysville; (2) a great number of properties in the basin of St. Mary River west of Marysville and including several on which a lot of exploratory work has been done; and (3) many scattered occurrences situated in sill rocks outcropping elsewhere in Cranbrook area. Among the Prairie properties the Park group is of special interest in that it has not only made ore shipments amounting

to, perhaps, 30 tons or more, but this ore was valued for its silver-lead content. The workings develop a fissure vein composed mainly of quartz, but containing considerable calcite and galena, the latter carrying low silver values. The other properties in this group have been inactive for many years and the impression gathered from an examination of many of them is that the veins prospected were either too small or discontinuous, or otherwise too low grade, to encourage further development. Among the more important properties farther up St. Mary River and its tributaries are the Evans and Whitefish groups on Evans Mountain south of Meacham Creek; the Alliance and Faller groups north of the same creek; the Mystery and Pollen properties on Alki (John) Creek; the Dominion group about 4 miles above St. Mary Lake; a number of properties on Pyramid Creek and Mountain; and the Bracebridge, Great Dane, and Welcome groups near the head of St. Mary River. These properties have prospected vein deposits as well as mineralized bodies of sill rock of less certain origin and have exposed a number of showings of both high-grade and low-grade copper and copper-gold ore. No shipments, other than perhaps small trial lots, are, however, to the writer's knowledge, recorded, failure in this direction being chargeable to a variety of difficulties in the way of finance, transportation, and management rather than to lack of encouraging mineralization. The work done, too, has been principally of an exploratory nature and, in spite of promising discoveries, the lack of capital has prevented their adequate development. Recently the condition of the copper market has discouraged active prospecting for this metal, though, in the case of the St. Mary properties as well as others in this district, the associated gold values appear, in some instances, to warrant special consideration. Development work has not been carried far enough to prove up substantial tonnages.

Properties of the third group include a number of prospects in the upper Moyie Valley and in the vicinity of Lumberton and Cranbrook. One of the more interesting is the old Prospector's Dream located on Old Baldy Mountain at the head of the North Fork of Weaver Creek. This property has been inactive for many years. The old workings, now inaccessible, prospected a quartz vein or veins, several feet wide, in a basic intrusive, probably a sill, cutting the Creston formation or rocks transitional from Creston to Aldridge. Several tons of rusty-weathering, cellular quartz piled up at one point is stated to carry average gold values of about $10 a ton.

Non-Metallic Deposits

MAGNESITE

Geological investigations near the western border of the Cranbrook quadrangle have revealed a large and conveniently situated deposit of crystalline, rock magnesite. The deposit forms an important constituent of a narrow belt of magnesite-bearing sediments crossing the low range of foothills between St. Mary River and Perry Creek and readily accessible, to within a few hundred yards, by road from Marysville. The most northerly observed exposures occur almost directly south of Marysville and less than a mile south of, and about 400 feet above, St. Mary River. From

this point the belt has been traced in a southerly to south-southwesterly direction to within a mile of Perry Creek. Its further possible extensions to the north and south are limited by strong faults extending up the valleys of these streams. As exposed, however, the belt has an average width of 150 feet or more; an average and fairly regular dip of about 60 degrees to the west; a length of over 4 miles; a vertical range of about 2,000 feet; and a contained average width or widths of crystalline magnesite conservatively estimated at 30 feet and possibly amounting to 50 feet or more.

The magnesite-bearing belt or, more simply, magnesite belt, is the intermediate member of what has been named the Old Town formation. The basal member of this formation consists of massive, mostly light-coloured, quartzites aggregating several hundred feet in thickness. The succeeding member is the magnesite belt, and the upper member is represented, in this locality, by 40 feet of greenish and dark grey, thinly bedded quartzites distinguished by numerous, annelid-like markings. The Old Town formation rests, apparently conformably but possibly disconformably, on purplish, argillaceous rocks of, presumably, the Siyeh formation of Precambrian age and is sharply separated from overlying, argillaceous, slaty beds of the Perry Creek formation of Lower Cambrian age. The entire succession is overturned towards the east, with the result that the youngest, or Perry Creek, formation occurs at the lower elevations and dips beneath the Old Town formation and the latter, in turn, underlies the Siyeh and older Precambrian formations as exposed higher up the slopes of the ridge between St. Mary River and Perry Creek.

The magnesite belt is composed, in part, of crystalline magnesite and, in part, of magnesite and impure magnesite interbedded with quartzitic and argillaceous sediments and, at one observed point, with narrow beds of limestone. Towards its upper and lower contacts the belt grades into adjoining members of the Old Town formation.

In tracing this belt from north to south exposures were not everywhere well shown and only at a few points, where cliffs, rock canyons, or other natural conditions permitted, could the belt be examined and measured in detail. Between these points, however, outcrops were observed almost continuously and were of sufficient size to indicate not only the persistence of the belt but also a considerable regularity to its constituent members. At one point about midway of its length the belt is displaced for 100 yards or so along an east-west fault, the southern half of the belt being shifted to the west relative to the northern half. It is not unlikely, too, that other small faults occur.

The purer magnesite occurs towards the middle of the magnesite belt. It varies from coarse to finely crystalline, weathers rough, and is commonly thinly coated rusty-brown. Fresh surfaces are pearly grey, white, and cream. In places the magnesite may be traversed by irregular, small veins and veinlets of quartz, or contain small knots of quartz, but for the most past the deposit seems relatively free of visible impurities. The lower part of the belt is composed chiefly of a thinly banded succession of reddish quartzitic and buffish magnesite-bearing beds, whereas the overlying part consists of magnesite interstratified with thin, greenish, argillaceous beds and, locally, at least, with thin, limestone strata, but also includes one or more bands, up to several feet thick, of higher grade

magnesite. Most of the better-grade magnesite forms a single band which, though not continuously exposed, is probably nowhere less than 15 or 20 feet thick and in one place was observed to have a thickness of at least 50 feet. Locally, the magnesite belt was observed to include one or more other bands of magnesite up to several feet thick.

Two chip samples of the magnesite deposit were obtained at points 1½ and 3 miles south of, and about 1,000 and 2,000 feet, respectively, above, St. Mary River. The samples (Nos. 388-R and 330) represent widths of 18 feet and 50 feet of the purest-looking magnesite at these respective localities. In addition, and particularly at the more northerly point, there appeared to be much material which, if occasion arose, could be readily sorted to provide magnesite of the same grade as the samples. The samples were submitted to the Mines Branch, Dept. of Mines, Ottawa, for analyses and were found to contain:

	No. 388R	No. 330
	Per cent	Per cent
SiO_2	4·54	4·40
Fe_2O_3	2·40	1·42
Al_2O_3	0·40	0·66
CaO	0·79	0·73
MgO	43·70	44·80
Loss on ignition	48·00	48·30

These analyses, save in their rather high silica content, compare favourably with those of the more important deposits of magnesite the world over. In this connexion, however, it might be pointed out, on the one hand, that these are analyses of chip samples taken at or close to the surface and consequently subject to whatever changes weathering may produce as well as such inaccuracies as this method of sampling involves, and, on the other, that in actual operation it might be found possible, by experienced sorting, to reject much of such impurities as are present and thereby secure a higher grade product than that indicated by an average sample.

It is interesting to note that the above magnesite deposit was not the first of its sort to be discovered in the district. A property owned by the Consolidated Mining and Smelting Company, and situated at the extreme headwaters of the north fork of Moyie River, contains a large deposit of magnesite of the same type as that described above and occurring under similar geological associations. This property is accessible by road and trail up Perry Creek. A large specimen of typical magnesite taken from an open-cut on this property was analysed by Mr. Fabry who submits the following determination.

	Per cent
Insoluble	2·39
SiO_2	5·92
Fe_2O_3 and Al_2O_3	5·11
CaO	1·79
MgO	42·09

These discoveries of large, and in the one case, conveniently situated, deposits of magnesite open up possibilities for the district in a new direction. Magnesite has many industrial uses, among the more important of which are those in the manufacture of: refractory materials, as firebrick, furnace linings, fireproof paints, etc.; oxychloride or sorel cement, used extensively as sanitary flooring, artificial marble, tile roofing, and other structural material; carbon dioxide; metallic magnesium; magnesium sulphate (Epsom-salts); magnesium chloride; and various others.

A mimeographed report (13, page 33) summarizes the situation with respect to production of magnesite and market conditions in Canada in 1931.

In conclusion it might be pointed out that although the Cranbrook deposits are enormous, figures as to their average composition must be based on a more comprehensive program of sampling than has yet been attempted. Nor is it known to what extent impurities in the form of silica, silicates, lime, etc., may either limit or increase its usefulness. In this connexion it may be of some interest to reproduce the following table (11) giving the comparative analyses of productive magnesite deposits in different parts of the world.

Number	SiO_2	CaO	FeO	Fe_2O_3	MgO
a	1·85	1·74	0·88	.....	45·20
b	2·07	1·02	1·03	.....	44·50
c	4·27	1·07	0·78	.....	45·02
d	1 to 5	1 to 3	2 to 7	.....	38 to 44
e	1·63	1·44	.....	1·36	45·75
f	2·28	1·35	.....	0·29	45·17
g	4·35	2·11	1·71	.....	42·62
h	1·60	7·89	.....	1·81	39·25
i	0·90	10·44	.....	.....	37·60
j	1·86	2·04	0·60	0·82	41·13
k	7·46	0·46	0·56	0·48	43·42

a Finch quarry, N.W. Magnesite Company, Stevens County, Wash. Laboratory, N.W. Magnesite Company.

b Allen Quarry, American Mineral Production Company, Stevens County, Wash. Composite analysis, American Mineral Production Company.

c Red Marble quarry, American Mineral Production Company, Stevens County, Wash. Sample from stock pile.

d Austrian magnesite, average analysis.

e Grecian magnesite, typical analysis.

f California magnesite, Porterville, Tulare County. Bull. 355, U.S. Geol. Surv., 1908, p. 56.

g Napa County, California.
Bull. 355 U.S. Geol. Surv., 1908, p. 56.

h Grenville district, Quebec. International Magnesite Company.
Geol. Surv., Canada, Memoir 98, 1917, pp. 38–41.

i Grenville district, Quebec, Shaw mine.

j Hydromagnesite, Atlin, B.C.
Rept. Minister of Mines, B.C., 1915, pp. 82–83.

k Bridge River district, B.C.

ORNAMENTAL STONE

A little quarrying has recently been attempted near Cranbrook on rocks of the Purcell sills, with the purpose, primarily, of finding out what uses such stone are best adapted for and to what extent it affords comparison or is capable of competition with occurrences of somewhat similar rock in other districts at home and abroad. Dark, crystalline stone of the character of the Purcell sills is not common and the fact that in the present area there are huge bodies of it convenient to transportation, as in the vicinity of the railway between Cranbrook and Lumberton, lends a particular significance to its investigation.

Some reference has already been made to the Purcell sills. They are predominantly dark green to almost black intrusives; show considerable variation in grain, texture, and shade; and are massive, tough, regularly jointed rocks from which it should be possible to secure blocks of almost any required size. Impurities in the form of veins and disseminated iron-sulphide minerals would locally be serious defects.

Much of the value of this stone for ornamental purposes will depend on how easily and well it can be polished and on the effect of such a polish. Experiments along this line are now under way at the Mines Branch, Ottawa, and results may be expected in the near future.

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BRISCO-DOGTOOTH MAP-AREA, BRITISH COLUMBIA

By C. S. Evans

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INTRODUCTION

The area dealt with in this report is in the mountainous region of southeastern British Columbia, approximately 40 miles west of the British Columbia-Alberta provincial boundary, with its southern limit about 120 miles north of the International Boundary. It is a northwesterly trending strip of country, 85 miles long, 10 miles wide at the southeast and 25 miles wide, at its widest, in the northwest. This strip is divided lengthwise into two parts by the, here, northwesterly flowing Columbia River: the eastern part includes Van Horne and Brisco Ranges of the Rocky Mountains, and the western part the Dogtooth Mountains of the Purcell Range.

The northern part of the area is traversed by the main line of the Canadian Pacific Railway, a branch line of which runs southeasterly through the area, along the east side of Columbia River.

Field work was begun in the season of 1925 under the direction and with the assistance of J. F. Walker, and was continued by the writer during the seasons of 1926 and 1927. Efficient field assistance was given by W. A. Jones in 1925, by E. J. Lees in 1926, and by G. W. Crickmay in 1927.

The writer thanks the members of the Department of Geology at Princeton University, especially Professors B. F. Howell and Edward Sampson, for assistance and criticism in the preparation of this report. Thanks are due Dr. C. E. Resser of the United States National Museum and Dr. Rudolph Ruedemann of the Geological Survey of New York State for palæontological determinations.

PREVIOUS WORK

Hector (1861)[1], while with Palliser's expedition, made some general geological observations in 1857-1859. Dawson (1885) on reconnaissance work in the southeastern Rocky Mountains notes the strata in Sinclair Pass (Sinclair Canyon) and the physiography of Columbia Valley, and reports a previous collection of fossils (Silurian age) made by A. P. Coleman from the east side of Columbia Valley. McConnell in 1886 made a geological section of the Rocky Mountains west to Golden, and Coleman (1888) made a reconnaissance of Dogtooth Mountains and Columbia River area northwest of Beavermouth. Ami, in 1891, carried out palæontological work along the railway between Revelstoke and the summit of the Rocky Mountains. Allan (1914) worked in Field map-area to the east from 1910 to 1912 and extended his mapping to the north part of the east slope of Brisco Range. Daly (1915) carried out geological reconnaissance between Golden and Revelstoke from 1911 to 1912. Burling made stratigraphic sections at the north of Brisco Range, an account of which is given in the Geological Magazine for 1922. Shepard (1922 and 1926) carried out structural and stratigraphic work along Columbia Valley in 1920-21 and again in 1924. Walcott (1924 and 1927) made many palæontological collections in Brisco Range in 1923. Walker (1925 and 1926) mapped Windermere map-area between 1922 and 1924, and in 1925 carried out reconnaissance work to the north in the main Purcell Range. A posthumous publication of Dr. Walcott (1928) discusses the formations of Brisco Range.

GENERAL CHARACTER OF THE AREA

Within the map-area, Columbia River Valley, a deep, wide valley, clearly marks the opposing limits of two great mountain systems; the Rocky Mountains to the east and Selkirk Mountains (Purcell, Selkirk, and Columbia Ranges) to the west. Van Horne and Brisco Ranges are the western flanking ranges of the Rocky Mountains within the map-area, and are lower in elevation than the main ranges farther east. Similarly, Dogtooth Mountains are the eastern flanking, lower mountains of the Selkirk system.

A view across any part of the area is most striking. The middle appears as a nearly flat-bottomed trough with high, abrupt walls. Along

[1] The date (and in some cases page numbers) will enable the reader to find the complete bibliographic reference in the list of papers, at the end of this report.

the bottom of the trough flows Columbia River which with its anastomosing channels occupies a relatively shallow inner trough in the floor of the much larger one (*See* Plate II A). Back from the walls are the higher, irregular mountain masses that bound the trough. This trough is a part of the Rocky Mountain trench (*See* Daly, 1912, page 26).

The area thus consists of four major topographic divisions: the Rocky Mountain trench which in the southeast includes two low intra-valley ridges; Brisco Range northeast of the trench; Van Horne Range also on the northeast of the trench, northwest of Brisco Range, and Dog-tooth Range along the southwest side of the trench.

ROCKY MOUNTAIN TRENCH DIVISION

The portion of the trench within the map-area has a wide, terraced bottom sloping inward to the low flood-plains of Columbia River (elevation 2,600 feet). From the outer edge of the terraced margins, steep walls (30-degree slope) rise to 7,000 feet and more, from which elevations, gentle but broken profiles, rise back to the higher elevations in the centre of the ranges. When viewed from the upper slopes of the walls, the relief between the terraced margins and the central depression of the trench is minimized, and the depth of the trench is so emphasized that it appears as a deep, flat-bottomed trough (Plate II B).

BRISCO RANGE

Brisco Range is bounded on the west by the trench, on the east by Beaverfoot-Kootenay valley, and on the north and south by Kicking Horse and Kootenay River Valleys, respectively. The map-area includes that part of Brisco Range that lies north of Sinclair Creek, whose valley is followed by the Banff-Windermere highway.

It has been the custom to divide the range into three ranges, from south to north, Stanford, Brisco, and Beaverfoot Ranges. Shepard (1926, page 625) upholds this division; Walcott (1924, page 3) and Walker (1926, page 3) oppose it. In the south of the map-area, Sinclair Creek and Swede Creek, heading against one another, have formed a relatively low pass (elevation 4,800 feet) through the range, which here consists of two, main, parallel ridges. The two ridges (the so-called Brisco Range) northwest from the transverse Sinclair Creek are in direct topographic alinement and are continuous structurally with the two ridges (the so-called Stanford Range) to the southeast. Thus the writer considers that the mountains here form one range, fairly deeply dissected by two transverse streams (that happened to head against one another) and not two distinct ranges. The western and lower ridge of this southern part extends northwestward to Library Creek, just north of Spillimacheen post office, where it dies out. Northeast of this point, a third ridge, extending northward from the headwaters of Luxor Creek, and lying east of the main ridge, also dies out. In a general way, the usage has been to term that part of the range northwest from the poorly defined area where these two flanking ridges die out, Beaverfoot Range, and that part to the south, Brisco Range. However, the dominant central ridge persists, and is continuous, topographically and structurally, from the so-called Brisco Range into and throughout the so-called Beaverfoot Range to the northwest. The writer sees no good

reason for continuing a cumbersome and needless nomenclature and, therefore, the whole range will be termed Brisco Range in this report.

Brisco Range has a trend of 317 degrees, which is nearly paralleled by its main structures. The maximum elevations of the main ridges are from 8,500 to 8,750 feet, whereas the flanking ridges seldom exceed 7,500 feet in altitude. No glaciers exist. The streams are small, and many of them are dry during the summer months. Five main streams, heading well back in the east of the range, cut through the western ridges in deep valleys. Tributaries to these streams have become adjusted to the structures, their valleys being cut in the anticlines that now expose the more easily eroded shale, and shale and thin limestone formations. Such erosion along the structures has formed the parallel ridges of the range. Luxor and Pinnacle Creeks, with two wind gaps, located east of Brisco, point to the existence of a consequent southwest drainage before the development of the present adjusted tributary system.

VAN HORNE RANGE

Van Horne Range is a wide, short range extending from Kicking Horse River northwest to Blaeberry River. Topographically it is a union of the northwesterly continuations of Brisco Range and the range next to the east (Ottertail Range). The western part of Van Horne Range has about the same appearance and elevation as Brisco Range. The central and eastern parts have many peaks over 9,000 feet in elevation. Access to the central part of Van Horne Range is difficult.

DOGTOOTH MOUNTAINS

Dogtooth Mountains are bounded on the northeast by Columbia River and on the west and southwest, respectively, by Beaver River and Spillimacheen River. From Beavermouth, at the junction of Beaver River with the Columbia, southeast for 40 miles, the range is clearly defined. Most of the summits are well over 8,000 feet in elevation, whereas the average elevation of Columbia River is 2,550 feet. Beyond this, the range is continued 22 miles to the southeast by a wooded ridge of about 4,500 feet elevation to where Spillimacheen River enters the Columbia. The southeastern part of this ridge, for 5 miles north of the mouth of Spillimacheen River, is higher than that part of it to the northwest and is defined by scarps on the southeast and northwest. The southeast and northwest parts of this 5-mile portion are known locally as Spillimacheen Mountain and Jubilee Mountain, respectively; but, inasmuch as a definite range to the northwest has been termed Spillimacheen Mountains, the writer will apply the single name Jubilee Mountain to this feature.

Daly (1925, page 2) has pointed out that Dogtooth Mountains are really continued north of the crosscutting Columbia River at Donald, by a low, wooded ridge that finally pinches out where the Columbia again enters the main trench at Bush River. This northwest extension of Dogtooth Mountains was not examined.

The trend of Dogtooth Mountains north of Twelvemile Creek is 325 degrees, southward it is 308 degrees. The eastern part of the range from west of Parson to Oldman Creek is characterized by steep, interstream, east-facing cliffs, with more gentle, southwest dip slopes. Such cliffs are occasionally repeated to the southwest. North of the bend in the middle course of Canyon Creek, and alined with the middle course, is a

scarp 10 miles in length (Plate III)) eroded in much mashed and interfolded argillites and limestones. The line of this scarp is thought to have been formed originally by a southwest-dipping thrust fault, though the scarp itself has been formed by headwall and lateral erosion of former mountain glaciers. The little ice now present at the base of the scarp is heavily covered with talus; in which flow patterns are well shown.

West of a line along Quartz and Canyon Creeks, the topography changes, for in this area slates are more abundant, the quartzite strata less massive, and the structure displayed is that of close and overturned folding. A number of peaks in this part exceed 9,000 feet in elevation, though in comparison with the Selkirks immediately to the west the alpine topography is subdued. On the west flank of this western part of Dogtooth, there are two topographic features known as Prairie Hills and Bald Mountain. These are flat-topped ridges whose upper surfaces lie at about 7,500 feet elevation and are 4,000 to 5,000 feet above Beaver River.

Quartz Creek and the upper part of Canyon Creek are eroded along structural trends, thus differing from most of the other streams of Dogtooth Mountains, notably Twelvemile Creek and those creeks between Canyon Creek and Donald, which all cut across the structures. The valleys of these northeast flowing, transverse streams of Dogtooth Mountains are in marked contrast with those of the southwest flowing streams of Brisco Range, where well-defined cirques, "U" profiles, and hanging valleys are much less common. This contrast between northeast and southwest slopes, which needs no explanation, exists at higher elevations at the present time, in both Dogtooth Mountains and Brisco Range. In Dogtooth Mountains many small glaciers occupy sheltered positions in the northeast slopes, and in Brisco Range, though no glaciers exist, characteristic mountain-glacier erosion-forms are well preserved in similar situations.

The ranges are at the stage of erosion in which maximum relief is developed. They are highest in their central parts, the slopes are steep, and the ridges and peaks are sharp. With the exception of Bald Mountain, Prairie Hills, and a small surface on a mountain north of Kicking Horse River, in the southwest part of Van Horne Range, no upland surfaces exist.

THE TRENCH WALLS

The eastern trench wall is formed by Brisco Range and Van Horne Range and is fairly uniform. The western wall is formed by the truncated spurs of the main Purcell Range in the southern portion, and by Dogtooth Mountains (the northeasterly *en échelon* range of the Purcells) in the north. The western limit of the trench where these two ranges overlap is obscure; no distinct wall is apparent. North of Parson the floor of the trench, between Van Horne and Brisco Ranges on the east and Dogtooth Mountains on the west, is between 3 and 4 miles wide. South of Parson, the eastern wall continues unbroken, but the continuation of Dogtooth Mountains into the low, wooded ridge, terminated by Jubilee Mountain, can no longer be regarded as the western wall, but appears more as an intravalley ridge (*See* Plate II A). The southern extension of the western wall along Dogtooth Mountains thus dies out, and its place is taken by the steeply truncated spurs of the main Purcell range 4 miles farther west across low land through which Spillimacheen River and its tributaries flow. Thus south of Parson the floor of the trench is about 8 miles wide.

The trench walls rise abruptly from the upper part of the terraced belts at elevations between 3,500 and 4,500 feet, and in a horizontal distance of 1·5 to 1·75 miles reach elevations of from 7,000 to 7,500 feet. Few deep valleys have been eroded back into Brisco Range so that the wall is nearly continuous, whereas the western wall formed by Purcell Range and Dogtooth Mountains has been deeply dissected by glacial and stream erosion, and the wall is there formed by alined, truncated spurs. At the top of the trench walls there is a distinct topographic break from which the surface slopes upward to the higher summit near the centre of the ranges. Many of the profiles formed in the rock walls of the trench are steeply inclined, slight curves, concave towards the centre of the valley, typical profiles of glacially eroded walls. Few glacial grooves or striæ were seen on the walls of the trench, though these are very well shown in some of the intravalley ridges to the west of Jubilee Mountain. A large erratic of gneissic igneous rock, a rock foreign to Brisco Range, was seen at an elevation of 6,600 feet beside the Harrogate trail to Beaverfoot Valley.

TERRACES, BENCHES, AND INTRAVALLEY RIDGES

On each side of Columbia River flood-plains, between them and the foot of the trench walls, is a dissected terrace belt. On the east side of the trench, south of Brisco, this terraced belt averages between 1 and 1·5 miles in width, and extends from an elevation of 2,600 feet—that of the flood-plains—to the foot of the trench wall at 3,500 feet. From Brisco northwards this belt is somewhat wider (1·5 to 2 miles) and the highest, well-defined terrace has an elevation of about 4,000 feet. On the west side of Columbia River, from Twelvemile Creek northward, the terraced belt has a width of about 2·5 miles and the highest terraces occur at an elevation of 4,800 feet. Sufficient time was not available for tracing out the different terraces, though such a survey would be necessary for a correct interpretation of the topography of the trench. The following is a tabulation of approximate elevations of the terraces in different parts of the trench.

Approximate Elevations of Terraces (in Feet)

East side of trench				West side of trench
Sinclair Creek	Kindersley Creek	Brisco post office	McMurdo to Golden	West of Golden
				4,800
				4,700
				3,850
				3,700
			3,500	3,500
	3,400	3,400		
3,300	3,250			3,200
	3,100	3,100	3,100	
3,000			3,000	
		2,900		
	2,800		2,780	
2,700	2,700		2,700	
2,650			2,650	

Many small outwash fans have been built out by the streams flowing into the trench from Brisco Range. These fans, though generally obscure to one on the floor of the trench, are clearly seen from the top of the east wall.

South of Library Creek no rock exposures were found in the terraced belt; but north of this, on the east side of the trench, an occasional rock outcrop in the terraces, and outcrops along the highway and railway at 2,650 feet elevation, north of McMurdo, indicate that the overburden is not continuously deep on the main terrace (elevation 3,500 feet) in this locality, but rather that the gravels forming it have filled in inequalities in a rock bench near the foot of the trench wall, and become thicker towards the Columbia, where the frontal slope of the terrace is defended by lower rock outcrops of a pre-aggradation valley. On the west side of the Columbia north of Twelvemile Creek, rock outcrops are more numerous, and the drift is nowhere very thick, though there is sufficient to obscure stratigraphic relations. Some of the higher benches show rock outcrops on their frontal slopes and crests, back from which there is a slight reverse slope behind which small ponds and swamps exist. On the lower, broader benches between Cirque and Twelvemile Creeks, narrow ridges (0·5 to 2 miles in length) occur paralleling the strike of the rocks. Some of these consist of rock more resistant to erosion than the rock on either side of them and were probably developed by normal stream erosion. Other of these ridges are of relatively soft slates and the ridges are probably due to the vagaries of differential scour of valley glaciers.

