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CANADA
DEPARTMENT OF MINES AND RESOURCES
HON. T. A. CRERAR, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

MINES AND GEOLOGY BRANCH
JOHN MCLEISH, DIRECTOR
BUREAU OF GEOLOGY AND TOPOGRAPHY
F. C. C. LYNCH, CHIEF

GEOLOGICAL SURVEY

MEMOIR 207

CRANBROOK MAP-AREA, BRITISH COLUMBIA

BY
H. M. A. Rice

OTTAWA
J. O. PATENAUDE, I.S.O.
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1937

Price, 25 cents. No. 2435

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CONTENTS

PAGE

PREFACE V

CHAPTER I

INTRODUCTION 1
Field work and acknowledgments, page 1; Previous work, page 1; General description of the area, page 2.

CHAPTER II

GENERAL GEOLOGY 3
Table of formations, page 3; Proterozoic, page 4; Lower Purcell series, page 4; Fort Steele formation, page 4; Aldridge formation, page 6; Creston formation, page 8; Kitchener formation, page 9; Siyeh formation, page 10; Upper Purcell series, page 11; Gateway formation, page 11; General summary of the Purcell series, page 12; Purcell igneous rocks, page 13; Extrusives, page 13; Intrusives, page 14; Age of the Purcell intrusives, page 18; Palæozoic, page 18; Cranbrook formation, page 18; Magnesite, page 19; Age of the Cranbrook formation, page 20; Eager formation, page 21; Granitic intrusives, page 21; Albitization of the syenite, page 23; Metamorphism, page 23; Age of the granitic intrusives, page 24; Cenozoic, page 24; Superficial deposits, page 24; St. Eugene silts, page 25; Pleistocene and Recent, page 25.

CHAPTER III

STRUCTURAL GEOLOGY 26
The southwest corner of the map-area south of St. Mary river, page 26; Kimberly area, page 27; St. Mary fault, page 29; Structures in the Rocky mountains, page 29; Discussion of the structural features, page 30; Origin of the Rocky Mountain trench, page 31.

CHAPTER IV

GLACIATION 33
Disappearance of the ice, page 34.

CHAPTER V

HISTORICAL GEOLOGY 36
Pre-Beltian, page 36; Late Precambrian (Beltian), page 36; Late Precambrian (Windermere), page 36; Lower Cambrian, page 36; Middle and Upper Cambrian, Ordovician, and Silurian, page 37; Devono-Carboniferous, page 37; Triassic, page 37; Jurassic, Cretaceous, and early Tertiary, page 37; Late Tertiary, page 37; Pleistocene, page 37; Recent, page 37.

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CHAPTER VI

PAGE

ECONOMIC GEOLOGY 38

Metalliferous deposits, page 38; Placer gold deposits, page 38; Tertiary deposits on St. Mary river, page 41; Lode deposits, replacements in sediments, page 42; Sullivan mine, page 42; Stemwinder and North Star mines, page 44; Kootenay King mine, page 45; Genesis of the replacement orebodies, page 46; Veins in sediments and syenite dykes, page 47; Lily May, page 47; Dibble mine, page 48; Fisher group, page 48; Palmayra group, page 48; Dardenelles group, page 49; Lily May extension, page 50; Big Chief group, page 50; Veins in faults, page 50; Try Again prospect, page 51; Bert group, page 51; Genesis of the veins in sediments, syenite dykes, and faults, page 52; Veins in diorite, page 53; Kootenay Selkirk group, page 53; Eagle's Nest claim, page 53; Origin of the veins in diorite, page 54; Other properties in Cranbrook area, page 55; General suggestions for prospecting, page 56; Non-metallic deposits, magnesite, page 56; Ornamental stone, Purcell diorite, page 59; Syenite, page 59; Clay, page 60.

INDEX 65

Illustrations

Map 396A. Cranbrook sheet, Kootenay district, British Columbia ..... In pocket

Plate I. A. View looking northeast across the foothills of the Purcell range 61
B. View looking east across the Rocky Mountain trench 61

II. A. Molar-tooth structure in Kitchener dolomitic argillite 62
B. Auriferous glacial material on Wild Horse river 62

III. Coarse-grained phase of the Purcell diorite 63

PREFACE

Many of the conclusions presented in the following report were reached by Mr. C. E. Cairnes during the season of 1932, or are based on data collected by him at that time.

Cranbrook Map-Area, British Columbia

CHAPTER I

INTRODUCTION

Cranbrook map-area, about 430 square miles in extent, is in the southeast corner of British Columbia, 50 miles north of the International Boundary. It is bounded on the north and south by latitudes 49° 45′ and 49° 30′ and on the east and west by longitudes 115° 30′ and 116° 00′ The northwest corner of the area mapped extends a few miles beyond these boundaries. Most of the area lies west of Kootenay river in the east flank of the Purcell range between the towns of Cranbrook and Kimberley. A part of the Rocky mountains is, however, covered by the eastern half.

FIELD WORK AND ACKNOWLEDGMENTS

Field work on which this report is based was commenced in 1931 by C. S. Evans, continued in 1932 by C. E. Cairnes, and completed in 1935 by the writer. An excellent topographic map on a scale of 1 inch to 2 miles was used as a base.

The work was greatly facilitated by the generous co-operation of all the inhabitants of the district. Special thanks are due to the officials of the Consolidated Mining and Smelting Company, Limited, for permission to camp on its property and to visit the Sullivan mine, and to W. A. Drayton for information regarding the Wild Horse River placer deposits.

Assistance in the field was given by D. F. Rice, A. J. Reid, and E. H. Maguire.

PREVIOUS WORK

The most extensive geological work in the past was done by Schofield, the results of which are embodied in a memoir (1915)[1] and a museum bulletin (1922)[2]. The work was done in reconnaissance fashion and covered a large area. It served a useful purpose in portraying general conditions and was an excellent foundation for the present detailed work.

Previous to Schofield's memoir brief reconnaissances were made by Dawson (1895)[3] and McEvoy (1899)[4]. In 1904[5] and again in 1913[6] Daly studied the Purcell series and made the first systematic attempt to subdivide the Precambrian rocks of British Columbia.

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[1] Schofield, S. J. (1915): "Geology of the Cranbrook map-area, British Columbia"; Geol. Surv., Canada, Mem. 76.

[2] Schofield, S. J. (1922): "Relationship of the Pre-Cambrian (Beltian) Terrain to the Lower Cambrian Strata of Southern British Columbia"; Geol. Surv., Canada, Mus. Bull. 35.

[3] Dawson, G. M. (1895): Geol. Surv., Canada, Ann. Rept., pp. 152–153.

[4] McEvoy, James (1899): Geol. Surv., Canada, Sum. Rept., pt. A, pp. 87–103.

[5] Daly, R. A. (1904): Geol. Surv., Canada, Ann. Rept., pt. A, pp. 91–100.

[6] Daly, R. A. (1913): "North American Cordillera, 49th Parallel"; Geol. Surv., Canada, Mem. 38.

GENERAL DESCRIPTION OF THE AREA

The Rocky Mountain trench trends northwest and divides Cranbrook area into two parts. The trench is a wide, fairly level valley extending in a slightly sinuous and remarkably continuous line through most of British Columbia. In the area, the bottom of the trench varies in width from 6 to over 10 miles. In detail the trench is uneven due to large depressions several hundred feet deep, mounds of glacial material, small rocky hills, and terraces (Plate I B.)

The contrast between the two sides of the trench is most striking. West of the trench the Purcell range is composed of bold ridges with peaks rising to heights of over 8,500 feet, separated by deeply incised valleys. The whole of this region is extremely rugged and traversed by few trails. The east flank of the range is deeply dissected and composed of irregular foothills, which lose height to the east until they merge into the alluvium of the trench (Plate I A). Occasional isolated mountains, 6,000 feet or more in height, occur right on the edge of the trench and interrupt the general easterly slope of the land surface. East of the trench the west margin of the Rocky mountains rises 6,000 to 8,000 feet in an abrupt wall broken by occasional deep valleys (Plate I B). This wall persists in a remarkably continuous line across the map-area and for a considerable distance beyond its limits. The Rocky mountains themselves consist of precipitous peaks 8,000 to 9,000 feet high and knife-edged ridges separated by deeply incised valleys and basins. Some parts are almost inaccessible and travel is extremely arduous.

Kootenay river flows sluggishly in a southerly direction down the trench and, in the area, is several hundred feet wide. St. Mary river, its chief tributary in this region, rises in the Purcell range and averages about 100 feet in width where it flows across the trench. Both rivers are strongly meandering, braided streams, and are at present greatly overloaded with silt and gravels. They have, however, cut bold cliffs several hundred feet high in glacial and pre-glacial lake deposits.

Cranbrook area is the "Dry Belt" of British Columbia and has an annual precipitation of about 15 inches. The temperature ranges from over 100 degrees in summer to 25 degrees below zero in winter. The summers are generally rainless and most of the agriculture depends on irrigation.

Red pine and tamarack (larch) are plentiful in the trench, but vegetation there is generally rather scanty. In the mountains, however, underbrush is often dense and the slopes thickly clothed with conifers to an elevation of over 6,000 feet.

Cranbrook has a population of about 4,000 and is the main industrial centre. Kimberley, now about the same size, has grown up around the Sullivan mine. Fort Steele was the original settlement in the area, but since the advent of the railway through Cranbrook the population has dwindled to a few hundred inhabitants.

CHAPTER II

GENERAL GEOLOGY

Most of the sedimentary rocks of the earth's crust were laid down in shallow, basin-like depressions in the continental blocks, known as geosynclines. One of the largest of these, the Cordilleran geosyncline, came into existence in the Precambrian and persisted with various modifications until the close of the Mesozoic. It consisted of a long, narrow depression extending from southern California to the Arctic ocean. In the part of this depression between Idaho and central British Columbia a uniform group of sediments was laid down during the late Precambrian. This group is known in the United States as the Belt Terrane and in Canada as the Beltian. In Canada it has been subdivided into the Purcell series and the Windermere series, and the former has been further subdivided into the Lower and Upper Purcell series.

By far the greater part of Cranbrook area is underlain by formations of the Lower Purcell series, but the lowest formation of the Upper Purcell series and two Cambrian formations appear in a few places.

Two groups of igneous rocks occur. The most widespread of these, the Purcell diorites, are Precambrian in age and occur principally as sills, dykes, and lavas. The other group, of late Mesozoic or early Tertiary age, consists of a few granodiorite stocks confined to the west side of Kootenay river, and of a number of small syenite dykes, most of which occur in the Rocky mountains.

Table of Formations

Cenozoic	Recent	Sands and gravels
	Pleistocene	Glacial drift
	Unconformity	
	Miocene	St. Eugene silts
	Unconformity	
	Late Cretaceous or early Tertiary	Syenite dykes Granodiorite stocks
	Intrusive contact	
Palæozoic	Lower Cambrian	Eager
		Disconformity (?)
		Cranbrook

Table of Formations—Concluded

Unconformity

Proterozoic (Beltian)	Upper Purcell	Gateway
	Lower Purcell	Purcell igneous rocks
		Intrusive contact
		Siyeh
		Kitchener
		Creston
		Aldridge
		Fort Steele

Base unexposed

PROTEROZOIC

Lower Purcell Series

The Purcell series is not less than 37,000 feet thick, and each component formation grades into the next with no suggestion of nonconformity.

The division of the series into formations is, therefore, based solely on differences of lithology and it is impossible to define accurately the boundary between formations or to locate them exactly in the field. The same rock types may occur in more than one formation, so that examination of outcrops over a considerable area is often necessary before the rocks exposed can be allocated with certainty to any particular formation.

With the exception of Fort Steele the names introduced by Daly[1] and Schofield[2] are retained.

FORT STEELE FORMATION

The name Fort Steele formation is given to a group of rocks underlying the Aldridge formation conformably. The formation outcrops on the front range of the Rocky mountains north of the town of Fort Steele. So far as can be ascertained this group of rocks has not been recognized elsewhere, and so constitutes a new formation in the Purcell series. It directly underlies the Purcell series as defined by Schofield. The thickness of the exposed section is about 7,000 feet, but as the base has not been recognized the total thickness of the formation is probably greater than this.

The lowest member of the Fort Steele formation is not less than 1,000 feet thick and consists of quartzite and argillaceous quartzite. Most of it is composed of pure white quartzite in beds up to 30 feet thick. The quartzite is an extremely hard, massive rock in which crossbedding is strikingly preserved. Large ripple-marks up to 4½ inches from crest to

[1] Daly, R. A. (1913): "North American Cordillera, 49th Parallel"; Geol. Surv., Canada, Mem. 38.
[2] Schofield, S. J. (1915): "Geology of the Cranbrook Map-area, British Columbia"; Geol. Surv., Canada, Mem. 76.

crest and ½ inch deep are not uncommon. The main constituent is quartz in ragged grains, up to 5 mm. in diameter, in a matrix composed of flakes of colourless mica and green biotite with occasional grains of potash feldspar, zircon, apatite, and sphene. Small areas of carbonate (probably in part calcite) and chlorite are present. In the upper part of this member the white quartzite gives place to thinner bedded, grey, impure quartzite.

The "white quartzite" member grades upwards into 2,000 to 3,000 feet of banded rock consisting of dark grey argillite and white to grey quartzite. The general occurrence of these rock types in alternating bands an inch or so wide gives the rock a striped appearance. Thicker beds of white, green, and reddish quartzite occur occasionally. The grey quartzite consists of quartz, usually in fine, ragged grains, in a matrix of fine shreds of colourless mica. In some places biotite is fairly abundant and in a few places tourmaline is remarkably plentiful. Microcline, plagioclase, zircon, apatite, argillaceous material, and magnetite occur in minor amounts. The Fort Steele argillaceous quartzite usually weathers to a sooty green or black which distinguishes it from somewhat similar types in the Aldridge in which rusty weathering is almost universal. Mud-cracks are common in the argillaceous parts of this member. It is possible that these "striped argillites" may, in places, grade laterally into white quartzites.

The "striped argillite" member is overlain by 2,000 to 3,000 feet of massive, black, calcareous or dolomitic argillite. These argillites are mostly featureless, but in places fine white lines parallel the bedding. Generally they weather black, but occasional beds weather a sooty buff colour. The rock is largely composed of carbonate, mostly calcite, with interstitial areas of argillaceous material containing fine shreds of mica and possibly some graphite. A little quartz is present, but most of it appears to be due to a slight silicification of the argillite. Near the base of this member occur narrow horizons of very striking, dark buff weathering, argillaceous dolomite. The fresh rock is a uniform grey-green, but on the weathered surface it is striped with alternating, sharply defined dark and light buff-coloured bands about an inch in width.

The uppermost member of the Fort Steele formation, 300 to 500 feet thick, consists of very massive, grey-green, dolomitic argillite. In one place the top of the member is a bluish limestone. The transition from the underlying black argillites is rather abrupt and the two members are separated, in some places, by a band of dark grey, slaty, rusty weathering argillite identical with some rocks of the Aldridge formation. The dolomitic argillites generally form massive, thick beds, many of which carry pods of calcite about 3 inches long elongated in the plane on the bedding. They generally weather a light sooty green, but some beds weather buff. The principal constituents are magnesian carbonates, colourless mica, and quartz. Sphene and tourmaline are usually present and in some places are plentiful. Potash feldspar, apatite, and zircon have been recognized. Large pyrite cubes are common.

Hitherto the Kitchener was the oldest formation in British Columbia known to contain extensive carbonate rocks. The carbonate horizon at the top of the Fort Steele formation is 20,000 feet or more stratigraphically lower than the Kitchener.

The Fort Steele formation is recognized in the field by four characteristic types of rock, which are very uncommon in the younger formations:

(1) Hard, white quartzites with very striking crossbedding.
(2) Thin-banded, dark grey argillite and light-coloured quartzite; dark weathering.
(3) Massive, black, black to dark buff weathering, limy argillite.
(4) Grey-green, dolomitic argillite with calcite pods in some of the beds.

The following are typical sections:

(1) Measured up the spur from Lakit creek to Lakit mountain.

Aldridge

Rusty weathering argillite and argillaceous quartzite.

	Feet
Fort Steele	
Grey-green, dolomitic argillite	345
Grey, rusty weathering, slaty argillite	30
Massive, black argillite, black to buff weathering; mostly limy	2,100
Chocolate-buff banded, argillaceous dolomite	50
Greenish grey, argillaceous quartzite	200
Black and white banded, argillaceous quartzites. Possible gap due to thrust faulting	1,050
Gap in section	825
Green, white, and red quartzite	200
Black and white banded argillite and quartzite	400
Massive, white, siliceous quartzite	220
Diorite sill	100
Massive, white, siliceous quartzite	560
	6,080

Base unexposed.

(2) Measured along the spur up the west face of the Rockies at the north end of the map-area.

Top unexposed.

	Feet
Fort Steele	
Massive, black argillites, black to buff weathering, mostly limy	800
Grey, rusty weathering, slaty argillite	180
Chocolate-buff banded, argillaceous dolomite	210
Massive, black argillite	150
Massive, white, siliceous quartzite	1,300
Black and white banded argillite and quartzite	210
Massive, white, siliceous quartzite	1,260
Green, siliceous quartzite	750
Gap in section	740
Massive, white, siliceous quartzite	240
Diorite sills	1,080
Massive, white, siliceous quartzite	180
Base unexposed.	7,100

ALDRIDGE FORMATION

The Aldridge formation is a geological unit of great thickness, persistence, and uniformity; it is, indeed, not less than 16,000 feet thick, or twice as thick as any other formation in the Lower Purcell series. It is composed essentially of grey, rusty weathering argillite and argillaceous quartzite, the latter occurring in beds up to 6 feet thick separated by narrow argillite partings. The formation is universally fine grained except

for two conglomerate beds on Kootenay King mountain which contain small argillite fragments and quartz pebbles up to half an inch in diameter. Generally the Aldridge formation is not limy, but some beds contain a noticeable amount of calcite and a few others hold lenses of limestone a few feet long. Details of the sedimentation are very well preserved and crossbedding, mud-cracks, and ripple-marks are abundant. Much of the argillaceous quartzite consists of light grey rock with fine, white lines parallel to the bedding. Near the base of the formation the transition to the Fort Steele formation is marked by the appearance of narrow beds of black, dark-weathering argillite and buff-weathering, grey-green, dolomitic argillite. Near the top of the formation the rock is almost everywhere argillaceous, with narrow bands of green, argillaceous quartzite alternating with grey argillite. This type of rock persists into the base of the Creston, the boundary between the two formations being drawn where the colour of the weathered rock changes from rusty to greenish.

The argillaceous quartzites consist of fine, ragged-edged, quartz grains and small flakes and aggregates of brown biotite. Plagioclase, about the composition of andesine, occurs sparingly. Calcite is usually absent, but may, locally, be abundant. Argillaceous material, garnet, tourmaline, zircon, sphene, magnetite, pyrite, colourless mica, chlorite, and apatite occur in small amounts. The argillites are generally smooth, dense looking rocks differing in composition from the quartzites only in a lower proportion of quartz grains.

Except towards the top of the formation the argillaceous quartzites predominate in the Purcell range. In the Rocky mountains, however, the formation is mainly argillite. Minor amounts of grey, argillaceous quartzite, however, occur near the base of the formation, as well as occasional beds, up to 30 feet thick, of light-coloured quartzite.

Some rocks on the southeast edge of North Star hill are identical with the grey-green, dolomitic argillite of the upper Fort Steele formation. These are believed to belong to the Fort Steele formation; as there are no outcrops of stratigraphically lower rocks in the vicinity, the belief cannot be verified.

