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DEPARTMENT OF MINES

HON. WM. SLOAN, Minister.
R. F. TOLMIE, Deputy Minister. W. FLEET ROBERTSON, Provincial Mineralogist.

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GEOLOGY AND ORE-DEPOSITS OF ROSSLAND, B.C.

By EVEREND LESTER BRUCE
Geological Survey of Canada

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To the Honourable William Sloan,
Minister of Mines, British Columbia.

Sir,—I have the honour to submit herewith a treatise on the "Geology and Ore-deposits of Rossland," by E. L. Bruce, of the Geological Survey of Canada, written as a thesis for his doctor's degree in Columbia University. With the consent and endorsement of the Director of the Geological Survey, Mr. Bruce has given this to the Department for publication.

I have the honour to be,
Sir,
Your obedient servant,

WILLIAM FLEET ROBERTSON,
Provincial Mineralogist.

Bureau of Mines, Victoria, B.C.,
April, 1917.

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NOTE.—*This report has been kindly submitted by E. L. Bruce, of the Geological Survey of Canada, and its publication is by the courtesy and permission of R. G. McConnell, Deputy Minister of Mines of the Dominion Government.*

The Directing Geologist, Wm. McInnes, writes as follows: "Mr. McConnell is quite willing that this paper should be published by your Department, and he agrees with me that the conclusions reached in it are in accord with those held by the Department and published in Drysdale's report. Bruce's paper is very considerably shorter than Drysdale's memoir, and since we cannot very well issue two reports so close together on the same subject, we shall be very glad to have you publish it."

GEOLOGY AND ORE-DEPOSITS OF ROSSLAND.

By Everend Lester Bruce.

INTRODUCTION.

The Rossland gold-copper mining camp is situated in the district of West Kootenay, southern British Columbia, six miles west of the Columbia river and five miles north of the International Boundary-line. The town of Rossland is reached either by Canadian Pacific Railway through the Crowsnest pass, from the main line by way of the Arrow lakes, or by Great Northern from Spokane.

The field-work upon which the following conclusions are based was done while assisting Dr. C. W. Drysdale, of the Canadian Geological Survey, in the examination of the camp, and to him and to the Director of the Survey the writer wishes to acknowledge his indebtedness for permission to use the data collected. To Professors Kemp, Berkey, and Johnson, of the Geological Department of Columbia University, thanks are due for advice and assistance in the preparation of this thesis.

The earliest geological work dealing particularly with Rossland was done by McConnell in 1894.* In that year he made a brief examination of some of the chief mines and described the character of the ore-bodies. Further work was done by him in 1896.† He recognized the great series of fragmental rock and classed them as probably Carboniferous. The igneous rocks he believed to be differentiated from a common magma. He described the ore-deposits, briefly classifying them as replacement deposits along lines of fissuring.

In 1900 Brock examined part of the area, describing the rocks between Sophie and Record mountains. In 1906 the preliminary report on the Rossland Mining District was published by Brock, representing detailed work on the most important area. Besides Mr. Brock's conclusions on the economic geology, those of Dr. Young on the general geological relations were incorporated. Daly's work along the boundary-line has also covered in a general way this area and gives much assistance in correlation.

Other articles on the various phases of the geology and mining industry of Rossland have appeared in the various scientific journals, and a bibliography of these will be found appended.

SUMMARY AND CONCLUSIONS.

The geological history of the area, as described in detail later, may be briefly summarized here.

Table of Formations.

Recent	River deposits.
Glacial	Silts.
	Till.
Pliocene-Miocenic	Sheppard granite.
	Pulaskite.
	Porphyritic monzonite.
Eocene-Oligocenic	Sophie Mountain conglomerate.
Jurassic	Basic dykes, tuffs, and flows.
	Normal monzonite.
	Diorite porphyry.
	Nelson granodiorite.
Triassic	Tuffs, agglomerates, and flows.
Carbonic	Augite porphyrite.
	Mount Roberts slates and tuffs.

* Annual Report, Geological Survey of Canada, 1894, Part A, page 35.
† Annual Report, Geological Survey of Canada, 1896, Part A, page 22.

The ore-deposits consist of: (*a*) Gold-quartz veins; (*b*) biotitic gold-copper deposits. Structurally, the latter occur as fissure-veins, replacement deposits, and impregnations. The ores are chiefly pyrrhotite, pyrite, chalcopyrite, with other sulphides in less amount, and free gold. These have been deposited in two periods of mineralization corresponding to the two great batholithic intrusions. The localization has been brought about mainly by the peculiarities of the fissuring of the granular igneous rocks under torsional stresses and by the influence of the various wall-rocks on precipitation.

PHYSIOGRAPHY.

The Cordillera of British Columbia is believed to have been originally a region of complex, folded mountains with strike-faults. Long-continued erosion reduced the topography to a post-mature condition. Uplift followed, and stream erosion, aided to a considerable extent by glaciation, has carved wide straight valleys along the old fault-lines. Thus the mountain masses are separated by pronounced depressions which Daly has used as boundaries for the mountain systems, each system having a trench of the same name to the west of it. The Rocky Mountain system has to the west of it the Rocky Mountain trench dividing it from the Purcell system. West of the latter is the Purcell trench, occupied by the northward flowing Kootenay river, marking the boundary between the Purcells and Selkirks. To the west of the Selkirks is the Selkirk trench, in which the Columbia river flows southward, dividing the Selkirk system from the Columbia system. In this latter division Daly has made a subdivision of the group of mountains between the Kettle river and Lower Arrow lake. These are the Rossland mountains and surround the mining district and town of Rossland.

This whole area has been subjected to many and complex changes. The crumpled and altered older rocks present evidence of the mountain-making epochs through which they have passed, while the great masses of coarsely crystalline igneous rocks now exposed at the surface show that much material must have been removed by erosive agencies. Consolidated stream-gravels mark the courses of old rivers, and the smoothed and rounded mountain outlines show the work of a glacial period in which all but the highest peaks of the Rossland mountains were covered with ice.

As a result, the topography is marked by an upland surface of gentle curves and low gradients beneath which the recent streams have incised deep valleys. The work of the streams, assisted by the work of the valley glaciers, has largely destroyed the old upland surface, but from high points, by imagining the deep recent valleys filled in, the old slopes can be approximately restored and a mental picture obtained of a gently rolling surface broken by a fairly large number of residual hills rising above it.

Over a large area in eastern British Columbia and the adjoining States the concordance of summit-levels, when viewed from an elevation, is a striking feature. When seen from the top of mountains reaching 6,000 feet or over, the ridges and rounded peaks of the Rossland mountains fall into an upland that, while by no means absolutely flat, yet presents a rather smooth surface. The slopes are always less than 10 degrees, except where isolated mountain masses rise above the surface. Beneath these gentle slopes the rivers have cut deeply. The Columbia has cut 2,000 feet below the point where the slope increases, and Sheep creek has intrenched itself nearly to the same extent. The rocks underlying the upland are of varying resistance, but the undulating surface is only locally affected by the kind of rock underlying. Granites, slates, and shales have alike been bevelled across without the general smoothness of the outlines being lost.

It has been suggested by Daly* that this accordance of summits is due to Alpine glaciation and to the position of the tree-line. Wherever peaks were high enough to support glaciers, erosion by that agency would tend to reduce the higher points more rapidly than the lower and so produce a more nearly uniform surface. Erosion above the line where rocks are protected by forest-growth is more active than on the surface covered by vegetation. Hence because of glacial erosion in high altitudes and more active weathering the higher points will wear down more rapidly than the lower and so reach an approximate level.

The theory more widely appealed to is peneplanation or the reduction of a land area approximately to sea-level. Elevation, with the resulting rejuvenation of the streams, would lead to the incision of steep-sided valleys below the level of the old surface.

* Journal of Geology, Vol. XIII., page 105.

In the regions adjoining that under particular consideration an erosion surface of Eocene age has been described by various writers. Dawson* considered the interior plateaux of British Columbia an elevated peneplain of Eocene age. Lindgren† describes the Salmon River district as an area worn down to a gentle topography and then elevated. Calkins‡ describes the Cabinet and Purcell ranges of western Montana as appearing like a "maturely dissected plateau." Smith§ recognizes a peneplain in the Cascades which he believes is Pliocene, and he is of the opinion that in that district there never has been an earlier one. Willis recognizes a peneplain over the Galton range, and Umpleby‖ describes one in Idaho, which he refers to the Eocene. From these views it seems that an Eocene pepeplain was developed in the interior which was not developed, or was completely destroyed by a Pliocene peneplain, in the Cascades.

If any peneplain of Eocene age was ever developed over the Rossland mountains no remnants of it are to be found. The Cretaceous and probably the early Eocene represent a period of erosion which was ended by the deposition of river-gravels. These are believed to be Eocene-Oligocene in age. They may represent the deposit of rejuvenated streams carrying down great loads of material from a newly uplifted land surface that had suffered deep sub-aerial decay and had been approximately base-levelled. Such a sequence of events seems quite possible, but, so far as observed, no physiographic proofs of it remain.

The early Tertiary sediments are intruded and tilted by granite rocks which now underlie most of the conglomerate remnants. The tilted beds are bevelled by the upland surface, a large part of which consists, however, of the granite of these Tertiary batholiths. The coarsely crystalline character of the igneous rocks shows that a considerable depth of overburden has been removed since their consolidation. It is evident, therefore, that the age of the upland cannot be earlier than Pliocene.

This long period of base-levelling was closed by uplift and the rejuvenated streams began to incise narrow steep-sided gorges in the old surface. It seems as if the uplift was progressive with temporary base-levels which allowed the streams to broaden out their valleys. Further uplift left the former valley-bottoms as rock benches. The gorges were cut to a considerable depth, but before much dissection of the interstream areas occurred, climatic changes brought on glacial conditions. The beginning of this period was, no doubt, marked by valley glaciers which finally became large enough to unite into a continental glacier covering all but the highest mountains. The close of the period was again marked by valley glaciers.

The effect of the continental glacier was to round and smooth the surface The valley glaciers, on the other hand, deepened the gorges already cut, leaving an evidence of their activity in hanging valleys. McCambridge creek, a tributary of Trail creek which joins it half-way from Rossland to Trail, has a decidedly hanging relation to the main stream.

At the close of the glacial period large supplies of debris were emptied into the rivers from the valley glaciers still existing about their headwaters, and, as a result, their beds were aggraded. The Columbia was filled to a depth of probably 400 feet with stratified gravels. With the disappearance of the glaciers, the supply of debris diminished and the river began to cut into this deposit, and, as it swung from side to side, terraces at different levels were produced. This process is still active in parts of the Columbia's course. The terraces of Trail creek are cut in fine white silt, with a thin surface layer of pebbles on each terrace. These terraces are found almost to the altitude of Rossland. The formation of deposits in the Columbia would normally produce a ponding of water in its tributary, but, as the terraces occur almost 2,000 feet above the Columbia, this explanation is insufficient. It is possible that a tongue of ice occupied the main valley after Trail Creek valley was free, and in the lake thus formed the white silts were laid down. The withdrawal of the barrier was followed by the production of terraces in the usual way.

A peculiarity in the drainage relation of Trail creek and Little Sheep creek may be related to the same phenomenon. The headwaters of these two streams are fairly close together and for a little distance they flow in nearly parallel valleys. At the town of Rossland the divide is notched by a low and fairly wide gap. If we assume that the ponded lake in Trail Creek valley

* Transaction, Royal Society of Canada, 1890, L.
† Professional Paper 27, United States Geological Survey.
‡ Bulletin 384, United States Geological Survey.
§ Professional Paper 19, United States Geological Survey.
‖ Journal of Geology, Vol. XX., page 139.

rose high enough to flow across the divide into Little Sheep creek, the occurrence of this depression is easily explained as due to valley-cutting when the Trail Creek lake emptied by way of Little Sheep creek.

The regional events affecting the physiography may be summarized as:—

1. Cretaceous-Eocene erosion cycle possibly carried to late maturity.
2. Early Pliocene cycle carried to late maturity or old age.
3. Late Pliocene—early Pleistocene gorge-cutting.
4. Pleistocene glaciation.
5. Recent terrace-cutting.

The forces of erosion acting on rocks of unequal resistance have produced certain physiographic forms of local importance. Hard rocks are exposed as ridges standing above the general level, while easily weathered rocks are marked by gulches with but small streams.

One of the very prominent ridges forms a cliff on Columbia avenue at the west end of Rossland. It rises about 50 feet above the rock bench on which it stands, and where the excavation has been made through it for the street it is about 150 feet wide. It consists of an elliptical mass of pulaskite intrusive into monzonite. The latter weathers more rapidly than the younger alkali syenite, leaving it standing out as a prominent ridge. Similar pulaskite ridges are found near the *O.K.* mine and at several points on the road from Rossland to Trail.

The *Centre Star* gulch and that in which the *Josie* tramway is built owe their positions to soft mica dykes. The streams in both these valleys are small, while the valleys are deep and steep-sided. In the Centre Star gulch vertical rock-faces 20 to 25 feet in height rise from the valley-floor. These walls are monzonite, while no doubt the rock between them is mica lamprophyre, since the mine-workings show a dyke of almost the exact width of the gulch which would project to the surface at that point. The weathering of mica dykes can be observed at many places. In the railroad cuttings monzonite shows no weathering, while mica dykes already show a tendency to take spheroidal forms.

GENERAL AND STRUCTURAL GEOLOGY.

PALÆOZOIC.

The early part of the geological record is missing in the Rossland district, the earliest formation being late Palæozoic. The basal group includes several types of rocks of different origins and doubtless of different age. All have, however, passed through severe regional metamorphism and form such an intricate complex that, for the present, they are grouped under one name. They are in part igneous, in part marine sedimentary. No later marine sediments occur. The only other sedimentary beds are the early Tertiary conglomerates and the Pleistocene gravels, sands, and silts of fresh-water origin. The dominant rock types are igneous, including deep-seated intrusions of batholithic and possibly laccolithic structure, dykes, surface flows, and volcanic fragmentals. The absence of sedimentary deposits of known age makes the correlation of the great series of igneous rocks a matter of much uncertainty. Some types are so similar in composition that a slight variation might produce a facies in one very nearly resembling a rock type which is ordinarily quite distinct and possibly of different age and origin. Added to this, the action of mineralizing solutions has so altered the rocks that similar end results have been produced from rocks that were no doubt originally quite different.

Mount Roberts Formation.

As mentioned above, this is not a single rock type, but consists of many whose intricate structure and rather severe metamorphism has, as yet, made their separation impossible. Some of these types are quite distinct and they will be described, but no attempt will be made to outline the distribution of each.

