THE GEOLOGY AND ECONOMIC GEOLOGY OF THE CRANBROOK DISTRICT BRITISH COLUMBIA

by

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ABSTRACT

The following paper embodies the results of four months spent in making a geological reconnaissance in the vicinity of Cranbrook, British Columbia in 1932 under the aegis of the Canadian Geological Survey.

Definite evidence is presented to show that the Wisconsin ice-sheet in the lower parts of the area, stagnated, broke up, and melted away in situ; a phenomenon which, as far as the writer is aware, has not been reported so far from the margin of the sheet. The erosive power of the ice appears to have been strictly limited, in contrast to the tremendous erosion which it accomplished over most of British Columbia. Evidence is also presented suggesting a pre-Wisconsin period of glaciation.

A detailed description of the stratigraphy and structure is given with particular emphasis on the pre-Cambrian (Beltian) succession.

A series of pre-Cambrian sills and dykes are described in detail. Border phases rich in ferro-magnesian minerals and quartz are present and their origin by differentiation of the magma and assimilation of silica from the intruded quartzites is suggested and critically discussed. The sills are found to contain a species of hornblende differing considerably from any that has been described in the literature, and its chemical and optical properties are given in detail.

Mineralization is believed to have taken place at two periods; one in the pre-Cambrian and one in the late Mesozoic or early Tertiary. The evidence for this opinion is presented in detail and examples described. Some of the ore-bodies of pre-Cambrian age are believed to be magmatic segregations and the evidence in support of this belief is stated and discussed.

The geological history and the physiography is outlined and three theories as to the origin of the Rocky Mountain Trench briefly considered.

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INTRODUCTION

The Cranbrook area lies in the southeast corner of the province of British Columbia (see Key Map plate 1A, p. 2A). It comprises a section of the country lying immediately to the west of the Rocky Mountains and includes a part of the Rocky Mountain Trench and the eastern slopes of the Purcell Range. This report deals with an area of about 600 square miles lying between 49° 15' and 49° 45' north latitude and longitude 115° 40' and 116° 15' west.

Field Work:

During the field season of 1932 the Geological Survey of Canada maintained a party in the Cranbrook area under the direction of Dr. C.E. Cairnes. The writer was fortunate in securing a position on this party as student assistant and the following report is based on data and specimens obtained at that time. The general and stratigraphic geology was worked out as carefully as time would permit and particular attention was paid to the economic geology. The original plan for the study of the area included the resumption of the work in 1933 for the purpose of obtaining more data at critical points and increasing the area covered. The fulfillment of this plan was prevented by unforseen circumstances. A large scale topographic map was used as a base, but, unfortunately, it is not available to the writer for this report. The map used here is based on one published on a scale of one inch to the mile by the Minister of Lands. (c.f. map in pocket)

Acknowledgements:

The kindness of the Director of the Geological Survey of Canada in permitting the use of data obtained while in his service, as well as that of Dr. Cairnes in his active cooperation and help has put the writer under a debt that is gratefully acknowledged. The writer also wishes to express his thanks to Dr. F.L. Ransome, under whose general supervision this paper was prepared, and to Drs. Ian and Catherine Campbell for help in the details of its presentation. Appreciation is also expressed for the assistance of other members of the staff of the California Institute of Technology.

Topography:

The Purcell mountains, which rise to heights of 8,500 feet, occupy the western half of the Cranbrook area. To the east they dip under the alluvium of the Rocky Mountain Trench, a relatively flat prairie, which occupies the eastern half of the area. The Kootenay River flows southward along the Trench and it and its tributaries form the main drainage.

The mountains of the Purcell Range are separated by deeply incised valleys, and are rather irregular in form according to the nature of the rocks from which they have been cut; the softer calcareous sediments of the Kitchener formation producing smooth, round-topped hills (Plate I B, p 2A and Plate III A, p 94), in contrast to the rugged peaks and bold cliffs of those cut in the Aldridge quartzites

Plate I

Key map of a part of British Columbia showing the location of Cranbrook and the area discussed in this report.

View looking south from Sullivan Hill along the east margin of the Purcell range illustrating its irregular nature in contrast to the west face of the Rocky Mountains as illustrated in plate II.

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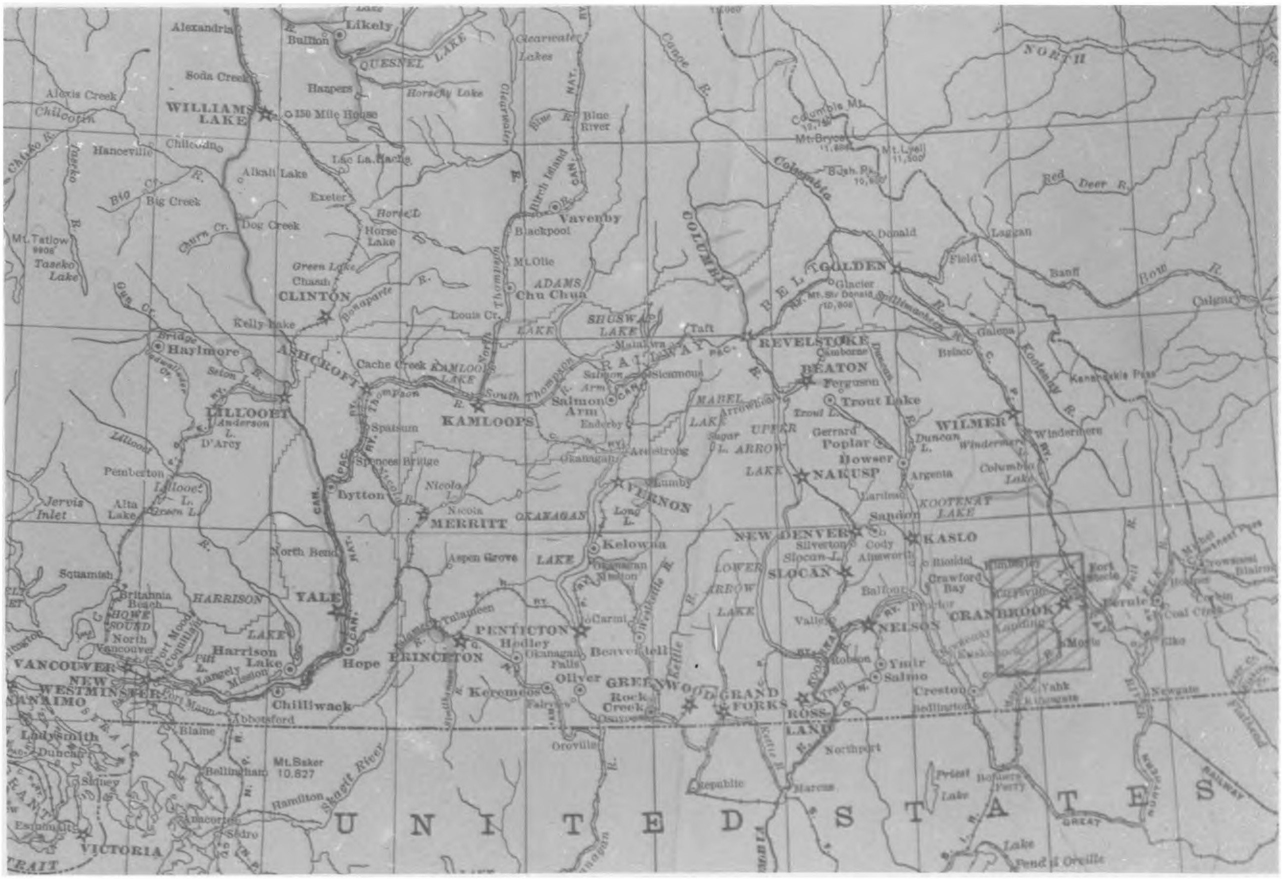


Alexandria
Likely
Bullion
QUESNEL LAKE
Soda Creek
Hazgers
Horsefly Lake
Alexis Creek
Chilcotin
WILLIAMS LAKE
150 Mile House
Blue River
Hanceville
Alkali Lake
Exeter
Big Creek
Dog Creek
Vavenby
Blackpool
Mt.Tatlow
Taseko Lake
Horse Lake
Mt.Olie
Green Lake
Chasm
CLINTON
ADAMS
Chu Chua
Louis Cr.
SHUSWAP LAKE
Kelly Lake
Taft
Haylmore
ASHCROFT
Cache Creek
KAMLOOPS LAKE
South Thompson
Salmon Arm
Sicamous
LILLOOET
Anderson L.
D'Arcy
Spatsum
Spences Bridge
Enderby
Armstrong
Okanagan
Lumby
VERNON
Pemberton
Lytton
Nicola
MERRITT
OKANAGAN
Jervis Inlet
Alta Lake
Green L.
North Bend
Kelowna
Aspen Grove
LAKE
Squamish
Britannia Beach
HOWE SOUND
North Vancouver
HARRISON
YALE
LAKE
Harrison Lake
Hope
PRINCETON
PENTICTON
Hedley
Okanagan Falls
Beaverdell
Carmi
VANCOUVER
NEW WESTMINSTER
NANAIMO
Mission
Chilliwack
Abbotsford
Keremeos
Oliver
GREENWOOD
GRAND FORKS
Rock Creek
Ladysmith
Duncan
Blaine
Oroville
Mt.Baker 10.827
Bellingham
Sidney
Hamilton
Skagit River
VICTORIA
Anacortes
UNITED STATES
Canoe R.
Columbia
COLUMBIA
Mt.Bryce
Bush Pk.
Donald
GOLDEN
Glacier
REVELSTOKE
Field
Laggan
Red Deer R.
Banff
Bow R.
Calgary
Beaton
Ferguson
Trout Lake
Galena
Brisco
Kananaskis Pass
ARROW
UPPER
Gerrard
Poplar
Duncan
Dowser
WILMER
Windermere
NAKUSP
Argenta
Columbia Lake
Sandon
KOOTENAY LAKE
KASLO
NEW DENVER
Silverton
Cody
Slocan L.
Ainsworth
SLOCAN
Crawford Bay
LOWER ARROW LAKE
Riondel
Balfour
NELSON
CRANBROOK
Fort Steele
Fernie
Coal Creek
Robson
Ymir
Salmo
Creston
ROSSLAND
Northport
Newgate
Marcus
Republic
Priest Lake
Bonners Ferry
Pend d'Oreille
Lake
GREAT
RAILWAY

and the accompanying Purcell sills. Glaciation has modified the previous landscape everywhere. The average height of the mountain-tops gradually diminishes to the east until the rock surface dips under the alluvium of the Trench. The effect produced is that of a sea lapping against a very irregular coast with many deep bays and jutting promontories.

The Rocky Mountain Trench (Plate II, p 4A and Plate III B p, 9A) may be described as a flat-bottomed valley from two to over ten miles in width extending in a line of low sinuosity and remarkable continuity from Montana to Alaska, a distance of well over a thousand miles. In the Cranbrook area the floor of the Trench is built up of fine, unconsolidated, detritus overlain, almost universally, by deposits left by the retreat of the ice. In the resulting surface are many depressions formed by melting out of large bodies of stagnant ice so that, what appears at first glance to be a relatively featureless plain, is broken by long and unexpected depressions of a hundred feet or more in depth.

Drainage:

The Kootenay river, where it traverses the area, is several hundred feet in width and has a curious braided appearance; a fact which is very noticeable on the map accompanying this report. Its high sinuousity suggests the meandering of an old stream, but it is evident that it is still labouring to distribute the abundant material left in its course at the time of the retreat of the ice. In this respect it reminds one strongly of glacial streams seen in northern British Columbia and Alaska, and suggests that the river is, or has been very recently, greatly overloaded. A large part of its present course was occupied by a Pleistocene Lake through the sediments of which it has cut to a depth of several hundred feet, leaving bold cliffs.

The St. Mary's River is the main tributary of the Kootenay in the northern part of the area. During the last ten miles of its course it averages about a hundred feet in width, and has cut bluffs, in places several hundred feet high, through the sediments of the St. Mary's Sills and morainic material. For six or seven miles east of St. Mary's Lake the river occupies a wide rounded valley. (Plate VII A, p 43 A) The St. Mary's, like the Kootenay River, has a very winding course and a strong tendency to become braided. (c. f. Map)

The St. Mary's River has a number of important tributaries most of which occupy broad, V-shaped valleys with relatively straight courses and few interlocking spurs. Hellroaring Creek is an exception, however, since its valley is U-shaped throughout.

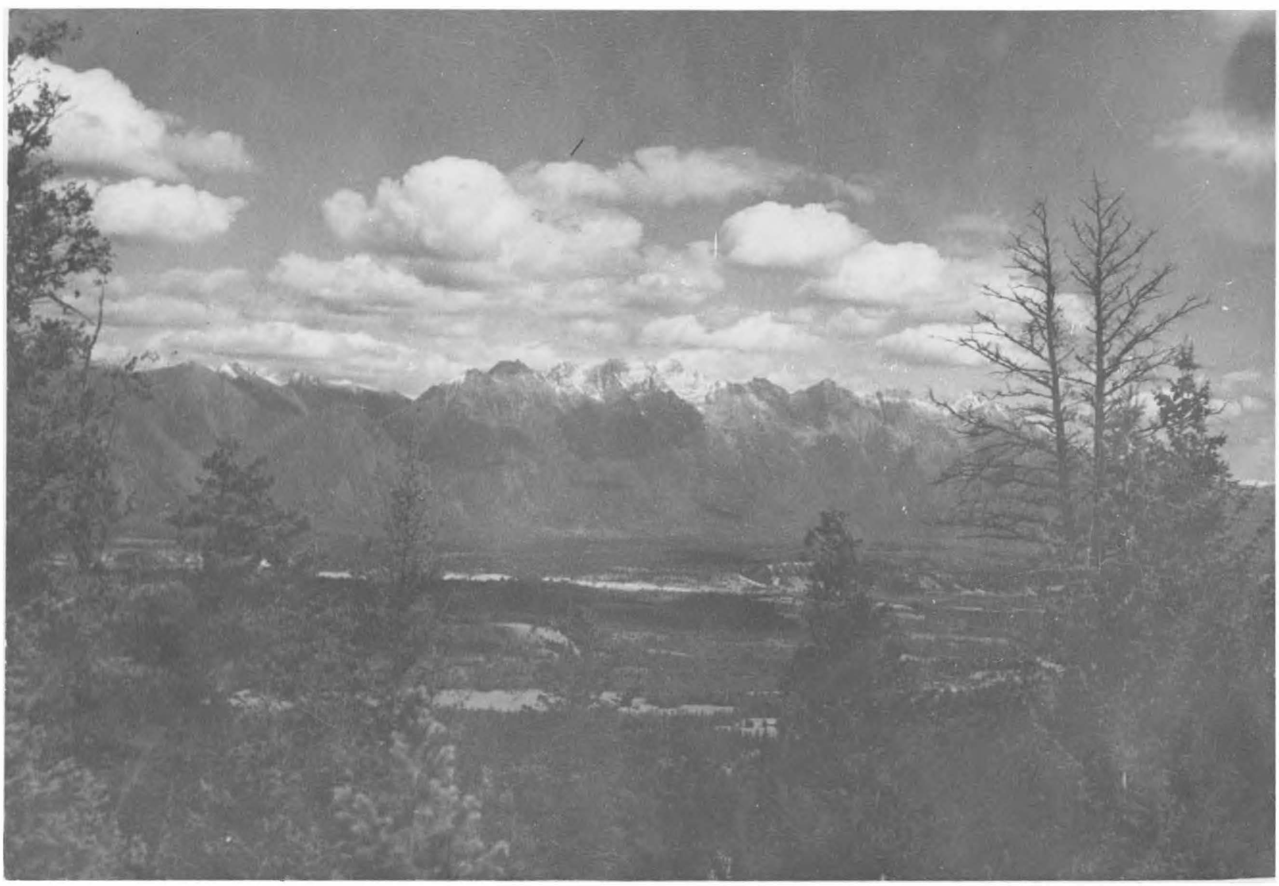
The southern part of the district is drained by the Moyie River, also a tributary of the Kootenay but joining it south of the International Boundary.

Several small streams, the most important of which is Cherry Creek, follow irregular courses across the Trench to join the Kootenay to the east of Cranbrook.

Plate II

A. View looking east across Wycliff. Note the rolling nature of the St. Mary's Prairie and the farm land. The St. Mary's River is in the right of the picture. Note the abrupt wall of the Rocky Mountains in the background and contrast it with the west face of the Purcell Range in Plate I B, or III A.[p9A] This is believed to be an eroded fault scarp.

B. View east from Signal Hill across the Trench to the Rocky Mountains in the background. The cliffs cut by the Kootenay River in the St. Mary's Silts in the middle distance. Note the kame near the front center, facing south.



Climate and Vegetation:

The Cranbrook area lies in the Dry Belt of British Columbia and the precipitation is consequently low, averaging about 15 inches per year. The temperature ranges from over 100° in the summer to 25° below zero in the winter. The summers are generally rainless and most of the agriculture depends on irrigation.

The slopes of the Purcell range are generally heavily wooded with conifers of various kinds, while red pines and tamarisk are fairly plentiful over the surface of the Trench. The underbrush is seldom very thick.

History, Industries etc.

In the early '60s placer gold was discovered in various streams in the Cranbrook district. When the richer deposits became exhausted prospecting was stimulated and several valuable lode mines were found and developed. A small amount of aggricultural activity followed the establishment of steady production from the mines but the necessity for irrigation and the scarcity of a suitable supply of water has prevented farming from becoming an important industry.

Cranbrook, a city with a population of about 4,000, is the main center of trade in the area, and it and a few small settlements such as Marysville and Wycliff serve the farming population. (Plate IIA, p 4) Kimberly is nearly as large as Cranbrook and owes its existance almost entirely to the Sullivan mine. Moyie was a flourishing little town during the period of active production of the St. Eugene mine, but has since dwindled in importance to a small hamlet.

Previous Geological Work:

In 1900 McEvoy (21) made a reconnaissance survey of the Cranbrook area during which he made a topographic and geologic map. In 1904 Daly made a study of the Purcell range along the International Boundary (13) and in his report named and described the Purcell series. The first detailed work in the Cranbrook area was done by Schofield during the field seasons of 1909, 1910, 1911, 1912, and a part of 1913. (14) Schofield modified Daly's description of the Purcell series after studying it in the type locality, and traced it north into the Cranbrook area. In 1922 he returned to the area and added to his previous conclusions. (15) Work in the area was resumed by the Geological Survey of Canada in 1931 under the leadership of Dr. C. Evans. Ill health unfortunately forced him to abandon the undertaking early in the season and the task was assumed by Dr. Cairnes in 1932.

Accessibility:

The Kettle Valley branch of the Canadian Pacific railway enters the area from the south and runs north along the east side of the Moyie lakes and on to Cranbrook. To the north of Cranbrook it swings east out of the district. A branch line runs from Cranbrook to Kimberly.

The whole of the Trench and most of the east face of the Purcell range is readily accessible by road and trail, but further west the topography is very rugged and trails increasingly scarce.

GLACIATION

The entire Cranbrook area is believed to have been covered by a continental ice-sheet which was a part of the Cordilleran Ice-sheet.

Evidence of glaciation is abundant in nearly all parts of British Columbia, and geologists soon realized that the province has been extensively glaciated. In 1890 Dawson (55, pp 153-154) described the nature and extent of the ice-sheet that had done this and proposed the name "Cordilleran Glacier" for it. He says that "he has been led to believe that this part of the Cordillera of the West was, in the Glacial period, covered by a great confluent glacier-mass," and, after having described some of the places where its limits were observed, he goes on to say, "Having thus surrounded the area of this great glacier, it was proposed to name it the Cordilleran Glacier in order to distinguish it from the second and larger ice-cap by which the northeastern part of the continent was at the same period more or less completely covered. The Cordilleran Glacier, as thus defined, had, when at its maximum development, a length of nearly 1,200 miles." Coleman (56, pp 12-13) summarizes the present knowledge of the Cordilleran Ice-sheet and says that at its maximum development "the valleys were filled to the brim and the interior tableland of British Columbia was covered. Thus a great mass of ice accumulated over the whole of British Columbia and the southern part of Yukon Territory, hemmed in on the northeast side by the main range of the Rockies and to a less extent on the southwest by the Coast Range.

"In the central parts the ice reached an elevation of about 8,000 feet but, owing to the arrangement of the mountain ranges, could escape freely only toward the northwest, where it feathered out in the southern part of Yukon Territory, and toward the southeast, where the great mountain trough passed into the United States" --- "The area covered with ice was about 1,200 miles long, running parallel to the Pacific coast, and from 250 to 400 miles broad, and included not less than 350,000 square miles." The Cranbrook district is located in the southern part of this area.

Matthes (54, p.54) gives the following lines of evidence for the recognition of glacial action in mountainous regions, for an elaboration of which the reader is referred to his paper:- 1. grooved and polished rock surfaces; 2. characteristic topographic forms; and 3. deposits of ice-borne rock debris. Examples of these criteria found in the Cranbrook area will now be presented.

1. Grooved and polished surfaces.

Old Baldy mountain, situated on the divide between Perry Creek and the Moyie River, is 7,725 feet above sea level and comparatively isolated. It is composed of hard quartzites and has a beautifully rounded, smooth crown with abundant ice-made striae and grooves. The movement of the ice is shown by them to be in a general southeast direction, and cannot be directly related to the present topography. Furthermore all the high peaks examined show the same phenomenon

Plate III

A. View looking northwest. The Purcell Range in the background. North Star Hill in the center of the picture.

B. View from Sullivan Hill east across the Trench: The Rockies in the background. Note the depression formed by the melting out of a body of stagnant ice in the ldft middle distance and the S-shaped esker near the center of the picture.

to a greater or lesser extent. Many of the valleys also show striae and grooves on their flanks paralleling their courses.

On the Prairie land of the Trench almost every little knob of rock protruding from the alluvial cover resembles a roche moutonné, and shows beautiful grooving, striation, and even polish in some instances. All these indicate a general movement of the ice to the southeast; that is, they suggest a movement along the floor of the Trench paralleling that on the high mountains.

2. Characteristic topographic forms.

The topographic forms most typical of glaciation are, according to Matthes, U-shaped, troughlike valleys, having spurless parallel walls, hanging side valleys , truncated spurs, and cirques. Although valleys showing these phenomena are not the common types in the Cranbrook district, several of them, Hellroaring Creek and the upper St. Mary's River, for example, furnish perfect illustrations of these features. (Plate VIIA p43A)

3. Deposits of ice-borne rock debris.

Matthes considers this to be the most reliable record of glacial activity and, since piled-up moraines occur all over the surface of the Trench (Plate III B, p 9A) and along the beds of most of the streams draining the Purcell Range, and terraces of glacial debris occur flanking many of the valleys, it is quite certain that there must have been glaciation in all parts of the Cranbrook area.

The evidence presented above, however, indicates two distinct stages of glaciation: (A) by a continental ice-sheet followed by (B) alpine glaciation. A brief summary of the evidence will be given to indicate the existance of these two types. (c.f. 57)

(A) Continental Glaciation.

1. The mountain tops all show grooving, striae, etc. and have evidently been strongly glaciated. C.f. Old Baldy.

2. The whole surface of the Trench shows abundant evidence of glaciation.

3. There is a correspondence in the direction of movement of the ice in both places as indicated by striae etc, which can only mean that a single ice-sheet covered both regions.

4. Local topography does not appear to have played any part in controlling the direction of movement of the ice across the mountain tops or across the Trench. In other words all local irregularities in the land surface were filled in by stagnant ice.

Thus it is apparent that the entire Cranbrook area, to an elevation of not less than 7,800 feet, was covered by a mass of ice moving in a south to southeast direction.

(B) Alpine Glaciation.

1. Cirques. Typical cirques are preserved in the hills round the headwaters of Matthew creek and, in fact, all through the higher Purcells.

2. Straight, U-shaped valleys. Certain of the

valleys, notably Hellroaring Creek and the upper St. Mary's Valley, illustrate this item and the two succeeding ones beautifully, although in the majority of valleys they do not appear. (Plate XVII A, p 43A)

3. Hanging valleys.

4. Truncated spurs.

5. Direction of movement of the ice controlled by the local topography. Grooving and striae are common on the sides of the valleys paralleling the streams occupying them, showing that the movement of the ice has been directed by the shape of the valley.

It seems only logical to suppose that an alpine stage of glaciation must result from the waning of a Continental ice-sheet if the relief be sufficiently great. During the period of continental glaciation the ice-sheet must move as a whole, mostly, as Coleman points out, (56, p 12) by flow of the upper layers, but, as soon as enough of the land surface projects through the shrinking sheet to interrupt this movement and direct it down the valleys, alpine glaciation must commence if the relief of the ice surface be sufficient to permit flow. This has evidently happened in the Cranbrook area. The change in the direction of the movement of the ice may, at times, have resulted in its complete reversal.

<u>Glacial History of the Cranbrook Area:</u>

It has long been realized that the Pleistocene Ice Age was not a simple unit comprising a single advance and retreat of the ice, but a highly complex period, including a number of major periods of glaciation separated by interglacial periods when the temperature was as warm or warmer than at present and the site of the former glaciars freed from ice. (56, p 27) It is natural that the most satisfactory attempts to work out the succession of glacial and interglacial stages in North America were along the southern edge of the continental ice sheet where the deposits left by each advance were not entirely destroyed by the succeeding ones. The standard section for the Pleistocene for the United States has consequently been worked out along the line of maximum advance of the ice in Iowa, Wisconsin and Illinois. Five distinct stages have been recognized and called 1. the Wisconsin, 2. the Iowan, 3. the Illinoisan, 4. the Kansan, and 5. the Nebraskan, (Table I Column I, p 13a) the last being the oldest. (58 and 59) In 1931 Blackwelder (53) observed four stages of glaciation in the Sierra Nevadas and correlated them with the eastern divisions. (Table I Column 2) In 1930 Matthes (54) recognized at least two stages of glaciation in Yosemite Valley which Blackwelder correlated with his divisions (Table I Column 3). Prior to this a considerable amount of work had been done on the glacial deposits in northern Washington and the southwest of British Columbia. Willis (60) working alone in 1898 and with Smith (61) in 1899, recognized two stages of glaciation in Puget Sound which he called the Vashon and the Admiralty, the latter being the oldest, which were separated by the Puyallup interglacial period. (Table I Column 4) He did not believe that the interglacial period was very warm and, indeed, he says "so far as is now known, the latter (Puyallup) epoch is not represented by deposits formed under climatic conditions indicative of an entire absence of glaciers from the region." (60, p 146) Willis describes the Admiralty till, underlying the Puyallup sediments, as being deeply weathered, but Bretz says (62, p 14) that the "Admiralty till is nowhere deeply weathered although sometimes it is stained by percolating waters." Bretz (63) also found that the Vashon ice-sheet was more extensive than the Admiralty since it covers areas that had never been glaciated. On the south end of Vancouver Island Clapp, in 1917, (64) also recognized two stages of glaciation which he was able to correlate with those of Willis. He also believed that the Puyallup interglacial period was fairly short and that the ice never completely retreated during it. Sediments of the Puyallup, he believed, were chiefly derived from the Admiralty till, and large boulders, dropped by floating ice, occur in all its marine sections. These conclusions confirmed those he had reached while working in the neighborhood of Saanich in 1913. (65, pp 107-120) Just to the north of this area, on Texada Island, McConnell (66, pp 39-43) also found two stages of glaciation separated by about 200 feet of interglacial sands and silts. He made no attempt to correlate them with Willis' divisions, but it is quite evident that they are the same. The correlation of the Vashon with the Wisconsin of the standard section is obvious since they both represent the last

Table I

Correlation of Pleistocene Glacial Epochs

Column I	Column 2	Column 3	Column 4	Column 5	Column 6	Column
Iowa~~n~~ and Illinois	East Sierra Nevadas	Yosemite	Puget Sound etc.	Spokane	Alberta and Montana	Cranbrook
Wisconsin	Tioga		Vashon	Wisconsin	Wisconsin	Wisconsin
Peorian Interglacial		Wisconsin	Puyallup Interglacial Admiralty(?)			
Iowan	Tahoe			Spokane(?)	(?)	(?)
Sangamon Interglacial						
Illinoisian	(?)					
Yarmouth Interglacial						
Kansan	Sherwin	El Portal Glacier Point.				
Afton Interglacial				-(?)	Albertan	Albertan (?)
Nebraskan	McGee					

advance of the ice and a climatic condition that was common to both parts of the continent. It had already been suggested by Dawson in 1890. (67, p 54) The correlation of the Admiralty is not so easy to determine. The general consensus of opinion appears to be that the Puyallup was a comparatively short period and it is therefore suggested that the Admiralty be correlated with the Iowan. Two glacial stages, probably corresponding to the Vashon and the Admiralty, were recognized by Bretz near Spokane, Washington, in 1913. (68) The youngest he believed to be Wisconsin, but the older he named the Spokane, making no suggestion as to its correlation. (Table 1, Column 5) He found some evidence, also, of a third, still older, stage. In 1896 Dawson (69) recognized a till to the east of the Rocky Mountains close to the International Boundary which he called the Albertan. In 1913 Alden and Stebinger (70, p 571) decided that this till represented the earliest advance of the Cordilleran Ice-sheet, and should be correlated with the Kansan or Nebraskan stages. They also believed that there may have been a second pre-Wisconsin advance of the Cordilleran ice. (Table 1, Column 6)

The above review was given in order to arrive at an idea of the probable glacial history of the Cranbrook area by comparison with the adjoining areas. The history thus inferred is as follows. The earliest glaciation likely to have occured in the area corresponds to the Albertan epoch. As this probably took place, according to Blackwelder (53), between 1,350,000 and 6,350, 000 years ago, it is unlikely that any but the vaguest evidence is preserved. The Albertan glaciation was followed by a warm interglacial period which was at least a million years long. This period may have been interrupted by at least one advance of the ice, corresponding to the Illinoisian epoch, but this is not known definitely to have occurred in the Cordilleran Ice-sheet. There is little doubt that, at the time of the Admiralty epoch probably about 100, 000 years ago, ice occupied the entire area. The Puyallup interglacial period, following the Admiralty epoch, is known to have been a short one even at Puget Sound near the edge of the ice-sheet, and the change in climate was not at all profound; consequently it is more than likely that, in the Cranbrook area nearer the center of the Cordilleran glacier, the ice may merely have become slightly thinner and never have been removed. The Admiralty epoch may, therefore, have passed into the Wisconsin without a recognizable break, and the term Wisconsin is used below to include both epochs. The retreat of the Wisconsin ice-sheet ushered in Recent times and, since it commenced only about 25,000 years ago, evidence of the Wisconsin ice should be well preserved.

In the following paragraphs an effort will be made to indicate the evidence for the various stages in the glacial history of the Cranbrook area outlined above from the theoretical considerations. There is no indisputable evidence of an early stage of glaciation in the Cranbrook area, but there are three groups of facts that suggest that one may have existed. They are (1) Topographic evidence; (2) The nature of the section including the St. Mary's Silts; and (3) The Placer Deposits.

1. Topographic Evidence.

Perry Creek Valley is an example of the commonest type of valley to be seen in the Cranbrook area. The following features are apparent in it.

a. Relatively straight course.

b. No interlocking spurs.

c. Parallel, smooth sides.

d. V-shaped cross section

e. Placer deposits along its bottom that are believed to be pre-Wisconsin in age.

Of these a, b, and c, are evidence of the influence of ice action, while d and e suggest normal stream action. In addition to these features the slope of the valley walls becomes much flatter above an elevation of about 1,000 feet from the valley floor and the sides are more deeply dissected.

Figure I (Bottom of page 16)

Sketch showing the change of slope in the side of the Perry Creek Valley. Note the curving streams and rounded interstream divides of the upper part contrasted with the steep, straight streams and the flat interstream areas of the lower.

As a result the tributary streams change grade when flowing from one slope to the other although their valleys can scarcely be considered to be hanging. One explanation of this phenomenon is that the main valley was occupied by a glacier 1,000 feet thick which remained there for a sufficient time to permit the valley slopes to weather back by normal side-wall erosion above this level. If this took place in Wisconsin time, features d and e could not be expected. Another hypotheses, and one which the writer favours, and which also accounts for the other features enumerated above, is the following:-

a. A stage of pre-Wisconsin glaciation resulting in the production of a normal U-shaped glacial valley. (fig. 2 p 18)

b. A long interglacial period during which the bottom of the valley was cut down by stream erosion producing the steep-sided lower portion and the upper part of the valley weathered back to form the flatter upland slopes.

c. The advance of the Wisconsin ice which smoothed down the irregularities.

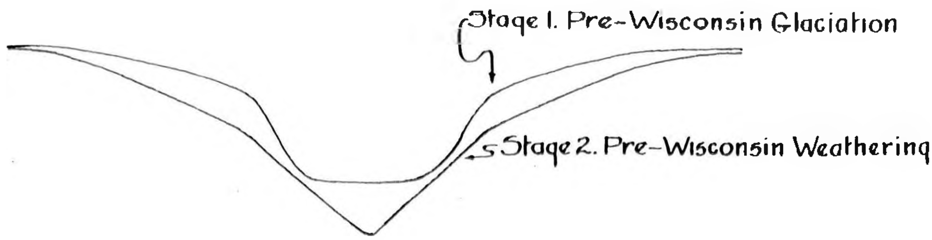


Figure 2

Diagram showing a possible explanation of the change in slope in the sides of Perry Creek Valley. Stage 1 shows a hypothetical cross-section of the valley at the close of a period of pre-Wisconsin glaciation when the valley had been heavily scoured by the ice and had assumed the shape illustrated.

Stage 2 illustrates the result of normal weathering on a valley of the shape left by stage 1. The bed has been cut down by stream erosion and the walls modified to form a wide V. Above the limit of the previous glacial erosion the original slope has also been somewhat modified but a distinct difference in slope still remains. Glaciation of the Wisconsin stage hardly modified this valley at all so that its shape at the close of the Interglacial Period has been preserved almost unchanged.

2. The Nature of the Section including St. Mary's Silts.

This section will be discussed in detail when dealing with the superficial deposits, (p) and will, therefore, only be mentioned here. A succession of glacial deposits overlie a thick series of silts and gravels which, in turn, lie on an apparently unglaciated rock surface. The glacial deposits are undoubtedly composed of material deposited by the Wisconsin ice. The St. Mary's Silts are believed, on fossil evidence, to be Pleistocene in age and to have been deposited under conditions of tropical climate. The probability is that they are interglacial in age, as will be shown later, and, if that be so, there must have been a stage of glaciation earlier than the time of their deposition.

3. Placer Deposits.

Full discussion of this subject will be deferred to the section on Economic geology and it is sufficient to say that in the Cranbrook as in the Cariboo District (71, p 215) many of the deposits are pre-Wisconsin in age and are probably interglacial.

There is, thus, a suggestion that there was a stage of glaciation followed by an interglacial period during which the St Mary's Silts were formed, some of the placer deposits laid down, and the valleys assumed practically their present form. The amount of the erosion of the valleys from a true glacial type, the thickness of the St. Mary's Silts, the profound change in the climate, and the time required to accumulate the placers suggest that this period must have been a very long one. The early glaciation, therefore, if present, probably correlated with the Albertan stage. (Table 1, Column 7)

It is quite clear that the stage of ice action whose evidence is so abundant in the area must belong to the Wisconsin epoch since it represents the last advance of the Cordilleran ice, its deposits show very little dissection by streams, and little general weathering, and they may be traced continuously to deposits being left by glaciers still present in the Rockies and elsewhere. If the Admiralty epoch be present it must be represented by the lower members of these glacial deposits since no evidence of glaciation can be recognized below these except the vague suggestion of the stage that probably correlates with the Albertan. If this is so, evidence of the Puyallup interglacial period is missing and it was probably not sufficiently accentuated in the area to leave recognizable signs.

Limits of Glacial Erosion:

Although the entire Cranbrook area was covered by ice, there are many places that have either escaped glacial erosion entirely or where it has had little effect.

Although the valley of Hellroaring Creek is a beautiful example of a glacially-scoured valley most of the valleys in the area are quite different. Perry Creek has already been described as a good example of the commoner type. Proof that the latter valley has been glaciated recently rests in the fact that striae are found at many points on the sides and that there is a considerable quantity of boulder-clay along the bottom. No widening of the base of the valley has, however, been accomplished, and pre-Wisconsin gold bearing gravels are preserved, overlain by moraines. It is evident, therefore, that the ice in the valley has done little more than polish off some of the more prominent features and has certainly not been an active eroding agent.

Another excellent example of this is furnished by the valley of Fish Lake (Figure 3). It is a deep, narrow

Figure 3

Sketch map showing the head of Fish Lake Valley.

valley whose walls slope at nearly 40° to form a V-shaped gorge, often only 20 yards across at the bottom. It shows no evidence of having been glaciated, but rather resembles a young, stream-cut valley. It heads in a depression whose floor is covered by moraines. Two other valleys lead out from this depression and one into it, all of which show evidence of severe glacial erosion. It is impossible for Fish Lake Valley to have been cut by stream action in post-glacial times since it is obvious that any streams flowing into its upper end must have dissected the moraines at its head and these have not been disturbed. The only explanation which seems to satisfy the conditions is that Fish Lake Valley owes its present shape chiefly to pre-glacial erosion and that it has since been filled with a large body of relatively stagnant ice that melted out with little or no movement at the close of the Wisconsin stage.

The St. Mary's Silts, to be discussed later, are known to be earlier than the last epoch of glaciation and are overlain unconformably by glacial material. They were evidently over-run by a large body of ice which disturbed them hardly at all. Those knobs of rock that showed through the alluvial cover or were close to the surface when the ice advanced, were ground off and polished, but the ice was incapable of carrying off more than a small amount of the main mass of the unconsolidated material.

An interesting and puzzling feature is the occurrence of placer gold in such streams as the Moyie, Palmer's Bar, and the Perry. These streams have all been glaciated and yet they contain a considerable amount of placer gold. Later discussion will show that it is unlikely that much of this could all have been accumulated in post-glacial times. Although gravels frequently show some disturbance by the ice and workable deposits occasionally occur in the morainic material itself, many of them are overlain by glacial detritus and it is obvious that, had the ice acted as a powerful eroding agent, they would have been swept out of the channels in which they are still found.

Most of the outcrops of ore show primary minerals up to the grass roots; as is to be expected in any glaciated country. There are, however, two notable exceptions; the North Star mine and the Society Girl mine. The outcrops of the Society Girl, and its workings to a depth of from thirty to forty feet, show a remarkable assortment of secondary minerals and hardly any primary ore. About a mile away the outcrops of the St. Eugene mine, which is undoubtedly a related deposit, show primary minerals right up to the surface. The secondary ore of the Society Girl must be a remnant of pre-glacial weathering that has escaped erosion. The conditions at the North Star mine are reported to be the same, but the writer has not had an opportunity to examine them himself.