The grey colour and universal rusty weathering are the best criteria for recognizing the Aldridge formation.

The following are detailed sections:

(1) Measured along the railway on the east side of Moyie lake.

	Feet
Creston	
Grey-green, banded argillite. Dark green weathering	
Aldridge	
Grey-green, banded argillite. Rusty weathering	400
Massive, thick-bedded, grey quartzite. Not much red weathering	675
Platy, grey, argillaceous quartzite	700
Gap in outcrops	1,400
Grey, massive quartzites	125
Massive and thin-bedded, rusty quartzite and argillite	3,850
Rusty, thin-bedded, argillaceous quartzite	800
Massive quartzite	1,650
Very light-coloured, hard quartzite	1,800
Base unexposed.	11,400

(2) Measured along the ridge from Wild Horse river to Kootenay King mountain.

	Feet
Creston	
Grey-green, banded argillite. Dark green weathering	
Aldridge	
Grey-green, banded argillite. Rusty weathering	200
Greenish, banded argillites	700
Banded, dark grey argillite	1,000
Possible gap in section due to thrust faulting	
Grey-green, banded argillite	3,600
Grey, white-lined argillite	1,400
One bed of fine-grained, limy, grey quartzite	
Massive, banded, grey, white-lined argillite	750
Some beds of light-coloured quartzite	
Sandy, grey, white-lined argillite	900
Massive, dark argillite	1,200
Buff-weathering, grey, white-lined argillite	300
Some beds of siliceous white quartzite	
Massive, grey, white-lined argillite	1,750
Massive, white quartzite	100
Grey, white-lined argillite	750
Greatly foliated argillites with some grey and white quartzites. Thickness uncertain	1,750
Diorite sill	500
Grey argillite	1,700
	16,600
Fort Steele	
Green-grey, dolomitic argillite.	

CRESTON FORMATION

The Creston formation is about 6,300 feet thick and is fairly uniform in composition although varying widely in colour. It consists chiefly of argillaceous quartzite and quartzite, both occurring in beds from 1 to 4 feet thick (30 feet in one instance) with narrow partings of argillite. The commonest type is massive, watery green, medium- to fine-grained argillaceous quartzite. Purple and white varieties are plentiful. All of these types grade into each other very rapidly along the strike, often in a few feet. Diagnostic of the Creston formation is a light-coloured quartzite traversed by a network of fine purple lines. The formation contains occasional beds of grey argillite and argillaceous quartzite which may be indistinguishable from beds of the Aldridge formation. A light green argillite with darker green bands is very striking. At the base of the formation banded green and grey argillites, usually not more than 100 feet thick, form a distinct member; on the hill to the south of Maus creek they are considerably thicker. The formation as a whole is not limy, but buff-weathering, calcareous beds are not uncommon, especially near the top. The non-limy quartzite usually weathers green or purple. Ripple-marks and mud-cracks are abundant throughout the formation and, at one place, rain-prints were observed.

Quartz is much the most abundant mineral, usually occurring in fine grains that exhibit straining and re-growth. Feldspar and colourless mica are locally common. Magnetite and pyrite are often present, the former

frequently well crystallized in small octahedra. The green and purple types owe their colour to the presence of chlorite and hematite, respectively. Carbonates, tourmaline, and biotite occur in small amounts.

Rocks of the Creston formation differ from those of the Aldridge in the colour of the quartzites, the green or purple weathering, and, microscopically, in the relative abundance of the feldspar and scarcity of biotite.

The following is a detailed section measured along the east side of Moyie lake.

	Feet
Kitchener	
Grey-green, massive, limy, buff-weathering, argillaceous dolomites	725
Creston	
Green and purple, siliceous quartzite; some limy beds	725
Green and purple argillite and quartzite; ripple-marks and mud-cracks	725
Purple, green, and grey, massive quartzite; some rusty weathering	1,150
Very silicious, grey quartzite; some beds like Aldridge types	650
Green and purple quartzite; ripple-marks	500
Green and purple argillites and quartzites; mud-cracks and ripple-marks; some limy beds	2,150
Grey and green, thin-bedded, green-weathering argillite	400
	6,300
Aldridge	
Grey-green, rusty-weathering argillite.	

KITCHENER FORMATION

The Kitchener formation is believed to be not less than 6,000 feet thick, but at no place could a satisfactory section be measured. The bulk of the formation is composed of variously coloured calcareous and dolomitic argillites, generally buff weathering, thin bedded, soft, and in many places severely sheared and contorted. Mud-cracks are very common; ripple-marks occur in the more sandy members.

Near the base of the formation the prevailing colour of the argillites is green; either a watery green, similar to the Creston quartzites, or a light, creamy green. Higher up in the section dark grey and light, creamy grey, dolomitic argillites are more usual. Less common are dark and light green, banded argillites, and pink, red, and purple, dolomitic argillites. Very massive beds, a few feet thick, of buff-weathering dolomite, which are not unlike the concretionary dolomites in the Gateway formation, occur in a few places. Dark grey, slaty argillites containing little or no carbonate occur occasionally. A peculiar type of rock, which is diagnostic of the Kitchener, consists of fragments of fine-grained calcite a few inches long set in a cement of coarser calcite or dolomite with small amounts of quartz and a few flakes of colourless mica. On an exposed surface the calcite fragments weather out to produce the structure to which Bauerman[1] has given the name "Molar-tooth" (Plate II A). Fenton[2] believes this structure to be caused by the action of algæ.

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[1] Bauerman, H. (1884): "Forty-ninth Parallel of North Latitude West of the Rocky Mountains"; Geol. Surv. Canada, Rept. of Prog., pt. B, pp. 1-42.

[2] Fenton, C. L. (1931): "Algæ and Algal Beds in the Blet Series of Glacier National Park"; Jour. Geol., vol. 39, pp. 670-686.

The rocks of the Kitchener formation generally weather to a buff colour, often in bands of slightly different shades that impart to them a striped appearance. They are extremely fine grained except for a few beds of dolomitic, argillaceous quartzite which has a pronounced sandy appearance on the weathered surface. Carbonates (calcite and dolomite) are universal and, in certain beds, constitute 95 per cent of the rock. Colourless mica and argillaceous material are fairly abundant. Quartz and feldspar occur as scattered grains; apatite, tourmaline, zircon, magnetite, and pyrite are occasionally present.

The writer found it impossible in the field to separate the Kitchener from the lower part of the Siyeh as originally defined and it was not until the name Siyeh was restricted to certain argillaceous members at the top of the original formation that mapping was found to be at all possible. The Kitchener formation, therefore, remains as defined by Schofield except that a considerable part of the Siyeh has been added to it. The proper location of the Kitchener-Siyeh boundary is by no means settled, however, but must be deferred until detailed work is done in some region where the latter formation is better exposed.

The following is a section measured along the east side of Moyie lake to Prudhomme creek.

	Feet
Siyeh	
Olive-green, platy, argillaceous quartzites.	
? Gap in section	400
Kitchener	
Dark grey, limy, buff-weathering argillites	1,440
Gap in section	200
Creamy, grey, dolomitic argillite	320
Thin-bedded argillite with some sandy beds	600
Creamy, grey, limy, buff-weathering argillite	300
Gap in section	600
Dark grey, buff-weathering, limy argillite	200
Gap in section	500
Green and grey, limy, buff-weathering argillite	420
Dark grey, limy argillite. Molar-tooth structure	620
Diorite sill	20
Gap in section	600
Creamy green, buff-weathering, dolomitic argillite	380
Greenish grey, buff-weathering, dolomitic argillite	200
	6,400 to 6,800
Creston	
Massive, green, thin-bedded, argillaceous quartzite. Some buff-weathering beds.	

SIYEH FORMATION

The name Siyeh was given by Baily Willis[1] to a limestone formation occurring on Siyeh mountain, Montana. Schofield[2] limited it to an argillaceous and calcareous formation above the Kitchener. In Cranbrook area it was found impossible to distinguish the lower, carbonate beds from the Kitchener, and in this report the term is still further restricted to the

[1] Willis, Baily (1902): "Stratigraphy and Structure, Lewis and Livingston Ranges, Montana"; Geol. Soc. Am. Bull., vol. 13, pp. 305–352.

[2] Schofield, S. J. (1915): "Geology of the Cranbrook Map-area, British Columbia"; Geol. Surv., Canada, Mem. 76.

upper part of Schofield's Siyeh which, west of Kootenay river, consists almost entirely of argillite and argillaceous quartzite. In the Rocky mountains, however, dolomitic beds frequently occur in this zone and there the location of the boundary between the two formations is a matter of opinion.

The Siyeh is probably between 1,000 and 2,000 feet thick. A poorly exposed section north of Moyie lake measures 2,200 feet. South of Marysville the approximate thickness is 1,000 feet. In the only section in the Rocky mountains showing both boundaries the formation is 700 feet thick, but the accuracy of this figure is rendered uncertain by faulting.

The typical Siyeh consists of thin-bedded argillite and argillaceous quartzite; purple, red, mauve, olive-green, watery green, and dark grey in colour. Combinations of purple or mauve and green rocks in thin bands are common and rather diagnostic. "Green striped" argillites, like those occurring in the Creston and Kitchener, are locally abundant. Mud-cracks and ripple-marks are very common. The most abundant constituent of the argillites is quartz in small, ragged grains. The rest of the rock is largely composed of colourless mica and argillaceous, possibly tuffaceous, material. Grains of feldspar, hematite, and tourmaline occur occasionally. Carbonates are generally absent.

These argillites are generally not hard to identify as Siyeh, but in places, particularly in the Rocky mountains, they occur interbedded with pinkish and greenish, light-coloured dolomites which may easily be confused with rocks of the Kitchener or Gateway formation. The Purcell lavas occur only in the upper part of the Siyeh, and when they are seen identification of the formation is positive, otherwise it is often uncertain.

Upper Purcell Series

GATEWAY FORMATION

The Gateway formation occurs only in a few places near the eastern edge of the map-area and on the edge of the trench, and is nowhere well enough exposed to permit the measurement of a section. Daly[1] gives 2,025 feet as the thickness near the International Boundary.

In Cranbrook area the formation consists of red, purple, olive-green, pink, greenish grey, grey, creamy green, and white argillaceous quartzite, dolomitic quartzite, and dolomite. The dolomitic rocks appear to be more common towards the base of the formation and are universally buff weathering. Ripple-marks and crossbedding are common in the more sandy members. Well-preserved casts of salt crystals occur in many places and are diagnostic of the formation. Many of the dolomitic beds show concretionary structures, some of which are a foot in diameter. Associated with these concretionary beds are beds of pisolitic and oolitic dolomite and of argillaceous and siliceous dolomite which show oolitic structures only in thin section. Many pisolites occur within the concretions and also form the bulk of the material between them. In Cranbrook area no such struc-

[1] Daly, R. A. (1913): "North American Cordillera, 49th Parallel"; Geol. Surv., Canada, Mem. 38, p. 107.

tures are known to occur in any of the older formations, but in Montana concretionary dolomites are considered diagnostic of the Newland formation which is correlated with the Kitchener.[1]

Quartz is always present in rocks of the Gateway formation and is frequently the most plentiful constituent. It commonly occurs in extremely fine grains, but occasionally in grains up to 5 mm. in diameter. Carbonates, mostly dolomite, form the bulk of many of the Gateway rocks, but in some of the argillaceous quartzites they are absent. In the latter most of the material around the quartz grains is colourless mica. Feldspar is usually absent, but locally occurs in considerable amount. Argillaceous material is common and is usually stained a deep red with hematite. Chlorite, zircon, biotite, apatite, pyrite, and magnetite have been recognized.

The boundary between the Siyeh and the Gateway has not been determined definitely. Strata lying above the Purcell lavas are considered to be Gateway and those below the uppermost flow Siyeh. This is a fairly satisfactory subdivision in Cranbrook area where flows are always present, but in localities where the lavas do not occur it is doubtful if a division could be made at this point. This problem, like that of the Siyeh-Kitchener boundary, will have to await the study of localities where exposures are more numerous.

General Summary of the Purcell Series

The Purcell series in Cranbrook area has a total thickness of not less than 37,000 feet exclusive of the Gateway formation, whose thickness is not here known.

The formations composing it grade into each other with no suggestion of a break and possess lithological similarities that make them extremely difficult to distinguish from each other. The rocks are almost universally fine-grained and impure and consist of argillaceous quartzites and argillites, of which many are dolomitic. It is clear that they are shallow water deposits throughout from the prevalence of mud-cracks, ripple-marks, and crossbedding.

The Purcell basin, in which they were laid down, covered an area of not less than 10,000 square miles. Both Walcott[2] and Bauerman[3] believed that the basin was occupied by a lake having no connexion with the sea. Although it is hard to be believe that a depression so large and persistent could remain unconnected with the sea, certain facts bear out this hypothesis.

(1) Walcott believed that the absence of life, other than possible algæ, in the Purcell series, and the sudden appearance of abundant life, of a fairly highly developed nature, in the Lower Cambrian indicated that the Purcell series was of non-marine origin. He argued that, had the Purcell series been of marine origin, the ancestors of the Cambrian fauna should be present.

(2) Thousands of examples of ripple-marks were observed in Cranbrook area by the writer and, with only two exceptions, they were all of the

[1] Campbell, Ian: Personal communication.
[2] Walcott, C. D. (1910): "Abrupt Appearance of the Cambrian Fauna"; Smith. Coll., vol. 57, No. 1, pp. 1–16.
[3] Bauerman, H. (1884): "Forty-ninth Parallel of North Latitude west of the Rocky Mountains"; Geol. Surv., Canada, Rept. of Prog., pt. B, pp. 1–42.

symmetrical or wave-ripple type. Kindle[1] has pointed out that in tidal waters symmetrical or current ripple-marks must predominate and that symmetrical ripple-marks are evidence of lacustrine deposition.

In the Gateway formation casts of salt crystals are abundant at several horizons and there can be no doubt that, during this epoch at least, the Purcell lake was saline or at least brackish.

The Purcell series appears, therefore, to have been laid down in a shallow lake of great extent which was, for a part of the time at least, brackish. The basin containing this lake sank slowly and at a comparatively uniform rate during the accumulation in it of 37,000 feet of sediments.

Schofield[2] concluded that the Purcell series was Precambrian in age because it is overlain unconformably by Lower Cambrian strata. Since then, in Windermere area, Walker[3] found that the Windermere series overlay the Purcell series with some angular discordance and contained a basal conglomerate. This series also underlies the Lower Cambrian unconformably, and is considered by him to be Precambrian. The Purcell series is, therefore, Precambrian in age, and in Cranbrook area the period of erosion before the deposition of the Lower Cambrian formations was probably continuous and sufficiently long to allow the deposition of the Windermere series to the north.

Purcell Igneous Rocks

Most of the Purcell igneous rocks are dioritic in composition and form sills, dykes, and lavas.

EXTRUSIVES

Beltian lavas were first described by Finlay[4] and later named and further described by Daly[5].

The Purcell lavas were extruded during the last stages of the deposition of the Siyeh formation, and in Cranbrook area occur in almost all the localities where the Siyeh is exposed. Purple and green tuffs occur in small amounts interbedded with the lavas. No other period of volcanic activity is known in the area.

The Purcell lavas vary in composition between andesite and diabase, the former being the more common. They are generally massive, green, fine-grained rocks, commonly amygdaloidal, and occur in individual flows from 1 to 30 feet thick. They are always considerably altered, the ferromagnesian minerals being completely changed to chlorite and epidote. The plagioclase is, however, recognizable in some cases and consists of andesine with a composition of about Ab 63 per cent An 37 per cent. Hematite in large segregations 3 inches or more in diameter is common. Other constituents occurring in small amounts are magnetite, pyrite,

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[1] Kindle, E. M. (1917): "Recent and Fossil Ripple-Mark"; Geol. Surv., Canada, Mus. Bull. 25, Geol. Ser. 34.
[2] Schofield, S. J. (1922): "Relationship of the Precambrian (Beltian) Terrain to the Lower Cambrian Strata of Southern British Columbia"; Geol. Surv., Canada, Mus. Bull. 35, Geol. Ser. 42.
[3] Walker, J. F. (1926): "Geology and Ore Deposits of Windermere Map-area, British Columbia"; Geol. Surv., Canada, Mem. 148, pp. 6–20.
[4] Finlay, G. I. (1902): "Igneous Rocks of the Algonkian Series (Lewis and Livingston Ranges, Mont.)"; Geol. Soc. Am., Bull., vol. 13, pp. 349–352.
[5] Daly, R. A. (1913): "North American Cordillera, 49th Parallel"; Geol. Surv., Canada, Mem. 38, pp. 207–220.

quartz, calcite, colourless mica, garnet, apatite, and, possibly, orthoclase. The amygdules consist of calcite, quartz, chlorite, and hematite.

Since the Purcell lavas are interbedded with the Siyeh strata it is evident that they are Precambrian in age and were extruded under water.

INTRUSIVES

The intrusive phases of the Purcell igneous rocks are widely distributed in Cranbrook area in all the formations of the Lower Purcell series. They are much more abundant than indicated on the map, for only the larger bodies can be plotted on a map of this scale. They take the form of sills and dykes, of which the sills are much larger and are economically more important. Both dykes and sills have the same composition and are undoubtedly directly related to one another.

The sills occur throughout the Lower Purcell series, but are largest in the Fort Steele and Aldridge formations. They vary in size in Cranbrook area from thin sheets, a few feet thick, to huge, tabular masses 700 feet or more thick. Elsewhere, even larger sills have been observed: Kirkham[1] mentions one in Idaho that is 2,000 feet thick. Individual sills have been traced for many miles and throughout this distance they maintain a uniform thickness and show no tendency to develop into laccoliths. A body of diorite on the east side of Matthew creek, at first sight a single sill 1,000 feet or more in thickness, is actually a multiple sill, none of the components of which are thicker than a few hundred feet.

The dykes are seldom over 50 feet thick and occur throughout the Purcell series. In contrast with the sills, however, they are most abundant in the Kitchener formation.

Northeast of Marysville occurs a highly irregular intrusive which passes into sills and dykes at the extremities. The outcrops here are not very plentiful, and the shape figured on the map is, consequently, only an approximation of the actual form.

The Purcell sills have been the subject of great interest since they were described by Daly. Not only are they the most abundant igneous rocks in the area, but they are genetically related to certain mineral deposits.

They are composed of dark green, holocrystalline rocks with an average grain size of 2 to 3 mm. There, is, however, a zone in the upper quarter of most sills where the rock is extremely coarse grained. The most striking characteristic of this zone is plume-shaped amphibole crystals an inch or more long (Plate III).

The following is a list of the mineral constituents of the normal rock and their average proportions:

	Per cent
Amphibole	50
Plagioclase	40
Quartz	4
Ilmenite and (or) magnetite	2
Other accessories	4

[1] Kirkham, Virgil R. D., and Ellis, E. W. (1926): "Geology and Ore Deposits of Boundary County, Idaho"; Idaho Bur. Mines and Geol., Bull. 10.

The amphibole occurs as the plume-shaped crystals mentioned above, and also in blades and as minute idiomorphic crystals within the quartz and feldspar crystals. The larger crystals are poikilitic, containing abundant inclusions of quartz, feldspar, and magnetite. Schofield[1] believed that it formed by deuteric alteration from augite.