The wide, terraced belt between the Columbia and the east slope of the main Purcell Range in Windermere area continues northward, but in the south of the map-area is separated from the Columbia River depression by Steamboat Mountain, an intravalley ridge of from 5,000 to 6,000 feet elevation. Northwest of Steamboat Mountain this belt of fairly even-surfaced terraces gives way to a low-lying area with a lumpy and broken topography formed by numerous, rocky knolls and ridges of Purcell and Windermere strata. This belt is limited to the west by the main Purcell Range, to the northwest by Spillimacheen Mountains, and to the north and northeast by the southeast continuation of Dogtooth Mountains. It is at the north of this low area that the western wall of the trench dies out along the main Purcell Range and reappears, 3 to 4 miles to the northeast, as a well-defined wall on the eastern slope of Dogtooth Mountains.

Jubilee Mountain, having a scarp-like eastern slope, borders the west side of Columbia River flood-plains, and may be regarded both as the southeastern termination of Dogtooth Mountains and as the most northeastern intravalley ridge.

MAIN RIVERS

Columbia River, with an average gradient of 6 inches a mile, meanders in its flood-plains on the floor of a depression about a mile wide. In the south of the area this depression lies at the east side of the trench, east of the intravalley ridges, but north of Parson it occupies a median position in the narrowed trench floor. The Columbia is here a graded stream occupying one main channel or dividing into several which unite again downstream. During high water (June and July) only the

trees and bushes growing on the natural levees serve to mark the courses of the various channels. Many saucer lakes persist throughout the year.

In the north, at Donald, Columbia River leaves the supposed valley of the old trench river, and cuts across the north end of Dogtooth Mountains to where it is joined by Beaver River, near Beavermouth. From there it flows northwestward, gradually converging with the older part of the trench which it meets at Bush River. In its course across the north end of Dogtooth Mountains, Columbia River occupies a valley in which the following features are noted. The valley shows glacially scoured walls between 4,000 and 7,000 feet in elevation; benches and terraces occur between 3,000 and 4,500 feet elevation; a "V" valley, 2,000 feet wide at the top of the "V", occurs between elevations of 2,500 and 3,000 feet; a rock canyon 50 to 100 feet deep has been cut in the bottom of the V-shaped valley; the large valley has a relief of 5,500 feet and is 8 miles wide from its crest at 8,000 feet on the south to its crest at 5,000 feet elevation on the north.

This wide valley undoubtedly existed in Tertiary time and was probably occupied by a through-flowing tributary to the trench river, for which Schofield (1920, B, page 93) and Dawson (1885, page 28) have postulated a southward flow. Beaver River with other drainage from the northwest may have occupied this valley. In support of this, attention may be called to the presence of an old channel running to the northeast at an elevation of about 4,250 feet, about 2 miles east of the present lower course of Quartz Creek. This channel was no doubt occupied by Quartz Creek when it was tributary to an east-flowing river, which it would thus meet in a downstream direction. The Columbia was probably deflected to the west through this valley at some stage towards the end of the Pleistocene, and has since cut the "V"-shaped valley and the inner canyon.

Kicking Horse, Beaver, Blaeberry, and Spillimacheen Rivers are the main tributaries to Columbia River within the map-area.

Kicking Horse River makes a sudden "hairpin" turn at Leanchoil (at the southeast of Van Horne Range), and cuts across the north end of Brisco Range in a deep valley. Allan (1914, page 26) thinks that Glenogle Creek, with pre-Glacial Kicking Horse River northeast of Leanchoil, once formed the headwaters of a river flowing southeast along Beaverfoot-Kootenay Valley; that a pre-Glacial stream eroding headward, east from Golden, produced a fairly low divide between its waters and those of a tributary to Glenogle Creek; that glacial erosion lowered this divide, and that later damming forced the Kicking Horse waters westward, since which time some of the terraces and the present canyon have been formed. Damming by glaciers or by glacial debris is the only explanation that can be entertained for the diversion of Kicking Horse River across the north end of Brisco Range. The diversion probably occurred when the summit divide was somewhat over 4,400 feet in elevation, since Kicking Horse River has cut through a ridge (elevation 4,350 feet) 2 miles east of Golden, in a sharp, V-shaped valley to a depth of about 900 feet, below which again is the present inner canyon. Also, west of Glenogle, lower Kicking Horse Valley shows glacial modification down to the 4,000-foot contour, but below this there is a V-shaped valley with a relief of about 800 feet, and

again in the bottom of it the present inner canyon is cut. A similar feature has already been described in Columbia Valley west of Donald. The V-shaped valleys in both instances do not show definite signs of glacial erosion. Two explanations may be given: the first, that both the V-shaped valleys and inner canyons have been eroded post-glacially; the second that the V-shaped valleys may have been eroded by streams during the Pleistocene, possibly in an interglacial stage, and because they are in valleys transverse to the general ice movement they may have been occupied by stagnant ice only, if by any ice at all, during late and lesser glaciation. It is to be noted that both these valleys were strongly scoured by earlier valley glaciers.

Spillimacheen River has its source just to the east of Bald Mountain, and thence flows southeast to join Columbia River at the south end of Jubilee Mountain, 50 miles distant. Its southeastern direction of flow, opposed to that of Columbia River, has been noted by Coleman (1889, page 97) and Schofield (1920, B, page 93) as evidence that the trench river flowed southward in pre-Glacial time.

Blaeberry River occupies a valley that seems to have had a normal development while occupied by a southwest flowing river.

UPPER SURFACES

Above a topographic unconformity, at about 7,000 feet elevation on Prairie Hills and Bald Mountain, is a surface that though it has a maximum relief of about 1,000 feet yet appears by contrast with the surrounding mountains as a low, rolling upland. The relief is largely due to cirquation and a few very small glaciers still persist. The topographic unconformity marks the upper limit of erosion by former valley glaciers, whose upper limt of erosion is also well shown on the truncated, interglacier spurs on the east slope of the Selkirks (Daly, 1915, Plate XXXIX). This upland surface of from 7,200 to 8,000 feet in elevation, appears as a linear depression between the much higher peaks of the Selkirks (up to 10,000 feet) to the west, and the higher ridges and peaks of the remainder of Dogtooth Mountains (8,600 to 9,300 feet) to the east. Beyond the limits of the map-area this linear upland surface can be traced to the southeast for 15 miles, and to the north it appears across the lower Beaver River. The strata of the Selkirks in this locality and of that part of Dogtooth Mountains east of Quartz Creek consist chiefly of massive quartzites and thus contrast with the phyllites, slates, and thinner-bedded quartzites found on Prairie Hills and Bald Mountain. However, two bands of fairly massive strata cross Prairie Hills obliquely, and to the southeast, together with the thin-bedded strata, form ridges and peaks 500 to 1,300 feet above the highest points of Prairie Hills. This would seem to indicate that this upland surface is not due merely to erosion of less resistant rocks. It is difficult to date this upland surface, to show how much it has been modified by glaciation, or to what degree it owes to faulting its altitude and relation to the higher mountains. However, the writer suggests that it represents a wide valley that existed in a region of moderate relief, in late Cretaceous or early Tertiary time, in support of which may be noted that the upland

exists now as a long, narrow depression, it trends obliquely across the structures, similar strata to the east of Bald Mountain form much higher elevations, and its surface is on an average 4,500 feet above Beaver and Columbia Rivers, both of which flow in valleys that must have been present in Tertiary time.

A small upland surface (0·5 by 0·25 of a mile) exists on a mountain just north of Kicking Horse Canyon, 4 miles east of Golden. This surface, which has an elevation close to 7,400 feet, is nearly flat and is developed across the edges of the Wonah quartzite, on the northeast limb of a syncline, strongly overturned to the southwest. The elevation of this surface is 4,800 feet above the floor of the trench and about 1,000 feet lower than the elevations of the accordant summit level of Brisco Range to the south, and of the western part of Van Horne Range. No other remnant of an upper surface was seen in Van Horne or Brisco Ranges; though it seems probable that spur crests, to the north of this upland remnant, in Van Horne Range, represent continuations of this upland surface, but are now reduced to narrow ridges by dissection. An examination of the spacing of transverse streams between Blaeberry and Kicking Horse Rivers indicates that the preservation of the surface noted is due, more or less fortuitously, to the wider spacing of transverse streams in its neighbourhood. This surface, which the writer thinks is not a local one due to glacial action, but instead is a remnant of a former surface of comparatively low relief, was, of course, developed subsequent to the deformation generally supposed to have taken place at the close of the Cretaceous, or in early Tertiary time. It was probably developed at the same time as the upland surface on Bald Mountain and Prairie Hills, since which time the surface of comparatively low relief has been dissected to a depth not less than 4,800 feet. This depth may be more or less than the amount of uplift that has taken place since the inception of dissection. There seems to be no definite evidence by which the amount of uplift may be valuated.

GENERAL GEOLOGY

Late Precambrian to Devonian strata are exposed within the map-area. The only igneous rocks observed were several thin flows, of very limited exposure and presumably of Lower Cambrian age, and several highly altered beds of volcanic origin (tuffs or flows) occurring in Late Precambrian strata.

In Dogtooth Mountains, Late Precambrian and Lower Cambrian strata occur, whereas in Van Horne and Brisco Ranges the strata are from Upper Cambrian to Devonian in age. The outcrops in the intra-valley ridges of the central topographic division, the Rocky Mountain trench, show to some extent the relations between the older and younger strata of Brisco Range and Dogtooth Mountains, respectively, for here Precambrian to Silurian rocks are present.

Stratigraphic Divisions

		Dogtooth Mountains	Steamboat and Jubilee Mountains	Brisco Range	Van Horne Range
Palæozoic	Middle Devonian			Harrogate	
	Silurian		Brisco	Brisco	Brisco
	Ordovician		Beaverfoot	Beaverfoot	Beaverfoot
				Wonah	Wonah
			McKay group	Glenogle and McKay groups	Glenogle and McKay groups
	Upper Cambrian	Canyon Creek	Jubilee	Jubilee	Ottertail (?)
					Chancellor
	Middle Cambrian				Undivided
	Lower Cambrian	Donald	Donald		
		St. Piran	St. Piran		
		Lake Louise			
		Fort Mountain			
Late Precambrian	Windermere	Horsethief Creek	Horsethief Creek		
			Toby		
	Purcell		Mount Nelson		

PRECAMBRIAN

The Precambrian strata are confined to districts lying west of Columbia River. In Windermere area, immediately south of the district being described, Walker (1926, pages 5-20) recognized the presence of two great series of Precambrian sediments separated from one another by a marked unconformity. The lower of the two series he recognized as the Purcell series, there represented only by an upper part, divisible, in descending order, into the Mount Nelson and the Dutch Creek formations. The unconformably overlying series was named by Walker the Windermere series and divided into the Toby conglomerate below and the Horsethief formation above. Since the term Horsethief was preoccupied, the present writer proposes that the term Horsethief Creek be substituted.

Walker (1925, pages 222-227) made a reconnaissance survey of the east slopes of Purcell Range from Windermere area to Spillimacheen River and found that the upper Purcell strata extended northward past Steamboat Mountain in a broad anticline pitching northward. To the

north he found the Toby conglomerate on the flanks of the same fold and still farther north he recognized the overlying Horsethief Creek formation. The work of the present writer has resulted in tracing the Horsethief Creek formation north along the whole length of Dogtooth Range where it is the only representative of the Precambrian succession.

Mount Nelson Formation

Within the limits of the area examined by the writer, the Purcell series is represented by the Mount Nelson formation alone, and this member occurs only at the north end of Steamboat Mountain where it is faulted up against Palæozoic strata. The outcrops are of crystalline limestone and quartzite. The formation is described by Walker (1926, page 10) as consisting of crystalline magnesian limestones and slates with, at the base and near the top, massive, white quartzites. The maximum observed thickness is stated to be 3,400 feet, but the uppermost part was destroyed by the erosion preceding the deposition of the Toby conglomerate.

Toby Conglomerate

The Toby conglomerate in Windermere area is stated by Walker (1926, pages 13-14) to vary in thickness between 50 and 2,000 feet. Only one small outcrop of this formation was seen. It occurs on the Brisco-Wilmer wagon road, north of Steamboat Mountain, and with some overlying Horsethief Creek strata is adjacent to the area of Mount Nelson strata mentioned above.

Horsethief Creek Formation

This formation in Windermere area is described by Walker (1926, pages 14-15) as varying in thickness between 4,000 and 5,000 feet. It is stated to be largely of grey, green, and purplish slates with some lenticular beds of conglomerate and, at different horizons, numerous thin interbeds of crystalline limestone.

Extensive exposures of Horsethief Creek strata occur in the western part of Dogtooth Mountains and the measures are divisible into four members. (1) (Top). Upper shale member. Consists of vari-coloured slates and phyllites; with interbands of quartzites and grits and a few, thin limestone layers. It has a thickness of 1,140 feet at Twelvemile Creek. (2) Limestone member. Massive, magnesian buff and blue limestone in places holding interbands of slate and sandstone. Strata above and below this massive magnesian limestone that are dominantly limy are included in the member. Thickness varies between 150 and 650 feet. (3) Lower Slate member. Vari-coloured slates and phyllites with some quartzite, sandstone, and limestone interbands. Associated with these are some green, chloritic, schistose strata holding metacrysts of a micaceous habit that have been spread along the cleavage planes by later movement. Thin sections of this rock show altered hornblende, and biotite, chlorite, ferruginous carbonate, kaolinized feldspars, chalcedony, and much magnetite and limonite. It may be an altered flow or tuff. Thickness, 1,000 feet or more. (4) Feldspathic, coarse quartzite and pebble conglomerate member. Chiefly heavily bedded, feldspathic quartzites

and pebble conglomerates with interbands of slates and phyllites. Thin sections of the quartzites show fragments of quartz and feldspar up to 4 mm. in diameter. The average size of the particles, which are subrounded, is 1 mm. The quartz is strained and granulated, and a little secondary growth of the particles is evident. Most of the quartz grains appear to have been derived from igneous rock or veins, but some of the rounded grains show rounded suture mosaics, as if they had been derived from previously granulated but healed quartz in gneiss or schist. The amounts of feldspar differ in the thin sections examined. There is rarely less than 1 per cent and occasionally 5 to 6 per cent. Microcline occurs most commonly, then orthoclase, microperthite, and albite-oligoclase. All except the orthoclase are but little altered. The groundmass consists of fine-grained quartz, carbonate, and sericite. A blue-grey phyllite, with scattered, rounded and subangular grains of opalescent quartz up to 5 mm. in diameter, occurs at several horizons. The quartz in these is strained and fractured. In some of the siliceous members carbonate has replaced finely granulated quartz and may form up to 40 per cent of the rock. The pebble conglomerates contain rounded and subangular fragments of quartz up to an inch in diameter, the matrix of which in some specimens is much finer quartz grains (2 mm. to 0·5 mm.), whereas in others it is predominantly argillaceous. Feldspar in rounded and subangular grains 2 to 8 mm. in diameter forms from 5 to 8 per cent of the rock, and some fragments of purple and green argillite occur. In one outcrop, where unfortunately the relations to underlying strata could not be observed, a pebble conglomerate with a green argillite matrix itself formed the matrix between angular fragments of green argillite from 4 inches to 4 feet in length. Thickness about 3,000 feet.

A gently undulating erosion surface at the Horsethief Creek-Fort Mountain contact occurs at the top of the Upper Slate member at Twelvemile Creek. In all other sections, Horsethief Creek and Fort Mountain strata showed no measurable difference in attitude, though the Fort Mountain strata rest on different horizons of the underlying Horsethief Creek at different localities. One fragment of *Newlandia* was the only fossil found in the formation.

Daly (1915) in mapping the northern part of Dogtooth Mountains divided the strata into three formations, from highest to lowest, Ross quartzite, Nakimu limestone, and Cougar quartzites, and placed the base of the Cambrian about midway in the Ross quartzite. Drysdale (*See* paper by Burling, 1918, page 146) reported finding upper Palæozoic fossils in the Laurie formation, near Laurie Station (20 miles west of Dogtooth Mountains), a formation that Daly's structure shows to underlie the Cougar quartzite and Nakimu limestone in their type locality, Cougar Creek. In the northern Dogtooth Mountains, the strata mapped by Daly as Nakimu and Cougar formations are of Precambrian age. Thus, if Laurie formation actually does underlie these formations to the west Daly must have misidentified as Nakimu and Cougar the strata so designated in Dogtooth Mountains. It is the writer's opinion, however, that such misidentification was not made, but that, in all probability, the structural relations of the Laurie and Cougar were not interpreted correctly, near Laurie Station. This opinion is supported by Daly's (1915, page 68) observed contorted zone in the Laurie. It is for this reason that the stratigraphic terms used

by Daly in the northern Dogtooth Mountains are not adopted in this report. Horsethief Creek strata are probably of the same age as Hector and Corral formations of Field map-area, which were established by Walcott in 1910. According to strict priority Walcott's names should be used rather than Horsethief Creek, but since Walker found complete sections of these strata, with the underlying Toby conglomerate, in Windermere area, and was able thereby to show that Horsethief and Toby formations comprised a distinct Precambrian series above the Purcell series, it is thought advisable to adopt Walker's nomenclature.

The source of the material composing the Horsethief Creek strata is not known. The feldspathic quartzite member, the lowest here exposed, indicates both by the size of the particles and by the freshness of the fragments of microcline, microperthite, and albite-oligoclase that the source of the material was not far distant. The feldspathic quartzite beds of this member are 20 to 100 feet in thickness and alternate with siliceous phyllites, banded slates, and argillites, and the whole appears to be a fluviatile deposit. The limestone member is probably marine and so may be the two argillaceous members with their thin (1 to 6 inch) beds of sandstone, a few bands 25 to 50 feet thick of quartzites, and thin limestone bands several of which are quite black. It seems probable that the strata were laid down under alluvial piedmont conditions, with changes from time to time to lake or marine deposition.

The writer found numerous instances of crumpling in the banded phyllites, that could only have taken place by slumping movement before the rock hardened. In every case noted, from Twelvemile Creek to the north of Prairie Hills, the shortening occurred in a southeast-northwest direction. This may indicate that the shoreline had a northeast trend.

PALÆOZOIC

Fort Mountain, Lake Louise, and St. Piran

The earlier Lower Cambrian strata of Dogtooth Mountains consist of two massive quartzite formations, separated by a formation that is dominantly argillaceous. A similar succession occurs in Field map-area, where the formations were named by Walcott (1908, 1912 A) from the top, downwards, St. Piran, Lake Louise, and Fort Mountain. The identity of the basal Lower Cambrian in Dogtooth Mountains with these formations of Field map-area is not positively established. However, in both areas, a massive, purplish quartzite rests on presumably late Precambrian, is overlain by a dominantly shaly series of strata, which again is overlain by massive, pinkish, and grey quartzites that conformably underlie highly fossiliferous Lower Cambrian slates containing many Lower Cambrian fossils. In Field map-area Walcott found a sparse Lower Cambrian fauna in the St. Piran and Lake Louise formations, whereas only one definitely known Lower Cambrian fossil was found, at one locality in Dogtooth Mountains, close to the top of the upper quartzite formation. These basal Lower Cambrian strata unquestionably represent dominantly sandy deltaic deposits that presumably were derived from land lying to the west of the areas under consideration. Although this in turn may not be used as proof, it does, however, suggest that the beds in Field map-area

may have been deposited in marine waters at the same time that corresponding beds of the Lower Cambrian of Dogtooth Mountains area were deposited higher in a delta in brackish or fresh water, and thus account for the absence of fossils in these strata in the map-area. Thus, although there is not sufficient proof to identify positively the three stratigraphic divisions of the basal Lower Cambrian in Dogtooth Mountains with the named formations of the basal Lower Cambrian in Field map-area, the writer thinks the evidence is sufficiently sound to make use of Walcott's formational names. These formations are well exposed in the eastern part of Dogtooth Mountains and in a broken syncline along the east side of Prairie Hills. The following section was measured in high cliffs between Lang and Cirque Creeks 12 miles northwest of Golden.

	Feet
St. Piran formation—2,360 feet thick	
Rusty sandstone with *Callavia* and vertical worm burrows	20
Quartzite beds, 1 to 3 feet thick, alternating with beds of brown-weathering argillite, 3 to 4 feet thick	131
Massive, jointed, pinkish grits and quartzites, showing much crossbedding	674
Platy, sericitic sandstone with thin argillite interbeds	235
Pinkish quartzites with some beds of pebble conglomerate 1 to 3 feet thick. Many beds show crossbedding	1,200
Quartzites in layers 10 to 20 feet thick, alternating with thinner beds of purplish, argillaceous, fine-grained sandstone	100
Lake Louise formation—1,050 feet thick	
Predominantly argillites, slates, and phyllites—grey, green, brown, and purplish. Some thin, sericitic quartzite interbeds	700
Alternating sericitic quartzites, sericitic argillites, and phyllites, with an occasional 5-foot bed of quartzite	350
Fort Mountain formation—2,000 feet and more in thickness	
Alternating purplish quartzite and fine-grained, sericitic, argillaceous sandstone. The quartzite beds are generally much the thicker	2,000?

The basal Lower Cambrian strata thin rapidly to the south, for at Twelvemile Creek, 18 miles to the southeast of the locality of the above section, the total thickness is only 1,514 feet. In Twelvemile Creek section the St. Piran is 325 feet thick, the Lake Louise 634 feet thick, and the Fort Mountain 555 feet thick. Still farther south, in Windermere map-area, these basal Lower Cambrian rocks are absent and higher (Upper?) Cambrian strata rest on Horsethief Creek strata.

The beds of massive quartzite range in thickness from 1 to 10 feet and in some cases show no minor stratification, but crossbedding is frequently marked. Some of the beds are lenticular and pinch out in several hundred feet. Erosion surfaces of a local nature are visible in various places. The average size of the grain in most of the quartzite beds falls between 0·25 and 1·0 mm., but beds from 1 to 3 feet thick, of fine pebble conglomerate (pebbles 5 mm. to 1 cm.), are present, and occasional, thin, irregular layers, a few inches thick, hold well-rounded pebbles 1 to 3 cm. in diameter. In general, the particles larger than 0·4 mm. are subrounded to rounded, and those of lesser diameter subrounded to angular. Thin sections of the quartzites show feldspar, commonly 3 to 4 per cent, occasionally less than 1 per cent, and in one instance 10 per cent. The feldspars are much the same as those found in the lowest member of the Horsethief Creek strata and consist of microcline, orthoclase, microperthite. and albite-oligoclase, decreasing in abundance in the order named. Ortho-

clase is commonly much altered, but the other feldspars are surprisingly fresh. Zircon, apatite, titanite, and tourmaline also occur in small amounts. Most of the grains have a coating of iron oxide, quite thin in the pinkish quartzites, but thicker in those of a purplish red colour, where the oxide also occurs as part of the remnant. The quartz grains are strained, often granulated, and commonly show secondary growth. The cement varies greatly: silica, iron oxide, carbonate (occasionally up to 40 per cent of the rock), sericite, and chlorite.

Walcott (1910) has described the relation of the Lower Cambrian and the Precambrian in Bow River localities. He found the attitudes of the two groups of strata to be concordant in any one section, but recorded that angular fragments of the underlying slates occur in the base of the Fort Mountain conglomerate, that this conglomerate varies in thickness, that a difference in lithology exists between the Cambrian and Precambrian rocks, and that the base of the Cambrian rests in different places on different strata of the underlying formation. All these features were held to indicate a pronounced break between the Cambrian and Precambrian.

Daly (1915, pages 87-93), in discussing these points, thinks that the angular fragments in the base of the conglomerate do not show a significant time break, and states that "the composition and habit" of the Fairview (Fort Mountain) conglomerate is matched by "many beds of conglomerate far down in the Precambrian of the Rockies." Variations in the mode of deposition of the underlying strata are put forward to account for the differences exhibited by the strata underlying the Fort Mountain conglomerate in different localities.

It is admittedly difficult to evaluate any erosion surface seen between non-fossiliferous concordant strata in any one section, but where such a surface occurs or seems to occur just below a particular horizon over an extensive region, as in the present case, it seems altogether likely that the surface indicates a time break of considerable duration. And if, as in the present case, the strata displaying the erosion surface belong unmistakably to horizons differing in age from district to district, then the erosion surfaces surely are indicative of an appreciable time break.

The writer is convinced that in southeastern British Columbia a period of erosion due to uplift without marked tilting or folding preceded early Cambrian deposition. Within the map-area at least 1,000 feet of strata appear to have been eroded.

The writer had previously thought that the St. Piran to Fort Mountain formations of Dogtooth Mountains were to be correlated with the Cranbrook quartzites of Cranbrook map-area, and northward from there to Mount Grainger (Walker, 1926), but recent work by Cairnes (personal communication) suggests that such correlation may not be correct.

Changes of level, accompanied by slight vulcanism, occurred after the deposition of St. Piran formation, though there is no clear proof that erosion took place within the map-area. A 2-foot bed of cobble conglomerate occurs immediately below the *Olenellus-Rustella* zone at Twelvemile Creek, where it forms an even bed resting on the St. Piran formation. Again, on the west side of Quartz Creek, 13 miles southeast of Beavermouth, a conglomerate with boulders of quartzite, limestone, and argillite up to 2 feet in diameter, underlies a small outcrop of Donald strata.

An amygdaloidal basic flow, 20 feet thick, occurs between Donald strata and St. Piran formation on a mountain at the head of Oldman Creek, where it is exposed for 1,000 feet along the strike. Ten miles to the southeast a 60-foot bed, having lenticles 10 to 15 inches in length, of a fine-grained, greenish rock speckled with magnetite, in a sparse matrix of clastic material, occurs at the same horizon. Thin sections of the lenticles show lath-shaped outlines of plagioclase now largely replaced by calcite, and much euhedral magnetite. This rock may represent a pillow lava.

Donald Strata (Lower Cambrian)

Donald strata overlie St. Piran formation conformably in Dogtooth Mountains. The best exposures are on the southwest-dipping limb, and in downfaulted blocks in the centre of the major anticline in the eastern part of Dogtooth Mountains, and on the west wall and floor of the trench between Twelvemile and Lang Creeks. A narrow strip of Donald strata occurs below and in front of a thrust fault in the central part of Dogtooth Mountains between the headwaters of Quartz and Twelvemile Creeks.