From this discussion it is obvious that, in many parts of the Cranbrook area and particularly in the east slopes of the Purcell Range between the St. Mary's River and Moyie Lake, the ice of the Wisconsin stage was by no means an active agent of erosion. This conclusion is in agreement with that of Johnston and Uglow, formed from a study of the Cariboo District. They say, "the narrow, V-shaped valleys were eroded only slightly by the ice." and again, "What seems to have happened, however, in Barkerville area, is that during the great part of the period the area, except possibly on the uplands, was actually protected from erosion by the ice-sheet which was nearly stagnant." (71, pp 27 and 30) Coleman also says: "The Cordilleran ice-sheet did its chief work around its margins. In the interior valleys and the central tableland of British Columbia often very little evidence of ice action is found, and one must climb the mountains to find boulder clay, erratics and striated surfaces. The currents of ice were to a large degree superficial, the lower level remaining almost quiescent." (56, p. 13)

The erosive power of ice depends, among other things, on its ability to transport, which varies in inverse proportion to the amount of material available and directly with the velocity of flow. Now the relief of the Rocky Mountains on the east and the Purcell Mountains on the west was undoubtedly great, and feeders to the main ice-sheet from each of them must have brought down huge quantities of material. The load must therefore have been heavy. Again the grade down Trench is comparatively slight and the general trend of the land surface much the same. The velocity of flow, it must be remembered, depends on the grade of the surface of the ice and not on the slope of its bottom contact (79), but there is no evidence of any particular accumulation of ice to the north that would make a noticeable disparity between the lower and the upper surfaces. In other words there is every reason to believe that the flow, at least along the Trench, was comparatively sluggish. There is, therefore, the requisite combination of abundant material and low velocity of flow to give overloading and so to account for the lack of eroding in the Trench. The lack of scouring of the valleys needs a different explanation. From the appearance of the striae and grooving, the direction of movement of the ice as a whole was southeast to south. During the period of continental glaciation most of the valleys, particularly those transverse to the direction of the movement of the ice, were apparently filled with more or less stagnant ice over which the rest moved. Coleman (56, P. 13) suggests that the central ice-sheet of British Columbia was more or less hemmed in by mountain ranges and so accounts for the sluggish movements of the main ice-sheet and its lack of erosion. With the melting away of the main ice-sheet alpine glaciation commenced and the ice started moving down the valleys. The ice in such valleys as Perry Creek and the Moyie River would have to move towards the main mass of the ice in the Trench which may still have been very thick. Hence, although the valleys themselves may have had a steep gradient, the slope of the surface of the ice, which actually controls the rate of flow, was probably relatively slight. The ice would therefore move sluggishly and lack the ability to do much eroding.

Dissipation of the Ice:

The method of retreat of the ice from the mountainous parts of the area was evidently normal. The steps were as follows.

1. The continental sheet thinned down until the hills and ridges emerged and alpine glaciation commenced.

2. The dwindling of the amount of the ice produced normal retreat of the valley ice. According to Flint (72) such a retreat may be expected to go through the following stages:

a. Retreat to higher relief.

b. Increased lobation.

c. Local advances producing crescent-shaped moraines.

d. Local lakes with stratified deposits and deltas.

e. Previous crescent moraines channelled by the outwash streams.

f. Kame terraces which show that the movement of the ice smoothed out the irregularities of the ice-face contact.

The number of valleys that show glaciation in the Cranbrook area proves that the ice-sheet was divided into many lobes during its last stages: that is, it establishes point b. Stages c, d, and e are all illustrated by Perry Creek and f can be seen to the southeast of Moyie Lake.

On the floor of the Trench, however, normal retreat does not appear to have taken place since none of the above stages can be recognized. Instead the following facts have been observed:

1. Many small lakes were evidently formed all over

the area during the retreat of the ice, since the moraines frequently show well-bedded, silty members interbedded with them and cross-bedded delta deposits are common. Examples of these are frequent in the section exposed by the cut of the St. Mary's River and on the side of the road east from Kimberly where it crosses Cherry Creek. While these lakes are not unlike those of point d above, their number and the great area covered by them, as well as the evidence of the variation in the direction of their outlet, serves to distinguish them from the lakes left by normal retreat.

2. There are many terraces with irregular ice-contact faces variously oriented. The surface of these terraces are often horizontal but kettles are nearly always present. Very few of them show post-glacial dissection. Excellent examples occur near Wycliff.

3. Large kettles, often a mile or so in length and several hundred feet in width are common all over the surface of the Trench, indicating that the main mass of the ice had broken up into a number of separate bodies.

4. The streams occupying these depressions are invariably "underfit". Sullivan Creek, a tributary of Mark Creek near Kimberly, furnishes a particularly good example of this. Fig 4 For most of its course this creek meanders aimlessly over the floor of a glacial depression 100 to 200 feet ~~high~~ deep and several hundred feet across. About a third of the distance from the head of the depression the creek enters it from the west over a small cascade and the valley above this point has never been occupied by any stream.

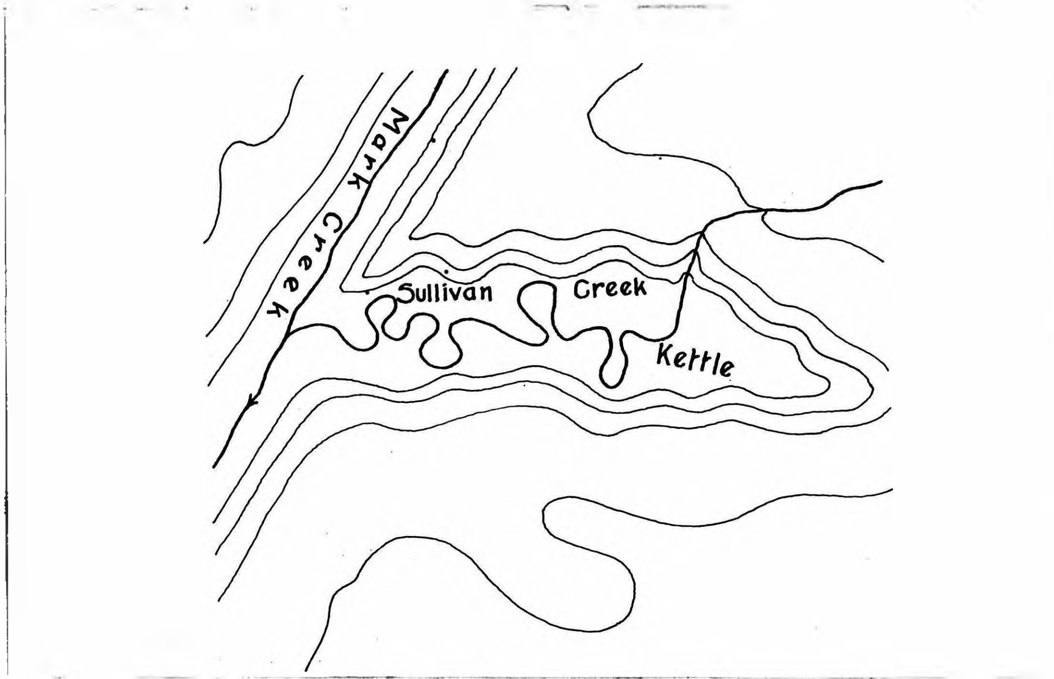


Figure 4

Sketch map of Sullivan Creek. This sketch illustrates an underfit stream occupying a glacial depression. Walls of the depression are composed partly of stratified gravels and partly of morainic material and represent "ice-contact" faces. Scale about one inch to the mile, contour interval about 50 feet.

5. Moraines, eskers, etc., are distributed with no apparent system all over the region. (Plate III B, p 9A)

For many years after the study of continental glaciation began, the disappearance of ice-sheets was believed to have been accomplished by normal retreat: that is, by the melting back of the edge of the sheet while its forward movement as a body continued. In 1898 Jefferson (73) suggested that parts of the ice-front might have stagnated, and in 1904 Fuller (74 p 181) summarized the evidence favouring the idea. For some time after this, the hypothesis was entertained and amplified but always restricted to local applications and it was not until 1924 that Cook (75) suggested its areal application. In 1929 Flint (72) summarized the existing ideas and presented new facts to show that the Wisconsin ice-sheet, where it had pushed beyond the mountain barriers south of the St. Laurence River from the Adirondacks to Maine, became practically if not entirely stagnant and never regained motion. In 1933 Brown (80) showed that in central Massachusetts the ice left the upper regions first leaving long tongues in the valleys which were stagnant and melted out after the deposition of many kames along their flanks. For a full discussion of the subject the reader is referred to Flint's paper, but his main facts and lines of evidence regarding it will be briefly quoted here since they epitomize the observations made in the Cranbrook area.

1. The initial stage consists of a broad, sheet covering most of the region.

2. The melting is differential and tends to break up the sheet into a number of separate bodies.

3. Lakes form, especially marginally, and the ice shrinks inwards.

4. Sediments accumulated in these lakes produce marginally flanking terraces when the ice finally disappears.

5. Post-glacial drainage produces underfit streams.

6. There may be no dissection of the terraces by post-glacial drainage.

7. The terraces may face in any direction.

Regarding the terraces Flint came to the following conclusions:-

a. They nearly always are more or less horizontal.

b. One face is an irregular, ice-contact sheet.

c. Spill-ways are present and the foreset beds face towards them.

d. Kettles are nearly always present near the ice-contact faces.

The facts observed in the Cranbrook area, enumerated on pages 26 and 27 check with all the items in the above list with the single exception of item c. Unfortunately, the idea of stagnation was not in the writer's mind while he was in the field, so that spillways from the small lakes may have been present but overlooked from a lack of directed observation. The agreement of the expected conditions with those actually found is so striking that it is believed to prove that the retreat of the ice from the surface of the Rocky Mountain Trench in the Cranbrook area was accomplished by stagnation and dissipation instead of by normal retreat. This method of removal of the ice has been demonstrated all along the southern fringe of the Pleistocene ice-sheet but, as far as the writer is aware, it has never before been reported as far within the area of continental glaciation as the Cranbrook district, over 150 miles.

STRATIGRAPHY

The area covered in this report is underlain largely by pre-Cambrian sediments which were laid down in the Cordilleran geosyncline. This geosyncline came into existance in the early Proterozoic and is the largest, oldest, and longest enduring of such troughs known. (1) It lasted, with minor changes, until the Laramide Revolution at the close of the Mesozoic and consisted of a long trough extending roughly north and south from the Pacific ocean, where the southern boundary of California now lies, to the Arctic ocean close to the present eastern boundary of the Yukon.

During the Proterozoic a uniform series of sediments, not less than 35,000 feet thick, was laid down in the portion of the basin corresponding to the Cranbrook area. This series was composed of materials derived from the erosion of a land-mass lying to the west and consists of fine, bedded clastics with minor amounts of conglomerates and some limestones and dolomites. It has been called the Belt Terrane or Beltian and has been divided by Canadian geologists into the Purcell and Windermere series, separated by a minor unconformity. Only the lower, or Purcell series, has been recognized in the Cranbrook area. In this area the Purcell series has a general dip to the northeast and is overlain in places by Cambrian rocks; the youngest consolidated sediments recognized.

Only two groups of igneous rocks occur to any extent. The more prominent is the Purcell diorite forming sills, dykes, and flows of pre-Cambrian age. ~~Really~~ areally rather insignificant, but probably of great economic importance, are granitic rocks of late Mesozoic or early Tertiary age which occur in occasional stocks and bosses.

The formations that occur in the area, with their approximate thicknesses, are given in Table II. p32A The Base of the Purcell series is not known and the thickness of the Aldridge, the lowest formation, may be much greater than that given. All the formations of the Purcell series are conformable and no striking lithological differences can be observed. The contact between formations is generally gradational rather than abrupt and its exact location depends largely on personal opinion.

The Purcell Series

Rocks of the Beltian system can be traced over hundreds of square miles of northwest North America and exhibit a uniformity, both laterally and vertically, that is astounding. To the south they extend without interruption across the International Boundary into Idaho and Montana. Allen (9) has found them in the western ranges of the Rocky Mountains and Walker (10) has traced them practically continuously to the north as far as Windermere Lake. The western boundary is somewhat complicated by the intrusion of granites connected with Nelson batholith, but Walker (11) has recognized Beltian rocks to the east of Kootenay Lake.

The earliest description of the Beltian was by the pioneer geologist G.M. Dawson (2) who recognized it on the Canadian side of the International Boundary in 1885, al-

TABLE OF FORMATIONS

Table II

Era	System	Series	Formation	
	Quaternary	Recent	Marysville sands	0-10' Loam and sand.
		Pleistocene	Wycliff drift	75' Boulder clay.
			St. Eugene Silts	200' Gravels and silts.
Late Mesozoic or early Tertiary				Granite stocks, bosses and dykes
Paleozoic	Upper Lower Cambrian		Perry Creek #	6,000' Shales, limestone, and chert
	Proterozoic Beltian	Purcell	Old Town	
			Annelide	200' Magnesite, quartzite.
			Mission	
			Quartzite	600' Quartzite.
			Purcell igneous rocks	Sills, dykes, bosses, and flows
			Siyeh	2,200' Mainly argillites.
			Kitchener	6,150' Limestones and argillites
			Creston	5,900' Mainly quartzites.
			Cherry Creek	1,000' Argillites.
			Aldridge	11,200' Quartzites and argillites.

Base unexposed

Includes the Eager formation.

though it was not until later that the name was applied. In 1886 McConnell (3) noted it in the course of his reconnaissance trip across the Rocky Mountains. No more work was done on these rocks in Canada until 1904 but a considerable amount of investigation was carried on in Montana and Idaho by Davis, Lindgren and others (4). In 1899 Walcott (49) found fossils in some of the upper formations of the Belt Terrane, and, in his introduction to their description, he summarizes the information available on the series up to that time. In 1902 Willis (5) made a careful study of the Lewis and Livingstone ranges of Montana and his work resulted in the first systematic subdivision of the Belt Terrane and the naming of the formations. He was accompanied by Finlay who wrote an account of the igneous rocks found in the series (6). In 1904 Daly traced Willis' formations into the International Boundary section and made the first detailed description of the Canadian Beltian which he believed to be part Cambrian and part pre-Cambrian. In 1906 Walcott (7) described the Belt Terrane again and found clear evidence of an unconformity between it and the Cambrian. He therefore concluded it to be Algonkian in age. By this time the Belt Terrane had proved to be an important series economically and in 1908 Ransome and Calkins (8) described its relations to the ore-bodies of the Coeur d'Alene in Idaho. The reconnaissance work of Calkins and MacDonald (35) in 1909 through Idaho and Montana gave some idea of the tremendous extent of the series. From that time to the present many geologists have worked in various parts of the Belt Terrane, particularly on its economic problems.

The Purcell series was first named and carefully described by Daly in 1904 (12). This description was printed unchanged in 1913 (13). Daly's table is reproduced in column 1 of Table III (p 34A). Schofield, in 1915, (14), recognized another formation below Daly's Creston which he called the Aldridge, and identified with a part of Daly's Kitchener and which, he found, should have been mapped below the Creston instead of above it. In the same report Schofield correlates the Moyie with the rest of Daly's Kitchener which he found was stratigraphically below the Siyeh. The term Moyie formation was therefore dropped. The Gateway formation, named and described by Daly (13, p 107) in the Galton range, was also recognized by Schofield in the Cranbrook area to the east of the portion covered by his report. The table as amended by Schofield is given in column 2 of Table III. In 1922 Schofield described the Purcell series again in a small pamphlet published by the Geological Survey of Canada. (15) In this paper he reports the occurrence of Cambrian rocks in the Cranbrook area. A thick band of white quartzite, found underlying the fossiliferous Cambrian shales, Schofield called the Cranbrook formation and believed to be conformable with the overlying Cambrian. Three hundred feet of the Siyeh was also recognized above the Purcell lava. Schofield's second table is reproduced in Column 3. Work done in the season of 1932 necessitated a few changes. Measurments of the Aldridge showed this formation to be even thicker than the earlier estimates. The boundary between the Kitchener and

Table III

TABLE CORRELATING THE FORMATIONS OF THE PURCELL SERIES

Column 1 Daly 1904	Column 2 Schofield 1915	Column 3 Schofield 1922	Column 4 Present Report	
			Perry Creek ---- 6,000	Lower Cambria
	Gateway ---- 2,000			
		Eager ------ 300 Cranbrook -- 600 Purcell Lava	Oldtown -------- 800 Purcell Lava	
Kitchener -- (in part)	Siyeh ------ 4,300	Siyeh ------4,500	Siyeh --------- 2,200	
Moyie Kitchener (in part)	Kitchener -- 4,500	Kitchener - 4,500	Kitchener ------ 6,150	
Creston (in part)	Creston ---- 5,000	Creston --- 5,000	Creston -------- 5,900	Purcell Series pre-Cambrian
			Cherry Creek --- 1,000	
Creston (in part)	Aldridge --- 8,000	Aldridge -- 8,000	Aldridge -------11,200	
Kitchener (in part)				

the Siyeh was placed further up the stratigraphic column so as to include some of the lower Siyeh, as originally mapped, in the Kitchener. The Cranbrook formation was found to be conformable with the Siyeh and to underlie the Cambrian unconformably and was therefore placed in the pre-Cambrian although its correlation with the Gateway could not be assured. Since the name Cranbrook has also been applied to definitely Cambrian formations elsewhere, the name of this formation was changed to the Old Town formation. It was subdivided into the Mission quartzites and the Annelide sub-formation. An additional formation, the Cherry Creek, was recognized between the Aldridge and the Creston. The table as finally amended is reproduced in column 4. Table III.

The Aldridge Formation

The Aldridge is the oldest formation in the district and was first so called by Schofield (14, p 25) in 1912 after the deserted hamlet of Aldridge at the outlet of Moyie Lake.

The Aldridge formation covers the greater part of the Cranbrook area, which is not surprising when it is remembered that it is twice as thick as any of the succeeding formations and, in most occurrences, is comparatively flat lying. The best section is that exposed in the Moyie Lake region where the beds form a simple anticline whose axis plunges to the north.

A section was measured on the east shore of the Moyie Lakes along the railway cuts, and south of the lakes along the road to a point some four or five miles south of Aldridge. The structures are comparatively simple here and the thickness obtained, 11,200 feet, is fairly reliable for the part of the formation measured. Unfortunately the base of the section was not seen and, indeed, Aldridge is known to continue for a considerable distance beyond the last attitude measured. The complete formation is, therefore, undoubtedly thicker than this figure. A rough measurement taken in the area north of the St. Mary's River gave a thickness of 22,000 feet. The structure there is, however, rather complex and outcrops are not very good.

The Aldridge forms a geological unit of great thickness, persistance, and uniformity. It is composed of a series of quartzites, argillaceous quartzites, and argillites with the argillaceous quartzites predominating. It is white to grey in colour except where it has suffered contact metamorphism. In the Moyie region, where it is comparatively free from any metamorphism, it is composed of beds of uniform thickness, averaging about four or five feet, with narrow partings of softer argillite. Beds containing small lenses of limestone appear occasionally which, in an isolated outcrop may be confused with later members of the Purcell series. The limestone occurs in small, rather irregular bodies, five or six feet long by six inches wide, although occasionally they may be bigger. Conglomerates have been reported by Schofield to occur further to the southwest but none were seen in the area (14, p 26). Details of the sedimentation are beautifully preserved in the quartzites. Cross-bedding and small scour channels are easily recognized and individual beds can be seen to grade from a quartzite at the bottom to a more argillaceous rock at the top. Ripple-marks and mud-cracks occur over wide areas. (Plate VII B, P 43A)

The argillaceous quartzites are composed of small angular interlocking grains of quartz from 0.05 to 0.10 mm in diameter set in a matrix composed almost entirely of serecite needles. Striated feldspars and biotite flakes occur in small amounts. Small garnet crystals are occasionally seen. These rocks grade into the argillites through a diminution in the quartz content. In some places there is a considerable and characteristic development of large flakes of mica. Pyrite and magnetite occur in small grains through all types. The argillites of the Aldridge formation usually have a smooth appearance which differentiates them from the grey, rather fibrous argillites of the Perry Creek series.

Outcrops of the Aldridge are almost universally stained reddish-brown by a thin coating of limonite. The two characteristics, reddish weathering and grey colour, are the best guides to the recognition of Aldridge in the field.

Detailed Section:

The following are the details of a section measured along the railway on the east side of Moyie Lake.

675 feet. - Massive, thick bedded grey quartzites. Not much red weathering.

700 feet. - Platy, grey argillaceous quartzites.

1400 feet. - Gap in outcrops.

125 feet. - Grey massive quartzites.

3850 feet. - Massive and thin-bedded rusty quartzites and argillites.

800 feet. - Rusty thin banded argillaceous quartzites.

1650 feet. - Massive quartzites.

1800 feet. - Very light coloured, hard quartzites.

10, 000 feet.

Correlation:

The equivalent formation in Montana and Idaho has been named the Pritchard formation, (17) and Calkins (25) measured 800 feet of it in the Coeur d'Alene.

The Cherry Creek Formation:

Work done in the Moyie Lake region disclosed a considerable transition zone between the Creston and the Aldridge formations making it hard to decide on the location of the boundary between the two. It was not until further work was done in the corresponding horizon north of the St. Mary's River that the full extent of this zone was realized. At the same time it was found to have characteristics permitting it to be distinguished from the underlying and overlying formations. It was therefore decided to give it a formational name and to map it separately. As the best exposures of it were found in the region of Cherry Creek to the east of Kimberly it was called the Cherry Creek formation. It occurs in four long, narrow zones in the Cranbrook area, the best sections being in the type locality and along the Moyie Lakes.

The thickness of this formation, measured at the type locality is about 1,000 feet. Along the side of Moyie Lake the thickness may be a little less, but the section is not so well exposed.

The Cherry Creek formation is composed almost entirely of thin bedded argillites with occasional beds of argillaceous quartzites. The argillites are composed of alternating, thin beds of greenish grey and grey rock, often only a fraction of an inch thick, giving the formation a characteristic striped appearance. The base of the section is predominantly grey and so merges into the Aldridge the boundary between the two formations being set at the first pronounced appearance of the striped rock. Near the top the green beds become thicker, coarser grained, and more frequent until the formation passes into the typical Creston argillaceous quartzite. When the amount of argillites becomes insignificant the rock is considered to be Creston. Individual beds may easily be confused with either the Aldridge or the Creston and the distinction is easier to make after a little experience in the field than to describe on paper; a fact which is indeed true of all the members of the Purcell series. Rusty weathering is usually absent or is present only in minor amounts in the outcrops; instead the rocks tend to weather greenish. Details of the sedimentation are very clear and ripple-marks and mud-cracks are common.

Creston Formation:

The name Creston, after the town of Creston on the Kettle Valley Railway close to the International Boundary, was first used by Daly (13, p 12C) to describe a thick series of quartzites and argillaceous quartzites which he believed to lie at the base of the Purcell series. Schofield, however, showed that it was underlain by the formation he called the Aldridge. Schofield limited the name Creston to a series of quartzites and argillaceous quartzites lying between the Aldridge and the Kitchener. The limits of this formation, as set down by Schofield, have not been changed by subsequent work and the formation stands as he defined it. Schofield, however, in his original mapping, sometimes confused it with members of the other formations.

The Creston occurs in many parts of the area, often outcropping in bold bluffs and forming the tops of several of the mountains and higher ridges. In spite of this, the only complete section at all well exposed is that at Moyie Lake. The area along Perry Creek has assumed some importance on account of the gold-quartz veins found in it.

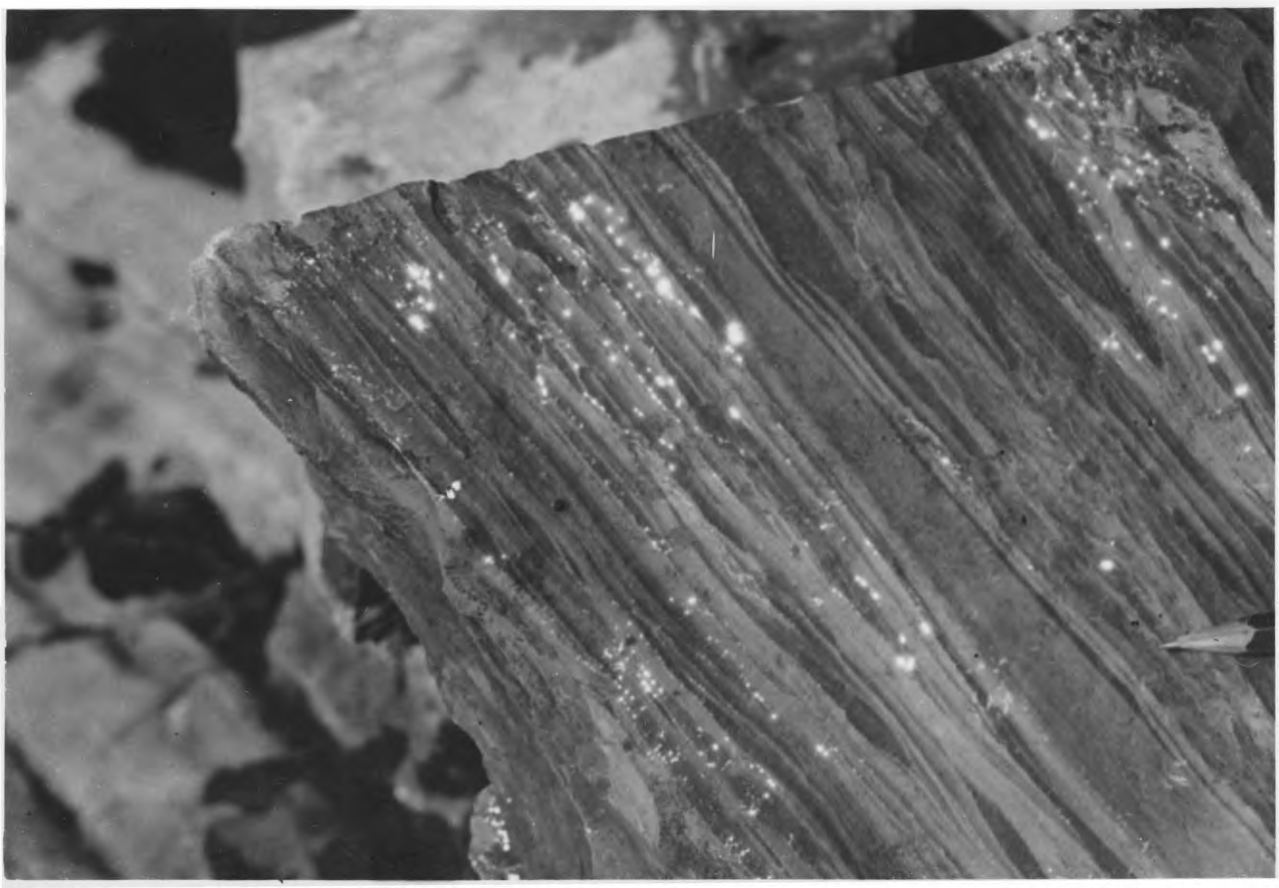
Daly's figure of 9,500 feet for the thickness of the Creston is undoubtedly too great and is believed to have included part of the Aldridge formation. Schofield, working along the Moyie Lake, gives 5,000 feet for the thickness which checks that of 5,900 feet obtained by careful measurement in 1932 in the same locality. At no other place could a reliable figure be obtained, but a rough measurement suggests that this is a good average for the thickness of the Creston elsewhere in the district.

The Creston formation consists mainly of argillaceous quartzites and quartzites occurring in beds three or four feet thick with thin argillite partings. The quartzites are mainly of two types, green and purple. The green rocks are the commonest and consist of argillaceous quartzites with a general watery green colour. The purple quartzites are light coloured rocks with fine purple lines usually parallel to the bedding but often in a complicated network of fine threads. (Plate V A, p 41 A). Occasionally the purple colour is an intrinsic part of the rock itself, but more often it is imparted by the thin lines. The origin of these lines is obscure. Since they cross each other they cannot be depositional features, nor is there any definite evidence to show that the rocks have been brecciated and cemented by the purple material. The colour is probably due to fine grains of hemetite. These rocks often change suddenly along the strike into the green quartzites, the change being effected in a few feet. The argillaceous partings may be either green or purple, taking their colour from that of the quartzites they are separating. Limestone lenses are not uncommon, especially towards the upper part of the section, where they weather buff and stand out prominently in the outcrops. (Plate VI A, p 42 A) Grey quartzites, very similar to those occurring in the Aldridge, are found in the Creston, but not as frequently as would be surmised from Schofield's description. When they do occur, however, it is impossible to tell them from the Aldridge except by their stratigraphic relation to other more easily recog-

Plate V

A. Photograph of a block of Creston Quartzite showing intersecting purple lines. About 1/3 natural size.

B. Photograph of a block of green banded Creston argillaceous quartzite. This type is often met with in both the Kitchener and the Siyeh formations. About natural size.



nized types. A common variety of the quartzites is a fine-grained argillaceous rock light green in colour with very pronounced bands of darker green, fractions of an inch in width. (Plate V B, p 41 A) This banded rock is very striking but indistinguishable from certain members of the Kitchener and Siyeh. Ripple-marks and mud-cracks are beautifully preserved, especially the former, and rain spots were seen along the shore of Moyie Lake. Some of the ripple marks are 3 inches from crest to crest and 1½ inches deep. (Plate VI B, p 42 A, and Plate VIII A, p 44 A)

The Creston is the most easily distinguished of all the members of the Purcell series. The purple-lined quartzites are known only in this formation and the massive green types occur sparingly in any of the others. As the top of the section is reached the limestone lenses become more abundant and when they become prominent the rock is mapped as Kitchener.

<u>Detailed Section:</u>

The section measured along Moyie Lake was composed of the following members:

725 feet. - Green and mauve siliceous quartzites. Some limey beds.

725 feet. - Green and purple argillites and quartzites. Ripple-marks and mud-cracks.

1150 feet. - Purple, green and grey massive quartzites. Some brown weathering.

650 feet. - Very siliceous grey types. Some

Plate VI

A. Photograph of an outcrop at the top of the Creston formation. Note the lenses of limestone. When these assume importance the rock is considered to belong to the Kitchener formation

B. Photograph of an outcrop of the Creston formation on the east side of Moyie Lake. Note the abundance of ripple marks.

bands like Aldridge.

500 feet. - Green and purple quartzites. Some ripple-marking.

2150 feet. - Green and purple argillites and quartzites. Mud-cracks and ripple-marks. Some limey bands.

5900 feet.

Correlation:

The formation occuring in Montana equivalent to the Creston is called the Revalli and consists mainly of white, siliceous quartzites (51). The purple type does not occur there and the green quartzite is not at all common, but, apart from the colour, the general nature of the two formations is very similar, and the limits outlined above may be applied closely.

Kitchener Formation:

The Kitchener formation was named by Daly after the town of Kitchener on the Kettle Valley Railway and applied to a quartzite formation which was later identified as Aldridge by Schofield. In other places in the boundary section, Daly mapped limey rocks as Kitchener which were afterwards believed to be the stratigraphic equivalent of the Siyeh. These were probably Kitchener according to the later definition. Schofield defined the formation more clearly and his definition, with certain modifications, was made the basis for the mapping of the formation in the present report.

The Kitchener is developed in many parts of the

Plate VII

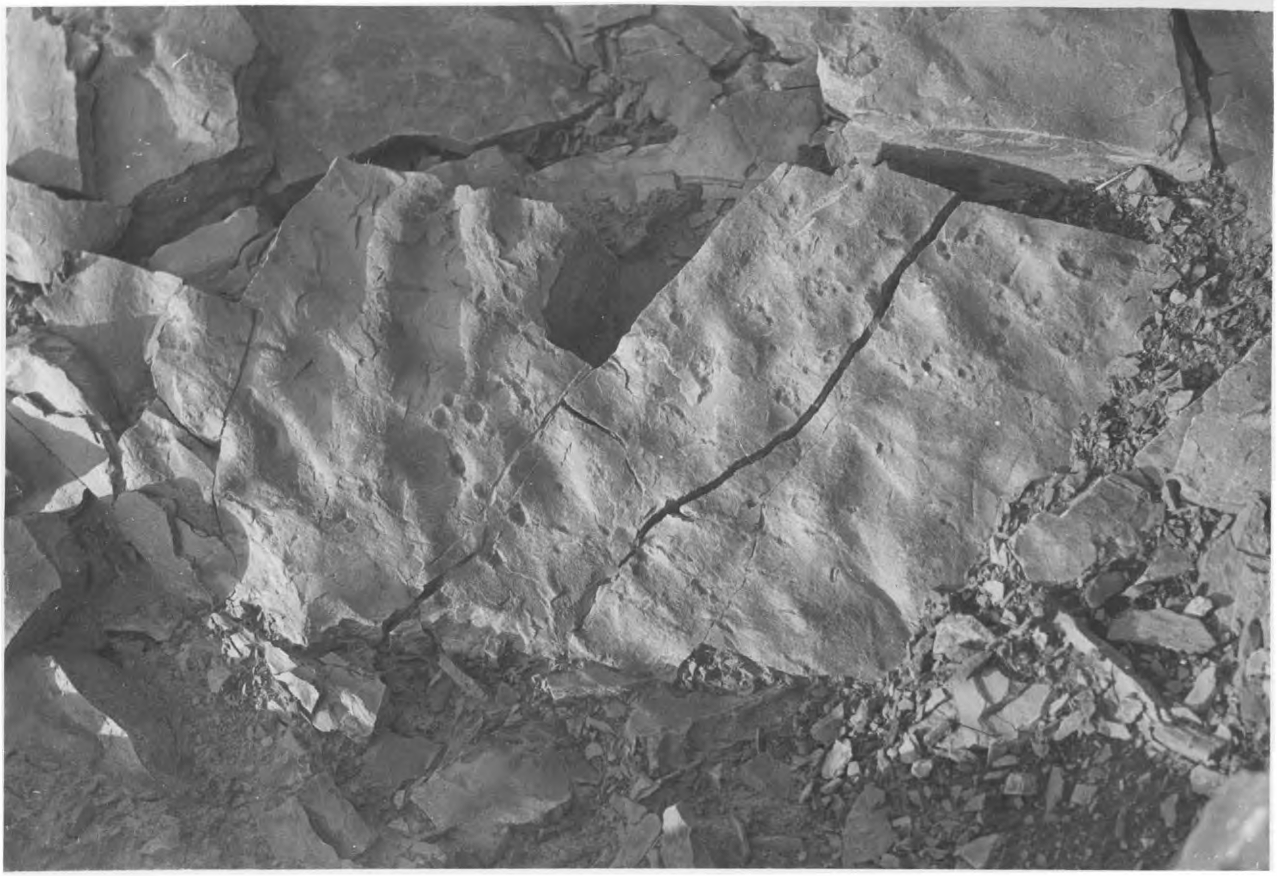
A. View looking west up the valley of the upper St. Mary's River. Note the U-shaped cross-section.

B. Photograph of a slab of Aldridge argillite showing mud-cracks. See text p37

area but nowhere is a complete section exposed. The region at the head of North Moyie Lake has been used as the type section and the lower two thirds of the formation is well developed, but the upper part, including the contact between it and the Siyeh, is known from a few outcrops only. The upper Kitchener is, however, well exposed south of Marysville and also to the southeast of St. Eugene Mission so that, by combining all three areas, a good idea of the complete section can be obtained. In the St. Eugene Mission locality, although the base of the section is not exposed, all the known types of Kitchener have been seen.

Schofield measured the Kitchener along the Moyie Lakes and obtained a thickness of 4,500 feet while the writer, in the same locality obtained a thickness of 6,150 feet. Considerable confusion has always been experienced in determining the boundary between this formation and the Siyeh. After a consultation with Dr. Ian Campbell it was decided to follow the practice of the Montana geologists and to limit the Siyeh to a thin formation of distinctive rocks at the top of the section and to include the questionable and confusing rocks below this with the Kitchener. After having put this into practice it was found to facilitate mapping greatly and to be an entirely practical subdivision. The difference in the figures obtained by Schofield and the writer is thus explained. Rough estimates made in other localities check this thickness as closely as can be expected.

The main characteristic of the Kitchener is its high lime content, and it is this characteristic and effects



resulting from it that serve to distinguish it in the field. It must be remembered, however, that all the other formations carry limey lenses in places and a positive diagnosis can seldom be made from a single outcrop. The limestones are often siliceous and always highly impure and argillaceous, green, grey or purple in colour, and very fine-grained. The grey and green types are the most common. Interbedded with the limestones occur calcareous quartzites and calcareous argillites which are also grey, green, and purple. Mud-cracks and ripple-marks are common throughout the formation. All the calcareous members weather light buff and the outcrops stand out strikingly. At other times segregations of calcite in little worm-like concretions weather out forming what Baureman (19) has described as molar-tooth structure. (Plate IX, p 45 A) The effect is very striking and easily recognized in an outcrop even at a considerable distance and is characteristic of the Kitchener. Fenton (16) has studied these structures in Glacier National Park and concludes that they are undoubtedly organic and were produced by calcareous Algae. Occasionally grey argillites occur in the Kitchener which are comparatively free from lime. A green, striped, argillaceous quartzite, exactly like that described in the Creston, was seen in several places. (Plate V B, p 41 A) Pyrite cubes are common in some members of the Kitchener, sometimes attaining dimensions of an inch or more. The Kitchener is generally thin-bedded and alternating beds often weather different shades of buff giving the rock a characteristic, striped appearance. (Plate VIII B, p 44 A)

Plate IX

Photograph of an outcrop of the Kitchener formation showing well developed Molar-tooth structure.

Detailed Section:

Below are the details of the Moyie Lake Section.

1900 feet. - Limey greenish argillaceous quartzite.

350 feet. - Gap in section.

400 feet. - Grey argillite and quartzite, thin-bedded and limey.

750 feet. - Green, grey, and purple, limey argillaceous quartzite.

150 feet. - Green, thin-bedded cherty rocks.

Diorite sill.

750 feet. - Buff-weathering, limey rocks. In part cherty.

950 feet. - Buff, limey rocks; typical molar-tooth structure.

900 feet. - Grey-green, massive and thin-bedded, limey rocks; buff weathering.

6150

Correlation:

The Kitchener, as defined at present, includes a good deal of the series originally mapped as Siyeh both by Daly and Schofield. In Montana similar rocks occur in the same stratigraphic position and have been called the Newland formation. In the Newland, however, the molar-tooth structure has not been seen, and the limestones are sometimes concretionary. (51)

Siyeh Formation:

In his description of the "Algonkian" rocks of the Lewis range, Willis (5, p. 323) gave the name Siyeh to a limestone formation occurring on Siyeh mountain. This formation was mapped in the Clarke and Galton ranges by Daly using Willis' definition. In the Cranbrook area Schofield limited the term Siyeh to a series of argillaceous and calcareous rocks lying above the Kitchener. In 1932, as has already been mentioned, the name Siyeh has been limited to a relatively narrow horizon of argillites and calcareous argillites intercalated with the Purcell flows, lying conformably above the Kitchener. By this definition the limestones are all included in the Kitchener with which they form a lithological unit distinct from the overlying argillites. Since the term Siyeh, as originally proposed, was used to define a limestone formation, and is undoubtedly largely the equivalent of the Kitchener, the desirability of continuing the name is rather questionable. It has been used in this report, but later workers may decide to change it for some more distinctive term.

The Siyeh is not a very extensive formation, but it occurs in four localities in the Cranbrook area. The most complete section is possibly that exposed in the hills to the southeast of St. Eugene Mission which may be considered as the type locality. South of Marysville and on Cranbrook mountain the Siyeh is also well developed.

Daly reports thicknesses of 4,100 feet and

4,000 feet in the Lewis and Galton ranges respectively. Since these include at least a part of the Kitchener they cannot be applied to the Siyeh as redefined for the Cranbrook District. Schofield gives a thickness of 4,000 feet for the Siyeh measured at Cranbrook and Baker mountains. The same objection is also true here and furthermore the structures are not yet definitely known and there may be some repitition. The thickness of 2,200 feet given for the formation was estimated from the sections exposed east of St. Eugene Mission and on Cranbrook mountain. In both places it is difficult to get a good section and the figure is not as accurate as that for the earlier formations. The thickness south of Marysville is about 1,000 feet, but here difficulty was experienced in locating the boundary between the Kitchener and the Siyeh. The rocks of the two formations are very similar and the exposures not good. It is evident, however, that the formation is a comparatively thin one as compared with the rest of the Purcell series and its thickness is probably between 1,500 and 2,000 feet.