The amphibole has already been described by the writer and the following extracts are from his paper.[2] "The amphibole was found to be of two different types designated as "A" and "B," both of which never occur in the same sill. The optical and chemical properties are given in the following tables:

Chemical Analyses[3]

—	Type "A"	Type "B"
	Per cent	Per cent
SiO_2	42·80	44·66
Al_2O_3	11·26	12·64
Fe_2O_3	15·06	15·13
FeO	14·21	8·85
MgO	3·82	4·85
CaO	10·08	10·70
Na_2O and K_2O	1·92	1·80
H_2O at 100°C	0·16	0·15
H_2O at 300°C	0·38	0·35
	99·69	99·13

"The deficiency shown in both analyses is represented in part by manganese which, although not determined, is present in both types of amphibole.

Optical Properties

—	α	β	γ	$\gamma-\alpha$	$Z \wedge C$	Calculated	
						2V	Sign
					Degrees	Degrees	
Average type "A"	1·661	1·677	1·682	0·021	17	58	Neg.
Average type "B"	1·641	1·657	1·662	0·021	18	58	Neg.

Pleochroism

—	Type "A"	Type "B"
X	Pale yellow	Pale yellow
Y	Olive-green	Olive-green
Z	Greenish blue	Greenish blue

[1] Schofield, S. J. (1915): "Geology of the Cranbrook Map-area, British Columbia"; Geol. Surv., Canada, Mem. 76, p. 58.

[2] Rice, H. M. A. (1935): "Amphibole from the Purcell Sills, British Columbia"; Am. Min., vol. 20, No. 4, pp. 307–309.

[3] Eisenhauer, Ed., analyst.

Absorption

$Y>Z>X$ $Y>Z>X$

"Both types resemble common hornblende, but have a higher iron content, a smaller extinction angle, a different pleochroism, and "B" lower indices of refraction. It is noteworthy that the relations $Fe_2O_3>FeO>Al_2O_3$ (Type "A") and $Fe_2O_3>Al_2O_3>FeO$ (Type "B") are of rare occurrence in amphiboles of the hornblende group and have been reported only from alkaline rocks. In this case being described the rock is a normal diorite.

"No varieties intermediate between the two types are known."

The plagioclase varies according to the type of amphibole present. With type "A" it ranges from oligoclase to acid andesine (Ab 88 per cent to Ab 60 per cent) and with type "B" from basic andesine to acid labradorite (Ab 54 per cent to Ab 46 per cent). It is usually fresh and shows very little twinning.

Quartz is always present, but there is seldom over 4 per cent of it in the normal rock. Magnetite and ilmenite occur in considerable amounts and leucoxene is almost always associated with these minerals. Pyrite, chalcopyrite, and pyrrhotite, probably all in part at least primary, are occasionally present. Apatite and biotite may be present in small amounts.

Many of the sills in Cranbrook area show border phases 5 to 20 feet wide, which differ in composition from the bulk of the sill. A zone carrying up to 75 per cent amphibole and 25 per cent quartz is developed along both margins of these sills. Plagioclase is sometimes entirely absent from this zone and is always much scarcer there than in the body of the sill. The enrichment of these border phases in both amphibole and quartz is rather interesting and no single process of differentiation is adequate to explain it.

Amphibole is among the first minerals to crystallize out of a cooling magma and will, therefore, first begin to develop close to the contact of the magma with the intruded rocks. If the decrease in the temperature is sufficiently slow amphibole will continue to crystallize out near the margins as long as that part of the magma is supplied with the necessary constituents. When the rock finally consolidates the marginal zone will be more plentifully supplied with amphibole than the body of the sill. Such a supply may have been provided in various ways, probably the most likely is by the streaming of volatiles away from the interior of the body.[1]

A process of this type would not produce an enrichment in quartz, which is one of the last minerals to crystallize. The increase in quartz in the margins of the sills is believed to be due to assimilation of quartz from the intruded argillaceous quartzites. The most telling argument in favour of this hypothesis is that one component of a multiple sill near Lumberton, in contact with diorite instead of sediments, has the usual enrichment in amphibole in the border phase but shows no increase in quartz.

The argillaceous material in the intruded sediments has probably also been assimilated and connected into amphibole,[2] thus still further enriching the zone already rich in amphibole from other causes.

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[1] Grout, Frank F. (1932): "Petrography and Petrology"; McGraw Hill.
Fenner, C. N. (1931): "The Residual Liquids of Crystallizing Magmas"; Min. Mag., No. 134, Sept., pp. 539–560.

[2] Idem.

A specimen taken from the middle of one of the sills in Cranbrook area is a melatonalite (328) according to the Mode classification (Johannsen, 1928, page 52) and andose, class II, order 5, rang 3, subrang 4, according to the C.I.P.W. classification. One taken from the marginal zone of the same sill in an abnormal rock (324) in the Mode classification and also an abnormal rock class III, order 4, rang 4, subrang 3, in the C.I.P.W. classification. The rocks in the marginal zone are, therefore, abnormal types which provide further evidence that they are not normal differentiates.

Contact metamorphism in the sediments adjacent to the sills is usually confined to a belt 5 to 10 feet wide paralleling the margins of the sill and is seldom very severe.

In the argillaceous quartzite this belt is characterized by the development of biotite, often segregated into patches. The rock between these patches is comparatively pure quartzite and the biotite has evidently been formed from the impurities in the original quartzite by the influence of the sills, probably without addition of material from the magma. In some places chlorite is developed, either instead of or from the biotite. The rock is then a siliceous green quartzite difficult to distinguish from the green Creston quartzites.

Where the sills are in contact with calcareous rocks the metamorphic zone consists of green, extremely fine-grained, cherty looking rock which appears to be largely composed of vesuvianite, epidote, wollastonite, and garnet with varying amounts of the original constituent of the rock. For such a rock the term " calc flintas " has been introduced.[1]

Along the upper margins of certain sills on Mark creek and Matthew creek a much more intense metamorphism has affected argillaceous quartzites for a distance of 100 feet or more from the contact of the sill. In this zone, particularly close to the sills, the sediments have been completely recrystallized and, in places, granitized, and biotite, hornblende, and feldspar developed in considerable abundance. The rocks so altered resemble granitic, igneous rocks, but field and microscopic evidence conclusively prove them to be altered sediments.

Daly[2] and Schofield[3] have described a " granitic " differentiate, granophyre, or micropegmatite, occurring along the upper margin of certain sills, which they believed was derived by differentiation from the magmas of the sills with which they are associated. The descriptions and Rosiwal analyses of this " granitic " differentiate suggest that it resembles very closely the granitized sediments found by the writer in Cranbrook area. The type localities for the " granitic " differentiate have not been seen by the writer, but Waters[4] visited them in 1928 and concluded that the " granitic " phase is most probably either metamorphosed, impure quartzite or portions of the sills whose composition is altered by assimilation of quartzitic material. He also found acid patches, partly assimilated inclusions of quartzitic material, at different horizons throughout the sills, and not necessarily confined to the upper zone as supposed by Daly and

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[1] Harker, Alfred (1932): "Metamorphism"; p. 38. Methuen and Co., Ltd.
[2] Daly, R. A. (1913): "North American Cordillera, 49th Parallel"; Geol. Surv., Canada, Mem. 38, pp. 221–225.
[3] Schofield, S. J. (1914): "The Origin of Granite (Micropegmatite) in the Purcell Sills"; Geol. Surv., Canada, Mus. Bull. 2, Geol. Ser. 13.
[4] Waters, A. C.: Personal communication.

Schofield. There is, therefore, a possibility that the "granitic" differentiates were produced by the granitization of sediments instead of by any process of differentiation.

AGE OF THE PURCELL INTRUSIVES

For the following reasons the Purcell intrusives are considered to be related to the Purcell lavas, to be Precambrian in age, and to have been intruded during, or shortly before, the Siyeh epoch:

(1) The lavas and the fine-grained facies of the intrusives are similar in appearance. The two probably have the same composition, but the lavas are too badly altered to permit accurate determination of their composition.

(2) The Purcell lavas are sufficiently abundant in Cranbrook area for the exposure of their intrusive equivalents also to be expected. The Purcell intrusives are the only rocks known in the area that could be related to the flows.

(3) No sills or dykes known to belong to the Purcell intrusives have been found in any of the formations above the Siyeh.

(4) The sills are very large and coarse grained in the Fort Steele and Aldridge formations and become increasingly smaller and finer grained in the younger formations. This would indicate that the sills were intruded while the Fort Steele and Aldridge formations were the most deeply buried, that is before the period of folding that started towards the close of the Mesozoic.

PALÆOZOIC

CRANBROOK FORMATION

The name Cranbrook formation was applied by Schofield[1] to some quartzite beds outcropping near St. Eugene mission. The formation has since been seen at a number of localities in Cranbrook map-area and is now known to include a series of quartzites, conglomerates, and carbonate rocks which overlie the Purcell series unconformably. The formation is variable both in thickness and composition.

The base of the Cranbrook formation west of Kootenay river consists of about 600 feet of quartzite which rests unconformably on the Siyeh and on the Purcell lava. These quartzites also occur on the south side of Boulder creek, where they overlie the Gateway and Siyeh formations and the Purcell lavas.

They are massive, coarse-grained, siliceous rocks, white, rose-red, green, and grey in colour. They occur in beds up to 4 feet thick separated by thin partings of argillite. Small beds of conglomerate, with quartz pebbles up to an inch across, occur locally. The basal member in places carries small fragments of the underlying rocks. Ripple-marks and cross-bedding occur locally.

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[1] Schofield, S. J. (1922): "Relationship of the Precambrian (Beltian) Terrain to the Lower Cambrian Strata of Southeastern British Columbia"; Geol. Surv., Canada, Mus. Bull. 35, Geol. Ser. 42.

The quartzites are composed mainly of quartz grains up to about 1 mm. in diameter cemented by carbonate (dolomite, magnesite, and some calcite), serpentine, and talc. Hematite, magnetite, sphene, zircon, colourless mica, and tourmaline occur in small quantities.

They are distinguished from the other formations in the area by their extremely siliceous nature and light colour; such rocks elsewhere in the area are abundant only in the base of the Fort Steele formation.

Magnesite

In the locality south of Marysville, which is considered the type locality, the quartzites grade into thin-bedded, sandy magnesite which, in turn, grades into a bed of rock magnesite about 150 feet thick. Although the magnesite is considerably contaminated by quartz and calcite near the margins of the bed, a central band 30 to 50 feet thick is remarkably pure. It is coarsely crystalline, light creamy grey on a fresh fracture, and weathers to a rough surface, light buff-grey in colour.

In the Marysville locality the magnesite occurs in a belt, terminated by faults, some 4½ miles long. This locality is the only known occurrence of magnesite in the map-area west of Kootenay river. Three occurrences have, however, been found in the Rocky mountains:

(1) On the east flank of what is known locally as Red mountain, just east of the eastern boundary of the map-area.
(2) On the ridge at the head of Wallenger creek.
(3) On the south side of Boulder creek just above the trail.

The belt of magnesite exposed at locality (1) may extend to locality (2), although exposures of it could not be found.

In the Marysville locality the magnesite grades upwards into a series of green quartzites, about 200 feet thick, distinguished by numerous annelid-like markings. These quartzites consist of well-rounded grains of quartz cemented by chlorite, serpentine, and talc with minor amounts of hematite, sphene, and zircon. Similar rocks occur in the Cranbrook formation south of Boulder creek, but elsewhere the upper member of the formation consists of blue-grey, blue-weathering limestone.

The Jefferson-Wardner limestones[1] south of Cranbrook map-area are similar in appearance to those occurring in the upper part of the Cranbrook formation, but they differ in age and the two are not to be correlated with each other.

The section of the Cranbrook formation, as it occurs west of Kootenay river and south of Boulder creek, therefore, consists of a magnesite bed overlying light-coloured quartzites and overlain by green quartzites. At the localities on Wallenger creek and on Red mountain, however, the place of the quartzites is believed to be taken by coarse conglomerates resting unconformably on the Siyeh and Gateway formations. In these two localities, also, the upper quartzites grade upwards into blue limestone. In the extreme northeast corner of the area the magnesite horizon is absent.

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[1] Schofield, S. J. (1915): "Geology of the Cranbrook Map-area, British Columbia"; Geol. Surv., Canada, Mem. 76, pp. 55–56.

There the base of the formation consists of conglomerate, which grades upwards through sandy, carbonate rocks with narrow beds of fine conglomerate, like those occurring in the typical Cranbrook, to blue limestone.

The conglomerates are extremely variable in thickness and appearance. They overlie the older rocks with a distinct angular unconformity and vary in thickness from 1 to 100 feet. Where the magnesite horizon is present (the Wallenger Creek and Red Mountain localities) the conglomerates consist of well-rounded boulders of quartzite up to 10 inches in diameter cemented by sand and carbonates. In the northeast locality they consist of angular blocks of the underlying Gateway formation. There the cement, also sand and carbonate, has evidently filled cracks in the Gateway and cemented loose pieces lying on the old erosion surface. South of the map-area, a thick bed of conglomerate, composed of angular fragments of argillite cemented by carbonates and sand, lies on the Siyeh at Peavine creek and on the Gateway on the northeast slope of Baker mountain. In one place about half the coarse constituent of the rock is formed of well-rounded pebbles of Purcell lava.

All the conglomerates described above are believed, for the following reasons, to belong to the Cranbrook formation, and are correlated with the basal quartzite of the type section:

(1) At two localities the conglomerate is overlain conformably by magnesite exactly similar to that occurring in the type locality for the Cranbrook formation.

(2) The conglomerates on the north side of Boulder creek occur at the same horizon as the basal quartzites of the Cranbrook formation on the south side of the creek.

The variable nature of the Cranbrook formation is probably due to the fact that it was deposited during the early stages of transgression by a sea over a fairly rough land surface. Conglomerate and sandstone were, therefore, formed locally in depression or river valleys, and, on higher ground, angular terrestrial debris was cemented without previous aqueous erosion.

No identifiable fossils have been found in the Cranbrook formation. The annelid-like markings are, however, almost certainly organic, and there are microscopic fragments with systematically developed dark dots in the basal quartzite which are also believed to be organic. These fragments are similar to some found by Evans[1] in the Lower Donald formation[2] of Lower Cambrian age which he calls "punctate" forms.

Age of the Cranbrook Formation

Since the Cranbrook formation is overlain by the Eager formation, upper Lower Cambrian in age, it cannot be younger than the Lower Cambrian. It may conceivably be equivalent to the Precambrian, Upper Purcell, or Windermere series, but the following evidence seems to the writer to point to Lower Cambrian age.

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[1] Evans, C. S.: Personal communication.

[2] Evans, C. S. (1932): "Briscoe-Dogtooth Map-area, British Columbia"; Geol. Surv., Canada, Sum. Rept., pt. A, pp. 122–123.

(1) It overlies the Purcell series in places with marked unconformity.

(2) It is different lithologically from any of the Beltian formations.

(3) The annelid-like markings and the "punctate" forms, particularly the resemblance of the latter to those found in the Lower Donald, suggest that the Cranbrook formation is Palæozoic rather than Precambrian in age.

(4) Schofield[1] has correlated the basal quartzites of the Cranbrook formation with certain quartzites and conglomerates conformably underlying the lower Cambrian Burton formation at Ram creek and Elko.

EAGER FORMATION

The Eager formation occurs along the western margin of the trench and on Boulder creek. A section capable of satisfactory measurement is nowhere exposed, so that the thickness of the formation is not known. It is, however, probably over 6,000 feet thick.

The bulk of the formation consists of dark grey, often rusty-weathering, argillite, distinguishable from the Aldridge argillite by a silky, fibrous appearance. Blue-grey, olive-green, and reddish, platy argillites also occur in places. They are all soft, easily deformed rocks and are almost everywhere foliated. The formation is not generally limy, but beds of calcareous argillite may occur in any part of it and white and grey, crystalline limestone occurs northeast of Wycliffe, in the highest recognized part of the formation. Small, light-coloured, calcareous lenses, an inch or so long, occur in much of the formation.

The Eager argillites are composed of quartz grains cemented by colourless mica, chlorite, and argillaceous material. Calcite may be abundant or entirely absent. Feldspar, biotite, apatite, zircon, magnetite, and pyrite occur in small amounts.

The Eager formation is known to be upper Lower Cambrian in age on the evidence of trilobites found by Schofield, near St. Eugene mission.[2] It has been correlated by Schofield with the lower part of the Burton formation near Elko, B.C., and by Walker[3] with the Mount Whyte formation in Field map-area. Both correlations are made on fossil evidence.

The Eager formation does not everywhere overlie the Cranbrook. It may have been deposited only in local basins, or may originally have been more widespread and later eroded away. Although the contact is nowhere well exposed the Eager formation appears to overlie the Cranbrook formation with a slight disconformity.

GRANITIC INTRUSIVES

The rocks included under this name are of little areal significance, but their relationship to many of the mineral deposits in Cranbrook area makes them of economic importance. They occur in two main forms; granodiorite stocks and syenite dykes.

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[1] Schofield, S. J. (1922): "Relationship of the Precambrian (Beltian) Terrain to the Lower Cambrian Strata of Southeastern British Columbia"; Geol. Surv., Canada, Mus. Bull. 35, Geol. Ser. 42.

[2] Idem.

[3] Walker, J. F. (1926): "Geology and Ore Deposits of Windermere Map-area, British Columbia"; Geol. Surv., Canada, Mem. 148, p. 16.

The granodiorite occurs along the north side of St. Mary river as a number of small stocks which outcrop in the trench. No other such bodies occur within the map-area, but a stock a mile or so in diameter is exposed farther south at Kiakho (Fish) lake, and others occur west of the area. There is evidence indicating that a similar intrusive body, not yet exposed by erosion, may also occur on Matthew creek.

These bodies may possibly enlarge downwards and unite at depth and, if they so do, the greater part of Cranbrook area may be underlain by granitic rocks, and the stocks be but cupolas projecting from the roof of a batholith.

The granodiorite is a light grey to pink, coarse-grained, porphyritic rock. It consists principally of large phenocrysts of orthoclase and smaller crystals of zoned plagioclase which vary in composition between oligoclase and albite. Interstitial quartz is always present and may form 10 per cent of the rock. Hornblende and biotite are present, but are never abundant. Magnetite, apatite, and sphene are common accessories, the latter being rather abundant. Augite occurs in some of the border phases. Aplite and pegmatite dykes are associated with some of the stocks.

Small syenite dykes are very common in the area east of Kootenay river. These dykes do not exceed 50 feet in width and are, consequently, too small to be shown on the map. They occur all through that part of the Rocky mountains within the map-area and are especially abundant on Lakit and Boulder creeks. West of Kootenay river they have been seen near Kiakho lake, and one has been cut by diamond drill holes near the Sullivan mine. Two larger bodies of syenite occur outside the map-area; one on the east fork of Wild Horse river and another, a small stock, on the plains near the mouth of Bull river, southeast of the map-area. The syenite dyke near Kiakho lake is probably related genetically to the granodiorite stock occurring there.

The syenite dykes, where unaltered, are white, pink, or grey, and vary from extremely fine-grained to coarsely porphyritic rocks. They are all sodic and grade in composition from monzonites to syenites and quartz syenites.

The principal constituents are potash feldspars (orthoclase and microcline) and plagioclase. The primary plagioclase probably varies from andesine to oligoclase, but most of the specimens show a considerable amount of clear, secondary albite. Hornblende and biotite are the commonest ferromagnesian constituents; neither is at all abundant. Diopside was recognized in one specimen. Quartz is usually present in exceedingly small amounts and is never abundant. Titaniferous magnetite or ilmenite, partly altered to leucoxene, is occasionally present. Apatite, zircon, and sphene occur as accessories, the first two only in small amounts. The potash feldspars show a slight dusting of sericite and kaolin; the ferromagnesian minerals are largely altered to chlorite. Calcite is fairly common. Colourless to light yellow garnets were seen in two specimens, in one of which they are extremely numerous.

