CANADA

DEPARTMENT OF MINES AND RESOURCES

MINES, FORESTS AND SCIENTIFIC SERVICES BRANCH

GEOLOGICAL SURVEY BULLETIN
No. 14

GEOLOGY OF PART OF THE SELKIRK MOUNTAINS IN THE VICINITY OF THE MAIN LINE OF THE CANADIAN PACIFIC RAILWAY, BRITISH COLUMBIA

BY

V. J. Okulitch

OTTAWA
EDMOND CLOUTIER, C.M.G., B.A., L.Ph.,
KING'S PRINTER AND CONTROLLER OF STATIONERY
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PREFACE

A principal purpose of Geological Survey Bulletins is served by the publication, from time to time, of reports dealing with problems encountered by the geologist in the course of field work. These may be of either local significance and readily soluble with the data at hand, or of wider scope, and of particular interest because of their theoretical implications.

In the present report, Professor Okulitch, of the University of British Columbia, has brought his considerable field experience with the late Precambrian and early Palæozoic succession of formations to bear on the great thickness of unfossiliferous strata exposed in the rugged Selkirk Mountains along the main line of the Canadian Pacific railway. Based on the position of the basal Cambrian *Olenellus* zone well down in the corresponding section of the Dogtooth (northern Purcell) Mountains, and at a still lower stratigraphic horizon in the Rocky Mountains, the author has postulated a transgressive sea in which formations laid down in the west are older than the corresponding eastern formations, and as a result of which the strata at the Precambrian-Palæozoic boundary may be inferred to have been eroded from the entire Selkirk Mountain section. The problem this presents to stratigraphic nomenclature is outlined, and a tentative practical solution proposed that should stimulate further investigations in this critical region.

GEORGE HANSON,
Chief Geologist, Geological Survey of Canada

OTTAWA, March 10, 1949

GEOLOGY OF PART OF THE SELKIRK MOUNTAINS IN THE VICINITY OF THE MAIN LINE OF THE CANADIAN PACIFIC RAILWAY, BRITISH COLUMBIA

INTRODUCTION

The writer spent 6 weeks of the field season of 1948 examining the geological section across part of the Selkirk Mountains exposed in the vicinity of the Canadian Pacific railway, mainly between Albert Creek and Beaver River, in the Glacier Park map-area. The particular purpose of this study was to gain more information on the nature and stratigraphic position of the Precambrian-Palæozoic boundary and, if possible, to collect fossils from the Nakimu limestone, as well as other formations. Implied in these two problems was a third, on correlation with the known geological sections adjacent to the section studied.

The first two objectives of this study, namely, discovery of fossils and the establishment of the Precambrian-Palæozoic boundary, were not achieved. No fossils were found in any of the formations exposed along or near the railway line, and, consequently, the Precambrian-Palæozoic boundary could not be established. However, new information on the stratigraphy, structure, and correlation of the formations represented came to light, though the time spent in a search for fossils did not permit as adequate coverage of other phases of the work as could have been desired.

The writer is indebted to Mr. George Bailey, Vice-President of the Canadian Pacific Railway Company, and to Mr. C. Reid, Superintendent at Revelstoke, for permission to use the line as means of transportation. To Mr. Norman Brewster, Station Agent at Glacier and member of the Alpine Club of Canada, and to the park rangers and Canadian Pacific Railway employees within the area studied, the writer wishes to express his appreciation for innumerable courtesies. Mr. Raymond V. Best, D.F.C., discharged his duties as student assistant very efficiently.

LOCATION

The section studied (*See* Figure 1) is that exposed along or near the Canadian Pacific railway on either side of Glacier, which lies about 50 miles west of Golden and 60 miles east of Revelstoke. This section is in the midst of the high peaks of the Selkirk Mountains, a part of the range that may be referred to as the "High Selkirks" in contrast with the somewhat lower and less rugged eastern and western flanks of these mountains. The part studied in greatest detail extends from Flat Creek in the west to Stoney Creek in the east, a distance of some 15 miles in a straight line. For purposes of correlation, however, it was found necessary to examine the section from Albert Canyon to Beavermouth, a total distance of about 73 miles along the railway. The section, therefore, traverses slightly more than the full width of Glacier National Park.