The dominant rocks in the Siyeh are highly colored argillites. The two commonest types are olive green and purple and they are largely non-calcareous. The olive green colour is usually distinctive from the more emerald tint of the Creston and the Kitchener, but this distinction cannot be relied upon implicitly since there are many exceptions. The purple argillites are very similar to certain thin-bedded purple argillites in the Kitchener. A very distinctive and characteristic type is a combination of the two colours producing a thin-banded rock with alternating layers of purple and green argillite a fraction of an inch thick. This rock is well developed at the base of the Mission Quartzite south of St. Eugene Mission. Some limey lenses are present and also some quartzite but neither is at all common. Mud-cracks and ripple-marks were seen in several places. A few bands of dark grey, slaty rocks occur, but are rare. South of Marysville the typical rock is an argillaceous quartzite with alternating layers of dark and light green exactly like the striped green rock occuring in the Kitchener and the Creston (Plate V B, p 41 A). Purple rocks are, however, interbedded with it especially near the top of the section. The Purcell lavas occur as an integral part of the Siyeh, but will be discussed when dealing with the Purcell intrusives and extrusives. They form a certain guide for the recognition of the Siyeh. If they are not present, unless the stratigraphic position is fairly well known it is difficult to be sure of the Siyeh except in very good exposures.

The examination of a thin section of the Purple Siyeh threw some light on its origin. The section was taken from a specimen obtained on the top of Cranbrook mountain. The rock is fine-grained and dark, greyish-purple in colour, and shows a great deal of alteration. The main bulk of the rock consists of white mica and chlorite, occurring in scaly aggregates replacing the other minerals; the feldspars altering to mica and the amphibole to chlorite. Quartz is not common but occurs in large, well rounded grains often composed of several crystals. Microcline is present although not common. Orthoclase is the commonest feldspar and occurs in medium sized grains considerably fractured and altered. Some plagioclase may be present. Amphibole is probably common, but has been largely altered to chlorite. Hematite is abundant in grains or cementing the other minerals and is evidently the pigment colouring the rock. The estimated proportions of the constituents are as follows:-

White mica	40%
Chlorite and amphibole	20%
Hematite	20%
Feldspars	15%
Quartz	5%

Correlation:

The Siyeh, as defined in this report, corresponds to the upper part of the Siyeh as used by Willis, Daly, and Schofield. While the formation they describe is essentially limestone, the Siyeh in the Cranbrook district is mainly argillite. This definition of the Siyeh, however, corresponds closely with the limits set for the Striped Peak formation occurring in Montana in a similar stratigraphic position (51).

The Old Town Formation:

When Schofield revisited the Cranbrook area in 1921 (15) he recognized a Lower Cambrian fossiliferous shale underlain by a white and rose coloured, coarse-grained quartzite. In his opinion the quartzite overlay the Siyeh unconformably and was conformable with the fossiliferous shales. He called the quartzite the Cranbrook formation and considered it to be Cambrian in age. During the field season of 1932 several more exposures of the quartzite were found and the conclusion was reached that it was pre-Cambrian instead of Cambrian in age. For reasons already mentioned it was decided to substitute the name Old Town for Cranbrook formation until a more accurate correlation could be made. The formation has been subdivided into the Mission Quartzite, and the Annelide sub-formation.

The Mission Quartzite:

Only three occurrences of the Mission Quartzite are known, but, fortunately, at two of these it is well exposed. The original discovery was made on the northeast side of some low hills on the edge of the Trench where it is exposed in patches along a relatively narrow strip extending from the north bank of the St. Mary's River southeastward to Signal Hill. South of Marysville exposures of the Mission Quartzite occur in a narrow band extending south to southwest between the St. Mary's fault and the Perry Creek fault, a distance of five miles. At the north end of this locality exposures are excellent. The only other known occurrence is at the head of Hellroaring Creek where a small section is exposed.

Schofield gives a thickness of 600 feet for the Cranbrook formation measured southeast of St. Eugene Mission where the Annelide sub-formation is largely missing. Further measurements both here and at the locality south of Marysville checked this figure and 600 feet has been accepted as the thickness of the Mission Quartzite.

The greater part of the Mission Quartzite is a hard, white, rock with an average grain size of about a millimeter in diameter. In contrast with the Purcell series this rock is generally almost pure quartz and very free from argillaceous material. In the Marysville locality the quartzites occur in beds up to five feet thick, separated by thin layers of green argillite. (Plate X B, p 53 A) On Signal Hill both rose-red and greenish quartzites are found and south of Marysville red and grey varieties are common. Small conglomerate beds occur from time to time with pebbles up to an inch across but are rather local in extent. Structures are well preserved and cross-bedding and ripple-marks are common.

The Mission Quartzite is generally an easy formation to recognize. The pure, granular, white quartzite is very seldom found elsewhere in the Purcell Series; the only rocks that might be mistaken for it are some of the silicified and bleached quartzites of the Aldridge where they are in contact with the Purcell Sills. The rose variety occurs in no other formation.

The Annelide Sub-Formation:

The Annelide sub-formation was named after some peculiar markings, resembling worm burrows, seen in it south of Marysville, the type locality. It occurs in all the localities described for the Mission Quartzite.

The formation varies considerably in thickness but averages about 200 feet.

The base of the formation, at the type locality, grades into the Mission Quartzite and consists of red, white, and grey quartzite with a high content of magnesite. This transition zone is about 70 feet thick and grades upwards into about 90 feet of high grade magnesite. At the top and bottom of the magnesite zone small siliceous lenses can be seen but there is little calcite and the center 40 feet is remarkably pure. Narrow partings of green, sandy argillite a few inches thick appear near the top dividing the magnesite into beds four or five feet thick. Occasionally lenses of limestone or dolomite occur, several feet long and a foot or so thick. In one place a little pyrite was seen. In the lower transition zone the magnesite is often segregated into little lenses which weather buff and give the rock a striking mottled appearance.

A bed of soft, argillaceous quartzite about 40 feet thick lies conformably above the magnesite. It is

Plate X

A. Sharp fold in the Creston quartzites. Note the absence of any fracturing except recent jointing. Considering the hardness of the rock deformed this is a surprising fact.

B. Outcrops of the Mission Quartzite. Note the massive nature of the rock and the thickness of the beds.

rather a sandy, coarse-grained, greyish-green rock and shows abundant worm-like markings that have given the formation its name. Unfortunately it has not been possible to identify these but there is little doubt that they are either worm casts or burrows or else algal growths. Some of them were also seen in the interbeds at the top of the Mission Quartzite.

Relations of the Old Town Formation to the Purcell Series:

At Schofield's type locality southeast of St. Eugene Mission the Old Town formation appears to be lying on the Siyeh with a slight disconformity. At the base here, there is a thin bed of conglomerate containing pebbles of the underlying Siyeh, and there is a sharp lithological break. It was partly a study of this exposure that led Schofield to believe the series to be Cambrian. North of the St. Mary's River, however, the base of the section is again well exposed and beds of quartzite a foot or more thick, exactly like the typical Mission Quartzite, occur in what is undoubtedly the top of the Siyeh. In the same way beds of purple argillites, similar to the Siyeh, occur well up into the base of the Mission Quartzite. A careful examination of the zone between the two formations failed to reveal anything in the nature of a definite break in the lithology and, although the conditions under which the Siyeh and the Mission Quartzite were deposited were different, it is clear that there was no cessation of sedimentation during the transition from one set of conditions to the other. The two formations are, therefore, conformable. A similar transition is evident south of Marysville except that here both the Siyeh and the argillite interbeds in the Mission Quartzite are green. On Signal Hill the structures are more complicated but a detailed examination showed that the two formations are also conformable here.

To summarize the evidence:-

1. Except at Schofield's type locality the two formations appear to be conformable and to grade into each other over a distance of 20 or 30 feet.

2. No difference can be seen between the argillite partings in the quartzite and the underlying Siyeh.

3. The Old Town formation is believed to be overlain unconformably by the lower Cambrian.

The Old Town formation is therefore believed to overly the Siyeh conformably and to be a part of the Purcell Series.

Correlation:

Elsewhere in British Columbia the formation overlying the Siyeh is known as the Gateway. The Old Town formation should, therefore, correlate with the Gateway, but, unfortunately, the writer is not sufficiently familier with that formation to make any definite assertion. The formation in Montana, equivalent to the Gateway, is known as the Camp Creek. (51)

General Discussion of the Purcell Series:

The Purcell Series, in the Cranbrook District, has a total thickness of at least 26,450 feet and perhaps much more. It forms a continuous lithological unit and the formations composing it grade into each other, from top to bottom, with no suggestion of a break and possess lithological similarities that are the despair of the field geologist.

While the series presents a definite unity, there is a distinct progressive change in the nature of the sediments. At the base of the Aldridge, quartzites are the rule, although they are very impure and there are many interbedded argillites. As the top of the Aldridge is reached the sediments become finer and more argillaceous and these prevail throughout the Cherry Creek formation. The Creston is again a quartzite formation, but towards the top the sediments become argillaceous once more. With the beginning of the Kitchener a long period commences during which great thicknesses of calcareous rocks were deposited. Part of these, at least, are known to have been of organic origin. (16) With the Old Town formation quartzites again appear and are remarkably pure. They pass upwards into the carbonate rocks of the Annelide sub-formation.

In spite of the vast age of the Purcell Series the major and even the minor folds are beautifully clear and the attitude of the beds seldom in doubt. Even the more intimate details of the sedimentation are often as clear as in a recent sandstone.

Schofield deduces the following climatic conditions during the deposition of the Siyeh. "The Siyeh argillite is characterized by the presence of alternating greyish-green and purple to chocolate-brown argillites, the latter being especially distinguished by the presence of abundant sun-cracks. The climate at the beginning of Siyeh time must have been alternating humid and arid, since it is believed that such climatic conditions are necessary for the formation of alternating greenish-grey and purplish strata." (14, p 39) Schofield quotes Barrell (20, p 292) as his authority for his deductions. Since the quartzites of the Purcell Series consist of very fine quartz and feldspar grains generally mixed with muddy material derived from the decomposition of ferromagnesian minerals, and, since, as a rule, the feldspars did not break down, there appears to have been a preponderance of mechanical erosion over chemical (14, p 39) and a fairly rapid accumulation of the sediments.

<u>The Purcell Basin:</u>

The part of the Cordilleran geosyncline in which the Purcell Series was deposited has been called the Purcell basin and certain facts can be deduced concerning it.

1. The sediments collected in it are either quartzites, argillites, or impure limestones. All of these may be shallow water deposits although Tyrrell says that marine argillites are usually laid down between 100 fathoms and 2,500

fathoms. (76, p 214)

2. Ripple-marks and mud-cracks occur throughout the entire Purcell series. Mud-cracks, obviously cannot form unless the unconsolidated sediments are exposed to the air. The ripple-marks seen in the Cranbrook area were both symmetrical (wave ripples) and asymmetrical (current ripples). Kindle (77, p 42) believes that the maximum depth at which the former type can be produced is 50 fathoms. The fine ripples, such as were observed in the area, are probably formed at depths considerably less than this. Speaking of asymmetrical ripple-marks, Kindle says "there is no reason why -- these may not be found at any depth known in epicontinental waters." The last phenomenon is therefore inconclusive, but the evidence of the two previous ones indicates that the Purcell basin was comparatively shallow at all times; a conclusion that is not denied by the nature of the sediments.

3. Sedimentation was continuous and resulted in the accumulation of at least 26,450 feet of material. The Purcell basin was, therefore, not drained throughout this time and, since it was always shallow, the floor must have been sinking more or less continuously.

4. Sediments of the Purcell series have been recognized over an area of 200 miles by 40 of 50 miles. The extent of the Purcell basin must have been at least as great as this and was probably considerably more.

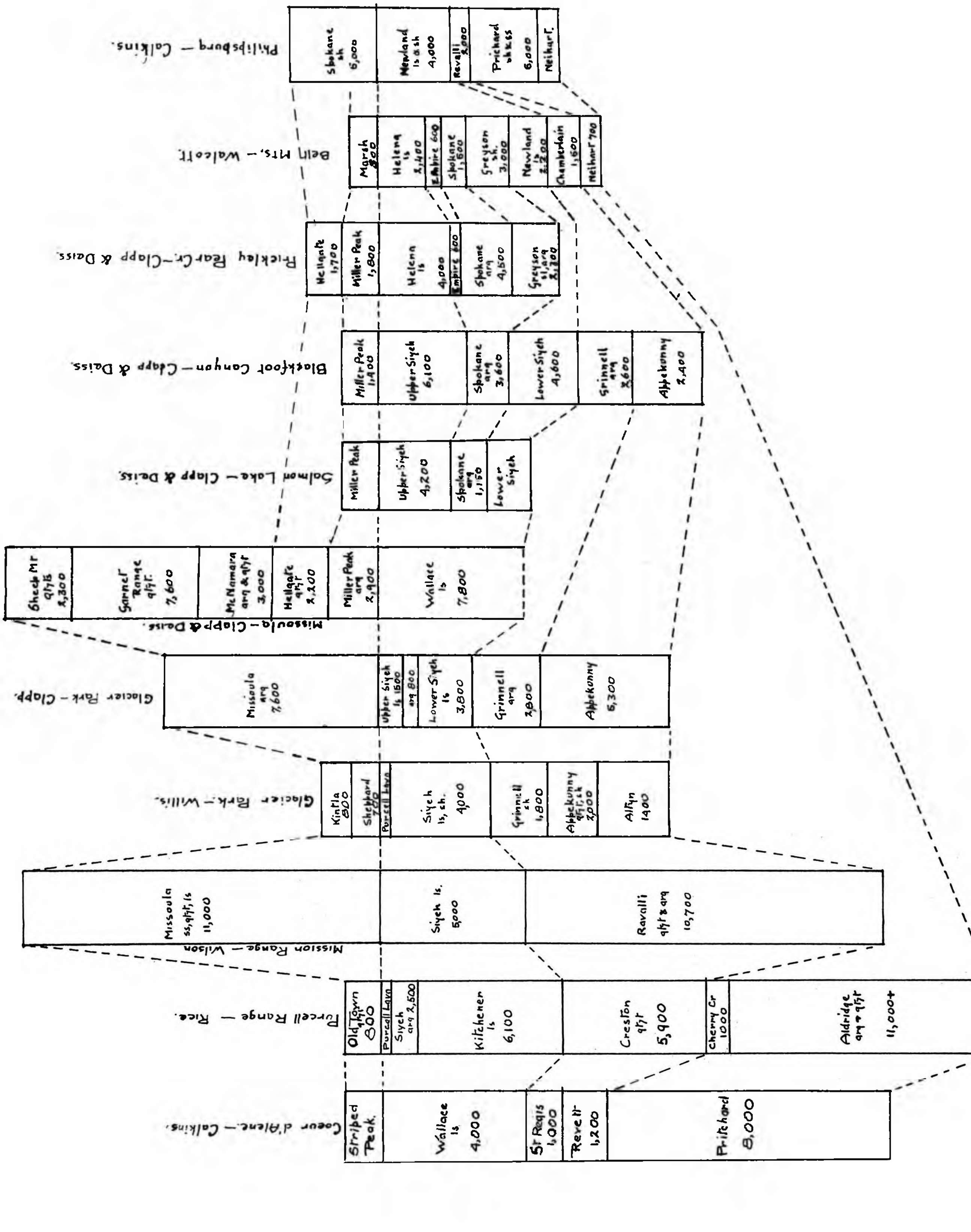
5. Walcott (18, p 1) believed that the Purcell basin was a shallow, brackish or fresh-water lake. He based his

conclusions on the sudden appearance of abundant life in the overlying Cambrian. Bauerman (19, p 25 B) also believed that the presence of pseudomorphs of salt crystals in the Gateway indicated that the Purcell basin had no connection with the sea. Neither of these lines of evidence are at all conclusive, and it seems doubtful if such a large basin could remain for so long a time without connection with the sea. The whole matter must be deferred, however, until further work reveals some more definite criteria.

Both Daly and Schofield believed that the sediments were derived from the erosion of mountains lying to the west of the Purcell sea. Daly concluded this from a study of the formations southwest of Kootenay Lake and those in the Purcell range. He found a thick series of sediments in the first locality which he believed to be the co-relatives of the Purcell series and which he called the Summit series. He found these to be considerably coarser than the Purcell series and concluded therefrom a westerly land mass for both series. Later workers have shown that the Summit series should be correlated with the Windermere series (11) which is considerably younger than the Purcell series , and his reasoning is therefore not valid. Schofield, however, found a coarsening of the sediments to the west within the Purcell series itself. He reports a considerable amount of conglomerate in the Aldridge near Goat River which lies beyond the map to the southwest, and there is no reason to believe that his conclusions are not correct. The work done in 1932 was over too limited an

TABLE IV

GENERAL CORRELATION TABLE



area to arrive at any independant conclusions on this matter.

Correlation of unfossiliferous formations can only be based on stratigraphic and lithologic evidence. In a series as uniform as that of the Beltian this is extremely difficult and cannot be entirely satisfactory. The attempt has nevertheless been made, and Table 4 p 59A is the result, based largely on a correlation table given by Clapp. (17)

Age of the Purcell Series:

In the earliest reconnaissance work both Dawson (2, p 148 B) and McEvoy (21, p 87) believed that the Purcell series was Cambrian in age. Daly, (13, p 119-138) after working along the International Boundary, decided that it was somewhat older and placed the lower part of his Creston formtion in the pre-Cambrian. Schofield's opinion, and one with which the writer concurs, is that the whole Purcell series is pre-Cambrian in age.

During the course of his early work in the Cranbrook area Schofield spent some time in the Elk River valley at Elko in the western part of the Rocky Mountains examining the top of the Purcell series. There he found two formations overlying the Gateway conformably and a number of Cambrian formations overlying these unconformably. The following is his section for this locality:- (25, p 6)

Devonian ---------- Jefferson limestone -- 300 feet.

Disconformity

Middle Cambrian -- Elko formation ------ 90 feet.

	Burton formation -----	60 feet.
Lower Cambrian ---	Burton formation -----	18 feet.
Disconformity		
Pre-Cambrian -----	Roosville formation --	1,000 feet.
(Beltian)	Phillips formation --	500 feet.
	Gateway formation ----	1,000 feet.
Base unexposed.		

He goes on to say; "Although no structural features emphasize the presence of an unconformity at the base of the Burton, yet from other evidence such an unconformity is believed to exist." The Purcell series in this locality is therefore believed to be unconformably overlain by a Lower Cambrian formation.

In 1932 a considerable amount of data was collected to show that the Lower Cambrian formation (Perry Creek formation) overlies the Old Town series unconformably. A careful telemeter survey of the type locality southeast of St. Eugene Mission made the following facts clear:-

1. The Perry Creek formation lies on different horizons of the Old Town series.

2. There is a very striking difference in the degree of metamorphism in the argillites of the two series.

3. Except for the annelide-like markings, the Old Town series contains no fossils while in the overlying Cambrian formation they are abundant and well preserved.

South of Marysville, however, the actual contact between the Annelide formation and the Perry Creek is exposed for several hundred feet. The Annelide formation consists of a succession of sandy quartzites while the Perry Creek is argillaceous throughout. There is a sharp line of contact and the lithological break is profound, but there is no direct evidence of an unconformity.

In 1922, 1923, and 1924 Walker, (10, p 6-20) working in the Windermere Map area to the north of the Cranbrook district, collected evidence to show something of the magnitude of the break between the Cambrian and the Purcell series. He was able to trace the Gateway, Phillips, and Roosville of the Ram Creek section into his area and found another formation overlying them conformably. He describes a series 4,000 to 7,000 feet thick overlying the Purcell series unconformably which he called the Windermere series. This series he believes to be pre-Cambrian in age since the Lower Cambrian rests in different places on different horizons of the Windermere, indicating an interval of erosion between the times of deposition of the two series. Speaking of the contact between the Purcell series and the Windermere he says: "The Purcell sediments were subjected to folding in pre-Windermere time, as is indicated by the angular unconformity between the two series. The unconformity is marked, though the discordance seldom reaches 45°. There is little difference between the degree of metamorphism exhibited by the two series, and this fact, coupled with the moderate angular discordance, indicates that the pre-Windermere folding was of a broad, open character. There must, however, have been a considerable uplift to give a relief that would account for the formation of the great basal conglomerate of the Windermere series."

The Purcell series must, therefore, be pre-Cambrian in age with an interval of time between its deposition and that of the Lower Cambrian to allow some diastrophism, the deposition of the Windermere series to the north, and a further interval of erosion.

Perry Creek Formation:

On the hills in the salient between Perry Creek and the St. Mary's River dark grey argillities were observed that showed some properties differentiating them from any member of the Purcell series. The succession was called the Perry Creek formation and was eventually found to include the Lower Cambrian Eager Shales of Schofield. (15, p 12)

The type locality for the Perry Creek formation is the region already mentioned. The formation also occurs to the east of Wycliff where it appears to be a block within the zone of the St. Mary's River fault. Another small block in the same general zone occurs to the west of Wycliff but is known only from a few scattered exposures. An important locality extends to the southeast of the St. Eugene Mission paralleling the belt of Old Town and it is in this zone that all the known outcrops of the Eager formation occur.

The top of the Perry Creek has not been observed and it is therefore impossible to measure a complete section. Measurements were made, however, at the locality east of Wycliff which gave 6,000 feet for the thickness of the section exposed there but, since both the top and bottom of it are bounded by faults, the figure merely indicates that the series is a thick one.

Too little is known about the Perry Creek formation to subdivide it at the present time, but there is little doubt that, with further information, such subdivision could be made.

The Perry Creek formation consists of greenish-grey to grey, slaty argillites. When sheared they have a peculiar silky, fibrous structure that is highly characteristic. The argillites are not notably calcareous, but limey beds occur all through the series which tend to weather slightly buff-coloured. There is a considerable development of pyrite and some rusty weathering. Some of the argillites show, across the foliation, small lenses of limey material half an inch or so in length. These give the rock a spotted look that is a good guide to the formation. (Figure 5) In the highest part of the section known, dark grey to almost black cherts are intercalated with beds of white and grey crystalline limestone. This part of the series may be deserving of a separate formational name but too little is known about it at the present time to apply one.

The phase of the Perry Creek known as the Eager formation consists of three types of argillites all of

Figure 5

Sketch showing appearance of some of the Perry Creek and Eager argillite with the lenticular, calcareous spots mentioned in the text, p 64. Natural size.

which grade into each other. Two of these are soft, fine-grained, smooth rocks one of which is brick-red in colour and the other olive green. The latter resembles some of the rocks found in the Siyeh. The third type is a bluish-grey, rusty weathering sandy argillite that bears a considerable resemblance to the Aldridge argillites. Trilobites remains have been found in all three types.

Age of the Perry Creek Formation:

Well preserved fossils, mostly trilobite remains, have been recovered from the Eager formation, and a collection reported on by Walcott contained the following species:- (15, p 12)

Callavia, c. f. nevadensis - Walcott.

Wanneria, n. sp. ?

Mesonacis gilberti - Meek.

Wanneria, c. f. fremonti - Walcott.

Olenellus, c. f. fremonti - Walcott.

Prototypus senectus - Billings.

Speaking of them Walcott said: "This fauna belongs to the upper portion of the Lower Cambrian and it is essentially the same as that found above the tunnel at Mt. Stephen, B.C., and also found more or less all along the Cordilleran system down into southern Nevada."

The corellation of the Perry Creek and the Eager has been made on the following grounds:-

1. There is a very striking lithological similarity between certain types of the Perry Creek and the Eager. The type of rock referred to bears no resemblence to any seen in the other formations in the area.

2. Although no fossils were found in place in the Perry Creek, even after a dilligent search, three pieces of fossiliferous float were found near outcrops of that formation. Two of these were found at the type locality for the Perry Creek where no Eager has ever been seen, and the third on the east slope of Signal Hill a considerable distance beyond the limits of the Eager outcrops. All three are of rock that is typical of the Perry Creek.

3. At no place has the Eager been found without the

presence of the Perry Creek being discovered nearby, although efforts to trace one into the other have, so far, been unsuccessful.

It is therefore concluded that the Eager is a slightly foliated portion of the Perry Creek series and that the whole series is Upper Lower Cambrian in age.

Correlation:

Schofield (15, p 35) has correlated the Eager formation with the lower part of the Burton on fossil evidence obtained by Burling (22, p 125). Walker (10, p 16) has also correlated it with the Mt. Whyte formation in the Field Map Area (9, pp 3-66).

Superficial Deposits

The whole basin of the Trench is occupied by a great thickness of unconsolidated material. The best exposures of it are seen along the lower part of the St. Mary's where the river has cut a deep trench through these deposits, leaving bold bluffs several hundred feet high. Since recent work has led to no important changes Schofield's subdivision of these deposits (14) is given in Table II, p 32 A.

A number of detailed sections were studied at various points along the St. Mary's River and from them the generalized section given below was compiled. A great amount of lateral variation made the task of generalization a difficult one and two of the detailed sections are reproduced to illustrate this variation.

<u>Generalized Section:</u>

Recent ------- Marysville Sands.

Silts, sands and gravels, coarser at the base --------------------------------- 10 feet.

Unconformity.

Pleistocene -- Wycliff Drift. (of Wisconsin age)

Boulder clay with sandy lenses some of which are of considerable extent ---- 75 feet.

Unconformity.

St. Eugene Silts.

Silts, sands and gravels; calcareous, rusty weathering and carrying fossils in places ---------- 200 feet.

Resting on a rough, rocky outcrop ---- 285 feet.

Section taken directly opposite Wycliff, and on the south bank of the St. Mary's River.

Recent ------- Marysville Sands.

Silts --------------------------------- 10 feet.

Unconformity.

Pleistocene -- Wycliff Drift.

Boulder Clay ------------------------- 80 feet.

Unconformity.

St. Eugene Silts.

Massive, poorly sorted conglomerate, better sorted at the top. Lignite and wood ---------------------- 140 feet.

Base unexposed. --------------------- 230 feet.

Section taken on the north bank of the St. Mary's River about three miles east of Wycliff.

Recent ------- Marysville Sands.

	Loamy sand ------------------------	3 feet.
	Unconformity.	
Pleistocene -- Wycliff Drift.		
	Boulder clay ----------------------	30 feet.
	Unconformity.	
	St. Eugene Silts.	
	Fine, calcareous silts -------	100 feet.
	Gravel or loose conglomerate --	50 feet.
	Silts ------------------------	5 feet.
	Boulder clay (?) of gravel ---	25 feet.
	Non-limey, fossil bearing, rusty silts ----------------	50 feet.
	Rusty gravels with lignite ---	15 feet.
	Base unexposed -------------------	278 feet.

<u>The St. Eugene Silts:</u>

The St. Eugene Silts were laid down in a Pleistocene lake which occupied the portion of the Rocky Mountain Trench now traversed by the last ten miles of the St. Mary's River. The limits of this lake are very imperfectly known, but it was undoubtedly a large one. The silts appear to be similar to those found in the Cariboo District by Johnstone and Uglow who say:- "The silt, (in the Cariboo District) judging by its even stratification and wide extent, was deposited in a series of lakes formed during the Pleistocene time."

The lower part of the section consists of gravels partly consolidated by a calcareous cement and most exposures are stained with limonite. Some sandy beds occur in this part of the section which carry a well preserved fossil flora. Pieces of lignitized wood are common and seams of lignite two or three feet thick occur. The upper part of the formation is finer grained and consists of limey, well-bedded, floury silts with intercalated lenses of gravel. It is just possible that some of these gravels may be glacial deposits, and there is a possibility that the upper part of the section may be younger than the lower. However, no sign of any unconformity could be recognized.

Age:

A study of the fossil flora found in the base of the St. Mary's Silts was made by Hollick (14, p 90) who identified it as Pleistocene in age and made the following comments. "An analysis of these identifications indicates that at least a warm temperate climate must have prevailed in the Kootenay Valley at the time when this flora was living there. The presence of the genus Ficus alone is sufficient evidence on this point, inasmuch as this genus is tropical, for the most part, in its distribution, and only three species range as far north as the southern United States. The other genera are so widely distributed, north and south, that, regarded by themselves, they would have but little significance as climatic indices. The prevailing large size of the leaves, however, indicates a luxuriant growth such as would probably obtain only in a climate milder than that of the middle United States, and is corroborative of the evidence furnished by the genus Ficus in this respect."

The St. Eugene Silts are overlain unconformably by moraines of the latest glacial stage and are thus definitely older than the Wisconsin Ice-sheet. The possibility of different ages for the top and bottom has been mentioned but is not sufficiently likely to deserve further discussion. The fossil evidence indicates that they are Pleistocene in age but does not determine whether they are pre-glacial or inter-glacial. Arguments in favour of each hypothesis are summed up below.

Facts in favour of a pre-glacial age:-

1. In every case where the contact between the base of the St. Eugene Silts and the underlying consolidated rock is exposed, the rock surface is irregular and shows no sign of having been glaciated.

2. The basal member of the formation, in each of these occurrences, is composed of fragments of the underlying rocks. If it were formed from re-worked glacial debris it would be expected to show a greater heterogeniety with many pebbles of composition different from that of the underlying rocks, a condition illustrated by the glacial deposits overlying the Silts. The basal gravels do not, therefore, appear to be re-worked glacial deposits.

3. Boulders of the Purcell diorite in the gravels of the formation often appear to be badly decomposed which

suggests that a considerable interval of time has elapsed since they were deposited in their present position. (53)

4. Pieces of wood found in the base of the formation have been almost completely lignitized. Speaking of the lignite found in the Cariboo District, Johnston and Uglow say:- "The lignite --- may have been formed in interglacial time, but if so, it seems remarkable that such complete alteration should have taken place. More probably it is of pre-glacial (late Tertiary) time."

5. The beds of the Silts have been seen to dip as much as 5° or 10° to the east suggesting minor diastrophic movement since the time of their deposition. The silts are extremely fine-grained and were obviously laid down in a body of still water and, therefore, horizontal. (77) The dip cannot be depositional, ~~consequently~~.

Facts in favour of an interglacial age:-

1. The deposits are very slightly consolidated, which would scarcely be expected should they be pre-glacial in age. Late Tertiary sediments in the Okanagan district, for example, are fairly completely lithofied. (78, pp 100A-108A)

2. In the chapter on glaciation evidence suggesting an early stage of glaciation was cited. Only one stage is represented above the Silts, unless the upper part of the section is considered to represent a period of glaciation later than the Wisconsin. Even if it were so, this could not correlate with the Albertan which the early stage of glaciation is believed to be. The Albertan stage of glaciation must therefore have taken place before the deposition of the St. Mary's Silts

and the erosion of the inter-glacial interval must have removed all traces of it.

5. In composition and thickness the St. Eugene Silts are similar to those described by Dawson (23, p 251 B) and Drysdale (24, p 150) from near Ashcroft which are underlain by an older boulder-clay.

Assuming as a hypothesis that the St. Mary's Silts were laid down during a long warm to tropical inter-glacial period following the Albertan glacial epoch, and that erosion during that time removed almost all traces of the glaciation of that epoch, the arguments in favour of a pre-glacial stage can be answered satisfactorily.

1. Evidence of glaciation of the rock surface was destroyed by erosion before the deposition of the Silts.

2. Erosion had destroyed the components of the Albertan tills and the gravels in the sections examined were deposits formed by normal erosion and deposition.

3. The decomposition of the boulders could have been accomplished under suitable conditions since Albertan times.

4. The elapse of time since the close of the Albertan may have been sufficiently great to form the lignite under suitable conditions.

If the pre-glacial age be assumed the arguments in favour of an interglacial age are not so easy to answer. It is therefore felt that the hypothesis of an inter-glacial age is more consistant with the known facts and that age is tentatively assumed. If it is correct the interglacial period must have been a very long one with a warm or even tropical climate.

The Wycliff Drift:

This formation consists essentially of massive, structureless boulder clay resting on a glaciated surface, or overlying the St. Eugene Silts unconformably. It varies considerably, both as to the proportion of boulders to clay, and in the average size of the boulders which range from small pebbles to huge blocks 5 or 6 feet long. Many of these boulders show well preserved striations. Numerous lenses of sand and gravel are interbedded with the boulder clay some of which are so large that they may, in a limited exposure, be mistaken for a separate formation. About half the boulder clay is strongly limey, as if the clay were formed by the comminution of a calcareous rock. The Wycliff drift forms the greater part of the present land surface along the Trench, although locally it is overlain by the Marysville Sands. It was evidently deposited during the retreat of the Wisconsin ice-sheet, and varies in thickness in a short distance from practically nothing to over two hundred feet.

The Marysville Sands:

The Marysville Sand occurs as a superficial deposit mainly confined to the Rocky Mountain Trench and its vicinity. It consists of stratified sands apparently laid down in depressions in the underlying glacial drift, probably by sheet-flood erosion. It is a comparatively unimportant formation with a maximum thickness of fifteen feet, and has done little to mask the structure of the morainic material.

IGNEOUS ROCKS

The igneous geology of the Cranbrook area, is, on the face of it, comparatively simple. Only two types of igneous rocks are at all abundant:- 1. The Purcell diorites, and 2. Granitic stocks and bosses. The former are of pre-Cambrian age and the latter late Mesozoic or early Tertiary. The Purcell diorites are by far the more abundant.

The Purcell Diorites

The Purcell sills and dykes have been the subject of great interest since they were described by Daly in 1912. (13, pp 221-225) The sills have been cited as showing typical examples of differentiation in place, and the variations so produced have been accounted for in several ways. They are genetically connected with one of the types of ore deposits in the Cranbrook area.

The Purcell intrusives are found almost everywhere in the Purcell series below the top of the Siyeh. Occasionally an area of a square mile or so may be without them, but this is exceptional and they are often extremely abundant. They assume three general forms:- 1. Dykes, 2. Bosses, and 3. Sills.

Purcell Dykes:

Although the Purcell dykes are not as common as the sills they are widely distributed in the Cranbrook area and are particularly abundant in the upper part of the Purcell series. Although they are small in comparison with the gigantic sills, bodies 50 feet wide are not uncommon and they have been traced for a distance of a mile or more. They are undoubtedly genetically connected with the sills and probably served as feeders to them as well as to the Purcell lavas, although no direct evidence of this was seen. Since the petrography is identical with that of the sills a separate discussion of this is unnecessary.

The Purcell Boss:

This type of intrusive is known only from a single locality, a mile or so east of Marysville. The reader is referred to the areal map to assist in following the description, and, although on account of the scarcity of outcrops the mapping of this body is largely diagramatic, it is believed to be sufficiently accurate to justify the conclusions drawn. The following are the observations made and the conclusions reached from them:-

1. The main intrusive is a boss-like body from which apophyses of various sizes extend with as much irregularity as do the arms of an octopus. As the distance between the offshoots and the parent mass increases the former become more regular and finally assume the appearance of normal sills. A connection between the dykes and the true sills is thus suggested.

2. The minerology of the boss is the same as that of the sills:- the only variations seen within the boss were in the grain size and in the proportion of ferromagnesian min-

erals, and nowhere were phases seen that are different from those occuring in the sills.

3. The sediments are highly metamorphosed in the vicinity of the intrusive. This metamorphism is not of a different type from that associated with the sills, but is rather more extensive. It is concluded from this that the intrusion of the boss was accompanied by the release of a greater abundance of volatiles than usually follow the intrusion of the sills, although those volatiles were apparently of the same type as those accompanying the intrusion of the smaller bodies.

4. A great number of quartz veins were seen in all parts of the intrusive, in some of which sulphides are locally abundant. These veins are similar to those found in the normal sills, but were more frequent and generally larger which supports the conclusion just stated regarding the relative abundance of the volatiles.

5. The sediments are much more contorted in the vicinity of the intrusives than elsewhere in the same region. Two explanations for this come to mind:-

a. The sediments were deformed before the intrusion, and the subsequent crushing formed a zone of weakness into which the igneous magmas found their way. The crumpling and contortion in the vicinity of the intrusive is generally extremely severe, so severe, in fact, that if produced by a stress external to the locality, evidence of it should be apparent for some distance in the direction from which such a stress was imposed. The sediments however, to within a hundred feet or less of the intrusive body on all sides, are very regular in their attitude and it seems highly improbably that they could have transmitted the force that produced the degree of contortion observed in the area now largely occupied by the intrusive.

b. The magma was forced in under considerable pressure and so deformed the sediments. This would seem to be the most likely hypothesis although there must have been some initial weakness in the sediments to localize the intrusions at these points. In this connection it is interesting to note that Daly (25, p 64) and Iddings (82, p 313) suggest that sills must be forced in under at least sufficient pressure to lift the weight of the superincumbent sediments.

In brief then, the exposures in this locality are believed to represent a boss-like body of essentially the same composition as the normal sills that was intruded under considerable pressure in a zone of weakness in the sediments. Mineralizers accompanied the intrusion and metamorphosed the adjacent sediments while a number of sill- and dyke-like apophyses were injected into the deformed sediments from the parent boss. Further away from the main body of the intrusive these apophyses became more regular and indistinguishable from the sills occurring in other parts of the district.

The Purcell Sills:

Sills are the commonest form taken by the Purcell intrusives. In contrast to the dykes, which are common er in the upper formation of the Purcell series than in the lower, the sills are larger and more abundant in the lower formations and particularly so in the Aldridge. So abundant, indeed, are they that it was found impossible to show them all on the map on the scale at which the work was carried on. In spite of this there are not many places in the Cranbrook area where a complete section of a sill is exposed.

They conform to Daly's definition of a true sill (25, p 64) since they were intruded into the strata at a time when the latter were definitely horizontal. They do not, however, invariably parallel the strata continuously. On the west face of the Rocky Mountains opposite Cranbrook, three or four sills are clearly exposed for a length of several miles. Seen from a distance of three or four miles it is apparent that some cross-cut the structures at very low angles; a relationship that would probably be missed by a detailed examination. The sills vary in size from thin sheets only a few feet thick and correspondingly limited in extent to immense bodies over a thousand feet thick and a number of miles long. One sill in Idaho (81, p 37) that is evidently related to the Purcell sills, was found to be over 2,000 feet thick and another was traced for a distance of over 39 miles. In almost all cases there is little variation in thickness along the strike and they show no tendency to become laccoliths.

Looked at as a whole the sills in the Cranbrook area present a remarkable uniformity in appearance but a detailed study shows them to be more complex than is at first realized. It is believed that some of the sills may be multiple. This was first suspected after the detailed examination of a sill exposed in some bluffs near Lumberton where the following relationships can be seen. A sill 215 feet thick is exposed across its full width and shows a concentration of ferromagnesian minerals along both contacts. (Figure 6) This

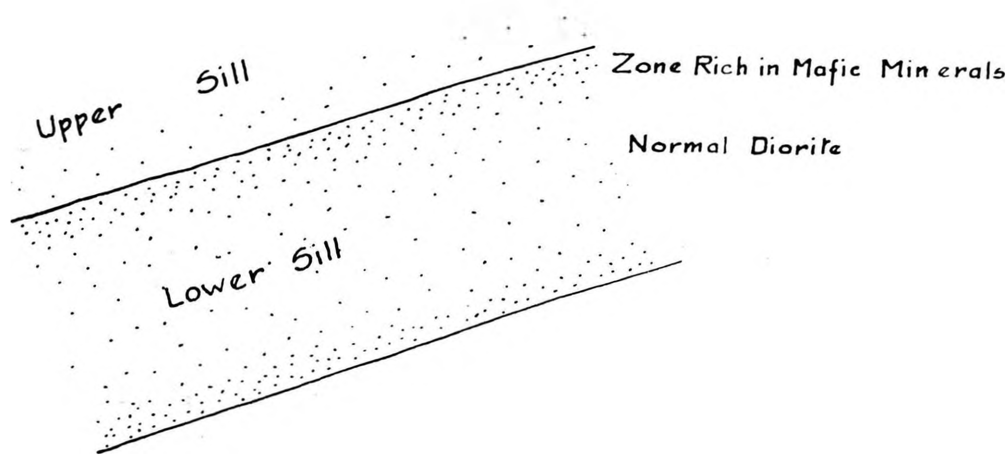


Figure 6

Sketch showing the concentration of the mafic minerals near the borders of the Purcell sills. This sill is 215 feet thick.

concentration is seen in nearly all the sills, but, in this instance, the rock beyond the upper contact is again that of the Purcell intrusives. It was at first believed that the basic zone represented a concentration of ferromagnesian minerals within the body of a single sill, but it was later concluded, for the following reasons, that such was not the case.

a. No basic concentrations are known to occur in any other sill except along the margins.

b. The concentration cannot represent an altered zenolith because all the intruded rocks in this locality are quartzites which are more siliceous than the intrusive and could not produce such a rock. (83)

c. The change in the texture going upwards from the normal rock to the basic phase is gradational, but from the basic phase to the normal rock in the upper exposures the transition is very abrupt.