The succession of strata from the base of the Donald to a 30-foot bed of crystalline limestone (Plate IV B), a good horizon-marker 300 to 400 feet above the base, is quite constant and well exposed; but the higher strata have been destroyed by recent erosion in most of the areas traversed, and in the few sections where they do occur the lithology differs, and because of faulting, drag-folding, and cover, the succession is not definitely known. A generalized section starting at the base is as follows.

	Feet
1. Six-inch, hard sandstone beds alternating with slates	25 to 100
2. Sandy limestone alternating with slates	150
3. Green slates, limy, and, or, sandy in different localities	120
4. Massive, hard sandstone	0 to 35
5. Cream-coloured, coarsely crystalline limestone reddish at base	30 to 40
6. Alternating, impure limestone, sandstone, and slates	400 to 800
7. Limy slates with dark, dense, limestone nodules and bands	800

It is doubtful if the maximum observed thickness of member No. 7 lies entirely above the alternating strata of member No. 6 of other sections; that is, the upper part of the alternating beds may grade laterally into the lower part of the limy slates. Fossils were collected from many localities and from all horizons except from the green slates (No. 3) and the bed of massive quartzite No. 4. The collections were examined by Dr. Resser who reports that all are of Lower Cambrian age. As yet the fossils have been determined as to genus only. The following faunal horizons are indicated. In Member No. 1, *Rustella, Kutorgina, Hyolithes, Salterella, Rustella, Olenellus,* and other Mesonacids. In Member No. 2, *Rustella, Salterella,* Archæocyathid, and Mesonacids. In the 30-foot to 40-foot band of crystalline limestone, Member No. 5, Archæocyathids, Mesonacids, and Agraulid tail, and *Kutorgina, Micromitia, Bonnia, Olenellus, Rustella, Hyolithes, Salterella, Dorypyge.* The genera collected from Members 6 and 7 are *Olenellus* and other Mesonacids, *Obolus, Micromitia, Kutorgina, Dorypyge, Bonnia,* and *Girvanella.*

The total estimated thickness of the Donald strata in the vicinity of Canyon Creek is 1,500 ± feet. At the northeast end of Jubilee Mountain, 30 miles to the southeast, it is but 200 feet thick. The fauna of this southeastern exposure corresponds to that of the upper part of Donald strata near Canyon Creek, and thus the strata overlap towards the southeast.

Until specific identifications of the fossils are available, close correlation of the Donald with other Lower Cambrian formations of southeastern British Columbia cannot be made. The Donald strata are correlated, tentatively, with the lower part of the Mount Whyte formation of the sections at Mount Bosworth (Walcott 1917, and Burling 1914) and those of Grainger Mountain (Walcott 1924, page 30); also with the lower part of Burton formation at Ram Creek (Schofield 1922, page 13, Walker 1926, page 17) and with the Eager formation near Cranbrook (Schofield 1922, page 12).

Canyon Creek Slates (Middle? Cambrian)

Canyon Creek slates are well exposed along Canyon Creek in the terraced belt west of Columbia River 6 miles south of Golden. They consist of dark grey slates with thin, shaly lime bands and a few thin beds of limestone. The only fossils found are sponge spicules, some of which occur in radiating groups much resembling those figured by Walcott (1920) from the Middle Cambrian Stephen formation in the Rocky Mountains.

The most southern exposures of these slates are at Twelvemile Creek, from where they extend northwestward in a band about 1½ miles wide to Canyon Creek, a distance of about 4 miles. From Canyon Creek they continue northwestward for 10 miles to Holt Creek, the exposures narrowing until at Holt Creek the beds disappear and are probably faulted out. These same slates occur on the western edge of the terraced belt of the trench northwest from Oldman Creek to and beyond Columbia River Canyon. The nature of the contacts with the bounding formations is not known. In both the areas described, Donald strata lie to the west of the exposures of Canyon Creek slates and an Upper Cambrian horizon of McKay group strata lie to the east. The outcrops of Donald strata and McKay group are dominantly of shale along their exposed contacts with Canyon Creek slates, and because all these shaly strata are isoclinally folded and intricately drag-folded where so exposed, the writer was unable to define clearly the limits of Canyon Creek slates, or the nature of the contacts. They occupy a stratigraphic position between a Mesonacid-bearing Lower Cambrian horizon and a *Dikelocephalus* horizon of the Upper Cambrian, that is fairly high up in the Upper Cambrian. Thus they may belong to the Middle Cambrian or to the lower part of the Upper Cambrian, both of which are represented by thick successions of strata 20 miles to the east, in Field map-area. Burling (1922, page 255) records that Middle Cambrian fossils were found by Ami in Columbia River Canyon west of Donald in a locality that might be within the northern area of Canyon Creek slates as mapped by the writer. It seems probable, then, that the Canyon Creek slates are of Middle Cambrian age.

Because of the complex structure of these slates their thickness could not be measured, though probably they are at least 2,000 feet thick.

Undivided Middle and Upper Cambrian

The strata included here consist of thin and thick-bedded limestones, some of which weather buff, some bluish grey, and others show ½ to 2-inch banding of blue and buff. The outcrop of this limestone band occurs in a strip ½ to 1½ miles wide that extends from Leanchoil, at the "hairpin" bend of Kicking Horse River, northwest to Blaeberry River, a distance of 25 miles. This band is bounded in outcrop to the northeast by buff-weathering shales, probably Allan's (1915) Chancellor formation, and to the southwest by alternating shales and limestones of the lower part of McKay group. Upper Cambrian fossils were collected from beds in the limestone band in several localities 2 to 3 miles southeast of Blaeberry River. Others, similarly of Upper Cambrian age, were collected at localities in this band to the southeast near Kicking Horse River. At an elevation of 6,500 feet on the west slope of Mount Hunter 2½ miles northeast of Palliser a small collection of fossils was obtained from this band in massive blue limestone, 100 feet thick, among which was a crustacean, probably Esmeralda (C. E. Resser, personal communication) which is a Middle Cambrian (Burgess shale) genus. Lying immediately to the northeast of this Middle Cambrian limestone, and within the band, fossils of Upper Cambrian age were collected. Since the structure is complex in the limestone band, and closely spaced traverses were not made across it, it is not known whether or not other outcrops of Middle Cambrian occur, and for this reason it has been mapped as Undivided Middle and Upper Cambrian strata.

To the southwest of the band of Undivided Middle and Upper Cambrian limestones there is a wide, overturned syncline, so that in going from the syncline to the northeast towards the limestone band progressively older strata are encountered. Alternating shales and limestones, highly drag-folded, are in contact with the southwestern edge of the limestone band, and these belong to the lowest part of McKay group exposed here, which is very poorly fossiliferous. However, a few fossils were found in the eastern and lowest part of McKay group, near Leanchoil, among which was an Homagnostus of high Upper Cambrian or possibly Ozarkian (Ulrich) age (B. F. Howell, personal communication). At Mount Hunter, as already noted, this high Upper Cambrian zone of McKay group strata is in contact with Middle Cambrian beds and these in turn with Upper Cambrian beds, lower in the Upper Cambrian than the lowest zone of McKay group. Thus a fault must be inferred between the McKay group strata and Middle Cambrian in this locality. Two miles northwest of Leanchoil a fault with a low east dip was observed between McKay group strata and Upper Cambrian beds of the limestone band. This evidence, together with the highly contorted structures to the west of the band, leads the writer to place a northeast-dipping fault between the limestones of the band and the strata of McKay group to the southwest.

The northeastern edge of the limestone band appears to dip steeply beneath the buff-weathering shales that farther southeast have been mapped by Allan (1915) as Chancellor formation.

Jubilee Limestone (Middle, and, or, Upper Cambrian)

Jubilee limestone derives it name from Jubilee Mountain, the most northeastern intravalley ridge in the map-area, where it is well exposed.

It consists of massive-bedded, cliff-forming magnesian limestone, generally grey in colour, and weathering grey to white. Some bands are siliceous and on weathering these stand out from the purer limestone in irregular relief. Stratification is rarely shown except by bedding joints; but occasionally, as at the south of Jubilee mountain, ½-inch bedding is seen. At this same locality the lower beds are reddish and contain some beds of intraformational conglomerate, the fragments of which consist of fine-grained magnesian limestone; the matrix consists of a similar carbonate which, however, contains in irregular distribution numerous, subrounded quartz grains up to 2 mm. in diameter.

Jubilee limestone is exposed throughout its whole thickness of 2,000 feet on Steamboat and Jubilee Mountains. It also occurs in the centre of an anticline on the west side of Brisco Range south of Sinclair Creek, and as a narrow strip bordering the west side of Red-wall fault which crosses Sinclair Creek 2½ miles northeast of Columbia River. The Brisco Range exposures are incomplete.

At the south end of Steamboat Mountain, Jubilee limestone rests on Horsethief Creek strata, whereas 25 miles to the north, at the northeast corner of Jubilee Mountain, it is seen resting on Lower Cambrian Donald strata.

Walker (1926, page 22) considers this limestone, which he mapped in Windermere area, to be "the stratigraphic and, in general, the lithologic equivalent of the Ottertail formation of Upper Cambrian age of Field map-area, 40 miles distant along the strike of the strata," and uses the name Ottertail for it. Walcott (1924, page 20, and 1927, page 165) tentatively correlated this limestone with his Lyell, 100 to 130 miles to the northeast.

No fossils have been found in this limestone in Windermere or Brisco-Dogtooth map-areas. At Jubilee Mountain Mesonacids are found 100 feet below its base, and Upper Cambrian fossils were found just above it. South of Windermere map-area, Walker's Ottertail formation rests on Middle Cambrian Burton and Mount Whyte (upper part), and on Lower Cambrian (?) Cranbrook formations; in Windermere area it rests on Windermere series. Thus it may belong to either Upper or Middle Cambrian. Jubilee limestone is exposed only at the south of the map-area, whereas Canyon Creek slates occur only at the northwest, and so the stratigraphic relation of these two formations is not known.

Olenus Beds (Upper Cambrian)

The Upper Cambrian fossil *Olenus* was found in thin, blue-grey limestone beds associated with grey shales in a wooded and drift-covered area north of Jubilee Mountain. Small outcrops of Donald strata, St. Piran formation, Jubilee limestone, and Olenus beds occur with a relation that suggests several faults at least and because of the drift it was not possible to determine the stratigraphic position of the Olenus beds.

This is the first known occurrence of *Olenus* in the Rocky Mountain region and so the relative position of these beds to other Upper Cambrian formations cannot be given from the fauna, which was identified by Dr. Resser as follows: *Olenus* sp., *Psuedagnostus* sp., *Agnostus reticulatus*,

Agnostus pisiformis, Housia?. Dr. Resser is of the opinion (personal communication) that it may belong below the Goodsir (*Housia canadensis* zone).

McKay Group

Following Jubilee limestone in stratigraphic section in the southeastern part of the area, and Canyon Creek slates in the northwestern part, there is a thick succession of alternating shales and limestones that include faunal horizons from Upper Cambrian to Chazy age. The writer was unable to separate these strata into their constituent formations for mapping purposes, and hence they are shown in one colour on the map. The name is taken from John McKay Creek, a tributary to Sinclair Creek, where the most complete and least disturbed section was measured.

The McKay strata are variable, but consist for the most part of alternations of blue-grey limestone and grey shales. The alternations vary from those in which shales and limestone, equal in amount, alternate, in 1-inch layers, to those where alternations of 20-foot bands occur. In the thicker bands of limestone the limestone may be thin bedded with quite thin shaly partings, or be made up of 1 to 4-foot beds of limestone. The thicker shale bands usually include some thin interbeds of limestone. The upper part of the group is more persistently thin bedded and is rusty weathering, with ripple-marks and mud-cracks, below which there is a thickness of 1,500 feet of alternations of shales and limestone, in which intraformational limestone conglomerates are abundant. At McKay Creek, massive, blue limestone occurs beneath the intraformational conglomerates, but the base of McKay strata is not exposed here. The lower part of the McKay, exposed on the west side of Columbia River, from Canyon Creek north, is quite shaly and contains 6 to 12-inch beds of light blue, crystalline limestone. No simple complete section of McKay strata is exposed within the map-area. The measured section at McKay Creek is over 3,000 feet thick and there are present, in addition, drag-folded and drift-covered strata estimated to represent an additional thickness of about 1,000 feet; the base is not exposed.

McKay strata are exposed extensively in Brisco Range where, with the exception of small areas of Jubilee limestone outcropping in the vicinity of Sinclair Creek, they are the lowest strata outcropping. Wide exposures occur in the western part of Van Horne Range. Small outcrops occur on the floor of the trench east and west of Columbia River, north of Harrogate, and in somewhat larger areas in Steamboat and Jubilee Mountains where with a thickness of 2,000 feet they are contained between the Jubilee limestone and the Beaverfoot formation of Richmond age.

The section following was made at McKay Creek, about 2 miles north of Sinclair Creek. Only the more characteristic generic determinations of the fossils have been made, for which thanks are due to Dr. C. E. Resser. The graptolites were identified by Dr. Rudolf Ruedemann.

Feet | Feet

Top. Wonah quartzite (here 60 feet thick)

55. Thin-bedded, argillaceous limestone: light grey, weathering yellowish. Anastomosing outweatherings showing nodular and fine, irregular bedding. "Linguoid current ripples" (Holmes 1921, page 167)

50 feet below Wonah—*Orthis*

55

342. 6 to 36-inch beds, medium to dense-grained, crystalline, grey limestone; weathers grey with irregular outweatherings. At 38 feet from top of member occurs a band of conglomeratic dolomite that consists of oval and crescent-shaped fragments of dark blue-grey dolomite, up to 1 cm. in length, cemented by a light yellow, sugary-textured dolomite that contains clear quartz grains up to 4 mm. in diameter

57 feet below Wonah quartzite

Phyllograptus

115 feet below Wonah quartzite

Isoteloides

139 feet below Wonah quartzite

Amphion

Diplograptus (possibly *dentatus*)

195 feet below Wonah quartzite

Orthis

319 feet below Wonah quartzite

Orthoid Brachiopod

Xenostegium 397

116. 1 to 4-inch beds of argillaceous limestone. Some layers nearly all shale and quite lenticular, pinching out in a few feet. In other layers the argillaceous material is dolomitic and contains nodules, 3 inches long and about 1 inch thick, of dense, dark blue limestone, around which the very fine bedding lines of the argillaceous material bend. Some layers replete with broken fragments of trilobites; a shallow water concentration of shells and moults

453 feet below Wonah quartzite

Plectorthis

477 feet below Wonah quartzite

Isoteloides

489 feet below Wonah quartzite

Megalaspis

513

373. 1 to 15-inch jointed limestone showing irregular bedding lines $\frac{1}{4}$ to $\frac{1}{2}$ inch apart. Most of this member consists of finely crystalline blue limestone with thin layers of rusty weathering, argillaceous limestone. Some layers are dolomitic

637 feet below Wonah quartzite

Very peculiar brachiopods, unidentified

667 feet below Wonah quartzite

Plectorthis

685 feet below Wonah quartzite

Orthoid Brachiopod

697 feet below Wonah quartzite

Plectorthis

823 feet below Wonah quartzite

Orthis

An horizon at 865 feet below Wonah quartzite is stated by Dr. Resser to be of Canadian age (Beekmantown) 886

14. Thin-bedded limestone with a few thin chert bands 900

475. Dense, grey, dolomitic limestone joints 2 feet, occasional cherty bands. In some places the chert encloses joint blocks of the dolomite. No fossils found. (This member was seen only at McKay Creek and north end of Steamboat Mountain.) 1,357

113. 4 to 10-inch beds of blue-grey, crystalline limestone. Also with chert bands associated with thin, light grey, dolomitic layers. Some beds of intraformational conglomerate occur.

Fossils from 1,365 feet below Wonah quartzite stated by Dr. Resser to be of Canadian age (Beekmantown) 1,470

1,565. Alternating, large bands, from 3 to 20 feet thick, of 4 to 12-inch, bedded, bluish grey limestone, and shale with interbeds $\frac{1}{4}$ to 1 inch thick of dense, blue limestone. Numerous limestone beds are intraformational conglomerates

2,161 feet below Wonah quartzite

Kainella

2,939 feet below Wonah quartzite

Symphysurina

3,035 feet below Wonah quartzite

Lingulella

Symphysurina 3,035

At this horizon drag-folding becomes marked, and measuring of section was discontinued

600 (estimated). Drag-folded, thin beds, from the bottom of which a *Symphysurina* was collected 3,635

750 (estimated). 1 to 4-foot, bedded, blue-grey limestone 4,385

. . . . Base not exposed . . . . . .

No other thick, continuous section, capable of being measured with any degree of accuracy, was found within the map-area, but numerous collections of fossils were made from partial sections. From such collections, and those at McKay Creek, the succession of faunal zones given below was made, in which the McKay Creek section has been used as a standard.

Fossil Zones in McKay Strata

Chazy	*Orthis* *Phyllograptus* [1]*Ampyx* *Isoteloides*	Zone 8
	Orthis [1]*Megalaspis* *Ampyx* *Orthis*	Zone 7
Beekmantown	*Amphion* [1]*Diplograptus* possibly *dentatus*	Zone 6
	[1]*Xenostegium* *Plectorthis* *Gastropod* *Shumardia* [1]*Megalaspis* *Plectorthis* *Gastropods*	Zone 5
Ordovician (Ozarkian of Ulrich)	[1]*Ozarkispira* *Xenostegium* *Ellesmeroceras ?* *Bellefontia ?* *Isoteloides* *Plectorthis*	Zone 4
	Obolus *Syntrophia* *Hystricurus* [1]*Kainella* *Apatokephalus* *Keytella*	Zone 3
	Ozarkispira *Isoteloides* *Symphysurina* [1]*Symphysurina* *Lingulella* [1]*Symphysurina*	Zone 2
Upper Cambrian	[1]*Dikelocephalus* (*Briscoia* zone reported from same beds by Walcott (1924, page 45))	Zone 1

The successive faunal zones are named after the most characteristic and constant fossil of each zone. These are marked [1] in the above list and repeated for easy reference below.

Ampyx—zone 8; *Megalaspis*—zone 7; *Diplograptus*—zone 6; *Xenostegium*—zone 5; *Ozarkispira*—zone 4; *Kainella*—zone 3; *Symphysurina*—zone 2; and *Dikelocephalus*—zone 1.

In Brisco and Van Horne Ranges there is a succession of graptolite-bearing dark shales that have been mapped as Glenogle shales and on the map and in structural sections are shown as lying above McKay group strata. In the central and eastern part of Brisco Range these shales have a thickness of 1,500 to 1,600 feet, whereas they are very thin or absent

entirely on the western slope of Brisco Range, 3 or 4 miles distant. The Glenogle shales are, however, of the same age as the upper part of McKay strata, and represent a black shale facies deposit, ranging in age from Beekmantown to Chazy, corresponding to a dominantly limestone facies of the McKay group deposited in the same range of time. Few fossils other than graptolites are found in the Glenogle, whereas the corresponding limy facies of McKay holds chiefly trilobites, brachiopods, gastropods. However, at McKay Creek, *Diplograptus*, possibly *dentatus* of 3rd Deep Kill zone, was found in McKay strata in zone 6 as shown above. At the same locality *Phyllograptus and Ampyx* of Normanskill age were found together in the limy McKay facies and several miles to the east these two fossils were found in the black shale facies. Thus the upper part of McKay group has Normanskill (Chazy) and 3rd Deep Kill (Upper Beekmantown) horizons, as also has the Glenogle shales. The 2nd and 1st Deep Kill zones known to be present in Glenogle shales, and of older Beekmantown than the 3rd Deep Kill zone, will probably correspond to zone 5 of the table above, though it is probable that the lowest Beekmantown of the McKay group is older than the lowest (1st) Deep Kill zone of the Glenogle shales.

In 1922 and 1923, Dr. Walcott carried out stratigraphic investigations in the southern part of Brisco Range and considered the succession of formations to be: Ordovician—Glenogle, Sinclair, and Sarbach; Ozarkian—Mons; Upper Cambrian—Lyell (Walcott 1924, pages 35-39). Later work by Walker (1926) led Walcott (1928, 75, No. 5, page 220) to regard Sinclair as a synonym for Glenogle and the term Sinclair is, therefore, dropped. In the same publication, on page 222, he states, "It is highly probable that the Glenogle shales are the stratigraphic equivalent of a portion of the Sarbach formation." From an examination of the fossil lists given for Sarbach formation (volume 75, No. 5) it would appear that Sarbach formation is probably equivalent to part of the Glenogle shales rather than as stated by Walcott, and that the Sarbach may go lower in Beekmantown than the basal part of the Glenogle shales. The lowest faunal zone of Walcott's Mons formation (Briscoia zone) is now considered (Resser, C. E., personal communication) to belong to Upper Cambrian, probably contained in Sabine formation of Schofield (Royal Society, 1920, page 76). The Lyell of Brisco Range is the Jubilee limestone with which we are not concerned here. A comparison, then, of the writer's group names and Walcott's formations (revised) is as follows.

Walcott		Evans	
Chazy and Canadian.....	Glenogle	Chazy and Beekmantown.....	Glenogle
Canadian.....	Sarbach	Beekmantown	
Ozarkian.....	Mons	to	McKay group
Upper Cambrian.....	Sabine ?	Upper Cambrian	

The present status of the formations listed above is indicated in the remarks of Dr. C. E. Resser in reporting on the collections from McKay group.

"The foregoing determinations are only general, but will serve to show the stratigraphic succession. Most of the indefiniteness is due to a lack of knowledge as to where to draw the faunal boundaries above and below the Mons series. For instance the fauna containing trilobites *Xenostegium* and *Megalaspis* may all be Canadian (Beekmantown) in age, but that has not yet been proven. Further, the upper boundary of the Sarbach is somewhat involved in the question as to what Megalaspis really is, a point which has not been entirely settled as yet. . . . . (and referring to the writer's collections) . . . . 'several new trilobite genera are represented and most likely many of the species are new. . . . .'"

In Windermere map-area, which adjoins the present map-area in Brisco Range south of Sinclair Creek, Walker (1926) mapped as Goodsir formation the strata placed in McKay group by the writer. He states "This formation is considered to be the lithologic and stratigraphic equivalent of the Goodsir formation of the Field map-area." Walcott (1928, pages 235-237) strongly objects to this correlation and as far as the faunas of the two areas are known, his objections are justified. The writer is unable to prove whether or not the McKay group is to be correlated with the Goodsir strata, but has some evidence that may help to solve this question.

In order, however, to explain the controversial nature of the correlation, the history of the usage of the term "Goodsir" is given below.

The term Goodsir was originated by Allan (1911, page 180, and 1914) who applied it to strata on Mount Goodsir in Ottertail Range and estimated it to be 6,040 feet thick. He found fossils in the lower 300 feet and these were determined by Walcott as of Ordovician age. Allan defined the Cambrian-Ordovician boundary as being at the junction of the underlying Ottertail and overlying Goodsir. He found no fossils in the upper part of the Goodsir, and the top of the Goodsir was not defined, for the "formation" continued to the summit of the mountain. Walcott (1912, B, page 230) described the fossils found by Allan and referred the faunule without any reservation to the Ceratopyge zone. Allan (1913, pages 180-1, and 1914, pages 94, 99, 100, 101) states that in Beaverfoot Range, Goodsir strata grade up into the Graptolite shales. Burling (1915, page 98) states that he has discovered several faunal horizons in the Goodsir, and that additional collections from the nearby basal *Ceratopyge* horizon indicate that the lower part of the Goodsir should be correlated with the Upper Cambrian Orr formation of the House Range section Utah.

Raymond (1922, page 208) questions the identification of the form *Ceratopyge canadensis* from the lower part of the Goodsir of Goodsir Mountain, suggests it be called *Housia canadensis*, but states there can be no doubt that the faunule belongs to the *Ceratopyge* zone. Burling (1922, B, page 255) reiterates his belief that the faunule is of Upper Cambrian age and again states (1922 A, page 458) that in Beaverfoot Range middle and upper portions of the Goodsir have yielded a number of fossil horizons, of the part of the geological column between the Upper Cambrian and the Canadian (Beekmantown). As yet, he states, he is unable to locate the exact position within the Goodsir of the Cambrian-Ordovician boundary. Walcott (1925, page 94) adopted Raymond's suggestion and applied the

name *Housia canadensis* to the form he had earlier identified as *Ceratopyge canadensis*, stating that it came from the Upper Cambrian, Goodsir formation on Mount Goodsir and at Moose Creek, southeast of Leanchoil.

Shepard (1926, pages 662, 628) applied the name Goodsir to the strata of Brisco Range that Walcott designated as Mons and Sarbach formations. Walker (1926, pages 22-24) adopted the name Goodsir for the strata on Stanford Range, below the Glenogle shales and above an horizon that he correlated with the Upper Cambrian, Ottertail formation. Walker states that strata north of Stoddart Creek, Brisco Range, correlated by Walcott (1924, pages 35, 36) with the Mons formation found between Banff and Glacier Lake, and said by Walcott (1923, page 459) to be of Ozarkian age, belong to the Goodsir. Walker collected fossils at several localities from strata at the top of his Goodsir, just below the Glenogle shales. These were examined by Walcott who reported they were from an horizon higher than any in his Mons and that they were of Canadian (Beekmantown) age. Walker states that in Windermere area, the lowest zone in the Goodsir may be somewhat older than the zone in the basal part of the formation on Mount Goodsir.

Walcott (1927) stated that the true Goodsir is confined to the east of a great fault that passes along the east slope of Brisco Range. The Goodsir, according to Walcott, was laid down in a seaway that had little connexion with another to the west in which the Mons, Glenogle, and other strata were deposited. The strata of the two basins have been brought into juxtaposition along the great fault mentioned above.

According to Walcott (1928, pages 232-237) a restudy of the fauna of the basal part of the Goodsir on Mount Goodsir reveals that it is undoubtedly of Upper Cambrian age, and that the strata should be correlated with the Upper Cambrian, Orr formation, Utah. Since fossils are unknown in the greater part of the very thick, so-called Goodsir formation of Mount Goodsir, the age of these upper beds remains unknown. The Goodsir does not extend west of the great fault passing along Brisco Range; on the west side of this fault, the strata, by some called Goodsir, that lie beneath the Glenogle shales, belong to the Mons formation of Ozarkian age and, therefore, are much younger than the Upper Cambrian fauna found in the basal part of the type Goodsir. Walcott states that it may be that the Mons may be represented in the upper part of the great thickness of the original Goodsir, but that no existing evidence favours such a supposition. He suggests that the name Goodsir should be applied only to the lower fossiliferous part (300 feet) of the Goodsir or else be used as a series name for the entire 6,040 feet of strata referred to the Goodsir by Allan.