The largest exposure of this complex occurs as a broad band on the western slope of Red mountain, and, excepting for a band of igneous rocks occupying the valley of Little Sheep creek, extends well up the eastern slope of Mount Roberts, from which the formation takes its name. Other small outcrops are found in the Deer Park range and on Monte Christo and Columbia and Kootenay mountains.

Three types are found with gradations from one to the other which seem to argue for a close relationship in deposition, although the end numbers may be deposited under very different conditions. These types are:—

(*a.*) A soft black, possibly carbonaceous, slate:
(*b.*) Lighter coloured, harder, and more arenaceous slate:
(*c.*) Tufaceous beds, with possibly intercalated flows.

The first two types often show a distinct gradation from one to the other, and this seems to be due to original differences rather than to alteration since deposition. The black slates are soft, very fine-grained, and dense. The lighter slates are more arenaceous, and, at times, calcareous. The arenaceous forms are finely banded, due both to differences in colour and in size of grain. It is possible that they are, to some extent at least, tufaceous. The calcareous varieties often contain cherty concretions, and it was in such a variety above the *O.K.* mine that Mr. Brock discovered the only fossils yet found in this formation in this area. In all the slaty types the parting seems to be always parallel to the original bedding. A tufaceous rock, very probably belonging to this same complex, outcrops on the road to the Columbia and Kootenay. It is light buff in colour, but little altered, and shows indistinct bedding. In a great part of the area where these rocks are exposed silicification and the alteration of the sulphides disseminated plentifully throughout them has so altered the original character as to make the recognition of their nature and structure very difficult. The dip is by no means constant. There seems no doubt that part at least of the sediments are underlain at a slight depth by the intrusive batholiths. These intrusions have to a greater or less degree disturbed the strata above them, and where erosion has reached down almost to the igneous rock the sediments exposed are tilted and twisted out of the normal dip and strike of the rocks farther from the contacts and not so directly affected by the igneous body. The average strike is nearly north and south, and on the western slope of Red mountain the dip is to the west at low angles. On the eastern slope of Mount Roberts the beds are tilted up sometimes into vertical positions. Apparently the igneous rocks separating the two areas were intruded along a line of structural weakness, probably an old fault.

The effect of the various igneous invasions on the Mount Roberts formation has been very considerable. The mechanical effects have been the fracturing and tilting of the older rocks; the chemical effect is expressed by their severe alteration. The amount of pyrite, pyrrhotite, arsenopyrite, and chalcopyrite disseminated through the rock is sufficient to give the surface a reddish colour in many places from the oxidation of these minerals. Sulphides can be deposited contemporaneously in sediments, but the localization of the disseminations at Rossland along certain zones, rather than in certain beds, is evidence that they are introduced rather than original. Sulphides were deposited in the veins from igneous sources, and the disseminated sulphides of the sediments probably come also from igneous sources. Silicification also accompanied the ore-deposition and the same process affected the sediments. The effect does not seem to be any more pronounced near the intrusives than farther away. However, over a large part of the area the layer of Mount Roberts formation that covers the batholithic rocks is rather thin, and so no part is any great distance from igneous rocks even where the surface distance is considerable. Also the igneous rocks often cut across the bedding, and hence impregnating solutions have had a favourable opportunity to enter and diffuse through the beds for long distances.

The conditions under which the various rocks of this period were deposited must have varied considerably. Argillaceous, arenaceous, and calcareous shales, possibly with conglomeratic members, are associated with volcanic fragmentals. The lower beds are almost entirely shales and were deposited probably under subaerial delta conditions and in shallow water near shore. The occurrence of marine organisms shows that at some periods the sea covered this area, and the presence of some limestone marks an interval of fairly deep and quiet waters. At different times and becoming more frequent in the latter part occurred volcanic eruptions. The fine ejectamenta were well assorted, probably by falling into the sea, and now form well-banded tufaceous layers. These become more and more frequent until the conformable beds referred to the Triassic consist largely of such material. Thus the rock record of the Mount Roberts formation is that of a land area of slight enough relief to produce fine-grained delta deposits with which are associated marine beds. There was considerable contemporaneous volcanic activity, and as an end stage either the land disappeared entirely or became so low that tufaceous material constituted the whole supply of debris.

The determination of the age of the Mount Roberts formation depends on its lithological character and on a few poorly preserved fossils. On the basis of the organisms it has been believed to be Carbonic. Lithologically, it is very similar to the Lower Cache Creek series, described by Dawson.* His description of such rocks on the Thompson river is perfectly applicable to the Mount Roberts formation at Rossland. He recognized the shallow water or continental character of the sediments in southern British Columbia. He says:—

"In the southern part of British Columbia the Cache Creek group shows some evidence of littoral conditions toward the west slope of the Gold ranges, probably indicating the existence of land areas there."

Umpleby† also describes a similar series in Washington and assigns it provisionally to the Carboniferous. This late Palæozoic series apparently covers a large area in southern British Columbia and Washington, but how extensive the original area of deposition was is unknown. The present outcrop of strata referable to this period forms a broad north-and-south belt extending north of the Thompson river and south of Republic, Washington. Eastward it thins out against the Archean of the Selkirks, and westward it disappears under the Columbia lava plains.

TRIASSIC.

The rocks referred to the Triassic are volcanic fragmentals, with associated flows and intrusive masses of augite porphyrite with accompanying dykes. No fossils occur in the clastic rocks and the correlation is purely lithological.

The Clastics.

It is believed that in the highly inclined beds forming the slopes of Mount Roberts the beds rise in the time-scale going westward. The lower slopes consist of the slates with interbedded tuffs assigned to the Mount Roberts formation. Higher up the mountain, and presumably younger in age, the volcanic fragmentals become the dominant rocks and finally entirely replace the slates of the typical Mount Roberts formation. These latter beds are placed as Triassic. They are made up of fragments of volcanic material of all sizes; some of the beds are agglomeratic, but most of the series consist of finer material, in some places so fine that the rock is very dense with a conchoidal fracture. The material is usually rather perfectly sorted, producing a well-marked banding often with very thin laminæ. The colour varies from light to dark grey. The beds are nearly vertical at times, but ordinarily the dip is steep to the west. So far as can be seen, the upper beds are absolutely conformable on the lower Mount Roberts beds up to a point about 100 feet below the summit of Mount Roberts. The effusive rocks capping the peak are horizontal, and for this reason have been assigned to a later period. Associated with the clastic beds are thin dykes and possibly interbedded flows of rocks with about the composition of andesites.

Augite Porphyrite.

The parent rock of these small intrusives and flows forms one of the important rock-masses of the district. This is the augite porphyrite which is the surface rock on Columbia and Kootenay mountain, on Red mountain, and at several other points.

In appearance there is some variation in these different localities, but in general the rock is fairly constant in its characteristics. On Red Mountain it is deep green in colour, with stout greenish-black prisms of pyroxene usually visible to the naked eye. Hornblende needles and laths of feldspar are sometimes present. The size of the individuals varies greatly, and often in short distances the rock will change from a type crowded with large well-formed phenocrysts to a dense, deep green variety with no phenocrysts visible. This may be due to the agglomeratic structure that can often be seen on weathered surfaces, oval patches then showing with a lighter colour than the surrounding rock. These seem to be of the same composition as the rock between them, and probably represent fragments produced by a slight movement after the first crystallization, the fragments being recemented by the same magma, but the new crystallization having a finer texture.

In all types of the porphyrite a platy jointing is at times rather pronounced, but the direction of these master-joints is not constant. In the north-east drift of the fourteenth level of the *Centre Star* the strike is N. 14° E., dip 65° E. East of the shaft on the same level the strike

* Annual Report, Geological Survey of Canada. Vol VII., page 41B.
† Geological Survey of Washington, Bulletin No. 1, page 17.

is N. 75° E.; while still farther east in the same drift it is N. 55° E., dip 85° S.E. In the same workings a contact between augite porphyrite and diorite porphyrite is exposed. The platy jointing passes from one rock into the other without any apparent change.

The relation of the augite porphyrite to the Mount Roberts is that of an intrusion which along the borders sends out sills into the sediments, but on the whole has an irregular contact and breaks across the bedding. It seems to have a laccolithic relationship to the beds, which are found both above and below the porphyrite in some of the mines. Apparently the augite porphyrite is the deep-seated rock representing the volcanic period in which the tuffs lying above the Mount Roberts slates were ejected. Its consolidation thus represents a considerable length of time, and the production of the agglomeratic structure found in the porphyrite is more easily understood.

The contact between augite porphyrite and other igneous rocks is seldom sharp, but the typical rocks are usually separated by a zone of hybrid rocks several feet wide. This is the case between diorite porphyrite and augite porphyrite and between monzonite and augite porphyrite. Silicification by mineralizing solutions has also served to mask contacts. Diorite porphyrite occurs in bands in the augite porphyrite in a way that suggests dykes, but often a gradual transition from one to the other seems to argue for differentiation. Thus typical diorite porphyrite with needle-shaped plagioclases and hornblendes gradually acquires stout augite prisms, and finally the rock becomes typical augite porphyrite. However, the closely similar composition may make possible the crystallizing of pyroxene from a hornblende rich magma near the contact with pyroxene-bearing wall-rocks, and so the border-zone may have the appearance of a transition rock when in reality the diorite porphyrite is younger.

Again, in the case of the monzonite and augite porphyrite, the contact is a zone rather than a definite line. Wherever typical representatives of the two are in sharp contact a fault is the explanation. The contact between the eastern mass of monzonite and the augite porphyrite of the central area has a varying pitch to the west. In the upper workings of the *War Eagle* the pitch is very low and the contact surface is undulating. The result is that the drifts follow the contact-zone for considerable distances, and it seems wider than is actually the case. Rocks later than the monzonite have sharp contacts with the augite porphyrite.

As has been shown, the augite porphyrite is intrusive into the lower conformable beds that are of late Carbonic age, and for this reason it has been considered to be Triassic. The flows interbedded with the purely volcanic fragmentals have compositions very nearly that of the augite porphyrite and are believed to be of the same age, and hence the upper part of those beds may also be Triassic. Triassic beds of great thickness are found both to the north and south, and in lithological character the Rossland beds are very similar to the Nicola series, for which Dawson* gives the following section:—

	Feet.
Limestone	20
Fine-grained feldspathic rocks sometimes well bedded, generally grey	1,800
Tuffs or ash rocks passing into agglomerates with some fine-grained felsites, grey, purplish, and green	7,840
Chiefly diabase agglomerate; several calcareous beds. Dark felsites	3,930
	13,590

Since there are at Kamloops, 160 miles to the north of Rossland, nearly 15,000 feet of Triassic and 3,000 feet on the Snake river to the south,† the Rossland rocks of similar character have been assigned to the Triassic, although no palæontological evidence has been found.

JURASSIC.

The rock types referred to the Jurassic are all igneous. They are of three chief varieties, with some smaller associated masses of other types. The important rocks are: (1) A representative of the widespread grey Nelson granodiorite; (2) dykes and interfingering masses of a diorite porphyrite that is believed to be closely related to it; and (3) the normal monzonite. The minor rock types are lamprophyric dykes. Besides these, some flow-rocks may also belong to this age.

* VII. Annual Report, Geological Survey of Canada, Part B, page 54.
† XXII. Annual Report, United States Geological Survey, Part 2, page 580.

Nelson Granodiorite.

The Nelson granodiorite occurs as two separate, roughly oval areas just west of Rossland, on Little Sheep creek. Three other small exposures cut up through the stratified rocks on the western slopes of Red mountain. Outside of the immediate vicinity of Rossland it forms the extensive mass which Daly has called the Trail batholith. The edge of this main batholith lies about half-way from Rossland to Trail and forms the surface rock on both sides of the Columbia at the latter place. The type receives its name from its development around the city of Nelson, on Kootenay lake. The usual rock as occurring at Rossland is rather coarsely equigranular in texture and light to dark grey in colour. Sometimes it develops a porphyritic habit, but only rarely shows the gneissoid tendency that characterizes the Nelson granodiorite in many localities.

The main mass of granodiorite west of Rossland is distinctly intrusive into the slates and tuffs of the Mount Roberts formation. The small oval exposures are completely surrounded by stratified rocks and seem to indicate that the batholith underlies a large part of the older rocks at comparatively shallow depths. In the mine-workings some of the deeper levels are in a granular greyish rock which, although sometimes appearing as a very old rock, probably represents the top of the Nelson granodiorite batholith. The contact of the Trail batholith with the Mount Roberts sediments is a brecciated belt that Daly has called a "shatter-zone." This zone grades from sediments cut by stringers of igneous rock to igneous rock with inclusions of sediments. Daly's explanation of the zone is that, as the batholith invaded the enclosing rocks, the main mass was preceded by a network of dykes and stringers working out along joints, fractures, and bedding-planes. These separated the roof into individual blocks which sank into the depths of the magma and were absorbed. In this way the intrusive prepared its own chamber. As the magma cooled the borders became more and more viscous and the freeing of blocks less rapid until as the end stage the border-zone solidified, retaining the rifted blocks in the position in which they happened to be. The width of the zone in this case is probably due to the present surface being almost parallel to the contact of the batholith with its roof.

The relationship of the granodiorite to the monzonite is rather obscure. No good contacts with the normal monzonite are exposed, but near the big loop of the Great Northern Railway, west of Rossland, granodiorite and porphyritic monzonite are in contact in one of the cuts. The interfingering of the two rocks is so intimate that the relative age is uncertain, but the monzonite is believed to be the younger. The tongue-like mass of monzonite in the area south of Little Sheep creek has the appearance of a real intrusion into the granodiorite. Pulaskite and a number of later basic dykes also cut the granodiorite.

From these relations the Nelson granodiorite appears to be younger than the Palæozoic and probably was intruded at the time of the tilting of the Carbonic and Triassic beds. Its age is probably Jurassic, as suggested by Brock.* Similar rocks have been described from various other localities, the Jurassic having been over a large part of the Cordilleran region a mountain-making epoch with immense accompanying intrusions of granitic rocks.

Diorite Porphyry.

Occurring as irregular tongues and masses, especially in the augite porphyrite, is a rock which, while somewhat similar in appearance to that rock, yet has certain distinctive characteristics. On the weathered surface it is quite easily recognized, needle-shaped hornblende crystals and lath-shaped feldspars standing out prominently. Augite is occasionally present, more commonly on the borders of the mass. The rock shows a rather well-marked flow-structure, and this orientation of the feldspars gives it an almost silky lustre on a fresh fracture.