Access to the park is possible only by means of the railway. Within it are fairly numerous and reasonably well kept trails that permit access to the higher areas above timber-line. The lower slopes of the High Selkirks are thickly covered with vegetation, and resemble, in this respect, the valleys of the Coast Range. As a result, it is nearly impossible to make good progress away from the trails. At higher elevations the country is generally open, but the steepness of the terrain practically requires that the geologist be a mountaineer as well.

PHYSIOGRAPHY

The section examined traverses the highest parts of the Selkirk Mountains, where the relief ranges from 4,000 to 7,000 feet between the summits and the major valley bottoms. The highest peaks rise to more than 11,000 feet above sea-level, whereas the elevation of Glacier, in the valley of Illecillewaet River, is given as 3,817 feet. The valley walls rise abruptly to an elevation of about 8,000 feet, above which level stand the bare high peaks and ranges. The extreme ruggedness of the mountains is to a large extent due to the resistant folded quartzites that underlie much of their slopes.

At least three stages of deglaciation are apparent. The ice-cap stage is manifested by glacial striæ and pavements at elevations of more than 8,000 feet. Such striæ, running roughly from north to south, were observed on Mount Abbott and Glacier Ridge. The intense alpine stage is shown by the now vacated cirques and the recently abandoned glaciated valleys; and the present, late alpine stage, by the still existing snowfields and glaciers.

Physiographically the region is in the stage of late youth or early maturity, as only the major streams approach gradation. More detailed descriptions of the topography of the region can be found in previous publications of Wheeler, Daly and Palmer.

PREVIOUS WORK

George M. Dawson (1890, 1891, 1893, 1901)[1] was the first to investigate the geology of the Selkirk Mountains. His investigations, although admittedly of a reconnaissance nature, laid the foundations for all later work. His general conceptions of stratigraphy, structure, and geological history of the region were fully presented in papers published by the Geological Society of America in 1891 and 1901. Dawson described and subdivided the great mass of sedimentary and metamorphic rocks exposed in the Selkirks, and proposed correlations with the Shuswap region to the west and the Rocky Mountains region to the east. He also presented the first structure-section across the Selkirks (1891, pp. 168, 174).

Daly (1915) followed Dawson's interpretation of the geology of the Selkirk Mountains very closely; he expanded the formational descriptions, but did not materially change the correlations nor the interpretation of structure. He recognized two divisions of sedimentary rocks—the older, Albert Canyon division and the younger, Glacier division of Beltian and Cambrian age. The total estimated thickness of the two divisions was

[1] Dates (in parentheses) are those of references at end of the report.