The exposures are therefore believed to represent two separate intrusions, the basic phase belonging to the lower one. For reasons mentioned below, it is believed that the lower sill was intruded later. Daly says that a multiple sill is "a compound intrusion of sill form and relations, and is the result of successive injections of one kind of magma along a bedding plane", (25, p 65). The body described above appears to conform to this definition. This discussion has been introduced here to show that, when drawing conclusions from observations made from specimens taken across one of the Purcell sills that is not completely exposed, great care must be exercised to be sure that these specimens were obtained from a single, homogeneous body.

Petrography:

Megascopically the Purcell diorite is a grey-green, dark coloured rock in which hornblende is the most prominent mineral. The rock may be a fine, even-grained one in which the dark and light coloured minerals are so distributed as to give the rock a speckled appearance which may best be described as a "salt and pepper" texture, or more commonly, medium to fairly coarse-grained. These, and particularly the latter type, are characterized by the development of long and conspicuous prisms of amphibole. (Figure 7) The fine-grained

Figure 7

Sketch showing a plume-shaped crystal of amphibole as developed in certain coarse-grained phases of the Purcell sills. Natural size.

facies is naturally found in the smaller sills and near the margins of the larger ones, although the rock may be coarse-grained right up to the contact.

Under the microscope the sills were found to be of two distinct types very closely related, but distinguished by the nature of the plagioclase and of the amphibole. The following minerals were identified in the various slides examined:- amphibole; plagioclase; quartz; micropegmatite; magnetite; ilmenite; biotite; apatite; leucoxene; calcite; and epidote.

Amphibole:

The amphibole is by far the most abundant mineral present in all the slides. (Plate XI, A,B,C, and D, p 84A) It varies from 45% to 70% according to Rosiwal determinations and occurs in minute blades and in crystals that grow to two inches long or more and curve and branch so as to resemble plumes. (Figure 7, p 82) Minute idiomorphic crystals also occur within the quartz and feldspar crystals. The prism faces are usually idiomorphic against the other minerals but no terminal faces appear in the larger crystals. The amphibole is often highly poikalitic with abundant inclusions of quartz, feldspar, and magnetite. The mineral is usually quite fresh, but in some slides it is partly altered to chlorite.

A careful examination of its optical properties was made using the immersion oils method outlined by Larsen (126, pp 1-27) and two partial chemical analyses were obtained. The indices of the immersion oils were determined by means of an Abbé refractometer and temperature corrections applied in all cases.

As a result of these studies the amphibole was found to be of two types which have been called type "A" and type "B" for convenience. Both types resemble common hornblende more closely than any other amphibole but, at the same time, do not correspond to any examples that the writer has been able to find in the literature.

In table V, p 85 the optical properties of the amphiboles obtained from a number of specimens of the Purcell diorites, together with those of a similar amphibole from a specimen of ore believed to be related to the sills, have been set down. It will be seen that type A is distinguished from type B by having higher indices of refraction. Later it will also be seen that type A has a much greater content of FeO. In Figure 8 the indices of the two types of amphibole have been

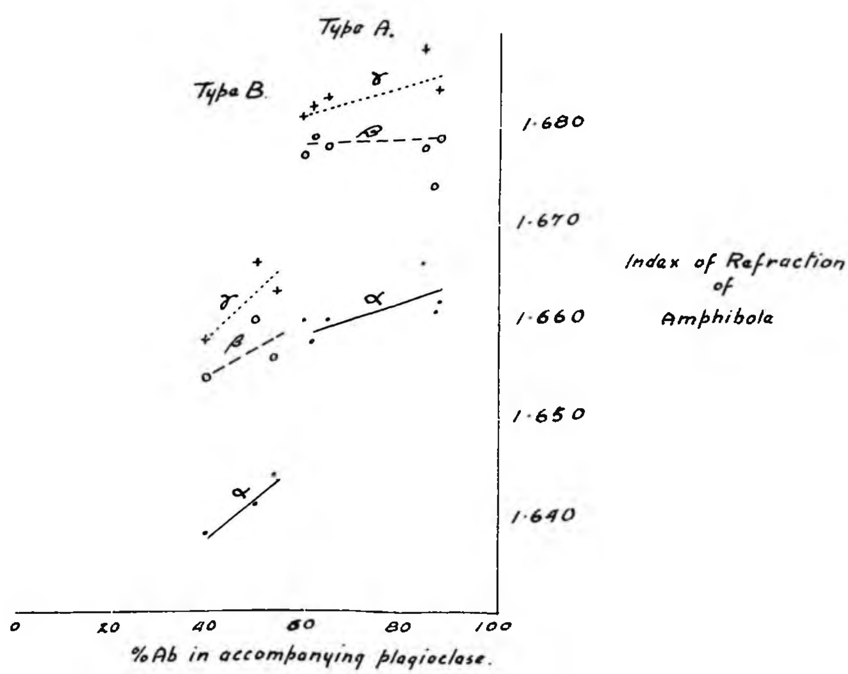


Figure 8

Plate XI

Tonalite. Purcell sill near Lumberton. Shows Ilmenite (black), hornblende (H), quartz (Q), and plagioclase (P). Note the abundant inclusions in both the quartz and plagioclase and the skeleton crystal of ilmenite.
Upper nicol out. # 513R X22.

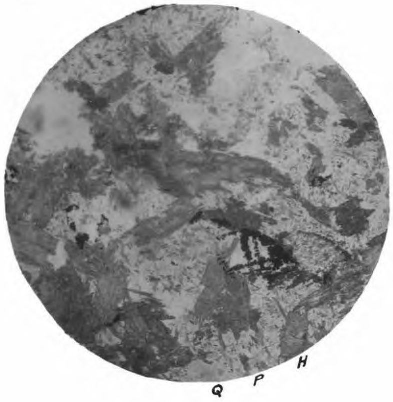
Tonalite. Note the absence of twinning in the plagioclase and the difficulty of distinguishing it from quartz.
Crossed nicols. Same field as A X22.

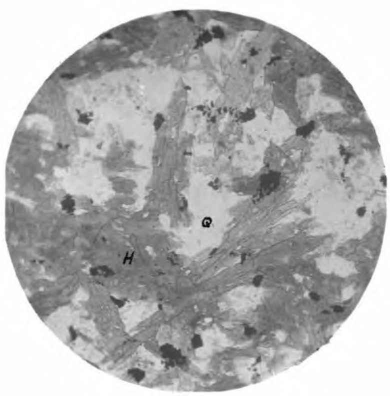
Abnormal phase. Purcell sill near Lumberton. Shows hornblende (F), quartz (Q), and magnetite (black specks). There is some plagioclase present but it cannot be recognized in the illustration. Note the tendency for the quartz to replace the hornblende in the center of the slide.
Upper nicol out. # 509 X62.

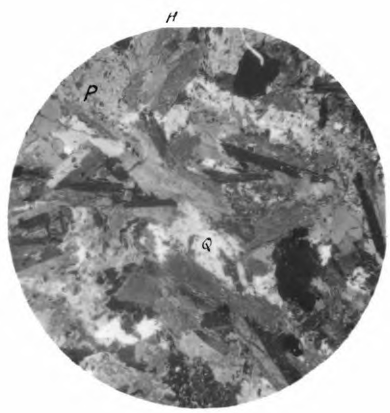
Tonalite. Purcell sill south of Aldridge. Shows hornblende (H), quartz (Q), and plagioclase (P). Note the quartz replacing the plagioclase near the point P.
Crossed nicols. # 3R X22.

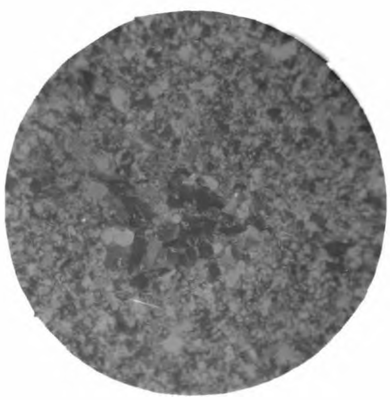
Metamorphosed Aldridge argillaceous quartzites. Shows cluster of biotite blades in the center of the field. Note the fine-grained nature of the quartzite.
Crossed nicols. # 294R X62.

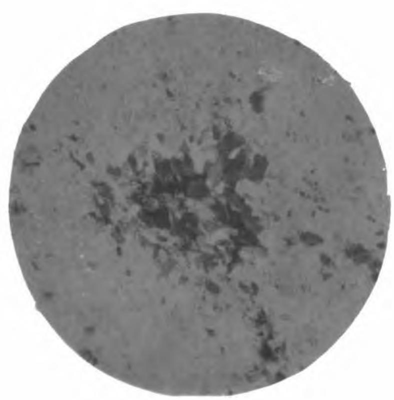
Same field as E. Note the scarcity of biotite in the area surrounding the biotite cluster.
Upper nicol out. X62


Q P H


Q
H


H
P
Q





Optical Properties of the Amphiboles Found in the Igneous Rocks of the Cranbrook Area

Table V

Type A.

No	Spec. taken from	α	β	γ		$Z \wedge C$	Calculated 2V	Optic Sign
86C	Purcell Sill near Loco;(@ base)	1.661	1.674	1.676	.015	15°	43°	neg
91C	Purcell Sill near Loco;(115' from base, about center)	1.662	1.679	1.684	.022	18°	57°	neg
97C	Purcell Sill near Loco; (close to top)	1.666	1.678	1.688	.024	18°	84°	neg
3R	Purcell Sill from road south of Aldridge.	1.658	1.679	1.682	.024	17°	41°	neg
513R	Purcell Sill from road south of Aldridge near Lumberton. Upper Sill. (61' from base)	1.660	1.677	1.681	.021	17°	51°	neg
517R	Purcell Sill from road south of Aldridge. (114' from base)	1.660	1.678	1.683	.023	17°	55°	neg
461R	Differentiate ore from the Mystery Mine	1.659	1.675	1.678	.019	17°	46°	neg
	Average for type A	1.661	1.677	1.687	.021	17°	58°	neg

Type B

No	Spec. taken from	α	β	γ		$Z \wedge C$	Calculated 2V	Optic Sign
101C	Purcell Sill near Lumberton. Lower Sill. (halfway up)	1.644	1.656	1.663	.019	18°	76°	neg
102C	Purcell Sill near Lumberton. Lower Sill. (near top)	1.638	1.654	1.658	.020	18°	53°	neg
276C	Purcell Sill from Lone Tree Butte.	1.641	1.660	1.666	.025	19°	58°	neg
	Average for type B	1.641	1.657	1.662	.021	18°	58°	neg
481R	Granodiorite at Fish Lake	1.685	1.692	1.698	.013	28°	85°	neg

The three indices of refraction of the amphiboles in the Purcell sills ~~is~~ are plotted against the Ab ratio of the accompanying Plagioclase. The two types A and B appear to form a discontinuous series.

• denotes α

0 denotes β

x denotes γ

plotted against the Ab ratio of the plagioclase accompanying them in the rock and it is clearly illustrated that the two types form a discontinuous series. The break from type A to type B is too abrupt for them to be gradational into each other.

In table VI, p 87, the chemical analyses and optical properties of a number of amphiboles given by Niggli (127, pp 462-467) have been contrasted with the average for each of the two types found in the Purcell sills. The chief difference between the Purcell amphiboles and hornblende appears to lie in the increased content of iron oxide in the former and the smaller size of the optic angle, when the indices are comparable. Type B resembles some varieties of pargasite rather closely except that it is negative while pargasite is positive.

<u>Plagioclase:</u>

The plagioclase also occurs in two types related to the two types of amphiboles; that occurring with type A varying from oligoclase to acid andesine (Ab 88% to 60%; An 12% to 40%) and that occurring with type B from basic andesine

Table VI

Comparative Analyses of Hornblendes

	Type A	Type B	Hornblende Grenville Canada	Black Hornblende Edenville	Hornblende Canada	Pargas-ite Pargas
SiO_2	42.80	44.66	45.79	41.99	43.76	43.90
TiO_2	N.D.	N.D.	1.20	1.46	0.78	0.70
Al_2O_3	11.26	12.64	11.37	11.62	8. 33	12.52
Fe_2O_3	15.06	15.13	0.42	2.67	6.90	0.38
Fe O	14.21	8.85	0.42	14.32	10.47	5.95
MnO	N.D.	N.D.	0.39	0.25	0.50	N.D.
MgO	3.82	4.85	21.11	11.17	12.63	18.91
CaO	10.08	10.70	12.71	11.52	9.84	12.69
Na_2O	1.92	1.80	2.51	2.49	3.43	1.34
K_2O			1.69	0.98	1.28	1.30
H_2O-	.16	.15	0.67	.61	0.65	0.51
H_2O-	.38	.38	--	.08	0.10	0.10
F	N.D.	N.D.	2.76	.80	1.82	2.29
Total	99.69	99.13	101.04	99.96	100.49	100.59
$n\alpha$	1.661	1.641	1.6142	1.6583		1.6329
$n\beta$	1.677	1.657	1.6180	1.6701	1.67	1.6380
$n\gamma$	1.682	1.662	1.6332	1.6789		1.6579
$n\gamma - n\alpha$	.021	.021	.0190	.0206		.0190
2V	58°	58°	52°	81°42'		63°01'
Z C	17°	18°	27½°	23°48'	33.20	26°15'

Absorption	Type A	Type B	Hornblende Grenville Canada	Black Hornblende Edenville	Hornblende Canada	Pargasite Pargas
~~X Y Z~~				Dark brownish green		
X	Pale yellow				Olive green	
Y	Olive green				Olive green	
Z	Blue green				Dark blue green	
	Y > Z > X	Y > Z > X				

Data on Hornblende and Pargasite obtained from Niggli (127, pp 462-467) to acid labradorite (Ab 54% to 46%; An 46% to 54%). It is generally fresh and shows very little twinning, but in some slides it is so altered to serecite and kaolin that it is impossible to determine its exact nature. Next to the amphibole it is the most abundant mineral present in the Purcell diorites and Rosiwal computations have shown it to vary in amount from 4% to 41% of the rock. The determination of the amount is rendered rather inaccurate in some instances by the fact that the mean index of refraction is very nearly the same as that of quartz and it is often difficult to tell the two minerals apart. (Plate XI B, p 84A)

Quartz:

Quartz is always present, but usually in small amounts, from 2% to 10%, although there may be as much as 25% occasionally. It occurs in allotriomorphic grains and is usually interstitial. When it is particularly abundant it appears to have replaced both the plagioclase and the amphibole to a considerable extent. (Plate XI, C and D, p 84A)

Micropegmatite:

Small quantities of micropegmatite were seen in one or two slides made from specimens taken close to the edge of the sills.

Magnetite and Ilmenite:

One or the other of these minerals is always present and often in amounts up to 4%. The magnetite occurs in grains and patches up to a couple of millimeters in diameter, while the ilmenite often shows a rod-like development in the form of skeleton crystals surrounded by leucoxene. (Plate XI, A and B, p 84A)

Biotite:

Biotite occurs in small flakes, often associated with the magnetite. It is generally very scarce but 6% or 7% of it is present in some specimens.

Apatite:

Apatite is present in small amounts as minute prisms in all the slides examined.

Leucoxene:

Leucoxene is commonly developed as an alteration product of the ilmenite.

Calcite and Epidote:

These minerals are not common as a rule but occur in veins and patches in some specimens. They are both undoubtedly secondary minerals the calcite being derived from the lime in the surrounding sediments.

Contact Metamorphism:

The effect on the sediments of the intrusion of the sills varies tremendously in different places. As a rule noticeable effects are confined to a belt about five feet in width paralleling the contact but may be observed over a considerably greater width. Biotite is developed more or less all through the Purcell Series. Harker (84, p 209) suggests that the development of this mineral is indicative of a low grade of thermal rather than dynamic metamorphism, and that it is formed at the expense of such stress minerals as chlorite and muscovite. Within about 100 feet of the sills there is an increase in the amount of biotite; the amount becoming noticeably greater as the sill is approached. It is usually developed in flakes distributed uniformly throughout the rock but in places, notably near Lone Tree Butte, it is developed in patches up to 10 or 15 millimeters across. (Plate XI, E and F, p 84A) The rest of the rock in this case is a white quartzite and much purer than the average argillaceous quartzite. Harker says that "biotite is formed from chlorite, 'serecite', iron-ores, and rutile of the original sediments", (84, p 49) and it is probable that this process has taken place here under the influence of the increased temperature furnished by the sills and that the constituents of the biotite patches have been derived from the sediments in their immediate vicinity by diffusion of the constituents to form the concentrations of biotite. The rest of the rock is thus left comparatively free of ferromagnesian minerals. According to Bowen (85) such a migration is perfectly possible and may have been facilitated by the presence of volatiles emitted by the sills. This type of metamorphism probably represents merely a recrystallization of the original constituents of the sediments without the addition of material from the intrusives and variations in the amount of biotite represents variations in the nature of the original argillaceous quartzites and the degree to which metamorphism has proceeded.

There is often a zone of metamorphism a few feet wide directly adjoining the contact of the sills that is of a different type. The chief ferromagnesian mineral in this zone is an amphibole similar to that crystallized in the body of the sill. Biotite is also present but in subsidiary amounts. High grade thermal metamorphism might produce amphibole from the biotite by reversing Bowen's reaction series (84) but the amount of amphibole present is far in excess of the amount that could be formed in this way, and there can be no doubt that the greater part must be formed from materials provided by the magma itself. Micropegmatites also are frequently seen in the rocks that have suffered severe metamorphism close to the sills. (Plate XIII, F, p166)

When the sills are in contact with calcareous rocks a zone of metamorphism 5 to 10 feet wide consisting of a fine-grained, green, cherty looking rock appears. This zone consists essentially of vesuvianite and epidote with possibly some wollastonite and garnet, as well as varying amounts of the unaltered calcareous argillites. The rock ~~was~~ is so fine-grained that accurate determinations were impossible. It is a common type of alteration product to be formed from calcareous sediments consisting essentially of lime, silica, and alumina, and, according to Harker, (84, p 82) does not need a very high temperature. It probably corresponds to Burrow's "calc-flinta". (84, p 89) A peculiar type of rock is produced when this process operates on the phases of the Kitchener showing molar-tooth structure. The worm-like segregations are evidently fairly pure calcite, since metamorphism has simply recrystallized them while the rest of the rock has altered to the "calc-flinta".

It should be noted that the evidence of this metamorphism does not suggest a very high temperature for the sills at the time of their intrusion.

Review of the Literature:

The Pioneer work on the Purcell Sills was done by Finlay (6) in 1902, but the rocks with which he worked were all badly altered and he was unable to obtain much information about them. Daly (13) in 1913 and Schofield (88 and 14) in 1914 and 1915, however, described them more fully, and discussed them. A brief review of their conclusions is set forth below.

During his study of the Boundary district (13) Daly mapped 24 bodies of the Purcell diorites of which he concluded that 22 were true sills varying in thickness from 50 to 1,000 feet. The normal rock described by Daly is very similar to that described above by the writer, except that Daly found the plagioclase to be more basic; varying between labradorite and basic byownite, with an average of about basic labradorite (Ab 33%: An 67%). The rock is thus a hornblende gabbro. Daly's Rosiwal analysis is given in Table VII Column 1, p 93. Daly, however, described another type of rock which he called a "biotite granite of abnormal type" which he believed to be a differentiate of the sills. He says; "Variations from this gabbro type (the normal rock)

Table VII

Rosewal Analyses of Phases of the Purcell Sills and Zones of Metamorphism

	Column 1 Daly Hornblende gabbro	Column 2 Daly Biotite granite	Column 3 Daly Biotite diorite	Column 4 Mark Creek	Column 5 Mark Creek
Hornblende	58.7%	-	49.4%	40%	-
Quartz	4.0%	46.0%	11.7%	30%	30%
Labradorite	34.8%	-	-	-	-
Oligoclase	-	1.5%	-	10%	20%
Andesine	-	-	16.5%	-	-
Orthoclase	-	29.1%	-	-	-
Titanite & magnetite	1.4%	.5%	.1%		
Biotite	.9%	22.0%	22.0%	15%	40%
Apatite	.2%	.5%	.8%		
Calcite	-	.4%	-		
Accessories				5%	10%

are very common in most of the sills. These generally consist in an increase of quartz and biotite, along with the appearance of orthoclase, which is crystallized either independently or in the form of micrographic intergrowth with quartz. As these constituents increase in amount, the hornblende seems to preserve its usual characters, but the plagioclase shows a strong tendency towards assuming the zoned structure; the core averages basic labradorite, $Ab1An_2$, and the outermost shells average andesine, near Ab_4An_3. When the quartz and micropegmatite become especially abundant, the plagioclase averages acid andesine or basic oligoclase. In several thin sections the plagioclase is seen to be mostly replaced by orthoclase and quartz, which, with the still dominant hornblendes, form the essential substances of the rock."

"These changes in composition, indicating that the sill rock has become more acid, are always most notable along the upper contacts." (13, p) According to him the extreme phase of this variation is the "biotite granite", which he says shows a confused crystallization, entirely unlike a normal granite, and the feldspars of which are always badly altered and full of dust-like particles. His Rosewal analysis of this rock is given in Table VII, Column 2.

Intermediate between the normal gabbro and the granitic phase, and transitional to both types is a rock that Daly describes as differing from the gabbro only in containing abundant quartz and biotite. His Rosiwal analysis for this phase is given in Table VII, Column 3.

Daly accounts for the formation of these various types by the "Assimilation-differentiation theory". He says:- "the acid zone is thereby conceived as due to the digestion and assimilation of the acid sediments, together with the sugregation of most of the assimilated material along the upper contact." His reasons for assuming this are briefly:-

1. The sills were intruded in a horizontal position.

2. When they were intruded the sills were extremely hot, as witness the great horizontal extent and the uniform thickness. This excess of heat would permit an unusual amount of assimilation.

3. Similarity in composition between the granitic phases and the intruded quartzites.

4. Composition of the other sills in the region. Daly believed that all the sills he examined showed a tendency to become more acid at the top although only in one or two instances was the extreme granitic phase actually present.

5. The field evidence shows an acutal digestion of the quartzites by the gabbro, both on the contacts and in Xenoliths.

Briefly then, Daly deduces the following series of events during and after the intrusion of the sills.

1. The injection of a quantity of magma of approximately the composition of a normal gabbro. This magma had considerable super-heat and great fluidity.

2. The assimilation of the intruded rocks by the magma; a process facilitated by the super-heat.

3. Gravitational differentiation of the resultant mixture with the acid phases segregated at the top.

Schofield also described the Purcell Sills in considerable detail in Mem 76 (14, pp 56-75 and 88). He believes that they are of two distinct types; simple and composite (85, p 5). The simple sills consist almost solely of gabbro. He directs most of his attention to the composite type and says that they "vary in composition from a hypersthene gabbro to a very acid granite or grano-phyre with intermediate members between these two extreme types" (14, p 57). The greater part of these consists of a rock which Schofield calls a hornblende gabbro and which has essentially the same composition as that described by Daly, although Schofield believes that all the hornblende has been formed from pyroxene by deuteric alteration (14, p 62). He also reports a considerable amount of micropegmatite and interstitial quartz. According to him, this rock grades into both a basic and an acid type. The basic phase Schofield calls a hypersthene gabbro, describing it as a dark grey, crystalline rock of granitic texture, in which the principle minerals are labradorite and pyroxene. The pyroxene he found to be of two kinds; hypersthene and augite, in about equal amounts. Hornblende is very common and in this rock too, Schofield believes it to be a secondary mineral after the pyroxene.

His description of the granophyre is essentially the same as Daly's of the biotite granite. He reports that the gramophyric zone is usually at or near the top of the sills but that its size bears no relationship to the thickness of the sill. He gives two examples of the zoning:-

1. A sill occurring on the International Boundary consists of an upper gabbro zone 26 feet thick passing downwards into a granitic phase 80 feet thick which, in turn, passes into a lower gabbro zone 30 feet thick.

2. Another sill near St. Mary's Lake has an upper granitic layer 70 feet thick which passes gradually downward into a gabbro layer also 70 feet thick.

Schofield also described some sills in which schlieren of acid material are elongated parallel to the contacts.

Schofield's conclusions are as follows:- "The Purcell Sills represent intrusions from a single intercrustal reservoir of a series of magmas - acid magmas - which gave rise to composite sills whose rock types vary in the same sill from a granite (micropegmatite) to a gabbro; and basic magmas which gave rise to simple sills of gabbro.

"The reservoir may be assumed to have been stratified according to density, having a relatively acid portion collected in the irregularities and projections of the roof and grading downwards into more basic materials.

"Crustal movements would furnish fissures which would tap this reservoir at various levels. In this way a separation of the acid and basic materials would occur so that the acid and basic materials would rise through separate fissures and spread out between the strata as sills. Some exotic material was gathered up from the walls of the fissures through which they passed, and in part assimilated by the rising magmas. The magmas would also probably assimilate some of the enclosing Purcell sediments but not enough to materially affect their composition.

"The simple sills solidified in the usual manner of such intrusives, while the acid material differentiated under the influence of gravity giving rise to composite sills." (88, pp 31 and 32)

These conclusions are decidedly different from those of Daly.

Discussion of the Purcell Sills:

A number of thin sections of specimens taken from various sills in the Cranbrook area were examined and the results of Rosiwal analyses and estimations of the proportions of minerals made from them are listed in Table VIII, p 99. The normal rock is a diorite with approximately the following mineralogical composition.

Plagioclase	40%
Amphibole	50%
Quartz	4%
Ilmenite and Magnetite	2%
Other accessories	4%
	100%

It must be noted, as has already been said, that the diorite is of two distinct types. One type varies from a quartz diorite to a basic diorite and consists of amphibole (A) and a

Table VIII

Roseval Analyses of Specimens from Various Purcell Sills

Specimen No.	Plagioclase %	Plagioclase %Ab	Quartz %	Hornblende %	Hornblende Type	Biotite %	Ilmenite %	Remarks
3R	41.4	62	10.2	45.3	a	Tr	1.9	Qtz Diorite. Qtz replacing amphibole in places
77C	45	88	Tr	40.	-	-	.8	Diorite. Some epidote.
86C	25.9	87	2.3	68.5	a	Tr	Tr	Basic Diorite. Base of sill
87C	20.0	84	9.6	67.5	a	Tr	1.0	Basic qtz diorite. 23 ft. above 86C. Some micropegmatite.
91C	35.6	88	3.2	45.2	a	7.2	3.3	As above. 115 feet above 86C.
97C	3.7	85	13.2	72.1	a	Tr	2.3	Abnormal type. At top of sill
101C	23.8	54	4.0	71.0	b	-	.6	Basic qtz diorite.
102C	33.4	40	4.0	53.7	-			As above. Probably same sill.
129C	35	?	?	60	-			Badly altered.
509R	10	60	25	60	a	-	.4	Abnormal type. Base of sill. Shows silicification.
513R	37.5	60	13.7	46.4	a	-	2.1	Qtz Diorite. 61ft above 509R.
517 R	38.8	65	7.9	48.9	a	2.1	1.0	Basic Qtz Diorite. 114ft above 509R
522R	27.8	62	4.6	63.5	a	Tr	4.1	As Above. 199 ft above 509R. Near top of sill.

plagioclase varying from oligoclase to acid andesine, while the other lies between a basic diorite and quartz gabbro and carries amphibole (B) and a plagioclase between basic andesine and acid labradorite.

A variation from these normal types occurs towards the margin of the sills where there is a great increase in the amount of the amphibole and a decrease in the amount of the plagioclase, and also an increase in the quartz content. In some cases the amount of quartz is in excess of the plagioclase and the rock becomes an abnormal type. (86, p 25) The increase in percentage of ferromagnesian minerals and the increase in the quartz content are believed to have been produced by different processes and are therefore considered separately.

It has been mentioned above that Schofield believed that all the amphibole in the sills was produced by the alteration of pyroxene. He does not state directly at what stage he believed this alteration to have occurred, but, to judge from the context, he must have meant during the last stages in the consolidation of the magma. Colony (90, p 172) believed that the deuteric alteration of pyroxene to amphibole commonly occurs, associated with the end phase quartz. With a great excess of silica the pyroxene would be converted to biotite and amphibole and he gives as a criterion that the amphibole penetrates the feldspar in sharp, needle-shaped crystals. This last feature is not particularly true of the Purcell sills although small crystals of amphibole are often seen within the body of the feldspar crystals.

Shand remarks "Pyroxene and amphibole are dimorphous forms of the same chemical compound or compounds, and whether the P-phase or the A-phase is formed must depend less on the chemical than on the physical conditions prevailing in the magma-system. Dimorphous phases do not form side by side except within a very narrow range of conditions, so the appearance of pyroxenes and amphiboles in the same rock must indicate a change of conditions, from those favourable to pyroxene formation to those favourable to amphibole formation." "The precise conditions which determine the change from pyroxene production to amphibole production are not clearly understood, but there is some evidence to support the view that an essential condition is the increasing concentration of fugitive substances in the residual magma." (89, pp 120 and 121) It is more than possible that the amphibole in the Purcell Sills may have had such an origin, although there is no direct evidence to indicate so in the localities studied. The amphiboles never appear to be pseudomorphic after pyroxene, nor was pyroxene seen in any of the sills in the Cranbrook area. Schofield, however, reports that it does occur in the sills to the south of the area and that he has seen amphibole with a core of pyroxene. (88, p 6) If the amphibole is indeed a product of deuteric alteration two rather interesting conclusions may be drawn for the Cranbrook area.

a. There was probably a considerable concentration of volatiles in order to produce the amphibole from the pyroxene. (89, p 121)

b. The conditions under which the alteration was accomplished were sustained for a sufficiently long time to permit the process to go to completion; a conclusion which is consistant with the complete absence of zoning in the plagioclase.

Daly concluded from the great lateral extent of the sills that they were considerably superheated when they were intruded. The conclusions already reached from a consideration of the metamorphism, however, do not suggest that such superheat was present. Tyrrell (76, p 17) says "sills spread to a distance which is dependent on the hydrostatic force with which they are injected, the temperature, degree of fluidity, and the weight of the block of strata which they have to lift in order to make room for themselves." To these an additional factor might be added; the temperature of the intruded rocks, since this would exert a profound influence on the rate of cooling. The temperature of the ~~intruded~~ magma is, therefore, only one of a number of factors. In the case of the Purcell Sills, the hydrostatic force is believed to have been sufficiently great to deform the intruded sediments in the vicinity of the boss. The magma is also believed to have contained a considerable amount of volatiles and the presence of volatiles has long been known to decrease the viscosity of a magma. (87, p 196; 25, p 288; etc.)

Grout (87, p 149) gives a temperature gradient of a little over 1°C per 100 feet of depth of sediments. The stratigraphic depth of the base of the Aldridge below the top of the Siyeh is at least 26,000 feet and their temperature before the intrusion of the sills must have been in the neighborhood of 280°C if 20°C be assumed as atmospheric temperature and 1°C be added for each 100 feet of depth. The temperature of the magma when it started to crystallize was probably somewhere near 870° (89, p 56) which would give a difference in temperature between the crystallizing magma and the sediments of about 590°C and promote rapid cooling.

Cooling could not have been rapid, however, since the temperature of the magma was maintained at the point of crystallization for a sufficiently long time to prevent the development of zoned feldspars, and also, probably, to permit the complete alteration of pyroxene to amphibole. The great thickness of the overlying sediments would act as an excellent insulation and the temperature of the sediments in the vicinity of the intrusive could therefore be raised greatly without the necessity for a superheated magma.

It is suggested, therefore, that the Purcell Sills may have been intruded under considerable pressure without a great amount of superheat, but that they were well charged with volatiles, mostly water, which lowered the viscosity enough to permit the amount of lateral spreading observed.

Development of the Amphibole Rich Border Phase:

Mention has previously been made of the development of a border phase very rich in amphibole. Figure 9 represents the percentage amphibole occurring in different parts

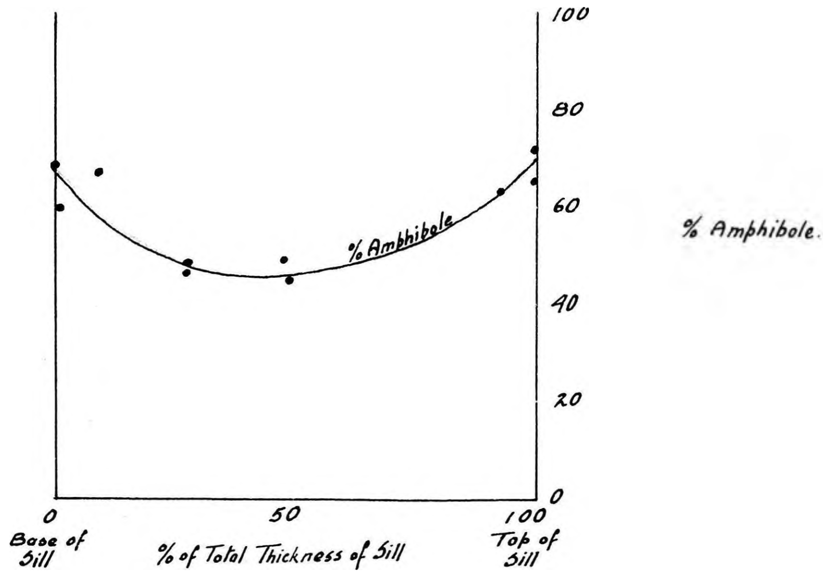


Figure 9

Diagram showing graphically the percentage of amphibole to the total rock found in different parts of the Purcell Sills. Data derived from the examination of samples taken systematically across two sills. Note the variation from about 45% near the center of the sills to 70% at the margins.

of the sills, the data being obtained by a study of thin sections made from specimens taken systematically across two sills. It will be noted that the amount of amphibole varies from a minimum of about 45% near the center of the sill to about 70% at the top and bottom. It must be emphasized that the concentration of amphibole is not at the bottom of the sills, indeed the writer recieved the impression that it was greater at the top although he was unable to secure quantitative data to confirm the idea. The megascopic examination of a number of sills confirms the data of the thin sections and the above generalizations.

Two possible ways in which such a concentration might be effected suggest themselves; 1. By hydrothermal metamorphism after the consolidation of the sill, and 2. by differentiation of the sills in place during crystallization.

If the segregations were produced by hydrothermal metamorphism certain phenomena should be expected.

1. There must have been a considerable addition of ferromagnesians to produce the enrichment found and the solutions must, therefore, have been rich in these elements. In this case it is to be expected that the sediments close to the contact would show the effect of having been soaked by such solutions. While a narrow zone, not more than a foot or so wide, has been enriched in ferromagnesians with the development of an amphibole similar to that in the sills, showing that no physico-chemical reasons prevented the process, the phenomenon is not as extensive as is to be expected. The quartzite indeed should be more pervious than the diorite and metamorphism would be more likely in them than in the igneous rocks.

2. If the amphibole in the margins of the sills were produced by hydrothermal alteration with the addition of material it is hardly to be expected that the mineral produced should be exactly the same as that in the center of the sill unless the solutions penetrated the entire body. In a sill 500 feet or more thick this does not seem possible, especially when the solutions apparently only affected the sediments for a foot or two from the contact.

3. Other evidence of hydrothermal alteration should be in evidence. Certain of the sills do show a development of epidote and chlorite near the contacts, but this is an exceptional condition.

4. End phases of the process might be expected to produce veins of some kind, depending on the nature of the solutions, penetrating both the sediments and the sills near the contacts. These are only seen in the rare cases of the epidotization mentioned.

Differentiation in igneous bodies like the Purcell Sills has long been a subject of controversy and as yet no satisfactory general theory has been advanced for it. The fact of differentiation has been established beyond question and a number of hypotheses have emerged from the intensive study of the subject during the last half century. It is believed that the abundant development of the amphibole near the borders of the Purcell Sills is due to differentiation, and the various hypotheses will therefore be briefly reviewed and their applicability to the case of the Purcell Sills considered. (Grout, 87, pp 249-252, and Stanfield, 91, pp 45-48)

Before entering on the discussion it might be noted that Grout considers the condition most favourable to differentiation to be the one in which slow cooling takes place in a basic magma, (i.e. with low viscosity) and mineralizers are abundant. It will be remembered that it has already been suggested that such a condition probably obtained when the sills were cooling, except that the rock can scarcely be called truly basic. Iddings (92, p 260) gives the following list of "agencies and conditions which may be appealed to as those most likely to affect to an appreciable degree the character of different parts of a body of liquid rock magma"; (a) changes of temperature; (b) changes of pressure; (c) loss or addition of gases.

Processes of Differentiation:

1. Fractional Crystallization.

The principle of fractional crystallization and its application to differentiation is too well known to warrant description here. It has been conclusively demonstrated by Bagley (95) and Daly (93) at Pigeon Point, Minnesota, by Pirsson (94) and others in the Shonkin Sag Laccolith, and in many other examples in North America and Europe. The classic example perhaps is the quartz diabase sill of the Palisades of the Hudson River where an olivine rich zone has been formed close to the base. It is obvious, however, that a process of this nature could not develop a zone of heavy minerals along the upper contact of a horizontal body, and it is therefore not applicable to the Purcell Sills.

The closely allied process of "Filter Pressing" has been described by Tyrrell as follows:- "As crystallization continues a loose mesh or framework of crystals with residual liquid in the interstices will ultimately be formed. If deformation of the mass occurs at this stage, either by the simple downward pressure of the lifted strata (in case of a sill or small laccolith), or by the oncoming of a lateral earth pressure, interstitial liquid will be squeezed out. The liquid will tend to move towards the regions of least pressure, and it may form bands and schlieren in the portion of the mesh least affected by the pressure, or may become a separate intrusive body." (76, p 158) Conditions observed in the field show none of the phenomena mentioned above and it is obvious that the production of the border phases in the Purcell Sills cannot be ascribed to this process.

2. Partial Miscibility.

It has been suggested that differentiation might possibly take place by the unmixing of liquid phases during the cooling of a magma, but Tyrrell says:- "It is, however, the almost unanimous opinion of petrologists that limited miscibility does not occur between fluid fock-forming silicates." (76, p 152)

3. Diffusion.

The process of differentiation by diffusion, known as the Soret effect, has been a favourite hypothesis for a number of years and is still adhered to by some petrologists. Bowen (85 and 86), however, conducted a number of careful experiments and determined that the diffusion of temperature occurred in silicate melts at the rate of 0.01 cm per sec compared with the diffusion of substance at the rate of 0.25 cm per day. From this he concluded that diffusion could only produce a zone of differentiation about 3 inches wide at the contact of the body after 125 years, and that all the material would have been derived from a marginal band 7 yards wide. The Soret effect can really only account for the growth of crystals and the spread of material from inclusions. Harker (97, pp 316-317) also made quantitative calculations on this problem and came to the same conclusions. ~~Opposite of this~~ Fenner, however (98) does not yet consider that the hypothesis has been entirely disposed of and suggests that diffusion may be much more rapid in silicate melts carrying certain other constituents, while Stansfield (91, p 27) believes that in a melt of low viscosity diffusion may be exceedingly rapid.