A few small green dykes of unknown age cut the Eager formation south of Marysville. They may be related to the granitic rocks, although alteration is too intense to allow lithological comparison.

Albitization of the Syenite

The albite in the syenite dykes is believed to have partly replaced both potash feldspar, and, to a certain extent, also the earlier plagioclase (andesine to oligoclase). The following conditions were observed and lead to this conclusion:

(1) Along the boundaries between two crystals of potash feldspar parts of both have been replaced by albite. The albite in both crystals is similarly oriented.

(2) Potash feldspar has been replaced along cleavage cracks by albite. Small lenses of this albite widen out at the intersections of transverse cracks.

(3) Albite, all similarly oriented, has developed in apparently unconnected areas all through certain of the potash feldspar crystals. The pattern has somewhat the appearance of an intergrowth, but the proportions of the two minerals differ more widely in different parts of a single crystal of potash feldspar than would be expected in an intergrowth.

For the following reasons it seems more likely that the albitization was accomplished by soda-rich residues of the original magma as a last stage of the consolidation of the rock than by later solutions of different origin:

(1) Small quartz veinlets cut the potash feldspar phenocrysts and are continuous with the quartz crystallized in the interstices between the phenocrysts. Albite occurs associated with these veinlets in a manner suggesting that the two formed at approximately the same time.

(2) The rocks, especially the potash feldspars in them, show little hydrothermal alteration.

In one body of syenite, phenocrysts, all very strongly albitized, make up 75 per cent of the rock, and most of the crystals forming the groundmass between the phenocrysts show marked flow structure. It seems probable that crystallization, in this case, had proceeded nearly to completion before the magma was intruded into its present position.

The calcite, present in many of the specimens, may in part be due to the liberation of CaO by the albitization of more calcic plagioclase.

Metamorphism

Many of the syenite dykes in the Rocky mountains have been altered to fine-grained chlorite, talc, epidote rocks in which none of the primary constituents can be seen. Certain dykes are associated with mineral deposits and most of these have been carbonitized. The sediments into which the dykes were intruded have been little changed by contact metamorphism.

The granodiorite is little altered, but the sediments in contact with the stocks have been altered in variable degree. At the Kiakho Lake stock the sediments are only slightly altered for a few feet from the contact, but near the most northerly stock they have been so altered by the development of mica that the original nature of the rock is almost unrecognizable. Northeast of Wycliffe, garnetite and marble have developed from limy

Eager rocks. Contact metamorphism, similar to, but more severe than, that near the most northerly stock has altered the sediments of the lower part of the Aldridge formation along Matthew creek to garnetifeous mica schists. In these schists Schofield[1] recognized the high-temperature, contact metamorphic mineral sillimanite. These schists were undoubtedly produced from the sediments by metamorphism, probably near the contact of a granitic body not yet exposed by erosion.

It is, therefore, apparent that the solutions and gases producing metamorphism in the intruded sediments escaped from the granitic bodies much more readily in some places than in others. Mineralizing solutions that may have separated from the magmas were presumably subject to the same vagaries and the location of ore-bodies was, therefore, probably due to the localization of the escaping solutions as well as to the structures and rocks through which they passed.

Age of the Granitic Intrusives

The granitic rocks of Cranbrook area cut the Lower Cambrian formations and are, therefore, post Lower Cambrian in age, but no further direct evidence of age is available.

They are similar in composition and texture to the rocks of the Nelson batholith and the stocks become more numerous to the west of Cranbrook area towards the Nelson batholith. It is, therefore, probable that the Nelson batholith and the granodiorites of Cranbrook area are directly related and of the same age. The Nelson batholith is believed to be Cretaceous, probably late Cretaceous in age.[2]

The syenite dykes are undoubtedly related to the granodiorite and, in the writer's opinion, are probably late phases of the same period of igneous activity. Alkaline rocks resembling the syenite in Cranbrook area are known in several parts of British Columbia,[3] and in each case they are believed to be late phases of granodiorite batholiths and of early Tertiary age.

It is, therefore, probable that the granodiorite of Cranbrook area is Cretaceous, possibly late Cretaceous, in age and the syenite somewhat younger and of early Tertiary age.

CENOZOIC

Superficial Deposits

Much of Cranbrook area, especially the floors of the trench and of the larger tributary valleys, is covered by a mantle of unconsolidated material. This material consists of:

(1) Silts, sands, and gravels of pre-Glacial age.
(2) Glacial drift, silts, sands, and gravels of glacial and fluvioglacial origin.
(3) Recently formed stream and delta deposits and alluvium.

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[1] Schofield, S. J. (1915): "Cranbrook Map-area"; Geol. Surv., Canada, Mem. 76, p. 77.
[2] Cairnes, C. E. (1934): "Slocan Mining Camp, British Columbia"; Geol. Surv., Canada, Mem. 173, pp. 74–75.
[3] Cairnes, C. E. (1928): "Geological Reconnaissance in the Slocan and Upper Arrow Lakes Area, Kootenay District, British Columbia"; Geol. Surv., Canada, Sum. Rept., pt. A, pp. 104–105.
McConnell, R. G., and Brock, R. W.: "West Kootenay Sheet"; Geol. Surv., Canada, Map 762.

ST. EUGENE SILTS

The unconsolidated deposits of pre-Glacial age consist of gravels, sands, and silts, and are known as the St. Eugene silts. The fine-grained phases of these deposits were laid down in a lake that once occupied that part of the Rocky Mountain trench now traversed by the lower reaches of St. Mary river. These deposits have been gently folded and cut by minor faults; one fault was observed with a throw of 10 feet. Their original extent may have been considerable, but they are now exposed in only four places. These are:

(1) In the immediate vicinity of Wycliffe.
(2) Two miles east of Wycliffe at the north end of a sharp bend in St. Mary river.
(3) On the road along the south side of St. Mary river 1½ miles east of St. Eugene mission.
(4) On the north side of the river directly opposite locality (3).

The base of the ideal section consists of gravels resting on an unglaciated surface. These gravels are overlain by calcareous sands and silts which are, in turn, overlain unconformably by glacial material. The gravels are exposed only at localities (1) and (2) and are probably very local in distribution. They consist of well-assorted, rounded pebbles, many of which are so decomposed that they may be crushed between the fingers. The interbedded and overlying sands contain many pieces of lignitized wood and fossil plant remains. A 2-foot seam of lignite is exposed in a short tunnel at locality (3).

Schofield[1] regarded these deposits as either interglacial or Pleistocene in age, but Hollock[2] from a study of the fossil plants, considered them to be more probably late Tertiary. Berry[3] agreed with Hollick that they are Tertiary and concluded that they are probably of Miocene age.

It is remarkable that the St. Eugene silts should have escaped removal by the ice. Bedrock is exposed at many places to the north of St. Mary river, and it is probable that the silts were laid down in a narrow basin whose long dimension was transverse to the direction of flow of the ice. Deposits in the lee of projecting knobs of bedrock may thus have been protected provided the ice was unable to erode bedrock deeply.

PLEISTOCENE AND RECENT

Glacial material occurs over the entire area except on the tops of the highest peaks. It consists mostly of boulder clay and till, but well-washed beds of gravel and sand are interbedded in places with the unsorted material. Thick deposits of silts accumulated in a large glacial lake occupying the area in the vicinity of the present junction of Kootenay and St. Mary rivers. These rivers have cut down through the silts that form bluffs several hundreds of feet high in places. Terraces of roughly sorted material occur at many different elevations in the valleys. Eskers are not uncommon on the floor of the trench.

A thin veneer of sand, probably formed by sheet flood erosion, overlies the glacial drift in many parts of the area. This and the valley alluvium and stream gravels are products of the present cycle of erosion.

[1] Schofield, S. J. (1915): "Cranbrook Map Area"; Geol. Surv., Canada, Mem. 76, pp. 87–91.
[2] Hollick, Arthur (1927): "The Flora of the St. Eugene Silts, Kootenay Valley, British Columbia"; Mem., New York Botanical Garden 7, pp. 389–464.
[3] Berry, E. W. (1929): "The Age of the St. Eugene Silts in the Kootenay Valley, British Columbia"; Trans. Roy. Soc., Canada, ser. IV, pp. 47–48.

CHAPTER III

STRUCTURAL GEOLOGY

The stratified rocks of Cranbrook area have, regionally, a northerly strike and an easterly dip. They have, however, been considerably folded and faulted on both a major and minor scale.

Most of the folds are broad, open flexures with axes trending north to northeasterly, but in several places strata have been overturned in close anticlinal folds.

The area is traversed by many faults, some with offsets of many thousands of feet, across which the structures do not extend. The area is thus subdivided into a number of blocks, the structures of each of which must be considered separately. The usual strike of the faults is northeast or east and the dip west or north. At first glance there would appear to be two distinct sets of faults, but it is more probable that the northeasterly faults swing to the east into the east-west faults and that there is a single set of curving faults. Both thrust and normal faults have been recognized, but many of the faults are so poorly exposed that their nature is in doubt. On most of them the greatest displacement is believed to be vertical, although there is probably some horizontal component of movement. Many of the major faults split so as to form fault zones a mile or more wide.

All the rock types in the area, except granodiorite, are foliated. The regional strike of this foliation is north and the dip from 25 degrees west to vertical. In the immediate vicinity of a fault, however, the only foliation visible is parallel to the fault.

The structures of the individual blocks, as delimited by major faulting, will now be considered.

SOUTHWEST CORNER OF MAP-AREA SOUTH OF ST. MARY RIVER

Two faults of large displacement occur in this area: the Perry Creek fault and the Moyie fault.

The Perry Creek fault follows closely the course of Perry creek to the south of the area and strikes northeast. It is not exposed in the area but its position is approximately located from stratigraphic evidence, and it has been traced for several miles to the southwest. Its dip is believed to be steep to the northwest and, since the Eager formation is in contact with the Creston, it must be a normal fault with a displacement of not less than 9,000 feet (*See* section accompanying map).

Farther east the Moyie fault passes through the southeast corner of the area in the vicinity of Rampart station, but since most of that part of the area is covered with drift even its approximate location cannot be determined. It has, however, been observed about 3 miles south of the map-area at the head of Peavine creek, from there traced southwest to the

International Boundary at Kingsgate,[1] and thence through Montana, where it is known as the Lenia fault,[2] a total distance of 118 miles. Kirkham believes it to be an overthrust fault, the west block having moved upwards relative to the east block, from 15,000 to 45,000 feet, along a plane never less than 45 degrees in slope. At Peavine creek the dip is about 60 degrees west, and, as the Aldridge on the west lies against the Siyeh on the east, it is an overthrust fault with a vertical displacement near that of Kirkham's smaller figure.

Between these two faults are two smaller faults parallel to the main fault, one near the Perry Creek fault at Booth creek and the other to the east paralleling the railway line northeast of Cranbrook. The latter is known as the Cranbrook fault. Both of these probably dip northwest and appear to be normal faults with a vertical displacement of about 1,000 feet.

A thrust fault, parallel to those mentioned, has been approximately located on the western edge of the map-area west of the Perry Creek fault. The Creston there is in contact with the Kitchener, and the displacement is probably a few thousand feet.

The strata south of St. Mary river east of the Perry Creek fault have a general northwesterly strike and a northeasterly dip. The beds on the west side of the minor faults generally dip more steeply than elsewhere, and this suggests that the faults are thrust, but stratigraphic evidence shows that the faults are normal.

In the angle between St. Mary river and Perry creek there is an anticline overturned to the east. Unless a fault, which was not recognized, occurs in the draw between the two small hills shown in the section (*See* Map) the east limb of this anticline passes to the east into an open syncline.

Near the main railway line about 5 miles northeast of Cranbrook the strata have been folded into a tight syncline which is cut off on the east by the Cranbrook fault.

KIMBERLEY AREA

This area occupies the northwest part of the map-area from St. Mary river to the boundary. Its most important structural feature is the Kimberley fault which occurs to the north and west of the Sullivan mine.

North of the Sullivan mine and east of longitude 116° 00′ a fault trending east and dipping about 70 degrees north has been located at five separate points. For the following reasons a fault is also believed to trend northeastward from Matthew creek, across Mark creek.

(1) In the canyon of Mark creek above the falls the rocks have been intensely silicified and have been foliated in a northeasterly direction. This zone of foliation and silicification continues along the low pass over to Matthew creek.

(2) About a mile from Matthew creek a fault is clearly exposed in this zone. This fault has a northeasterly strike and dips from 45 degrees to 25 degrees to the northwest.

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[1] Schofield, S. J. (1915): "Cranbrook Map-area"; Geol. Surv., Canada, Mem. 76, p. 94.
[2] Kirkham, V. R. D. (1930): "The Moyie-Lenia Overthrust Fault"; Jour. Geol., vol. 38, No. 4, pp. 364–374.

No evidence of faulting could be found west of Mark creek in continuation of the fault north of the Sullivan mine. At its most westerly exposure it appears to be swinging to the south and it is, therefore, assumed that the two faults just described are parts of a single curved fault, to which the name Kimberley fault has been given. West of Mark creek, however, outcrops are very few and this assumption cannot be confirmed.

The evidence regarding the nature of the Kimberley fault is extremely conflicting.

(1) Stratigraphic evidence on the two sides of the east-west part of the fault indicates a normal fault with a vertical displacement of about 25,000 feet; the north block having dropped with respect to the south.

(2) Structural evidence conflicts with this. North of the fault the strike of the formations is generally north and the dip fairly low to the east. Nearer the fault the strike is northeasterly and the dip steep. This warping of the strata suggests that the north block was thrust in a southeasterly direction over the south block.

(3) Near Matthew creek, where the fault is exposed, the edges of the beds on the southeast side of the fault have been bent upwards near the fault plane in pronounced drag-folds. This drag-folding suggests that the northwest block had been thrust over the southeast block. The low dip of the fault plane, 25 degrees to 45 degrees, is more suggestive of a thrust than of a normal fault.

(4) If, at this locality, the fault were a thrust of the nature and magnitude suggested, the Fort Steel formation should be exposed northwest of the fault. It is not. In other words, here also the stratigraphic evidence indicates a normal fault.

The stratigraphic evidence seems irrefutable and the Kimberley fault is believed to be a normal fault with a vertical displacement of many thousands of feet.

The following hypothesis is offered to account for the facts observed. The fault may have started as a thrust, probably of no great displacement, and later, when compressive forces changed to tensile, became a normal fault of much greater displacement. In other words the direction of movement of the fault was, at some time, reversed. It is possible, of course, that the two parts are distinct faults; the east-west part a normal fault and the northeast part a thrust cut off to the north by the normal fault. This, however, does not explain the non-appearance of the Fort Steel formation west of the fault.

Within the curve of the Kimberley fault two smaller faults occur. One, the Sullivan fault, is exposed in the workings of the Sullivan and Stemwinder mines. It strikes about north 25 degrees east and dips from 60 to 80 degrees west. It is a normal fault occupying a crushed zone 30 to 40 feet wide, the west side of which has dropped 100 feet with respect to the east. The second fault occurs a short distance southeast of the Sullivan fault. It strikes about north 10 degrees east and dips 65 degrees to 75 degrees west. It, also, is probably a normal fault.

North of the Kimberley fault there is evidence to suggest the presence of several northeast trending, westerly dipping, normal faults. The location and number of these faults could not be determined and it is doubtful if any one of them has a displacement of more than a few hundred feet.

South of the Kimberley fault the strata are, in general, relatively flat lying, with open, northerly trending folds. The axis of one broad, fairly persistent anticline passes along the east side of North Star hill and just to the west of the Sullivan mine.

North of the Kimberley fault the general strike is northeasterly with varying dips to the east. A number of small folds parallel the strike, most of which are monoclinal flexures rather than distinct anticlines and synclines.

North of Wycliffe a small but persistent synclinal fold trends northeast and plunges at a low angle to the north. The east limb of this fold is complicated by minor faulting and much of it is covered with drift.

ST. MARY FAULT

The course of St. Mary river coincides with a zone of faulting that is, in places, over 2 miles wide. Outcrops are too few throughout this zone to allow the exact fault pattern to be determined, but the general trend is east. Two main faults form the boundaries of this zone and are connected by cross faults which subdivide the zone into a number of irregular fault blocks. The area north of the fault zone has moved upwards with respect to the area south of the zone, a vertical distance of 27,000 feet as measured at the west end of the zone. The Perry Creek and Booth Creek faults probably swing easterly into the zone, since they are not seen to cross it.

STRUCTURES IN THE ROCKY MOUNTAINS

Structures in the Rocky mountains are more complicated than those in the Purcells, but have the same trends and are essentially of the same general types.

The strongest zone of faulting occurs along, and to the east of, Wild Horse river. Near the mouth of Brewery creek this zone is a few hundred feet wide and the rocks in it, both Kitchener and Aldridge, have been sheared to fissile schists. The strike of the zone at this locality is northeast and the dip steep to the north. The northwest block appears to have been thrust up relative to the southeast block, a vertical distance not less than 20,000 feet. To the northeast the fault splits into not less than five major, and many minor, faults, all dipping northwest. The branch forming the westerly boundary of the zone is a thrust fault that probably continues along Wild Horse river to the edge of the map-area. In this fault, near the mouth of Victoria creek, is a large fault block composed of the upper part of the Fort Steele formation and the lower part of the Aldridge. Outcrops in this locality are few and the limits of the block figured on the map are, in part, hypothetical. The main zone of faulting, however, continues in a northeasterly direction to the east edge of the area. The larger faults in this part of the zone are normal, although some minor thrust faults have been recognized. The whole zone is traversed by innumerable, small, imperfectly known faults which have not been indicated on the map.

To the south of Wild Horse river a normal fault, with a vertical displacement of 5,000 to 10,000 feet, cuts in an easterly direction across Maus mountain to the south of Maus creek. The fault dips 70 degrees to the north and is occupied, in every place where it was observed, by a quartz vein up to 30 feet wide.

A fault of large displacement has been traced from Horseshoe creek, at the southeast end of Maus mountain, across the divide to the head of Lost creek, 18 miles east of the map-area. The western end of this fault strikes northeast, but the fault swings rapidly to the east and continues in an easterly direction as far as it has been traced. It dips steeply north and is apparently a thrust fault with a vertical displacement of about 14,000 feet.

A fault with a northwest strike and a steep dip is found in the extreme northeast corner of the area. As the formations there are all overturned it is impossible to be sure whether it is a normal or a thrust fault. The displacement is considerable since the Creston is in contact with the Gateway and Cranbrook formations.

A number of other faults are known east of the trench. Two thrust faults occur on the west face of the Rocky mountains: one about 1,000 feet from the base and the other trending northwest from Kootenay King basin. There are undoubtedly some northeasterly trending faults up Maus creek, but their exact location could not be determined.

The detailed structures in this part of the Rockies are, in many places, extremely complicated, but the broad features are generally apparent.

The formations north of the Wild Horse River fault zone are overturned from the west in a large anticline or anticlinorium. The folding is illustrated in the sections on the map accompanying this report. The axis of this fold runs north and the axial plane dips west.

South of the Wild Horse River fault zone the formations have a general easterly strike and northerly dip, but minor irregularities are locally so pronounced that they completely mask the major trends. Along the ridge of Maus mountain, for instance, the strata have been folded into a succession of anticlines and synclines which have a radius of curvature of 20 to 100 feet, and it is impossible to determine the general trend of the beds.