The diorite porphyry is intrusive into the Mount Roberts formation, and, underground, blocks of the stratified rock sometimes of large size are found entirely surrounded by the porphyry. Evidently they have been torn off by the intrusive and carried to their present position. It is also apparently intrusive into the augite porphyrite, although at many of the contacts one seems to grade into the other. This may be due either to assimilation of the older by the younger rock, or, as previously suggested, to a sort of mass action of the pyroxene-bearing augite porphyrite on the normally hornblendic diorite porphyry, resulting in the formation of pyroxene instead of hornblende.

* Summary Report, Geological Survey of Canada, 1900, page 74A.

The correlation of the diorite porphyry as Jurassic rests on its apparently close relationship to the Nelson granodiorite. Mineralogically the two are not unlike, although the usually porphyritic diorite porphyry with flow-structure is quite different in appearance from the massive equigranular granodiorite. The former, however, by a variation towards a more feldspathic and granular rock becomes very similar in appearance to the granodiorite. The evidence of this variation is clearly shown on the seventh level of the *Le Roi*. The first crosscut to the north from the main workings west of the shaft passes from augite porphyrite into diorite porphyry. Horizontal drill-holes show that the mass is oval in section, 200 x 250 feet in diameter. The first 40 to 50 feet of the drill-cores show typical diorite porphyry. This gradually changes to a light greyish granular rock as the central part of the pipe-like intrusion is reached. In deeper levels larger masses are encountered, and these unite so that in the deepest workings a large part of the country rock consists of a greyish granitic rock that is probably Nelson granodiorite. From this gradation it seems that the diorite porphyry is a border facies of the batholith of granodiorite, representing the fingering out of the magma into the older formations. The flow-structure may be due to a part of the magma having reached the surface, but, in part at least, may be the result of convection currents, since it is often developed in tongues which certainly did not connect with surface flows.

The relationship between diorite porphyry and monzonite is a doubtful one. The two are often found in contact in the mine-workings, but so intimately associated and so like in appearance that the relative age is uncertain. The diorite porphyry is very frequently found lying between augite porphyrite and monzonite, but so far no intrusions of diorite porphyry into monzonite have been found underground. A dyke-like mass of it on the surface near the drill-hall is possibly a roof pendant unabsorbed in the monzonite batholith. Both mica and non-mica dykes cut the diorite porphyry, and it is also intruded by dyke representatives of the later granitic intrusives.

Normal Monzonite.

Occupying an irregular oval area five miles long by one and three-quarters wide is a mass of monzonite. The greater diameter is east and west, with the city of Rossland near its western end. The outline of the mass is very irregular, and it is broken by many intrusions of later rocks. A broad belt of alluvium hides the rocks in the valley of Trail creek, but they are probably mostly monzonite.

This area is not occupied by one constant rock type, but shows wide variations in appearance and in composition. The most easily recognized variety is a coarsely granular dark-grey rock made up of feldspar, pyroxene, hornblende, and usually some mica. Variations consist in differences both in relative quantities of the various minerals and in size of grain. The different varieties are not all strictly of the same period, but are often found as intrusions into or inclusions in other types. Usually the more coarsely crystalline and more feldspathic seem to be later than the darker finer-grained rocks. Sometimes definite fragments of one are found in the other, as if entire solidification had taken place before the later rock appeared. At other times the included types seem to be segregations or possibly earlier crystallizations resorbed. On the whole, however, all these are rather similar rock types and are no doubt merely facies of the same intrusion.

Although the borders of the monzonite mass are very irregular, it sends very few definite dykes into the enclosing formations. On Columbia and Kootenay hill a dyke-like mass cuts across augite porphyrite, and at a few other places dykes from the monzonite intrude the Mount Roberts. The later age of the monzonite is best shown by the truncation of the alternate bands of slate and augite porphyrite on the southern border of the monzonite. Underground the evidence is not always satisfactory. The very flat and undulating nature of the contact as the monzonite plunges under the cover of augite porphyrite allows the drifts to follow the contact-zone for a considerable distance and makes the location of the point of contact difficult.

The normal monzonite is cut by a porphyritic monzonite that seems to be very similar to it, and also by an immense number of basic dykes, some of which may represent basic residuals from the monzonite magma, while others belong to later periods of intrusion. It is also cut by pulaskite dykes from the alkali syenite and by well-marked dykes of granite porphyry. A large dyke of this character is found south of Trail creek, and others are found at the *Le Roi*, one outcropping just below the headworks.

These latter dykes were formerly believed to be related to the Nelson granodiorite, since the largest of them seemed to be connected with a mass of that rock. For this reason the granodiorite was mapped as later than the monzonite. Building operations have exposed the contact of this dyke with a pulaskite dyke which it cuts. Evidently it does not belong to the granodiorite but to a much later intrusion. The other evidence seems to point to the monzonite being later than the granodiorite, and as no definite intrusions of diorite porphyry into monzonite have been proved, the monzonite is considered to be younger than the porphyry. The rather similar mineralogical character of the monzonite and granodiorite suggests that they belong to the same period of activity, the monzonite representing a later, the granodiorite and diorite porphyry an earlier intrusion.

Jurassic Effusive.

One representative of the effusives connected with the igneous activity of Jurassic age is believed to still exist. As previously described, volcanic tuffs and possibly lavas form a large part of Mount Roberts. The greater part of these are tilted at high angles. One hundred and twenty-five feet below the summit the dip is 54 degrees west. At the summit, however, is a lava-flow that is horizontal, with its basaltic jointing showing as vertical columns. It has the appearance of truncating the edges of the lower beds. Its composition is that of an augite latite and it probably is the surface representation of one of the Jurassic batholiths.

TERTIARY.

Eocene-Oligocene.

Although not occurring within the limits of the special Rossland map-sheet, the later conglomerate, believed to be early Tertiary, is here described, since the relation of the igneous rocks to it in a measure fixes the age of the intrusives. Two areas of this conglomerate are found near Rossland. The larger lies ten miles to the west on the top of Sophie mountain, the other about four miles south-east on the top of Lake mountain. It is likely that these are remnants of a once continuous deposit.

The conglomerates of the two areas are lithologically identical. As a rule they are coarse, with some lenticular bands of finer material. The pebbles range from grit particles in the finer bands to boulders of a foot or over in diameter. The larger part of the conglomerate has pebbles averaging an inch or less. Quartzite, chert, slaty material, serpentine, grey granite, gneiss, sandstone, jasper, and quartz are all represented. Towards the base greenstone pebbles and a few angular limestone fragments are present. Mr. Brock* also reports pebbles of an earlier conglomerate. The binding is siliceous. The beds on Sophie mountain now dip at rather high angles. They were probably laid down with a considerable initial dip, but their present attitude can have been attained only by a considerable tilting even if the initial dip is given a maximum value. The strike is nearly north and south, with the dip to the east.

The character of the sediments points to deposition by stream-action and the two remnants probably lie in the same old stream-valley. The heterogeneity of the materials is evidence that the stream was rapid, the finer grit-lenses representing deposition in the eddies of the stream. The thickness of the conglomerate is considerable and the supply of detritus was evidently large, probably due to the uplift of an old deeply weathered land-surface. The character of the surface upon which it was deposited is unknown, since it is now mostly underlain by igneous rocks intrusive into it.

The pebbles of the conglomerate are derived from the slates and greenstones of the Mount Roberts formation and from granitic rocks of the type of the Nelson granodiorite and the associated series. Many of the fragments come from rocks not known in the immediate neighbourhood. On the western side of Sophie mountain a 50-foot dyke of porphyritic rock occurs in the conglomerate. Brock* mentions such dykes and refers them to the Rossland granite. The Lake Mountain conglomerate is cut by a fresh granitic rock which Daly calls the Sheppard granite.

On the basis of a rather scanty flora Daly has referred these beds to the early Tertiary, and from their general character they seem to be similar to the Kettle River conglomerate and

* Summary Report, Geological Survey of Canada, 1900, page 67A.

to the Coldwater group described by Dawson in the Kamloops district, both of which have been considered of Eocene-Oligocene age.

Miocene-Pliocene.

Intrusive into the early Tertiary sediments are batholiths of two distinct types of acidic rocks. The earlier of these is represented in the Rossland area by the pulaskite dykes which are believed to be tongues from the Rossland alkali syenite, the main mass of which lies three miles north-west of Rossland. The later intrusive is the Sheppard granite occurring on Lake mountain, and to it are supposed to belong the granite-porphyry dykes found near Rossland.

Three large tongues of pulaskite lie close to the important mines. One lies west of Red mountain, striking north and south, another forms the ridge at the western end of Columbia avenue in the town, while a third lies south of Trail creek on the slopes of Deer Park mountain. Many other dykes are exposed along the upper road to Trail, the first of these forming a well-marked ridge as far north as the *Columbia and Kootenay* mine.

The pulaskite is usually a coarse-textured pure-white to deep-pink rock, made up almost entirely of large lath-shaped feldspars with some hornblende and biotite. In the typical rock the dark-coloured minerals are very subordinate in amount. The pulaskite has been little affected by metamorphism and resists weathering agents well. As a result, the outcrops of the dykes form prominent ridges with a thin soil cover.

The pulaskite cuts all the previously described formations. The broad band west of Red mountain intrudes Mount Roberts sediments, the elliptical mass in the town is intrusive into normal monzonite, and the dykes on the Trail road cut porphyritic monzonite. Near the *Le Roi* mill, in a rock-cut on one of the railway spurs, a narrow pulaskite-porphyry dyke of peculiar spotted appearance also cuts porphyritic monzonite. The pulaskite is cut by very few dykes of any kind. On the Trail road a basaltic dyke a foot wide cuts a pulaskite dyke about 50 feet wide. The strike of the two is the same. Formerly the pulaskite was thought to be the youngest important formation in the district. Building operations in the part of the town south of Trail creek have, however, exposed to better advantage the pulaskite tongue and the granite porphyry with which it is involved. The latter cuts across the pulaskite and shows a chilled zone along its borders.

Granite Porphyry.

The granite porphyry is a light-coloured distinctly porphyritic rock with phenocrysts of white feldspar set in a ground-mass that is sometimes a faint pink. It is very fresh and unaltered even in the vicinity of the ore-deposits. Two dykes of this rock of some size occur. The larger of the two is found with the pulaskite south of Trail creek, exposed as a small bluff on the street. The second is just below the *Le Roi* head-frame. This and several smaller ones are cut by diamond-drill holes underground. The strike of dykes of this intrusion is unique, being always nearly east and west, while the strike of all others is north and south.

The granite porphyry is very similar to what Daly has called the Sheppard granite, a small exposure of which occurs on the top of Lake mountain. This is intrusive into the early Tertiary. The relation of the pulaskite to this conglomerate is also intrusive, and hence these two igneous rocks are Miocene or Pliocene in age. No basic dykes are found in the granite porphyry, and hence the succession of these late Tertiary rocks seems to be: (1) Rossland granite and associated pulaskite; (2) basaltic dykes; and (3) Sheppard granite and associated granite porphry. The physiographic relations previously discussed make the age of the porphyry late Miocene or early Pliocene.

Dykes.

Besides the dyke-rocks just mentioned which can be referred to batholithic masses, there are an immense number of dykes of various kinds, many of which likely are the final expression of Jurassic igneous activity, some of which are of earlier age, while others are undoubtedly Tertiary.

Porphyritic Monzonite.

Many bodies of this rock, both as pipe-shaped intrusions and as more or less regular dyke-like forms, are found in the augite porphyrite, Nelson granodiorite, and normal monzonite. The rock is dark grey and very fresh. It makes a rather handsome building-stone and has been used in some of the Rossland public buildings. Mineralogically, it is much like the normal monzonite, but in the Ymir* district a gradation from a very similar porphyritic monzonite into a pulaskite has been observed. In the case of the Rossland rock, however, no such gradation has been seen and dykes of pulaskite are found cutting the porphyritic monzonite. The most prominent minerals of the rock are pyroxene, feldspar, and biotite. The pyroxene occurs as well-formed blocky crystals up to a quarter of an inch in length. The feldspar is usually white and a little smaller than the pyroxene.

Lamprophyre Dykes.

These dykes occur by hundreds in the mine-workings. In some parts they are so closely spaced that more dyke-matter than country-rock is to be seen in the drifts. The strike of all the lamprophyres is almost due north and south, the variation being so slight that the strike of the dykes can be taken as a guiding direction underground. The size of the various dykes varies from the width of a knife-blade up to the immense *Josie* and *Nickel Plate* dykes, the latter measuring 225 feet on the eleventh level of the *Centre Star*. The dip varies, but whether to the east or west is usually high, although almost flat dykes occur. Faulting has so dislocated the dykes that correlation, even for distances of a few hundred feet, is impossible except in the larger ones. There is also often a change in character in what seems without doubt to be parts of the same dyke. Thus mica dykes in depth sometimes become non-mica higher up, and large dykes carrying mica divide into smaller dykes that show no mica. Thus the distinction commonly made between the dykes as "mica" and "non-mica" does not always hold, although it serves as a useful field classification. A few of the more striking types will be described.

Dykes of the Josie Type.

Dykes of this type are by far the most numerous of all the occurring types. Some of them are large and traceable for a considerable distance on the surface and in depth. They consist of soft black rocks with very abundant biotite. They are very easily eroded and the outcrop is marked by gulches. Faults are localized along them, and this along with their softness gives considerable trouble in mining, and wherever the dykes are large the drifts have to be timbered. Usually columnar structure does not show, nor are the dykes noticeably finer-grained against the wall-rock. Later dykes, usually non-mica varieties, are sometimes intruded along the walls of mica dykes, or, as in the *Nickel Plate*, in the mass of the dyke itself. At times a later dyke can be seen following one wall for a distance, then cutting across and following the other wall.

The prominent representatives of this type are the *Nickel Plate* dyke, named from its occurrence at the *Nickel Plate* mine, the *Josie* dyke cut by the *Josie* shaft, and its offshoot the *Tramway* dyke. The rock in all these has a practically identical appearance. All dip at steep angles, the *Nickel Plate* being almost vertical, while the *Josie* dips steeply to the west. The *Tramway* is a smaller dyke and joins the *Josie* both horizontally and in depth.

War Eagle Type.

In this group are included dykes with a rather wide petrographic range, but apparently rather closely related in origin. They are dark grey to black, depending on the relative amount of feldspar, which is usually the only macroscopic mineral and as a rule has needle-shaped forms. These dykes have marked columnar jointing and so are easily distinguished from the dykes of the *Josie* class. They are later than the *Josie* dykes. The chief large and persistent representatives of the *War Eagle* type are the *East* and *West War Eagle* dykes, which consist of a band of parallel and rather narrow dykes which unite and divide along both strike and dip in the most intricate fashion.