This hypothesis would account for the amphibole rich phase of the Purcell Sills very readily, but the careful experiments of Bowen induce such confidence in his conclusions that it is felt that it cannot be advanced at present except as a possible suggestion. If Stansfield were correct and the presence of abundant volatiles were to make the magma exceedingly fluid so that diffusion could operate at a sufficiently high speed, it is difficult to understand why the crystals developing along the upper contact would not sink into the body of the magma.

The Soret effect depends on the difference in temperature at the contact and at the center of the sills to throw the system out of equilibrium, but two other conditions have been suggested to produce like results.

a. Differences in pressure between the top and bottom of a magma chamber. (87, p 249) This cannot produce appreciable differentiation in a body the size of the Purcell Sills.

b. Difference in surface energy. Stansfield (91, p 47) says:- "As a magma cools it may be that certain constituents become grouped at certain points preparatory to crystallization and that the surface energy at any one point may be different from that at some other point, because of the inherent properties of different materials. If these differences are sufficiently large it may be that they have the power to set the materials in motion and eventually to bring about a difference of relative concentration of various constituents in different parts of the magma basins as a result of the adjustment or partial adjustment of differences of surface energy. ------ It is conceived that diffusion actuated by differences of surface energy is capable of acting upon a dispersion of sulphides in a magma, resulting in their transfer to the outer margins of the magma basin, sides and top as well as bottom, where they may be bunched together by coagulation. It will be seen below that results such as these have been obtained in an experimental way in the case of metallic iron and various sulphides and oxides." In this way he suggests that the margin of an igneous body may become enriched with iron oxide and further experiments have shown that such segregations may be assimilated with the production of basic rock types. He goes on to say:- "The case of marginal concentration of metals, sulphides, and oxides has been produced experimentally in so many cases that the efficacy of this principle in the case of ore-bodies seems to be definitely established." (p 48) It is an interesting hypothesis and satisfactorily accounts for the pheromena observed in the Purcell Sills. In Table IX, p 112, the modes approximate chemical composition calculated from the theoretical composition of the minerals, and the norms are given for two specimens taken of the center and marginal phases of a sill. It is interesting to note the great increase in the total iron content in the marginal phase which seems to bear out Stanfield's hypotheses. Unfortunately no quantitative work has been done to establish the theory and it recieves but scanty treatment in the literature so that the amount of reliance that can be placed in it is uncertain.

4. Convection Currents.

This process is not applicable to the case being considered.

5. Streaming of Gases.

Volatile constituents of a magma will naturally escape from the margin of an intrusive body and the vapour pressure will therefore be reduced at that point. "Physic-

Table IX

The modes, approximate chemical composition calculated therefrom, and the norms of specimens 91C and 97C taken from the center and top of a sill about 230 feet thick near Lumberton.

Mode

	91C	97C
Amphibole	45.2	72.1
Oligo.(Ab 88%)	36.5	3.7
Quartz	3.2	13.2
Biotite	7.2	6.7
Magnetite	3.3	2.3
Apatite	.3	.4
Titanite	.3	Tr
Calcite	4.0	1.6
	100.0	100.0

Approx. composition

	91C	97C
SiO_2	48.4	49.3
TiO_2	.2	.1
Al_2O_3	15.5	10.6
Fe_2O_3	9.1	12.5
FeO	8.2	11.7
MgO	2.3	3.2
CaO	7.9	8.4
Na_2O	4.9	1.3
K_2O	1.1	1.5
H_2O	.3	.5
P_2O_5	.1	.2
CO_2	1.8	.7
	99.8	99.9

Norm

	91C	97C
Quartz	Nil	14.3
Orthoclase	6.7	8.9
Albite	41.4	11.0
Anorthite	17.0	18.6
Diopside	8.4	14.9
Hypersthene	6.5	11.6
Olivene	1.9	Nil
Magnetite	13.2	18.1
Ilmenite	.2	.2
Apatite	.3	.3
Calcite	4.1	1.6
Water	.3	.5
	100.0	100.0

C. I. P. W. Classification

	91C	97C
Class	II	III
Order	5	4
Rang	3	4
Subrang	4	3
Name	Andose	no name given

Mode Classification
(Johannsen, 86)

	91C	97C
Class	3	3
Order	2	2
Family	8	4
Name	Melatonalite	Abnormal rock

al chemists find good reason to believe that a streaming of gases in a magma to regions of reduced pressure occurs, the gases bearing with them constituents for which they have special affinity. Possibly there is a variation in osmotic pressure related to total pressure. The magma thus becomes heterogeneous and if it then solidifies it gives a rock series." (87, p 249) Fenner says that "it is not an effect of differences of temperature but of the tendency for volatile material to escape from the system, and that chemical reactions between the magma and the escaping volatiles are involved in an important manner". (98, pp 541-543) Escape of volatiles has undoubtedly taken place from the Purcell Sills and the transfer of femic material to the sediments for a depth of a foot or two shows that they were carrying the elements necessary for the development of the amphibole. It is, therefore, possible that such a process may have accomplished the differentiation seen in these bodies. The writer suspects that the amphibole rich phase is thicker and more intense along the upper contact than the lower, which would lead one to believe that the escape of volatiles played an important part in its development, since there must naturally have been a greater flow of them from the top of the sill than from the bottom. Unfortunately a further detailed study of these bodies is required before such an impression can be advanced authoritatively.

While it must be admitted that no definite conclusion can be reached as to the origin of the amphibole rich border phases of the Purcell Sills, there are three processes one or all of which may have led to the existing condition. They are:-

a. The Soret effect. Very doubtfully an adequate process.

b. Diffusion due to surface energy. A possible cause but one not sufficiently well understood to be applied with confidence at present.

c. Streaming of gases. This is the process most favoured by the writer. If further field work indicates that the border phase is indeed more extensive along the upper contact, this hypothesis will be considerably supported.

Increase of Quartz in the Marginal Phases of the Purcell Sills:

A glance at Table VIII, p 99 will show that the quartz content varies from practically nil to as high as 25%, and that, in nearly every case there is an increase in the quartz towards the margins of the sills. It has already been mentioned that this quartz is believed to have been derived from the intruded quartzites and the reasons for this assumption will now be given.

The majority of petrologists are agreed that assimilation of material from intruded rocks can and does take place. Shand says "a certain amount of assimilation of country rock has unquestionably taken place in certain cases" (89, p 68) Stansfield (91. p 28) believes that a magma may assimilate as much as one third of its volumn of limestone or shale, but that the material is so quickly diffused that a uniform rock of a normal type is produced. Daly (99, pp 292-301) lists eight instances of quartz having been assimilated by a diabase to produce a quartz diabase or a micropegmatite, and six by a gabbro to produce quartz gabbro or diorite. Daly considers that either superheat or gas fluxing is necessary to produce this (p 307) but Bowen says "there seems no reason, therefore, to doubt that direct solution of foreign material in superheated magmas cannot be a factor of importance in petrogeneses. ---- even saturated magmas may produce very marked effects in the way of incorporation of foreign material." (83, p 523) And later he goes on to say "Direct melting probably does not occur even when the inclusion is below in the reaction series, but takes place with little or no superheat by a reactive process." (pp 542-543) Bain (100) found evidence of assimilation in the Sudbury Sill and, indeed, examples are numerous throughout the literature.

In the case of the Purcell Sills a rock with the average composition of a diorite is considered to have assimilated material from an argillaceous quartzite. Bowen points out that "a magma can only react with (not dissolve) any mineral of the reaction series higher than itself." (83, pp 538-539) He says "A diorite magma cannot dissolve inclusions of gabbro, --- but --- will react with those inclusions and convert them into the hornblende and the plagioclase with which it is saturated." (p 541) The ferromagnesian minerals in the quartzite may therefore be considered to have reacted with the magma of the Purcell Sills to form hornblende of the type already developing there, while the silica dissolved and recrystallized as quartz. Stansfield (91, p 55) found that quartz only reacted very slightly with the melts under experimental conditions. Since the hornblende and the plagioclase are both minerals which are rather well saturated with silica, there must have been little tendency for the assimilated quartz to have reacted with them. An examination of the thin sections, however, showed that both minerals have been slightly replaced by quartz as if some reaction had taken place. (Plate XI, C and D, p 84A) Small amounts of micropegmatites were seen in some of the border phases of the sills. For a number of years micropegmatites were believed to represent direct magmatic phenomenon but it is now the opinion of a number of geologists that they are frequently formed by processes operating after the consolidation of the magma. Fenner says:- "It seems to have been satisfactorily demonstrated that micropegmatites, myrmekites, and similar aggregates have often been formed by post-magmatic processes." (98, p 522) And Grout (87, pp 247-248) lists five different processes by which they may be produced, replacement being among the most important. Anderson says:- "I am strongly disposed to doubt whether myrmekite is ever of primary origin, as many writers have claimed, and as Sederholm has rather reluctantly agreed it may be." (101, p 38) There is no reason, therefore, why the quartz in the borders of the Purcell Sills may not be derived by assimilation of the intruded argillaceous quartzites.

Actually the increase in the amount of quartz does not mean that very much of the wall rock has been absorbed, probably not more than about 10% in the most extreme cases.

If, on the other hand, it be suggested that the quartz has been produced in the border phase by a process of differentiation from the magma itself, it raises the unanswerable question as to how such a process could operate to segregate a heavy amphibole at the margins and the plagioclase at the center and, at the same time, segregate the quartz in the border phase. The only case of a sill whose upper contact was not with quartzites (specimens 509R to 522R Table VIII, p 99) showed only 4.6% of quartz in the slide made from a specimen taken from the top, while specimen 97C taken from a similar position in a sill in contact with the sediments showed 13.2% quartz. Since in every respect save in the quartz content the former sill has developed a normal border phase it suggests that the amount of quartz present is influenced by the type of rock into which the sill is intruded and that assimilation therefore does take place and results in an increase of the amount of free quartz present.

In table IX, p 112, approximate chemical compositions of two specimens taken respectively from the center and the border phase of a sill have been calculated from the mode. From these figures the norms have been calculated and contrasted. The method is naturally somewhat inaccurate but is satisfactory enough for the purpose required since the composition of the amphibole is known and the only other mineral of doubtful composition, biotite, occurs in relatively small amounts. According to Johannsen's classification based on the mode, (86, pp 40-53) specimen 91C, taken from the normal rock at the center of the sill, is No. -328- which he calls a melatonalite, the equivalent of a basic quartz diorite. (102, p 68) In the C.I.P.W. system of classification the rock is an Andose (163, pp 479-525), an extremely common type which includes quartz diorites and diorites, quartz gabbros and gabbros. On the other hand, the specimen taken from the marginal phase, specimen 97C, is No. -324- according to the mode classification, which is an abnormal type and to which Johannsen has given no name. (86, p 52) It should be noted that it varies from 91C No. -328- only by an increase in the quartz-feldspar ratio. According to the C.I.P.W. system this rock again appears to be an abnormal type. No known representatives of Rang 4 Subrang 3 are listed in Washington's tables. (103) Rang 3 Subrang 5 (persodic) is the nearest rock on the one side which is a Diabase Porphyry and on the other side is Rang 4 Subrang 4-5 (Koghose) which range from olivene basalt to quartz diorite.

If the marginal phase were a normal differentiate from the magma, a normal igneous rock should have resulted. The development of the quartz in the marginal zone cannot therefore be accounted for in this way, and it seems certain that there has been an assimilation of silica with which the minerals in the rock have not been able to react so that it has crystallized out as free quartz, and so produced an abnormal or hybrid rock.

It is therefore believed that the marginal phase of the Purcell Sills has been produced by two different processes or groups of processes:- 1. A process operating to develop hornblende along the margin by differentiation from the magma itself, possibly helped by small additions of femic minerals derived from the assimilated argillaceous quartzite, and 2. A process developing free quartz, derived from the silica of the intruded sediments. Since the border zone is several feet wide the silica may have been distributed through it, partly by diffusion and partly by the mechanical movement of the inclusions in process of assimilation.

The Biotite-Granite:

Some of the sills, notably one on Mark Creek opposite the main portal of the Sullivan Mine, show a zone of intense metamorphism along the upper contact. The Mark Creek Sill appears to grade upwards from the normal rock type into a rock containing 30% quartz, 15% biotite and 40% hornblende, represented by specimen 456R (Column 4, Table VII, p 93), from that to a rock in which hornblende is entirely absent but with 40% biotite, specimen 547R (Column 5, Table VII, and Plate XIIIF, p 166) and finally into the normal Aldridge quartzite. This is merely an extension of the type of contact metamorphism by the Purcell Sills noted before in the Aldridge quartzites, except that it is more intense. It is suggested that the first step in the process was the formation of biotite from the ferromagnesian constituents of the quartzites and its segregation into patches. Closer to the sill, as the temperature rose and the rock became soaked with volatiles escaping from the magma, amphibole developed directly by precipitation from the solutions and also by reaction with mafic constituents of the quartzites. In the immediate vicinity of the sill contact metamorphism became so intense and so much material was added to the sediments by emanations from the magma, that the rock produced is now indistinguishable from the phase of the igneous rock where the effect of assimilation is pronounced. The degree of metamorphism produced by this sill is markedly greater than by most of those seen in the Cranbrook area. It may be that the magma from which it was formed was especially abundantly supplied with volatiles or the rocks into which it was intruded were poorly consolidated and exceptionally susceptible of alteration.

The similarity between the metamorphic rock produced by this sill and the biotite granite or granophyre of Daly and Schofield is easily seen from an inspection of Table VII, p 93 A, and it is believed probable that the rocks described by them may have originated in a similar manner. The writer has had no opportunity to examine the localities they described, but Dr. A.C. Waters (52) visited them in 1928 and reports that exposures are poor and that later metamorphism is intense. The "granitic" phase, he thinks, is most probably either metamorphosed impure quartzite or portions of the sills whose composition is altered by assimilation of quartzite material. He found rapid changes in the composition laterally and acid patches at various horizons all through the sills; not necessarily confined to the upper zone as reported by Daly and Schofield. In many cases large inclusions were recognizable with more acidic phases of the diorite surrounding them and a considerable development of biotite.

It is therefore suggested that the biotite granite and granophyre of Daly and Schofield may be an extreme phase of alteration of the sediments or have been produced from the magma by the assimilation of siliceous material. Such a hypothesis received ample support in the literature: Quirk and Collins (104) have indeed used it to account for the development of large areas of granite and gneiss from Huronian sediments north of the Great Lakes in Canada. It is at least certain that no true granite occurs in the Cranbrook area that can recognizably be related to the Purcell Sills.

The Purcell Lava:

During the last stages of the deposition of the Siyeh formation, a number of flows were extruded. No other period of volcanic activity is known in the pre-Cambrian of the Cranbrook area and they are, therefore, very important horizon markers. Daly described them in the Boundary region and, since he found the greatest thicknesses of them in the Purcell Range, he named them the Purcell Lavas.

The earliest references to these flows is in the work on the Lewis Range by Willis and Finlay. (6) Finlay described the rock as a diabase with augite and plagioclase as the essential constituents. It is greatly altered, but the plagioclase was believed to be labradorite. Pillow structure is common, although the top of the flows is usually ropey. Daly (13, pp 207-220) examined a number of flows on the McGillivray, Clark, Galton and Lewis Ranges and decided that they were all related to each other. Generally he found them to be dark green, fine-grained rock, often vesicular or amygdaloidal, bur sometimes they carry large phenocrysts of plagioclase which Daly determined to be between acid labradorite (Ab 57%; An 43%) and acid oligoclase. Augite, green hornblende, quartz, orthoclase in small amounts, magnetite, and ilmenite were also recognized as primary consitiuents. They are nearly always considerably altered, with the development of abundant chlorite. The total thickness of the lava varies from 58 feet to 465 feet. Schofield (14, pp 76-78) described some good exposures of the Purcell Lava on Mount Baker, and similar rocks were seen on Cranbrook Mountain in the 1932 season. Schofield found the dominant rock to be a highly altered amygdaloidal or porphyritic basalt, but other types are not infrequent.

The Purcell Lavas are strictly confined to the Siyeh Formation and were seen in three out of the four localities where the Siyeh isknown in the Cranbrook District.

They range in colour from green to more or less black, but may be purple at times. Amygdaloidal types are common, but no porphyries were seen by the writer. The commonest type is a dark green, fine-grained rock, frequently amygdaloidal. A large flow of this type occurs southeast of St. Eugene Mission which is at least 210 feet thick. The base is a flow breccia and the top is amygdaloidal. The amygdules are mainly chalcedony, but specular hematite and calcite commonly accompany it. Some quartz veins occur which probably belong to the same period of mineralization as that filling the vesicules. On Cranbrook Mountain the base of the succession of flows is a reddish-purple breccia which seems to be much more acidic than the usual type. This passes upwards into a flow of the same composition and then grades into a darker and more green amygdaloidal rock. The amygdules are sometimes drawn into pipe-like cylinders giving the rock a most curious honeycombed appearance.

The lavas are obviously of the same age as the top of the Siyeh; pre-Cambrian.

Relation Between the Purcell Lavas and the Purcell Intrusives:

Schofield noted a close similarity in mineral composition between the Purcell flows and the Purcell intrusives and this he uses as his chief argument in correlating them. Unfortunately all the flows seen in 1932 were too badly altered to make it profitable to follow up this line of attack. There are, however, a number of facts that bear out this correlation. Tabulating the arguments inits favour they are:-

1. Similarity in composition. This is taken from Schofield and no attempt was made to confirm it by the work in 1932.

2. No sills or dykes were found in any of the formations above the Siyeh. In view of their abundance in the lower formations this is a very convincing argument. It is true that the formations above the Siyeh are not common in the area, but elsewhere, in the Windermere region, in the Boundary section, and south of Kootenay Lake, they are well exposed over large areas.

3. The sills are very large and coarse-grained in the Aldridge and become progressively smaller and finer-grained in the higher formations.

4. The Purcell intrusives are the only type of igneous rock developed in the Purcell Series that might be pre-Cambrian in age. If they are not related to the flows then the intrusive equivalents of the lavas are not known.

5. Purcell intrusives are always present in the formations immediately below the known outcrops of the flows.

Although the actual connection between the Purcell flows and the intrusives has not been found, the above evidence points so strongly to the correlation of the two that it can be accepted with confidence.

<u>Age of the Purcell Sills and Dykes:</u>

Since the correlation between the Purcell intrusives and extrusives is established, they must both be the same age pre-Cambrian and emplaced during the Siyeh Epoch.

GRANITES

Areally the rocks included under this name are relatively insignificant in the district, as they occur only in a few small stocks and bosses, but their probably relationship to the zinc-lead ores of the area make them of great economic importance.

The largest body of granite known to occur in the area is the one that outcrops at Fish Lake. This body is roughly circular and about a mile in diameter. It is cut in two by the deep cleft of Fish Lake Valley so that exposures are good and the contacts can be seen clearly. Three or four small bosses penetrate the alluvium of the Trench in a northeast-southwest line to the north of the St. Mary's River and a few miles east of Wycliff. The only other outcrops of granite occur on the ridge between Hellroaring and Angus Creeks. These have been mapped as two small stocks, but may very easily be connected and form a single large one. Granites are reported to occur on the hill to the west of the lower part of Matthew Creek and also around its head-waters, but the locality was not visited by any member of the 1932 party and they are, therefore, not recorded on the map.

Daly (25, p 104) believes that most stocks and batholiths have a downward enlargement and Grout (87, pp 35, 203 and 174) suggests that small grouped stocks may well be cupolas rising above the roof of a large batholith. Gillson describes stocks occurring with very similar relationships to those of the Cranbrook area which he believes to be connected to an underlying batholith. (105, p 77) It is reasonable, therefore, to assume that the Cranbrook stocks are connected to a larger body underlying them and that it is more than probable that the greater part, if not the entire, Cranbrook area is underlain by a body of granite of batholithic dimensions. The outcrops of granite would thus represent cupola-like projections that have been exposed by erosion.

Petrography:

The granites are light-coloured rocks, usually greyish or slightly pinkish, but the most striking feature about them is the occurrence of phenocrysts of orthoclase, often several inches in length. On the whole the rock is remarkably uniform in texture and, apart from the large phenocrysts, usually has a grain size of about five millimeters. Pegmatite veins and aplite dykes intrude the granite in places, but are not very common.

The essential constituents are orthoclase, plagioclase, quartz, biotite and hornblende. Microcline, perthite, and titanite occur as accessories.

The orthoclase is developed as large phenocrysts, and carlsbad twins can be seen commonly in the hand specimen. It also occurs in the groundmass.

The plagioclase is usually between oligoclase and albite, but, it is nearly always strongly zoned, and the average composition has not been determined.

Interstitial quartz is often abundant and may form as much as 30% of the rock.

Biotite and hornblende may occur separately or together in varying amounts but are never plentiful except in some of the marginal phases or in related dykes. The amphibole was examined by the immersion oils method in order to obtain data for a comparison with that of the Purcell Sills. Its optical properites are given in Table V p 85, and it is at once apparent that the two differ widely.

In certain border phases augite is present and the rock becomes an augite quartz diorite.

A microscopic examination of the rock showed it to be a granodiorite and the estimated proportions of the constituents are tabulated below.

Oligoclase (Ab 85%; An 15%)	50%
Orthoclase	33%
Quartz	10%
Hornblende	4%
Accessories	3%

Contact Metamorphism:

The amount of metamorphism along the contacts of the granites varies enormously from place to place. Where the intrusives cut the argillaceous quartzites of the Aldridge formation the sediments were bleached and biotite developed in knots and patches. With more intense metamorphism biotite and muscovite were developed to such an extent that the rock was transformed into a mica schist carrying abundant garnets. This extreme phase is beautifully exposed in the Canyons of Matthew Creek. The contact between the granite and the limestone members of the Perry Creek series was seen just to the north of Wycliff where massive garnet and epidote was developed in the calcareous rocks together with pyrite, chalcopyrite, and galena, and the rest of the limestone changed into a relatively clean marble. It is evident that the intrusion of the granite was often accompanied by the release of active mineralizing solutions.

Age:

A direct determination of the age of the granite cannot be made, but there is strong indirect evidence that suggests one fairly closely.

1. Daly says "Without known exception each batholithic invasion has followed more or less closely a period of strong crustal deformation affecting the older formations of the same region. This rule, -- seems really to have attained the dignity of a law." (25, p 93) The structural evidence indicates that the Cranbrook area has suffered deformation by only one period of folding and that it occurred during the late Mesozoic or early Tertiary. Since the stocks are believed to represent an underlying batholith it is reasonable to assign a similar age to it.

2. In the Kootenay area to the east, there is a batholith (the Nelson batholith) the rock of which shows a marked similarity to the Cranbrook granite. (26, p 196A) From the Cranbrook area to the Kootenay there is a continuous and increasing occurrence of stocks and small batholiths which, together with the pronounced mineralogical and textural similarities suggests that the two bodies are genetically related. The Nelson batholith is essentially a composite batholith ranging in age from the Jurassic to the early Tertiary.

3. Elsewhere in British Columbia, Washington, Montana, Idaho, (27, p 70) Oregon, (28), and California granites, showing similar characteristics, are known to have been intruded during the Jurassic and Cretaceous.

It is, therefore, most probable that the granite was intruded some time between the Jurassic and the early Tertiary, and most probably during the Cretaceous.

THE PERRY CREEK DYKES

Several small green dykes occur associated with the gold-quartz veins of Perry Creek. Examinations of thin sections showed them to consist essentially of amphibole and plagioclase with quartz, ilmenite, leucoxene, and apatite as accessories and chlorite, calcite and serecite as secondary minerals. Both the amphibole and plagioclase were considerably altered, making identification difficult. As far as can be made out the amphibole is common hornblende with a maximum extinction angle of about 20° and optically positive. The plagioclase appears to be andesine; Ab 60%. The estimated proportions of the minerals is as follows:-

Hornblende and chlorite --- 55%

Andesine and serecite ---- 35%

Accessories -------------- 10%

These dykes may be related to the Purcell Sills but a correlation cannot be based on the information available at present.

A dyke of similar appearance cuts the Perry Creek formation but was too badly sheared for any positive correlation. This dyke is evidently later than the Lower Cambrian and may be related to the granites.

STRUCTURAL GEOLOGY

The stratified rocks of the Cranbrook area have a general northwest strike and a low dip to the northeast. They have, however, been considerably folded and faulted and many minor complicated structures have developed. When the vast age of the sediments is realized and the fact that the district lies between the Rocky Mountains on the east and the Purcell and Selkirk ranges on the west, the geologist is amazed that the structures should be so simple. They will be considered below under three headings; folding, faulting and foliation.

Folding

The structural history of the pre-Cambrian and Cambrian sediments was one of vertical oscillation without accompanying folding or tilting until the revolution at the close of the Mesozoic, at which time compressive forces were developed from the northwest and southeast. These stresses buckled the sediments into a series of anticlines and synclines with axes normal to the direction of the stress and plunging to the north-northeast at fairly low angles. These structures have since been complicated by faulting and, as a result, although folding is more or less universal all over the area, it is seldom that more than one limb of a fold can be seen in a fault block. There are, however, four well developed major folds.

The Moyie Lake Anticline:

This is one of the best developed structures in the district. It consists of a broad anticlinal fold whose axis runs a little east of north along the east side of the Moyie Lakes and plunges at a low angle to the north. It is comparatively symmetrical and both limbs have a maximum dip of about 40 in opposite directions. The west limb is apparently passing into a syncline on the edge of the area mapped.

The Grassy Mountain Anticline:

The Grassy Mountain anticline (Figure 10) is a

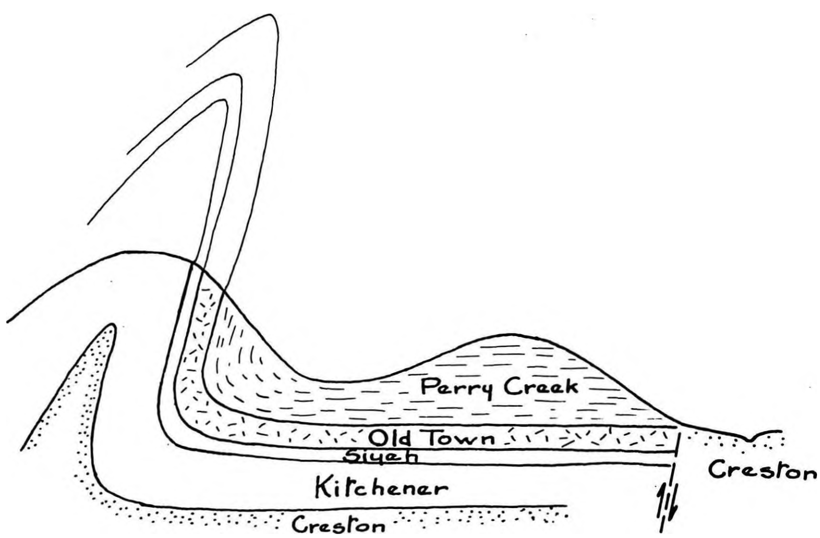


Figure 10

Sketch showing the hypothetical structure of the Grassy Mountain Anticline. It is terminated to the east against the Perry Creek fault. Approximate scale 1" equals 1 mile.

very tightly folded anticline with its axis running northeast and southwest along the ridge to the west of Perry Creek, and plunging to the north. The interesting feature of this structure is the fact that, although a great deal of it is in hard Creston quartzite, the folding is tight, so tight that the anticline was crossed twice without its nature being apparent from the attitude of the beds. The east limb is overturned and parallels the west limb, both dipping at about 70 to the west. At the northeast end of the structure the east limb straightens out, becomes flat lying, and so develops into an asymetrical syncline.

<u>The Signal Hill Syncline</u>:

The two anticlines mentioned constitute the largest structural features in the area, but on Signal Hill a smaller case of close folding is exposed. (Figure 11)

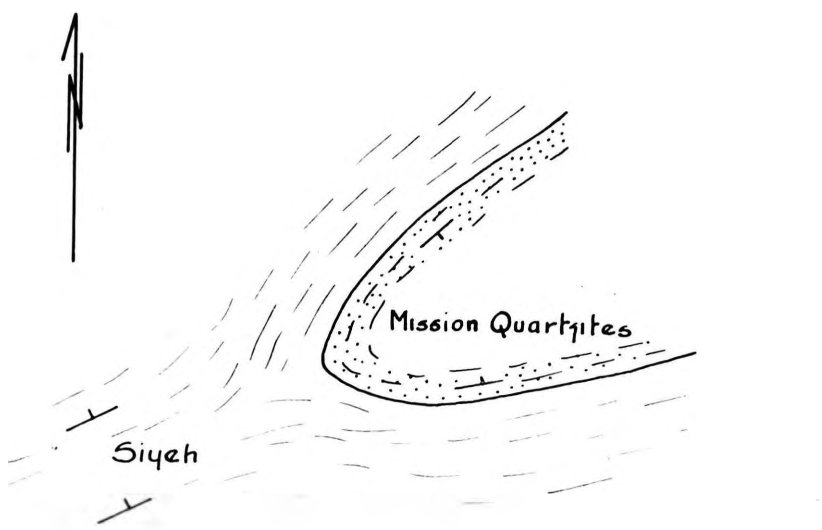


Figure 11

(Figure 11 from p 133) Sketch of the Signal Hill Syncline. Note the close folding in the Siyeh which makes the structure impossible to interpret in that formation. Approximate scale 3" equal 1 mile.

Here members of the Mission Quartzite and the Siyeh formation have been compressed into a synclinal fold. The axis of the fold strikes northeast and southwest and plunges to the northeast. The folding is so tight in the Siyeh and the resulting foliation so intense that it would be impossible to determine the nature of the structure were it not for the fact that it is clearly expressed in the more compotent Mission Quartzites. To the west the structure passes into a broad, rather irregular anticline.

There are many other structures in the area which are similar to those just cited, although on a smaller scale, and, even where the beds are comparatively regular, there are many minor irregularities. Broad anticlinal and synclinal folds are common with a plunge that coincides with the dip of the strata, and, north of the St. Mary's River, monoclinal folding with the axis parallel to the strike of the sediments is often seen. In the post-glacial canyon of Mark Creek, below the dam, a small anticline is exposed that illustrates some of this minor folding. (Figure 12, p 135) The fold, as a whole, is gentle but irregularities have developed with axes radial to the main fold. Some of these are small crumples and

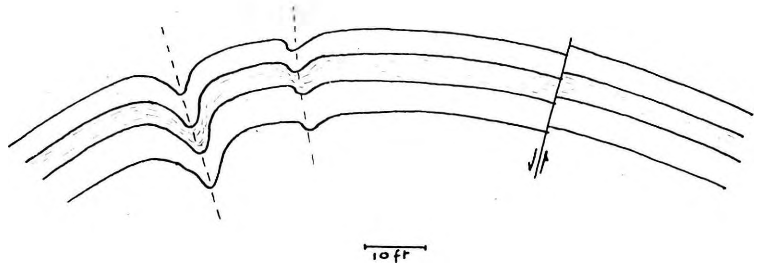


Figure 12

Small anticline in the side of Mark Creek showing minor radial folding and faulting.

others are actual faults with a small displacement.

One other example deserves mention. In the north face of the hill directly to the south of Old Town a sharp fold can be seen in massive Creston quartzite. (Plate X, p 53A) The two limbs of this fold form an angle of less than 40° and yet there is no sign of fracturing in the beds themselves. This lack of fracturing suggests that, at the time of folding, the beds must have been under a very heavy load and were semi-plastic or were much less densely lithified than at present.

Faulting:

Faulting is very common in the Cranbrook area but the faults almost invariably occur down valleys and are so covered by detrital material that none of them has actually been seen. Their position is therefore inferred from stratigraphic evidence and their dip is not known although it is believed to be steep. There are two main systems, one running northeast and southwest and the other east and west.

The Northeast-Southwest System:

The most important fault in this system is the Moyie fault. It passes just to the north of the head of Moyie Lake and is known to occur for two or three miles to the mortheast of this point. It is believed to extend for several miles at its normal trend, and then to swing south to cross the International Boundary beside the Spokane branch of the Canadian Pacific Railway. Its lateral displacement is not very accurately known, but the northwest block seems to have moved about ten miles to the northeast. It has been traced through Montana where it is known as the Lenia fault and the whole Moyie-Lenia system is at least 118 miles long, Kirkham (29) who studied it in 1930 decided that it was an overthrust fault, the west block having moved up, relative to the east block, from 15,000 to 45,000 feet along a plane never less than 45° in slope. He believed it to have been formed sometime between the Jurassic and the Eocene.

To the northwest of the Moyie fault there are four more faults in this system. They are known as the Signal Hill fault, the Booth Creek fault, the Perry Creek fault, and the Grassy Mountain fault respectively. The lateral movement on the Grassy Mountain fault is in the same direction as that on the Moyie fault but the direction of movement on the other three is reversed; the northwest block having moved to the southwest with respect to the southeast block in each case. This system can, therefore, be considered to represent three blocks divided by the Moyie and the Grassy Mountain faults, and in each case the northwest section has moved in a northeast direction relative to the southeast section. The center block has, however, been broken into four roughly equal slices, parallel to the length of the main block, by three faults, the northwest slice having, in each case, moved southwest with respect to the southeast slice.

East and West System:

This system is known from two faults only, but both are of considerable magnitude.

The St. Mary's River fault is the better known and careful mapping has shown it to be a fault zone which, in the region of Wycliff, is two or three miles wide. Cross fractures join the main longitudinal faults. Exposures along the belt are generally poor and the mapping is therefore not very accurate. The exact horizontal displacement is impossible to measure, but the north block has apparently moved east relative to the south block not less than ten miles.

The Finger Gully fault, named after the depression of that name where it was first recognized, lies about seven miles to the north of the St. Mary's River fault and also runs east and west. The displacement is, however, in the opposite direction, the north block having moved west about five miles. Excellence of outcrops has permitted the location of the fault within fifty feet in two places and it is believed to have cut the workings of the Sullivan Mine. There is even a likelihood that it may have cut off the ore-body below the present level of development, displacing it to the west.

A glance at the map shows clearly that the east-west faulting has interrupted the northeast-southwest and it is evident that it is the younger of the two although there is no reason to believe that they are not closely related in time and were produced by the same stresses.

There is also a system of small thrust faults striking roughly north-northeast and south-southwest and dipping at various angles to the west. In each case the west block has thrust up and to the east over the east block although the movement is never more than a matter of a few feet. These faults are evidently caused by the compressional forces that produced the foliation described in the next section and probably are not related to the major faults.

Foliation:

The whole of the Cranbrook area, particularly the northern half, has been subjected to a compressive stress applied in a west-northwest and east-southeast direction which has foliated all the rocks to some extent. The massive quartzites of the lower formations have naturally suffered less than the softer upper ones and in the former foliation is usually confined to the argillaceous partings between the beds of quartzite. The attitude of the foliation shows a remarkable uniformity over the whole area, and can sometimes be used to determine the reliability of a questionable outcrop. The strike varies from N 10°W to N 30°E although both extremes are rare, and the dip ranges from vertical to 40°W with the commonest dip about 70°W. The attitude of the beds has little or no effect on the direction of the foliation, and it is quite evident that it was formed after the main period of folding. The nature of the force that produced the foliation is well illustrated by an outcrop south of Wycliff. The formation at this point consists of a soft argillaceous rock with several thin, hard beds of quartzite about an inch thick running through it. (Figure 13, p 140) The softer part of the rock has been thoroughly foliated while the hard beds have been crumpled so that they have been shortened in a west-northwest and east-southeast direction. It is clear that it was a compressive force applied in this direction that produced the foliation in the incompetent member.

All the compressive features developed in the Cranbrook area were apparently produced by forces acting in a northwest-southeast direction at various stages in the history of the district. The first structures to be produc-

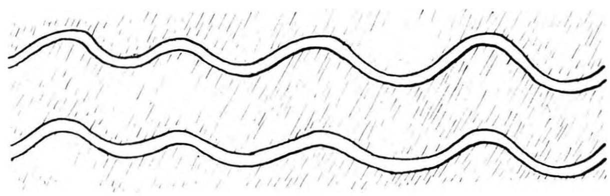


Figure 13

Sketch showing the nature of the stress producing the foliation. Note the crumpling of the small, compøtent, quartzite members and the foliation of the incompøtent beds. The foliation was evidently produced by a compression parallel to the bedding.

ed were the major folds and these were probably closely followed by the development of the main faults. Since no folding is known in British Columbia until the Jurasside revolution in the late Mesozoic, at which time the Selkirk Mountains are known to have originated, the folding in the Cranbrook area probably occurred at that time. It was probably accompanied by the intrusion of the granites. It may be that the intrusion of these rocks and the accompanying silicification stiffened the whole series so that, when the next thrust came in the early Tertiary, the Laramide revolution, the whole mass moved en block against the softer sediments in the Rocky Mountain geosyncline. Although this stress produced no folding in the Cranbrook area, the pressure must have been tremendous and relief was produced by the foliation of the softer formations and by the development of the small thrust faults.

The west face of the Rocky Mountains is believed to be an eroded fault scarp and it is interesting that no trace of any parallel structures appears in the Cranbrook area.

ECONOMIC GEOLOGY

The Cranbrook District has earned the reputation of being one of the most important mining areas of British Columbia. The Sullivan Mine alone would justify this for it is the largest producer of silver, lead and zinc in the Americas. (106, p 779) The St. Eugene and the Society Girl mines at Moyie, and the Stemwinder and the North Star mines at Kimberly have also played their part in producing the mineral wealth of British Columbia. All except the Sullivan are shut down at the present time and some of them are probably entirely worked out. In addition to the developed mines, a great number of prospects, scattered all over the area, are being investigated for silver, gold, lead, zinc, and copper.

Although at the present time no rich placer deposits are known, placer mining is still an important industry and is receiving a considerable stimulus from the fact that owing to the present depression, many men can find no other employment.

The district also contains some non-metallics. The magnesite discovered by the field party of 1832 in the Annelide formation bids fair to become the most important deposit of its kind in Canada, and the rock of the Purcell Sills is being quarried for building and ornamental stone although its suitability has not yet been fully determined.

The Lode deposits of the Cranbrook area fall into three subdivisions; 1. Silver-lead-zinc deposits; 2.

Gold-quartz veins of Perry Creek; 3. Deposits associated with the Purcell Sills, and will be discussed in this order.

The Silver-Lead-Zinc Deposits

To this type belong all the deposits that have been worked economically in this district. The important deposits are grouped in two localities:- a. the Sullivan, North Star, and Stemwinder mines around Kimberly; and b. the St. Eugene, Society Girl, Aurora, etc. in the vicinity of Moyie. There are, however, a number of less important deposits scattered in various parts of the area. Without important exception the deposits occur in the Aldridge formation, and usually in the massive, quartzitic types. The mineralogy of the two groups is essentially the same.

Mineralogy: (Plate XIII, C and D, p166)

Gold. Native gold was not seen in any of the specimens examined from deposits definitely known to belong to this type, but it is reported to occur in several prospects.

Silver. Native silver was not seen in any of the polished sections but it is reported to have occurred in the oxidised ores of the Society Girl Mine. Although none of the Cranbrook ores is particularly high in silver, Schofield reports that the average silver content of the ores from the district is about 3 to 4 ounces per ton per percent lead. (14, p 107) The investigations of similar ores have shown that up to about .35% (84 ounces per ton) of silver may be carried in galena in the form of minute specks of argentite or freibergite. (107 and 108)

Galena is economically the most important mineral to be found in these deposits. It varies in grain size from coarse cubes 10 millimeters across to very fine-grained steel galena. A glance at the table of paragenesis (Table X p 145) shows that galena is usually the last of the primary minerals to form.