DISCUSSION OF THE STRUCTURAL FEATURES

The presence of thrust faults and close-folded, overturned anticlines, and also of normal faults of great displacement, indicates that two sets of forces operated in Cranbrook area: compressional forces producing the two former features and tensional forces producing the latter.

There is no direct evidence as to the relative ages of these two sets, but it is more probable that the tensile forces followed the compressive forces as a normal reaction during a single period of orogeny than that they were independent and separated by an important interval of time.

Since there is no difference in the nature and trends of the structures in the Purcell range and in that part of the Rocky mountains lying within the area, both are believed to have been produced by a single orogeny, that is at approximately the same time and by the same sets of forces. It has been suggested that the easterly overturned strata and the westerly dipping thrust faults signify that the compressive forces originated in the west and that the structures were probably developed successively from that direction. The structures would, in that case, be somewhat older on the west than on the east, but would still belong to a single period of mountain building.

North of Cranbrook area, in the Brisco-Dogtooth area, Evans has pointed out that the structures in the ranges west of the trench differ from those in the west side of the Rocky mountains, and he believes that an interval of time elapsed between the formation of the westerly ranges and the Rocky mountains.[1] In that area the trench appears to occupy a zone of structural weakness between the two ranges. In the south, however, in the writer's opinion, this zone lies to the east of Cranbrook area and the trench owes its location to some other, unknown, reason.

The following evidence suggests that the mountain building took place over a long period of time between late Jurassic and early Tertiary:

(1) Syenite dykes have been intruded along fault planes and only a few have been slightly sheared by later movements along the same faults. The dykes were, therefore, intruded later than the main period of faulting and earlier than its final stages. The age of these dykes is believed to be late Cretaceous or early Tertiary, probably the latter.

(2) All the granodiorite stocks in Cranbrook area occur in the zone of the St. Mary fault. It is, therefore, probable that they were intruded after the development of the fault zone. The faulting, in that case, was earlier than the intrusion of the stocks which is believed to have taken place in the Cretaceous.

(3) Many of the major fault planes contain quartz veins, some of which carry considerable amounts of sulphide. This mineralization is believed to be related to the magma responsible for the granitic intrusives and must have taken place after the beginning of the period of faulting.

(4) Since the Miocene sediments are relatively undisturbed the period of mountain building must have come to a close before they were laid down.

(5) Evans[2] suggests that the structures in the Selkirk and Purcell ranges, to the north of Cranbrook area, were developed during the late Jurassic or early Cretaceous.

Although the orogeny described above is the main period of deformation in Cranbrook area, a period of open folding took place during the interval between the close of the Purcell epoch and the beginning of the Cambrian. As a result of this folding the Cranbrook formation was laid down on the older formations with a slight angular unconformity. There was also some uplift, with little or no folding, between the Cambrian and the Devono-Carboniferous, and again at the close of the Palæozoic.

ORIGIN OF THE ROCKY MOUNTAIN TRENCH

Evans[3] has summarized the theories that have been advanced to account for the formation of the Rocky Mountain trench. None of these is applicable to every part of the trench and it is clear that the trench is not a simple structure with the same history in every part.

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[1] Evans, C. S. (1932): "Brisco-Dogtooth Map-area, British Columbia"; Geol. Surv., Canada, Sum. Rept., pt. A., pp. 164–167.
[2] Idem., p. 167.
[3] Idem., pp. 168–170.

No conclusions were reached as to its origin in Cranbrook area. Certain facts were, however, observed and deserve mention.

(1) No important faults were anywhere observed that are parallel to the trend of the trench. Most of the floor of the trench is drift covered, but if faulting of sufficient magnitude to form the trench occurs within the depression faulting parallel to this main fault would be expected to occur on the flanks of the mountains adjoining the trench.

(2) The major faults trend into the trench instead of paralleling it, and they seem actually to cross it without being offset. A study of the map brings out the following:

(*a*) The St. Mary fault zone lines up with the Wild Horse River fault zone. Both are complicated zones and the north side has, in each case, moved up with respect to the south.

(*b*) The Cranbrook fault lines up with the fault through Maus mountain. In each case the northwest block has dropped with respect to the southeast block, and both faults have about the same apparent magnitude.

(*c*) The Moyie fault, although it is not exposed in the map-area, is known to pass through its southeast corner and probably lines up with the Horseshoe Creek fault in the Rocky mountains. Both are thrust faults with about the same displacement.

(*d*) The Kimberley fault has no known counterpart on the east side of the trench. The writer believes, however, that there is a fault at the foot of the Rocky mountains, just north of the map-area, that may be the extension of the Kimberley fault.

CHAPTER IV

GLACIATION

The glacial history of Cranbrook area presents some features of unusual interest. The ice in the Rocky Mountain trench and in the lower reaches of most of its tributary valleys accomplished little erosion and disappeared by the melting away of stagnant blocks of ice instead of by normal retreat.

The entire area, with the possible exception of the tops of the highest peaks, was covered during the Pleistocene by a continental ice-sheet which moved in a southeasterly direction parallel to the trench. As this sheet thinned down, and the ridges of the mountains emerged, a stage of active alpine glaciation ensued in which the direction of movement of the individual glaciers was controlled by local topography.

During both stages of glaciation active erosion was confined to the higher elevations: in the trench and in the lower stretches of its tributary valleys the ice is, for the following reasons, believed to have accomplished little or no degradation:

(1) The usual cross-section of the tributary valleys is V-shaped instead of the normal U-shape of strongly glaciated valleys, and true hanging valleys are rare.

(2) Workable placer gold deposits occur in some of the morainic material. The gold was derived from pre-glacial placer deposits, and the high proportion of gold to glacial material suggests that it was transported only a short distance by the ice.

(3) In places the ice over-ran unconsolidated Tertiary sediments in the floor of the trench without removing them.

(4) The ice has failed to remove certain areas of rocks showing Tertiary weathering and secondary enrichment of Tertiary age in some of the mineral deposits.

The following reasons are suggested to account for the lack of erosion accomplished by the ice. "The southward slope of the trench is comparatively slight. The rate of movement, of course, depended on the slope of the ice surface rather than on that of the rock bottom, but there is no evidence to suggest a preponderant accumulation of ice to the north or south to make the slope at the surface of the ice differ from that at the bottom. The flow of the ice along the trench, therefore, was comparatively sluggish. At the same time, feeders to the main ice-sheet from the Rocky mountains on the east and the Purcell mountains on the west probably supplied it with considerable quantities of debris derived from the higher peaks. The low velocity of flow and the large load supplied by the feeders may, therefore, have combined to produce overloading and so account for the lack of erosion in the trench.

"The inability of the ice in the tributary valleys to erode importantly during the alpine stage needs a different explanation. The ice in the eastward sloping valleys, such as Perry creek and Moyie river, would have to move toward the ice in the trench, which may have been very thick even during the last stages of alpine glaciation. As a result, although the valleys themselves had a steep gradient, the slope of the ice surface would have been relatively slight and the movement, consequently, sluggish.

DISAPPEARANCE OF THE ICE

"For many years the disappearance of all ice-sheets was believed to have resulted from normal retreat. In 1898, however, Jefferson suggested the stagnation of parts of the ice-front, and since that time the concept has been amplified and applied to various localities by many geologists. In 1929 Flint summarized the existing ideas and presented new facts to show that the Wisconsin ice-sheet, after it had pushed beyond the mountain barriers south of St. Lawrence river, from the Adirondacks to Maine, became practically, if not entirely, stagnant and never regained motion.

"It is believed that the ice disappeared from the Rocky Mountain trench in the Cranbrook district by such a process, a belief which is borne out by the close agreement of the following observations with Flint's criteria for dissipation by stagnation and melting.

"(1) Large kettles, often several miles in length, are common, indicating that the main body of the ice broke up into a number of separate masses of large size. This is one of the most important of Flint's criteria.

"(2) The moraines in many places show well-bedded, silty members and crossbedded delta deposits, indicating that many small lakes were formed during the disappearance of the ice. While these are not unlike the lakes left by normal retreat of an ice-sheet, they may be distinguished by their number, the great area covered by them, and the variations in the directions of their outlets. Flint suggests that these lakes formed along the margins of bodies of ice as they shrank.

"(3) Many terraces are present. These have an irregular ice-contact face, showing no evidence of movement of the ice. They generally have a horizontal, level surface, but small kettles are nearly always present. The terraces described by Flint show all of the foregoing characteristics. . . .

"(4) The streams occupying the large kettles wander aimlessly across the irregular bottoms and are too small to have excavated these depressions. In the terms of W. M. Davis they are 'underfit.'

"(5) Kames and eskers are distributed without apparent system over the entire floor of the trench. In normal retreat the distribution of these features is definitely related to the positions of the retreating glaciers." . .

"The known glacial hisory of the Cranbrook district is briefly as follows:

(1) The area was covered during Wisconsin time by the Cordilleran ice-sheet, varying from a few hundreds of feet in thickness in the mountains to many thousands of feet in the valleys. The ice as a whole moved to the southeast over a land surface physiographically resembling the present one.

Erosion was severe only among the high mountains; in the trench the ice over-ran unconsolidated material without disturbing it greatly.

(2) As the ice melted from the ridges alpine glaciers came to occupy the valleys and set up independent glacial systems controlled by the local topography. During this stage there was little glacial erosion in the lower stretches of the majority of the valleys or in the trench itself.

(3) In the mountainous parts of the area the retreat of the glaciers was normal.

(4) In the low-lying trench the ice stagnated and broke up into separate masses, many of large size, which gradually melted away."[1]

During the period of glaciation the drainage of the area was disrupted and many of the streams were permanently deflected from their previous channels.[2] In many cases the original course of a stream has been completely masked by deep accumulations of morainic material.

The main valleys tributary to the trench are, throughout most of their length, deep, widely flaring, and generally more or less distinctly trough shaped. In what may be termed the foot-hill country they are frequently steep sided and V-shaped. The sides of certain valleys traversing the foot-hill country change slope abruptly, generally along a well-defined line. From stream level to about 1,000 feet above it the valley sides are steep and the tributaries descend to the main stream in a series of cascades. Above this level the slopes are much more gentle and the slower moving tributaries occupy distinct valleys of their own.

Box canyons of recent origin occupy the bottoms of many of the valleys in the foot-hill country.

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[1] Rice, H. M. A. (1936): "Glacial Phenomena near Cranbrook, British Columbia"; Jour. Geol., vol. 44, No. 1, pp. 70–73.

[2] Cairnes, C. E. (1932): "Some Mineral Occurrences in the Vicinity of Cranbrook, B.C."; Geol. Surv., Canada, Sum. Rept., pt. A, pp. 74–82.

CHAPTER V

HISTORICAL GEOLOGY

The following is a brief statement of the geological history of Cranbrook area as interpreted from available data.

PRE-BELTIAN

The Purcell basin was formed in the area of depression of the Cordilleran geosyncline. This basin was flanked by a land mass composed, in part, of acid igneous rocks. None of this land mass is known to be exposed in British Columbia.

LATE PRECAMBRIAN (BELTIAN)

Lower Purcell time: the Lower Purcell series of sediments, not less than 37,000 feet thick, was deposited in the Purcell basin. This basin was, at all times, shallow, and was probably unconnected with the sea.

During the last stages of the deposition of the Lower Purcell series, in the Siyeh epoch, the Purcell lavas were extruded. This extrusion took place under water and the lavas are interbedded with the upper beds of the Siyeh formation. At, or about, the same time the Purcell sills and dykes were intruded, the larger sills in the more deeply buried Fort Steele and Aldridge formations. This intrusion was accompanied by the formation of disseminated copper deposits and quartz-calcite veins.

Upper Purcell time: the Gateway formation was laid down conformably on the Siyeh and Purcell lava. During a part of this time, at least, the Purcell basin was saline or brackish. At the close of this epoch there was a slight uplift accompanied by some open folding during which the basin was drained.

LATE PRECAMBRIAN (WINDERMERE)

Throughout Windermere time the part of the Purcell basin lying in Cranbrook area remained free of water. The elevation at the close of the Purcell period was probably not very great and erosion, consequently, not severe. At the close of the Windermere period, however, there was probably further uplift accompanied by minor folding, after which erosion was probably more pronounced.

LOWER CAMBRIAN

Early in the Lower Cambrian the area was flooded by the sea, possibly for the first time, and the Cranbrook formation was deposited unconformably on the Precambrian formations. Shortly after the deposition of the Cranbrook formation the Eager formation was laid down on it, possibly in hollows in an erosion surface. There may, or may not, have been an interval of erosion between the deposition of these two formations.

MIDDLE AND UPPER CAMBRIAN, ORDOVICIAN, AND SILURIAN

After the deposition of the Eager formation the area was uplifted and the strata possibly slightly folded. This uplift was followed by some erosion.

DEVONO-CARBONIFEROUS

During the Devono-Carboniferous the area again subsided and the southern part, at least, was flooded by the sea. In these waters the Jefferson and Wardner formations were laid down.

TRIASSIC

At the close of the Mississippian the area was again uplifted and a period of erosion lasting to the present time was initiated.

JURASSIC, CRETACEOUS, AND EARLY TERTIARY

Some time in the Jurassic a period of deformation, folding, and thrust and normal faulting started which probably lasted until the early Tertiary. This period of deformation produced the present structures of the Purcell and Rocky Mountain ranges in Cranbrook area.

During the latter part of this orogeny the granodiorite stocks and the syenite dykes were intruded and the main period of mineralization in Cranbrook area took place.

LATE TERTIARY

During and after this orogeny active erosion ensued, and the topography began to assume its present form. During this time gold was released by the erosion of gold-bearing mineral deposits and collected in some of the Tertiary streams to form rich placers. During the Miocene the St. Eugene silts were deposited in a lake formed at that time.

PLEISTOCENE

During the Pleistocene the area was covered by a continental ice-sheet which, as it disappeared, resulted in a stage of alpine glaciation. During both stages active erosion took place only at high elevations. The final disappearance of the ice in the trench and in the lower valleys took place by stagnation and melting. Large quantities of morainic material were deposited throughout the area. Silts, sands, and gravels were laid down in local lakes. Some of these lakes were flanked by blocks of stagnant ice, so that the deposits formed in them now stand as conspicuous terraces. The Tertiary placers were somewhat disturbed by movements of the ice, but not enough to prevent some of them being commercially operated at the present time.

RECENT

Deposits of stream gravel, alluvium, and sand were formed by the reworking of glacial material.

CHAPTER VI

ECONOMIC GEOLOGY

The early history of Cranbrook area is chiefly concerned with mining activity. In 1864 rich placer gold deposits were discovered on Wild Horse river, and also on Moyie river, Perry creek, Palmer's bar, and elsewhere, to the south and west of Cranbrook map-area. For some years these deposits were mined without the knowledge of officials at the coast so that there is no reliable record of the total amount of gold recovered. In all probability the recovery amounted to several million dollars.

Search for lode deposits followed the first rush to the placer diggings, and there is a record of assessment work done on claims on Wild Horse river and Lost creek in 1891. The following year important silver-lead-zinc deposits were discovered west of Kootenay river on North Star and Sullivan hills. The completion of the Crow's Nest branch of the Canadian Pacific railway in 1898 and the Kimberley branch the next year helped materially to stimulate interest in the district.

Although only one mine, the Sullivan, is at present producing, it has the distinction of being the largest silver-lead-zinc mine in the British Empire. Both the North Star and Stemwinder mines shipped ore in the past and, although no other property in Cranbrook area has made important shipments, the St. Eugene mine at Moyie, south of the area, made a profit of several million dollars before it was worked out. The district has, therefore, an enviable record, and there is no reason to believe that other commercial deposits do not exist in or adjacent to Cranbrook area.

The mineral deposits of Cranbrook area are many and varied. For purposes of description they have been classified as follows:

- Metalliferous deposits
  - Placer gold deposits
  - Lode deposits
    - Replacement deposits in sediments
    - Veins in sediments and syenite dykes
    - Veins in major faults
    - Veins in diorite
- Non-metallic deposits
  - Magnesite
  - Ornamental stone
  - Clay

METALLIFEROUS DEPOSITS

Placer Gold Deposits

References: Ann. Repts., Minister of Mines, British Columbia, 1874-1934.
Schofield, S. J. (1915): "Cranbrook Map-area"; Geol. Surv., Canada, Mem. 76, pp. 147-152.
Cairnes, C. E. (1932): "Some Mineral Occurrences in the Vicinity of Cranbrook, British Columbia"; Geol. Surv., Canada, Sum. Rept., pt. A, pp. 76-84.

The entire production of placer gold within the map-area, possibly amounting to over $1,000,000, has come from streams in the Rocky mountains. Placer deposits have been, and still are being, worked west of

Kootenay river, both north and south of the map-area, principally along the valleys of Perry creek, Moyie river, Weaver and Kiakho (Fish) creeks, and Palmer's bar. These have been described by Cairnes.[1] A considerable amount of gold was recovered from these deposits, but the production never equalled that from the Rockies.

The only important deposits of placer gold in the Rocky mountains within the area occur on Wild Horse river between Boulder creek and Brewery creek, and on the last mile of Boulder creek. These deposits were extensively worked in the past; first by surface and drift mining, and later by hydraulic mining. A considerable part of the area in which the gold occurs is at present covered by leases owned by W. A. Drayton. During the summer of 1935 an electrical (resistivity) survey was made of a part of his leases to determine the location of drift-covered channels missed by earlier workers. A tunnel was being driven during the winter of 1935-36 to explore likely ground indicated in this way. A large-scale operation is projected should the results of this exploratory work prove favourable. Down stream from Drayton's holdings part of the channel that was worked in the past is covered by a group of leases controlled by J. H. Norman and J. H. Dixon of Calgary. These leases received considerable attention during the season of 1935. In 1935, in addition to these two large operations, a number of individual miners were sniping.

The gold in the Wild Horse River placers occurs entirely in glacial material. This material consists, for the most part, of unsorted till composed of huge boulders 4 feet or more in diameter, surrounded by smaller boulders, cobbles, and sand. Occasional patches of boulder clay occur and small beds or lenses of sorted gravels and sands are present in many places (Plate II B).

The underlying bedrock is fairly smooth, but it contains channels in many places. These channels, or some of them at least, were probably cut by Wild Horse river before the epoch of glaciation. They are completely masked by the mantle of glacial debris and can only be seen where they are exposed in the sides of the present channel of Wild Horse river or in placer workings.

The gold is distributed all through the glacial material, but workable concentrations occur on bedrock, particularly along the channels in it. It is fairly coarse and mostly well rounded. One nugget worth $700 is reported to have been recovered in the early days.

The processes by which glacial deposits are formed result in the dispersion rather than the concentration of heavy minerals. It is, therefore, impossible that placer deposits as large and rich as those on Wild Horse river could have been derived directly from lode deposits through their erosion by the ice. During the long period of erosion that preceded the epoch of glaciation many thousands of tons of rock must have been worn off the land surface and the gold content of mineral deposits occurring in them set free. Most of the gold liberated in this way in the drainage basin of Wild Horse river would concentrate in that creek or its tributaries and, if there were sufficient of it, would form rich placer deposits. It is from these Tertiary placers that the present deposits on Wild Horse river are believed to

[1] Idem.

have been formed. Even granted a rich source of this nature it is evident that the ice filling Wild Horse River valley moved only a short distance, otherwise the dilution of the Tertiary placers with glacial material would have rendered them too low grade to be mined profitably.

The history of the Wild Horse River placer deposits is interpreted to be as follows:

(1) During the Tertiary placer gold deposits formed along Wild Horse river and its tributaries.

(2) The entire area was covered by ice during the Pleistocene. This ice moved sluggishly down Wild Horse River valley and at no time did it accomplish much erosion along the bottom of the valley.