Centre Star Dyke.

The *Centre Star* dyke, like the *East* and *West War Eagle* dykes, is in the upper levels a zone similar to those described above. Below the sixth level these separate tongues unite into one broad strong dyke so different in appearance that it merits a separate description. It is traceable to the deepest workings, attaining a width of 25 to 30 feet. It has marked columnar structure. The rock consists chiefly of feldspar, pyroxene, and mica, and in general appearance is very similar to the porphyritic monzonite previously described.

* *Ymir Mining Camp, Memoir 94, Geological Survey of Canada, page 39.*

Spokane Type.

A rather peculiar dyke is one of the later intrusives. It is conspicuously porphyritic. The ground-mass is fine-grained in texture and dark grey in colour. The phenocrysts are very large, consisting of feldspars and brown hornblendes sometimes half an inch in length. The hornblendes are well-formed crystals with a diamond-shaped cross-section. The feldspars are stout square individuals with a white to slightly greenish colour. Plates of biotite are sometimes present. These dykes have a pronounced columnar structure and are apparently later than the previous types.

Conglomerate Dyke.

In the *Josie* workings there is a prominent dyke known as the "white" dyke, from the large number of inclusions of a light-coloured granite which it contains. It outcrops on the surface near the *Le Roi* mill as a dyke about 10 feet wide cutting porphyritic monzonite. It has been observed to a depth of at least 700 feet. It consists of a large number of fragments of all sizes with a ground-mass of fine-grained, sometimes porphyritic, igneous rock. The foreign material is mostly rock of granitic types, sometimes gneissoid, but other more basic types are also present and some pure quartz pebbles. The shape of all these is flattish to oval and they have the appearance of forms produced by water-action. Some have striations and most of them are arranged with their long axes parallel to the walls of the dyke. The east wall is formed by a dyke of the *Spokane* type and the ground-mass is somewhat similar.

An explanation of the origin of this dyke offers some difficulties. The usual explanation for such forms is that the inclusions represent fragments torn from older formations and carried up by the molten magma.

The rounding is explained by rubbing against the walls and against one another, and also by the absorptive effect of the magma. The appearance of the inclusions, however, is that of ordinary water-worn boulders, and the alteration is so slight that rounding by the molten magma seems unlikely. Even the gneissoid varieties are not attacked along their structure-lines. Further than this the heterogeneity of the material requires some other explanation.

The one suggested is briefly as follows: Older formations in the district contain conglomerates, and if this later dyke has cut through such a layer it might easily have carried along a part of the conglomerate bed, the fine matrix of which could be easily absorbed by a magma which would have such slight action on larger particles that striations would still be retained. Umpleby describes a flow conglomerate in the Republic district which involves but little difference in the nature of the problems concerned.

QUATERNARY.

Mantling the solid rock over a large part of this section with a very continuous cover lie the deposits of Glacial and Post-Glacial times. This drift-cover extends far up the sides of the mountains, and only where cliffs occur and on the highest peaks does solid rock appear above the unconsolidated material. This material consists of the debris from the great Cordilleran glacier which overrode all but the highest peaks, material from the valley glaciers that filled the stream channels in the later stages, and the alluvial deposits of recent stream-action.

The deposits of the first class are found filling the hollows up to an altitude of about 6,500 feet. Large erratics are found even on the top of Sophie and Lake mountains. As a rule the deposits consist of fairly coarse till in which the boulders are not at all sorted. These are of various kinds, with the granite rocks common in the district predominating. The work of the valley glaciers is recorded in the white and yellowish silts of Trail creek. These are exceptionally fine and apparently represent the finely comminuted material from the glacier that filled upper Trail Creek valley and tributary streams while the mouth was still blocked. The evidences for this are considered in dealing with the physiography. The stream deposits found immediately after the glacial period are well preserved in terraces along the Columbia river. They consist of mediumly coarse well-assorted gravels that are evidently the product of rather rapid overloaded streams. The pebbles are well rounded and consist of all varieties of rocks known to exist in this drainage-basin, with the hard kinds naturally predominating.

The recent deposits of the region consist of the fans building at the present time wherever the gradient of the mountain streams decreases sufficiently to allow them to deposit their loads.

The character of these fans varies with the character of the depositing stream, being coarse in the case of rapid streams, finer in the case of less rapid streams, and varying also with the character of country through which the stream flows. Trail creek is building a delta in an eddy of the Columbia river which is made up of the very fine silts previously mentioned, which it is eroding in its lower course.

SKETCH OF GEOLOGICAL HISTORY.

The geological history of the region as interpreted from the preceding descriptions is recorded only from late Carbonic times. The conditions then obtaining were marine, as shown by the limestones, occasionally developed, and by the presence of marine fossils. The predominance of the clastic sediments that form the shales is evidence that the area lay near enough the shore of that age to receive the finer sediments brought down from the old land. There was considerable volcanic activity as shown by the tuffs interbedded with the marine sediments, and this increased steadily throughout the Triassic, which is almost completely represented by tuffs and flows. The intrusive representative of this period is the augite porphyrite which seems to have a roughly laccolithic form in the older part of the sedimentary series.

A period of disturbance tilted the clastic beds, and these were truncated by an erosion period, since the volcanic fragmentals of the latter period do not seem to be conformable on the lower strata. The first great batholithic intrusion of rocks of granodioritic composition was probably the deep-seated phenomenon which accompanied the extrusive volcanic activity represented by these later tuffs.

A long period of denudation, lasting through the Cretaceous and probably part of the early Tertiary, cut deeply into the clastics, flows, and intrusives, possibly reducing the whole region to a condition of post-maturity. This period of active degradation of the land-surface was followed by river deposition in the Eocene and Oligocene. The deposits, as shown by the remnants still left, are conglomerates with great and sudden variations in the size of the pebbles. They seem to have been laid down in fairly rapid streams.

This second period of sedimentation was followed by the intrusion of a series of batholiths of alkaline character represented by the pulaskite and by the Sheppard granite. There are no extrusives recognized as belonging to these, since the erosion periods that followed have scoured off great thicknesses of overlying rock. The last of these intrusions may have been in Pliocene times, and it was followed by a period of erosion long enough to allow a surface of low gradients to develop, bevelling the formations and exposing the latest granitic rocks, so that they now form the surface formation over wide areas.

Uplift of this post-matured surface as a unit rejuvenated the streams which incised themselves in steep-sided valleys to a depth greater than that of the present valleys. This period of gorge-cutting occupied the late Pliocene and must have been of long duration, probably extending into the Pleistocene period. The climatic change which brought on the glacial period probably had as its first effect a period of valley glaciation. As the conditions became more extreme the amount of ice increased until the whole Cordilleran area was covered, excepting the higher peaks. Return of more normal conditions again brought on valley glaciation. One of these tongues occupied the Columbia valley for some time after the disappearance of the ice from the neighbouring country. The heavy erosion by these valley glaciers supplied the main streams with abundant debris, which filled the old valley to a considerable depth. Excavation of this is still going on, and the amount of material already removed can be estimated by the terraces at several elevations on the Columbia and its main tributaries.

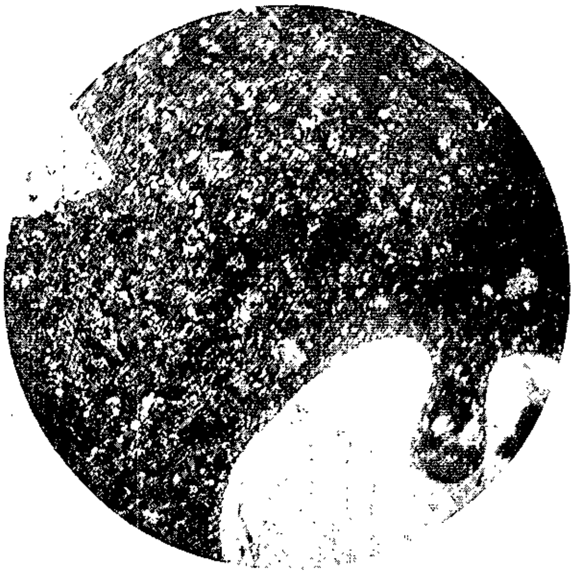
In recent times the streams have built small deltas at favourable places. Trail creek is at present forming such a deposit in the eddy where it joins the Columbia.

ECONOMIC GEOLOGY.

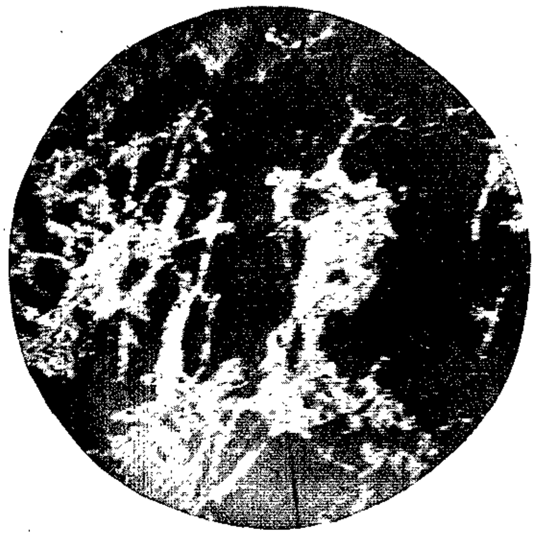
HISTORICAL REVIEW.

The earliest mining in the West Kootenay District was that done for lead by the Hudson's Bay Company on Kootenay lake in the early twenties of the last century. The industry, however, did not develop. At the time of the Cariboo placer activity some of the prospectors worked along the West Kootenay creeks, and in 1885 the Dewdney trail, passing down Trail creek past the present site of Rossland to the East Kootenay placers, was built. In the eighties

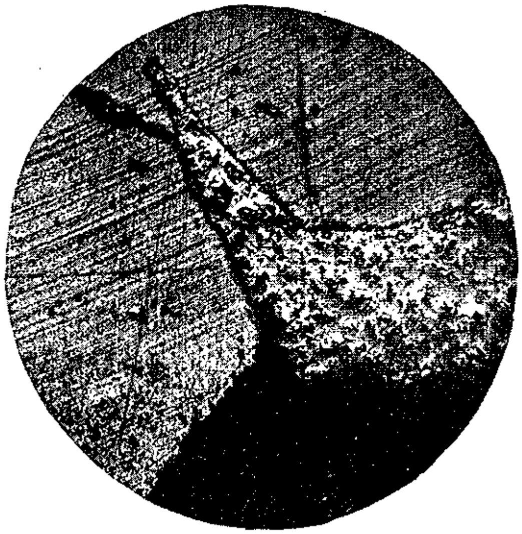
Basaltic Dyke cutting Pulaskite on Trail Road.



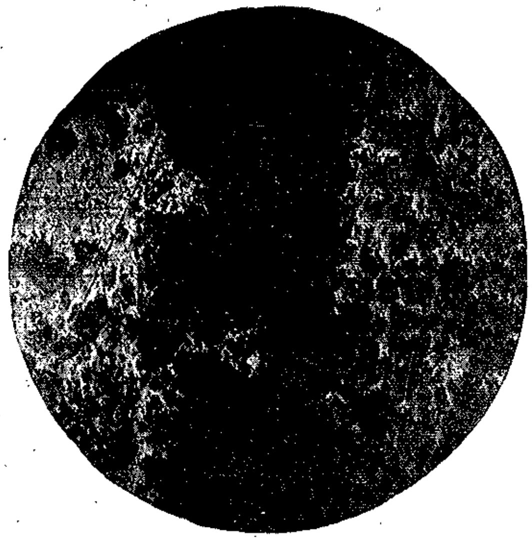
Granite Porphyry showing Reabsorption of Quartz Phenocrysts. Crossed Nicols.



Pyrite (white) cutting Pyrrhotite (black).

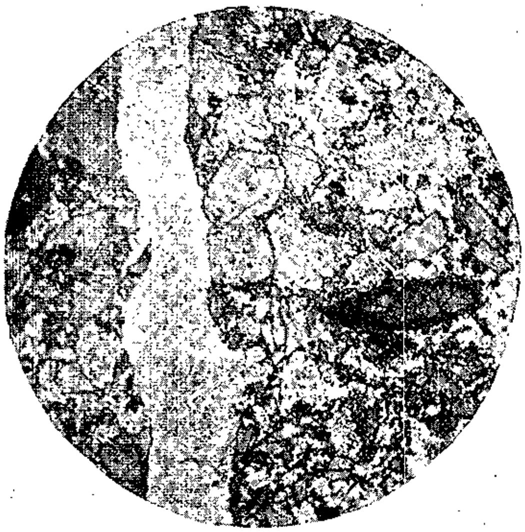


Chalcopyrite cutting Pyrite (lined) and Pyrrhotite (black).



Pyrrhotite (black) cutting Chalcopyrite (white), Josie Mine.

Monzonite, War Eagle, Third Level. Crossed Nicols.



Quartz Stringer in Silicified Diorite Porphyry, Le Roi Mine.

the Boundary District was staked. In 1883 ore was discovered at Ainsworth, on Kootenay lake, and in 1886 discoveries of rich ore near the present town of Nelson led to its establishment as a trading-post. The first claim to be staked in the Rossland district was the *Lily May* in 1887. It was relocated in 1889. In 1890 two miners from the *Lily May* crossed the valley of Trail creek and in one day located the *Centre Star*, *War Eagle*, *Idaho*, *Virginia*, and *Le Roi* claims. The *Le Roi*, which afterwards became such a wonderful producer, was given for the payment of $12.50 for recording fees.

Development was at first slow owing to lack of transportation facilities, but the building of a wagon-road to Trail in 1893 led to enough ore being shipped to encourage investments. In 1895 the Trail smelter and a tramway to the mines were started, the smelter beginning operations in 1896. In that year came the first railway connection, the Red Mountain Railway to Spokane. A period of inflation followed by the usual depression retarded development to a considerable extent. As a result of the failure of the small original companies, strong corporations were formed and up-to-date plants were installed, with a great reduction in working costs. A further step in this direction was the construction of a power plant at Bonnington Falls, on the Kootenay river. In 1899 a sudden decline in War Eagle stock had a bad effect on the reputation of the camp, and labour troubles closed some of the mines for a part of 1901. Litigation over the troublesome apex law under which the claims were staked added to the difficulties, but this was finally settled by the amalgamation of the companies, and the development of the camp in recent years has been steady and uninterrupted.

TYPES.