Sphalerite is the most ubiquitous mineral in the Silver-Lead-Zinc deposits. It often forms the greater part of the sulphides present and is usually the iron-bearing variety, marmatite.

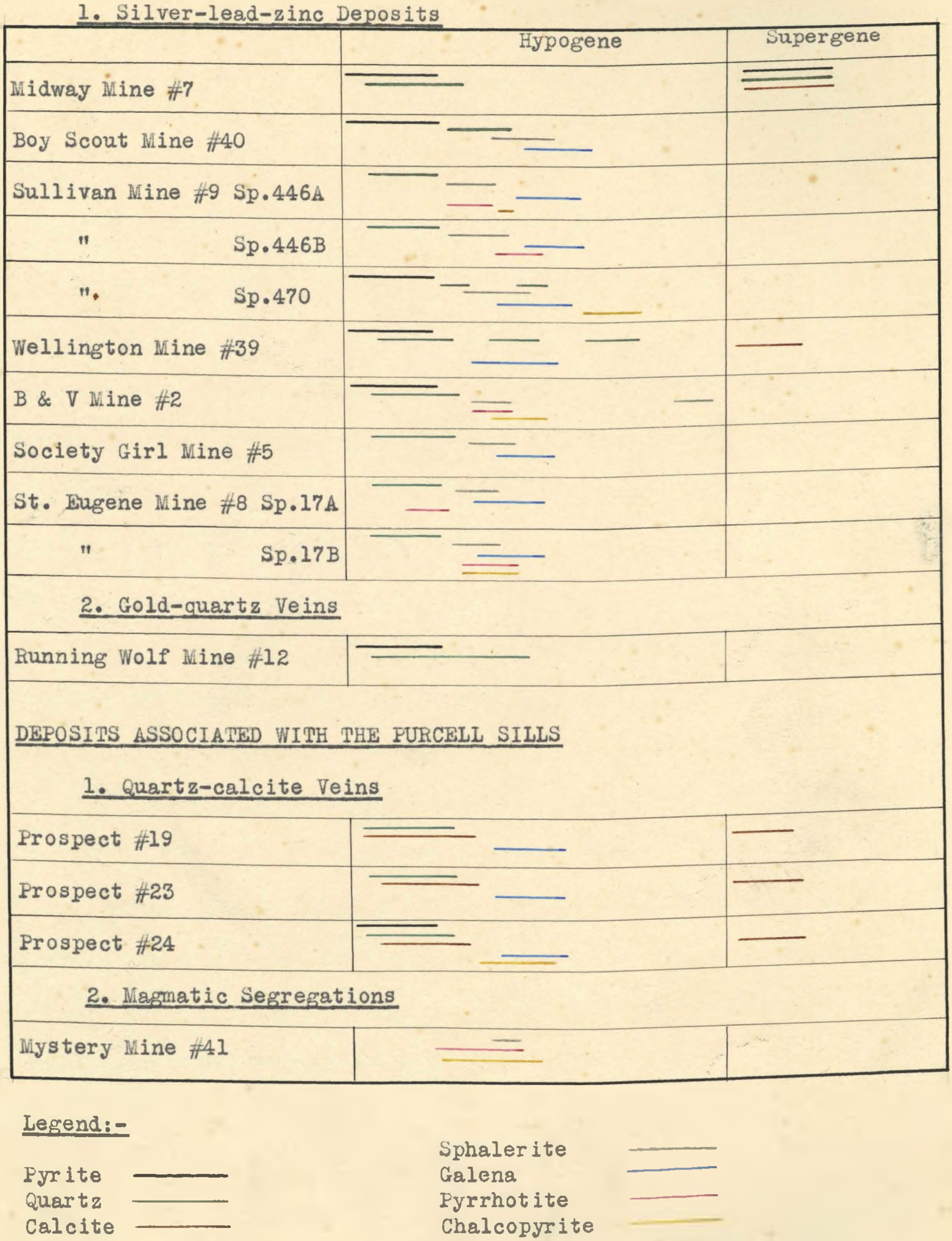
Pyrrhotite is the form of iron sulphide most commonly developed in these ores, and often occurs to the exclusion of pyrite. In the Sullivan Mine it is found in the deeper parts of the ore-body while pyrite is developed nearer the surface. Vogt (109, pp 636-644) has shown that pyrrhotite has a much lower melting point than pyrite even under high pressures, and he says:- "FeS_2 crystallizes while FeS, on the other hand, separates in liquid phase and remains in this condition till near the termination of the solidification of the rock." (p 644) It is therefore not surprising that pyrrhotite occurs in massive bodies in many of the deposits.

Pyrite. In view of the fact that pyrite is usually such a common mineral in ore deposits, it is rather surprising to find that, in the Cranbrook area, it is abundant only in one or two deposits and in many of them it is

TABLE X

PARAGENESIS OF THE CRANBROOK ORES

DEPOSITS ASSOCIATED WITH THE GRANITIC INTRUSIVES



entirely absent. It is one of the first minerals to form in these ores, certainly the earliest sulphide, and is never known to be overlapped by any mineral except quartz. In most of the polished sections examined it was found to be noticeably anisotropic which is evidence that it has been strained.

Arsenopyrite occurs in a few of the deposits in small quantities but was not seen in any of the polished sections examined.

Chalcopyrite. Although chalcopyrite is never abundant in the ores of this type, it occurs sparingly in most of them. It is one of the late minerals to form and in one case is even later than the galena. (Spec. 470, Table X, p 145)

Cassiterite was not seen by the writer but is reported to occur in the Sullivan Mine in amounts sufficient to warrant concentration. (110, p 375)

Quartz is the only important gangue mineral. It started to develop early, overlapping the pyrite in part, and is frequently found in two or three generations. It also occurs as unreplaced remnants of the original quartzites. In most of the ores, however, it is present in relatively small amounts, the ores being composed of almost solid sulphides.

Magnetite was recognized in the ore of the St. Eugene Mine but was not seen in any of the polished sections. It was probably one of the earliest minerals to crystallize.

Calcite is very rare in this type of deposit and was never found as a hypogene mineral.

Cerussite ($PbCO_3$) occurs in the oxidised zone of the Society Girl and North Star Mines.

Grunerite. (Plate XIII C, p 166) An amphibole, identified as grunerite, was recognized in the ore of the St. Eugene Mine. Its optical properties were worked out by the immersion method and are given in Column 1, Table XI, p 148A. In column 2 are the properties of grunerite from Pierrefitte, Hautes-Pyrenees, (III, p 481), having a $FeSiO_3$/(Mg,Mn,Ca)SiO_3 ratio of 81.4 to 18.6. Column 3 gives the indices of pure $FeSiO_3$ taken from Dana-Ford. (112, p 578) On page 573 Ford says:- "the values (of the indices) decrease regularly with the decreasing percentage of the iron molecule." It is suggested, from the Table, that the St. Eugene grunerite is closer to pure $FeSiO_3$ than it is to the Pierrefitte grunerite and it is safe to assume that it is exceedingly rich in iron. An amphibole which is also believed to be grunerite was seen in the ores of the Society Girl and the Sullivan Mines.

Garnets were seen in the ore from the St. Eugene and Sullivan Mines, but no attempt was made to discover their exact nature. Schofield (14, p 109) found that those occurring within the ore-body were manganese-bearing and had developed before the metallic minerals. He also recognized almandite in two places in the wall-rock close to the ore-bodies.

Pyromorphite (PbCl) Pb_4 $(PO_4)_3$ occurs in well developed crystals in the oxidised zone of the Society Girl Mine. Its chemical and crystallographic properties have been

Table XI.

Optical Properties of Grunerite.

	Pierrefitte[1]	St. Eugene Mine	$FeSiO_3$[2]
Indices	1.676	1.682	1.680
	1.693	1.704	1.707
	1.707	1.714	1.726
Birefringence	.031	.032	.046
Optic sign	Neg.	Neg.	Neg.
Ext. Angle Z c	13°32'	13°	10° to 15°
Optic angle 2V		84° 26'	Large
Pleochroism		Faint yellow	
		Faint yellow	
		Bluish Green	

1. Pierrefitte, Hautes-Pyrenees, France. (111, p.481).

2. Pure $FeSiO_3$. Dana-Ford, (112, p.578).

worked out by Bowles (113).

Paragenesis

An examination of Table X, p 145, which is a graphical portrayal of the conclusions drawn from the study of a number of polished sections of ores from various deposits, enables the following summary to be made.

Pyrite is always the first mineral to form when it is present. In the Midway Mine it occurs in two generations, the latter possibly being supergene.

Quartz is usually close to the pyrite in time, but overlaps it to a considerable extent. Not only does it continue to form after the cessation of the deposition of pyrite, but it often occurs in two or more generations.

Sphalerite and Pyrrhotite were generally deposited simultaneously. There are exceptions, however, as in Specimen 17A from the St. Eugene Mine, where the pyrrhotite is distinctly earlier than the sphalerite. Generally, although the sphalerite is often slightly the earlier to start to form, the two minerals overlap for the greater part of their development. In the B. and V. Mine sphalerite is developed in two generations. The second is separated by a wide interval of time from the earlier and may even be supergene.

Chalcopyrite is not an abundant mineral in the specimens and its relations are often hard to determine. It appears to vary considerably as to the time of its crystallization, sometimes being associated with the sphalerite and pyrrhotite, and sometimes with the galena.

Galena is among the last of the sulphides to form but is occasionally followed by chalcopyrite.

Calcite occurs only as a supergene mineral.

The mineral assemblage shows that the deposits were formed at high temperatures and that they belong either to Lindgren's hypothermal or pyrometasomatic groups. (106) On page 718 he gives the following list of minerals that do not occur in mesothermal deposits or any of lower temperature. He says:- "such minerals as the pyroxenes, and amphiboles, the garnets, apatite, ilmenite, magnetite, specularite, pyrrhotite, tourmaline, topaz, the brown and green micas, and the spinels, are almost entirely absent. (From medium and low temperature deposits). In the veins and replacement deposits formed at high temperature one or more of these minerals are commonly present." Three of these, namely amphibole, garnet, and pyrrhotite, occur in considerable abundance in the ores being discussed, and a fourth, magnetite, is also present occasionally. Since the pyrometasomatic deposits are those directly connected to an igneous intrusive, the silver-lead-zinc deposits of the Cranbrook District, which are not visibly associated with igneous rocks, must belong to the hypothermal class. Silver-lead-zinc deposits of this type are not common. The famous Broken Hill Mine in New South Wales (116) however, belongs to this class and is very similar to the Sullivan Mine. Both are in pre-Cambrian rocks and are predominently lead-zinc deposits with garnet and other high-temperature minerals in the gangus.

General Geology and Structure:

It has already been mentioned that all the important deposits of this class occur in the argillaceous quartzites of the Aldridge formation. While pure quartzites are not readily susceptible to alteration, the more argillaceous variety, which is generally the type constituting the Aldridge formation, should be expected to show the effect of the presence of mineralizers at high temperature. Such is not the case, however. In the Sullivan Mine the ore generally consists of massive sulphides and there is often a sharp line of contact between the solid ore and the quartzites, and the latter, a few inches away from the contact, shows no more metamorphism than is common for the region. This is not invariably true, however, since patches of hard black chert have been developed in the footwall of the Sullivan ore body in places. In both the Sullivan Mine and the St. Eugene small bodies of chlorite schists studded with garnets occur in the vicinity of the veins. These are so different from the rocks produced by the general alteration of the Aldridge that the original rock from thich they were derived must have been of a different type. The presence of chlorite and hornblende suggest that it was probably an igneous rock. (87, p 431)

Few igneous rocks are found near any of the silver-lead-zinc deposits, and those that do occur, belong to the Purcell intrusives. A group of dykes and sills of that formation occurs in the west end of the Sullivan Mine and one dyke is reported in the St. Eugene. Schofield points out that the sills in the Sullivan Mine are earlier than the ore, (14, p 112), and the writer has seen them where they have been replaced and altered by the mineralizing solutions. The process tends to produce a hornblende-chlorite rock with a certain amount of sulphides scattered through it. Although no garnets were seen in any of the metamorphic rocks that could be definitely related to the Purcell intrusives, it is most likely that the chlorite-garnet rock is an alteration product of the Purcell diorite. (84).

The structure of the ore-bodies in the Kimberly locality is somewhat different from that of the Moyie Lake veins. The Sullivan ore-bodies which serve as excellent examples of the Kimberly type, take the form of huge tabular masses, 1,000 feet or so long and up to as much as 240 feet thick. They have been followed down the dip for a vertical distance of between 2,000 and 3,000 feet and show no sign of dieing out. They have been formed by profound and, at times, complete, replacement of beds of quartzite by solid sulphides, the replacement being highly selective. That is to say a folded bed of quartzite made up of fine members an inch or two thick may be completely replaced so that every fold is faithfully reproduced in the ore and clearly visible owing to the fact that one member may be replaced by pyrrhotite, the next by galena, and a third by sphalerite. (Plate XII, p 161) In a similar way a certain part of the ore-body may be composed of solid galena and another of solid sphalerite or pyrrhotite while elsewhere galena, sphalerite and pyrrhotite or pyrite occur in an extremely fine-grained, intimate mixture. At the contacts, too, the boundary between the ore and the wall rock may be extremely sharp and replacement almost complete right to it. Yet, as has already been pointed out, beyond the contact, the wall rock has often scarcely been altered at all. The Sullivan ore-body occurs in an anticline of low curvature pitching at about 23^{o} to the east with many minor irregularities. The mineralizing solutions appear to have travelled along a certain horizon of the Aldridge quartzites, and more or less completely replaced the rock. The footwall is generally very regular but occasionally the ore follows small cross fractures into the hangingwall for a few feet and may then replace another bed of the quartzites for a considerable distance paralleling the first one and leaving only a few feet of unreplaced rock between the two. No channels by which the solutions originally reached the replaced horizons have been found.

There is some post mineral faulting and one north-south fault, the Sullivan fault, has displaced the northwest end of the ore-body of that mine a few hundred feet. This part of the mine is particularly interesting since, beyond the fault, the character of the mineralization changes from a replacement by solid sulphides of unfractured sediments, to a replacement by sulphides and quartz along a fissure. The vein so formed is unimportant economically but serves as a link between the Sullivan type of deposit and the Moyie type.

The deposits of the Moyie region are so similar to those of the Sullivan that there is no doubt that they are genetically related. The same minerals are present in both types and consequently the unusual association of galena and high-temperature minerals such as garnet, amphibole, and pyrrhotite, is common to both. There is, however, slightly more quartz in the Moyie type. The paragenesis is identical. Both types are essentially replacement deposits and the northwest end of the Sullivan ore-body is typical of the Moyie type of mineralization. The structure of the two types is, however, distinct. While the Sullivan type consists of replacement along the bedding of the quartzites, the Moyie deposits are all connected with two main parallel fissures striking a little north of west and dipping on an average at 70° south. They cross the axis of the Moyie anticline more or less at right angles and suggest tension cracks formed by stresses produced during the formation of that structure. Schofield says:- "The walls bounding the fissures show little evidence of relative displacement, the greatest movement observed being 18 inches." (14, p 118) It is interesting to note that Ransome and Calkins, (8, pp 134-135), believed that the displacement in the ore-bearing fissures of the Coeur d'Alene was a matter of inches rather than feet. It is possible that the two types of ore-shoots in the lead-zinc-silver deposits of the Cranbrook district may represent slightly different temperatures of deposition; the Moyie type being high temperature, hydrothermal deposits and the Sullivan possibly in part pneumatolytic. There is, however, no mineralogical evidence to support such a hypothesis.

A number of veins of a type similar to the Moyie, occur in various parts of the Cranbrook district. None of them is of much importance.

Genesis:

The silver-lead-zinc deposits of the Cranbrook area occur over a considerable range of depth (at least 4,000 feet in the Sullivan Mine) and contain several high temperature, hydrothermal minerals. They must, therefore, have been formed by ascending high temperature solutions and be genetically connected with the intrusion of igneous rocks on a considerable scale. Lindgren says:- "The hypothermal deposits are formed, we believe, from aqueous solutions at a comparatively high temperature say from 300° to 500° C. These solutions were formed by differentiation from batholithic magmas at no excessive depth." (106, p 719) The Cranbrook ore deposits may, therefore, be related:-

(a) To the Purcell Sills or the magma from which the sills were derived.

(b) To the granodiorite stocks or to the underlying batholith; or

(c) To a magma that is not represented by any igneous rocks exposed in the district.

(a) Members of the Purcell intrusives partly replaced and metamorphosed by the ore-bearing solutions have been seen in the Sullivan Mine. The alteration is so pronounded in places that the solutions appear to have been entirely out of equilibrium with the rocks and there seemsto be little likelihood that the mineralization could have been an end phase of the period of igneous activity to which the sills owe their origin. Some of the dykes in the west end of the Sullivan Mine do appear to cut across the massive sulphides as if they were later, but the edges of the bodies show a considerable amount of alteration and small veins of sulphides penetrate the igneous rocks for fractions of an inch. It is therefore believed that the highly selective, ore-bearing solutions attacked the quartzited vigorously but were relatively impotent to replace the dykes. The latter have maintained their identity and now appear to be cutting across the ore-body.

The sills were intruded into the Purcell series during the time of the deposition of the top of the Siyeh, and while the whole series was horizontal. If the ore-bodies are related to the Purcell intrusives, their depth stratigraphically below the top of the Siyeh should measure their depth below the surface when they were formed, which, in turn, should be a rough indication of their temperature of formation provided no large intrusives operated to modify the temperature conditions seriously. No large bodies of Purcell diorite, the only igneous rocks intruded at that time, are known to occur near any of the silver-lead-zinc deposits and the temperature at the time of ore deposition, and consequently the nature of the ores, should be related to the depth at which the ore was deposited. The following is a list of the more important deposits with their depths calculated from the top of the Siyeh, and their characteristic mineralization. Complications and uncertainties in the structures make some of the figures rather unreliable, but they are sufficiently accurate for the purpose:-

Depth	Name	Mineralization
43,000 (?)	Boy Scout	Pyrite, sphalerite, galena.
43,000 (?)	Wellington	Pyrite, chalcopyrite, galena.
29,000 (?)	Sullivan	Pyrite, pyrrhotite, sphalerite, galena.
26,000	Payroll	Gold, small amounts of sulphides.
19,000	Midway	Pyrite, gold, small amounts of sulphides.
17,900	B. and V.	Mixed sulphides.
17,900	Aurora	Sphalerite, galena.
17,400	Society Girl	Sphalerite, galena.
17,100	St. Eugene	Sphalerite, galena.
500	Prospect #10	Chalcopyrite, secondary copper ores.

It will be noted from the table above that most of the pyrite occurs in the bodies formed at depths below 17,900 feet. There is, therefore, a suggestion of zoning with respect to the depth below the Siyeh. Unfortunately deposits of a similar type, for example the Aurora, Society Girl, and St. Eugene, are located close to each other so that there is no reason to believe that the areal distribution may not be a more important factor in producing the similarity of mineralization than the depth relationship. A clue to the origin of the ore-deposits therefore cannot be gained from this line of argument.

It will be shown later, when describing the veins directly connected with the sills, that they have certain pronounced mineralogical differences from the silver-lead-zinc deposits; a fact which suggests that the two originated from different sources.

It is therefore most unlikely that the silver-lead-zinc deposits of the Cranbrook district are related to the pre-Cambrian, Purcell intrusives.

(b) These deposits may be related to the granodiorite. The granitic stocks in the Cranbrook area are relatively insignificant in areal extent, nor does the ore appear to be assiciated particularly with them. Reasons have been given, however, for believing that the greater part of the area is underlain by a granitic body of batholithic dimensions which is probably related to the Nelson batholith. The ore may well be derived from this body and located above critical irregularities in the unseen roof. Ransome describes a similar condition in the Coeur d'Alene in the following words:- "At first glance the monzonite masses appear inadequate to account in any way for the ore deposits, some of which, as at Wardner, are 8 miles from the nearest small exposure of the intrusive rock. Moreover, the distribution of the ore deposits shows no obvious symmetry with reference to the monzonite areas. The monzonite exposures, however, are merely the upper parts of masses which become larger with depth, so that some of them doubtless coalesce a few hundred feet below the surface, and the erosion of a few thousand feet of rock from the whole region would probably expose a large area of monzonite in the central part of the district, with smaller outlying areas where at present no intrusive rock is known." (8, p 135)

The abundance of ore associated with the Nelson batholith and other similar and related bodies in the region adjoining the Cranbrook area shows that there is every reason to expect to find ore connected with the intrusion of the Cranbrook batholith. Some of these districts are:- The Slocan; (26) Rossland; (117) Phoenix; (118) Boundary; (81) and the Coeur d'Alene. (8)

The degree of metamorphism in the vicinity of the stocks varies greatly, but in many places it is intense. At Matthew Creek, for instance, the Aldridge quartzites have been entirely transformed to garnetiferous mica schists in which Schofield reports having found sillimanite. (14, p 27) Occasionally, as at the locality mentioned just north of Wycliff, where the granite is intruded into calcareous horizons in the Perry Creek formation, chalcopyrite, galena, sphalerite, and pyrite can be seen in small quantities in the resultant metamorphic rock. It is, therefore, clear that the intrusion of the granite was, at times, accompanied by active mineralizing solutions, released at high temperature, which were capable of depositing the minerals found in the silver-lead-zinc ore-bodies.

Although no ore-bodies have been observed that were directly connected to the granitic rocks, three mineral deposits, the Boy Scout, the Wellington, and the B. and V., occur not far from granitic stocks; the two former to the south of St. Mary's Lake and the latter near Fish Lake. In all these prospects, especially the two former, the wall rock is very much more metamorphosed than the Aldridge quartzite generally is, and is, in places, a mica schist. In the Wellington Mine a number of pegmatite dykes, evidently related to the granite, occur in the vicinity of the mineralization. In all three deposits, pyrite occurs instead of pyrrhotite, the iron sulphide present in most of the deposits in the Cranbrook area, and quartz is much more common than in the normal Sullivan and Moyie types of ore-body. Otherwise the mineralization is the same and the paragenesis is identical. The inference to be drawn from this variation is that the presence of the granites had a controlling influence on the nature of the mineralization; in other words it was genetically connected ~~to~~ it.

It has already been mentioned that the veins of the Moyie region were formed along fissures which probably relieved stresses set up during the folding of the Moyie Lake anticline. It has been suggested also that the folding of the anticline took place in the late Jurassic or Cretaceous and was affected during, or immediately before, the period of intrusion of the granite which took place during the last stages of the Jurasside revolution. (25, p 96) The channels followed by the ore-bearing solutions would therefore have been formed at the most suitable time to receive the emanations from the granitic rocks and the three conditions for the formation of an ore-body, suitable host rocks, suitable openings for the solutions, and suitable solutions, would be complied with.

The majority of the folding in the Sullivan Mine is pre-mineral. Although Schofield reports some folding in after the period of mineralization, ore has certainly replaced previously folded beds. Complicated folding such as that illustrated in Plate XII, p 161 could not have taken place without leaving recognizable evidence of fracturing and recrystallization. The relation of the ore to the time of folding therefore also suggests a post-Jurasside date for the ores.

(c) The last hypothesis, that the ores may be related to some igneous rock that has not outcropped or has been overlooked in the district, is one that may be used if all others fail. The igneous history of British Columbia does not suggest the likelihood of any intrusives other than the granitic rocks of late Mesozoic age or the Purcell Sills being the source of the ore.

The weight of evidence, therefore, suggests that the silver-lead-zinc ores of the Cranbrook district were derived from the magma that gave rise to the granitic stocks. The deposits are consequently late Mesozoic or early Tertiary in age, and belong to Emmons' "Cryptobatholithic" class. (119, p 36)

Plate XII.

Photograph of a specimen of sulphide ore from the Sullivan Mine. The specimen contains pyrrhotite, galena, sphalerite, and small amounts of the unreplaced argillaceous quartzite. Note the extremely selective nature of the replacement which has preserved the original structure of the rock. Natural size.

Gold-Quartz Veins of Perry Creek

The gold-quartz veins of the Cranbrook area are confined to a single locality, along Perry Creek, and a relationship to some sub-surface igneous body is strongly suggested.

The veins are generally large and persistant, up to 30 feet in width and often hundreds of feet long. Although galena, sphalerite and pyrite have been seen in them, sulphides are usually absent and always very scarce. Quartz is the only gangue mineral and is white to glassy and massive. Banding is rare and drusy structures are absent. Gold is reported but unfortunately has not been found in economic quantity. The bodies are true fissure veins with sharp walls, but there is often a considerable amount of silicification in the adjoining rocks. With the exception of a few small Perry Creek dykes, no igneous rocks have been seen in any of the workings or even close to them.

Gold-quartz veins have a wide range of deposition, occurring as epithermal, mesothermal, and hypothermal deposits. It is believed that those in the Cranbrook area belong to the hypothermal class, but it must be admitted that, with deposits so sparcely mineralized as those of Perry Creek, a definite conclusion is hard to reach. Lindgren describes the quartz of the hypothermal deposits as being massive, without banded or drusy structure and often glassy or semi-transparent (106, p 746), a description that is applicable to the Perry Creek veins.

The origin of the veins is obscure. Kirkham and Ellis believe that the gold-quartz veins of the boundary region of Idaho are pre-Cambrian and related to the Purcell Sills (81, p 45). No evidence appears in the Cranbrook area to support such a conclusion. It is fairly certain, however, that the veins are genetically connected either to the Purcell intrusives or to the granitic rocks.

Deposits Associated with the Purcell Sills

A number of mineral deposits occur in the Purcell Sills that are believed to be directly related to them. None has proved to be of commercial importance but some are sufficiently large to warrant attention and will doubtless be worked successfully in the future. There are two types: the commoner is in the form of quartz-calcite veins and examples are seen almost everywhere the Purcell Sills occur. The other type, magmatic seggregations, is illustrated by only two deposits, but both are attractive from the economic standpoint.

Quartz-Calcite Veins:

Quartz-Calcite veins are present in nearly all of the Purcell Sills, but are commonly either barren or else so small and sparsely mineralized that they are of no commercial importance. As might be suspected the larger and more highly mineralized veins occur in the largest sills and, since these occur in the lowest formation of the Purcell series, the Aldridge, it is there that prospecting has been most profitable.

The bodies may vary from narrow stringers close to the margin of the sills, to veins up to five feet in width and several hundred feet long. The average dimensions are probably about 50 feet by 2 of 3 feet. The vein on Prospect 23 is rather typical of the larger ones. (Figure 14) This

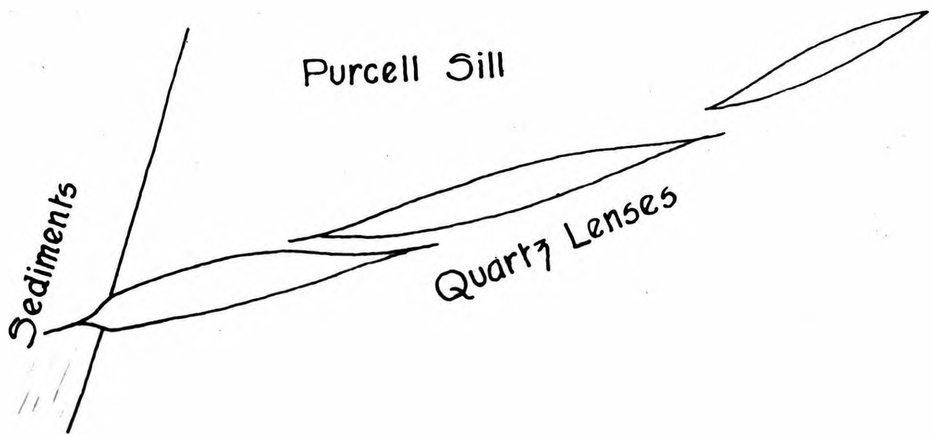


Figure 14

Sketch of quartz-calcite vein in a Purcell Sill. Note the en echelon arrangement of the quartz lenses and the manner in which the vein stops on passing out of the sill into the sediments.

vein consists of a steep dipping fracture at least 900 feet long penetrating the sill at an oblique angle to the line of contact with the sediments. In it a number of en echelon quartz lenses have been formed, the largest close to the contact. The veins die out with remarkable abruptness on passing from the sill to the sediments.

The gangue is quartz and calcite in variable proportions, either mineral predominating. The sulphide mineralization is simple in most deposits, (Plate XIII, D, p 166), in prospects No 19 and No 23 for example galena was the only sulphide seen in the polished specimens although in No 19 a few specks of pyrite were noticed in the field. Chalcopyrite, however, may be fairly abundant. A fact which deserves emphasis is that sphalerite is exceedingly scarce and pyrrhotite occurs hardly at all.

The paragenesis is as follows:- (Table X, p 145) Pyrite appears to be the first mineral to form, although it was not observed in enough specimens to make certain. It was, however, overlapped by quartz and calcite which were deposited together except that calcite continued to form after the deposition of the quartz ceased. The remaining sulphides appear to have crystallized at approximately the same time, although chalcopyrite may have started to form slightly earlier than galena. Both are later than the gangue minerals and replace them. Incrustations in one vein examined suggested that there may have been a second stage of quartz-calcite deposition which was later than the deposition of the sulphides. Supergene calcite is present in all the sections examined.

Plate XIII.

A. Polished section of ore from the Mystery Mine. Typical of the magmatic segregation ores. Shows chalcopyrite (C) and pyrrhotite (Py), cut by hornblende (H). The chalcopyrite and the pyrrhotite are approximately the same age and the hornblende somewhat later. No. 461 R. X 95.

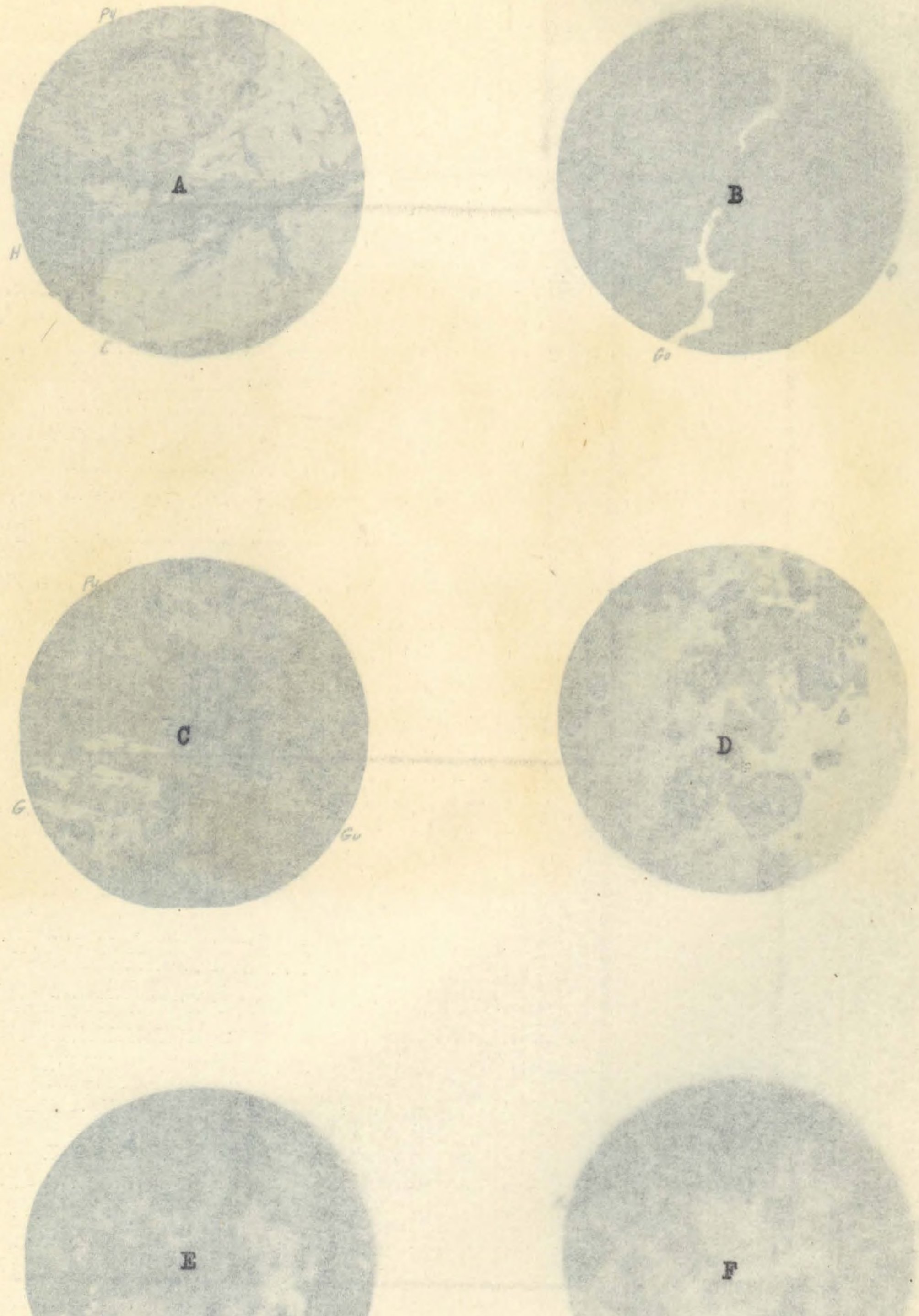
B. Polished section of ore from the Payroll Mine. Shows a veinlet of gold (Go) and petzite (dark gray in vein) cutting through quartz. The petzite is evidently the same age as the gold. No.42 R. X 95.

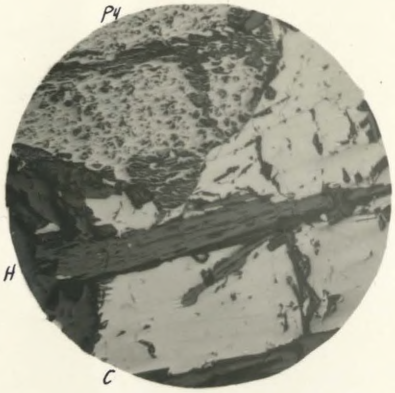
C. Polished section of ore from the St. Eugene Mine. Shows galena (G), pyrrhotite (Py), sphalerite (S), quartz (Q), and grunerite (Gu). Note the grunerite evidently cutting the sulphides. Pyrrhotite is more abundant in the ore than would appear from this illustration. No. 17BR. X 95.

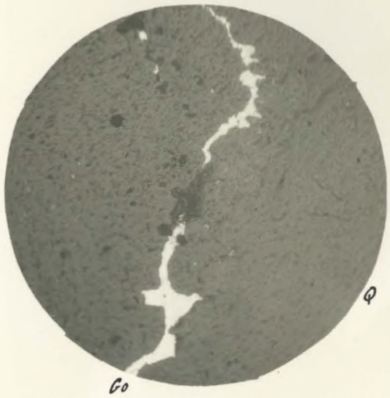
D. Polished section of ore from prospect 24. Shows pyrite (P), chalcopyrite (C), galena (G), quartz (Q), and calcite (Ca). This is typical of the quartz-calcite veins in the Purcell sills. The calcite is ~~being~~ replaced by the sulphides and is evidently hypogene. No. 322R. X 95.

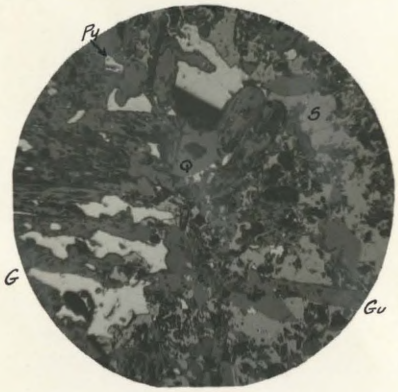
E. Polished section of ore from the Sullivan Mine. Shows pyrrhotite, (Py), sphalerite (S), galena (G), and remnants of the unreplaced argillaceous quartzite (dark). Note the intimate mixture of sulphides. No. 466R. X 95.

F. Metamorphosed Aldridge quartzite from a specimen taken close to the contact with the Purcell sill on Mark Creek described in the text (page 119). Shows biotite (B), magnetite (black specks), quartz (Q), feldspar (F), and micropegmatite (in the center of the field). Crossed Nicols. No. 487. X 62.


A
B
C
D
E
F


Py
H
C


Q
Go


Py
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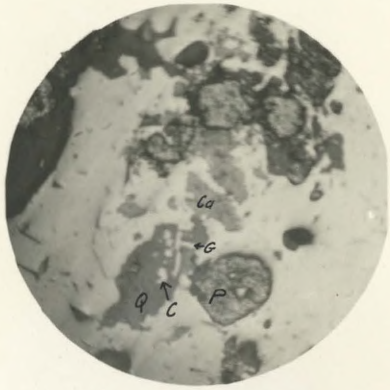
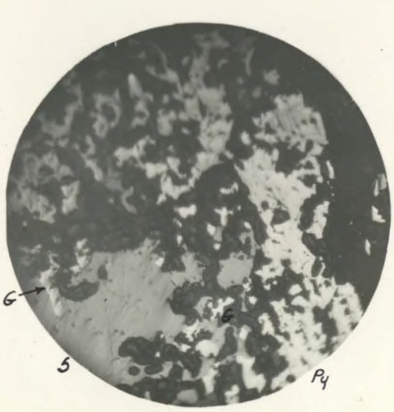
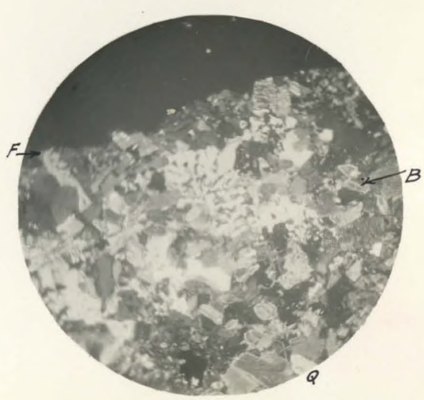

Ca
G
Q
C
P


G
G
S
Py


F
B
Q

The ore-shoots always occur in the veins close to the contacts of the sills with the sediments. A lens that carries say 10% lead at the contact will be completely barren 10 or 15 feet away from it. It is this fact that has prevented the development of commercial ore.

Magmatic Segregations:

The two known occurrences of magmatic segregations are both in large Purcell sills intruded into the lower members of the Aldridge formation. They occur as irregular bodies without abrupt boundaries, at any point within the sills, and are believed to be not less than 200 to 300 feet in diameter.

Pyrrhotite and chalcopyrite are the most abundant sulphides and often occur in massive, intimate mixtures. (Plate XIII A, p 166) Sphalerite is rare. Pyrite is reported to occur but was not seen by the writer. Quartz is occasionally present but only in very small quantities; Schofield reports having seen it intergrown with orthoclase as micropegmatite. (14, p 142) Hypogene calcite has not been seen. The most important gangue mineral is an amphibole whose optical properties were found to be the same as those of the amphibole (type A) of the Purcell sills. It occurs in lath-shaped crystals developed idiomorphically against the sulphides. No terminal faces are present and spots of chalcopyrite are developed within some of the crystals. A grey mineral which may be chalcocite was seen, but in such small quantities that identification was impossible.

The paragenesis (Table X, p 145) is rather difficult to determine since the constituents of the ore appear to have crystallized at approximately the same time. Pyrrhotite may be slightly the oldest but was undoubtedly overlapped by the chalcopyrite. The time of deposition of the sphalerite is uncertain except that it undoubtedly belongs to the same period of mineralization as the other sulphides. The amphibole was probably developed throughout the entire time of the formation of the sulphides.