(3) The pre-glacial stream gravels and their included placer deposits were transported a short distance by the ice and were deposited as moraines in the area between Boulder and Brewery creeks.

(4) The saturated morainic material was locally sorted, so that much of the gold accumulated on bedrock, principally along channels in the bedrock.

(5) After the disappearance of the ice, Wild Horse river formed its present channel by cutting down through glacial material and, in places, deeply into the bedrock. The auriferous glacial material through which it cut was reworked and recent placer deposits were formed along its present channel.

There is an opinion current among the miners on Wild Horse river that as all the commercial gold placers worked so far occur on Boulder creek and on Wild Horse river below Boulder creek, the gold found in the placer deposits must have come down Boulder creek. This is not necessarily so. Gold may have come down Wild Horse river as well as down Boulder creek during the Tertiary, but important accumulations of it in the upper part of Wild Horse river may have mostly been swept out by the ice. The present location of the known placer deposits may, therefore, be due rather to the vagaries of ice erosion than to the position of the source of the gold.

The future of the placer deposits on Wild Horse river depends on the discovery, in the part already worked over, of areas of bedrock, particularly channels in bedrock, which have been missed in the past, and on the discovery of new deposits in the creek above Boulder creek. In the latter part erosion by the ice appears to have been more severe than lower down the creek and most of the placers were swept out by the ice. In certain places, however, irregularities in the local topography may have permitted placers to form in spite of this. Although the possibility of finding commercial placer deposits in this part of the creek is not as good as in the lower stretches it should not be overlooked.

The bedrock topography along Wild Horse river has been almost entirely masked by the mantle of glacial material, and the solution of its problems can only be expected to follow detailed work. Certain suggestions can be made which may be of value if it be kept in mind that they are general ideas and require checking by detailed work.

(1) The original course of Wild Horse river probably coincided roughly with the present course of that stream along that part that flows past the north end of Lone peak. Its bed was there probably in about the same position as the rim of the present canyon.

(2) *It is doubtful if Wild Horse river at any time flowed to the east* of Lone peak, but if it did so the old channel probably lay along the west side of the floor of the present valley.

(3) Part of the ice that moved down Wild Horse valley must have escaped down the valley to the east of Lone peak and there is, therefore, a chance that placer deposits may exist on Maus creek opposite the mouth of this valley. Two or more shafts have been sunk in this region and coarse gold is reported to have been recovered at a depth of 90 feet. Large boulders and a heavy flow of water were encountered, and these are reported to have prevented the enterprise from being commercially successful.

(4) Gold is being recovered from Boulder creek about half a mile from its mouth. Placer deposits that may have existed above this point have probably all been swept out by the glacier that moved down this valley.

(5) From Boulder creek to the forks of Wild Horse river bedrock was not seen on the hill-side above the flume on the southeast side of the present course of the stream. It is possible that the original course of Wild Horse river lay to the southeast of the present channel.

TERTIARY DEPOSITS ON ST. MARY RIVER

The St. Eugene silts consist of unconsolidated silts, sands, and gravels of Tertiary (Miocene) age. Gravels occur at the base of the sections in the immediate vicinity of Wycliffe and at the north end of a sharp angle in the river 2 miles east of Wycliffe. The gravels are well sorted, partly decomposed, and stained a rusty red. They are probably stream gravels, but might be delta deposits. For the following reasons it is considered possible that gold may occur in commercial quantities in these gravels:

(1) Since placer deposits of Tertiary age are believed to have been formed in certain parts of the area, Tertiary stream gravels anywhere in the area may contain placer deposits.

(2) These gravels are definitely Tertiary in age.

(3) They contain small quantities of gold in the outcrops.

If well-sorted, water-lain deposits of this type contain gold, it will be concentrated mainly on, or near, bedrock along the old stream channel. The fact that only small quantities of fine gold can be obtained from the outcrop does not, therefore, necessarily prove that commercial quantities of gold may not occur elsewhere in the gravels. To explore thoroughly these gravels it is necessary to determine whether they are delta or stream deposits, and if the latter to determine the course of the original channel and to test the gravels along bedrock in the deepest part of the old channel. If they are stream gravels there is an excellent chance that commercial deposits will be found, but it is necessary to sound a note of warning.

(1) The gravels are pre-glacial in age, but they need not, of necessity, contain economic placer deposits.

(2) They may not be stream gravels, in which case commercial quantities of gold are unlikely to occur.

(3) It may prove impractical to find the old channel.

(4) The favourable part of the deposits may have been eroded away by the ice.

(5) The gravels are partly cemented and the cost of working the deposits may be too great to make their operation commercially successful.

It can be readily seen, therefore, that exploration in this locality cannot be undertaken with any certainty of success and will probably involve a considerable outlay of capital to test the deposits thoroughly. Chances of success, however, appear to be sufficiently great to warrant at least a preliminary investigation.

Lode Deposits

REPLACEMENTS IN SEDIMENTS

Only two groups of deposits of this type are known in Cranbrook area; (1) the Sullivan, Stemwinder, and North Star mines, and (2) the Kootenay King mine. They are, however, the most important mineral deposits in the area. The nature of these deposits can best be indicated by a description of the examples.

Sullivan Mine

References: Ann. Repts., Minister of Mines, British Columbia, 1896 to 1934.

Corless, F. V. (1902): "Notes on the Geology of Southeastern British Columbia"; Bull. Can. Min. Inst., vol. 5, pp. 512-513.

Schofield, S. J. (1915): "Cranbrook Map-area"; Geol. Surv., Canada, Mem. 76, p. 130.

Staff of the Consol. Min., Sm. Co., Ltd. (1924): "The Development of the Sullivan Mine and Process for the Treatment of Its Ores"; Trans. Can. Inst. Min. Met., vol. 27, pp. 306-370.

Cairnes, C. E. (1932): "Mineral Occurrences in the Vicinity of Cranbrook"; Geol. Surv., Canada, Sum. Rept., pt. A, p. 94.

The Sullivan mine is located on the south slope of Sullivan hill about 1½ miles northwest of Kimberley. The main adit is driven from the north side of Mark creek about a mile west of Kimberley and taps the ore-body about 1,100 feet below the surface.

The Sullivan ore-body was staked in 1892, and after it had been held for seven years by the original locators was bonded by the Sullivan Group Mining Company, controlled by Colonel Redpath and associates. Only a small amount of prospecting was done until the Kimberley branch of the Canadian Pacific railway was completed in 1899, at which time systematic development was commenced and a shipment of ore was made in 1900. A smelter was constructed at Marysville, but owing to difficulties encountered in the treatment of the complex ore both smelter and mine were shut down in 1907. In 1909 the original company was reorganized under the name of the Fort Steel Mining and Smelting Company and the property was optioned to the Consolidated Mining and Smelting Company of Canada, Limited. The option was exercised in 1910. The main problem confronting the new owners was the development of a satisfactory metallurgical process to treat the Sullivan ore, for it was on this factor that the success of the enterprise hinged. In 1920, after a long period of experimental work, a process of flotation was devised by which the ore could be concentrated into products suitable for economic smelting. It was then that the operation of the Sullivan mine became commercially successful and the deposit assumed the prominence among the lead-zinc mines of the world it still

maintains. The ore is at present concentrated at Kimberley and the concentrates shipped for smelting to the company's plant at Trail. Although the tonnage treated was considerably reduced during the recent depression the concentrator is once again operating at capacity. In 1934, 1,744,151 tons of ore were treated in the concentrator with an estimated recovery of 6,370,000 ounces of silver, 322,000,000 pounds of lead, and 121,000,000 pounds of zinc.[1]

The general structure of the Sullivan deposit is comparatively simple. The ore-bodies occur in an east-plunging fold on the eastern limb of an open anticline. The axis of this anticline strikes roughly north. The plan of the ore zone on the lower levels forms roughly the east segment of the circumference of a circle whose chord runs north and south. Commercial ore in this part of the zone is restricted to two ore-bodies, one at each end of this segment. Between these the zone is heavily mineralized with iron sulphides. Each of these ore-bodies is upwards of 1,000 feet long and has a maximum thickness of 240 feet at right angles to the walls of the deposit. The dip of the ore zone varies from a few degrees to 45 degrees east, with an average dip of about 30 degrees east. The north end of the ore zone is displaced by the Sullivan fault.

The ore has formed by a highly selective replacement of laminated sediments by sulphides in such a manner that the original structures of the sediments, bedding, folding, etc., are perfectly preserved. The principal minerals are galena, sphalerite, pyrite, and pyrrhotite. The original laminæ of the sediments are represented by bands in the ore in which galena, sphalerite, or iron sulphides predominate. Minor amounts of the following minerals also occur: jamesonite, cassiterite, a complex tin sulphide (?), chalcopyrite, marcasite, tourmaline, garnet, actinolite, tremolite, and grünerite.[2] The sphalerite is the black, iron-rich variety, marmatite. In much of the ore, replacement by sulphides has been almost complete and practically no gangue minerals are present. Introduced quartz is comparatively scarce in the true replacement ore. The faulted extension of the ore-body contains a considerable amount of quartz and the zone of mineralization, at the northern end, becomes a quartz vein.

The paragenesis of the predominant minerals is as follows: pyrite, when present, was the earliest mineral to form and was followed closely by quartz. Sphalerite and pyrrhotite, deposited more or less contemporaneously, formed during and after the last stages of the deposition of quartz. Some galena formed at the same time as the last of the sphalerite and pyrrhotite, but the bulk of it was probably deposited somewhat later. The galena was accompanied by small amounts of chalcopyrite.

The combination of such minerals as garnet, tourmaline, cassiterite, and pyrrhotite, which usually form at high temperatures, with galena, which develops at lower temperatures, is unusual. Schwartz[3] believes that an interval of time elapsed between the deposition of the high-temperature minerals and the galena, allowing a considerable drop in temperature. In some of the specimens examined by the writer the deposition of

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[1] Ann. Rept., Minister of Mines, British Columbia, 1934, pt. E, p. 31.

[2] The writer is indebted to the chief geologist, Albert Jure, for many of the data given here.

[3] Schwartz, G. M. (1926): "Microscopical Features of Sullivan Ore"; Eng., Min. Jour., vol. 122, pp. 375–377

the galena was indeed distinctly later than that of the sphalerite and pyrrhotite, but in others the deposition of the two groups appears to overlap and there is no indication of a significant lapse of time. The only other important deposit of similar ore is the Broken Hill mine in Australia.[1]

The sediments in the ore zone have been so thoroughly replaced by ore minerals that there is little direct evidence of their original nature. They are, however, considered to have been dolomitic argillaceous quartzites,[2] and, for reasons given later, probably lie in the transition zone between the Aldridge and the Fort Steele formations.

Most of the folding of the mineralized beds apparently took place before the mineralization, for the ore minerals in small drag-folds have not been fractured. Some post mineral folding has, however, taken place.[3]

The ore does not grade into the sediments bordering the ore-bodies, and the contact between the ore and wall-rock is remarkably sharp. These sediments do not differ greatly in degree of metamorphism from similar sediments elsewhere in the area. In the foot-wall of the south ore-body, however, the sediments have been silicified to a hard, dark-coloured chert impregnated with pyrite and pyrrhotite, but carrying no galena or sphalerite. The significance of this zone is not known to the writer.

The sediments are cut by a number of Purcell dykes which, where they traverse the ore zone, have been profoundly altered and largely replaced by ore minerals. Outside the ore zone they differ in no respect from Purcell dykes elsewhere in the area. They appear to have had some damming effect on the ore solutions because the ore-bodies are wider below than above the dykes. It is clear that the Purcell dykes were intruded before the period of mineralization.

A sodic monzonite dyke, 50 feet or so thick, occurs in the hanging-wall of the ore-body a short distance from it, and is evidently related to the syenite dykes found elsewhere in the area.

Stemwinder and North Star Mines

References: Ann. Repts., Minister of Mines, British Columbia, 1896-1934.
Schofield, S. J. (1915): "Cranbrook Map-area"; Geol. Surv., Canada, Mem. 76, pp. 133-135.
Corless, F. V. (1902): "Southeastern British Columbia"; Bull., Can. Min. Inst., vol. 5, pp. 512-513.

The North Star mine is on the east slope of North Star hill about 2 miles west of Kimberley. The Stemwinder mine is on Mark creek directly between the North Star and the Sullivan mines. Both properties are owned by the Consolidated Mining and Smelting Company, Limited, but neither is in operation at the present time. Prior to 1910 a considerable tonnage of high-grade ore, largely lead carbonate and native silver, was shipped from the North Star mine. Schofield has described these properties at some length and the reader is referred to his report for details concerning them. Briefly the deposits are essentially the same as the Sullivan and undoubtedly had a similar origin. The mineralized horizon of the North

[1] Lindgren, W. (1928): "Mineral Deposits," pp. 777-778; McGraw-Hill.
[2] Jure, Albert: Personal communication.
[3] Schofield, S. J. (1915): "Cranbrook Map-area"; Geol. Surv., Canada, Mem. 76, p. 131.

Star mine dips roughly parallel to the slope of the hill and has been folded in such a manner that only two synclinal basins of ore remain, the rest having been removed by erosion.[1]

Kootenay King Mine

References: Ann. Repts., Minister of Mines, British Columbia: 1919, p. 115; 1929, p. 228; 1928, pp. 281-282; 1929, pp. 295-296.

The Kootenay King mine is located near the summit of the front range of the Rocky mountains on Kootenay King mountain. It is reached by a good horse trail, some 5 miles long, from the road up Wild Horse river. A good camp has been established in the basin a short distance from the workings.

The property was staked by William Meyers of Fort Steele (in the early nineties) and was acquired by W. B. Dornberg and associates in 1925. In 1928 it was taken over by the Kootenay King Mining Company who did a considerable amount of diamond drilling, and, in the same year, optioned it to the Britannia Mining and Smelting Company. The latter company explored the ore-body by tunnelling and diamond drilling and dropped their option in 1929.

The ore occurs in a bed of grey-green, dolomitic argillite, in the transition zone between the Fort Steele and Aldridge formations.

The sediments in which the deposit occurs were strongly folded prior to the mineralization. Small drag-folds suggest that, in places, strata have been overturned. A thrust fault of considerable magnitude occurs to the west of the mine and several small, possibly post-mineral, faults occur in the workings.

A fine-grained, white, sodic monzonite dyke, identical with that in the Sullivan mine, occurs in the Kootenay King, and several small syenite dykes cut the formation in the vicinity of the ore-bodies.

The ore is very similar in appearance to that of the Sullivan deposit. It consists essentially of fine-grained galena, sphalerite, and pyrite with little gangue other than unreplaced parts of the original sediments. The laminations in the replaced rock appear in the sulphides, as bands of slightly different composition, in a manner similar to the Sullivan ore. The mineralogy is, however, slightly different. The sphalerite instead of being dark brown or black as in the Sullivan ore is light green, and not easily distinguished from some of the silicates in the unreplaced rock. The predominant iron sulphide in the Kootenay King ore is pyrite instead of pyrrhotite as in the Sullivan. Both light-coloured sphalerite and pyrite have a lower proportion of iron than have black sphalerite and pyrrhotite, and the Kootenay King ore was apparently formed from solutions with a lower content of iron than was the Sullivan ore.

The pyrite generally occurs as cubes of microscopic size. The interstices between the cubes are filled with galena and sphalerite. The two latter minerals probably crystallized together and later than the pyrite.

At the north end of the mineralized zone is a quartz vein a few feet wide. This vein is quite distinct from the main ore zone and occupies a steeply dipping fracture approximately perpendicular to the bedding. In

[1] Idem.

one part of this vein an open-cut has exposed some solid galena, but elsewhere the vein appears to be barren.

The structures in the vicinity of the ore zone are very complicated and can be solved only by systematic, detailed study. It would be necessary to solve these structures in detail before the exploration of the possible continuations of the ore-bodies could be carried out to the best advantage. Some general facts were noted during the brief examination made by the writer and deserve mention:

(1) The ore occurs in one or more horizons on the east limb of an anticlinal fold. This ore is exposed in open-cuts and in No. 1 and No. 2 tunnels.

(2) No. 3 tunnel is in barren rock. It is on the opposite side of a strong fault from the ore exposed in the upper tunnels and the open-cut, and could not be expected to pick up the extension of that ore. Future exploration should aim at following the extension of the mineralized beds north and west in the hope that, if they do so continue, commercial ore-bodies may be found in them. Exploration east of the fault zone may well be deferred until the results of this work are known.

GENESIS OF THE REPLACEMENT ORE-BODIES

The Sullivan, North Star, Stemwinder, and Kootenay King mines have certain features in common:

(1) The ore occurs as a differential replacement of dolomitic quartzites.

(2) These sediments lie in the zone of transition between the Aldridge and the Fort Steele formations. This is definitely known at the Kootenay King and inferred at the Sullivan, North Star, and Stemwinder mines for the following reasons:

(*a*) No beds of the extent and nature of those replaced are known except in this zone.

(*b*) The horizons appearing in the Sullivan mine are, as far as can be determined by stratigraphic measurements, in the base of the Aldridge formation.

(*c*) At the foot of North Star hill, on the east side where the lowest strata in this region are exposed, grey-green, dolomitic argillites occur identical with those in the top of the Fort Steele.

(3) The ore-bearing horizons have been subjected to considerable folding prior to the mineralization.

(4) The ore-bodies lie on the east sides of large faults. These faults in places contain quartz veins carrying sulphides and the crushed rock in the zone of faulting is commonly highly silicified. They are, therefore, believed to be pre-mineral features.

(5) The ore-bodies have been subjected to post-mineral normal faulting.

(6) Members of the granitic rocks occur in both mines.

From items (3), (4), and (5) it is deduced that the mineralization occurred during the late stages of the main orogenic period in the area; that is in the Cretaceous or early Tertiary.

For the following reasons the source of the ore is believed to be the magma from which the granitic rocks were derived:

(1) The ore is believed to have formed at approximately the same time as the intrusion of the granitic rocks; that is during the Cretaceous or early Tertiary.

(2) Granitic rocks are present near both properties.

(3) Cassiterite, which is considered always to be a product of acid intrusives, occurs in the Sullivan mine.

The following sequence of events is suggested to account for the origin and position of the ore-bodies:

(1) Thick beds of banded dolomitic argillite, theoretically favourable for replacement, and apparently of the type that has been replaced by the sulphides to form the ore, occur between beds of argillaceous quartzite only in the zone of transition between the Aldridge and the Fort Steele formations.

(2) In the vicinity of the mines described pre-mineral thrust and normal faulting deformed these beds and produced in them structures suitable for the passage of the mineralizing solutions.

(3) The faults were sufficiently deep seated to tap the source of the mineralizing solutions. The fault zones may then have acted as channels for these solutions to enter the structures produced by the above processes.

(4) The solutions on entering these structures replaced certain chemically suitable horizons and so produced the ore-bodies.

VEINS IN SEDIMENTS AND SYENITE DYKES

Quartz veins cutting the sediments, or in syenite dykes, are exposed in a number of places, and at some of them a considerable amount of development work has been done. As yet none of this work has opened up ore in commercial quantity. The following is a description of the most important of these prospects.

Lily May

Reference : Ann. Rept., Minister of Mines, British Columbia, 1934, p. 29.