The Rossland occurrences are of two classes, gold-quartz veins and biotitic gold-copper deposits. Brock has classified the latter on the basis of structure as: (1) Fissure-veins with or without replacement of the country-rock; (2) lodes or zones of fissuring or shearing with the ore-minerals forming a network of veinlets in the fractures and eating into and replacing in whole or in part the intervening fragments of the country-rock, replacing the wall-rock or developing along particular fractures; (3) irregular impregnations in the country-rock.

FISSURING.

The more important ore-deposits are of the first two of these types, and the fissure systems seem to have controlled almost entirely the payable ore. The fissuring is extremely complex and of different ages. It may best be considered as (1) fissuring taking place before mineral deposition and (2) fissuring after deposition. Not all fissures of the first class are mineralized, and no doubt there are fissures later than the earliest ore-deposition and earlier than the last important introduction of minerals. Of the earlier fissures there are then two varieties—(*a*) mineralized and (*b*) non-mineralized. Even the mineralized fissures are not simple in history, but probably represent two or more periods of movement, with a distinct character of mineralization connected with each movement.

The area of most intense rock-dislocation lies on the western slope of Red mountain, mostly between the *Josie* dyke on the west and the *Nickel Plate* dyke on the east. Within this limit the most important ore-deposits so far discovered are situated. The most pronounced fissure is probably that of the *Le Roi-Centre Star* vein system. The strike of this is approximately N. 60° E.; the dip rather steep to the north, with an average between the second and twelfth levels of 80 degrees. In the *Centre Star* workings it is a fairly definite single zone, but in the *Le Roi* it divides into three known as the main, north, and south veins. The *War Eagle* is much less regular. Its general trend is about N. 65° W., the dip to the north-east. Between the first level and the eighth the dip averaged 62 degrees. The continuation was not found on the ninth level, but a diamond-drill hole ran into ore 570 feet to the north-east of where the vein should have been. This has been followed downward to the sixteenth level with an average dip of 38 degrees. It has been considered that a flat fault had thrown the vein to the extent indicated. Recently, however, what seems to be the continuation of this lower zone has been found above the ninth level, and it seems likely that the two are separate parallel shear-zones.

Three other vein systems are recognized, but both the dip and strike of these are variable. The *Josie* system is approximately east and west. The *Hollywell* parallels the *Centre Star* 450 feet north of that zone. The *Peyton* has a strike of N. 30° W. A peculiar feature well marked in some parts of the *Hollywell* vein is an opening of the platy jointing of the rocks. The filling of these wedge-shaped openings from the main fissure gives an irregular serrated margin to the deposit. The character of the fissure in the igneous rocks remains fairly constant, but a rather general association of the fissures with the contacts between diorite porphyry and the other rocks is to be observed. Wherever the fracture-zones pass into the slaty rocks of the Mount Roberts formation the fissures lose their clean-cut definite nature and become zones of mashing and crumpling in the soft, yielding clastic formations.

Fissures previous to the mineralization but not themselves carrying mineral are numerous. They are characteristically nearly due north and south in strike, and the dip may be either to the east or west, but is usually at high angles. The majority of these have passed through more than one period of movement. The earliest dislocations were associated with the intrusion of a great number of lamprophyric dykes mostly carrying large amounts of biotite. These soft dykes have localized all later fissuring tending to anything near parallelism with themselves. Nearly every one of them has well-marked faults either within its own mass, along one or both walls. The slickensides show that these subsequent movements have sometimes taken place in two directions. On the third level of the *War Eagle* two sets were observed on the wall of a mica dyke, one of which was vertical, the other dipped 20 degrees to the south. Later fractures cutting across the dykes lose their clear-cut identity in the dyke material, while those that meet them at a small angle are deflected, in some cases never emerging on the opposite side, in other cases only after having run parallel to the dyke for some distance. This phenomenon sometimes gives the dyke the deceptive appearance of being younger than the faults crossing it.

The age of the fissures is fixed in a general way, since they cut the formations as late as the monzonite and are believed not to cut the pulaskite. Only a few basic dykes, and these not of the kind associated with the fissures, are found in the latter rock. The mechanics of the complicated system of premineral fissuring and its localization may be explained in the following manner: The north and south movements would naturally be along the previously intruded lamprophyric dykes, and the amount of movement would be roughly proportional to the size of the dyke. There are two very large mica dykes, the *Josie* and the *Nickel Plate* bounding the area of greatest fracture. If the movement along these was of a differential nature the stress developed in the block between would be rotational, and would be relieved by a set of fractures corresponding to the ore-filled fissures described.

The number of fissures later than the ore-deposition is large, but their effect on the ore-bodies is not important. The displacement is in most cases only a few feet and from a practical standpoint is negligible. In many cases these seem to have been merely an oscillation, often along an old fault-zone, which left the opposite sides of the fault in about the same relative position as before the movement. The strike of these later fissures is usually northerly. The dip is either to the east or west and usually fairly steep. Only a few of them can be traced with any degree of certainty for any great distance either along the strike or down the dip. A definite single fault in one drift may break into a large number of small ones in workings only a few hundred feet away. Some of the major faults can be traced downward for three or four levels, but below that it is impossible to be sure of the identity of any excepting those associated with the larger dykes.

THE ORES.

The ores of the Rossland district fall into two large classes. The important type consists of a mixture of sulphides. The other consists of free gold in quartz. This latter type, while less important than the first, has produced considerable gold, although none of the deposits are now being worked. The best example of this kind of deposit is at the *O.K.* mine, where the vein consists of quartz with free gold and only a small amount of sulphides.

The minerals appearing in the sulphide type of ore-bodies are pyrite, pyrrhotite, chalcopyrite, arsenopyrite, molybdenite, bismuthinite, galena, sphalerite, and magnetite. Pyrite occurs disseminated throughout the country-rock, especially in the Mount Roberts formation, and this variety is only slightly auriferous. It is also found as a prominent constituent of the vein-fillings and there may carry considerable gold. Pyrrhotite is apparently of two generations, the later variety being auriferous, while the first is, at best, low grade. Chalcopyrite is much less in amount than pyrrhotite in the ordinary ore, but sometimes predominates. It is auriferous.

Arsenopyrite occurs both as impregnations and as a minor constituent of the large ore-bodies; molybdenite, sphalerite, galena, and magnetite are occasional minerals.

The mineralogical character of the ores even of the sulphide type varies widely. Even in parts of the same vein the relative amounts of the various constituents are not at all the same. In general, however, it may be said that, in the mines on Red mountain, pyrrhotite is the most abundant ore-mineral, followed in order by pyrite and chalcopyrite. In the working mines arsenopyrite, molybdenite, galena, and sphalerite are rare, but in some of the smaller prospects, especially in the Mount Roberts formation, these latter minerals become the more prominent, and magnetite is also commonly present.

The details of the minerals occurring in some of the important stopes will show more clearly this variation. Samples from the *Josie* system of veins show only pyrrhotite from the fifth and thirteenth levels, while samples from the fourth and seventh levels show pyrrhotite and chalcopyrite, but in varying proportions. On the fourth level pyrrhotite predominates, while in one stope of the seventh level chalcopyrite is the more abundant. In the *Centre Star-Le Roi* vein system the same variation is observed, but pyrrhotite is always in excess of chalcopyrite and varying amounts of pyrite appear. In the *War Eagle* veins a sample from the third level shows pyrrhotite alone. One from the fourth has pyrrhotite, chalcopyrite, and some sphalerite. In the deepest stope at present opened pyrrhotite, pyrite, and chalcopyrite are the ore-minerals. Surface samples from veins in the Mount Roberts formation show a wider mineralogical range. The *Coxey* vein, parallel to the *Centre Star* system but farther north, carries magnetite, pyrrhotite, molybdenite, arsenopyrite, and chalcopyrite in differing proportions at various points. At the *Lily May*, south of Rossland, the constituents are galena, sphalerite, chalcopyrite, pyrrhotite, and stibnite in about this order of abundance.

The gangue accompanying the ore-minerals in the sulphide-deposits is chiefly more or less altered country-rock. A subordinate amount of quartz is usually present and some calcite. In some of the veins calcite becomes more important with depth. In small amounts a large variety of minerals is found, such as wollastonite, garnet, epidote, chlorite, biotite, serpentine, actinolite, and zeolites.

In the gold-quartz veins along with free gold some sulphides are found. These are, however, very subordinate in amount. The gangue in this case is entirely quartz.

The metals recovered from the Rossland ores are gold, silver, and copper, with gold as the most important. The gold content to the ton of ore decreased steadily to 1907, falling from 2 oz. a ton in 1894 to 0.33 oz. in 1907. Since then it has risen to 0.44 oz. and for the last few years has remained fairly constant. Silver has dropped with many fluctuations from 2.88 oz. in 1894 to 0.30 oz. in 1911, while copper has fallen from 56.6 lb. a ton in 1894 to 13.5 lb. in 1911. The decrease is due less, probably, to failure in the ore value than to decrease in mining, transportation, and smelting costs, which allows much lower-grade ore to be treated than formerly. The values to the ton plotted for the three metals give curves which, in the case of copper and silver, show a rather marked sympathy. The gold curve does not follow the others very closely. Thus it seems likely that silver is mainly associated with the chalcopyrite, while gold may occur with the other sulphides or as free gold in altered and silicified country-rock. It is certain, at any rate, that a varying percentage of the gold does exist in the free state, but whether in the sulphide or in the wall-rock is less certain. Molybdenite, bismuthinite, and arsenopyrite, are auriferous, sometimes highly so, as in the impregnations near pulaskite dykes at the *Giant* and *Jumbo*. Galena and sphalerite carry considerable silver.

PARAGENESIS OF THE ORE-MINERALS.

Not only does the relative amount of the different ore-minerals vary in different vein systems, and even in different parts of the same system, but also the order of deposition. Examination of ore samples reveals a rather complex sequence in mineralization, and it is quite evident that there are at least two periods of sulphide-deposition. The first period consisted chiefly of the introduction of pyrite and pyrrhotite relatively poor in the precious metals. Later disturbances were followed by a second sulphide period characterized by chalcopyrite, pyrite, and pyrrhotite, with possibly other minerals, all of which carried considerably more gold and silver than the first mineralization. The considerations upon which these statements are made are as follows: (1) It is evident from the ore associations to be given in detail later that pyrite and pyrrhotite occur as the earliest of the sulphide minerals cut by chalcopyrite, and that there are instances in which pyrrhotite is found undoubtedly later than chalcopyrite; (2) at some places at least the pyrite and pyrrhotite are very low grade, while in other places they rank as important ore-minerals; (3) some of the large stopes of solid sulphides do not carry their values uniformly distributed, but in streaks which may possibly be due to a later sulphide period; (4) veins are known carrying mixed sulphides with good values up to a cross-dyke, beyond which one mineral, and that very low grade, forms the fissure-filling.

Polished specimens of ore from the *Centre Star* fourth level stope 410, fifth level stope 588, and thirteenth level, *Le Roi* eighth level stope 895, and *Josie* 900-foot level show only pyrrhotite. Specimens from *Centre Star* third level, Josie 1,300, and *Le Roi* 1,200 show pyrrhotite and chalcopyrite, the pyrrhotite being the older mineral. Another sample from the 1,200-foot level of the *Le Roi* has pyrite cut by chalcopyrite. Ores from the 1,100- and 1,200-foot levels of the *Centre Star* and the eighth of the *War Eagle* consist of pyrite cut by pyrrhotite. In the *City of Spokane* tunnel, *Centre Star* stope 426, *Nickel Plate* 300, and *War Eagle* 1,452 the order is pyrite, pyrrhotite, and chalcopyrite. Ore in the *Hamilton* vein, however, shows pyrite cutting pyrrhotite, and in the 737 stope of the *Josie* chalcopyrite is cut by stringers of pyrrhotite. A small stringer of sphalerite cuts chalcopyrite in ore from *War Eagle* stope No. 1152. A sample from the surface exposures on the *Coxey* has pyrrhotite cutting magnetite. Determination of a general order of deposition from such scattered samples is liable to introduce errors, but as there is evidence from the ore values for at least two periods of pyrite and pyrrhotite deposition the following order is suggested:—

1st. { 1. Pyrite and magnetite.
2. Pyrrhotite.

2nd. { 3. Pyrite.
4. Chalcopyrite.
5. Pyrrhotite, sphalerite.

The relation of pyrite and magnetite and pyrrhotite and sphalerite is not shown in the samples examined. The paragenesis of the accessory ore-minerals arsenopyrite, molybdenite, bismuthinite, and galena is also unknown, but as they are all of rather high gold and silver content they probably belong to the period represented by Nos. 3, 4, and 5.

The mineralogy and order of deposition is somewhat similar to that at Ducktown, where Kemp* found pyrite, pyrrhotite, chalcopyrite, and finally a coarsely crystalline variety of pyrrhotite associated with later quartz veins which cut the chalcopyrite.

The sulphide-deposits occur as well-defined fissures or as intersecting veinlets replacing fractured wall-rock. The straight and persistent *Hamilton* vein to the west of the *Josie* dyke is of the first class, and the chalcopyrite vein in stope 737 of the *Josie* is a particularly good example of the simple fissure. It also lies to the west of the *Josie* dyke. It has a fairly regular width of 12 feet and is almost vertical. The country-rock is diorite porphyry but little attacked and not much fractured. At places the almost solid chalcopyrite which forms the filling may penetrate for a short distance into the wall, but the boundary between clean ore and barren rock is remarkably sharp. At various points a thin layer of rock, consisting mostly of secondary biotite, separates fresh diorite porphyry from solid ore.

The predominant structure of the deposits is that of zones of crushing with replacement of the country-rock. Sometimes this replacement is so complete that none of the friction breccia is left, while at other places pieces of altered rock still remain. Only parts of a fragment may be replaced, and samples are sometimes found in which the augite phenocrysts of augite-porphyrite country-rocks are perfectly retained in a ground-mass of sulphides. Along the borders of solid sulphide masses ore stringers are found working outward into the enclosing rock in a network which becomes less distinct as distance from the main mass increases until only the merest threads of sulphide are observable. Alteration processes extend still farther into the country-rock. As a rule no open fissures are found, but some small openings exist. These are lined near the vein with well-crystallized calcite and zeolites evidently belonging to the last stages of mineralization.

The minerals commonly found metasomatically replacing country-rock are pyrite, pyrrhotite, chalcopyrite, molybdenite, sphalerite, galena, arsenopyrite, quartz, calcite, actinolite, and biotite. Pyrite and arsenopyrite are found both massive and as well-formed crystals, especially in the

* *See* Ducktown, Tenn. (Kemp), Transaction A.I.M.E., Vol. 31, page 244.