The points at issue seem to be two: the age of the fauna present in the lower 300 feet of the original Goodsir; and the horizons possibly represented by the overlying great thickness of the original Goodsir. According to Raymond the fauna of the basal Goodsir is of Ordovician age; Walcott maintained it was of Late Upper Cambrian age. Had the name Goodsir formation been restricted to the fossiliferous lower 300 feet, it is probable that no one would have contended that Goodsir formation occurs in Brisco Range. Walker seems to have assumed that there was contemporaneous, or partly so, deposition in both areas and that both areas were in the same basin. So far as the writer is aware this cannot be con-

tradicted. Walcott postulated that the deposits of the two areas were laid down in separate basins from seas that were not contemporaneous. There are no known facts denying or supporting this. The apparent absence of fossils in the upper part of the original Goodsir remains still to be explained.

Walcott (1927, 75, No. 4) writes

"No fossils have been reported from the Goodsir, Ottertail or Chancellor formations of the Beaverfoot-Kootenay River area [the valley southeast from Leanchoil] that are upturned against the northeast side of the Beaverfoot-Brisco-Stanford range, but as soon as the great Kootenay fault is crossed to the strata on the southwest side of the fault, fossils are abundant, in the Silurian, Brisco-Beaverfoot; Ordovician (Canadian), Glenogle and Sarbach; Ozarkian, Mons; and Upper Cambrian Sabine formations. Almost in a step one passes from a singularly barren series of shales and limestones to a record of abundant and varied marine life. This indicates that the seaway of the Goodsir trough had little direct connection with the great Cordilleran seaways and their faunas. . . ."

Walcott (1928) located the above fault as "on the northeast slope of Beaverfoot Range, opposite Glenogle" where it brings the limestones of the Goodsir and Mons in close proximity. The writer is in agreement with Walcott in assuming the existence of a fault of some considerable magnitude between Ottertail Range and Brisco Range, though the writer did not recognize it either on the northeast slope of Beaverfoot Range (redefined as Brisco Range, page 108) nor in the direct continuation along the strike of the same strata in Van Horne Range. There may well be a fault opposite Glenogle in the locality given by Walcott, but even so it does not mark a line separating non-fossiliferous shales and limestones on the east from abundantly fossiliferous shales and limestones on the west, for the barren shales and limestones extend well to the west of Glenogle. To explain specifically. Kicking Horse River between Leanchoil and Golden cuts obliquely across the structures which are as follows: an anticline, overturned towards the southwest and exposing McKay group strata, lies between Golden and a point 5 miles east of Golden; the centre of the syncline, overturned in the same direction exposes Glenogle shales and still younger strata from this point easterly for 3 miles to Glenogle—and from Glenogle southeasterly for 11 miles there is an overturned limb of this syncline consisting of shales and limestones of McKay group. Just east of Leanchoil and extending northwesterly throughout Van Horne Range there is a zone of faulting and mashing, and it is along this zone that the writer assumes the major fault to lie between Ottertail and Brisco Ranges. East of Glenogle the shales and limestones of the writer's McKay group are remarkably barren of fossils, and west of Glenogle, the Glenogle shales, Beaverfoot and Brisco formations, are quite fossiliferous, but the strata lying below Glenogle shales, in the anticline at the west of Brisco Range, are for the most part barren. It is in this western anticline that a considerable thickness of barren limestones and shales, somewhat lighter in colour than the highly fossiliferous strata of McKay group that were traced northwards from Sinclair Creek to Horse Creek, begin to appear. Four miles southeast of Horse Creek, an *Ozarkispira* was found in McKay strata 110 feet below the Glenogle shales and *Kainella* and *Symphysurina* were found in the canyon 2 miles east of Golden, well down in the section of McKay group exposed in this anticline. Between these two zones there is estimated to be

nearly 2,000 feet of barren strata. Several traverses were made across this anticline south of Kicking Horse River and north of Horse Creek without finding a single fossil in the McKay group strata, whereas farther south in Brisco Range fossils were abundant. Thus it is seen that the very sparsely fossiliferous shales and limestones appear well to the west of the great Kootenay fault as proposed by Walcott, and the change in the sediments and their fossil content is not to be explained by a fault. Two suggestions are offered. The first is that the fossiliferous strata and the barren ones may be contemporaneous and the presence or absence of fossils is to be explained by the difference in conditions during deposition within one basin—as currents, salinity of water, depth of water, and so on. The second suggestion is that in the area between Golden and Horse Creek there is an interfingering or recurrent overlapping of deposits of slightly different age of a shifting basin of deposition.

Some few fossils were found in the slates and limestones 1 mile west of Leanchoil on the railway, in strata (McKay group) that occur low down in the northeast limb of the overturned syncline. Dr. B. F. Howell (personal communication) reports, that of the Agnostids some appear to be Upper Cambrian, and one an *Homagnostus* of late Upper Cambrian or Ozarkian age. Dr. C. E. Resser examined another collection from the same locality and reported that Upper Cambrian or Ozarkian horizons were suggested. Thus, the lower fossiliferous strata in the anticline west of Glenogle belong to the lowest zone of the Mons *(Symphysurina)* and the lowest fossiliferous strata east of Glenogle hold late Upper Cambrian or Ozarkian fossils. The highest both east and west are younger than the lowest Deep Kill zone of Beekmantown age. Because the slates and limestones are over 4,000 feet in thickness, were deposited within the same age limit, probably of no great interval, and because of the similarity of the strata, the writer is inclined to favour the first suggestion above, and to account for the apparent interfingering by a shifting from time to time of the locus of conditions unfavourable to life or its preservation in the sediments.

The series of limestones and shales exposed on the northeast slope of Brisco Range at Kicking Horse River and the continuation of these strata in Van Horne Range were placed in the Goodsir by Allan, and with this Walcott agreed. The writer was not able to show whether they should be placed in the Goodsir or not, since these strata could not be traced east beyond the zone of faulting east of Leanchoil. Allan probably is right, but there is as yet no proof to show that any of the strata of Goodsir formation of Ottertail Range should be correlated with any of the strata of somewhat similar lithology of Brisco Range, though the writer is of the opinion that Goodsir as a series is to be correlated with McKay group, admitting that certain members (formations) present in one range may well be absent in the other.

GLENOGLE SHALES (ORDOVICIAN)

The Glenogle shales include the arenaceous shales, black shales, and limy shales that occur below the base of the Wonah quartzite and represent a black shale facies contemporaneous with the limestone and shale facies of the McKay group (*See* pages 129, 130). Neither the lower nor the

upper boundary is lithologically distinct, for the alternations of limestone and shale of that part of the McKay strata that underlies them grades upwards into the limy shales of the lower part of Glenogle shales, and the upper beds of the Glenogle become progressively more arenaceous as the overlying Wonah quartzite is approached. The upper 100 feet of these arenaceous shales contain several 8 to 10-foot beds of massive quartzite, quite similar to the quartzite beds in the Wonah formation.

The Glenogle shales have their greatest thickness at the summit of Brisco Range, and eastward in the range, and are continuous from Windermere map-area at the south, to Moberly Peak in Van Horne Range, near the northern limit of the map-area. The shales thin rapidly from 1,200 to 1,600 feet at the summit of Brisco Range, to 100 feet 3 to 4 miles to the west, and they seldom appear in the east wall of the trench. The known exposures are confined to Brisco and the western part of Van Horne Ranges.

McConnell (1886, page 220) was the first to publish an account of these beds at Glenogle and termed them the Graptolitic shales. In 1922 Burling (1922 A, page 456) proposed the name Glenogle shales for these strata and stated that they ranged from Canadian (Beekmantown) to Chazy age. Walcott (1924, page 34) and Clark (1926, page 136) collected from the beds at Glenogle and published an account of the faunas. In 1924 Walker (1924, pages 24-31) discovered, in Windermere area, a thick section of Glenogle shales remarkable for the number and preservation of its graptolites. Identifications by Ruedemann showed that these belonged to the three Deep Kill zones (Beekmantown). The writer traced the outcrop of these shales from Windermere area to Glenogle and beyond into Van Horne Range. During this work many collections were made and the Graptolites obtained were identified by Ruedemann who reported the presence of Normanskill (Chazy) forms in addition to the three Deep Kill zones found by Walker. The table given on page 136 shows the zones found present in some of the sections made.

Table Showing Zones Found in Glenogle Shales at Different Localities

—	Windermere Map-area	9 miles	Sinclair Creek	16 miles	Luxor Creek	5 miles	Pinnacle Creek	12 miles	Harrogate	8·5 miles	Beard Creek	10 miles	Whisky trail, 4 miles southeast Horse Creek	9 miles	Glenogle
Normanskill															
3rd Deep Kill															
2nd Deep Kill															
1st Deep Kill															

Given below is a list of the fossils found by the writer in the Normanskill zones at Pinnacle and Beard Creeks as identified by Ruedemann.

Diplograptus (*Glyptograptus*) *teretiusculus* (Hisinger) var.
Euglyphus Lapworth
Cryptolithus
Isotelus
Didymograptus sextens Hall
Climacograptus cf. *eximius* Ruedemann

Many, though not all, of the forms listed by Walker from his section at Windermere Creek were collected by the writer and no list of these will be given. However, other forms not reported from Walker's section but belonging to the Deep Kill zones are given below.

Third Deep Kill zone: *Bryograptus pusillus* Rued.
Didymograptus cf. *patulus* Hall
Didymograptus spinosus Rued.
Tetragraptus taraxacum Rued.
Dawsonia sp. nov.
Second Deep Kill zone: *Didymograptus bifidus* Hall

The following list, though it is based on a collection made in 1891 by H. M. Ami at Glenogle slate quarries, and identified by Dr. Ruedemann as a "typical Normanskill fauna", is here published for the first time:

Thamnograptus capillaris (Emmons)
Azygograptus n. sp.
Corynoides gracilis mut. *perungulatis* Rued.
Nemagraptus gracilis (Hall)
N. exilis (Lapworth) var. *linearis* Rued.
Didymograptus serratulus Hall
D. sagitticaulis Gurley
D. cf. *subtennis* (Hall)
Dicellograptus sextans Hall
Diplograptus calcaratus var. *incisus* Lapworth
D. euglyphus Lapw.
Climacograptus parvus Hall
C. eximius Rued.
Glossograptus ciliatus Emmons
Retiograptus geinitzianus Hall
Cryptograptus tricornis (Carruthers)

The list below is made from ten collections from 3rd Deep Kill at Glenogle, obtained by Mr. Ami; but since the stratigraphic horizons have not been given to the writer, a single list of the forms present is presented:

Climacograptus pungens Rued.
Cryptograptus antennarius (Hall)
Didymograptus euodus Lapworth
D. spinosus Rued.
D. filiformis Tullberg
D. walcottorum nov.
D. cf. *patulus* Hall
Diplograptus n. sp.
D. (*Glyptograptus*) *dentatus* (Brgnt.)
D. (*Glyptograptus*) cf. *dentatus* (Brgnt.)
Glossograptus echinatus var. nov.

Loganograptus logani (Hall) var. *pertenuis* Rued.
Phyllograptus angustifolius Hall
P. cf. *ilicifolius* Hall
P. anna Hall
P. typus Hall
Protistograptus n. sp.
Retiograptus cf. *tentaculatus* Hall
Tetragraptus taraxacum Rued.
T. n. sp.
Trigonograptus ensiformis (Hall) var. nov.

Dr. Ruedemann writes:

"This collection contains the zone of *Diplograptus dentatus*, our uppermost Deep Kill shale. The most common fossil of this collection is *Didymograptus filiformis* Tullberg. It appears on surfaces of the shale, often almost to the exclusion of all others, and is undoubtedly the most characteristic form of this horizon in the Glenogle shale. It is also remarkable that all these beds belong to the same horizon."

The writer was unable to recognize criteria whereby the Glenogle shales could be divided into lithologic units corresponding to the different faunal horizons, though it is not unlikely that such subdivision could be made. Failure to do so is due in part to scarcity of continuous fresh exposures and the frequent crumpling and faulting (well shown at Beard Creek) of the shales. Dr. Ruedemann[1] states:

". . . . there must, however, be breaks between these Deep Kill zones you have in the Glenogle series, as their faunas are pretty well separated. For theoretical reasons, I should expect a larger break between the second and third Deep Kill horizons, but also a distinct break between the Deep Kill and Normanskill shales, for their faunas have no forms in common."

Wonah Quartzite

This formation name was applied by Dr. Walcott (1924, page 49) to a fine-grained, white quartzite as seen in his Sinclair Canyon section, and was correlated by him with the quartzites found in the lower part of the Halysites beds of McConnell (1886, page 21 D) and Allan (1914, pages 101-102). Such correlation has been proved correct by the present field work.

The Wonah quartzite is medium-grained, compact, and heavily bedded. It is generally white or pinkish, but in some localities parts of it are quite reddish. In several localities light brown beds of friable sandstone occur. Oscillation ripple-marks and crossbedding are seen in several places, though characteristically the detail of bedding surfaces is lacking. The sand is well graded, medium grained, and clean. The above description applies to the massive, easily mapped part of the formation, but the rather abrupt change between it and the underlying Glenogle apparent when viewed from some little distance is seen to be gradational when examined in detail. The graptolite-bearing shale beds of the Glenogle grade upwards into arenaceous shales, and then into shaly sandstone, containing several 8 to 10-foot beds of massive quartzite. No horizon-marking fossils were found either in the quartzite or in the upper part of the thin-bedded, argillaceous sandstones.

Wonah quartzite occurs in Brisco Range and in several small outcrops on the east floor of the trench, just south of Harrogate and again at Beard Creek, and with the Beaverfoot-Brisco formations makes up the bold

[1] Ruedemann, R.: Personal communication.

front of Van Horne range from Kicking Horse River to Moberly Peak. It is not seen to the west of Columbia River, though Shepard (1926, page 627) has mapped it on Steamboat Mountain. The quartzite on Steamboat Mountain appears, however, to belong to the upper part of Mount Nelson formation, and at this place is brought into contact with Palæozoic formations by faulting.

In the western part of Brisco Range at the south of the area, Wonah quartzite is only 30 feet thick; a few miles to the east, still within Brisco Range, it attains a thickness of 200 feet. Northward the quartzite becomes much thicker, for it is 1,000 feet thick east of Castledale and about 1,500 feet thick at Horse Creek. Northward from here it has a thickness of about 1,000 feet and is last mapped at Moberly Peak, 5 miles north of Golden. On Jubilee and Steamboat Mountains, Beaverfoot (Richmond) formation rests on strata of the McKay group, the Wonah quartzite being absent.

Poorly preserved orthids, not specifically identifiable, were found in the platy lower part of the quartzite on the east slope of Moberly Peak. Besides these no fossils other than some indeterminate branched markings and several crinoid stems have been found in this formation. The limestone immediately and conformably above it contains a Richmond fauna, and graptolites of Chazy age occur in the lower part of the transition zone between it and the Glenogle, at Pinnacle and Beard Creeks, and at Glenogle. A Chazy fossil *Ampyx* was found in the McKay group (limestone and shale facies corresponding to the top of Glenogle shales) 11 feet below the massive quartzite at McKay Creek. Thus the age may be Chazy, Richmond, or some age between these. Wonah quartzite was laid down under near-shore conditions; and Walcott (1924, page 50) suggested that it represents the beach sands of the transgressing Silurian (Richmond) Sea. Shepard (1926, pages 624-628) doubts this origin because of the thickness of the quartzites (about 1,500 feet) at the north end of Brisco Range. To the writer it suggests an along-shore deposit due to persistent and fairly strong currents, that would form bars and sand spits. This would account for the sparse presence of marine fossils (crinoid stems), the ripple-marks and crossbedding, and the occasional presence of beds of very well-rounded and frosted grains of quartz that undoubtedly are wind-blown deposits. Also it would account for the clean, even-graded character of the sand of which it is formed.

Beaverfoot and Brisco Formations (Ordovician (Richmond) and Silurian)

The writer was unable to map these formations separately in the field, and they are shown by one colour on the map. The formations consist of thick to thin-bedded, semicrystalline limestones, of which the greater part is magnesian. The colour of the fresh surface differs from place to place from nearly black to white; but the dull, powdery coating, white to light salmon-grey in colour, formed on the weathered surfaces and obscuring the colour of the fresh rock, was found to be a never-failing guide to the identification of these formations. In general, the lower part (included in the Beaverfoot formation, though not continuing to the top of it) is dark in colour, less massive, and contains some "stinksteins" and

bands of dark chert. The upper part is more heavily bedded and lighter in colour, contains some bands of grey chert, and near the top it is formed of light-coloured, massive, magnesian limestone containing numerous, scattered, rounded grains of sand.

It occurs extensively in Brisco Range and in the western part of Van Horne Range. The lower part of this limestone occurs in relatively small outcrops at the north ends of Steamboat and Jubilee Mountains where it rests directly on McKay strata and forms the youngest beds there exposed. At Harrogate, where the complete section was measured, the two formations have a combined thickness of 1,882 feet. This is close to the thickness given by Walcott (1924, pages 47-49) and no section measured, or estimated from strike and dip and the topography, exceeds 2,000 feet, though Shepard (1926, page 626) has given a total thickness of 4,600 feet. The outcrops on Jubilee and Steamboat Mountains are limited upward by the present erosion surface, so that the only guide to the thinning of the formations to the west is given by Walker's (1926, page 34) Horsethief Creek sections, where thicknesses of 200 feet and 25 feet occur between the enclosing strata; Goodsir (McKay group) below and Devonian above. The Beaverfoot and Brisco formations are cliff-forming and, together with the Wonah quartzite, are much more resistant to erosion than the Glenogle and Goodsir strata, so that they form the highest ridges and peaks of Brisco Range. These formations, together with the underlying Wonah quartzite, were included in the "Halysites Beds" by McConnell (1886, page 21 D) in 1886. Burling (1922, A, pages 453-4) in 1922 called attention to the Richmond fauna, and renamed these strata as the Beaverfoot formation, from a section made on the Whisky trail, east of McMurdo, where the strata are repeated by folding. He included the quartzites (Wonah of Walcott) in his Beaverfoot, and apparently found no Silurian, as only the lowest beds are here exposed, though the Silurian and Devonian occur at Horse Creek, just to the north. Walcott (1924, pages 32-48) in 1924 redefined the name Beaverfoot, to apply to that part of the limestones containing the Richmond fauna, and proposed Brisco formation to apply to the overlying strata containing a Silurian fauna. This practice is followed by Walker in the report on Windermere map-area, and by the present writer.

A complete section from the top of Wonah quartzite, through the Beaverfoot and Brisco formations, into the Devonian, was made 1 mile north of Harrogate trail to Beaverfoot Valley. This section is given below. Determinations of Ordovician and Silurian fossils and the accompanying notes are made by Miss A. E. Wilson. The Ordovician fossil names following, marked with an asterisk, are described in Geological Survey of Canada, Museum Bulletin No. 44, 1926.

Section at Harrogate. This section was measured across overturned beds and starts at the base.

Thickness	Description and Fossils	Distance above base
Feet		Feet
	Top of Wonah quartzite	
52	Limy and sandy shale, grading upward into argillaceous limestone. Carbonaceous markings and a *Hyolithes*.....	52

Thickness	Description and Fossils	Distance above base
Feet		Feet
45	Light grey, salmon-weathering, fine-grained, crystalline limestone containing **Dinorthis rockymontana* Wilson **Rhynchotrema increbescens occidens* Wilson **Plectorthis sinuata* Wilson **Streptelasma distinctum* Wilson **S. prolongatum* Wilson **Rhyncotrema kananaskia* Wilson	97
139	Thin-bedded, sandy limestone, some $\frac{1}{8}$-inch layers of sandstone. Many corals and crinoid stems. **Orthis* cf. *marshalli* Wilson and a new genus of sponge	236
46	Dark grey, dense, magnesian limestone weathering to a mottled light and dark salmon-grey colour. Contains bands and nodules of chert. Numerous corals weathered out, in poor preservation. *Beatricia nodulosa* Billings **Dinorthis* cf. *columbia* Wilson "These fossils so far are representative of the Richmond fauna as found in Beaverfoot formation."	282
204	Salmon-grey-weathering, dense, dark, magnesian limestone. Top 100 feet has numerous chert nodules. Contains indeterminate corals	486
30	White-weathering, dense, magnesian limestone, 12-inch bedding joints, but shows $\frac{1}{16}$-inch bedding planes	516
35	Dark grey, heavily bedded limestone with some crinoid stems. Weathers salmon-grey	551
5	Grey, thin-bedded limestone, weathers white	556
99	Heavily bedded, light grey, magnesian limestone weathers plaster-white. Contains *Pentamerus, Virgiana, Atrypina, Leptaena* "This is representative of the typical *Virgiana* fauna of the Silurian".	655
25	Heavily bedded, dark grey, magnesian limestone with some thin beds of same type at top. Contains *Pentamerella* of several new species. "This represents a Silurian fauna not heretofore represented in the Geological Survey of Canada collections"	680
43	6-inch to 18-inch, bedded, white, magnesian limestone	723
586	Dark grey, magnesian limestone weathering salmon-grey. Bedding joints are spaced from 2 inches to 4 feet apart. Fossils have not been determined specifically. The following genera are represented. *Orthis, Stropheodonta, Whitfieldella, Halysites, Favosites, Kionoceras, Streptelasma, Atrypina, Camarotoechia, Hormotoma, Cyclonema, Palaeofavosites*	1,309
184	Thin and thick-bedded, white-weathering, light grey, magnesian limestone with some cherty layers at top	1,493
389	Heavily bedded, cliff-forming, light grey limestone containing scattered, well-rounded sand grains. Contains *Stropheodonta* and *Cyrtina*....	1,882

Referring to the last two fossils collected, Miss Wilson states "The above groups represent a Silurian fauna. Many of the species differ considerably from the representatives of the several genera in the eastern Silurian."

A thin bed of hard sandstone at the top of the last member given above is arbitrarily used by the writer to mark the base of the overlying Middle Devonian.

At Sinclair Creek (Walcott, 1924, page 12) and also in southern Windermere map-area (Walker, 1926, page 33) lenses of shale-bearing Silurian graptolites occur within Brisco formation. Part of the report by Ruedemann on the Silurian graptolites collected by Walcott at the Sinclair Creek locality is quoted below. "The faunule consists of:

Monograptus sp. nov. This form is closely related to *Monograptus spiralis* (Geinitz).

Monograptus marri Perner. This form is practically identical with the European species.

Retiolites (*Gladiograptus*) *geinitzianus* Barrande, which is the same as *R. venosus* Hall from our Clinton.

. . . The faunule from Sinclair Canyon in British Columbia is hence fairly safely correlated with that of the Gala-Tarannon beds of Britain and also with the Clinton graptolite shale of New York (Williamson shale).

Thus, the lower Ordovician part of this succession of limestone, the Beaverfoot formation, is correlated with the Richmond. The lower part of Brisco formation is found to contain the typical Silurian "Virgiana" fauna, but the upper part cannot at present be correlated with any of the Silurian occurring in eastern North America.

Harrogate Formation[1] *(Middle Devonian)*

Harrogate formation, consisting of fairly thin-bedded, dark, dense limestone, with occasional shaly-lime seams, represents the youngest strata found within the folded ranges of the map-area. The basal beds show an alternation of dark, dense limestone, sandy, light-coloured, magnesian limestone, and hard, sandstone beds 2 inches to 6 feet in thickness. The base of the Harrogate formation has been placed arbitrarily by the writer at the lowest occurrence of these sandstones, and it is thus placed midway between the highest Silurian and lowest Devonian fossil horizons found in the Harrogate section; that is, in the middle of 700 feet of the section where no fossils were found.

The outcrops of Harrogate formation occur infolded within the Beaverfoot-Brisco formations of the main central syncline at Pinnacle Creek, Harrogate, and Horse Creek. A small outcrop at the mouth of Sinclair Canyon has been preserved by downfaulting. It is altogether probable that other small exposures of Harrogate formation exist within the wider areas shown on the map as Beaverfoot-Brisco formation, where such have not been crossed by traverses. No unconformity was observed between Harrogate and Brisco formations, though a considerable hiatus is represented between the highest Silurian and lowest Devonian fossils that were found. The greatest thickness seen, that at Harrogate, measured 698 feet.

Collections made at the following localities are reported on by Mr. E. M. Kindle:

Section 1 mile north of the Harrogate trail to Beaverfoot Valley. This section is continuous with that of the Beaverfoot-Brisco formations in this locality. The measurements denote distance above Wonah quartzite.

[1] Proposed by F. P. Shepard, Jour. Geol., vol. XXXIV, p. 626 (1926).

Feet		Feet
Top	Brisco formation	1,882
77	Sandy limestone, with an occasional thin bed of blue-weathering, dense, dark limestone. Several thin beds of quartzite also occur	1,959
50	Alternating, dense, dark limestone (with conchoidal fracture), 2 to 3-inch quartzite beds and thin, argillaceous limestone	2,009
85	Dark limestone	2,094
3	Quartzite	2,097
10	Dark limestone	2,107
6	Quartzite	2,113
88	Dense, dark limestone, with a few 1-foot quartzite bands	2,201
84	Dense, dark blue limestone, with 4 to 18-inch bedding and a few limy shale layers, from which the following were obtained	2,285

Lot 8038. 2,232 feet above Wonah quartzite
Schizophoria striatula
Schuchertella sp.
Gypidula n. sp.
Spirifer sp.
Pterinea ? sp.

Lot 8132. 2,237 feet above Wonah quartzite
Favosites sp.
Stromatopora sp.
Archaeocidaris sp.
Strophalosis sp.
Schuchertella sp.
Martinia sp.
Nucula sp.
Platyostoma sp.

Lot 8058. 2,242 feet above Wonah quartzite
Productella sp.
Schizophoria striatula
Schuchertella sp.
Reticularia richardsoni
Proetus haldemani

Lot 8133. 2,244 feet above Wonah quartzite
Productella cf. *coloradensis*
Schuchertella sp.
Schizophoria striatula
Atrypa sp.
Atrypa reticularis
Spirifer sp.
Reticularia cf. *fimbriata*
Cyrtina ? sp.