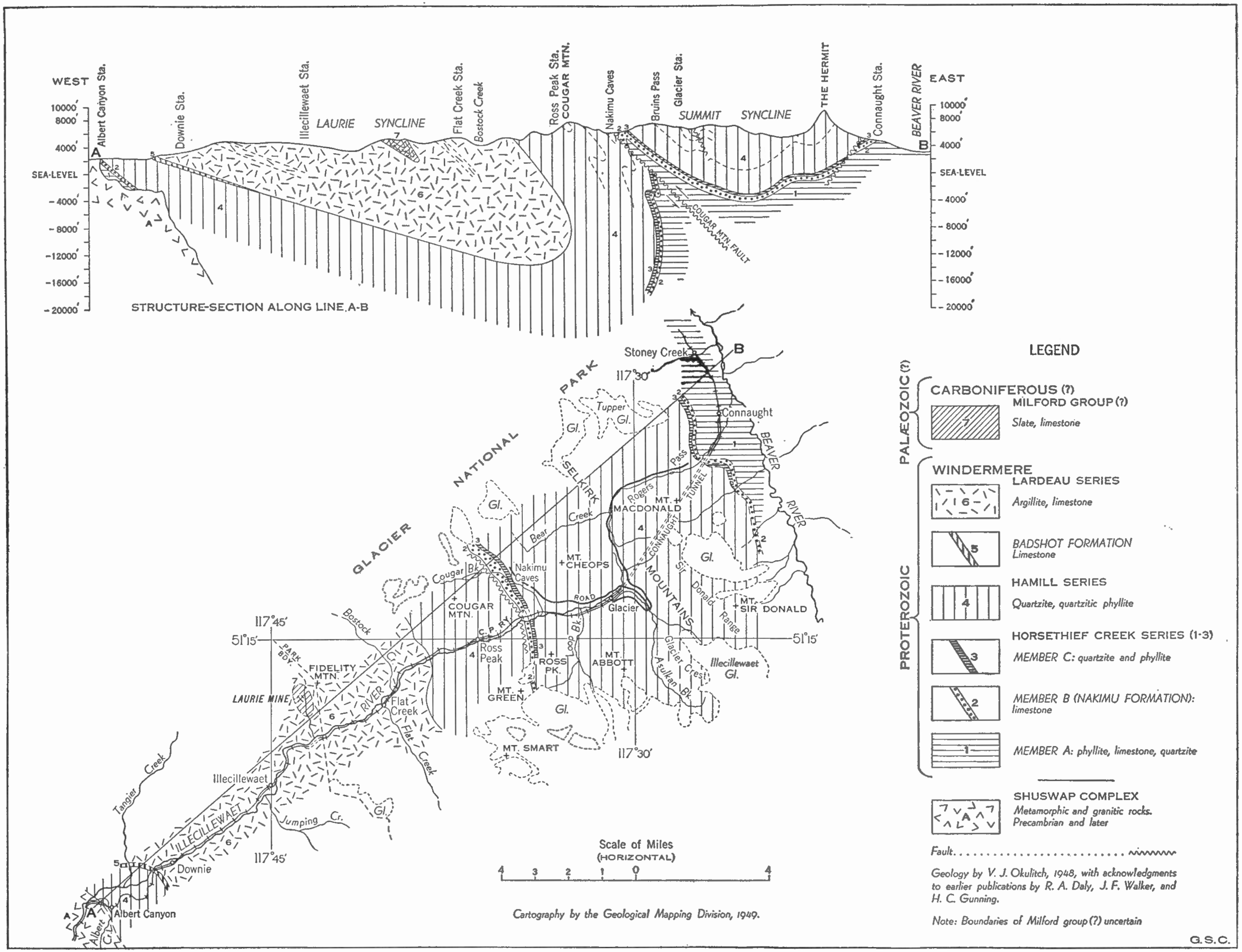

Figure 1. A. Geological sketch of formations in the vicinity of the Canadian Pacific railway, Glacier Park map-area British Columbia.
B. Structure-section from Albert Canyon to Beaver River Valley.

given as more than 32,000 feet. The sediments were described as overlying the pre-Beltian Shuswap rocks of possibly Archæan age, and the whole was interpreted as being folded into relatively simple open homoclines, synclines, and anticlines. Both divisions of the Selkirk series were subdivided into several formations, based on broad lithological characteristics, and Daly attempted to correlate them with known formations of the Rocky Mountains (*See* Table I). A diagrammatic cross-section, Figure 2, indicates the essential conception of structure reached by Daly and earlier by Dawson.

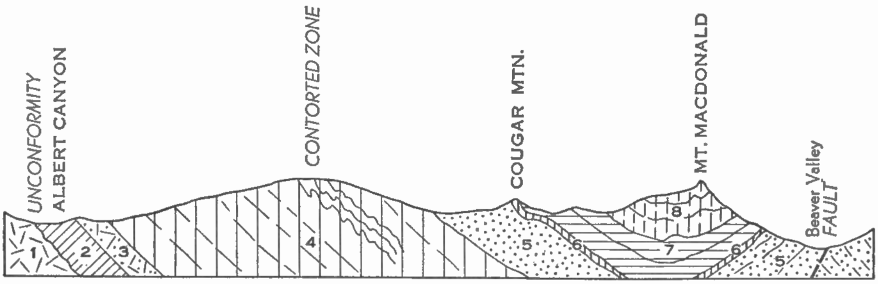

Figure 2. Structure across Selkirk Mountains (after R. A. Daly, 1915). 1, Shuswap; 2, Moose; 3, Illecillewaet; 4, Laurie; 5, Cougar; 6, Nakimu limestone; 7, Ross; 8, Sir Donald.