Mount Roberts sediments. Of the non-metallic minerals produced by the vein-forming solutions biotite is the most prominent. In the wall-rock near the ore a brownish radiating variety of this mineral is often abundantly developed, sometimes forming a layer 3 to 4 inches thick of almost pure biotite. Quartz and calcite are also found in considerable amounts bordering the sulphides and working out into the unaltered rock, but on the whole the effect of the solutions seems to have been to remove both silica and calcium from the rocks affected. This is very well shown in analyses of fresh and altered monzonite and augite porphyrite.

	20.	21.	34.	35.
SiO_2	50.89	40.02	54.49	37.32
TiO_2	0.80	0.46	0.70	0.87
Al_2O_3	17.00	16.13	16.51	19.30
Fe_2O_3	0.97	...	2.79	...
FeO	7.60	14.98	5.20	16.10
MnO	0.14	0.11	0.10	0.10
MgO	5.41	12.90	3.55	10.81
CaO	9.82	1.05	7.06	1.47
CuO	...	...	...	Trace.
K_2O	1.31	8.17	4.36	8.55
Na_2O	3.35	0.67	3.50	0.33
H_2O	0.06	0.13	0.07	0.14
H_2O+	1.14	2.82	1.18	3.01
P_2O_5	0.19	0.03	0.20	0.19
S	0.43	0.39	0.23	0.36
CO_2	0.28	0.24	0.10	Trace.
	99.39	98.37	100.04	98.75

NOTE.—Analyses taken from reports of the Department of Mines, Canada.

No. 20—Augite porphyrite, *Josie* drift, *War Eagle*, 10 feet in foot-wall side. Fresh.

No. 21—Augite porphyrite altered to biotite in the vein.

No. 34—Monzonite east of mica dyke, 700-foot level, *Le Roi*.

No. 35—Monzonite altered to west of mica dyke, 700-foot level, *Le Roi*.

The samples were evidently taken as free from sulphides as possible, and the change shows clearly the character of the alteration. Iron, potassium, and magnesium have increased while silica, calcium, and sodium have diminished. At other points in the vein different conditions might give different reactions with precipitation of the elements here removed, and hence silicification and the introduction of calcite.

The existence of contact-metamorphic conditions in the deeper zones is marked by small amounts of a deep-red garnet in the sulphides and the rather abundant occurrence of epidote and actinolite in the wall-rocks of the lower levels. The amount of epidote is sometimes large enough to give the rock a banded appearance, and a sample from the tenth level of the *War Eagle* is at least one-third epidote. Apparently the alterations at depth occurred under high pressure and temperature, while those of the upper part are characteristic of aqueous solutions at moderate temperatures and pressures.

ORE-SHOOTS.

The distribution of values is not uniform, but, as in most ore-deposits, they are concentrated in favourable localities. The size of the ore-shoots depends somewhat on the way in which the term is defined. Lower-grade ore can now be worked than could formerly, and hence the size of a shoot increases with the decreased operating costs.

Probably the largest body of ore ever worked in the camp was that opened up by the *Le Roi*. This was found on the east side of the *Josie* dyke. It had a stope length of 600 feet and was followed down to the 900-foot level. A width of 30 to 60 feet was mined. The values were not evenly distributed, but occurred in zones through the sulphides. The largest stopes now being worked are No. 1452 on the fourteenth level of the *War Eagle* and No. 895 on the *Le Roi* 800-foot level. The former has been opened for a length of about 100 feet and a width of 30 to 40 feet. It has been crosscut 200 feet below the fourteenth level. The ores here are pyrite and pyrrhotite with some chalcopyrite. The sulphides form intersecting veins 2 to 3 feet in width, in altered diorite porphyry. The *Le Roi* stope belongs to the same type, with a somewhat smaller amount of sulphides. It is being mined to a width of about 50 feet. The ground is badly broken and mining costs, except for timbering, are low. This increases the width of payable ore considerably.

The relation of the ore-shoots to the character of the country-rock is influenced by the different physical properties of the various formations. In all rocks of a hard but brittle character, such as the monzonite, diorite porphyry, granodiorite, and augite porphyrite, the fractures produced are much alike and the ore-bodies are essentially of the same character. On the other hand, the same forces acting on the yielding shales and tuffs of the Mount Roberts formation have produced zones of mashing which are impregnated to some extent, but were evidently too impervious to receive ore-bodies of important size.

The factor of chief importance in the localization of the ore-shoots has been the north-south faulting in large part controlled by the dyke system. Along the basic dykes, especially the soft mica-bearing varieties, there has been considerable movement. The gouge produced has retarded circulation of mineralizing solutions along the intersecting ore-fissures and caused a considerable enrichment of the ore-zone at that point. The fault rather than the dyke seems to be the important element, since there are large shoots not bounded by dykes. As a rule, however, they are found against basic dykes, usually on the under-side if the dyke is not vertical. A striking example is the original ore-body of the *Le Roi*. This has as its western boundary the *Josie* dyke, which has been much affected by faults along both walls. Beyond it the ore has recently been found displaced 300 feet. The cross-fractures are not themselves mineralized to any great extent, and for this reason might at first seem to be entirely later than the ore. The movement along them, especially in the mica dykes, has developed impervious secondary products that prevented the ore solutions from penetrating, and for this reason they are not filled with minerals.* Very often also, as in the example mentioned later, faulting along the old fissure has taken place.

There are also cases where the sulphides have continued on the opposite side of the dyke and associated fault, but where the values have decreased very appreciably. The low-grade sulphides probably represent a first period of mineralization. Later a slight second fracturing followed the ore-zone, but was stopped or deflected at the intersecting dyke or fault, and as a result the later period of richer mineralization affected a fissure in the zone extending only as far as the intersection. On the third level of the *War Eagle* the workings follow a fault-zone K with well-marked walls. This is crossed by a strong fault E with a heave of 30 feet. North-west of fault E pyrite is developed in K, but no values, while south-east of the fault there is good ore that follows the foot-wall of K for 125 feet and then crosses to the hanging-wall. Apparently there was originally a pyrite-filled fissure. This was faulted by E, and at the same time or later a fissure opened south-east of the fault, and this was later filled by sulphides with payable values.

On the eighth level of the *Centre Star* a similar case occurs. A fairly definite sulphide-filled fissure has been cut by a nearly flat fault. The relative movement has been about 15 feet. In the part of the vein above the fault the values are too low to mine, while that part below the fault carries good ore.

It is difficult to estimate the influence of depth in an ore-body of such variable mineralogical character. On the whole, while the fissure systems remain in the same formation, the character of the ores even in the deepest workings remains the same. When, however, they pass either laterally or in depth into the Mount Roberts formation the character immediately changes. The fissures are less distinct and some of them are almost entirely filled with fine granular calcite.

GENESIS OF THE DEPOSITS.

The composition of the ore solutions can be approximately determined from the minerals that have been deposited and the changes produced near the fissures. The main substances are:—

Silica.

In the sulphide-deposits quartz is not a very prominent mineral, occurring only as small blebs. In places, however, the wall-rock is silicified and tiny quartz stringers are observable.

* Ransome, P.P. 62, United States Geological Survey.

The quartz may to some extent be derived from the alterations of the wall-rocks themselves. In the gold-quartz veins quartz becomes an important mineral, and it is evident that these solutions were highly siliceous. In this case the alteration of the adjacent wall-rocks could not supply the large amount of silica, which must therefore have been introduced by the ore solutions from other sources.

Carbonates.

Calcite occurs as an impregnation of the wall-rocks and as well-formed crystals in open fissures. In the deeper levels of the *Centre Star* it appears prominently as a fissure-filling. This arrangement seems to be evidence for precipitation of calcite in the deeper parts of the vein, while the upper parts are filled with sulphides.

Fluorides.

The presence of fluorides in the solutions is marked by the presence of the fluorine-bearing mineral apophylite. It is found always in vuggs and seams.

Sulphides, Sulpharsenides, and Aulphantimonides.

The large quantities of sulphides which are found both in the ore-bearing fissures and zones and as crystals in the rocks show that the amount of dissolved sulphides present must have been enormous. The disseminated character of the well-crystallized pyrite and arsenopyrite, produced by easy diffusion on the part of the sulphur and arsenic compounds, shows how active and far-reaching these solutions must have been. Antimony was present in small amount as recorded by the rather rare occurrence of stibnite.

Iron, Nickel, Cobalt, and Copper.

The iron sulphides and sulpharsenides are by far the most abundant ore-minerals. Considerable copper and a little nickel and cobalt are associated with the iron. Evidently the ore solutions were supersaturated with ferrous compounds, since so large an amount of pyrrhotite has been deposited. Copper is usually much less abundant, probably not exceeding one-fiftieth of the iron content. At times, however, as in some of the *Josie* stopes, chalcopyrite predominates. Nickel and cobalt are present only in small amounts.

Alkalies.

Potassium-bearing minerals are abundant in the altered rock. Biotite is the most common of these and sometimes forms the mass of the altered rock. Evidently alkalies were in considerable amount in the ore solutions. Analysis of altered rock shows that the soda of the original monzonite and granodiorite has been removed and potassium added.

Gold and Silver.

Although minor in amount, gold and silver are the important elements from an economic standpoint. Both are found in intimate association with the sulphides, and it seems reasonable to suppose that they were held in solution in the same manner and precipitated by the same reactions as the base metals. A varying amount of gold even in the sulphides is in the free state, but the larger part is evidently in some sort of chemical compound.

Nature of the Solvent.

The problem of the nature of solutions that could carry the metallic elements mentioned above, together with many that occur in minor amounts, next arises. Becker found that many sulphides are soluble in sodium sulphide solutions and that gold also yielded to such solutions. Silver sulphide and galena differ from the others in this respect, but according to de Senarmont they are dissolved in water, saturated with hydrogen sulphide, at high temperature and pressure. The Rossland ore solutions had a considerable quantity of potassium which may be assumed to act in the same manner as sodium, and hydrogen sulphide no doubt was also present in quantity. Boric acid and fluorine probably aided solution to some extent.

From these conditions it is concluded that the solutions from which the Rossland ores were deposited contained SiO_2, CO_2, H_2S, F, Bo, Fe, Ni, Co, Sb, As, Au, Ag, Cu, Zn, Pb, Ca, Na, K, Mo.

All of these, excepting a small part of the SiO_2 which may be derived from the wall-rocks, are probably contributed by the great batholiths that have at various times intruded the older rocks. There is evidence of various periods of mineralization, and no doubt the ore solutions were different, but at all times the metals were likely present as sulphides in solution in magmatic waters, which contained enormous amounts of alkali sulphides and hydrogen sulphide, with some carbon dioxide, boric acid, and fluorine.

Conditions, Time, and Methods of Deposition.

The presence of garnet and epidote indicates that the lower part of the deposits as now found was formed under contact-metamorphic conditions with high temperature and pressure. The upper parts of the deposits were formed under hydrothermal conditions and medium temperatures. The last minerals to form—namely, the zeolites and calcite—crystallized at fairly low temperatures. Wohler gives a temperature of 180° C. as that necessary for the formation of apophylite. Apparently then the ores were deposited by solutions at high pressure and temperature which, as they moved upward along the fracture-zones, became solutions of medium temperatures with mineralizers, such as fluorine, hydrogen sulphide, etc. The fall in temperature and pressure resulted in deposition of part of the material in solution. This was no doubt aided by the reactions between the wall-rocks and the ore-bearing solutions. If the retention of the metallic sulphides depended on the presence of potassium in the waters, the removal of that element by the biotitization of the country-rocks would necessarily cause the deposition of part of the ore-minerals.

The origin of these solutions carrying such large amounts of alkaline sulphides along with carbon dioxide and fluorine must have been magmatic. As previously shown, there were at least two periods of mineralization. The first period probably corresponds to the closing activities of the Jurassic batholithic intrusions that ended with the intrusion of the great mass of normal monzonite. The later more alkaline magma of the pulaskite invasion introduced a much smaller amount of sulphides, but by its high alkaline content it would be capable of carrying considerable amounts of gold, and to it is attributed the production of the richer zones in the older deposits and the very rich impregnations that are found near pulaskite dykes.

The history of the ore-deposits may be summarized as follows: The batholithic invasions of Nelson granodiorite, diorite porphyry, and monzonite were accompanied by fracturing of the older rocks by a somewhat torsional stress. In these fracture-zones the solutions and emanations from the cooling magma deposited rather low-grade sulphides. The intrusion of the Tertiary alkali syenite (pulaskite) batholith was accompanied by a second fracturing which largely followed the earlier shear-zones. In these the highly alkaline solutions from this intrusive deposited sulphides which were much richer in precious metals than the Mesozoic sulphide-deposition.

Secondary rearrangement by descending waters has had but little effect on the Rossland deposits. Primary sulphides were found practically at the surface. Along wet seams a little malachite has developed, but as these seams do not extend to a great depth the main mass of the deposits is entirely unaffected. Ground-water stands at about 50 feet, and from that level to about 400 feet the amount of water pumped increases. In this zone flat diamond-drill holes are always wet and same carry a large flow of water. Below the 400-foot level the amount of water steadily decreases until at 1,000 feet the workings are practically dry and no pumping is necessary.

PETROGRAPHY OF THE IGNEOUS ROCKS.

The great batholithic or laccolithic intrusions affecting the Rossland district fall into two groups—the earlier Mesozoic period of augite porphyrite, monzonite, and granodiorite intrusives, and the Tertiary period of more acidic character represented by alkali syenite and granitic rocks with some dykes of a more basic character.

ROCKS OF THE BATHOLITHIC INTRUSIONS.

Augite Porphyrite.

The augite porphyrite in the hand specimen varies considerably in appearance. It is usually greyish to greenish black, with prisms of dark-greenish pyroxene visible to the naked eye. They are usually nearly square. They vary in size and may become so small as to be unrecognizable.

Under the miscroscope the rock is found to be distinctly porphyritic, with relatively large phenocrysts in a fine-grained ground-mass. The primary minerals are pyroxene and plagioclase, with apatite as an accessory constituent. The secondary products are uralite, sericite, kaolin, calcite, and chlorite. Nearly every section shows a trace of introduced sulphides. The plagioclase shows extinction angles measured from the albite twinning lamellæ averaging 20 degrees. The variety is thus near labradorite. The pyroxene is in well-formed crystals of a light-greenish colour and often twinned. They are of an early period of crystallization and are included in the feldspars. The borders show alteration to uralite. The ground-mass consists mostly of very small crystals of pyroxene with some feldspar. The recast analysis shows that feldspar and pyroxene are about equal in amount. The calculated variety of feldspar is rather more acidic than the microscopic examination indicates.