Lot 8134. 2,252 feet above Wonah quartzite
Crinoid stems
Productella cf. *coloradensis*
Martinia meristoides Meek

Lot 8135. 2,262 feet above Wonah quartzite
Cystiphyllum sp.
Cystiphyllum cf. *americanum* var. *arcticum*
Productella cf. *coloradensis*
Schizophoria striatula
Schuchertella sp.
Atrypa reticularis
Atrypa sp.
Martinia richardsoni
Martinia meristoides

Lot 7986. 2,277 feet above Wonah quartzite

Productella sp.
Pugnax sp.
Eunella cf. *lincklaeni*
Atrypa reticularis
Martinia maia
Ambocoelia sp.
Spirifer n. sp.

295 Salmon-brown weathering, 1 to 15-inch bedded limestone, well fractured and containing numerous cup corals and crinoid stems. Partly covered by drift 2,285

2,580

.....Drift.....

The following collections were taken from another outcrop of Harrogate formation close to the Harrogate trail, just east of the Wonah quartzite, at 4,000 feet elevation. It is apparently from this outcrop that Shepard[1] and Kirk[2] previously made collections. The following forms were identified by Mr. Kindle:

Lot 7979

Zaphrentis sp.
Aulophyllum ? *richardsoni*
Cystiphyllum americanum var. *arcticum* ?
Productella spinulicosta
Productella sp.
Schizophoria striatula
Schizophoria mcfarlanei
Schizophoria sp. Young
Atrypa reticularis
Atrypa sp.
Spirifer sp.
Reticularia fimbriata var. *compactus* (Meek)?
Martinia meristoides
Martinia richardsoni
Cyathophyllum quadrigeminum
Martinia cf. *meristoides*

The following fossils were collected by the writer in the brecciated outcrop of Harrogate formation at the mouth of Sinclair Canyon at an elevation of 2,800 feet:

Lot 7980

Favosites ? sp.
Aulopora minima Fenton
Cladopora sp.
Productella cf. *coloradensis* Kindle
Schizophoria striatula
Schizophoria mcfarlanei
Martinia richardsoni
Spirifer fimbriata var. *compactus* (Meek)
Atrypa reticularis
Actinopteria sp.
Orthoceras cf. *montanense* Raymond

[1]Shepard, F. P.: Jour. Geol., vol. XXX, p. 366 (1922).
[2]Walcott, C. D.: Smithsonian Misc. Coll., vol. 75, No. 1, p. 31 (1924).

Mr. Kindle states:

"The several lots of fossils listed above represent the same general fauna. This fauna is quite unlike any Devonian fauna known in the Banff sections or elsewhere to the eastward in the ranges of the Rocky Mountains. It is allied to a fauna which was first reported from the Lockhart River and Lower Mackenzie in sub-arctic Canada by F. M. Meek (1867). A fauna considered to be identical with the Lockhart River fauna was collected by E. M. Kindle on the south shore of Great Slave Lake in 1919 at Pine Point. This fauna, which was designated as the *Martinia richardsoni* zone (Cameron, 1922) of the Pine Point formation, bears a strong resemblance to the Columbia River Valley fauna now under consideration. The identity of *M. richardsoni* and other species in the Pine Point fauna which is known to lie below the Upper Devonian, with forms in the Columbia Valley fauna, leads to the correlation of the latter with the Middle Devonian. The presence of *Schizophoria mcfarlanei* and *Proetus haldemani* in both the British Columbia fauna and the Lower Mackenzie Devonian fauna furnishes additional evidence of the identity of the two."

STRUCTURAL GEOLOGY

The area dealt with includes parts of two mountain systems. The western part lies in the most northeastern part of the Selkirk system; the eastern part lies in the flanking southwest range of the Rocky Mountains. These two mountain systems are separated here by a deep, wide valley that is a segment of the Rocky Mountain trench. This trench extends along the western side of the Rocky Mountains from south of the 49th parallel of latitude nearly to the Yukon boundary, in latitude 60. Daly (1912) defined it as a trench, since, though continuous as a major lineament, it now contains the headwaters of many rivers with divides separating them, and thus simulates, broadly interpreted, a military trench cut across undulating ground. It is to be noted that although most of the descriptions previously given (Daly, 1912, Schofield 1920 B) state that the trench is continuous, there is an area between the headwaters of Crooked and Parsnip Rivers and the "Big Bend" of the Fraser, in which the trench fades out, and then seems to start again along the upper Parsnip 20 miles farther east.

The origin and structure of the trench as a whole are still a matter of conjecture. This is so since only a small part of the geology along the trench has been worked out in detail, and also because the trench floor, 3 to 8 miles wide, is mantled with glacial and river deposits. Interpretations of the structures must be made from the observed structure of the bordering ranges. However, the final structural sections of this report cross the trench in one of the narrowest places where areal mapping has been done, and where the exposures in the bordering ranges are exceptionally good. At this section thrust faults and overturned folds have occurred in the mountains on each side, towards the trench.

The structures along this short section within the map-area are tied in with the structures across the Rockies along the Canadian Pacific Railway (McConnell revised by Allan) and with what little is known of the Selkirk Range structures.

The writer concludes that both the Selkirk system and the Rocky Mountains were formed by compression from the west; that the structures are formed predominantly by thrust faulting towards the northeast, and that the overturning and thrust faulting towards the trench from the east are to be interpreted as underthrusts; that though compression from

the west formed both the Selkirk system and the Rocky Mountains that the Selkirk system was formed some considerable time before the Rocky Mountains, probably in late Jurassic or early Cretaceous.

Detailed Structures in Brisco-Dogtooth Map-Area

A series of structural sections is given in which the attempt is made to keep inference and observation distinct. The sections in the southern part of the area show only the ranges on the east side of the trench, since

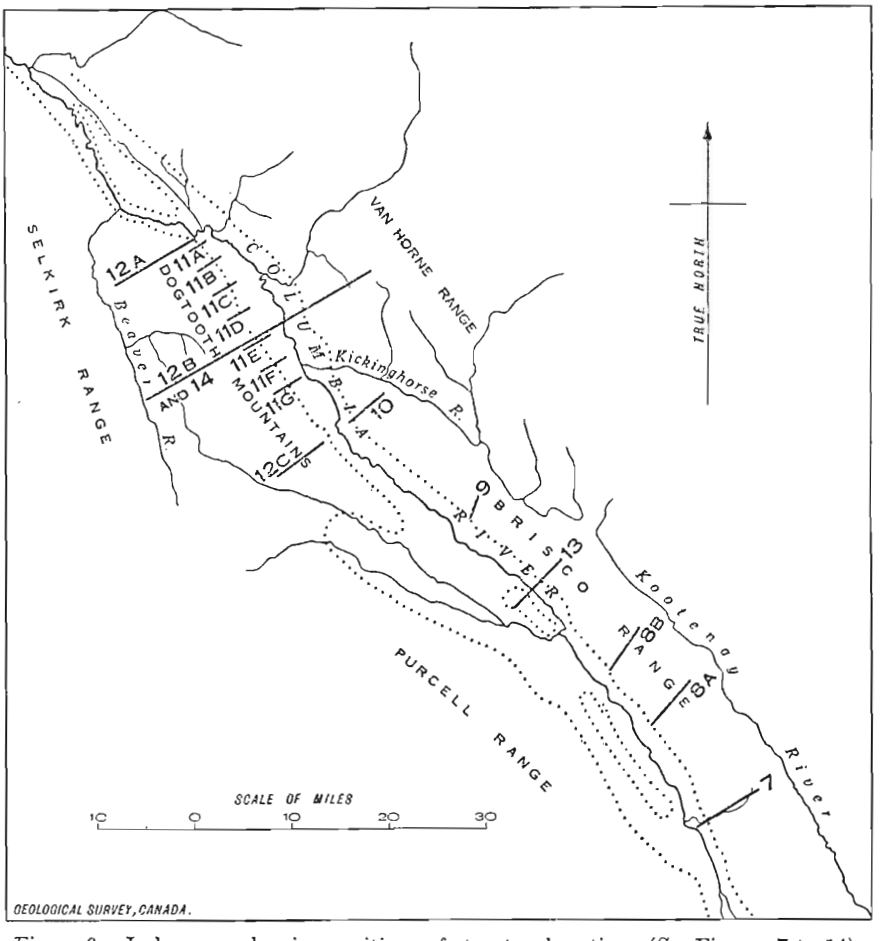


Figure 6. Index map showing positions of structural sections (*See* Figures 7 to 14); outlines of trench are shown by dotted lines.

the trench floor in this part is quite wide and the mountains to the west are beyond the limits of the map-area.

These sections are given to illustrate more clearly than word descriptions the structures found in the area; to indicate just what inferences have been made, so that the reader may decide for himself whether or not

the writer's conclusion is justified that the same type of structure as is shown in the northern part also occurs at the south of the area. Figure 6 shows the positions of these sections in the map-area.

BRISCO RANGE

The strata of Brisco Range are compressed into fairly close folds, that for the most part are overturned towards the southwest. The overturning is pronounced in the northwest part of the range, where the axes of the folds dip about 60 degrees to the northeast, whereas at Sinclair Creek, at the south the axes are nearly erect. Fifteen miles northwest of Sinclair Creek the overturning to the southwest becomes distinct and so continues to Kicking Horse River and northwest into Van Horne Range.

Of the folds, three are continuous for the whole length of the range; a central syncline and parts of the anticline on either side of it. This syncline lies at the northeast side of the range at Sinclair Creek, where it is badly broken, whereas just south of Kicking Horse River it lies at the southwest side of the range: that is, the syncline crosses the narrow Brisco Range in a distance of 60 miles along the strike. These main folds are complicated in places by subordinate folds and in places by considerable faulting. Short sections of other folds are exposed in the western part of the range at Sinclair Creek and in the eastern part of it along Kicking Horse River. Incompetent, thin-bedded members (shales and shales alternating with limestones) show pronounced drag-folding.

Identical horizons are higher in the folds in the centre and eastern part of the range than they are close to the trench, so that Brisco Range appears to consist of the western part of an anticlinorium; such an anticlinorium is, however, not completed to the east and this folding was probably caused by overturning and overthursting towards the southwest (this is later interpreted as underthrusting).

Normal strike faults, transverse faults, oblique faults, and thrust faults occur.

Section at Sinclair Creek (Figure 7)

In this, as in the following sections, the attitudes of the horizons shown are either observed or inferred from attitudes of higher or lower strata that are exposed. Faults shown in unbroken lines are observed faults, though of course their projections to depth are inferred.

The main Brisco syncline occurs at the east of this section and west of it there are three synclines and four anticlines. This section does not indicate general overturning towards the southwest, but rather overturning outward from the centre of the section.

Fault No. 3, known as Red Wall fault, because of its wide band of reddish weathering fault breccia, is vertical for the depth it is exposed by the relief of this part of the range. It is interpreted as a steep thrust fault from the southwest because of the relations and attitudes of the strata on either side of it. Two miles north of the section Red Wall fault passes under the gravels of the trench floor and it may be continuous with the fault necessarily inferred between Jubilee Mountain and Brisco Range as shown in Figure 13.

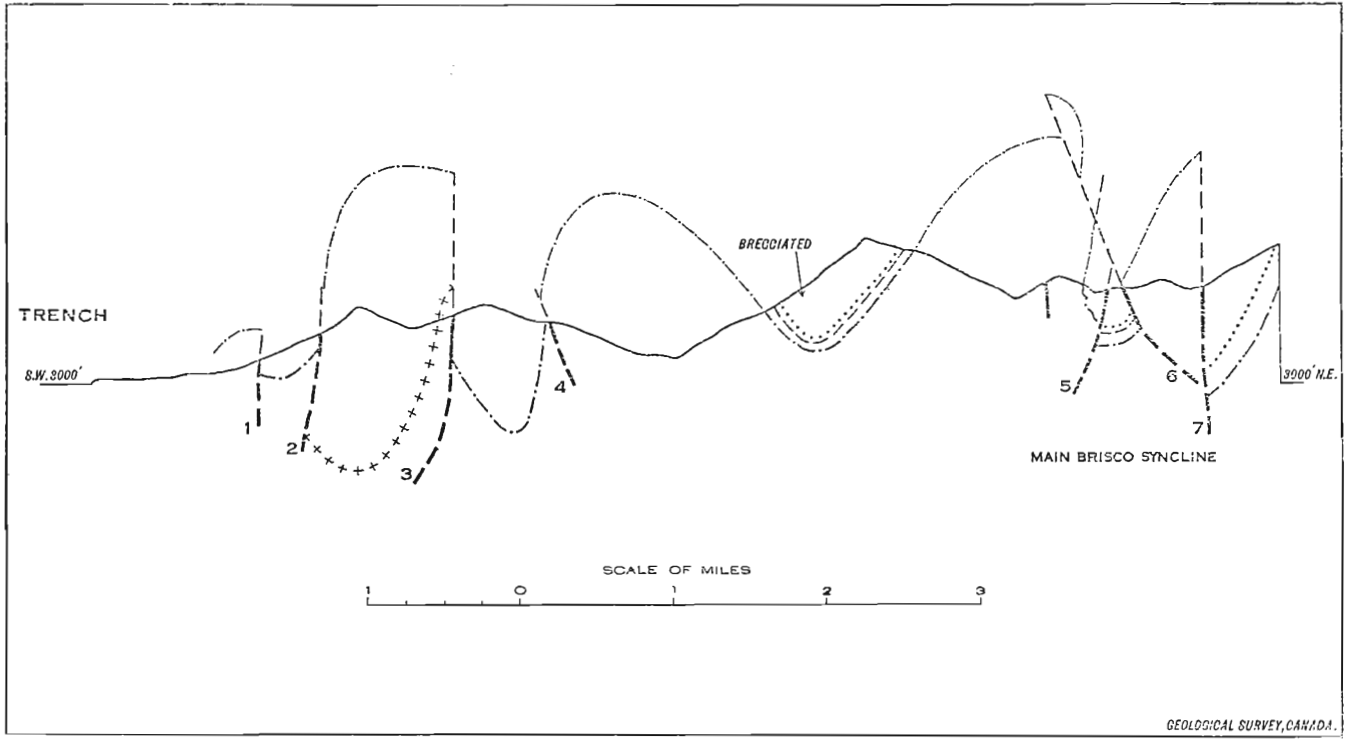


Figure 7. Sinclair Creek section (*See* Figure 6). Base of McKay strata, a line of crosses; top of McKay strata, a line of pecks and dots; base of Wonah, a line of pecks; base of Beaverfoot-Brisco, a line of dots.

Faults 5 and 6 are exposed through a relief of about 2,000 feet and so their attitudes in this section are known. Half a mile north of the section these two faults converge and one fault was traced northward for 4 miles where it is found to be a quite flat thrust dipping northeast. In the section, crumpled strata occur on the west side of fault 5 and are overturned towards the northeast, and on the east of fault 6 where they are overturned towards the southwest. The major anticline to the west of fault 5 is slightly overturned towards the northeast. From this it appears that fault No. 5 is a steep thrust from the southwest and that fault No. 6 is a thrust from the northeast that has cut fault No. 5 and is, therefore, later than it. In the section shown in the figure fault No. 6 has a steep northeasterly dip, whereas 4 miles farther north it is almost flat.

Fault No. 7 is exposed through a relief of 3,000 feet and is vertical, and south of the section it cuts and displaces fault No. 6. Its stratigraphic displacement is about 6,000 feet.

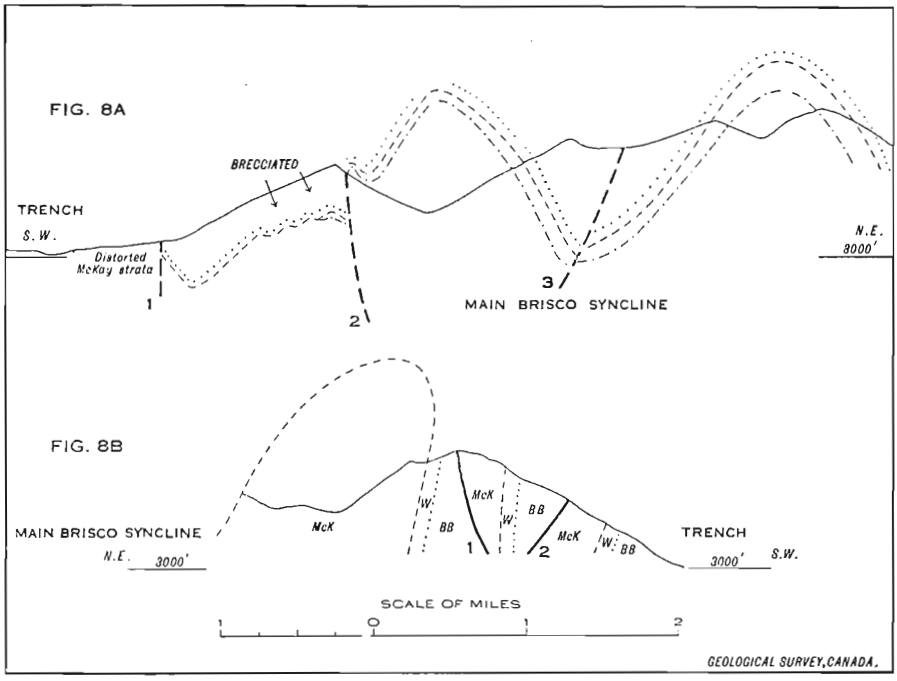


Figure 8. Luxor Creek section (Figure 8A), and section north of Brisco (Figure 8B) (*See* Figure 6). Base of Glenogle, a line of pecks and dots; base of Wonah, a line of pecks; base of Beaverfoot-Brisco, a line of dots. McK = McKay strata; W = Wonah; BB = Beaverfoot-Brisco.

Section at Luxor Creek (Figure 8 A)

This section shows the typical attitude of the folds at the southern end of Brisco Range where the axes of the folds are nearly vertical. It also illustrates the westward thinning of Wonah Quartzite and Glenogle shales. The syncline cut by fault No. 3 is the main Brisco Range syncline.

Fault No. 2 has a steep dip and is of relatively small displacement. From the crumpling of the strata just east of it and the incipient faulting indicated by brecciation west of it, it is thought to be a thrust fault with steep northeast dip.

Section North of Brisco (Figure 8 B)

The areal map in this locality shows repetition of strata indicative of imbrication, west of a major anticline that is slightly overturned to the southwest. The attitudes of the faults and the strata are those found in two traverses, one along the ridge shown in profile in the figure, and the other around the base of the ridge, that on the average is 1 mile north. The writer is not prepared to offer a graphic solution of this structure, though it may be that the structure section represents imbrication from the southwest that was rotated backward towards the southwest, by later compression. If, as the writer supposes, the Red Wall thrust fault is continuous northwestward from Sinclair Creek to Jubilee Mountain, then this thrust lies in the trench to the southwest of the section here shown, and the imbrication may have originated as minor thrusts in front of it. The anticline at the east of the section lies just to the west of the main Brisco Range syncline.

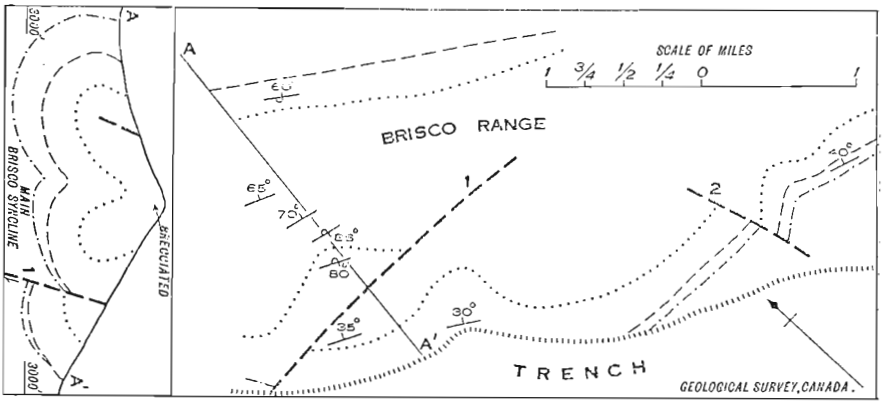


Figure 9. Plan and section north of Parson (*See* Figure 6). Base of Glenogle, a line of pecks and dots; base of Wonah, a line of pecks; base of Beaverfoot-Brisco, a line of dots.

Section North of Parson (Figure 9)

This plan and section are given to illustrate the oblique faults that occur here and at Harrogate. The double syncline shown in the figure illustrates the nature of the main Brisco Range syncline in the northern part of the range.

The block contained between faults Nos. 1 and 2 has been rotated in an anti-clockwise direction with a downthrow on fault No. 1 and an upthrow on fault No. 2. This rotation appears to have taken place under compression and the southwestern limb of the syncline, developed in Wonah quartzite, was probably turned backward at this time. The displacement of this block is suggestive of a couple as well as directed compression, and may possibly be taken to indicate differential movement in a northwest-southeast direction between the trench and Brisco Range.

Section at North End of Brisco Range (Figure 10)

This section illustrates the pronounced overturning to the southwest that occurs in the northern part of Brisco Range. The main Brisco Range syncline (here double) occurs on the southwest slope of the range. The fault shown at the east of the section is exposed for 1,000 feet in relief, is vertical, and is accompanied by considerable brecciation of the strata.

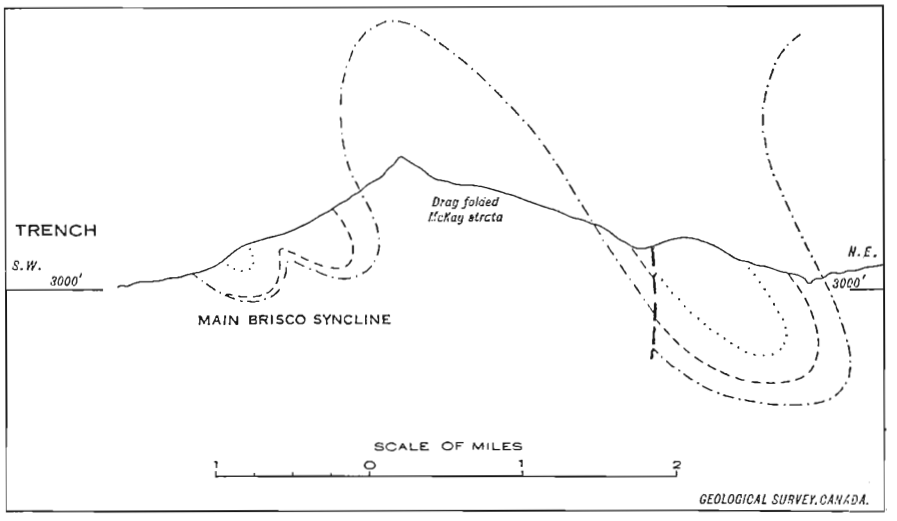


Figure 10. Section at north end of Brisco Range (*See* Figure 6). Base of Glenogle, a line of pecks and dots; base of Wonah, a line of pecks; base of Beaverfoot-Brisco, a line of dots.

DOGTOOTH MOUNTAINS

Before the structures of Dogtooth Mountains proper are dealt with, the structural relation of the strata of the eastern part of these mountains to the strata of the trench floor will be examined.

The exposures in the trench are not extensive, but they are distributed in such a way as to indicate that the trench here is underlain by strata of McKay group (Upper Cambrian to Ordovician). The strata exposed in Dogtooth Mountains are of late Precambrian and Lower Cambrian age.

In the eastern part of the Van Horne Range and in the Field map-area (Allan) there is a succession of about 15,000 feet of Middle and Upper Cambrian strata lying between probable correlatives of part of the McKay group and Donald strata. With the exception of a fairly thick series (2,000 feet +) of black slates at Canyon Creek and in Columbia River Canyon northwest of Oldman Creek, none of this succession is exposed in the trench or Dogtooth Mountains at the north of the map-area. It is impossible to say whether or not much of the Middle and Upper Cambrian succession of Field map-area really exists in the stratigraphic section of the Dogtooth Mountains-Rocky Mountain trench area, or whether it may have been faulted out so as not to appear in the exposures.

Farther south in the writer's area, and in Walker's Windermere area which lies next south, Upper Cambrian to Devonian strata thin rapidly to the west and only quite thin sections of some of them overlap westward across the trench; others disappear entirely. At Jubilee Mountain, 35 miles south of the sections of Figure 13, there is but 2,000 feet of magnesian limestone between Donald and McKay group strata, and it is probably of Upper Cambrian age.

Thus there is an unknown factor present that makes estimates of fault displacements conjectural and in some places makes it questionable if faults do exist. On the whole it seems reasonable to suppose that much of the Middle and Upper Cambrian succession of Field map-area really is absent in this area, as it clearly is at Jubilee Mountain, farther southeast along the trench. The fault inferred to be present by the writer along the foot of the eastern slope of Dogtooth Mountains is so inferred without assuming that any of the 15,000 feet of Middle and Upper Cambrian strata, other than the black slates exposed here, is present in the stratigraphic column of this locality.

In Figure 11 there are seven southwest-northeast sections from the eastern part of Dogtooth Mountains eastward out on to the trench floor. They are taken at about 5-mile intervals between Canyon Creek and Columbia River Canyon, and are given to present the evidence on faulting between the eastern front of Dogtooth Mountains and the trench. All faults shown in unbroken lines in the figure were observed both in plan and in relief provided by deep, transverse stream valleys (*See* Plate IV A). The attitudes of the strata as shown were also observed.

Although there is a narrow band of cover between the Lower Cambrian of Dogtooth Mountains and the high Upper Cambrian (McKay group of the trench floor) a fault must be inferred in sections E and F, for the Lower Cambrian strata of the east slope of Dogtooth Mountains cannot be accommodated in the narrow drift belt between their lowest exposures and the exposures of McKay group strata, under any other assumption. The reason for assuming the attitude, as shown, for fault No. E, will be dealt with later.

In section C there must be a fault between exposures of the mountain slope and the nearly vertical exposure of Donald strata—fault 5 A. The inferred fault 5 B may or may not be present.

In section G there is shown a band of black slates between Lower Cambrian and Upper Cambrian strata and in these slates fossil sponges (aggregates of spicules) were found resembling those obtained from the Mount Stephen formation of Middle Cambrian age in Field map-area. To the south of section G of this figure this band of slates widens considerably, but is missing to the northwest from section F to section A, inclusively. However, a fairly wide band of these same slates is exposed in Columbia River Canyon west of Redgrave, so that it is probable that they have been faulted out in the sections northwest of No. G. Thrust fault No. 5 is assumed present in section G because the black slates have here a much narrower width than farther south and also as a projection of fault 5 south from section F.