Ore-deposits formed by segregation from igneous rocks have been studied by geologists for many years, and two main classes of such ores have been redognized; oxide ores, and sulphide ores. It is to the latter class that the segregations of the Cranbrook area belong. Niggli classifies the type represented by the Cranbrook deposits as auriferous pyrrhotite-chalcopyrite deposits of the ortho-magmatic type, (120, p 48). Lindgren says:- "That sulphide minerals may crystallize from a magma has been ascertained beyond a doubt, but the number of minerals which have this origin is limited to a few species, mainly pyrrhotite, pyrite, chalcopyrite, molybdenite, sphalerite, and pentlandite; arsenides like niccolite and sperrylite are also known," (106, pp 893-894). Stansfield conducted a number of experiments with artificial melts and came to the following conclusion:- "From a consideration of the results of experimental melts of rock materials containing a certain amount of metals, sulphides or oxide ores, evenly distributed, it is concluded that the separation of metals, sulphides or oxides from magmas may take place rapidly if the conditions are suitable for the separation. Thus ore-bodies may have been formed in comparatively short periods of time." (91, p 181) Sulphides and rock forming silicates appear to be miscible to some extent at high temperatures but with the lowering of the temperature they become immiscible and the sulphides will separate as tiny globules. These globules tend to coalesce under the influence of various forces such as gravitational sinking, flotation, the Soret effect, differences of surface energy, and cohesion, and so form masses of considerable size. Bowen observes that, "Sulphide liquids may separate from silicate magmas, carrying with them only their appropriate share of the volatile components in their partitioning between the two liquids, and giving thus a sulphide liquid, with moderate amount of volatiles which is as definitely a magma as the associate silicate magma." (96, p 172) Stansfield also described the process in the following terms:- "The igneous magma is intruded either as

1. a homogeneous liquid which later separates into two parts - a silicate magma and a sulphide or oxide magma (that is Vogt's idea of the process) or,

2. in the form of a suspensoid system in which liquid silicate (with some dissolved sulphide or oxide) is the dispersing medium, and the excess of sulphide or oxide over the amount soluble at any given temperature is the dispersed liquid phase.

"It does not matter, practically, which of the two conceptions of the original condition is correct, because even if originally homogeneous owing to complete mutual solution of silicate and sulphide or oxide at high temperatures, the liquid separates into two parts on cooling." (91, p 142)

The magmatic segregations of the Cranbrook district were believed to have that origin for the following reasons:-

1. The ore merges into the wall rock without a definite boundary.

2. There is no evidence of interaction having taken place between the wall rock and the liquid from which the ore was deposited; that is, the two must have been in equilibrium.

3. Identically similar amphiboles developed in the ore and the rock.

4. No hydrothermal minerals appear in the ore or the adjacent rock.

5. Microscopic evidence shows that all the minerals in the ore crystallized at approximately the same time.

6. No minerals appear in these deposits that are not found in magmatic segregations elsewhere.

7. Minute quantities of chalcopyrite and pyrrhotite can be seen throughout many of the sills.

As a result of his experiments Stansfield came to the following conclusions:- "The effect of temperature in controlling the products of magmatic consolidation is clear. Pyrrhotite gives way to bornite and bornite to chalcocite at high temperatures. Pyrrhotite takes the place of pyrite at high temperatures. With decreasing temperatures the mineral series successively deposited may be chalcocite first, succeeded by bornite, and then by chalcopyrite." (91, p 182) The ore-deposits in the Purcell sills therefore appear to have been formed at medium temperature for this class of deposit, since although pyrrhotite is the only iron sulphide, chalcopyrite is the commonest copper mineral and possibly, since the occurrence of the chalcocite is in doubt, the only one.

It has been stated that ores of this type always occur at the base of the sill but field observation led Stansfield to the opinion that "Sometimes the ore-bodies are found near the base of the intrusive rock, as a result of gravitational settling. In other cases they are found along the lateral borders or even along the upper contacts of the intrusive body. These latter occurrences cannot be explained by gravitational settling." (91, p 141)

In many deposits of this type stresses imposed upon the igneous body may cause the migration of the ore while still liquid. Daly (99, p 564) says that two processes have been recognized in the Sudbury Sill. 1. the separation of the ore into a liquid phase, and 2. its subsequent migration to the point where it crystallized. He also points out that the ore may remain liquid at a temperature below the melting point of the rock from which it separated. It is doubtful if a movement of this nature occurred in the Cranbrook deposits since there does not appear to have been any structural deformation at the time of the intrusion of the sills to force the liquids to migrate, and the boundaries between the ore and the wall rock are not sufficiently sharp to suggest that the ore had assumed its present position after the consolidation of the two components, sulphides and silicates, and that they crystallized in situ.

Relationship Between the Differentiate Ores and the Quartz-Calcite Veins:

The quartz-calcite veins are, for the following reasons, believed to be genetically connected to the magmatic segregations.

1. No segregations are known without normal quartz-calcite veins being present nearby.

2. The quartz-calcite veins developed in those sills carrying the segregations contain chalcopyrite, pyrite and pyrrhotite; high temperature minerals; while elsewhere they usually predominate in galena. If the veins have a genetic connection to the segregations the higher temperature minerals would be expected to occur near the differentiate ore-bodies.

3. The restriction of the quartz-calcite veins to the sill suggests a genetic connection between the veins and the sills. It is obvious that such a connection exists between the sills and the segregations. It is therefore most likely that the veins and the segregations also have a genetic relationship.

The quartz-calcite veins are therefore believed to be related to the differentiate ores and hence both to be derived from the Purcell Sills, directly or indirectly, and are, therefore, pre-Cambrian in age.

Description of Mines and Prospects

The following descriptions are not designed to be exhaustive, nor to cover the entire list of important deposits in the area, but rather to furnish examples of the various features mentioned above. A list of the more important deposits will, however, be given in Table XII, p 174 together with the numbers by which they are designated on the map.

The Sullivan Mine No.9:

This mine is typical of the broad scale silver-lead-zinc replacement found in the deposits occurring in a limited area in the vicinity of the town of Kimberly. The Kimberly locality is the most important in the whole Cranbrook district, for it contains, besides the famous Sullivan Mine, the North Star (No. 50) and the Stemwinder (No. 49) Mines. The entire locality is underlain by Aldridge quartzites with a general north and south strike and a low dip to the east in a series of gentle monoclines. Purcell sills are common, but they are especially abundant in the flat northeast of Marysville and to the east of Matthew Creek.

The Sullivan Mine itself lies on the south slope of Sullivan Hill, the main tunnel being driven from the valley of Mark Creek. It has been an important producer for many years and its enormous ore-reserves insure that it will remain a factor in the world's production of lead, zinc and

Table XII.

Table of Mines and Prospects.

The numbers correspond to those on the map.

1. The Payroll mine.
2. The B & V mine.
4. The Prospector's Dream.
5. The Society Girl mine.
6. The John Dee prospect.
7. The Midway prospect.
8. The St. Eugene ~~prospect~~. Mine
9. The Sullivan mine.
10. Prospect # 10.
11. Prospect # 11.
12. The Running Wolf prospect.
13. The Bluebird prospect.
14. Prospect # 14.
15. Prospect # 15.
17. Prospect # 17.
19. Prospect # 19.
23. Prospect # 23.
24. Prospect # 24.
29. The Aurora mine.
30. The Guindon prospect.
39. The Wellington prospect.
40. The Boy Scout prospect.
41. The Mystery mine.
42. Gold Ridge and Chance prospects.
43. Swenson's prospect.
45. Vernnica prospect.
46. Homestake mine.
47. Birdie L prospect.
49. Stemwinder mine.
50. North Star mine.

silver for a considerable time to come.

History:

The Sullivan Mine was discovered in 1892 by Pat Sullivan and his associates. (14) In 1896 it was bonded by A. Hansen of Leadville, Colorado, and later by Col.Redpath and Judge Turner of Spokane Washington, who formed the Sullivan Mining Company. From 1896 to 1899 only a little prospecting was done as the fine-grained and complex nature of the ore made profitable smelting a difficult task, and any attempts to operate were soon discouraged. In 1899 when the Kimberly branch of the Canadian Pacific Railway was finished, systematic development was started and the first shipment of very carefully hand-sorted ore was made in 1900 on the promise of reasonable freight rates. In 1903 a smelter was built at Marysville but extremely careful hand sorting was necessary to give satisfactory results and in 1907 it finally ceased to operate. In 1909 the group was reorganized as the Fort Steele Mining and Smelting Co. and bonded to the Consolidated Mining and Smelting Co. of Canada. In 1910 the option was exercised and an initial shipment of 23,000 tons was made to the company's smelter at Trail, B.C. By 1915 this was raised to 44,650 tons of hand-sorted concentrates. In the same year a main tunnel 9 by 12 feet, was started in the side of Mark Creek, 600 feet below the lowest workings, to cut the ore at 7,000 feet from the portal. In 1916 zinc ore was treated at Trail for the first time and pyrite was used for the manufacture of sulphuric acid. The main tunnel struck ore at the expected place and was continued to a total length of 10,015 feet. Active development was carried on and the mine soon had 10 miles of underground workings. In 1920 the ore was found to be amenable to the new process of floatation, and a thousand ton concentrator was built at Trail to treat the Sullivan ore by this process. It was then decided to build a concentrator at Kimberly. By 1923, one was completed and from then on concentrates only were shipped to Trail. It was found necessary to grind the ore to 85% below 200 mesh in order to free the minerals one from another. At the present time the concentrator has a capacity of 6,000 tons per day, and is running on a basis of 20 days per month. (115, p 334) The average grade of the ore is reported to be 10 to 11 per cent lead and 12 to 13 per cent zinc. The lead and zinc production for British Columbia during 1932, almost the entire amount coming from the Sullivan Mine, was lead 252,007,574 pounds (115,p353) and zinc 130,546,957 pounds. (p 552)

General Geology:

The Sullivan ore-bodies occur in a low anticlinal fold plunging to the east from ten to sixty degrees with an average of about 23° . The major folding is earlier than the mineralization, but there may be some later minor folding (114, p 311). Schofield indeed reports post-mineral folding. He says:- "In the upper workings close folding later than the ore deposition increases the real width of the ore. This is well shown in the glory hole at the time of the writer's visit." (14, p 131) He does not, however, appear to have considered the possibility of the same result being produced by the replacement of beds {previously} thickened by folding.

The deposit lies in the Aldridge formation which here consists of thin-bedded argillite and argillaceous quartzite. Except for the prevailing regional metamorphism the rocks are ~~superficially~~ fresh to within a few inches of the ore-bodies. Indeed ripple-marks have been seen a few feet from the footwall of the main mass of the ore.

Economic Geology:

The ore-bodies on the upper levels are rather irregular, but at depth they become more simple. Thus on the 3900 level, the whole ore zone forms the segment of a circle roughly subtending an angle of little less than 90 . (Figure 14) The two ends of this zone form two ore-bodies each about

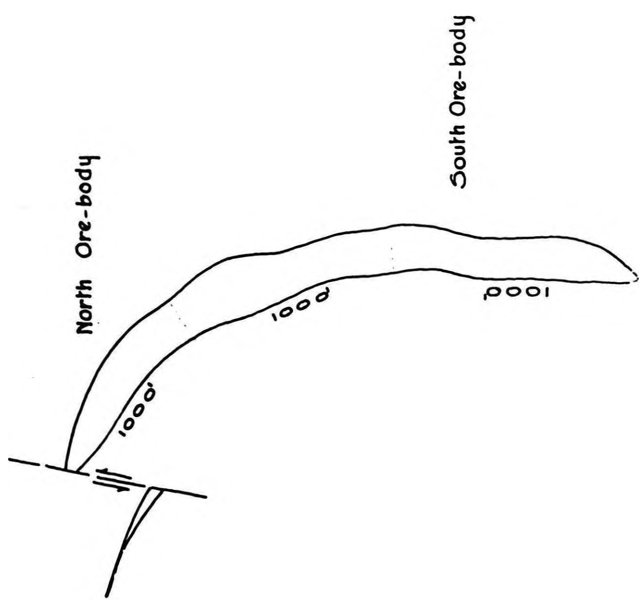


Figure 14

(Figure 14, continued from page 177) Sketch of the Sullivan ore-body on the 3900 level. The north and south ore-bodies are separated by a zone of massive pyrite and pyrrhotite. The extreme north end of the ore-body is displaced by the Sullivan fault.

a thousand feet long and varying from 50 to 250 feet from wall to hanging. Between them lies a barren zone, also about a thousand feet long, composed of solid sulphides. The upper part of this zone is all pyrite, while, on the 3900 level and below, it is all massive pyrrhotite. The general dip of the ore-bodies varies from horizontal near the top to 45° east further down, although reverse dips are known in places. The north end of the zone terminates against the Sullivan fault, which strikes north to northeast, and dips steeply west. Vertically the west block has moved down 200 feet and horizontally south 500 feet with respect to the east block. The ore zone continues beyond it but only small bunches of quartz and sulphides have been found.

The ore has been formed by complete replacement of certain beds of argillaceous quartzite and shows the original structures remarkably preserved. (Plate XII p 161) It is formed of alternating bands of fine-grained galena, sphalerite, and pyrrhotite, and presents a selective replacement of different bands in the rock by different minerals. The footwall is generally regular and the change from rock to ore is very abrupt, but the hanging wall shows some important irregularities.

While the change from ore to country rock is just as sudden a smooth hanging wall may be broken and a tongue of ore project into the back. When this is followed it is often found that another bed of argillaceous quartzite has been replaced for some distance parallel to the first and perhaps only separated from it by a few feet of unaltered rock. These irregularities often cause considerable inconvenience in the actual operation of the mine. The footwall of the north ore-body is composed of typical Aldridge quartzites, with no apparent difference from that in any other part of the formation. The footwall of the south ore-body, however, shows a good deal of alteration. It has been metamorphosed into a hard, black, flinty chert, full of pyrite and pyrrhotite but with no galena or sphalerite.

In the upper part of the mine there are a number of vertical, pre-ore, Purcell dykes. Several of these cross the ore zone some of which appear to have been extensively altered and replaced by ore minerals, while others have largely been unaffected by the mineralization. The upper part of the mine is now mostly inaccessible and therefore, as there are some notable differences between it and the lower working, Schofield's description will be quoted here. (14, pp 132-133) At the time of his visit, the main tunnel was driven at a depth of 100 feet below the surface and it is this part of the mine that he describes in the following terms. "The ore-body is arranged in distinct zones which grade imperceptibly into each other. The center of the lode is occupied by a fine-grained mixture of galena and zinc-blende in which masses of purer galena occur as large lenses. It is these lenses that constitute the valuable ore shoots in the mine. They occur either singly or as two parallel shoots separated by one of poorer grade. The gangue in this inner zone is absent except for a few idiomorphic crystals of a pink manganese-bearing garnet. This inner zone gradually passes exteriorly into a fine-grained mixture of pyrite, pyrrhotite, and zinc-blende, which contains as a gangue numerous crystals of an almost colourless garnet with some grains of actinolite or possibly diopside. The sulphides gradually diminish in amount and finally give way, especially on the footwall, to a fine-grained chert which is present when the country rock is a heavy-bedded purer quartzite, and is absent when a more argillaceous slaty member constitutes the wall rock. No garnets or other gangue minerals were noted in this cherty zone. The chert gradually passes into the normal quartzite in which with one exception all contact minerals such as garnet, diopside, and actinolite, are absent." In the lower part of the mine garnets are not known to occur and the only gangue minerals seen in the polished sections were quartz and amphibole. The ore-bodies, too, are different in character, since they consist of masses of relatively solid sulphides with a sharp contact between them and the barren wall rock.

In the lower part of the mine pyrrhotite, sphalerite and galena, were the commonest (Plate XIII E, p 166) sulphides. Pyrite was seen in a specimen taken from the edge of the ore-body, but was not found in any of the other specimens. Pyrrhotite and pyrite apparently never occur together in the Sullivan Mine. The sphalerite was the dark, iron-bearing variety marmatite. Chalcopyrite was present in one specimen but is evidently extremely rate. The only gangue minerals seen were quartz and amphibole and neither are at all common. The quartz generally represents unreplaced remnants of the Aldridge quartzite but some of it may result from the solution and reprecipitation of quartz derived from the wall rock and some by precipitation of a primary silica contained in the mineralizing solutions. The amphibole occurs in extremely minute prismatic crystals too small for accurate determination, but, since it resembles the amphibole developed in the St. Eugene Mine and shows the same relationship to the ore it is probably grunerite. It is developed idiomorphically against the sulphides.

The paragenesis is diagrammed in Table X, page 145. The first mineral to form was one of the two iron sulphides, pyrrhotite or pyrite but, since they were never seen together, their relations to each other are not known. The sphalerite is a little later than the pyrrhotite but overlaps it considerably. It was followed by the galena, but, here again, there is some overlap. Chalcopyrite was probably developed during the early stages of the deposition of the galena.

The life of the Sullivan Mine is assured for many years to come. Not only are the blocked out reserves very large, but there is no apparent diminution in the size or grade of the ore downward. Indeed, diamond drilling has proved its continuation in depth for several thousand feet.

<u>The St. Eugene Mine:</u> #8

This is the most important mine in the Moyie Lake area. It is situated on the east side of Moyie Lake close to the town of Moyie, and is owned by the Consolidated Mining and Smelting Company of Canada.

<u>History:</u>

The history of the St. Eugene Mine is rather interesting, and as it is, in a sense, typical of the district, it will be given in detail. Quoting from Schofield (14, p 119) "Father Coccola, Roman Catholic priest at the St. Eugene Mission, by showing the Kootenay Indians specimens of the different ores of the valuable metals, impressed upon their primitive minds the importance of discovering deposits of these minerals. Peter, one of the Kootenay Indians now resident at the Mission, on a hunting trip around the Moyie Lakes, brought back a specimen of clean galena ore from the hill on the east side of Lower Moyie Lake. James Cronin, a mining engineer, while on his way to Fort Steele, visited the St. Eugene Mission, and was told the story of the discovery of rich silver-lead ore. In company with Father Coccola and the Indian, he journeyed to Moyie and located the Peter and the St. Eugene claims in 1893. On the advent of the Canadian Pacific railway, John Finch of Spokane, Washington, purchased the holdings of the Father for $12,000 and this money was used in building the beautiful church now to be seen at the St. Eugene

Mission. The development of the St. Eugene Mine now progressed rapidly under the management of Mr. Cronin. Later, the Moyie and the Lake Shore group of claims, which lie between the St. Eugene and Moyie Lake, were purchased and the St. Eugene Consolidated Mining Company formed. In 1905, the properties of this company were taken over by the Consolidated Mining and Smelting Company. The total amount of development work underground to September 30, 1913, is 19.79 miles." "The total production of the St. Eugene Mine since its discovery to September 30, 1913, has been 1,017,106 tons of ore containing 5,365,232 ounces of silver and 229,305,721 pounds of lead, having a given value of $10,626,608."

The mine has been developed by 18 or 19 tunnels driven from the surface or off shafts, and a shaft has been sunk to a depth of 800 feet below the level of the lake.

Economic Geology:

The ore deposits of the St. Eugene Mine occur as lenses or shoots in a rather complicated system of fissuring. These fissures cut a series of Aldridge quartzites and

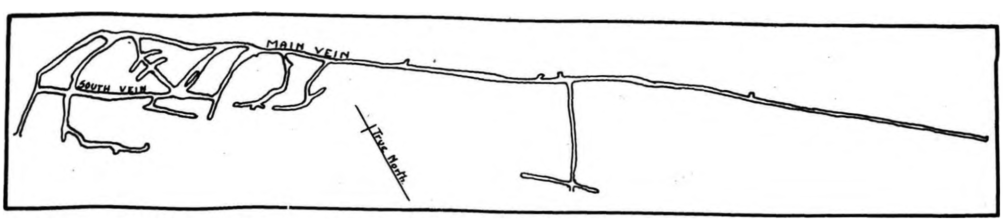


Figure 15

(Figure 15 continued from page 183) Sketch map taken from G.S.C. Mem 76 of the 800 level of the St. Eugene Mine. Both the two main veins and the intersecting avenues are illustrated.

argillaceous quartzites lying on the west side of the Moyie Lake anticline very close to its crest. The strata vary in strike from N 25°E to N 5°W and in dip from 40° N to 10° N, although the former dip is rare. In the argillaceous beds the ore-shoots are narrow and relatively unproductive, while in the more massive quartzites they widen out.

There are two main fissures striking from N 67° W to E-W, and dipping from 60° S to 75° N. A number of cross fissures, locally called avenues, join the main fissures which are usually about 600 feet apart and converge downward and to the west. Schofield reports a lateral movement along the main fissures of not over 18 inches. The avenues vary from N 15° E to N 50° E and dip very steeply. Ore occurs either in lenses in the main fissures or in the avenues, and is probably most frequent at the junction of the two. In the upper levels the ore is mostly confined to the main fissures while in the lower levels it is usually in the avenues. The ore consists mainly of coarse-grained galena, with minor amounts of sphalerite, pyrrhotite, magnetite, chalcopyrite, and pyrite, and has been deposited by replacement along channels provided by the brecciation induced by the fissuring. A small amount of gangue is present which consists of pink garnet, amphibole, quartz, and some calcite. Alteration extends only a short distance into the wall rock, which, a foot or so from the vein appears to have suffered no change. Reports say that pyrite, pyrrhotite, and sphalerite were more common around the periphery of the ore bodies than in the centers, but there is said to be no increase in the sphalerite in the lower levels. Quartz appears to be more abundant in the upper levels than in the lower.

The following minerals were recognized under the microscope; (Plate XIII E p 166) Quartz, pyrrhotite, sphalerite, chalcopyrite, grunerite, galena, and an unidentified silicate. The optical properties of the grunerite were studied carefully and they are given in Table XI, p 148 A. The optical properties of grunerite from Pierrefitte, Hautes-Pyrenees, France, (30, p 479) which also occurred in a lead-zinc ore not unlike the St. Eugene ore are also given in Table XI for comparison. Sphalerite, probably marmatite, is the most abundant sulphide, but pyrrhotite is also common. The latter sometimes occurs replaced by the sphalerite and sometimes definitely cuts it. It also occurs in lines of small blebs within the sphalerite as if deposited from ex-solution. A mineral, which it was not found possible to identify but which is probably a silicate, occurs in fine hair-like threads along the cleavage of the galena and occasionally in the sphalerite.

Paragenesis:

The paragenesis is diagrammed in Table X p 145A and little need be said to supplement the graph. Magnetite was not observed under the microscope but was probably the earliest mineral to form. Grunerite crystallized out during the entire period of sulphide deposition and probably continued to form for some time after that. The unknown silicate probably represents a later, unrelated stage of mineralization. No supergene minerals were observed on the very surface.

No igneous rocks are known near the ore-bodies except for one small vertical dyke whose relationship to the ore is not known. A dark green, foliated rock composed largely of actinolite and full of garnets appears in certain parts of the ore-body, however, which may represent a highly altered Purcell diorite.

The Society Girl Mine: #5

The Society Girl Mine is situated about two miles east of Moyie, beyond the St. Eugene Mine and at an elevation of about 5,000 feet. It adjoins the east boundary of the St. Eugene and is a continuation of the same zone of fissuring and mineralization as that mine and the Aurora. A good waggon road leads to it from Moyie. It has been operated in the past on a small scale, most of the mining being confined to the extraction of the oxidised ore, but it is now shut down. The development consists of two tunnels and a shaft; the two former are blocked and the latter only accessible for the upper fifty feet.

The primary ore is essentially the same as that of the St. Eugene and the two deposits are evidently genetically related. The deep oxidised zone is, however, interesting and warrants description. It extends to a depth of over 50 feet and the primary minerals found below, galena and sphalerite, occur only occasionally as small kernals surrounded by masses of secondary lead and zinc minerals. These minerals consist of pyromorphite, cerussite, malachite, azurite, and possibly, anglesite andmimetite. Silver is reported to occur in the proportion 1 ounce of silver to 5½% lead. The origin of this zone has already been discussed in the section on glaciation and it is believed to be due to pre-glacial weathering.

The B & V Group: #2

The B & V Group of claims lie about seven miles southwest of Cranbrook.

The wall rock underlying the area covered by the claims consists entirely of Aldridge quartzites and slaty, argillaceous quartzites. They have an average strike of about N 50° W and commonly dip at about 15° NE. The only igneous body seen on the group was a dyke about 20 feet wide which was evidently an off-shoot of the granitic stock occupying the lower end of Fish Lake Valley about a mile northwest of the boundary of the group. To the southeast, about the same distance, are a number of large Purcell Sills.

Three short shafts, an 80 foot adit, and a number of open-cuts have exposed a series of narrow quartz veins with a general east-west strike and a steep dip. Small ore-shoots occur at intervals but otherwise the veins are often entirely barren of sulphides. Minerals observed were pyrrhotite, pyrite galena, sphalerite, chalcopyrite and arsenopyrite. Gold is reported in amounts varying from $2 to $16 per ton. Under the microscope pyrrhotite was found to be the most common mineral occurring in grains up to 1.5 mm across. Pyrite was comparatively scarce and has been largely altered to pyrrhotite. Partially altered remnants of pyrite are still to be seen. Sphalerite occurs in two generations. The first as grains in the quartz and pyrrhotite, and the second as thread-like veinlets cutting all the minerals including the earlier sphalerite. Both generations are the iron rich variety marmatite. The paragenesis is diagrammed in Table X, p 145.

~~The~~ Arsenopyrite is not found often in the Cranbrook area and, in the B & V Mine it occurs in the wall rock close to the veins rather than in the vein itself. Biotite in books up to 20 mm across is common in many of the veins and, together with the presence of the minerals pyrrhotite and arsenopyrite, suggests that the veins were formed at high temperature.

The presence of pyrrhotite and sphalerite and the absence of calcite in the gangue distinguishes this mineralization from the quartz-calcite veins that are believed to be associated with the Purcell Sills. The mineralization on the B & V is probably related to an underlying granitic mass of which the Fish Lake stock is an offshoot, and it may represent the high temperature form of the silver-lead-zinc deposits of the Cranbrook area.

The Payroll Group of Claims: #1

The Payroll group is the only prospect on which gold was actually seen and it will therefore be described.

The group is located on Nigger Creek about a mile above its junction with the Moyie River.

Several tunnels and open-cuts have exposed an irregular quartz-calcite vein cutting across massive beds of Aldridge quartzite. A Purcell dyke about 40 feet in width occurs in the vicinity of the vein in which small amounts of pyrrhotite and chalcopyrite were seen. Pyrrhotite, chalcopyrite and gold were seen in the hand specimens from the vein and under the microscope a telluride which appears to be petzite $(Au,Ag)_2Te$. (Plate XIII C, p166) The gold and petzite appear to be about the same age and occur in fine veinlets running between the grains of the quartzite. Small amounts of an undetermined grey mineral occurred which showed innumerable fine threads of gold all through it.

The origin of this mineralization is undetermined, but the close association with the Purcell dyke and the presence of primary calcite in the gangue suggests that it may be related to the Purcell intrusives. Kirkham and Ellis believe that the gold bearing veins in Northern Idaho are derived from the pre-Cambrian sills. They say:- "All of the veins in or connected with the basic sills have apparently derived their gold from the sills themselves. The reasons for arriving at this conclusion are; First, that the sill rock was found to contain pyrite and pyrrhotite carrying gold in extremely small amounts; second, that the sills are unmistakably of Beltian age and are therefore pre-batholithic. These two facts point to a magmatic segregation of gold-bearing sulphides within the sills themselves, since the veins are not sufficiently continuous in any direction to have obtained their mineralization from an exterior and later source." (81, p 49)

The Running Wolf Group #12

The Running Wolf is located on the south side of Perry Creek about a mile up the tributary French Creek at an elevation of 5,000 feet and serves as an illustration of the gold-quartz veins of Perry Creek.

Five tunnels have been driven on a number of quartz veins three of which are now caved in but the main one

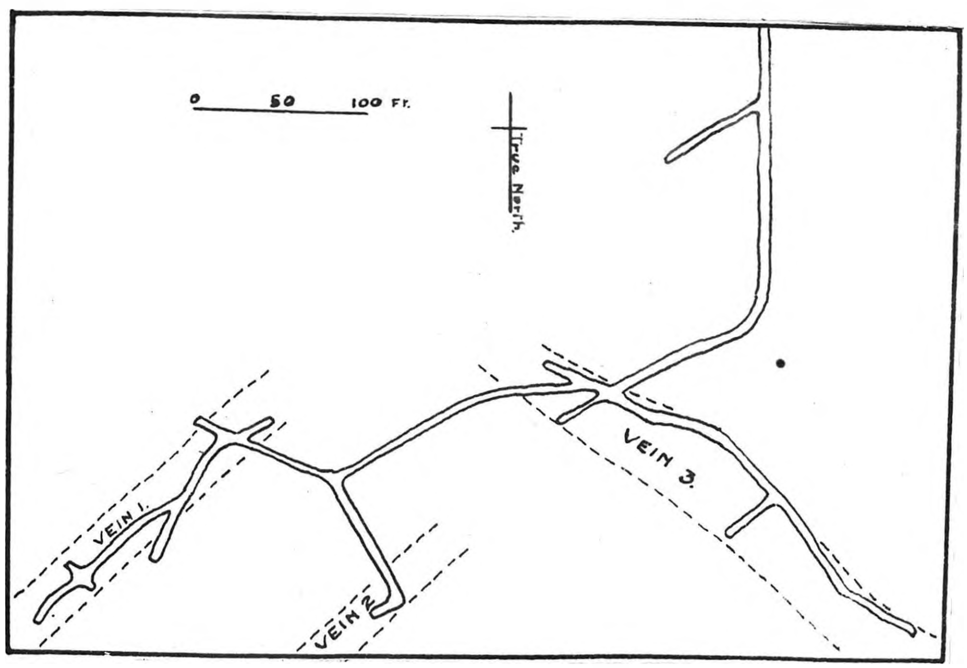


Figure 16

(Figure 16 continued from p 190) Sketch map taken from G.S.C. Mem 76 of the main tunnel of the Running Wolf Mine.

is still open. It exposes three veins, as illustrated in the figure, cutting massive but considerably altered Creston quartzite. The veins are about 30 feet wide and consist of solid white quartz without sulphides except for a few specks of pyrite. Post-mineral faulting has disturbed them slightly. The veins are strong and persistent and it is evidently only the paucity of gold values that prevents them from being of commercial importance. Under the microscope the pyrite was found to be strongly anisotropic and has evidently been severely strained since its crystallization.

No igneous rocks occur anywhere in the vicinity and the origin of the mineralization is obscure.

<u>Prospect</u>: #24

This prospect is cited as a typical example of the quartz-calcite veins associated with the Purcell Sills. It is located to the northeast of Marysville on the west side of the mass of intrusives related to the Purcell boss described in the section on the igneous geology.

A series of trenches has exposed a vein for a length of about 200 feet with a width of from one to two feet occurring in the fine-grained, salt and pepper phase of a Purcell Sill. It strikes at N 50° W and dips vertically. The vein is fairly uniform in width and remarkably persistant. Small veinlets run off into the wall rock from the sides but alteration of the diorite is confined to an inch or so from its contact with the vein.

The gangue is massive quartz and calcite with sulphides scattered irregularly all through it. The mineralization consists of pyrite, quartz, calcite, chalcopyrite, and galena. (Plate XIII D p 166) The calcite was found to comprise about 75% of the gangue and to have been deposited over the entire period of mineralization. It is also very noticeable that almost the entire amount of the sulphides occur in the calcite rather than in the quartz. Galena is the commonest sulphide and it and chalcopyrite appear to be approximately contemporaneous. Sphalerite is conspicuously absent.

The origin of this mineralization, as has already been pointed out, is believed to be the Purcell Sills or their parent magma.

The Mystery Group: #41

The Mystery group of claims furnishes an illustration of the magmatic segregations in the Purcell Sills. It is located on Alke Creek which flows into the St. Mary's River just above St. Mary's Lake. The claims are underlain by massive Aldridge quartzite intruded by one or more large Purcell Sills. The mineralization is of two types; 1. a zone of brecciation in the sill rock cemented by quartz stringers carrying pyrite and chalcopyrite and having a total width of about 20 feet, and, 2. a lense of nearly massive sulphides lying within the body of the sill and without distinct walls. The former is typical of the veins found elsewhere in the Purcell Sills and needs no further description, but the latter deserves special mention.

The diorite is of the normal type up to the edge of the ore-body, and no sign of any hydrothermal minerals can be seen. There was evidently no reaction between the ore or ore-bearing solutions and the wall rock at the time of deposition. The ore consists of a solid mass of pyrrhotite and chalcopyrite with long needles of an amphibole ~~mass~~ having the same optical properties as that in the normal sill rock developed all through it. (Plate XIII A, p166) Small specks of sphalerite occur and minute particles of a grey mineral, possibly chalcocite, are developed in both the pyrrhotite and the chalcopyrite.

The entire mineralization appears to have taken place almost simultaneously. Crystallization may, however, have started in the following order:- pyrrhotite, chalcopyrite, chalcocite (?), sphalerite (?), with the amphibole forming during the entire time.

The ore is comparatively high grade and, if further development indicates a body of sufficient size, there is no reason why it may not profitably be extracted should metal prices become more favourable.

The origin of this ore has already been fully discussed and will not be mentioned here.

The Future of the Lode Deposits of the Cranbrook District

Since there are three distinct types of deposits they must be considered separately in discussing the possibility of future development.

Silver-Lead-Zinc Deposits:

To this class belong all the mines that have been of economic importance although the Sullivan is the only one in active operation. The future of this mine has already been discussed and is assured for many years. Several other mines of this type, which have been worked, are now lying idle and there is reason to believe that some of them will be re-opened on the return of more favourable metal prices as they still contain ore in commercial quantity.

Prospecting has naturally been fairly thorough all over the area and it is certain that no ore-bodies on the scale of the Sullivan will be found outcropping plainly. On the other hand, the Aldridge formation appears in the greater part of the Cranbrook district and is known to be a favourable host for such mineralization, and the granite, the source of these ores, is believed to underly most of the area so that careful and scientific prospecting may yet reveal important ore deposits. To indicate the specific favourable localities is a harder task than to state the generalization. It may, however, be said with confidence that, ~~judging~~ from theoretical grounds as well as from ~~empirical~~ experience~~s~~ in the area, the massive quartzites found in the lower parts of the Aldridge formation are the most favourable for ore of the Sullivan and Moyie types, and the upper and softer formations, Kitchener and Siyeh, are not likely to prove profitable fields for prospecting. It is possible that a careful study of the metamorphism of the sediments might give some idea of the proximity of underlying bodies of granitic rocks and indicate likely spots for intensive prospecting. No attempt has been made as yet to undertake such a study.

Gold-Quartz Veins:

Although these are strong and persistant, gold has never been found in commercial quantity. Some gold is present, however, and it may be that ore-shoots of commercial grade may yet be discovered. Rich gold placers have been found in many parts of the area and it is still a question as to whether these were derived from the low grade veins known or from high grade shoots not yet discovered. The amount of intensive prospecting that has been done fruitlessly in an effort to find rich deposits of this type makes the first hypothesis appear to be the correct one. The increase in the price of gold has stimulated development on the known veins to such an extent that if commercial ore-shoots are not found within a short time, the outlook for this class of deposit will become extremely gloomy.

Quartz-Calcite Veins in Association with the Purcell Sills and Related Segregations:

It is doubtful if veins of this class will ever become great producers. The veins are strictly confined to the sills ~~themselves~~ and the development of ore-bodies is thus limited. On the other hand several of the veins show ore-shoots with a sufficient concentration of sulphides to make a workable grade of ore had the shoots been somewhat larger.

The ore in the segregations is relatively high grade, and only has to be proved to be in fair sized ore-bodies, to make an attractive enterprise as soon as base metal prices recover.

Deposits of this class are confined entirely to the sills and ore-bearing solutions cannot, therefore, have travelled very far. A locality with an abundance of large sills would, therefore, be a favourable one for the development of ores of this type, and would be most likely to be found near the base of the Aldridge formation. It is there that prospectors are recommended to search.

Placer Mining

Placer gold was being actively mined during the summer of 1932, but more because of the scarcity of other work, owing to the depression than with the hope of very lucrative rewards. Most of the miners with whom conversation was held were satisfied with getting from 50 cents to a dollar a day, and those approaching the latter figure were in the minority. The district has, however, had an interesting placer mining history and there is little doubt that much more gold still remains if it can be found and profitably ~~used~~ extracted.

In the late fifties or early sixties miners ~~came~~ from the California fields of '49, worked their way across the border and located rich deposits of placer gold on Wild Horse Creek, a tributary of the Kootenay River entering it from the east at Fort Steels. Not long after the first discovery, gold was also found on the west side of the Kootenay River in several Creeks. This gold was all shipped directly across the border into the United States and no record of the amount has been found. In 1874 the Canadian authorities became cognizant of this and an office was established in the district and the amount of gold produced recorded. There is no doubt that by this time the hey day of the deposits was past, but in the first year over $50,000 worth of gold was mined, mostly from the east side of the Kootenay River. For the next few years the production declined until in 1879 it reached a minimum of $17,000. In 1884, however, the production reached a maximum recorded of $57,862. Until 1895 it varied, the average being about half that of the maximum figure and in that year the discovery of silver and lead in the district turned the majority of the miners to prospecting for lode deposits and the production of placer gold dropped to $878. Since that time, although some gold has always been mined, placer deposits have never resumed importance.

At five localities in the area, details of which are given by Cairnes, placer deposits were being worked in 1932. (121, pp 76A-84A) They are:- Perry Creek, the St.

Mary's River; Palmer's Bar Creek and Vicinity; Fish Lake Valley; and the Moyie River and Weaver Creek.

There is so striking a similarity in the nature of the placer deposits in the Cranbrook area and those near Bakerville that the processes by which the two originated must have been similar. Four types of deposits can be recognized near Cranbrook each of which has its counterpart in the Bakerville area. (71, pp 50-52)

1. Placers in pre-Glacial Stream Gravels

In the Cranbrook area, deposits of this type are not common; an unfortunate fact since they furnish the most important producers of the Bakerville area. Pre-glacial, or at least pre-Wisconsin, accumulations of gravel are known in many parts of the area and it is possible that further exploration may still bring to light hitherto undiscovered ores containing valuable concentrations of gold. Unfortunately most of the likely regions are so covered by glacial detritus that preliminary exploration is rendered very costly and there is always the likelyhood that the cost of mining any gold found may be prohibitive. For these reasons deposits of this type have not recieved much attention in recent years. They are known on Perry Creek, however, and, in 1932, efforts were being made to exploit one of them by a shaft sunk in the rim of the channel and a drift from the bottom of it over to the deposits. Johnston and Uglow describe the Bakerville deposits in the following terms:- "They occur in ancient stream gravels resting on bedrock and in many cases buried beneath great or small thicknesses of glacial drift. These placers are by far the most important in the area and constitute the rich pay-streaks in the beds of the creeks, that were mined out, for the most part, in the early days. The gold-bearing gravels on bedrock vary from a few inches to ten or fifteen feet in thickness, ---- but in places nearly all the gold is directly on, or in cracks and crevices in, the bedrock. ---- The pay-streaks on bedrock are best developed in the narrow, deep parts of the creeks and do not occur to any extent in the wider upper parts near the sources of the creeks, where valley glaciation has been very pronounced. ---- The pay-gravels, in part at least, were deposited in pre-glacial times." (71, p 50) This description is entirely applicable to the Cranbrook area.