Diorite Porphyry.

Often very similar to the augite porphyrite in appearance, but rather different from it in mineralogical composition is the diorite porphyry. It is a greyish to greenish-grey rock with needle-like phenocrysts of feldspar and hornblende which often have a flow arrangement. Under the microscope it is always porphyritic, in some cases with a striking difference between the ground-mass and the minerals of the first generation. A faint trachytic arrangement is also sometimes noticeable. The phenocrysts are usually elongated crystals of hornblende, plagioclase, orthoclase, and usually pyroxene. The two feldspars vary in amount. Sometimes plagioclase predominates and in other sections orthoclase is developed almost to the exclusion of the triclinic variety. The composition of the plagioclase varies in different specimens from albite to oligoclase, and even in the same crystal strong and peculiar zonal structures are often strikingly developed, probably from changes in the magma. The hornblende is in well-formed needles strongly pleochroic from bluish-green to green to yellowish-green. It is often found about feldspar grains and also shows the rather unusual phenomenon of well-marked zonal growth. The orthoclase in some sections shows a ragged or patchy surface that suggests that it is anorthoclase rather than true orthoclase. The ground-mass consists of hornblende, feldspar, and, in the types where plagioclase is almost lacking, some quartz. Wherever sulphides have been introduced a secondary hornblende has developed along the ore, with sometimes a little biotite.

Nelson Granodiorite.

This is a medium-grained greyish rock with quartz feldspar and biotite or hornblende as the macroscopic minerals. In thin section it shows a granitic texture, with quartz, orthoclase, plagioclase, microcline, magnetite, hornblende, biotite, titanite, and apatite as primary constituents. The feldspars are somewhat altered to kaolin and sericite, while some chlorite is present from the basic minerals. The plagioclase is near andesine in composition. The biotite is a peculiar greenish-brown colour and is often in aggregates. The predominant minerals are quartz, orthoclase, and plagioclase. Biotite is fairly abundant, hornblende less so. Analyses are given on page 30 and a recast analysis on page 31.

Monzonite.

The normal monzonite is a somewhat variable rock. It may be fine-grained to coarse, dark to light grey. Usually granular, it at times becomes faintly porphyritic. A thin section of monzonite from the mass south-west of Rossland shows a granitic structure, with plagioclase, orthoclase, pyroxene, and biotite as the chief primary minerals. The secondary products are magnetite, chlorite, and uralitic amphibole. Plagioclase forms most of the rock. It occurs in lath-shaped twinned crystals whose extinction angles show the variety to be oligoclase-andesine. The orthoclase is untwinned and includes plagioclase and other minerals in a poikilitic fashion. Amphibole is deep green and largely, if not altogether, secondary, filling crevices and surrounding kernels of pyroxene. The pyroxene is in stout, well-formed light-green crystals. Magnetite is in considerable amount. Plagioclase seems to have crystallized in part at least before the pyroxene. A sample from drill-hole 274, *War Eagle* third level, taken 256 feet from the drift, differs only in the relative amount of the minerals present. Orthoclase is less in amount and hornblende almost lacking. The orthoclase shows good zonal structure. In this rock the order of crystallization is normal. Comparison of the analysis of this rock with typical monzonite shows a close agreement.

Pulaskite.

Pulaskite, the dyke representative of the large mass of Rossland alkali syenite just outside of the area, occurs in such large masses that it may be considered as belonging to the deep-seated rocks. It is light pink to white in colour, but with many variations, with increase or decrease of the basic minerals. These are not usually abundant. The feldspars are the most noticeable constituent in the hand specimen, often assuming lath-shapes that may attain a length of an inch or more. The thin section shows a granitic rock composed of orthoclase, biotite, hornblende, pyroxene, magnetite, and some plagioclase. Alteration has produced kaolin and hæmatite, with some secondary hornblende around the pyroxene crystals. Orthoclase makes up the bulk of the rock. It occurs in lath-shaped Carlsbad twins and also in square plates untwinned, but with a mottled surface. The plagioclase has thin twinning lamellæ and is albite. The pyroxene is in well-formed light-green crystals. The analyses show the alkaline character of the rock. Comparison of this with a sample from the main mass shows that the latter has a somewhat coarser and more granular structure. More hornblende is present and less pyroxene and plagioclase. The hornblende is a deeply pleochroic variety, changing from green to yellowish-green.

Sheppard Granite.

The Sheppard granite is a light grey rather porphyritic rock, with tabular feldspar crystals showing on the weathered surfaces. Microscopically it is porphyritic, with a large number of phenocrysts in a well-crystallized ground-mass. The primary minerals present are orthoclase, plagioclase, quartz, hornblende, pyroxene, titanite, and apatite. The rock is fairly fresh. There is a slight kaolinization of the orthoclase and most of the pyroxene is altered to chlorite. Orthoclase occurs both untwinned and with Carlsbad twinning. Plagioclase is towards the albite end and shows interfingering lamellæ. It is almost equal to the orthoclase in amount. Green hornblende and light-green pyroxene are present, the former rather abundant. Both are included in the feldspars. The ground-mass is largely quartz and orthoclase and has a somewhat granular appearance. This rock is believed to be the plutonic facies of the magma from which the granite porphyry to be described later came. The sample described was obtained from Lake mountain. The analysis quoted is of a specimen collected by Daly four miles east of this point.

DYKE ROCKS.

The dyke rocks consist of aschistic representatives of the batholithic rocks and lamprophyric intrusions, probably the residuals of the more acidic plutonic masses. The majority of these belong to the granodiorite-monzonite period, but a few are offshoots of the Tertiary intrusives. Minor changes in the mineralogy of these make an almost endless variety. Only the more prominent and characteristic types, however, are described.

Granite Porphyry.

The granite porphyry is a light-greyish fresh-looking rock with numerous tabular feldspar phenocrysts of a white to faint pinkish colour. Under the microscope it shows a decided porphyritic habit. The primary minerals are orthoclase, plagioclase, quartz, hornblende, pyroxene, biotite, apatite, and magnetite. The alteration products are sericite, chlorite, magnetite, and secondary hornblende. The phenocrysts are mostly plagioclase near the albite end with some orthoclase and light-green pyroxene. Some large quartz grains are present showing a very strong resorption effect (Photo No. 12). Most of the orthoclase and quartz, however, are in the ground-mass. Biotite occurs in small foils, with a tendency towards aggregates. Small green hornblendes are rather rare. Chlorite is common and much of the biotite is partially chloritized.

Porphyritic Monzonite.

The porphyritic monzonite is a fresh coarse-grained grey rock with large well-formed pyroxene crystals and somewhat smaller white to greenish feldspars. Biotite is sometimes abundant. In thin section the rock is seen to have a porphyritic habit, with a well-crystallized ground-mass. The primary minerals are plagioclase, orthoclase, pyroxene, biotite, hornblende, and apatite. Pyroxene of a drab colour forms the larger phenocrysts. Some green hornblende is present in irregular grains and much biotite is scattered through the rock. The plagioclase crystals are smaller than the pyroxene, lath-shaped, and near andesine in composition. Orthoclase is abundant. It has a mottled appearance and contains a great number of inclusions of the other minerals. Alteration has been very slight. A few fibres of sericite have developed in the feldspars and a little kaolin and the pyroxene phenocrysts are bordered by a narrow fringe of secondary hornblende. Some introduced sulphides are present.

Centre Star Dyke.

The deeper parts of the *Centre Star* dyke consist of a rock very similar in appearance to porphyritic monzonite, but less distinctly porphyritic. Mineralogically it is in parts somewhat similar, but in depth it becomes more basic. A slide taken from a specimen on the eighth level of the *Centre Star* consists of plagioclase, biotite, pyroxene, magnetite, and apatite, with a little olivine. Plagioclase and pyroxene make up the bulk of the rock, but biotite is prominent. The plagioclase, andesine-labradorite in composition, is considerably altered to sericite. The pyroxene is in light-green, well-formed crystals twinned and zonally grown. Some chlorite has developed. Most of the small amount of olivine is altered to serpentine. A specimen from presumably the same dyke on the fourteenth level differs in having in it a considerable amount of deep-brown hornblende. Some calcite and green hornblende have developed as secondary products. In both samples there is a tendency toward ophitic structure.

Augite Camptonite.

From rocks like those just described are gradations towards augite camptonite. One of these has been called for reference the *Spokane* type because typically developed in the tunnel of the *City of Spokane* mine. It is strikingly porphyritic, with phenocrysts of brown hornblende and feldspar an inch across. The ground-mass is fine-grained. Microscopically it is seen that the hornblende forms the larger phenocrysts, but plagioclase is more abundant. Pyroxene is also in some quantity and the ordinary alteration products are present. The plagioclase is in stout tabular crystals considerably altered and surrounded by reaction rims. Lath-shaped plagioclase of the variety andesine, pyroxene, and both green and brown hornblende form the ground-mass. A dyke 90 feet east of the *Centre Star* dyke, on the thirteenth level of the *War Eagle*, is somewhat similar. In this case the plagioclase is labradorite and some biotite is present. Alteration has produced considerable epidote, most of which is in radiating aggregates.

A dyke west of the *Centre Star* dyke, on the fifth level of the *War Eagle*, has a few large phenocrysts of white, zonally grown pyroxene and badly altered andesine in a fine ground-mass composed of rods of brown hornblende and feldspar. Considerable magnetite is present. A dyke 50 feet west of the *Tramway* dyke, *Josie* 400-foot level, differs only in having more plagioclase as well as some orthoclase and an extremely fine ground-mass. Other similar dykes are found 250 feet from the west end of the crosscut to the *War Eagle* on the ninth level of the *Centre Star* and 175 feet west of the *Centre Star* dyke in the south workings of the fourth level of the *War Eagle*.

Vogesite.

By decrease of plagioclase and increase of orthoclase, camptonites pass into vogesites. A rock that may be classed as the latter is found in a dyke in the *Iron Mask* tunnel, *War Eagle* fourth level, 340 feet from the portal. It is very fine-grained with rods of brownish hornblende and unstriated feldspar. Magnetite is abundant and alteration has produced calcite and epidote.

Kersantite.

Kersantites are dyke rocks characterized by the presence of biotite and plagioclase. A rock fitting this description occurs as a small dyke cutting the Nickel Plate dyke on the fifth level of the *Centre Star*. It has a strike parallel to the big dyke. It is composed of lath-shaped feldspar crystals that approach labradorite in composition and fibres of biotite. The two form a felt of tiny needles. A little serpentine and calcite are present. A mica dyke from the tunnel of the *Jumbo* mine near the pulaskite-contact consists of biotite, pyroxene, plagioclase, orthoclase, and apatite in order of their abundance. The plagioclase is andesine and the pyroxene a light-green variety. The interstices are filled by orthoclase. A fine-grained specimen of the *Josie* dyke on the third level of the *War Eagle* has a similar composition.

Minette.

By decrease of plagioclase and increase of orthoclase, kersantites pass into minettes. These may have hornblende or augite or may lack those minerals. Dykes of this type are also found. A specimen taken from the *Tramway* dyke on the 400-foot level of the *Josie* consists of biotite, pyroxene, apatite, and a little plagioclase set in a ground-mass of orthoclase. The pyroxene is nearly as abundant as the biotite. The "black" dyke on the same level has the same mineralogical composition. A mica dyke associated with the vogesite described from the *Iron Mask* tunnel is a minette carrying only small quantities of augite.

EFFUSIVE TYPES.

Augite Latite.

A hand specimen of a rock from near the summit of Mount Roberts which is believed to be a Mesozoic effusive shows a few black phenocrysts in a dark-grey to bluish-grey ground-mass. Some blebs of lighter green occur which suggest amygdules. In thin section it is porphyritic with trachytic structure. The primary minerals are orthoclase, plagioclase, hornblende, magnetite, and biotite. The usual secondary products are present, and probably much of the hornblende is secondary after pyroxene. The ground-mass is a felt of altered feldspar needles with pyroxene and much epidote. Some of the feldspar is still recognizable as orthoclase. The *cavities are apparently true amygdules filled with quartz and epidote. This rock is no doubt* similar to the augite biotite latite reported by Daly on Record Mountain ridge west of Rossland. An analysis of that rock is given.

	MONZONITE.		GRANODIORITE.						PULASKITE.	
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
SiO_2	55.25	54.49	65.10	66.46	62.08	50.89	59.06	77.09	61.86	62.59
TiO_2	0.60	0.70	0.54	0.27	0.73	0.80	1.08	0.05	0.15	0.54
Al_2O_3	16.53	16.51	15.82	15.34	16.61	17.00	16.24	13.04	19.07	17.23
Fe_2O_3	3.03	2.78	1.64	1.68	1.53	0.97	0.43	0.82	2.65	1.51
FeO	4.37	5.20	2.66	1.83	3.72	7.60	4.88	0.26	1.49	2.02
MnO	0.15	0.10	0.05	...	0.11	0.14	0.20	Trace.	0.01	Trace.
MgO	4.20	3.55	2.17	1.11	2.44	5.41	3.51	0.12	0.55	1.30
CaO	7.19	7.06	4.66	3.43	5.20	9.82	5.59	0.63	1.47	1.99
Na_2O	3.48	3.50	3.82	4.86	3.18	3.35	2.84	3.11	6.45	5.50
K_2O	4.11	4.36	2.29	4.58	3.29	1.31	3.95	4.50	5.75	6.74
H_2O	0.66	1.18	1.09	0.29	1.00	1.14	0.19	0.07	0.47	0.30
P_2O_5	0.43	0.20	0.16	0.08	0.30	0.19	0.21	0.10	0.08	0.11
S	...	0.23	...	...	...	0.43	...	...	...	Trace.
CO_2	...	0.10	...	...	...	...	...	...	...	...
SrO	...	...	...	...	0.03	0.28	0.12	...	...	Trace.
BaO	...	...	...	...	0.09	...	0.11	...	...	...
H_2O-	...	...	...	...	0.16	0.06	0.21	0.03	...	...
	100.00	99.96	100.00	99.93	100.47	99.39	98.62	99.82	100.00	99.83

NOTE.—Analyses I., III., IX. from Igneous Rocks and their Origin, Daly. Other analyses from Reports of Analyses of the Department of Mines, Canada.