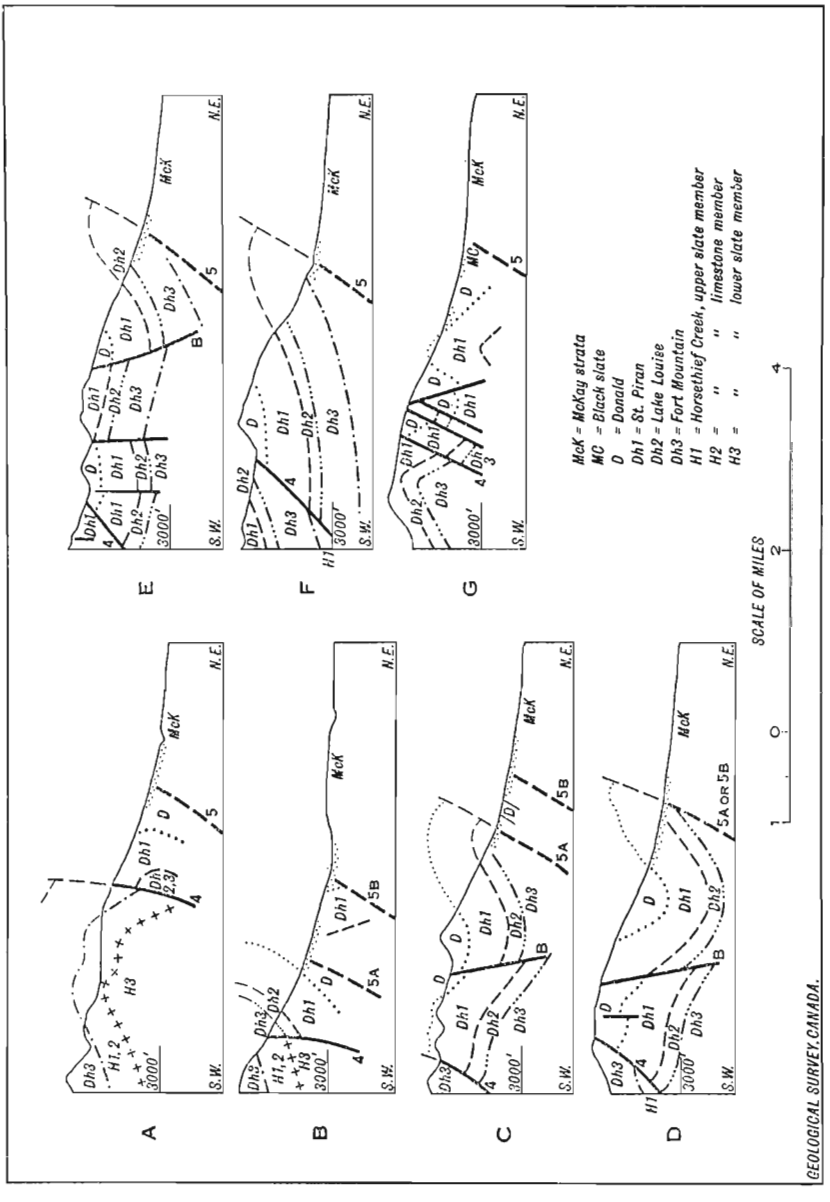


Figure 11. Sections through eastern part of Dogtooth Mountains (*See* Figure 6).

In sections A and B, Lower Cambrian strata are found to be overturned to the northeast on the east slope of Dogtooth Mountains and no exposures of black slates were found here. In section B, fault 5 A must necessarily be present, but fault 5 B is not so definitely necessary. The writer thinks it is present, however, for there is hardly room to accommodate the Donald strata and the black slates between the upper Dogtooth and McKay group exposures. Fault 5 is judged to be present in section A from the overturning just to the west and as a projection from the section farther south.

The fault itself was not seen, but glistening, paper-thin phyllites were found along the supposed line of the fault. These phyllites are similar to others that were found in other localities where fine, sandy, and limy argillites of various formations had been affected by demonstrable thrust faults.

The representation of fault No. 5 as a southwest-dipping thrust fault is based solely on the general structure of Dogtooth Mountains as discussed below, and on the observed overturning in sections A and B.

Section Across Dogtooth Mountains (Figure 12)

Here are shown three sections across Dogtooth Mountains, taken at about 12-mile intervals. Fault No. 1 is continuous throughout and exhibits the greatest stratigraphic displacement and the greatest local deformation of the nearby strata; minor folds recumbent for a distance of 1,000 feet are well exposed west of this fault.

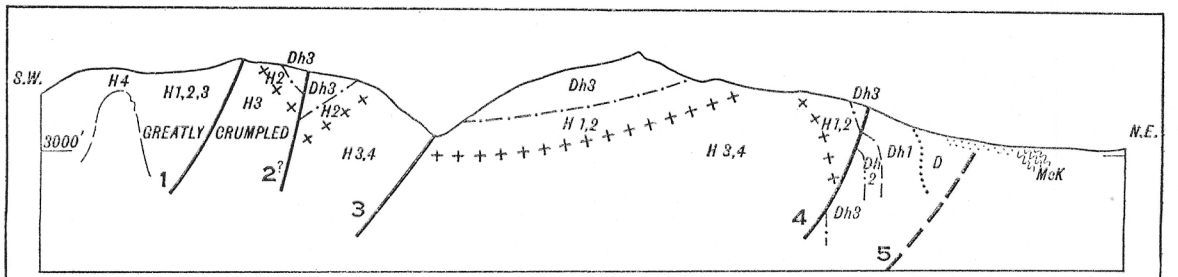
In section B, Figure 12, fault No. 2 is necessarily inferred between the narrow band of Donald strata lying to the west of it, and the Horsethief Creek strata on the east, but farther southeast the fault is observed where St. Piran formation lies to the east of it. Thus, the displacement along the fault No. 2 becomes less southeastward and it may die out near the southeast branch of Canyon Creek, or more probably bends westward to meet fault No. 1 to which it is subsidiary.

Fault No. 3 is inferred in section A, but is observed $1\frac{1}{2}$ miles to the southeast, from which point it was traced to a mile south of section B, where it is seen to occur as a southwest-dipping thrust fault just east of strata sharply overturned to the northeast. South of this exposure it trends along the middle course of Canyon Creek where it is hidden by drift and talus. It may join up with reverse fault No. 3 of section C, which, however, dips steeply to the northeast, but may be only a deformed part of the southwest-dipping thrust fault.

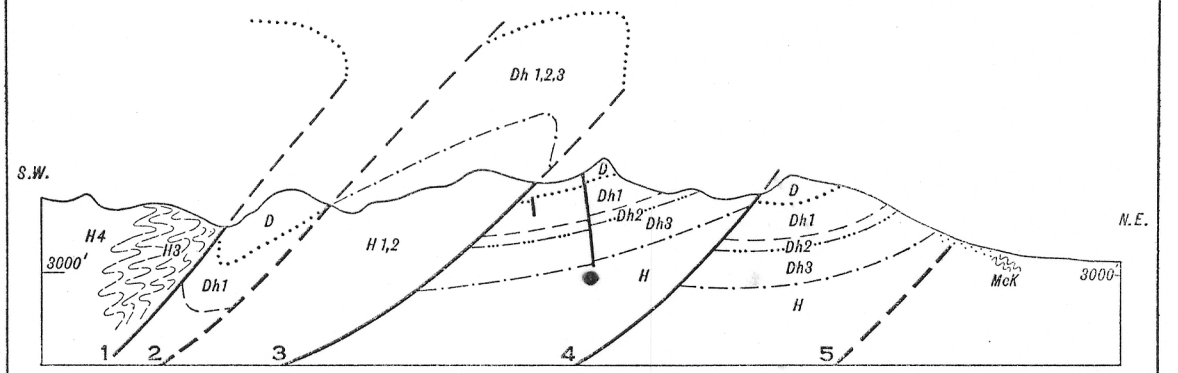
Fault No. 4 is the same fault that is shown by that number in Figure 11 and it is known to be a southwest-dipping thrust. It seems to die out between sections B and C and in all probability cuts back westward to join fault No. 3.

Fault No. 5 is the inferred fault of Figure 11 and its interpretation as a southwest-dipping thrust seems to be the most logical assumption considering the type of structure that lies to the west, as shown in the figure under discussion.

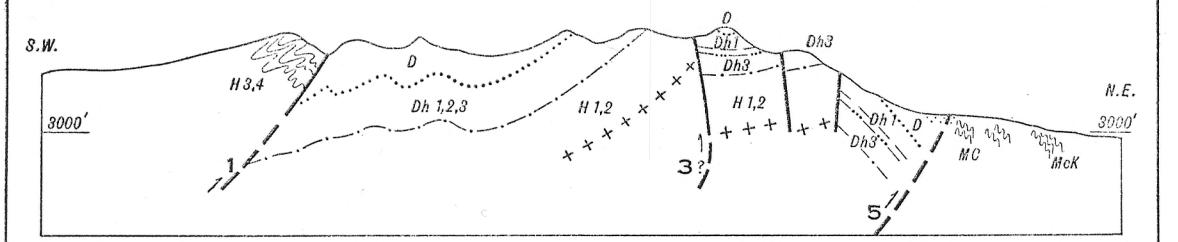
Faults 1, 3, and 5 appear to have affected relatively large blocks, whereas faults 2 and 4 are probably much shallower.



12 A



12 B



12 C

McK=McKay strata; MC=Black slate; D=Donald; Dh1=St. Piran; Dh2=Lake Louise; Dh3=Fort Mountain; H1=Horsethief Creek, upper slate member; H2=Horsethief Creek, limestone member; H3=Horsethief Creek, lower slate member; H4=Horsethief Creek, conglomerate member.

SCALE OF MILES

1 0 2 4 6

GEOLOGICAL SURVEY, CANADA.

Figure 12. Sections across Dogtooth Mountains (*See* Figure 6).

In general, east of fault No. 1 there was developed a tight syncline and anticline, both of which were relieved by faulting (faults 2 and 3); then a wider syncline in which relatively shallow faulting developed (fault 4), and then a major overturned anticline, in places including a minor syncline, east of which another thrust is developed (fault 5) along the eastern foot of Dogtooth Mountains. The normal faults shown in B and C of Figure 12 were developed in this eastern anticline.

JUBILEE MOUNTAIN TO BRISCO RANGE (Figure 13)

This section is drawn through one of the intravalley ridges, really a low southeastern extension of Dogtooth Mountains, eastward into Brisco Range. West of Jubilee Mountain there is a broad, low area, a re-entrant part of the trench floor, that is underlain by a northwest-plunging anticline of Windermere series.

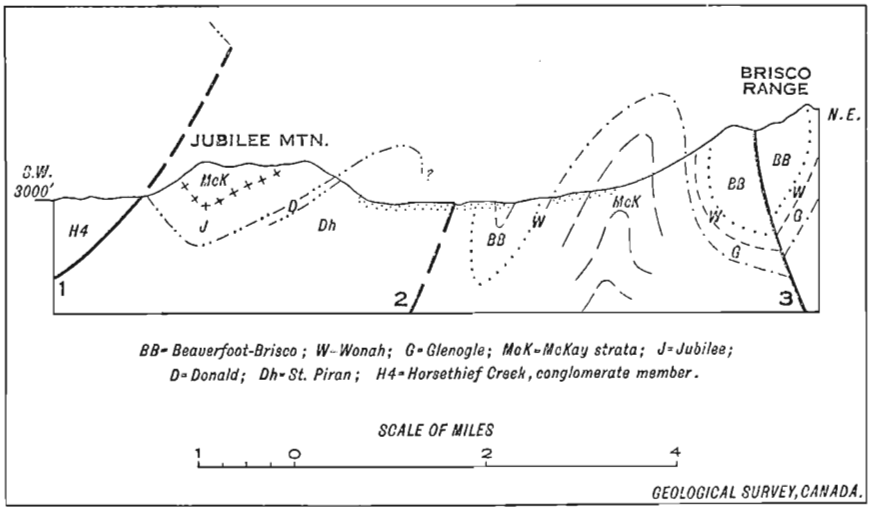


Figure 13. Section from Jubilee Mountain to Brisco Range (*See* Figure 6).

Fault No. 1 is observed at the surface and also in the workings of the Giant mine. It has been traced southeastward 10 miles from section 13 to Steamboat Mountain, from where it appears to swing westward to connect with Walker's thrust fault across Forster and Horsethief Creeks. This fault is considered to be the continuation of fault No. 1, of Figure 12, and if this is so then this fault has been traced for a distance of 95 miles.

At Jubilee Mountain the Jubilee limestone, 2,000 feet thick, rests on Donald strata and is overlain by McKay group. This limestone, which may be of Middle or Upper Cambrian age, does not occur to the northeast in Dogtooth Mountains, but it is probably younger than Canyon Creek slates that occur in the faulted zone shown in Figure 11, along the eastern foot of Dogtooth Mountains between the exposures of Donald and McKay strata.

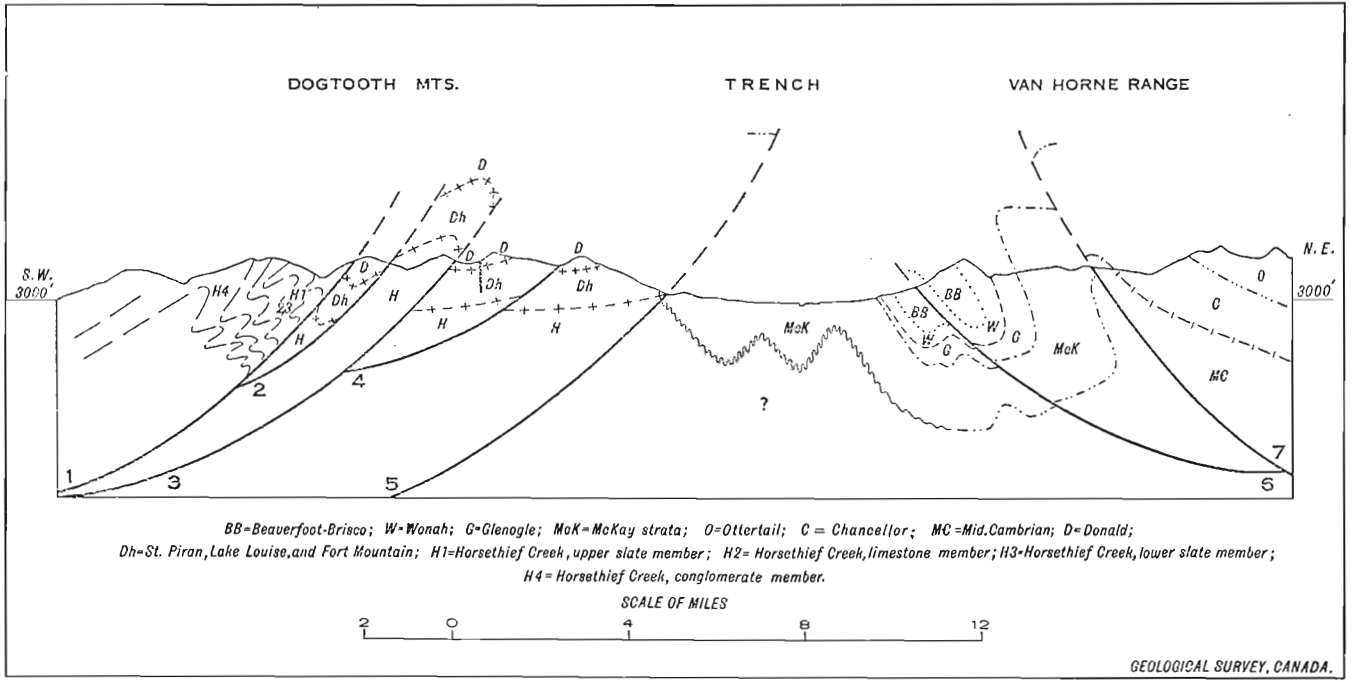


Figure 14. Section from Beaver River to Van Horne Range (*See* Figure 6).

Fault No. 2 was not seen, but the reasonable reconstruction of the structure as given in Figure 13 indicates that it must be present. Another factor to indicate this fault is that areal mapping shows structural trends on either side of where it is placed, that if produced would intersect at a fairly large angle. The writer also supposes that this fault is the continuation of Red Wall fault shown in Figure 7. Fault No. 3 is well exposed and of relatively small displacement.

SECTION FROM BEAVER RIVER TO VAN HORNE RANGE
(Figure 14)

With the exception of fault No. 5 all the faults shown in this figure were observed at the surface. Their positions as shown at depth are, of course, conjectural. The structural details of Dogtooth Mountains have been discussed already. In Van Horne Range the stratigraphic divisions from Beaverfoot-Brisco formations eastward to fault No. 7 appear a great deal thicker than where measured to the southeast in Brisco Range. They are here drag-folded and it is not certain whether the increase in width of exposure is due to thickening of the deposits, in part, or entirely due to the drag-folding.

The strata exposed in the trench floor are drag-folded and isoclinally minor folded. The structure here is thought to be as shown in Figure 14 since all the exposures of McKay group strata, close to Dogtooth Mountains, contain the lower faunal elements of the group; no other strata than McKay are seen here in the trench, and high, upper McKay occurs at the east of the trench. To meet the very probable assumption that only McKay strata occur under the trench it would require that several folds as shown occurred.

Fault No. 6 was seen at the surface, but was exposed for only a short distance vertically by the relief. It is interpreted as being an underthrust of relatively little importance and probably dies out at moderate depth. Fault No. 7 occurs along a zone of intense mashing and drag-folding where the strata have been strongly overturned to the southwest. The stratigraphic evidence for this fault has been presented on page 124. It appears to be a thrust fault dipping to the northeast, but is interpreted as being an underthrust from the southwest. Note its relation to the general structure as given below in Figure 17.

In the foregoing discussion of the structures from the west to the east of the area it will be noted that by far the most complete evidence comes from the north part of the map-area. The section through Jubilee Mountain, however, lies somewhat south of the middle of the area and the same general conditions seem to exist there as at the north. At Sinclair Creek fairly close folding with both southwest and northeast dipping thrust faults was demonstrated. The section given in Figure 15 below is after Walker and is taken 12 miles south of Sinclair Creek, through the middle of Windermere map-area. It shows just on the west side of the trench a major, sharply overturned anticline of Windermere series, whereas west of it again there is a fairly wide area in which the same series shows only gentle folds. The writer has no evidence to offer other than is indicated in the section, but maintains that the structure as shown strongly favours the

assumption that a thrust fault exists along the trench here between the Precambrian on the west and the highly disturbed Palæozoics on the east. Thus, to the west of the trench there are several southwest-dipping thrust faults in Precambrian and Lower Cambrian strata and these strata in many places show folds sharply overturned towards the northeast. East of this along the trench floor the strata are exposed to a very limited amount, but at the north end of the area, where they are best exposed, they consist of Upper Cambrian shales and thin-bedded limestones that are drag-folded and isoclinally minor folded. To the east of the trench, Upper Cambrian to Devonian strata are exposed and are overturned towards the southwest, throughout the greater part of the area. Several northeast-dipping thrust faults occur, as well as several thrusts dipping in the opposite direction. At the north of the area, and particularly along the line of the section of Figure 14, these strata show very strong overturning towards the southwest. Without relating these structures to the structures east in the Rockies it appears as if there had occurred overthrusting and overturning towards the trench from both the east and the west.

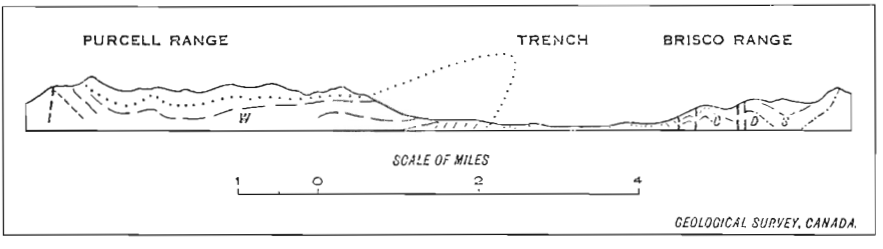


Figure 15. Section in Windermere area, after Walker. W = Precambrian; C = Upper Cambrian limestone; D = Upper Cambrian shale; S = Ordovician and Silurian.

Theoretical Considerations

The writer intends to connect his section across Dogtooth Mountains and Van Horne Range with a section across the Rocky Mountains and to make certain interpretations therefrom. Before doing this, however, it is thought advisable to state as clearly as possible just what the assumptions are that the writer's interpretations are based on. These assumptions are stated somewhat dogmatically, but chiefly so in the cause of brevity, and, it is hoped, clarity.

(1) Tangential forces of compression are greatest at some depth from the surface. No stated distance can be given but it is thought to lie somewhat below the midpoint between the surface and the zone of moderately easy flow to long-continued pressure. Figure 15 illustrates this conception and will be discussed after assumption 6.

(2) Thrusts are developed at depth, at some angle less than the theoretical 45 degrees angle to the tangential compressive force. Probably 35 degrees to 40 degrees.

(3) This angle usually continues from depth until near the surface when a break to the surface will frequently be more easily made by an almost vertical path. Especially is this so where tension faults develop at the surface due to the arching of the top part of the block. (Link, 1928, page 840.)

(4) The block thus separated by the thrust fault will be shoved up and away from the pressure and rise to the point where the resolved forces of the compression at depth are balanced by the weight and friction of the block. The forward part of the block will thus ride out over the surface, accomplishing this by bending and tension faulting.

(5) This over-riding front of the thrust will be shoved along and the original tension faults as well as new breaks will probably be arranged so as to give imbrication.

(6) The final result will be a thrust fault having at depth an angle of about 40 degrees to the surface (assuming the compression truly tangential), then curving upward where it breaks through to the surface, and then flattening out as the front of the block moves forward.

In Figure 16 M-N represents the surface, O-P, the rather indefinite zone at which rock flow will take place.

In the upper figure the forces are represented as vector quantities at the left, increasing to a maximum and then possibly decreasing. It is thought that they will decrease below a maximum, since in the zone of flow the pressure will be less directed and more of a hydrostatic nature.

A thrust C-D develops at depth and reaches the surface steeply at B, then as the force from the left continues the thrust block I will rise to the position II in the lower figure.

The front of the block rides out over the surface and is closely faulted.

There is now an important point to consider and one that leads the writer to maintain that thrust faults develop at depth close to the zone of flow. As the thrust block begins to move up and to the right in the figure, the face A C comes in contact with the triangle marked X, which it must displace as it moves to the right while forcing the thrust block farther up and to the right. In a fault of small displacement this triangle may seem insignificant, but on faults of appreciable displacement it is important, and is important independent of the angle of the thrust. In other words, it is impossible to have shortening in the upper part of the deformed (faulted) layer, which takes place by over-riding above the fault, without having shortening below it at depth. This triangle is probably displaced by being pushed downward into the zone of easy flow.

(7) Movement along thrust-fault planes probably takes place by quick, short reliefs of compression, but the time taken for the total displacement of the faults as now seen was probably great. A very approximate calculation of the fault displacements as represented in Figure 17 below, and supposing that the movement was about that of the San Andreas fault, would indicate that this faulting required over a million years even without taking into account periods of cessation of compression, which probably would occur.

61810—11

(8) It is conceived that during the time of relatively active compression several, to many, thrust faults would occur. Thus, then, above the zone of inception of these thrusts, there will exist a zone of considerable fracturing, so that the lateral transmission of pressure would probably greatly decrease. If, now, the compressive forces are more or less inactive for a time, cementation or other compaction will occur in this faulted zone, so that at the next appliction of compression at depth this zone will be able to transmit forward a great deal more pressure close to the surface than formerly. It seems reasonable to suppose that at such a time conditions favouring underthrusting at the surface will be very likely to occur.

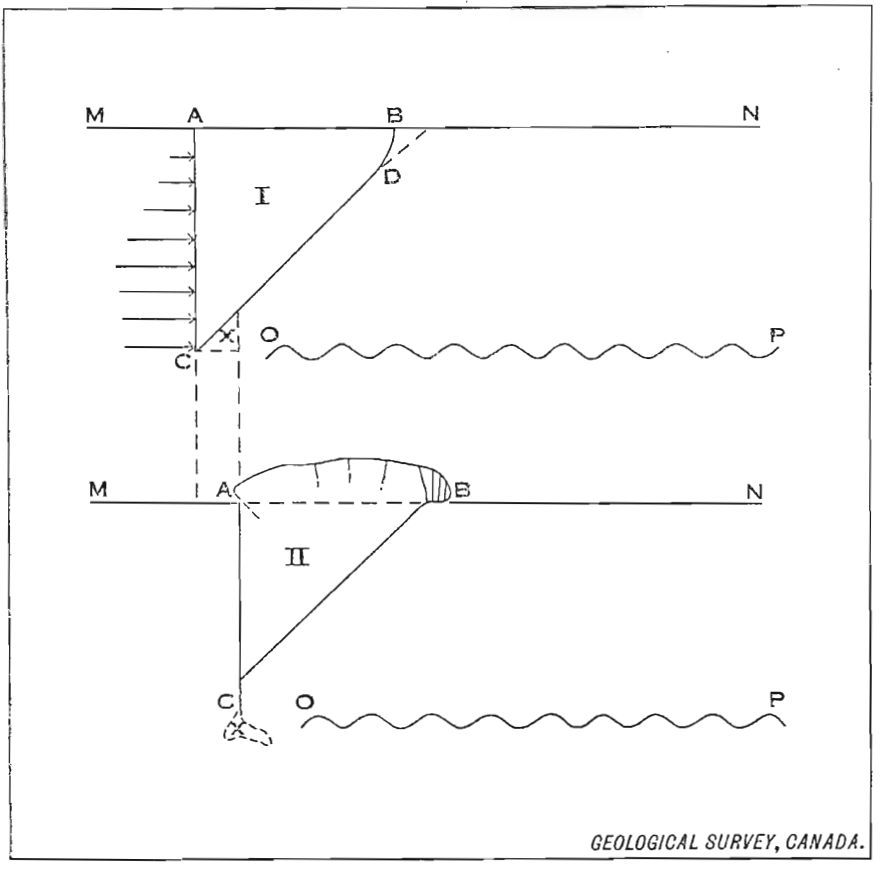


Figure 16. Diagram illustrating action of tangential forces of compression.