The Lily May group, owned by H. Kershaw of Fort Steele, is located above Wild Horse river at an elevation of 6,500 feet on the west side of Vertical mountain. Four shallow shafts and a short crosscut tunnel have exposed a narrow quartz vein over a length of about 260 feet. The vein varies from 6 inches to 3 feet in width and averages about 1 foot. It carries galena, a little pyrite, and, near the surface, some secondary anglesite ($PbSO_4$). The vein strikes north 10 degrees to 20 degrees west and dips 30 degrees to 40 degrees east into the hill. It occupies a fault with a displacement of a few feet. At the north end both fracture and vein die out. At the south end bedrock is covered by overburden. The downward extension of the vein may possibly have been cut off by a large fault, a few hundred feet east of the workings.

A quarter of a mile or so farther south two short tunnels expose sparsely mineralized quartz veins.

Dibble Mine

The property of Dibble Mines, Limited, is located at an elevation of 6,700 feet in Lost Creek basin. It is reached by a good horse trail, about 5 miles long, up Lost creek. Preliminary development in the season of 1935 was being done under the direction of G. M. Wittichen of Calgary. The deposit is in Creston argillaceous quartzites on the north side of the Lost Creek fault. Most of the deposits consist of small quartz stringers containing bunches of high-grade ore which, because of the cost of transportation, are too small to be mined profitably. Before the acquisition of the property by the present company a considerable amount of surface work was done on these stringers and a little ore shipped. During the season of 1935, however, a vein 2 to 3 feet wide, striking roughly east and dipping 70 degrees north, was encountered in the face of a tunnel 215 feet long. What is possibly the upward extension of this vein is exposed in an open-cut on the hill-side above the tunnel. The writer was not able to find the westward extension of the vein from the open-cut, although outcrops are plentiful in this direction. East of the open-cut the surface is covered by drift and the possibilities of the continuation of the vein in this direction are not known. In addition to the veins and stringers mentioned, a number of siliceous zones occur in the quartzites. These appear to be entirely barren and must not be confused with ore-bearing veins. The principal sulphide in the vein and stringers is tetrahedrite. The owners report that high assays in silver and gold are obtained from the tetrahedrite. The main vein had not been exposed for a sufficient distance at the time of the writer's visit to permit an estimation of its commercial possibilities.

Fisher Group

The Fisher group of claims, owned by E. H. Nagle and Clarence Myrene of Kimberley, is located, at an elevation of 6,500 feet, on the south side of Boulder creek. A 7-foot bed of dolomitic limestone in the Cranbrook formation, occurring in a greatly disturbed part of the Wild Horse River fault zone, has been shattered and the fractures so produced filled with quartz. This quartz forms a network of stringers an inch or so wide traversing the rock. The mineralized bed has been exposed in a deep open-cut and traced on the surface for several hundred feet. In the open-cut about 10 per cent of the mineralized bed consists of vein matter. The quartz veinlets carry galena, pyrite, and a little chalcopyrite. Picked samples from these veinlets taken by the owners are reported to run as high as 1·56 ounces of gold, and 104 ounces of silver a ton.

Palmayra Group

The Palmayra group, owned by Charles Reynolds and Emil Banks of Fort Steele, is on the northwest side of Wild Horse river at an elevation of 4,700 feet. It is reached by a trail about three-quarters mile long from the end of the automobile road along Wild Horse river. Five tunnels and a shaft have opened up one or more syenite dykes cutting Aldridge argillites. The dyke in the lowest tunnel (No. 1) is very irregular in shape, but apparently dips nearly vertically. This dyke, particularly the part of

it at the fork of the tunnel, has been faulted and considerably shattered. The fractures so produced have been filled with quartz and a considerable part of the dyke rock itself replaced by quartz. The quartz is mainly confined to the zone of intense shattering, but small quartz stringers occur all through the dyke. These stringers are confined to the dyke itself and do not persist into the argillites. The quartz is sparsely mineralized with pyrite and galena.

The deposits in the remaining workings cannot be directly related to that in No. 1 tunnel. These workings expose a flat-lying vein, 10 to 30 feet thick, which is considerably shattered and faulted. In tunnels Nos. 2 and 5 this vein occurs in or along the margin of a flat-lying dyke. In tunnels Nos. 2 and 3 sulphides are rather scanty, but in tunnel No. 5, which was being driven at the time of the writer's visit, galena is fairly abundant and is accompanied by some anglesite (lead sulphate). The vein there lies on the hanging-wall side of the dyke and dips at an angle of a few degrees into the hill. It does not appear in tunnel No. 4 and may have been displaced by a minor fault. Development work should be confined to establishing the continuity of this vein and to the outlining of possible ore shoots contained in it.

Dardenelles Group

References: Ann. Repts., Minister of Mines, British Columbia; 1896, p. 523; 1925, p. 229; 1934, p. E 30.

The Dardenelles group, owned by Charles Reynolds and Emil Banks, is under option to the Marysville Mining Company, controlled by E. Davis of Toronto. It is on the west slope of Vertical mountain above the end of the Wild Horse River road, at an elevation of 6,000 feet. The workings consist of three inclined shafts and an open-cut. The lowest shaft, situated near the cabin, is partly caved, but exposes a quartz vein in and along the margin of a severely altered, carbonatized syenite dyke which cuts Creston argillaceous quartzites. The strike of this vein is about north 40 degrees west and the dip 20 degrees south. Both it and the dyke appear to occupy a thrust fault and both have been subjected to later movements along this fault. The vein is from 1 to 3 feet wide and carries bunches of galena and chalcopyrite. Between 400 and 500 feet east of this shaft an open-cut has exposed a vein and dyke, also in the zone of a thrust fault. The relationship of dyke, ore, and faulting is similar to that in the shaft. A second inclined shaft has been sunk to a depth of 55 feet about 300 feet southwest of the first. This shaft exposes a different vein striking north 60 degrees east and dipping 25 degrees south. The vein is from 3 to 4 feet wide and occurs along the foot-wall of an altered syenite dyke. Fragments of the dyke occur in the body of the vein and the latter probably was formed, in part at least, by replacement of the dyke rock. Most of the vein is barren of sulphides, but a streak of almost solid galena up to 7 inches wide follows the centre of the vein parallel to the walls. The galena has, in places, been altered to anglesite. A sample taken by the resident engineer across 7 inches of this high-grade streak ran 0·08 ounce gold, and 5·0 ounces silver a ton, 43 per cent lead, and a trace of zinc[1]. The third shaft is located a short distance to the southwest of the second and is caved.

[1] Ann. Rept., Minister of Mines, 1934, p. E 30.

Lily May Extension

The Lily May Extension adjoins the Lily May on the west side and is owned by H. Kershaw of Fort Steele. The workings are located near the flume along the east side of Wild Horse river and about a mile north of Boulder creek. Three tunnels, from 10 to 25 feet long, have exposed a syenite dyke of irregular shape up to 7 feet wide, cutting Aldridge argillites. This dyke has been extensively shattered and carbonatized. It is traversed by numerous quartz veinlets and locally is largely replaced by quartz. The amount of quartz varies from place to place; one part of the dyke may be almost entirely replaced by quartz and another part, a few feet away, may contain only a few insignificant stringers. The quartz, in places, carries galena, chalcopyrite, pyrite, and a little siderite. The small amount of work done has, as yet, exposed no ore-body of commercial size.

Big Chief Group

Reference: Ann. Rept., Minister of Mines, British Columbia, 1934, p. E 30.

The Big Chief group is owned by E. H. Nagle and Clarence Myrene of Kimberley, and is located at an elevation of 6,000 feet on the north side of Boulder creek about 3 miles by trail from its mouth. The Big Chief deposit was staked before 1899 and a considerable amount of work was done on it during the next few years. The claims were allowed to lapse, and were re-staked by the present owners in 1934. The main tunnel has been driven along the hanging-wall contact of a 30-foot syenite porphyry dyke, with Eager argillites. A small syenite dyke, parallel to the main one, has been cut in the crosscut to the northwest. Near the portal of the tunnel a shaft has been sunk to a depth of about 30 feet and a short drift has been driven from the bottom of it, also along the hanging-wall of the main dyke. A few hundred feet down the hill another tunnel has been driven for about 45 feet in the foot-wall side of the large dyke exposed in the main tunnel.

The dyke is considerably altered and contains, in joints or fractures, quartz stringers from a fraction of an inch to 2 or 3 inches in width. These stringers carry galena, chalcopyrite, and pyrite, and some contain visible native gold. Parts of the dyke have been silicified and mineralized with pyrite, but these carry very little gold.

The value of the deposit is difficult to determine. As the stringers are too small to be mined separately it would be necessary to mine the entire dyke or, at least, selected portions of it. Careful bulk sampling is necessary to determine whether or not any of the material is ore.

VEINS IN FAULTS

Quartz veins, more or less mineralized with sulphides, occur in most of the faults observed. Several of these have had some preliminary development work done on them, but none is being worked at the present time. Their chief interest lies in the evidence they furnish as to the relative age of the faulting and the mineralization.

Try Again Prospect

The Try Again is owned by Teddy Warren of Fort Steele and is on Sixmile creek at an elevation of 4,400 feet. A zone of strong brecciation 2 or 3 feet wide occurs in a thrust fault which strikes roughly east and dips about 40 degrees north. The rocks on both sides of the fault are Fort Steele quartzites. This zone has been filled and the component fragments partly replaced by quartz carrying considerable quantities of chalcopyrite and a little pyrite. The development work consists of two short tunnels and an open-cut. The portals of both tunnels are side by side in well-mineralized quartz in the fault zone. Both were driven into the foot-wall block of the fault approximately at right angles to the strike of the fault. The longer tunnel has been driven along a cross fracture running south from the main fault. This fracture is mineralized for a short distance, but both fracture and mineralization die out near the face of the tunnel. The open-cut is located on the main fault about 100 feet west of the tunnel. It exposes vein matter similar to that in the portals of the tunnels. This property has not been worked for many years. There is a possibility that had the work been done along the main fault zone instead of on cross fractures copper ore in commercial quantity might have been developed. The sulphides may be distributed along the fault in shoots of economic size or may be limited to the intersection of the cross fractures with the main fault. Which of these is true could easily be determined by surface prospecting.

Bert Group

The Bert group of claims is owned by Bert Frisina of Cranbrook and is about half a mile east of the south end of Kiakho (Fish) lake, just to the south of the edge of the map-area. A zone of intense silicification, about 50 feet wide, is exposed more or less continuously for 600 feet in outcrops and open-cuts. This zone, which strikes roughly east and dips steeply north, follows a strong fault which has thrown the Creston into contact with the Aldridge. The brecciated quartzites are intensely silicified, and contain a little vein quartz and small amounts of pyrite. Thirteen samples taken by the owner gave an average assay of 0·05 ounce of gold a ton.

A syenite dyke 10 feet wide enters the fault zone at a small angle from the southwest, but apparently does not cross it. The dyke was undoubtedly intruded after the principal movement on the fault, and after the period of mineralization.

Several other examples of this type of deposit may be mentioned briefly.

The Maus Mountain fault is occupied by a quartz vein up to 30 feet wide which carries small amounts of pyrite and galena.

A fault cuts across the ridge north of Red mountain just east of the map-area. In the crushed zone of this fault small amounts of chalcopyrite and some copper stain occur. No work has been done on this zone.

The Kimberley fault, west of Mark creek, is thoroughly silicified and is mineralized with pyrite. Small quartz veins carrying a little pyrite and galena also occur in the Kimberley fault where it crosses Lois creek.

GENESIS OF THE VEINS IN SEDIMENTS, SYENITE DYKES, AND FAULTS

There is little doubt that the veins treated in the last three sections have the same origin and may, therefore, conveniently be discussed together.

The principal gangue mineral in these veins is quartz. The commonest sulphides occurring in them are chalcopyrite, galena, and pyrite. Sphalerite and tetrahedrite occur in a few. Gold and silver are scarce in most of them, but in some they occur in important amounts.

The age of the deposits is believed, for the following reasons, to range from the Cretaceous to the early Tertiary:

(1) The veins are not related to the Purcell intrusives, which are Precambrian, since some of them occur in Palæozoic formations.

(2) The veins occur in both normal and thrust faults and are seldom severely crushed by post-mineral movements. They were, therefore, formed near the end of the period of faulting, which is believed to have been in the Cretaceous or early Tertiary.

(3) Some of the deposits occur in syenite dykes which were probably intruded in the early Tertiary.

It is a generally accepted practice to relate mineralization to nearby igneous rocks that are known to have been intruded at about the time the mineral deposits were formed or to the magmas from which these rocks were derived. In Cranbrook area the granitic rocks are believed to have been intruded during the Cretaceous and (or) early Tertiary and they or the magmas from which they were derived are, therefore, the most probable source of the mineralizing solutions.

If it is accepted that the veins being discussed, and the replacement deposits of the Sullivan type, were both formed between the Cretaceous and the early Tertiary, and from solutions emanating from the granitic magmas, it is obvious that the two types of ore-body are directly related. It must be borne in mind, however, that although the preponderance of the evidence points to the above age and origin for both types of deposit definite proof is lacking.

VEINS IN DIORITE

Quartz-calcite veins containing varying amounts of sulphides occur in most of the large Purcell sills in Cranbrook area. Many of these have had some preliminary development work done on them, but no commercial ore has as yet been proved. The veins vary from a few inches to 50 feet or more in width and usually consist of about equal amounts of quartz and calcite. Calcite is not always present, but when it is it appears to have been deposited at about the same time as the quartz. These veins generally carry chalcopyrite, pyrite, galena, and sphalerite, either singly or in some combination. The veins occupy fractures cutting across the sills, in some cases from margin to margin. Both fractures and vein usually die out abruptly on passing from the sill into the sediments. Sulphides are generally confined to small, sometimes well-mineralized, shoots in the veins close to the margins of the sills. No shoot seen by the writer was large enough to suggest commercial possibilities.

Kootenay Selkirk Group

Reference: Ann. Rept., Minister of Mines, British Columbia, 1929, p. 296.

The Kootenay Selkirk group was originally the property of the Kootenay Selkirk Mining Company, but was re-staked in 1934 by Kelly and Thompson of Fort Steele. It is at an elevation of about 7,000 feet on the north side of the basin at the head of Sixmile creek, just off the north edge of the map-area. The workings consist of two tunnels and several open-cuts which expose irregular lenses of quartz and calcite with a maximum width of about 4 feet. The deposit occupies a fracture system in the upper part of a large Purcell sill and in a dyke-like off-shoot from it. Both sill and dyke cut grey-green, dolomitic argillites of the Fort Steele formation. A considerable amount of galena and a little pyrite and chalcopyrite occur in bunches along the quartz-calcite lenses. The ore has been somewhat disturbed by minor, post-mineral thrust faults.

Eagle's Nest Claim

The Eagle's Nest claim, located in 1935, lies at an elevation of 4,100 feet on the southwest slope of Maus mountain. A short tunnel has exposed a quartz vein about 4 feet wide in a diorite sill near its contact with Aldridge argillaceous quartzites. The vein carries small amounts of chalcopyrite and pyrite and both it and the sill have been cut by a number of faults with a displacement of a few feet. An interesting feature of this vein is that the quartz is, in places, full of fine needles of tourmaline. The presence of this mineral suggests that the vein formed at high temperature.

Another type of deposit in the diorite deserves mention: the "differentiate" copper deposits. Although no deposits of this type are known in Cranbrook area two occur to the west of the area. These are the Mystery mine on Alki (John) creek, and the Evans properties on Evans mountain.[1]

These deposits consist, in part, of disseminated sulphides concentrated into lenses within certain Purcell sills and, in part, of quartz-calcite veins. According to Cairnes and Schofield the disseminated ore constitutes a true magmatic differentiate and is, therefore, of the same age as the sills—Precambrian. The quartz-calcite veins are apparently genetically related to them and are, therefore, of the same age. The disseminated deposits consist of pyrite, pyrrhotite, and chalcopyrite with minor amounts of sphalerite in a gangue of the same composition as the normal sill rock; the same sulphides occur in varying proportions in the quartz-calcite veins. Regarding the economic possibilities of these deposits, Cairnes says: "From a large pile of ore at the portal, reported to contain 250 tons of high-grade, it is stated that a 250-pound sample gave an assay return of 19½ per cent copper and $10 in gold to the ton. Judging from the appearance of the ore and the amount and reported values obtained from this one small working, the deposit is worth further exploration."

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[1] Ann. Repts., Minister of Mines, British Columbia: 1904, p. 109; 1920, pp. 118–119; 1927, p. 267.
Schofield, S. J. (1915): "Cranbrook Map-area"; Geol. Surv., Canada, Mem. 76, pp. 144–146.
Cairnes, C. E. (1932): "Mineral Occurrences in the Vicinity of Cranbrook"; Geol. Surv., Canada, Sum. Rept. pt. A II, pp. 98–99.

ORIGIN OF THE VEINS IN DIORITE

The disseminated copper deposits and the quartz-calcite veins occurring with them are believed to have been derived from the magmas from which the sills were formed and are, therefore, Precambrian in age. The quartz-calcite veins in Cranbrook area, however, do not occur with disseminated deposits. There is, however, so striking a similarity between the majority of them and the veins directly associated with the known disseminated deposits that it may be concluded with some confidence that most, if not all, of the quartz-calcite veins in the diorite sills were formed during the Precambrian, and that their source was the magma from which the sills were derived.

Other Properties in Cranbrook Area

Name	Location	Owner	References[1]	Remarks
Black Bear and Mable	On Kimberley-Cranbrook road 1½ miles from Kimberley.	G. J. Spreull, Cranbrook	1926, p. 244	Quartz vein in Aldridge carrying galena, sphalerite, and pyrite.
Black Hill	Lone Pine hill		1919, p. 117	Quartz-calcite vein in diorite.
Copper Belt	Between railway and road 6 miles north of Cranbrook.	W. S. Santo, Cranbrook.	1923, pp. 206–207	Quartz veins in Kitchener carrying chalcopyrite and pyrite.
Coronado	East of sheet in Coronado basin	Charles Reynolds and Emil Banks.	1930, p. 241	Quartz veins in Palæozoic carrying chalcopyrite and tetrahedrite.
Dougherty	Near mouth of Brewery creek	Reverted to Crown	1904, p. 108	Considerable development. Small quartz veins in Aldridge.
Eagle Plume	Foot of Maus mountain	Teddy Warren, Fort Steele.	1924, p. 187	Quartz vein in Aldridge carrying some pyrite and chalcopyrite.
Grey Copper	Lone Pine hill	Geo. Leask, Cranbrook.	1919, p. 118	Small quartz veins carrying tetrahedrite in Aldridge close to a sill. Good gold and silver assays reported.
Luke	Lone Pine hill	J. T. Laidlaw	1917, p. 118	Quartz vein in diorite carrying chalcopyrite.
Park group	Lone Pine hill	Mrs. W. A. Chisholm, Kimberley.	1915, pp. 113–114; 1920, p. 128; Cairnes, 1923, p. 100.	Quartz veins in diorite carrying galena.
St. Tresa	Boulder creek, ¾ mile from mouth.	A. Suran, Cranbrook	1934, p. 30	Irregular quartz vein in Aldridge.
Victor	Head of Maus creek	Dan McIntosh, Cranbrook.	1904, p. 108; 1917, pp. 148–149; 1920, pp. 128–129.	Small quartz veins in Creston carrying galena, sphalerite, and pyrite. Much development work.
Yankee Girl	Lone Pine hill	Senator King and associates.	1919, p. 117	Quartz vein in metamorphosed sediments carrying chalcopyrite and pyrite.

[1]Dates and page numbers refer to Ann. Repts., Minister of Mines, B.C.

General Suggestions for Prospecting

The following suggestions can be made as a result of the detailed study of the geology of Cranbrook map-area.

(1) The most favourable stratigraphic position for replacement deposits appears to be the zone of transition between the Fort Steele formation and the Aldridge formation.