I.—Daly. Igneous Rocks and their Origin, page 23, Average Monzonite.
II.—Monzonite, Rossland, 700 feet, *Le Roi* mine.
III.—Average granodiorite, Daly, page 25.
IV.—Nelson granodiorite.
V.—Nelson granodiorite, two miles south of Trail.
VI.—Augite porphyry, *Josie* drift, *War Eagle* mine.
VII.—Augite biotite latite (extrusive equivalent of monzonite), Record Mountain ridge west of Rossland.
VIII.—Sheppard granite, south-east of Rossland, four miles east of Lake Mountain.

IX.—Average pulaskite, Daly, page 22.
X.—Pulaskite, Rossland.

	II.	IV.	VI.	X.	X (Norm.).
Quartz	...	14.22	...	...	...
Orthoclase	19.60	22.20	...	34.10	39.60
Plagioclase, Ab	29.35	40.93	28.39	46.64	44.60
" An	7.80	4.52	16.70	1.13	0.27
Biotite	9.40	6.55	...	5.86*	1.13
Hornblende	...	8.83	...	7.45	9.00
Pyroxene	23.76	...	34.70	...	...
Magnetite	1.15	1.45	1.41	0.70	3.15
Ilmenite	1.25	0.47	1.50	...	...
Rutile	...	...	...	0.54	...
Kaolin	5.40	0.85	3.68	1.30	2.06
Muscovite	...	...	8.32	...	...
Chlorite	...	...	2.93	...	...
Apatite	0.25	...	0.39	...	...
Calcite	0.20	...	0.45	...	...
Pyrite	0.25	...	0.81	...	...
	97.81	100.02	99.28	97.72	99.81

* Neph.

According to the quantitative classification these would be:—

No. II. Class Salfemane.
Order Gallare.
Range Camptonase.
Sub Range Kentallenose.

No. IV. Class Persalane.
Order Brittanare.
Range Toscanase.
Sub Range Toscanose.

No. VI. Class Salfemane.
Order Gallare.
Range Auvergnase.
Sub Range Auvergnose.

No. X. Class Dosalane.
Order Germanare.
Range Monzonase.
Sub Range Monzonose.

The deep-seated rocks at Rossland range from medium basicity in types such as augite-porphyrite and the normal monzonite to typical granodiorites, and in the later intrusions to rocks of rather alkaline character represented by the pulaskite masses. Comparison of these varieties with average rocks of each class shows a rather close agreement in all cases. The dykes, on the evidence of microscopic work, are in part aschistic representatives of these deep-seated masses and in part basic residuals. The former are augite-camptonites and vogesites, the latter minettes and kersantites. Besides rocks that can be definitely assigned to some of these classes, there are transitional varieties that do not correspond exactly to any type.

MINERALOGY.

In the description of the minerals occurring in the Rossland district those found only as rock-forming constituents are not included. Descriptions of those will be found in the discussion of the petrography.

While the variety of minerals found is rather large, well-crystallized species are the exception and the ore-minerals are practically always massive. Most of the minerals of the following descriptions are found in close relationship to the veins. The order of arrangement follows Dana's classification.

NATIVE ELEMENTS.

Gold.—Native gold was found in impregnations of arsenopyrite, pyrrhotite, pyrite, molybdenite, and bismuthinite near alkali-syenite dykes at the *Giant* and *Jumbo* mines. It is also found in small flakes in quartz veins in the mines of the *O.K.* group. A part of the gold of the ordinary sulphide ores is in the free state, the percentage of the free-milling gold varying from 10 to 50 per cent. of the total gold content. Some pockets of gold have been found in the sulphide ores.

Silver.—The ores are always argentiferous, but no native silver has been reported. Wherever galena occurs it is silver-bearing, but even in the ores free from galena, silver is present. It seems likely that it is associated with the sulphides in a relationship similar to that of the gold.

SULPHIDES.

Stibnite.—Stibnite occurs sparingly in a fine-grained massive form at the *Lily May.* It is associated with sphalerite, galena, pyrrhotite, and chalcopyrite.

Bismuthinite.—Bismuth sulphide is mentioned in the preliminary report on this district as occurrying in impregnations near pulaskite dykes at the *Giant* and *Jumbo* mines.

Molybdenite.—Molybdenite occurs in a fine-grained massive form and as scaly aggregates. At the *Velvet* mine, on Sheep creek, ten miles west of Rossland, there is a lens of soft flaky molybdenite 2 feet long by 3 inches across. The mineral is common in the veins of the *Coxey* and *Novelty* claims on the slopes of Red mountain. There it is the massive fine-grained variety.

Galena.—Lead sulphide is found rather sparingly in the *Centre Star*, *War Eagle*, *Josie* group of mines, but in the South Belt deposits it becomes one of the more important ore-minerals. At the *Lily May* mine considerable galena occurs in the massive form, showing cleavage cubes a quarter of an inch in diameter. It is argentiferous and associated with sphalerite, chalcopyrite, pyrrhotite, and a little stibnite.

Sphalerite.—In association with galena, zinc sulphide is one of the prominent minerals in the ores of the South Belt. It is found rather rarely in the deposits of Red mountain. A specimen from the eleventh intermediate level of the *War Eagle* shows a brownish-black variety of sphalerite cutting vein-like through chalcopyrite and pyrrhotite. Massive fine-grained sphalerite of a deep-brownish colour was also observed as small irregular veinlets and blebs in a greenish siliceous rock from the 900-foot level of the *Josie*.

Pyrrhotite.—This is one of the important ore-minerals. It is massive and granular in character, both coarse- and fine-grained, and probably of different ages of deposition. Some specimens show it as distinct veinlets cutting chalcopyrite, but this does not seem to always hold true. The pyrrhotite is auriferous, but the coarse-grained varieties are usually low grade. It nearly always carries a determinable amount of nickel and a trace of cobalt. Dickson states that the Rossland pyrrhotite agrees with the formula $Fe_8 S_9$. In the Sudbury ore he states that the nickel did not replace part of the iron in pyrrhotite, but occurred in the mineral pentlandite. So far no pentlandite has been recognized at Rossland, but Gersdorffite* NiAsS has been reported. Analyses of pyrrhotite from the *Monte Christo* gives Ni, 0.13; Co, trace. Samples from the *Evening Star* show Ni, 0.67; Co, 1.58.

Chalcopyrite.—Possibly the most important ore-mineral of the camp is chalcopyrite. It is always massive and fine-grained, occurring as veinlets and impregnations in association with pyrrhotite and pyrite. It carries both gold and silver values. A large part of the ore contains only a small amount of chalcopyrite, probably less than 1 per cent. Rarely, however, ore-shoots are found in which the sulphides consist largely of chalcopyrite, and the copper content will run up to 10 or 15 per cent.

Pyrite.—Pyrite of several generations is present in the rocks and ores. In the Mount Roberts slates it is a constant accessory, often forming cubes and cubo-octahedra a third of an inch in diameter. In the veins it is usually massive and is probably of different periods of

* Annual Report, Geological Survey of Canada, 1901, page 163H.

mineralization. Some of the pyrite carries but little gold, while in other samples it seems to rank with the pyrrhotite and chalcopyrite as an ore-mineral. As a rule, in the ore it shows no crystal outlines, but samples from the fourteenth level of the *War Eagle* contain large unmodified octahedra.

Gersdorffite nickel sulph. arsenide has been reported as small octahedral crystals from the *Columbia-Kootenay* vein.*

Marcasite.—No definite crystals of marcasite were found, but some of the sulphides are rather pale in colour and may be marcasite rather than pyrite.

Arsenopyrite.—Arsenopyrite occurs with sulphides as impregnations in the country-rocks, and also occasionally as a constituent of the vein-filling. In the stratified rocks of the South Belt and of Red mountain it is disseminated in the same manner as the pyrite, and by its weathering helps to give the rusty colouring to the Mount Roberts formation. Wherever much arsenopyrite is present the gossan assumes a yellowish colour. In the *Coxey-Novelty* vein arsenopyrite is a prominent mineral along with molybdenite and some chalcopyrite. There it is a fine-grained massive variety. In the South Belt crystals were found in the *Deer Park* vein showing the usual combination of the brachydome (011) and macrodome (101). The arsenopyrite is nearly always cobaltiferous, and some of it may approach danaite (FeCo) S_2 (FeCo) As_2 in composition. An analysis of such a specimen gave the following results:† As, 47.60; S, 19.70; Fe, 29.65; Co, 3.05.

OXIDES.

Quartz.—Quartz occurs as a massive milky-white variety in veins at the mines of the *O.K.* group. It carries free gold and some sulphides. The rocks near the main veins in all the mines are often highly silicified and quartz stringers are found in the workings.

Magnetite.—Massive magnetite showing good octahedral cleavage was found on the *Sunset* dump in the South Belt. It is also rarely a constituent of the Red Mountain ores. Specimens from the *Novelty* and *Coxey* claims show rather large amounts of it.

Limonite.—Hydrated iron oxides, mostly limonite, are found abundantly wherever the surface waters have had an oportunity to act. The rusty colour from which Red mountain derives its name is due to the alteration of disseminated sulphides to limonite. Fissures where surface waters have had an opportunity to act. The rusty colour from which Red mountain derives its workings are covered with a thin coating of the mineral. In old drifts stalagmites of limonite are forming, consisting of a hard brownish-black outer shell with a soft earthy filling.

CARBONATES.

Calcite.—Calcite is found in two varieties—a massive granular form filling fissures and as an impregnation in the rocks and as fine crystals in vuggs and open fissures. Some individuals are almost cubes with curved faces which render measurement difficult, but they approach the rhombohedron (0111). These are often twinned. Other specimens show combinations of the base, rhombohedra, and scalenohedra. The scalenohedral faces are dull and striated, while the other forms are bright and smooth. Measurements are not satisfactory, but approximate an index (1232) for the scalenohedron, which the cleavage shows to be a negative form. One rhombohedron has the index 0221, while another doubtful series of faces give the index 0775. Another specimen shows a combination of the basal pinacoid (0001), a scalenohedron with curved and striated faces possibly (1232), a rhombohedron corresponding to M (4041), and a series of rhombohedra the intermediate and best developed of which give angles nearly agreeing with the index (0554). Thus the forms recognized are:—

Basal pinacoid	0001	
Rhombohedra	0111	4041
	0554	0221
		0775
Scalenohedron		1232

Malachite.—Green copper carbonates is the common alteration product of the copper-bearing ores. It forms coatings on cleavage-planes and other openings, and colours the gouge in the upper portions of the fissures. It can be seen in the process of deposition wherever downward-seeping surface waters trickle into the mine-workings.

* Annual Report, Geological Survey of Canada, 1901, page 151H.
† Annual Report, Geological Survey of Canada, 1895, page 13R.

Azurite.—Blue carbonate of copper is not so common, but was observed in a small cavity in quartz at the *O.K.* mine.

SILICATES.

Wollastonite.—Wollastonite has been reported from Rossland, and the optical properties of a greyish bladed mineral from the *War Eagle* indicate that it should be referred to this species.

Actinolite.—Actinolite occurs in a sample of ore from the 600-foot level of the *Le Roi.* It forms rosettes of silky green needles between which chalcopyrite and pyrrhotite have been deposited. Also in a small cavity in monzonite from the *City of Spokane* tunnel small dark-green radiating needles of actinolite occur. It is an associate of the chalcopyrite ore of the *Deer Park* mine, and in general seems to be frequently developed as a secondary mineral near ore-bearing fissures.

Garnet.—Massive reddish-brown garnet occurs in the ores occasionally, and in vuggs small deep-red crystals are sometimes found. The usual form is the trapezohedron.

Epidote.—Epidote is a frequent secondary product of rock-alteration and is found in fissures and irregular masses in all formations, but more especially in the older granitic rocks. In the deeper levels the rocks sometimes exhibit a faint banding that seems to be due to the presence of epidote along certain zones.

Apophylite.—Apophylite is one of the most common of the crystallized minerals in the vuggs and the open fissures. Crystals of three different habits have been noted:—

(*a.*) Crystals of the type common in apophylite, consisting of the almost cubic form of the prism and basal pinacoid. The corners are usually modified by the unit pyramid. The colour of this variety is white with a pearly lustre.

(*b.*) The second type has the prism relatively elongated and the pyramid developed to the exclusion of the basal pinacoid. The colour is a faint pink.

(*c.*) The third type is flat tabular. The prism is only slightly developed and unstriated. The base and unit pyramid are the prominent forms. The crystals are aggregated either in parallel groups with the basal faces in contact or in radiating growths. The colour is pink.

Apophylite of the first type with crystals 1/5 inch in diameter forms an encrustation on brecciated vein-matter on the 1,200-foot level of the *Centre Star.* Crystals from the second level approach the second type, but still retain a small basal pinacoid.

Laumontite.—This mineral is also commonly found among the minerals of the vuggs. It forms delicate needle-like crystals showing the unit prism terminated by the orthodome (201). When first obtained the crystals are bright and transparent, but on exposure to surface conditions they lose water and soon become white and opaque and finally disintegrate.

Chabazite.—Chabazite occurs under the same conditions as and in association with laumontite. It forms almost cubic rhombohedra 1/8 inch in diameter and often forms penetration twins. The variety is white with a delicate pearly lustre.

Gmelinite.—Gmelinite has been reported as reddish white well-formed translucent crystals of rhombohedral habit occurring in the *War Eagle* workings.*

Prehnite. —Translucent prehnite. Olive-green when fresh, but becoming white on exposure, was found in the No. 3 *War Eagle* tunnel. Minute pyrite crystals were found on the surface.

Muscovite.—Muscovite is common as an alteration product and a constituent on the zone of secondary minerals developed by the ore solutions.

Biotite.—The black mica is also produced rather commonly in the neighbourhood of the ores.

Chlorite.—This mineral is found in large amounts in similar relationships as muscovite and biotite.

Serpentine.—Impure serpentine forms a rock type exposed at various places near Rossland. An outcrop is found on the Great Northern Railway near the *O.K.* mine. It is probably a product of the alteration of a pyroxenite or similar basic rock. Serpentine is also common in fissures and along fault surfaces.

Erythrite.—Hydrous cobalt arsenate forms as an earthy alteration product from cobaltiferous minerals. It is found chiefly as a thin coating on pyrrhotite or arsenopyrite.

* Annual Report, Geological Survey of Canada, 1899, page 2R.

† Geological Survey of Canada, Memoir 77, page 82.

Epsomite.—A silky hair-like encrustation frequently covers the walls of the drier workings. In undisturbed places these crystals often reach a length of 1½ inches, usually in curved forms. The substances examined consisted almost entirely of magnesium sulphate. A small amount of alumina was present and may represent a slight admixture of aluminum sulphates.

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