2. Pre-Glacial Bench Deposits:

Deposits of this type are not very common in the area, but are being worked to a small extent in the Fish Lake Valley. They occur at various elevations along the sides of the valley and consist of stratified gravel deposits with gold occurring along bedrock. They are evidently remnants of stream deposits that have escaped erosion. None has proved very rich, but they may have served as the source of some of the gold found in the lower parts of the valley and elsewhere in the district. A similar type of deposit is described by Johnston and Uglow in Barkerville. "Pay-streaks occur in places in gravels on the bedrock benches at various heights above the present creeks and in a few places in abandoned or partly abandoned stream channels high above the present creeks.

They are evidently pre-Glacial in age." (p 51)

3. Gold in Ground Moraines:

Most of the gold being mined in the vicinity of Palmer's Bar occurs scattered haphazard through unsorted morainic material. The grade is naturally very low and the repeated occurrences of huge boulders makes the material difficult to work. The gold is in very thin, round flakes and has evidently been stream worn before reaching its present position. Obviously the ice has swept out pre-existing placers in the course of its progress down the valleys and has diluted them with large quantities of detritus collected elsewhere, depositing the entire mass during its retreat. Deposits of this type are described from Bakerville, by Schrader (32) from Idaho, and by Clapp (64) from Vancouver Island. The writer has had an opportunity to examine the latter deposits and their similarity with the Cranbrook deposits is striking.

4. Deposits Formed by the Re-Working of the Ground Moraines:

Vigorous outwash streams re-worked much of the glacial material during the retreat of the valley ice and, in doing so, concentrated some of the gold contained in them. As a result small lenses of sorted, gold-bearing gravels occur at various levels in many of the moraines. Unfortunately the amount of material available was far in excess of the capacity of the streams and, as a consequence, sorting was never very complete and none of the deposits is either large or rich. Post-Glacial streams have been continuing the process but the time that has elapsed since the final retreat of the ice has been too short for any valuable concentrations to result.

Changes in Drainage:

Mention has been made in the section on Physiography of the post-Glacial changes in drainage. Many of the creeks, Perry Creek, the Moyie River, and Mark Creek, for example, have been very obviously deflected for short distances and several attempts to work the abandoned channels have met with indifferent success. There is no doubt, however, that some of the streams have been deflected at an earlier period. The Moyie River, for example, undoubtedly continued its northerly course out onto the Plain of the Trench at one time, ~~instead~~ instead of swinging to the southeast to the head of Moyie Lake as at present. Exploration of these abandoned channels might lead to the discovery of important placer deposits of pre-Glacial age. Unfortunately deep glacial accumulations have effectively masked the old ocurses so that their exact location is difficult to determine and development and mining may prove too costly to justify the attempt to do so.

NON-METALLIC DEPOSITS

Magnesite:

Mention has already been made of the occurrence of rock magnesite in the Annelide sub-formation. While magnesite occurs at every locality where the Annelide is known, the most important development of that mineral is in the belt running south from the vicinity of Marysville. Here a bed of high grade magnesite from 30 to 50 feet thick can be traced for over four miles and ~~with~~ over a vertical range of about 2,000 feet. This body was discovered by the Geological Survey party in the season of 1932, and has since been staked by the Consolidated Mining and Smelting Company of Canada who already owned a smaller body with the same geological associations lying above the headwaters of Perry Creek. The Marysville belt, although limited to the north and south by the St. Mary's River and Perry Creek faults respectively, contains an enormous amount of magnesite. Its extension at depth is, of course, not known, but its occurrences over a relief of 2,000 feet suggest a considerable vertical continuity. Even assuming a depth of not more than 100 feet and a width of 30 feet, over 6,000,000 tons must be present.

Cairnes describes the occurrence as follows:- "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 of 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." (121, pp 102A-103A). Pure $MgCO_3$ contains 47.6% of MgO and the relative purity of the Cranbrook magnesite can be appreciated from a comparison with the following analyses of two samples of it made by the Mines Branch, Dept. of Mines, Ottawa:-

	NO 388R	NO 330
	%	%
SiO_2	4.54	4.40
Fe_2O_3	2.40	1.40
Al_2O_3	0.40	0.66
CaO	0.79	0.73
MgO	43.70	44.80
Loss on ignition	48.00	48.30

Both samples are chip samples taken from the weathered surface; No 388R from a width of 18 feet and No 330 across 50 feet. There is no doubt that by careful hand sorting the grade could be improved considerably without prohibitive cost.

The uses of magnesite are manifold:-

1. For refractory material.

2. For oxychloride or Sorel cement which is used in roofing, stucco, artificial marble, etc.

3. In the manufacture of wood pulp.

4. In the manufacture of CO_2, although in recent years the use of limestone has largely surplanted that of magnesite.

5. For fire-proof paint.

6. For the production of metallic magnesium.

7. For the manufacture of magnesium sulphate (Epsom salts).

8. For the manufacture of magnesium chloride.

9. For the manufacture of light magnesium carbonate ($MgoH,3MgCO_3$).

10. For a number of miscellaneous purposes.

The origin of the Cranbrook magnesite is obscure. A body of magnesite of a rather similar type has been described from the Grenville District, Quebec, (122) where it is associated with dolomite and serpentine in a series of pre-Cambrian sediments. These deposits are believed to be formed from limestone by the action of magnesium rich solutions. The Cranbrook deposits may have a similar origin, but if so, the replacement has been almost complete and there is no alteration in any of the surrounding rocks that suggests the presence of magnesium bearing solutions.

Ornamental Stone:

"A little quarrying has recently been attempted near Cranbrook on rocks of the Purcell sills, with the purpose, primarily, of finding out what uses such stones are best adapted for and to what extent it affords comparison or is capable of competition with occurrences of somewhat similar rock in other districts at home and abroad. ------ Much of the value of this stone for ornamental purposes will depend on how easily and well it can be polished and on the effect of such a polish. Experiments along this line are now under way at the Mines Branch, Ottawa, and results may be expected in the near future." (121, p 105A)

GEOLOGICAL HISTORY

The Geological History of the Cranbrook district can be traced from the PreCambrian to the present, although there are many gaps and many steps are only imperfectly known. Events during certain stages are inferred from data appearing outside the actual area and are included to make the record as complete as possible.

A tabular statement is given below:

Present	Erosion and deposition along the lower courses of the rivers.
Late Pleistocene	Wisconsin stage of continental glaciation.
Middle Pleistocene	Long interglacial period(?) and the formation of the St. Eugene silts.
Early Pleistocene	Early stage of continental glaciation (?).
Close of the Tertiary and Early Pleistocene.	Erosion. Filling in of the Trench.
Late Tertiary(?)	Faulting and downwarping of the east margin of the district to form the Rocky Mountain Trench.
Paleocene(Laramide Revolution).	Strong thrust from the west producing foli tion and minor thrust faulting. Sever folding and overthrusting of the sediments inthe Rocky Mountain Geosyn cline to form the Rocky Mountains. Reversal of the drainage of the Kootenay river.
Close of Cretaceous	Erosion. Peneplanation probably not

	complete
Jurassic and Early Cretaceous(Jurasside revolution)	Folding followed by faulting, igneous intrusion (granite) and mineralization.
Triassic	Vertical (?) uplift and erosion .
Devono-Carboniferous	Vertical subsidence. Probably little or no submergence in area.
Middle and Upper Cambrian and Ordovician and Silurian.	Uplift and erosion.
Upper Lower Cambrian	Vertical subsidence and deposition of the Perry Creek Formation.
Late Precambrian(Windermere)	Slight vertical uplift resulting in the draining of the sea but with little erosion.
Late Precambrian(Beltian)	Formation of the Purcell Basin and the deposition of the Purcell series. Intrusion of the Purcell sills,etc. and mineralization.
Pre-Beltian	Formation of a land to the west of the area.

<u>Pre-Beltian</u>:

The sediments of which the Purcell series were formed are believed to have been derived from a land lying to the west of the Purcell basin . This land may have been in existence when the Purcell basin was formed or it may have been produced by the same deformation that depressed the area to be occupied by the Purcell sea. Schofield (14,p.98) believed it to be composed of gneisses and schists.

Beltian:

The Aldridge epoch: The origin of the Purcell sea is not known, nor is the nature of the first sediments to be laid down in it. The earliest record is that of the lowest member of the Aldridge formation. At that time the sea was evidently a uniform,shallow one, sinking at aboutthe same rate as the deposition.

The Cherry Creek epoch: As the top of the Aldridge was reached the sediments became finer grained, and thinner bedded ~~beside~~. Either the basin was becoming deeper so that the coarser sediments were deposited closer to the shore and not carried out over shoals and flats, or the land from which they were derived was wearing down faster than it was rising and the rivers were losing grade and could carry only fine muds and silts. It may even be that a change in the climate played a part.

The Creston epoch: At the close of the Cherry Creek epoch a gradual but profound change took place. The sediments once more became as coarse as in the Aldridge but the quartzites formed were less argillaceous. Pure quartzites, however, do not occur in the lower Purcell series, and it is evident that the sediments continued to be deposited in muddy flats and shoals, although the proportion of sand to mud increased to a maximum during Creston time.

Kitchener epoch: Occasional lenses of calcareous rocks appear from time to time in the earlier formations of the Purcell series, but in the Kitchener, they assume importance for the first time. The basin remained shallow but the sediments deposited were much finer grained. Nearly all of them are slightly calcareous and there are occasional lenses of nearly pure limestone. This lime is believed to be largely of organic origin.

The Siyeh epoch: There was, apparently, little change in the Purcell series during this time. For some reason there is a diminution in the lime content, but the sediments have the same fine-grained, muddy appearance as the Kitchener. During the close of the epoch, however, the vulcanism which produced the Purcell lavas took place. The absence of pyroclastics suggests that it was in the form of fissure eruptions and the flows apparently ran out over the flat lying muds of the Siyeh, probably in part sub-aqueously, since pillow structures are known to occur in them, although none was seen in the area. While the flows were being extruded the Purcell sills and dykes were intruded into the underlying formations and at the same time the mineral deposits of ~~the~~ pre-Cambrian age were formed.

The Old Town epoch: The close of the Siyeh was marked by a definite change. The base of the succeeding subformation, the Mission quartzites, is everywhere fairly coarse and often conglomeratic. There appears to have been an upwarping of the land to the west and a shallowing of the Purcell basin so that streams flowing from the land washed sand and fine gravels d down over the mud flats formed during the upper Siyeh epoch. The shallowing of the basin resulted in the draining of the sea from certain of the bars previously deposited and, on them, the overlying quartzites were laid down with somedisconformity. The elevation was evidently slight, however, since deposition was continuous over large parts of the a rea.

Conditions were uniform during the deposition of the Mission quartzites, and then a change took place which resulted in the formation of the Annelide sub-formation containing thick beds of what is now magnesite. The original nature of the beds and the manner in which they were deposited is not known. Life, of a humble nature, was undoubtedly present at the close of the epoch, but whether in the form of annelides or algae has not yet been determined.

Windermere and Earliest Cambrian:

Shortly after the close of the Old Town epoch a broad, vertical uplift took place, draining the entire region. It does not seem likely that the uplift could have been very great or that erosion could have been very severe since, as far as is known, the subsequent formations were laid down on about the same horizon in all parts of the area. A long time interval is, however, represented and during it 10,000 feet or more of sediments were laid down in the Windermere region to the north. It is suggested that the elevation raised the bed of the Purcell sea close to the existing water level so that erosion was at a minimum and deposition could not be effected. There was evidently little or no diastrophism in the area and both the elevation and the subsequent subsidence were probably purely vertical movements.

Upper Lower Cambrian:

During this time the basin was again vertically depressed and fine,muddy sediments with occasional lenses of limestone deposited in it. The submergence was probably never very great, although the sea may have been deeper than during the previous cycle. Life was evidently fairly abundant and already rather highly organized since trilobite remains are common and a few primitive brachiopods have been collected.

Middle and Upper Cambrian, Ordovician and Silurian.

The Cambrian period of submergence was a short one and during the Middle Cambrian, the seas were once more drained by a slight vertical uplift and remained out of the region until the beginning of the Devonian. The uplift was probably not sufficient,however,to permit active erosion.

Devono-Carboniferous Epoch.

In the early Devonian the land once more subsided vertically, and the sea flooded the area to the southeast of Cranbrook, although inundation may never have reached any part of the district represented on the map. Considerable thicknesses of limestone were,however, laid down to the southeast of the area and the land surrounding this basin must have been too low for much clastic material to form.

Triassic:

At the close of the Paleozoic, the seas were drained away from the area for the last time, either by another vertical uplift or by one accompanied by moderate folding. The vulcanism that was so active along the Pacific Coast at this time was apparently not present here.

Jurassic and Early Cretaceous (Jurasside Revolution)

The Jurasside revolution that was responsible for the intense folding of the sediments in the western parts of British Columbia and the formation of the Coast Ranges, expressed itself in the area as a period of rather moderate folding. This folding and the uplift accompanying it elevated the block of land from which erosion had carved the Purcell Range. At some time during this orogenic period the two main systems of faulting were developed and it was, in all probability, during its last stages that the granodiorite batholith was intruded. The second, and most important period of mineralization is believed to be related to this intrusion.

Close of the Cretaceous:

With the uplift of the above period, erosion, of course, became extremely active, but before peneplaination could be effected, a further diastrophic calamity interrupted the cycle.

Paleocene (Laramide Revolution):

The orogenic period known as the Laramide revolution consisted of a renewed thrust from the west. The sediments of the area strengthened by the intruded granodiorite and its accompanying silicification acted as a block, and transmitted the stress almost without deformation, to the softer sediments in the Rocky Mountain geosyncline to the east of the area. The only effect in the district was a min or amount of thrust faulting and some foliation and, presumably, elevation with the renewal of active erosion .

<u>Late Tertiary:</u>

At some time after the folding and elevation of the Rocky Mountains, possibly as a relief from the stresses set up at that time, extensive faulting took place along what is now their west face. The effect on the area was to downwarp its eastern margin to form the floor of the Rocky Mountain Trench, without producing any faulting in the area parallel to the Trench itself.

<u>Close of the Tertiary and Pleistocene:</u>

The remainder of the Tertiary and the early part of the Pleistocene was a period of erosion during which the hills of the Purcell Range and the Rocky Mountains were dissected, and the sediments washed down into the Trench.

At some time in the early Pleistocene there was, in all probability, a stage of glaciation of which almost all the evidence has been destroyed, which was followed by a long, warm interglacial period. ~~For~~ During the greater part of the ~~Interglacial~~ period, a large lake occupied a part of the Trench in which the St. Eugene silts were laid down. The topography upon which the Pleistocene deposits were laid had a relief of not less than 500 feet and very likely a great deal more.

<u>Late Pleistocene:</u>

The glaciation, of the Wisconsin epoch, which is responsible for nearly all the glacial phenomena to be observed today, put an end to this interglacial period. When at a maximum all or nearly all of the peaks of the Purcells were covered by the continental ice sheet, although erosion was not severe in the lower levels, and the ice apparently ran over the St. Eugene silts leaving them largely undisturbed.

As the ice melted away the glaciers occupying the valleys retreated to higher elevations but that occupying the Trench broke up and stagnated, leaving the surface of the ground covered with heaped up moraines and deep depressions. The drainage was profoundly influenced, many of the streams being permanently diverted from their former channels.

Recent:

Since the final retreat of the ice, the area has been subjected to active erosion in the higher elevations. After the removal of the ice from the main valleys the rivers entrenched the moraines in them and cut deeply into the St. Eugene silts, but of late, owing to the abundant material available to them throughout their entire courses, they have been aggrading rather rapidly and have assumed a braided appearance.

PHYSIOGRAPHY *

British Columbia, along the line of the International Boundary, may be divided into three main physiographic provinces (123). On the western border of the Province lie the various systems of the Coast Range and on the eastern, the Interior Mountain systems, while, separating the two mountainous tracts, is the upland of the Interior Plateau. The Interior Mountain systems, from east to west, are the Columbia Mountain system, the Selkirk Mountain system, the Purcell Mountain system, and the Rocky Mountains, all running roughly north and south. The Purcell Range is separated from the Selkirk Range on the west by the Purcell Trench, and from the Rocky Mountains on the east by the Rocky Mountain Trench. The two Trenches converge to the north and finally join, and so terminate the range. The area covered in this report includes portions of the eastern Purcells and the Rocky Mountain Trench.

The Purcell Range:

The Purcell Range has been carved out of the elevated, gently folded sediments of the Purcell Series with their accompanying diorite sills and minor granodiorite stocks, and has a relief of 6,000 to 7,000 feet. Although the relative hardness of the formations has influenced the shape of the hill tops, structure has apparently had little influence in the development of the mountains. The result of pre-Glacial stream erosion has been somewhat modified by glaciation, although few of the valleys appear to have been profoundly eroded by ice.

(*This section should be inserted before the section on Economic Geology)

The Rocky Mountain Trench:

The Rocky Mountain Trench is so well known a feature that a detailed description of it is not necessary. It starts just south of the International Boundary in longitude 115° west and extends northwestward for almost 1,000 miles forming the west boundary of the Rocky Mountains. Although its average width is only about 4 miles, it is one of the longest linear depressions i in the world and is particularly remarkable owing to the fact that the elevation of its floor does not vary over 1,000 feet. It is occupied by a number of rivers some of which flow north and some south; in the Cranbrook area, it is occupied by the south-flowing Kootenay River.

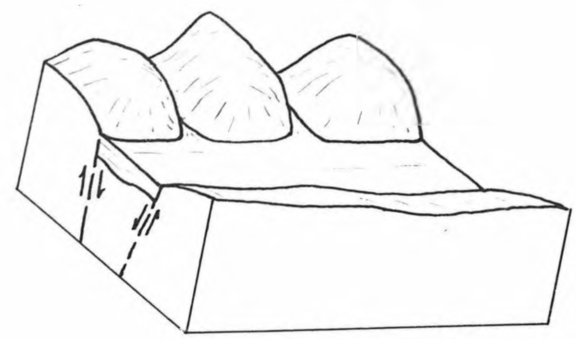
It is evident, both from the physiographic and stratigraphic evidence, that the Trench is located along a line of intense deformation and faulting, but details of its structure are often impossible to ascertain on account of the depth of unconsolidated material that has accumulated in it since its formation. There is no doubt that the west face of the Rocky Mountains represents a deeply eroded fault scarp, but the nature of this fault and of the block underlying the Trench is not so clear. In Montana there is evidence suggesting that the Trench is a graben lying between two faults (51) (Plate XIV A p. 216A), while to the north of the Cranbrook area near Windermere Lake Shepard determined it to be a deeply eroded horst (Plate XIV B, p. 216B). He says, "The findings of the 1924 season leave little doubt but that the supposition of a graben (made by Daly(13,p. 600)) is erroneous, at least for the parts of the Trench under discussion. "These relations are just the opposite of what

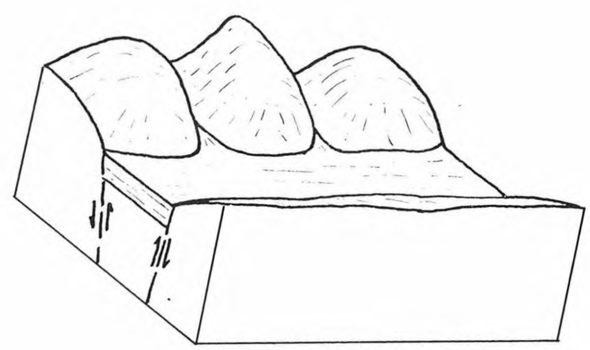
Plate XIV

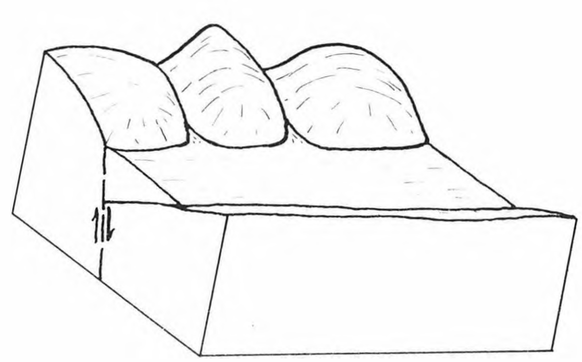
A. Block diagram illustrating the origin of the Rocky Mountain Trench as a graben. This is believed to be the case in Montana.

B. Block diagram showing the origin of the Trench as an eroded horst. Shepard has demonstrated this to be the case in the vicinity of Windermere Lake.

C. Block diagram illustrating what is believed to be the origin of the trench in the Cranbrook area. A block tilted along a single line of faulting.







would be found in the case of a graben and suggest a horst.--- The presence of a deep valley instead of an elevated tract along the horst is cértainly unusual. It is no doubt due to long-con tinued erosion which has exposed the weaker underlying formations, changeing an uplifted area into a depression" (124, p.640). In the Cranbrook area,however, there is no indication of a fault along the western margin of the Trench. The structure is therefore believed to be caused by a single normal fault or system of faulting located along the base of the western margin of the Rocky Mountains. By this fault, the sediments of the eastern margin of the Cranbrook area were tilted or downwarped to form against the fault scarp, a broad V. (Plate XIV C p.216A) The rocks exposed along the west margin of the Trench belong to the upper formations of the Purcell series and the overlying Cambrian strata, dipping at low angles eastward into the Trench, while the face of the Rockies is composed of the basal formation of the Purcell series, the Aldridge. Unfortunately, the entire floor of the Trench is covered by alluvium for a width of nearly 10 miles so that it is impossible to be sure that there may not be complications that are not indicated by the structures on each side.

The folding of the Rocky Mountains is known to have taken place during the Laramide Revolution and the fault that produced the west face of the range was formed at some time after this. Normal faults of this nature are the common result of tensional stresses set up after a period of folding and it may be that the faulting producing the Trench was accomplished during the close of the Laramide Revolution. It does not seem possible,however, that an interval of time as great as that since the Paleocene, the Laramide Revolution, could have elapsed without destroying the features still evident in the fault scarp forming the west face of the Rocky Mountains and it is felt probable that the faulting is of comparatively recent date. Since there are no structures in the Cranbrook area that can be correlated to the faulting in the Trench, there is no evidence in it to suggest the age of the formation of that feature.

Relation of Drainage to Faulting:

A glance at the map accompanying this report will be sufficient to enable the reader to see the remarkable way in which a number of the main streams are located along lines of faulting. For example Perry Creek, and the St. Mary's River.

A stream, while it is actively downcutting, will naturally follow zones of weakness in the rock over which it is flowing, and is therefore apt to be located along a line of faulting. As soon as it ceases to erode downward, however, weakness in the underlying rocks can have no further influence in determining its course,(125), Other factors being equal, it will depart from the locus of the fault a distance proportional to the time which has elapsed since it ceased to degrade. Both the St. Mary's River and Perry Creek are actively aggrading in their lower reaches at the present time, but since they are so closely located along lines of faulting, it must be inferred that the condition of aggradation is of fairly recent origin.

Post-Glacial Changes in Drainage:

The surface of the Rocky Mountain Trench is composed almost entirely of glacial material and the streams flowing across it are all consequent streams whose courses have been imposed upon them by the shape of the land surface as left by the waning of the ice.

Although glaciation has not affected the direction of the streams in other parts of the region so profoundly, almost all of them show its influence. One striking example is furnished by Cherry Creek at a point some eight miles from its mouth(fig. 14). The stream runs east across the surface of

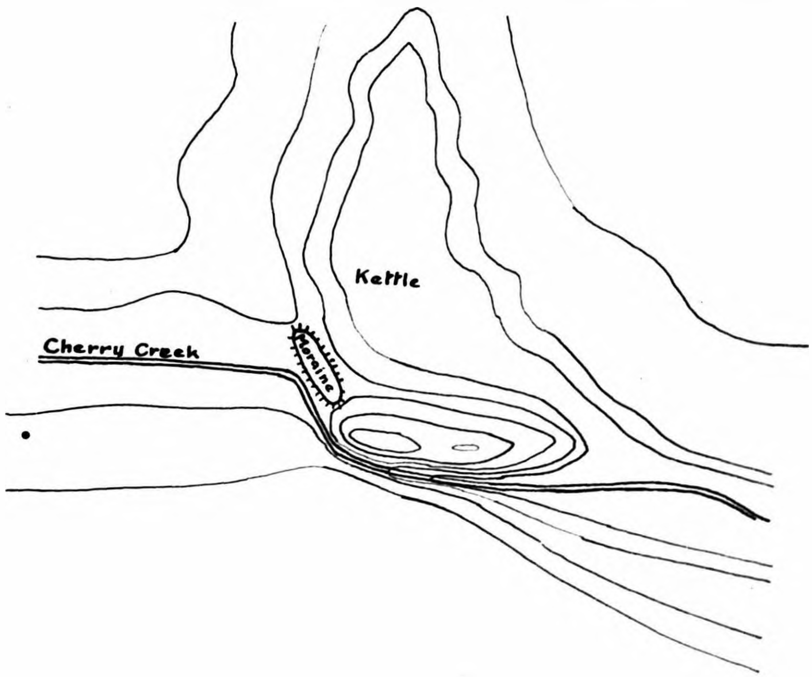


Fig. 14

Sketch showing the influence of glaciation on the course of Cherry Creek. Note the deflection of the creek by a low moraine and the post-glacial canyon cut through massive quartzites. Contour interval about 50 feet.

the Trench to a point not fifty feet from the edge of one of the large kettles previously described. The bottom of this depression is about a hundred feet below the bed of the stream. A low moraine,however, deflects the creek to the south where it has cut a box canyon through massive Aldridge quartzites to the level of the bottom of the depression. Mark Creek, Perry Creek, and the Moyie River have all been deflected out of their original channels in a similar manner. In some instances, that of the Moyie River has been described in the section on placer mining, the deflected stream has never resumed its original channel.

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A SAN DIEGO FAUNA IN THE NEWHALL QUADRANGLE, CALIFORNIA

by

H.M.A.RICE

Thesis Submitted in Partial Fulfillment

of

The Requirements for a Minor Problem

In Invertebrate Paleontology

A San Diego Fauna in the Newhall Quadrangle, Calif.

by

H.M.A.Rice.

Introduction

During the summers of 1917, 1918, and 1919 Dr. William S. Kew undertook the mapping of an area to the north and west of Los Angeles.[1] The area included a thick section of the Fernando formation which Kew was able to sub-divide into two formations, the Pico, lower Pliocene in age, and the Upper Pliocene and Pleistocene Saugus. Later workers[2 & 3] in the Pico to the east of Pico Canyon and elsewhere split the formation still further until the following sub-divisions, as summarized by Grant and Gale[4], p 32 were reached.

Pico formation.	Santa Barbara zone,	Upper Pliocene.
	San Diego zone,	Middle Pliocene.
	Jacolitos zone,	Lower Pliocene.

The name Fernando formation has consequently been dropped, and the term Saugus has been restricted to the terrestrial deposits at the type locality, near the town of that name.

While working in the Newhall Quadrangle, Kew mapped the unconformable contact between the Pico and the Saugus formations, and found that it ran in a northwesterly direction from the San Fernando - Newhall road at a point about half a mile south of the tunnel, to Pico Canyon. (See map. The plotting of this contact is copied directly from Kew's map.) When the new road was constructed along Weldon and Gavin Canyons, it exposed this contact in a number of places and confirmed Kew's mapping.

In 1930, George Taylor, then a graduate student at the California Institute of Technology, found a fossiliferous marine horizon in the base of the formation mapped as Saugus which had hitherto been believed to be entirely terrestrial at this point. In the fall of 1932 the writer undertook the examination of this fossiliferous horizon, and the following report is, in brief, his findings.

LOCATION

The horizons examined occupy a zone about three miles long and 400 to 800 feet wide. The southeastern termination of this zone is about a mile northwest of the San Fernando - Newhall highway, and it parallels the road down Weldon and Gavin Canyons on the northeast side to cross it at the point where the road turns north down Wiley Canyon.

STRATIGRAPHY

Jacalitos Zone: The strata below the unconformity were mapped as Pico formation by Kew who described the upper 395 feet of it in Towsley Canyon as "mainly brownish, fine sandstone, soft, with a few hard sandstone beds: fossiliferous." 1, p 73

He gives a long fossil list upon the basis of which, together with some further work, English determined the Pico in this locality to be "approximately equal in age to the Lower Purisima and probably belongs near the base of the Pliocene in the standard time scale." [5] The Lower Purisima has been correlated with the Jacalitos formation of the San Joaquin Valley,[4, p 60] and it is clear from this that Kew's Pico in the Newhall Quadrangle corresponds to the Jacalitos formation.

The San Diego Zone. The beds overlying the Jacalitos formation in the locality were mapped by Kew as Saugus, and believed to be non-marine and Upper Pliocene and Pleistocene. The examination of the base of this formation by the writer has brought out the following facts:-

There is, as Kew believed, a strong unconformity between it and the Jacalitos. The angular discordance is slight, but there is a very marked erosional irregularity and a most pronounced change in lithology. The uppermost beds of the Jacalitos are soft, fine-grained, dark bluish-buff, silty sandstones, while the formation immediately above the unconformity is coarse, poorly sorted, light buff conglomerate with the pebbles and boulders almost entirely composed of igneous material, mostly granitic, and often several feet in diameter. Rather crudely interbedded with this material are occasional thin beds of coarse, poorly consolidated, light buff sandstone. No fossils could be found in any of it, and it is strongly suggestive of alluvial fan material, and is therefore believed to be terrestrial in origin although positive proof of this is lacking.

This conglomeritic horizon was deposited in a basin whose southeast margin appears to lie on the Weldon Canyon road, about a mile northwest of the San Fernando - Newhall road, and the northwest margin about a half mile northwest of Wiley Canyon. It is probable that it was laid down in other basins beyond these limits, but the writer confined his attention to the location mentioned. In the center of the basin the formation is about 1,300 feet thick, thinning down in both directions from this point.

Overlying it conformably and, in fact, grading into it, is a belt of rather well bedded, coarse, light buff, sandstone and conglomerate, in beds ranging from one to three feet thick. These are generally fossiliferous and are the main thesis of this paper. They pass conformably upwards into strata almost exactly similar to those below and no boundary has been seen between them and the typical terrestrial Saugus. In fact all three formations appear to represent uniform and continuous deposition with a small marine transgression during the formation of the middle one. However, a disconformity, unless very pronounced, would probably not be observed in terrestrial deposits of this nature and may well exist.

The thickness of this fossiliferous zone is rather uniform, about 250 feet, and, although it appears to pinch out at both ends, there is good reason to believe that it recurs at many places in the same stratigraphic position. No effort has been made to trace it beyond the limits outlined on the map. The strata have a general northwesterly strike and dip varying from 29° northeast at the southeast end to about 40° northeast at the northwest end.

FAUNA

A fauna of 58 species was collected in the horizon described above, of which 53 were identified. The faunal list is appended; the analysis tabulated below is derived from a comparison with the lists found in the references given in the bibliography.

	No	%
Total species found ------------------------	58	
Species identified --------------------------	51	
Species living only north of Monterey Bay --	0	
Species living only south of Monterey Bay --	19	37
Species living both north and south --------	14	27
Pelecypods ---------------------------------	24	41
Brachiopods --------------------------------	2	4
Scaphopods ---------------------------------	1	2
Gastropods ---------------------------------	30	51
Vertebrates --------------------------------	1	2
Species now extinct ------------------------	18	35
Species found in the Lower Pliocene --------	30	59
Species found in the Middle Pliocene -------	46	90

	No.	%
Species found in the Upper Pliocene --------	19	37
Species found in the Lower Pleistocene -----	22	43
Species found in the Middle Pleistocene ----	29	57
Species found in the Upper Pleistocene -----	26	51

Certain peculiarities of this fauna should be emphasized.

1. It is essentially a warm water fauna, (37%), indicating a climate comparable to that existing in the region at the present time, and in marked contrast to that of the Santa Barbara and Timms Point zones.

2. The number of extinct species (35%) is sufficiently great to suggest an age greater than the Pleistocene.

3. Many of the species are normally shore-line forms.

4. There is a close correlation with the faunas of the San Diego (Middle Pliocene) zone in other regions. In connection with this Grant and Gale (4, p 46) give the following list as the type fossils for the zone:-

* Cancellaria hemphilli,

* Terebra elata, var martini,

* Arca trilineata,

Arca trilineata, var calcarea,

* Venus (Chione) securis, var fernandoensis,

* Pecten purpuratus, varieties,

* Pecten healeyi,

Pecten estrellanus, var cerrosensis,

Pecten swiftii, varieties,

* Terebratalia occidentalis.

Of these ten species the seven marked with the asterisk are found in the above fauna. The evidence of the fossils seems to point, rather strongly, to a warm-water, San Diego fauna, Middle Pliocene in age, and one representing a shore line facies.

GEOLOGICAL HISTORY

The basin in which the Jacalitos sediments were laid down was evidently drained at the close of the Lower Pliocene by an uplift of considerable magnitude, but without any pronounced folding, at least in the region considered. Erosion of the newly exposed formations took place and a fairly rugged topography was probably produced. Early in the Middle Pliocene terrestrial sediments began to accumulate, particularly in the depressions cut be erosion, and there was, possibly, a certain amount of downwarping of parts of the land. The bulk of the sediments of this period probably formed alluvial fans and fanglomerates, but some, especially in the latter stages, may have been deposited as deltas. Finally the subsidence reached a stage at which the sea invaded the area, roughly sorting the upper part of the accumulated terrestrial deposits and stratifying the new material furnished by the erosion of the adjacent land. The only facies present is essentially a shore-line one, and most of the sediments were laid down on the Middle Pliocene beach marking the limit of the San Diego transgression. The land adjacent to the shore line was fairly high and subjected to active erosion throughout the period of marine occupation. Sedimentary material was constantly and rapidly being furnished to the sea. An abundant marine fauna lived in this sea and their remains are well preserved in the sediments accumulated at that time.

During the deposition of about 250 feet of sediments the conditions, though variable, remained essentially the same. The land then gradually rose again before the close of the Middle Pliocene, and the sea was forced out of the area and has, probably, never returned. The marine sediments grade upwards into terrestrial, the only difference being the absence of sorting and of a marine fauna. The littoral sediments were evidently preserved from erosion by the advance of terrestrial deposition keeping pace with the retreat of the sea. The presence of an unconformity between the non-fossiliferous top of the San Diego and the Saugus formation is suspected but was not positively identified. Pronounced folding has taken place since the close of the Middle Pliocene, but there is no evidence in the area for dating it more closely.

Conclusions

The investigation outlined above has furnished additional evidence of the wide-spread nature of the San Diego transgression, and probably represents its limit at this locality.

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Appended is a list of the localities from which the above fossils were obtained. The numbers are California Institute of Technology Fossil Locality Numbers.

Locality 957. East wall of Gavin Canyon, on line between NW$\frac{1}{4}$ and SW$\frac{1}{4}$, 200' east of west line of Sec. 10, T 3 N, R 16 W, San Bernardino Base Line and Meridian, Newhall Quadrangle, Los Angeles Co., Cal.

958. Crest of spur on west side of Gavin Canyon, about 1000' N. of mouth of Towsley Canyon, and 3200' N 19° W of SE corner of section 9, T 3 N, R 16 W, San Bernardino Base Line and Meridian, Newhall Quadrangle, Los Angeles Co., California.

959. Crest of spur on north side of Gavin Canyon near head, 800' straight north of highway and 4450' S 49° E of NW corner Section 14 T 3 N, R 16 W, Newhall Quad., Los Angeles Co., California.

960. East wall of steep canyon 1000' straight north of highway up Gavin Canyon, and 1250' S 63° E of NW corner of Sec. 14, T 3 N, R 16 W, Newhall Quad., Los Angeles Co., California.

961. South wall of first main branch canyon entering Gavin Canyon from the west, north of Towsley Canyon, 2600' S 72° W of NE corner of Sec. 9, T 3 N, R 16 W Newhall Quad., Los Angeles Co., California.

962. Crest of ridge north of Gavin Canyon at about 1750' elevation, and 2000' N 24° E of juncture of Rice Canyon road with highway up Gavin Canyon, NW$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 10, T 3 N, R 16 W, Newhall Quad., Los Angeles Co., California

963. North wall of small canyon opening into Gavin Canyon from the west, about 1600' N. of Towsley Canyon, and about 2400' S 30°W, of the NE corner of Sec. 9, T 3 N, R 16 W, Newhall Quad., Los Angeles Co., California.

FAUNAL LIST

Pelecypods

	957	958	959	960	961	962	963
Arca (Arca) multicosta - Sowerby v. camuloensis - Osmont		x					
Arca (Arca) trilineata - Conrad				x			
Cardita monilicosta - Gabb	x			x			
Cardium quadragenarium - Conrad v. fernandoensis - Arnold			x				
Dosinia ponderosa - Gray		x					
Gari californica (?) - Conrad	x						
Laevicardium (Trachycardium) quadragenarium - Conrad		x					
Lucina (Here) excavata - Carpenter	x	x	x				
Lucina (Myrtea) nuttallii - Conrad		x					
Lucina (Miltha) xantusi - Dall			x				
Macoma secta - Conrad				x			
Macoma sp.	?						
Nuculana taphria - Dall	x		x	x			
Ostrea vespertina - Conrad	x	x					
Panope (Panope) generosa - Gould		x					
Pecten sp.							x
Pecten (Aequipecten) deserti - Conrad v. invalidus - Hanna		x	x	x			x
Pecten (Patinopecten) healeyi - Arnold			x	x			x
Pecten (Aequipecten) purpuratus - Lamark v. callidus - Hertlein	x	x	x	x			x
Pecten (Janira) stearnsii - Dall		x	x	x			x
Schizothaerus nuttallii - Conrad						x	
Solen sicarius - Gould	x	x	x	x		x	
Venerupis (Callithica) tenerrima - Carpenter		x		x			
Venus (Chione) securis - Shumard v. fernandoensis - English	x	x	x	x	x		

Brachiopods

	957	958	959	960	961	962	963
Dallinella occidentalis - Dall	x		x	x			
Lingula sp.				x			

Scaphopods

	957	958	959	960	961	962	963
Dentalium n sp.	x	x		x			

Gastropods

	957	958	959	960	961	962	963
Acteon (Rictaxis) painei - Dall v. grandior - Grant & Gale				x			
Astraea (Pomaulax) gradata - Grant & Gale				x			

Gastropods (cont.)

	Localities 957	958	959	960	961	962	963
Cantharus fortis - Carpenter v. angulatus - Arnold		x					
Cantharus fortis - Carpenter					x		
Clavus (Cymatosyrinix) pallidus aff empyrosia and paziana - Dall		x					
Conus californicus - Hinds		x					
Crepidula aculeata - Gmelin		x	x	x	x		
Crepidula adunca - Sowerby		x		x			
Crepidula onyx - Sowerby				x			
Crepidula princeps - Conrad	x	x	x		x		
?Cylichna sp.		x					
Fusinus barbarensis - Trask					x		
?Homalopoma paucicostatum - Dall	x						
?Margarites (Lirularia) lirulatus - Carpenter		x					
Mitrella c.f. carinata - Hinds v. gausapata - Gould		x					
Nassarius (Schizopyga) perpinguis - Hinds	x	x	x	x	x		
Natica (Tectonatica) clausa - Broderip & Sowerby				x			
Neptunae humerosus - Gabb		x	x	x			
Neptunae sp.	x						
Olivella pedroana - Conrad				x			
Polinices (Neverita) reclusianus - Deshayes v. alta - Dall	x	x		x			
Polinices (Neverita) reclusianus - Deshayes v. callosus - Gabb	x	x	x	x			
Surculites (Megasurcula) carpenterianus - Gabb v. tryonianus - Gabb		x					
Terebra (Strioterebrum) elata - Hinds v. martini - English	x	x	x	x			
Trochita filosa - Gabb	x	x		x			
Turritella cooperi - Carpenter	x	x	x	x	x	x	
Turritella vanvlecki - Arnold	x		x				

Vertebrates

	957	958	959	960	961	962	963
Shark's tooth		x					

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