(2) The most favourable formations for vein deposits are the Fort Steele, the Aldridge, and the Creston. The soft rocks of which the Kitchener and Siyeh formations are composed are apparently not sufficiently competent to shatter into structures suitable for the ingress of mineralizing solutions.

(3) Fractures in argillaceous quartzites have a better chance of containing important ore-bodies than those in argillites, for the reason that renders the Kitchener and Siyeh formations unsuitable for important mineralization.

(4) Syenite dykes may contain ore-bodies. The larger the dyke the better the chances of commercial sized ore-bodies.

(5) Major faults, in certain cases, acted as channels for mineralizing solutions. The vicinity of important faults should, therefore, be thoroughly prospected. Attention should not be confined to the actual fault zone as ore-bodies may have formed in structures in the adjoining rocks at some distance from the actual fault.

(6) The large Purcell sills may contain important disseminated copper deposits. The largest sills are in the Fort Steele and Aldridge formations and it is in these that the best deposits are likely to occur.

(7) The quartz-calcite veins in diorite have received a considerable amount of attention, and as yet no commercial ore-body has been found in them. The chance of finding ore in economic quantity does not appear to be sufficiently good to justify the expenditure of much time and money on their development.

NON-METALLIC DEPOSITS

Magnesite

The body of rock magnesite in Cranbrook formation south of Marysville was discovered during the field season of 1932. Since then this occurrence has been staked and is now owned by the Consolidated Mining and Smelting Company, Limited. During the season of 1935 other deposits in the Rocky mountains (described under the Cranbrook formation) were found. None of these appears to be as good grade as the Marysville deposit and they are farther from transportation. They are probably of no commercial value at the present time.

The Marysville magnesite deposit has been fully discussed by Cairnes[1] and the following extracts are from his report:

"The deposit forms an important constituent of a narrow belt of magnesite-bearing sediments crossing the low range of foothills between St. Mary river and Perry creek, and readily accessible, to within a few hundred

[1] Cairnes, C. E. (1932): "Mineral Occurrences in the Vicinity of Cranbrook"; Geol. Surv., Canada, Sum. Rept., pt. A II, pp. 98, 99.

yards, by road from Marysville. The most northerly observed exposures occur almost directly south of Marysville and less than a mile south of, and about 400 feet above, St. Mary river. From this point the belt has been traced in a southerly to south-southwesterly direction to within a mile of Perry creek. Its further possible extensions to the north and south are limited by strong faults extending up the valleys of these streams. As exposed, however, the belt has an average width of 150 feet or more; an average and fairly regular dip of about 60 degrees to the west; a length of over 4 miles; a vertical range of about 2,000 feet; and a contained average width or widths of crystalline magnesite conservatively estimated at 30 feet and possibly amounting to 50 feet or more."

The bed of magnesite is conformably interbedded with other members of the Cranbrook formation. In this locality it occurs in the east limb of an overturned anticline, and this limb may flatten to the east and form an open syncline.

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

"In tracing this belt from north to south exposures were not everywhere well shown and only at a few points, where cliffs, rock canyons, or other natural conditions permitted, could the belt be examined and measured in detail. Between these points, however, outcrops were observed almost continuously and were of sufficient size to indicate not only the persistence of the belt, but also a considerable regularity to its constituent members. . .

"The purer magnesite occurs towards the middle of the magnesite belt. It varies from coarse to finely crystalline, weathers rough, and is commonly thinly coated rusty brown. Fresh surfaces are pearly grey, white, and cream. In places the magnesite may be traversed by irregular, small veins and veinlets of quartz, or contain small knots of quartz, but for the most part the deposit seems relatively free from visible impurities. . . . Most of the better-grade magnesite forms a single band which, though not continuously exposed, is probably nowhere less than 15 or 20 feet thick and in one place was observed to have a thickness of at least 50 feet. Locally, the magnesite belt was observed to include one or more other bands of magnesite up to several feet thick.

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

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

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

"Magnesite has many industrial uses, among the more important of which are those in the manufacture of: refractory materials, as firebrick, furnace linings, fireproof paints, etc.; oxychloride or sorel cement, used extensively as sanitary flooring, artificial marble, tile roofing, and other structural material; carbon dioxide; metallic magnesium;; magnesium sulphate (Epsom salts); magnesium chloride; and various others.

"A mimeographed report[1] summarizes the situation with respect to production of magnesite and market conditions in Canada in 1931.

"In conclusion it might be pointed out that although the Cranbrook deposits are enormous, figures as to their average composition must be based on a more comprehensive program of sampling than has yet been attempted. Nor is it known to what extent impurities in the form of silica, silicates, lime, etc., may either limit or increase its usefulness. In this connexion it may be of some interest to reproduce the following table[2] giving the comparative analyses of productive magnesite deposits in different parts of the world.

[1] "The Canadian Mineral Industry in 1931"; Mines Branch, Dept. of Mines, Canada, March, 1932.
[2] "The Magnesite Deposits of Washington, Their Occurrence and Technology"; Washington Geol. Surv., Bull. No. 25.

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

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

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

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

d Austrian magnesite, average analysis.

e Grecian magnesite, typical analysis.

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

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

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

i Grenville district, Quebec, Shaw mine.

j Hydromagnesite, Atlin, B.C. Rept., Minister of Mines, British Columbia, 1915, pp. 82-83.

k Bridge River district, B.C."

Ornamental Stone

PURCELL DIORITE

Reference: Cairnes, C. E.: Geol. Surv., Canada, Sum. Rept. 1932, pt. A II, p. 105.

The Purcell diorite is a dark green, crystalline stone, generally free from objectional impurities, and of a rather uncommon type. Large bodies that are relatively free from joints occur in Cranbrook area close to transportation. It is capable of taking a good polish and is easily worked. Some of this stone has already been quarried and tests are being made by the Mines Branch, Ottawa. Its suitability for ornamental work has, however, not yet been established.

SYENITE

A large body of syenite occurs near the mouth of Bull river, southeast of Cranbrook map-area. This body is composed of light pink, coarsely crystalline stone, comparatively free from joints. No tests have been made on this rock, but it is nicely coloured and should take a good polish and be easily worked. It is located close to transportation.

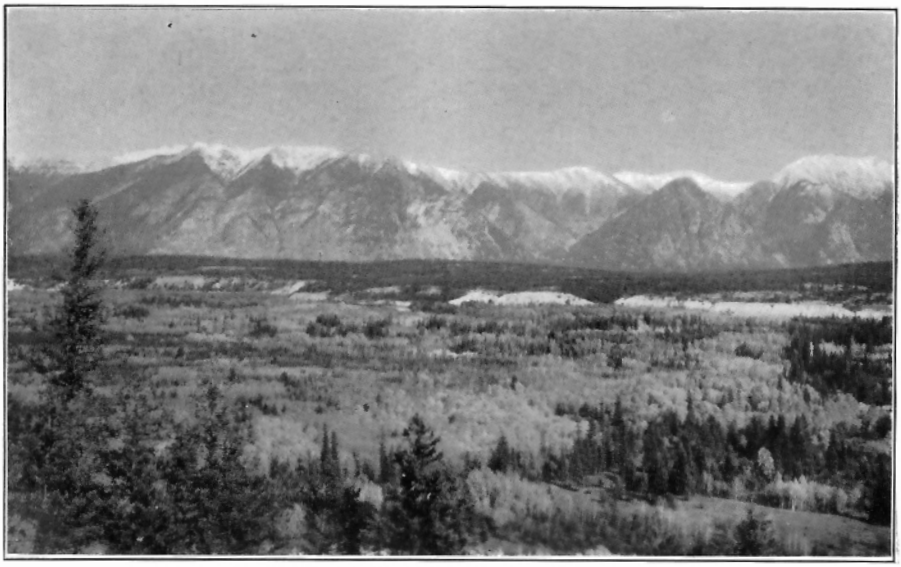
CLAY

The calcareous silts and clays of St. Mary river have been used for making brick. They have been discussed at considerable length by Ries[1] and this discussion is quoted by Schofield.[2]

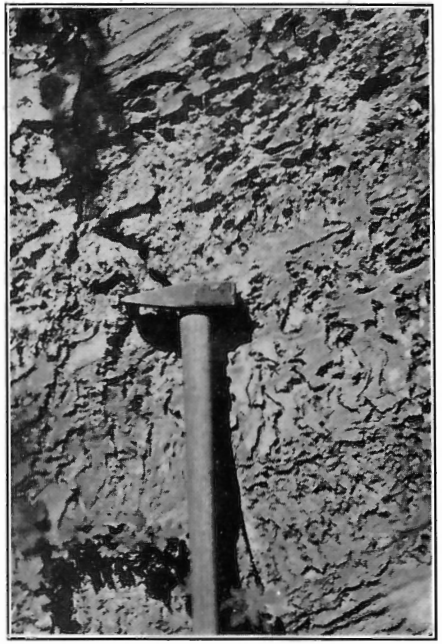
Brick formed from these materials is satisfactory for certain purposes, but the cost of transportation to important markets is too high at the present time for its manufacture to be profitable. It is not now being made.

[1] Ries, H. (1915): Geol. Surv., Canada, Mem. 65, p. 33.
[2] Schofield, S. J. (1915): "Cranbrook Map-area"; Geol. Surv., Canada, Mem. 76, pp. 152-159.

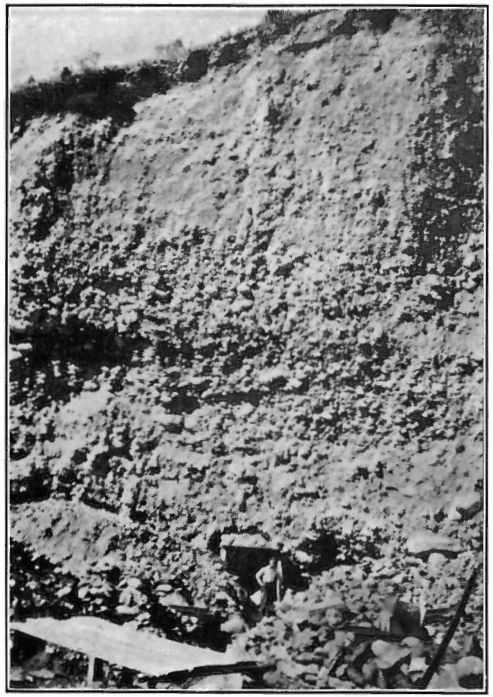
A. View looking northeast across the foothills of the Purcell range. The abrupt wall formed by the west margin of the Rocky mountains can be seen in the background.



B. View looking east across the Rocky Mountain trench. Bluffs cut by Kootenay river in glacial silts and till can be seen in the middle distance. Note the contrast between the margin of the Rocky mountains and the margin of the Purcell range shown in Plate I A.



A. Molar-tooth structure in Kitchener dolomitic argillite. This structure is very characteristic of the Kitchener formation.



B. Auriferous glacial material on Wild Horse river. Values are mainly concentrated on bedrock or in the first 4 feet of material overlying it. The tunnel in the picture has been driven on bedrock.

PLATE III

Coarse-grained phase of the Purcell diorite. Specimen taken from near the top of a large sill. Note the large, plume-shaped crystals of amphibole. About natural size.

INDEX

	Page
Acknowledgments	1
Aldridge formation	
Age	4
Character, description	6–8
Prospecting area	56
Alki (John) ck	53
Anticlinal folds	27, 29
Banks, Emil, prop	48, 49, 55
Beltian. *See* Lower Purcell	
Upper Purcell	
Bert gp	51
Big Chief gp	50
Black Bear prop	55
Black Hill prop	55
Boulder ck.	
Mining cls	55
Placer gold	39
Syenite dykes	22
Brewery ck., mining cls	55
Britannia Mining and Smelting Co., mining development by	45
Bull r., syenite dykes	22
Cairnes, C. E., work by	1
Cambrian, Lower	
See also Cranbrook formation	
Eager formation	
Correlation and history	3, 36
Cambrian, Middle	
History	37
Cambrian, Upper	
Correlation	37
Chalcopyrite	36, 48, 49, 51, 53, 55, 56
Chisholm, Mrs. W. A., prop	55
Climate	2
Consolidated Mining and Smelting Co., Ltd., acknowledgments to	1
Mining by	44, 56
Copper. *See* Chalcopyrite	
Copper Belt prop., description	55
Coronado basin	55
Coronado prop., description	55
Cranbrook, size	2
Cranbrook formation	
Age and history	3, 20, 36
Character, description	18–20
Prospecting ground	56
Creston formation, age	4
Character, description	8, 9
Prospecting ground	56
Cretaceous. *See also* Dykes	
Stocks	
Age, history	3, 37
Daly, R. A., previous work by	1
Dardenelles gp., description	49
Devono-Carboniferous, history	37
Dibble m., description	48
Dibble Mines, Ltd	48
Diorite, veins in	52, 56
Origin of veins in	54
Dixon, J. H., leases	39
Dornberg, W. B., prop	45
Dougherty prop., description	55
Drayton, W. A., acknowledgments to	1
Leases	39
Dykes, Lower Purcell series	
Age	18
Description	14
Dykes, syenite	
Age	24
Description, occurrence, metamorphism	22–24
Ore-bodies in	52, 56
Eager formation	
Character, description	3, 21
History	36
Eagle Plume prop., description	55
Eagle's Nest cl., description	53
Evans, C. S., work by	1
Evans mt	53
Evans properties, description	53
Extent of area	1
Faults	
Kimberley area	27–29
Rocky mts	29, 30
St. Mary River area	26, 27
Veins in	50, 52, 56
Fish ck. *See* Kiakho ck.	
Fisher gp., description	48
Forests	2
Fort Steele formation	
Age	4
Character, description	4–6
Prospecting areas	56
Fossils, Cranbrook formation	20
Frisina, Bert	51
Galena	45, 47
Gateway formation	
Age	4
Character, description	11, 12
History	36
Geology, economic	38–60
General	3–25
Historical	36, 37
Structural	26–32
Glaciation	33–35, 37
Gold, lode	
See Individual properties	
Placer	38–42
Granitic intrusives	4, 21–24
Granodiorite, St. Mary river	22
See also Granitic intrusives	
Age	37
Gravels	24, 25
Grey Copper prop., description	55

PAGE

Horseshoe ck., fault..... 30
Igneous rocks. *See also* Dykes
Sills
Age..... 13, 18
Granitic intrusives 21–24
Lavas..... 13
John ck. *See* Alki ck.
Jurassic..... 37
Kershaw, H., prop..... 47, 50
Kiakho (Fish) ck..... 39
Kiakho l., syenite dykes..... 22
Kimberley, mines near..... 55
Size..... 2
Kimberley fault.....27, 28, 32, 51
King, Senator 55
Kitchener formation
Age..... 4
Character, description 9, 10
Kootenay r., description..... 2
Syenite dykes 22
Kootenay King m., description.... 45, 46
Kootenay King mt., conglomerate. 7, 8
Mine on 45
Kootenay King Mining Co..... 45
Kootenay Selkirk gp..... 53
Kootenay Selkirk Mining Co..... 53
Laidlaw, J. T., prop..... 55
Lakit ck., syenite dykes..... 22
Lakit ck. and mt., section of
Fort Steele formation..... 6
Lavas, age, description, etc..... 13
Lead..... 44
See also Sullivan m.
Leask, Geo., prop..... 55
Lenia fault 27
Lignite..... 25
Lily May gp..... 47
Lily May Extension..... 50
Location of area..... 1
Lone Pine hill..... 55
Lost ck..... 38
Lower Purcell
See also Aldridge
Creston
Fort Steele
Kitchener
Purcell igneous rocks
Siyeh
Luke prop..... 55
Mable prop..... 55
McEvoy, James, previous work by. 1
McIntosh, Dan, prop..... 55
Magnesite, Marysville
Description, extent 19, 56–58
Maguire, E. H., field assistant..... 1
Mark ck., fault..... 27
Marysville, magnesite 19, 56
Syenite dykes..... 22
Marysville Mining Co..... 49
Matthew ck., fault..... 27

PAGE

Maus ck..... 55
Maus mt..... 51, 55
Meyers, Wm., prop..... 45
Mountain building, periods of..... 30, 31
Moyie fault 26, 27, 32
Moyie l., Creston formation..... 9
Kitchener formation 10
Section of Aldridge formation.... 7
Moyie r..... 38, 39
Myrene, Clarence, prop..... 48, 50
Mystery m..... 53
Nagle, E. H., prop..... 48, 50
Norman, J. H., leases..... 39
North Star hill..... 38, 44
North Star m., description..... 44–46
Ordovician..... 37
Origin of ore deposits.....52, 54, 56
Orogenic features 30, 31
Palæozoic
See Cranbrook formation
Eager formation
Granitic intrusives
Palmayra gp., description..... 48, 49
Palmer's bar, placer gold..... 38, 39
Park gp..... 55
Perry ck., placer gold..... 38, 39
Perry Creek fault..... 26, 27
Physiography of area..... 2
Pleistocene..... 25, 37
Pre-Beltian, history of area..... 36
Precambrian, late, history of area.. 36
Prospecting, hints to favourable areas 56
Proterozoic. *See* Lower Purcell
Upper Purcell
Purcell basin 36
Purcell diorite 59
Purcell lavas 36
Purcell range, description..... 2
Purcell series
See also Lower Purcell
Upper Purcell
Age, thickness, and extent..... 12
Igneous rocks 13–18
Purcell sills 56
Pyrite..... 45
Quartz-calcite veins 56
Recent..... 25, 37
Red mt..... 51
Reid, A. J., field assistant..... 1
Replacement ore-bodies in sediments 42, 46
Reynolds, Charles, prop.....48, 49. 55
Rice, D. F., field assistant..... 1
Rocky mts., elevations..... 2
Faulting in 29, 32
Section of Fort Steele formation. 6
Rocky Mountain trench, description,
age, and origin..... 31, 32
St. Eugene silts, description, origin. 25
Placer beds in..... 41
St. Mary fault..... 29, 32

PAGE

St. Mary r., description..... 2
Granodiorite..... 22
Placer beds 41
Silts..... 25
St. Tresa prop..... 55
Sands..... 24, 25
Santo, W. S., prop..... 55
Schofield, S. J., previous work by... 1
Sediments, veins in..... 47, 52
Sills, Lower Purcell series
Age..... 18
Description..... 14
Metamorphism..... 15–17
Relation to mineral deposits..... 14
Silts..... 25
Silurian..... 37
Silver. *See* Silver-lead-zinc deposits
Silver-lead-zinc deposits 38, 44
See also Sullivan m.
Siyeh formation, age..... 4
Character, description 10, 11
History..... 36
Sphalerite. *See* Zinc
Spreull, G. J., prop..... 55
Stemwinder m., description..... 44, 46
Faults in 28
Stocks, granodiorite 21, 22

PAGE

Stone, ornamental 59
Sullivan fault 28
Sullivan hill 38
Sullivan m., description.....38, 42–44, 46
Faults in 28
Suran, A., prop..... 55
Syenite dykes, veins in.....47, 52, 56
Ornamental stone from..... 59
Synclines..... 27, 29
Table of formations..... 3, 4
Terraces..... 25
Tertiary, history of area..... 37
Placer deposits 41
Triassic, history of area..... 37
Try Again prospect..... 51
Upper Purcell series. *See* Gateway formation
Veins, origin of..... 52
Vertical mt..... 49
Victor prop..... 55
Warren, Teddy, prop..... 55
Weaver ck..... 39
Wild Horse r., faults..... 29, 32
Placer golds 38, 39
Section of Aldridge formation.... 8
Wycliffe, silts 25
Yankee Girl prop..... 55