(9) That relatively low angle thrust faults may develop, depending on the local condition, in front of a thrust that has reached the surface steeply by way of a nearly vertical break. Such faults would affect only relatively small blocks. Low angle, major thrusts might develop depending on the position of a competent series of strata between less competent

ones. The angle of about 45 degrees would probably only hold where the series of strata affected had about the same strength throughout. It seems likely that where there are intercalations of quite incompetent beds (shales) of appreciable amount that the angle developed would be less than 45 degrees. A very simple illustration of this might be given. Suppose the layer to be acted upon by compression consisted of thick shale below, then a fairly thick, competent layer, and above this again another thick series of shale. On compression the shales above and below would be deformed and arch up or down according to their ability, and the competent member might break upward at 45 degrees and ride over itself, pushing aside the shales. As the "push block" surface transmitting the pressure moved forward, the shales would keep on deforming (almost by flowage) and arch upward or downward as they were able, and practically the whole horizontal movement of the "push block" would be seen in the overlap of the broken ends of the competent member. The example is so simple that it is not likely to occur, but it probably indicates what departure may be expected from the theoretical 45-degree angle by a corresponding departure of the arrangement of competent and incompetent beds away from a homogeneous layer.

(10) That heavy compression cannot be carried far forward in the crust without causing deformation, unless that part of the crust has been thickened and compacted by previous compression. An application of this will allow one to recognize from which direction the pressure has come. As an example, note the Rockies, their foothills and the plains to the east. Here the pressure must have come from the west.

(11) Depending on No. 10 it may be taken as a general though not invariable rule that if the pressure has come from the west then the faults at the west are older than those to the east. Over any tens of miles this rule must be so, in any shorter distances some (unknown) local conditions might permit a reversal of the rule.

(12) Depending on the detail of direction of application of pressure, or on the distribution of incompetent strata in the section, the initial fault might develop at an angle as low as 30 degrees to the surface. Shortening will take place on this fault until the compression that started it is balanced or relieved. On the next application of accumulating pressure a new thrust may develop ahead of this one and the block immediately above it will ride forward and up; whereas the block next behind it will be pushed forward and accommodate itself to the movement, not by riding up on the back of the block ahead of it, except to a certain small amount, but by its base sliding forward in the zone of flow, and by movement between it and the block ahead of it on the old fault surface, thus causing a rotation of this older block. In this manner the older faults nearer the active pressure become steeper than the younger ones ahead of this older block, though it is probable that the maximum steepening of the older faults is reached when the block with which it is associated is the third or fourth behind the newly formed thrust, along which movement is then taking place.

If this condition is so then the thrust faults found on the side of a deformed area towards the active pressure should be steeper than the thrust faults on the opposite side.

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Section Through Purcell Range and Rocky Mountains

Figure 17 presents a section, starting at Beaver River and drawn east to the plains in Alberta.

This section is given here in order that the structures at the trench in Brisco-Dogtooth map-area may be seen in relation to the general structure. The section across the Rockies has been redrawn to make use of later work, as that of P. S. Warren (1927) and G. S. Hume, and in order to omit the parts of the section previously given (McConnell revised by Allan) that are along the strike of the Rocky Mountains, since this former section had been made purposely along the route of the Canadian Pacific Railway and not at right angles to the strike.

The section in the foothills is from the work of G. S. Hume and close to the Rocky Mountain front from R. L. Rutherford (1927). The structure in the front ranges is adapted from McConnell (Sections E, F, Annual Report, part D, 1886), but the stratigraphic succession shown here is the writer's interpretation of McConnell's units in terms of the stratigraphy as established by P. S. Warren in Banff area.

Westward from Banff to Van Horne Range the section is from Allan's section along the railway. The attitudes of the faults at depth are, of course, interpretations by the writer.

The major faults in Figure 17 are numbered with simple numbers, whereas the minor or subsidiary faults are numbered after the major fault to the left with subscripts a, b, c, as necessary.

Faults 1 and 2 in Dogtooth Mountains are thought to be major thrust faults, whereas faults 1a, 1b, and 1c are taken as subsidiary faults to No. 1.

Fault 3 is interpreted as an underthrust of major proportions and fault 2a as a relatively minor underthrust.

Faults 3a, 3b, and 3c are normal faults, possibly developed behind thrust 4 during the arching of the block between it and thrust 3, during the compression.

Fault 5 is shown as vertical in Allan's section and the strata just to the east of it are overturned towards the southwest. The writer interprets this as an underthrust that dips to the northeast at depth.

Fault 7 is a major thrust that outcrops just west of Mount Edith and has as subsidiary faults 5a, 5b, 6a, 6b, and 6c.

Faults 7, 8, and 9 are taken as thrust faults of major importance. All the major thrusts and underthrusts so far mentioned have steep dips where they now emerge and are thus in contrast with the three thrusts that lie to the east, faults 10, 11, and 12.

In the foothill section only one flat thrust, 12, was previously shown, but Hume now thinks there is good reason to suppose that there is another flat thrust in this section, fault 11. (Hume, G. S.: Personal communication.)

Fault No. 10 happens to be exposed in an advantageous manner. The west part dips steeply to the southwest, but flattens out under the most eastern exposure of the "Rocky Mountain Front."

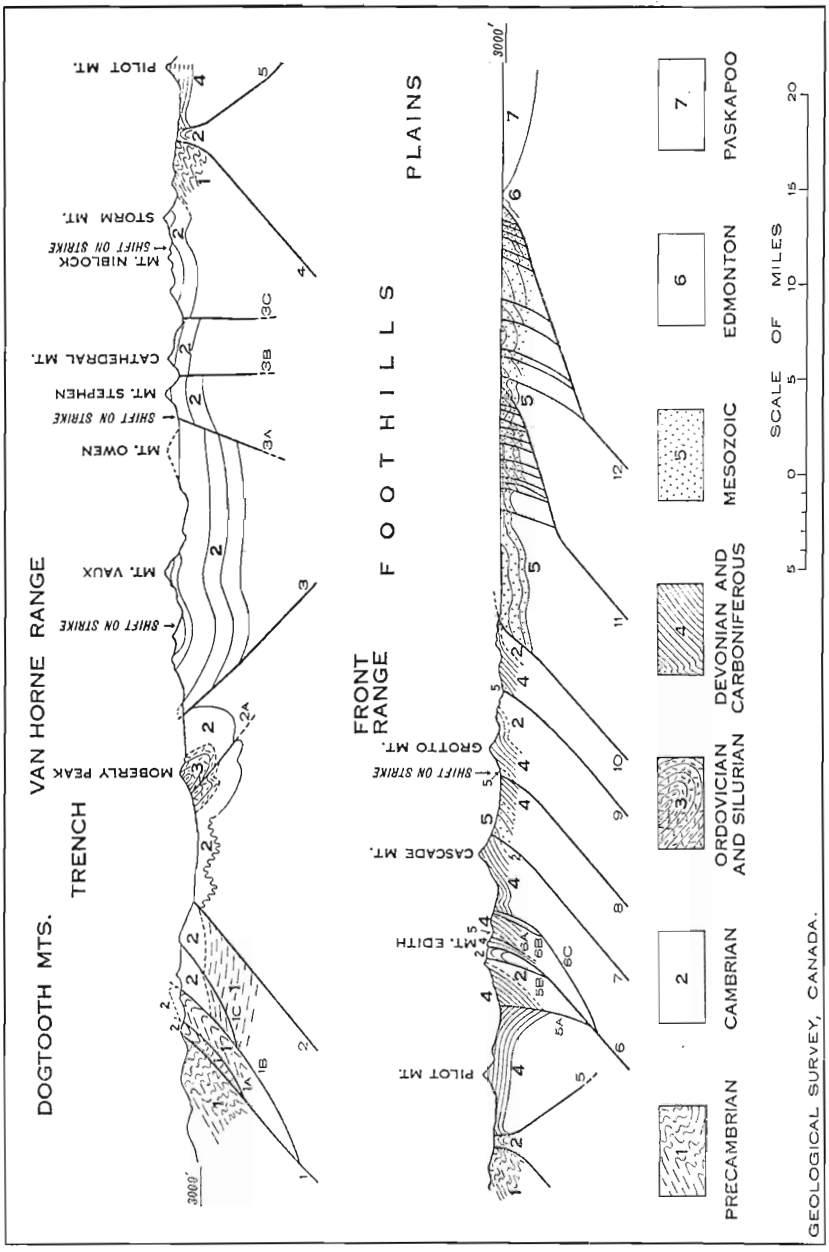

Figure 17. Section from Dogtooth Mountains to the Plains.

The writer thinks that this fault formerly rode out eastwards over the surface, but has been eroded back to just about the point of flexure from which it dips steeply to the southwest.

Faults 11 and 12 are interpreted as being flat thrusts in their upper parts and Hume (1931, page 259) has shown that fault 12 has a dip of about 20 degrees to the west. The stratigraphic displacement shown by these faults at the surface appears to be relatively small, so that the movement along their fault planes is probably not great. These faults also probably originated at depth, but the fault surface may have been deflected to the east at a low angle, through limestones and Cretaceous strata, and the eastward movement may have been taken up in many small imbrications as shown and these blocks, therefore, did not ride eastward over the surface.

No other flat thrusts are found west of fault 10 and this may be explained by these faults being older, so that erosion has succeeded in cutting away entirely the over-riding fronts of the thrusts.

AGE RELATION OF SELKIRK SYSTEM AND ROCKY MOUNTAINS

Criteria for dating the age of the faults in the mountains are lacking, since no strata higher than the Cretaceous are exposed in the eastern Rockies, whereas in the western Rockies and in Purcell Mountains Palæozoics are the youngest strata exposed.

In the foothill region Palæocene strata have been affected and farther south, south of the 49th parallel, later work seems to indicate that the Lewis thrust is either late Eocene or early Oligocene (Mansfield, 1927, page 382). As before noted, the time necessary for the great amount of movement along thrust planes, as illustrated in Figure 17, would be very long. Also, it is more likely than not, that there were pauses in the development of the compression, so that the structures shown in Dogtooth Mountains, though of the same type as those occurring farther east, may be much earlier than the structures of the foothills and Rocky Mountains.

Since direct evidence whereby the ages of the faults could be dated is lacking in Brisco-Dogtooth area and in the Rocky Mountains to the east of this area, it may be useful to review the evidence of an indirect or inferential nature.

Evidence in Support of the Greater Age of the Structures and Mountains West of the Trench

(1) Trends of the Trench and the Ranges East and West of It. The trends of the trench and of the Rocky Mountains are parallel and northwestward, but the mountains west of the trench, that is, the Purcell Range, the Selkirk Range, and the mountains west of Columbia Lakes, trend nearly north at an angle to the trench and are truncated by it and the Rocky Mountains. From these relations the writer concludes that the final structural delineation of the trench is much more closely associated with the building of the Rockies than with the ranges to the west. That is, that the last-formed mountains would influence most the final trends of the trench.

(2) *Evidence from Igneous Intrusion.* The evidence so far published indicates that Purcell and Selkirk Ranges were formed previous to the Rocky Mountains[1]. This evidence may be summarized briefly as follows. Many batholiths and smaller igneous intrusions are exposed in Purcell and Selkirk Ranges and many of these by connecting links (not always secure) have been related to Coast Range intrusion of late Jurassic or early Cretaceous age, whereas no batholiths are exposed east of the trench. The assumption usually made is that west of the trench mountain building and intrusion took place sufficiently long before the building of the Rockies to allow of the deroofing of the batholiths there, whereas they are not yet exposed in the Rocky Mountains.

The dating of the intrusions in Purcell and Selkirk ranges is, however, far from secure. Much of the dating has been made because of similarity of the plutonics to other plutonics for which it has been customary to assume a late Jurassic age. There are really two questions to be considered about these intrusions:

The dated age of the intrusions and the correlations of other undated ones with them by lithologic similarities.

The significance of the rather abundant occurrence of deroofed batholiths and stocks west of the trench, whereas but one alkaline intrusion of minor extent is found east of the trench.

Unquestionable evidence of Jurassic intrusion is found on Vancouver Island and in or near the east side of the Coast Range[2].

In all these localities Jurassic or lower strata are cut by the intrusives which, however, do not cut Lower Cretaceous strata that are exposed within these areas or close to them. Other later intrusions are also found. Again, on the east side of the Coast Range major intrusions are found that are post Lower Cretaceous as in Gun Creek (Dolmage, 1928), Chilko and Taseko Lakes (Dolmage, 1924), and in Yale District (Cairnes, 1923). From other areas in the Coast Range and in the Interior Plateau region the intrusions can only be dated as post Triassic or post Jurassic as in Bear River and Stewart area (Hanson, 1929), Slocan and Upper Arrow Lakes (Cairnes, 1928), Hedley (Bostock, 1929), and Lightning Peak district (Cairnes, 1930). Several intrusions are thought to be of Tertiary age.

Thus, evidence is fairly consistently present on Vancouver Island and in the main Coast Range for dating Jurassic and later intrusions, but so far very little evidence has been found in the interior and in the Columbia-Selkirk-Purcell system of mountains by which intrusions may be dated. Cairnes (personal communication) is of the opinion that the Nelson batholith and associated intrusions were emplaced in late Cretaceous, an opinion that is based on correlating the fracturing and mineralization of the Nelson

[1] Schofield, 1923, p. 98; 1915, pp. 84-102; 1920, p. 64.
Daly, 1906, pp. 358, 375.
Drysdale, 1915, p. 61.
Bancroft, 1919, pp. 43, 46.

[2] Vancouver Island
Clapp, 1917; Gunning, 1930;
Coast Range
McCann, 1922; Hanson, 1923, 1925; Cairnes, 1924;
Interior
Camsell, 1913.

batholith rocks with the compression of the Laramide revolution and on the later stage of differentiation indicated by the petrography of the eastern intrusions as compared with the western.

The probability is that the Mesozoic intrusion of the west is earlier than that of the east, but that it took place between Upper Jurassic and late Cretaceous. There are probably, also, some intrusions of Tertiary age.

The writer is of the opinion that there is considerable significance to the fact that there are numerous intrusions exposed west of the trench and but one, minor, alkalic one east of it, so far as is known. The question, of course, is raised as to whether this is a matter of age of intrusion and subsequent time allowed for erosion, as between Purcell-Selkirk Ranges and the Rocky Mountains, or is it something that should be explained solely by the type of structure that is found in the Rocky Mountains (thrusting)? For it might be said that the Dogtooths and the Rockies merely represent the eastern overthrust edge of a large area that has been compressed from the west, but that the area west of the trench had been deformed in some manner other than by overthrusting. This is probably not so, however, for there is some evidence that much the same type of structure (thrusting) extends at least to the western edge of Selkirk Range, where Gunning (personal communication) found marked overturning towards the southwest with shear zones that probably indicate northeast dipping thrust faults (more probably underthrusts). Unfortunately the section as given by Daly (1913 section) through the Selkirks cannot be considered in detail as the structure was put very much in doubt by the reported finding of Upper Palæozoic fossils in the Laurie (Burling, 1918) of Daly's Precambrian section. From what evidence there is the writer is of the opinion that much the same type of structure exists across Selkirk Range in this latitude as is exhibited in the Rockies and deroofed intrusions are included in this area. Thus the writer is led to believe that the exposure of batholiths west of the trench is due to intrusions previous to the building of the Rocky Mountains and their subsequent deroofing, rather than to structure.

In Windermere area Walker (1926) found that the thrust fault on Horsethief Creek is cut by a granite stock. This fault is thought to be a continuation of fault No. 1 of Figure 14. Elsewhere in the same report Walker places this intrusion as probably of the same age as the Nelson batholith (Jurassic?).

(3) *Occurrence of Igneous Pebbles in Cretaceous of the Foothills.*[1] At intervals from Oldman River to Red River, Lower and Upper Cretaceous conglomerates are found to contain igneous pebbles. Some of these are 5 inches in length and 2 to 3 inches in other diameter. Granitic and porphyritic types are found, the former being medium to fine grained and massive, that is not foliated. Russell found similar pebbles in the Paskapoo (Palæocene). These pebbles were probably carried by east-flowing streams from the area now occupied by Purcell and Selkirk Ranges which are 60 to 80 miles east of the foothills. The presence of the igneous pebbles in the Palæocene would indicate that a stream in the vicinity of the present Bow River had kept its course across the rising Rocky Mountains up to that time.

[1] Hume, 1929; Evans, 1929; Russell, 1932; Schofield, 1920.

(4) *Absence of Jurassic and Cretaceous Deposits in Selkirk-Purcell Area.* The area occupied by Selkirk and Purcell Ranges appears to have been a land mass from Lower Cambrian to the end of Devonian time. Thereafter there was deposited in this area marine strata and tuffaceous accumulations in Carboniferous and Triassic times (Walker and Bancroft, 1929, Cairnes, 1928, Schofield, 1920). The absence of Jurassic strata is to be explained by the probable initiation of upwarping that may have culminated in late Jurassic or early Cretaceous times, and the Cretaceous is absent since this area was undergoing erosion at that period.

No single argument offered to show that the Selkirk-Purcell Ranges were formed and the thurst structure effected in late Jurassic or early Cretaceous times is decisive, but it does seem that all these points considered together provide sufficient ground to favour this postulate.

Suggested History of the Structures in Brisco-Dogtooth Area

It is suggested that the Selkirk and Purcell ranges were formed with much the same structure as seen there at present, in late Jurassic or early Cretaceous time. The pressure came from the west and these ranges were formed with nearly north-south trends.

The area along the trench and for a short distance east might well be considered to have formed then a narrow foothill belt to the Purcells. After this there was a period of rest.

On the recommencement of pressure from the southwest considerable pressure was exerted by the compacted, near surface rocks of Dogtooth Mountains, and this pressure caused underthrusting on the east side of what is now the trench and resultant overturning toward the southwest. There is evidence to show that northeast dipping thrusts (underthrusts?) at Sinclair Creek are later than a southwest dipping thrust, though by what period of time is unknown (Figure 7). Thus the strata along the trench would have suffered deformation at two different times and provide a much sheared zone along which later erosion could easily work. Schofield (1920) thinks that the erosion along this structural line was caused by the diversion to it, by faulting, of the waters of the rivers that previously flowed eastward across the site of the Rocky Mountains. The early trench may have been in part a structural depression, though the present form and depth of the trench have resulted from erosion along a lineament. From the trends of the trench it seems that the pressure was directed, or at least applied, more from the southwest than it was during the orogeny of Selkirk and Purcell area.

The Trench Beyond the Map-area

49th Parallel (Schofield, 1920). The trench here occurs along the eastern part of a tilted fault block which has its larger downthrow along the east side of the trench. Devonian strata are exposed at the east of this block and rest on Purcell series. Purcell series occurs in both bordering ranges of the trench.

Bull River (Schofield, 1920). Devono-Carboniferous strata floor the trench, and are brought into contact with the lowest member of the thick

Purcell series by a fault at the east of the trench. The throw of this fault is very great.

Bull River to Sheep Creek (Schofield, 1920). The Purcell series occurs on both sides of the trench. The great fault noted at Bull River continues north to Sheep Creek and appears to have a smaller throw northward.

Windermere Map-area (Walker, 1926). Walker states

". . . . the Precambrian formations on the west side of the trench are overturned . . . . to the northeast. The Horsethief formation is exposed at several places on the east side of the trench, and is folded and faulted with the Palæozoic formations. The strata in the Stanford range are highly folded and faulted. The Palæozoic formations in the neighbourhood of the trench are thinning very rapidly to the west. It would appear that the intense folding and faulting in Stanford range were due in large part to the folding of the rapidly thinning Palæozoic formations against the resistant Purcell mass to the west. The trench at this point appears to have been eroded along the western margin of this area of intense folding and faulting where the shattering of the formations was probably greatest. There are no true border faults along the trench within the map-area."

The folds of Stanford Range are overturned to the southwest, similar to the folds in Brisco Range of the present map-area.

Surprise Rapids. (Coleman, 1889). Coleman postulates a great fault between Archæan (?) rocks to the southwest and Palæozoic rocks to the northeast of Surprise Rapids.

Upper Fraser River Within the Trench. Malloch (1909) made geological observations in this part of the trench; but since the stratigraphy is difficult of determination, he hesitated to postulate a trench fault. He noted that numerous faults occurred in the region. Schofield (1920) notes that the rocks in the floor in this section are badly sheared and crushed.

Finlay River. McConnell (1894) reports Shuswap rocks on both sides of the trench as far north as the mouth of Ingenika River. North from this point, strata of Laramie (?) age occur along the bottom of the trench and rest on Precambrian and Palæozoic strata. These Laramie (?) beds appear to be lake deposits laid down along a depression and they have been tilted from 10 to 40 degrees.[1]

These reports at least indicate that faulting of considerable importance and rather intense folding and crumpling occur along the trench. There is, however, little or no specific evidence to support the writer's postulate, indeed the evidence from near the 49th parallel would seem to be against it. The evidence from Windermere area, Surprise Rapids, and the upper Fraser River, might be taken as supporting the postulate, in a general way.

Suggestions Already Published to Explain Origin of Trench

The Trench a Graben (Daly, 1912)

From work along the 49th parallel Daly suggested that the trench is a graben. He later changed his opinion. There is no evidence for a graben in the writer's area.

[1] *See also* Geol. Surv., Canada, Sum. Rept. 1927, Part A, "Finlay River District", by Victor Dolmage.

The Trench Situated Along a Zone of Faulting of Great Vertical Displacement

(Daly, 1915)

Daly offered this explanation and the one given below after working along the main line of the Canadian Pacific Railway. He states "It seems more likely that the master fault of the trench is normal with downthrow on the northeast." Certain localities might favour this supposition, but the consideration of the structures as a whole is against this, in Brisco-Dogtooth area.

The Trench Situated Along a Line of Scission and Horizontal Movement

(Daly, 1915)

Daly notes that the trench is nowhere a typical graben and that throughout its length it lies in rocks of different ages, and its trend is fairly constant. For these reasons he suggests that it is located along a line of scission and horizontal movement. He states: "An analogy is found in the 600-mile San Andreas rift of California..... It is conceivable that a similar type of crustal scission, accompanied by vertical displacement vastly greater than that demonstrated at the California rift, is the true explanation of this remarkable trench of the Canadian Cordillera." No known major offsetting has been demonstrated as yet along the trench and the only indication of scission seen by the writer is given in Figure 9, where indeed it is so minor that it should not be used to support this supposition. Following up Daly's comparison of the Rocky Mountain trench and the San Andreas rift it is interesting to note that Kerr and Schenck (1915) show by sections that thrusting and overturning have occurred towards the San Andreas fault from both sides, in San Benito County.

The Trench Situated Along a Zone of Intersecting Thrust Faults

Shepard (1922) suggested that the trench between Canal Flats and Golden was eroded along intersecting thrust faults of two mountain wedges. He also noted the overturning of the strata on each side of the trench, in towards it, and suggested that this type of folding produced a depression. His general observations of the structure are those that are found in the area and it is quite possible that the faults towards the trench may be thrust faults of two wedges, which, however, the writer has interpreted as thrust faults on the west side and underthrusts on the east side.

The Trench Eroded Along a Zone Coincident with the Edge of the Middle Cambrian to Devonian Seas

Daly (1912, page 99) states: "From at least 60 degrees north latitude to about 52 degrees north latitude the western rim of the geosyncline ran roughly parallel to the course of the present Rocky Mountain trench. It is a question worthy of investigation whether there is a genetic connexion between the trench and this zone of shore-lines." Walker (1926,

page 40) probably had somewhat the same idea in mind when he noted "The Palæozoic formations in the neighbourhood of the trench are thinning very rapidly to the west. It would appear that the intense folding and faulting in the Stanford range were due in large part to the folding of rapidly thinning formations against the resistant Purcell mass to the west. The trench at this point appears to have been eroded along the western margin of this area of intense folding and faulting where shattering of the formations was probably greatest." It can only be said that the Middle Cambrian to Devonian strata thin out rapidly along the trench within the writer's area. What Daly and Walker would seem to suggest is that the area west of the trench was a positive area during much of the Palæozoic, at least while the area to the east was a negative one. Thus, a zone of weakness would exist in the basement rocks that might be reflected during the compression of later times.

The Trench Eroded Along a Horst (Shepard, 1926, page 640)

The writer saw no evidence in support of this suggestion and much evidence against it.

It should be pointed out that detailed geology has been done on only a small section of the trench and that until the detailed geology is done along most of the trench the method or methods of its formation will be very much in doubt.

ECONOMIC GEOLOGY

Placer Holdings on Quartz and Porcupine Creeks

Quartz Creek flows north-northwest and joins the Columbia at Beavermouth. Porcupine Creek is tributary to Quartz Creek and lies in a southward extension of the valley of the main stream.

Quartz Creek and the so-called Porcupine Creek have long been known to hold placer ground, and stories are current of gold having been found there by prospectors of the "early sixties." The first published account of which the writer is aware is given by Dawson (1889, page 131), who states that active work was carried on during the summer of that year, when twenty-three days of sluicing gave a recovery of something over $1,000. Work during the following year proved unsuccessful as the gold was "scattered amongst a mass of large boulders, which made it expensive to work."

In 1926 and 1927 work was done here by the Quartz Creek Syndicate formed of the following: Mr. C. P. Price, of Beavermouth, B.C., and Messrs. J. F. Townsend, C. Hassard, L. E. Anderson, and H. J. Read, of Medicine Hat, Alberta. Their holdings consisted of four bench claims and three creek leases. The creek leases are on Quartz Creek and extend 1½ miles northwest from the mouth of Porcupine Creek, 10 miles southeast of Beavermouth. The bench claims extend for 2 miles southeast of the junction of the creeks along the east slope of Porcupine Creek Valley.

Most of the season of 1926 was spent in digging the ditch, building the penstock, and laying the pipe-line to within hose reach of the ground chosen for washing, at the northwest end of the bench claims. The water supply was sufficient for two 2-inch nozzles under a head of about 200 feet.

A certain amount of interrupted sluicing done at the end of the season gave a recovery of $240 from about 225 cubic yards of ground. The greater part of the gold recovered consisted of 10 to 50 cent specks: the largest nugget found was valued at $12.

The work of 1926 seemed to promise success for the enterprise, but in 1927 it was found that the cost of handling the numerous large boulders of the deposit was so high that the work was abandoned.

The bench on which the bench claims were staked is situated on the east side of Porcupine Creek. The down-stream end is opposite the junction of Quartz and Porcupine Creeks at an elevation of 5,700 feet, and the bench extends southward for a little over 2 miles, where it meets the present creek at an elevation of 5,900 feet. Throughout this length the bench ranges in width from 200 to 700 feet, is heavily wooded, and, since it is not cut by streams, shows no exposures of gravel except at the workings. Here the average depth of the gravels is 6 feet, with overburden of forest decay and, occasionally, peat, from 1 to 3 feet. The gravels are poorly sorted, clearly of glaciofluvial deposition, and consist of sand and pebbles in which there are many rounded and subangular boulders up to 3 feet in diameter. The rock fragments are representative of the strata of the basin: quartzites, limestones, and slates. Beneath the gravels disintegrated, blue phyllite bedrock forms a layer averaging a foot in thickness. As far as can be seen from the area of bedrock exposed in the workings, the bench appears to have been cut in phyllite and to be slightly lower back from the rim.

The present creek is 600 to 700 feet below the level of the bench at its northwest end. The slope is steep from the bench rim down to just above the stream, where there is a narrow, but rounded, bottom into which the stream has cut a sharp notch 20 to 100 feet deep through old gravels, talus, and phyllites. The talus seems to have come from the steep rock slope on the west side of the valley. The slope above the bench is mostly covered with talus, but there are several small remnants of higher benches at elevations of 6,200 to 6,500 feet.

The creek leases are on an alluvial flat the surface of which is 3 to 20 feet above the bed of the creek. The material is finer than that of the bench and represents material derived by stream erosion of the steep, lower parts of Porcupine and Quartz Creeks above their confluence, and deposited because of the lower gradient below their confluence. Most of the ground is on the east side of the creek and the flats range in width from 100 to 1,000 feet; the depth of the alluvium is not known. The gravels may include some of the reworked bench gravels, as well as later materials carried down by the streams. Some work has been done here in the past and it is said that the values are better than on the bench. The lower parts of the valley opposite the bench are not regarded as favourable ground by the prospectors.

The gold found on the bench occurs in the glaciofluvial deposits and in the disintegrated phyllite. It is believed that this softened phyllite represents the original fresh bedrock at the time of deposition of the pay gravels. In about ten pans washed from the disintegrated phyllite the gold particles were in no instance larger than 3 to 5 cents; most of them $\frac{1}{2}$ to 1 cent. No information as to the actual extent of the payground is

available. Values of $1 to $2 a yard are said to have been obtained for several hundred feet up- and down-stream from the hydraulic pit at the northwest end of the bench claims. Similar values are also said to occur on the creek leases and colours are reported from the present stream gravels downstream to the Columbia.

The valley of Quartz and Porcupine Creeks is underlain by slates and phyllites, above which, as seen on the lateral ridges, occur limestone and quartzite strata. Many small veins and stringers of milky, white quartz parallel the cleavage of the slates and phyllites and a number of stronger veins occur in the massive strata. Small amounts of pyrite and occasionally galena and chalcopyrite are found in the veins and the secondary development of ferruginous carbonates is pronounced in the enclosing strata. Numerous, small, twinned crystals of arsenopyrite were recovered from the sluice-boxes, though on analysis these did not yield any gold values. One small nugget was found enclosing milky, white quartz in which there was some ferruginous carbonate (ankerite) as seen in the veins. No free gold has been seen in any of the veins, though quite small assay values have been reported. These veins are probably the source of the gold.

A little over 2 miles upstream from the mouth of Quartz Creek there is an old channel through which the lower part of this stream formerly flowed northeast to the Columbia. This channel might be worth prospecting, though there is no ready source of water and the gold if present probably would be fine.

Grizzly Creek between West Branch and the lower part of East Branch has cut through Horsethief Creek strata in which there are numerous quartz veins, and probably holds some placer gold.

Lead-Zinc Properties

JUBILEE AND LEAD MOUNTAINS

Lead Mountain—Rose Group

The Rose group is situated between elevations of 4,150 and 4,350 feet on the east slope of Lead Mountain, about 2 miles west of Columbia River, southwest of Castledale post office. On this property disseminations and replacements of galena and some sphalerite occur in a sandy, magnesium limestone, about 250 feet thick, overlain by drab slates and underlain by rusty grits dipping steeply to the southwest (60 degrees). Two adits, 100 and 250 feet long, respectively, have been driven westward into the limestone, and the surface is exposed by shallow pits and strippings. The limestone is closely fractured, and in most of the deposit the sulphides occur thinly seaming the fracture planes and as small, scattered pellets in the limestone. The 250-foot adit shows this type of mineralization for the first 130 feet from the mouth, the first and last 20 feet of this distance being the richest, with a lead content of about 4 per cent. From 130 feet to the face of the adit very little sulphide occurs. Such disseminations are also shown for about 500 feet along the slope on the surface, though a few 10-inch pockets of nearly solid galena were found at the entrance to the 100-foot adit. From an examination of the adit and the nearby surface

it is inferred that the pockets are isolated replacements. Samples from a stripping, 10 by 20 feet, just north of the 250-foot adit, are said to have given 20 per cent lead. The mineralization is seen to decrease inwards along both adits, but extends farthest in the 250-foot adit, the lower, so that the sulphides may be confined to a fracture zone of steeper dip than that of the formations and may be found at lower elevations in the eastern part of the limestone, close to the grits. An alternative explanation is that these deposits may be only marginal to a main zone of mineralization that may lie directly to the east of Lead Mountain and is now hidden by the drift.

Giant Mine. This property is described in the reports of the British Columbia Minister of Mines, for 1909, 1923, 1927, and 1929, and in the Summary Reports of the Geological Survey for 1925 and 1926.

In 1926 the property was acquired by the Pacific Mines, Limited, of Vancouver, under whose ownership several bodies of lead ore in barite and limestone were found by diamond drilling. A crosscut tunnel was later driven to the largest of these (Figure 18, Tunnel No. 5).

The geology is shown in Figure 18, and is outlined briefly below. The Giant mine is situated on the southwest slope of Jubilee Mountain, and is in Jubilee limestone in the western limb of a northwest-plunging syncline. Jubilee limestone is overlain by the basal beds of McKay group strata, here mostly shales. Both limestone and shales have steep dips. One-quarter mile west of the lowest exposures of Jubilee limestone, small outcrops of Horsethief Creek strata (pebble conglomerates) project through the drift. Regionally, Horsethief Creek strata are seen to be thrust against Jubilee and McKay, and other younger strata. This fault is disclosed in the tunnels and by the diamond drilling and is found to dip to the southwest at a moderate angle. It is shown to intersect the steep contact surface between Jubilee limestones and McKay strata, so that to the northwest Jubilee limestone no longer appears at the surface, but must occur as an inverted "V" below the surface.

From the map and cross-sections it may be seen that the mineralization is richer and more extensive towards the apex of the inverted "V" of Jubilee limestone. Thus, at the southeast in sections C and D, relatively little ore is found, and it is here that erosion has carried away the upper part of the inverted "V". To the northwest there is more ore and the best body found so far occurs in the apex of the "V" as shown in section A.

This suggests to the writer that the upper part of the inverted "V", where limestone is contained between shales (Horsethief Creek above the fault and McKay group strata in normal position above Jubilee limestone) has acted as a confined channel for the mineralizing solutions. It seems probable that other bodies of ore may be found in the limestone, where it plunges westward beyond section 2. This could be tested by diamond drilling from the ore-body in tunnel No. 5, feeling out as it were the top of the limestone "V".

The mineralization appears to be as follows: limestone replaced by barite; barite replaced by galena (and sphalerite); in some few instances a little galena is found in limestone without barite.

Tunnel No. 5 cut through 30 feet of ore with 12 per cent lead, and a raise driven from this tunnel up to tunnel No. 3 passed for 150 feet through

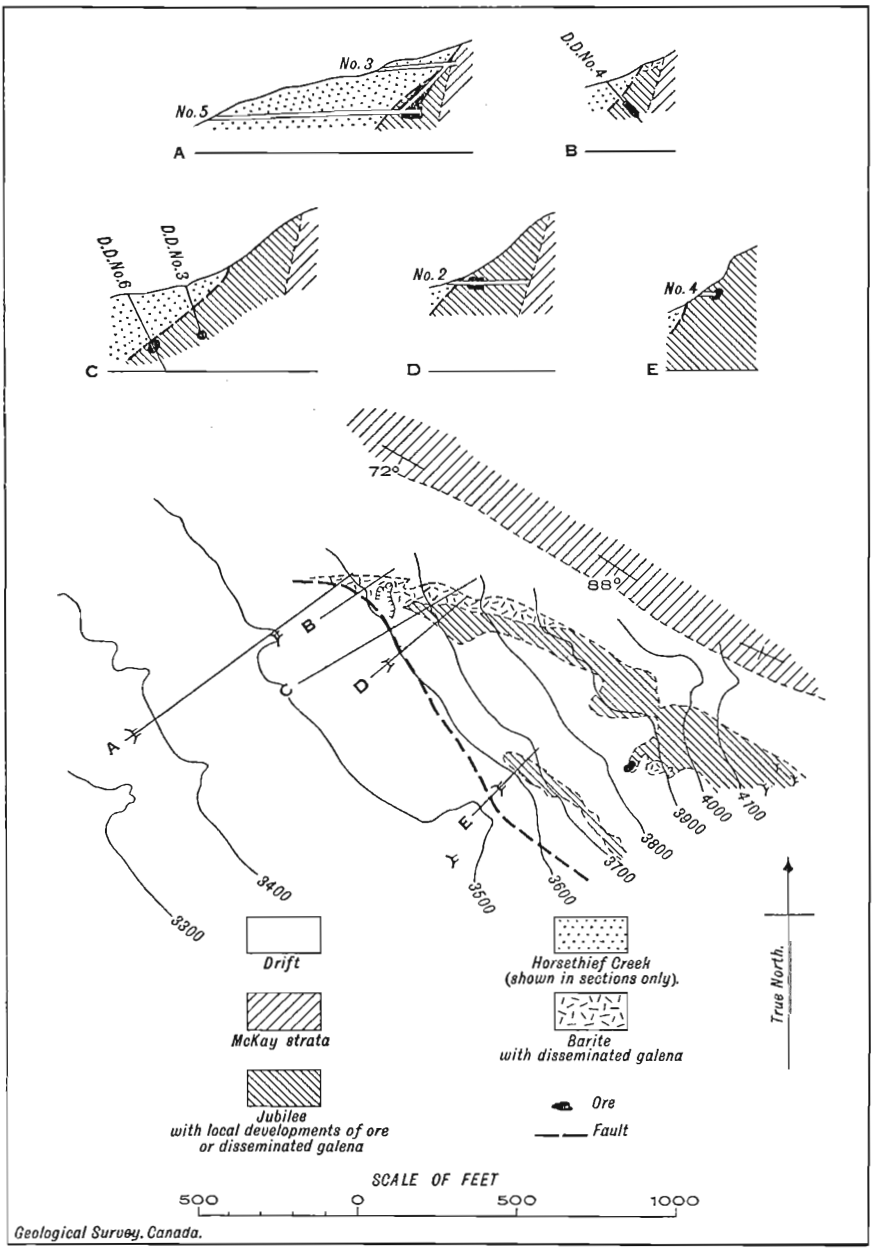

Figure 18. Plan and vertical sections of Giant mine, Jubilee Mountain.

ore that averaged 2·7 ounces of silver a ton and 11·6 per cent lead. Drill hole No. 4 passed through 28 feet of mineralization that ran 1·8 ounces of silver a ton and 1·9 per cent lead. Tunnel No. 2 cut through 14 feet of ore with 2·1 ounces of silver a ton and 10·6 per cent lead; and a body 4½ feet across, that assayed 0·7 ounce of silver a ton and 3·1 per cent lead, was cut by tunnel No. 4. The ore-bodies discovered in the workings as given above probably represent separate replacements in the limestone. Besides these ore-bodies there are irregular bodies of lead mineralization too poor to form ore in the barite and the limestone.

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BORINGS FOR WATER, OIL, AND GAS IN BRITISH COLUMBIA

By W. A. Johnston

(Geologist in Charge, Division of Pleistocene Geology, Water Supply, and Borings)

Comparatively little drilling for oil, gas, and water in British Columbia was done in 1932, though there was considerable interest in the possibilities of obtaining well water for irrigation and other purposes, particularly in dry areas such as Okanagan Valley. The possibilities of obtaining well water for irrigation in the Summerland municipality in Okanagan Valley were investigated by C. E. Cairnes of the Geological Survey. The results of the investigation indicate that favourable conditions for artesian water at shallow depths exist at places in the area. A report on the water conditions has been furnished to the municipality.

Drilling for oil and gas at the Patrick well at Australian, in Cariboo District, by the Cariboo Oil and Gas Company, Limited, was resumed and the well deepened about 500 feet. A total depth of 1,600 feet is reported to have been reached. The well passed through Tertiary sedimentary beds and below these a considerable thickness of igneous rocks or a conglomerate containing boulders of these rocks. What lies below this is not known, as no samples were received from the lower part of the well. The oil and gas possibilities of the area are discussed by W. E. Cockfield in Summary Report 1931, Part A.

Drilling by the Okanagan Oil and Gas Company in Kelowna district is reported to have reached a depth of 2,660 feet. A sample from this depth, examined by F. J. Fraser of this division, appears to be from an igneous granitic rock; the material is finely divided, so that it is difficult to determine the exact character of the rock from which it came. A discussion of the oil possibilities of the area is given by C. E. Cairnes in Summary Report 1931, part A, page 108. A point of interest in connexion with the underground water resources of the area is that water that rose to the surface is reported to have been struck in the well. Water was reported at about 550, 750, 810, 1,655, and 1,675 feet. The well has an elevation of about 600 feet above the level of Okanagan Lake and is located on the east half of Section 2, Township 26, Asoyos land district, 9 miles southeast of Kelowna.

In Sage Creek area in southeastern British Columbia diamond drilling was carried on by the Crow's Nest Glacier Oil Company. An attempt was made to deepen the old Crow's Nest Oil and Gas Company

well, but only about the same depth, 3,260 feet, is reported to have been reached. A few core samples were received which show that the lower part of the well is still in the siliceous dolomites of the Beltian (Precambrian) series which, in this district, are generally supposed to be overthrust on younger Cretaceous beds. A sample of what appears to be a residue of petroleum that accumulated in the lower part of the old hole was received. An account of the old boring is given by E. D. Ingall in Summary Reports 1924, part A, page 145, and 1925, part A, page 233.

OTHER FIELD WORK

Geological

G. HANSON. Mr. Hanson completed work in Portland Canal region, the results of which are to be embodied in a geological map and in a report dealing with the mineral resources of this very important region. The 1932 field season was spent in the country between Alice Arm and Portland Canal.

G. S. HOLLAND. Mr. Holland, under the supervision of C. E. Cairnes, completed the geological mapping of the west half of the Vernon 2-mile map-area (latitudes 50° to 50° 30′, longitudes 119° to 120°).

Topographical

W. H. MILLER. Mr. Miller commenced a topographical survey on a scale of 4 miles to 1 inch of Carmacks map-area, Yukon (latitudes 62° to 63°, longitudes 136° to 138°).

R. BARTLETT. Mr. Bartlett commenced a topographical survey on a scale of 4 miles to 1 inch of Quiet Lake map-area, Yukon (latitudes 61° to 62°, longitudes 132° to 134°). No adequate maps of Carmacks or Quiet Lake areas exist; they should prove of great value to persons entering these easily accessible districts, each of which is of prospective mineral importance. Geological work has already been commenced in Carmacks area.

G. C. TUTTLE. Mr. Tuttle commenced a topographical survey on a scale of 4 miles to 1 inch of a district in British Columbia, lying between latitudes 55° and 56° and longitudes 124° and 126°. This district embraces the headwaters of Nation and Manson Rivers and upper stretches of Omineca River. Mineral discoveries of value have been made in the area. A geological investigation of the field will be commenced in 1933.

J. A. MACDONALD. Mr. Macdonald made a detailed topographical survey, on a scale of 800 feet to 1 inch, of an area in the vicinity of Michel, British Columbia. This map is required in order that a detailed study may be made of the geological problems confronting coal mining operators in this important field.

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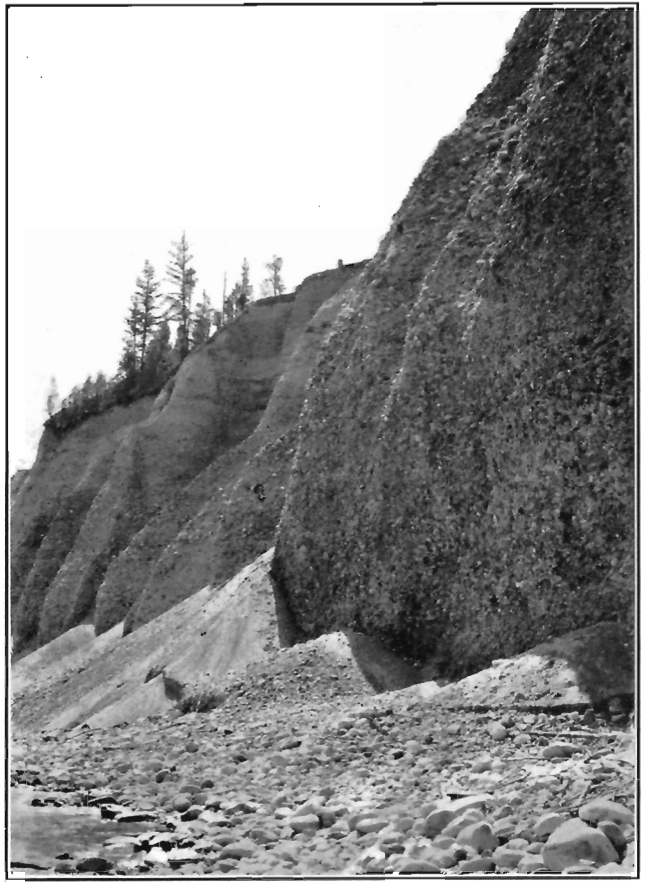
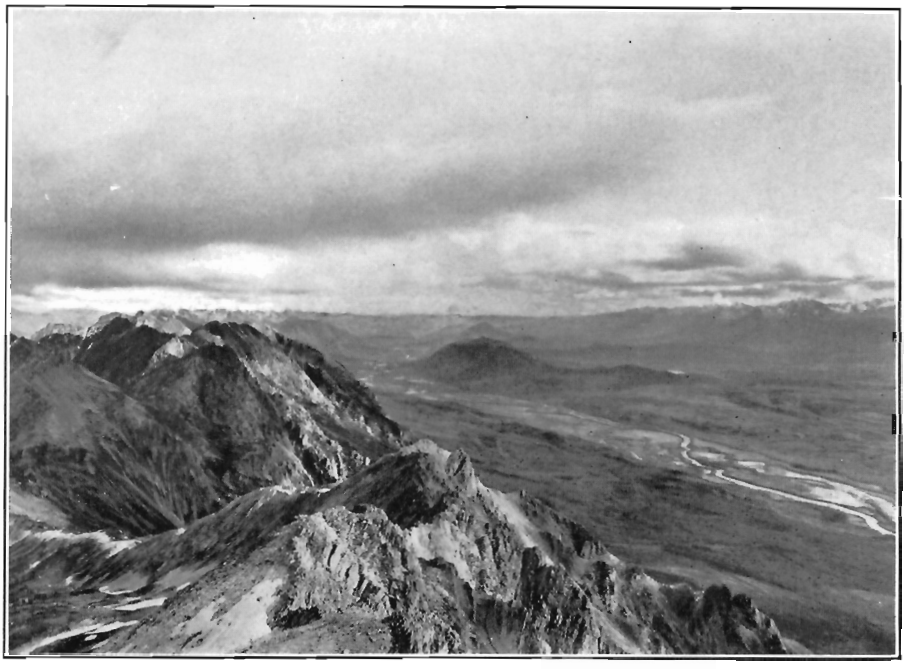
A. Old hydraulic workings below Perry Creek Falls and rim-rock of the old channel is visible in the left foreground; the top of the bench is about 400 feet above Perry Creek. (Page 78.)



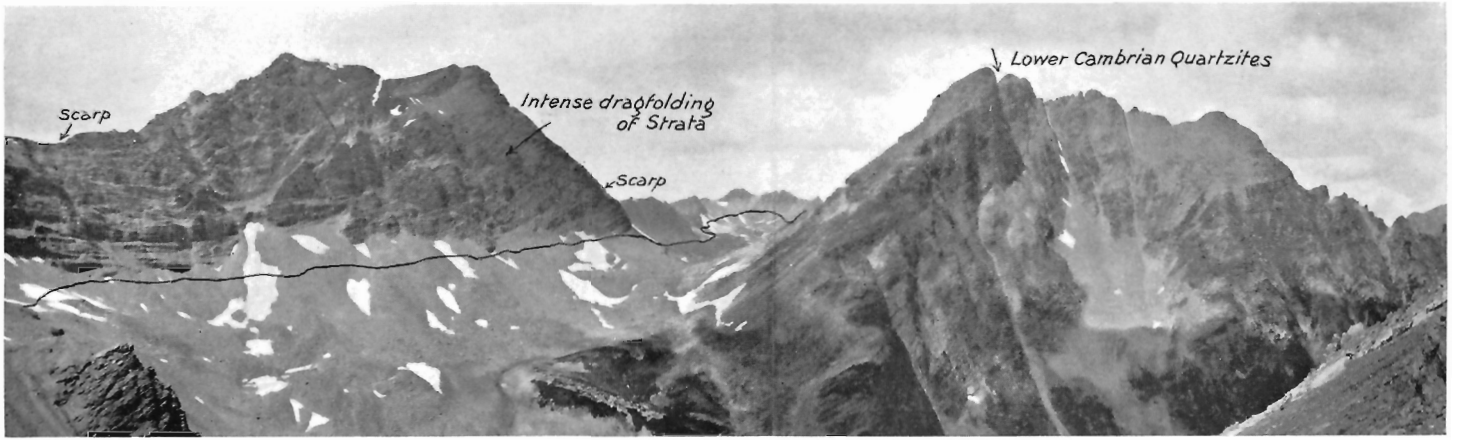
B. Gravel deposits of, presumably, Tertiary age along the south bank of St. Mary River at Wycliffe. (Page 80.)

181A II



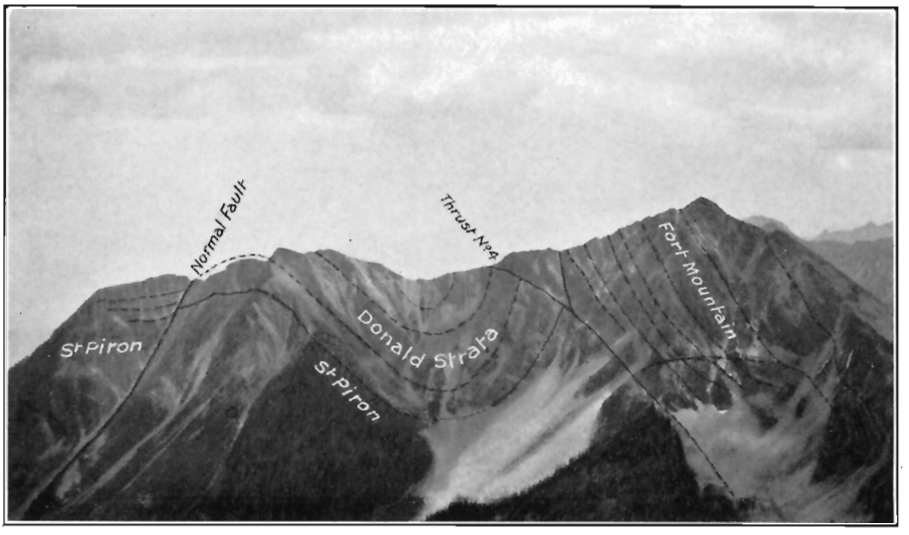
A. Looking south, from the Brisco Range near Parson, along the Rocky Mountain trench. Shows two intravalley ridges, Jubilee Mountain in middle distance and Steamboat Mountain beyond it. Note shallow, present flood-plain valley of Columbia River in trench, and steep walls of trench, Brisco Range at left and Purcell Range in distance. The trench floor here is much wider than farther north. (Photo by Wheeler 1907.) (Pages 108, 110.)

B. Looking east from Dogtooth Mountains at Twelvemile Creek. Brisco Range just across trench, high peaks of Ottertail Range in distance. Illustrates depth of trench and terraced floor cut into by present Columbia River. (Photo by Wheeler 1907.) (Page 108.)

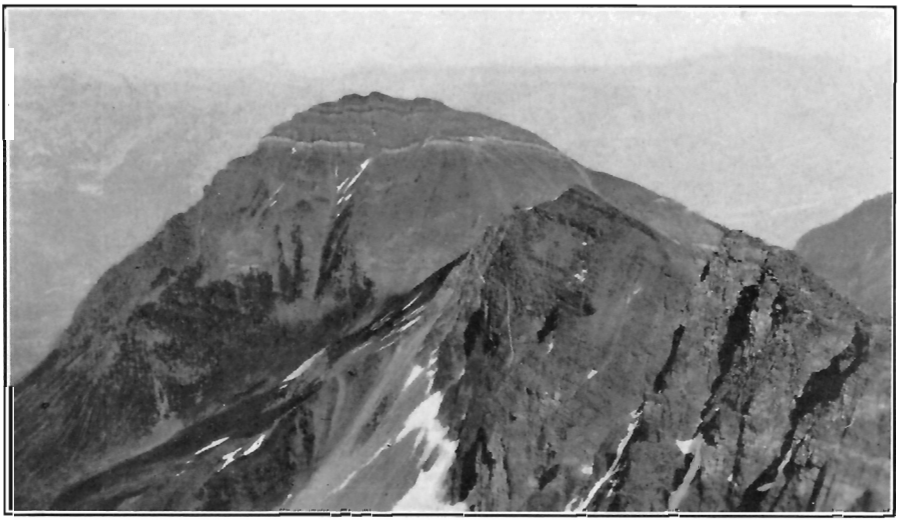


Dogtooth Mountains north of Canyon Creek. At left is erosion fault scarp at base of contorted Horsethief Creek strata thrust over Donald formation. The peak at right is of St. Piran quartzites. Heavy talus at left is underlain by ice in many places. (Page 110.)

PLATE IV



A. Thrust fault, eastern Dogtooth Mountains. (Page 152.)



B. Archaeocyathus limestone (white band) in Donald formation, eastern Dogtooth Mountains. (Page 122.)

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The annual Summary Report of the Geological Survey is issued in parts, referring to particular subjects or districts. This year there are five parts, A I, A II, B, C, and D. A review of the work of the Geological Survey for the year forms part of the Annual Report of the Department of Mines.