TABLE I

(*Correlations by R. A. Daly, 1915*)

	Castle Mountain-Bow River series (Rocky Mountains)	Selkirk series (Selkirk Mountains)
Middle Cambrian	Eldon limestone, 2,728 feet Stephen limestone, 640 feet Cathedral limestone, 1,595 feet	
Lower Cambrian	Mt. Whyte metargillite, 390 feet St. Piran quartzite, etc., 2,705 feet Lake Louise metargillite, 105 feet Fort Mountain (Fairview) quartzite, 600 feet	Sir Donald quartzite, 5,000 feet Ross quartzite (upper part) 2,750 feet
Beltian	Hector metargillite, etc., 4,590 feet Corral Creek quartzite, etc., 1,420 feet *Base concealed*	Ross quartzite (lower part), 2,500 feet Nakimu limestone, 350 feet Cougar quartzite, 9,700 feet Basaltic lava, 50 feet Cougar quartzite, 1,050 feet Laurie metargillite, etc., 15,000 feet Illecillewaet quartzite, 1,500 feet Moose metargillite, 2,150 feet Limestone, 170 feet Basal quartzite, 280 feet *Unconformity*

From west to east the Selkirk series of sedimentary and metamorphic rocks was believed, successively, to rest unconformably on the Shuswap orthogneiss, to dip easterly in a great homocline, and to form an open, essentially simple symmetrical syncline, whose eastern limb formed the west wall of Beaver River Valley (Purcell Trench).

H. C. Gunning (1929) mapped the eastern part of the Selkirks, covering in a general reconnaissance the area bounded by the Canadian Pacific railway, the North Fork of Illecillewaet River (Tangier Creek), Columbia River, and Bigmouth Creek. He disproved the presence of an unconformity between the Albert Canyon division of the Selkirk series and the Shuswap rocks of Daly. He also indicated the general similarity of the geology along the line of the railway and the Lardeau area to the south. Without committing himself on general correlations, he also indicated that the structure is far more complex than Daly's interpretation suggests.

The present work, taken in conjunction with that by Evans in the Purcell Mountains just east of Beaver River Valley (1933); Walker and Bancroft's in the Lardeau area to the southwest (1929); Rice's to the south (1941); and Gunning's report and map of the Big Bend area to the northwest (1929), makes it impossible to subscribe to either the correlations or the structures as outlined by Daly.

As is shown more fully in succeeding pages, the writer's conception of the geology of the area examined involves sedimentary rocks of Windermere and, possibly, Cambrian age grading westerly, due to increasing intensity of metamorphism, into the "Shuswap" rocks west of Albert Canyon. The strata are strongly folded in a series of westerly overturned and recumbent folds, and cut by at least one major low-angle fault. The folding and faulting have caused much repetition in the visible section.

The writer wishes to make it clear that, although, for the sake of ease of description, the conclusions are presented rather dogmatically, the available time, nature of the terrain, and size of his party did not permit him to obtain all the necessary facts to support every point in his conclusions. Rather, the conclusions are to be viewed as a mental picture obtained during a brief field season in an area of great structural complexity, lack of fossils, and exceptional physical difficulties of travel. They are not thought to be the final word on the problems presented, but rather a starting point from which more systematic field work could proceed.

GENERAL GEOLOGY

The rocks of the Canadian Pacific railway section and exposed along the valleys of Illecillewaet River, Bear Creek, and Beaver River are mainly those of the Windermere system, previously described in Windermere map-area, in the Dogtooth Mountains, in the Kootenays, and in Lardeau map-area.

The system is exposed in two major synclines and in a tight overturned anticline cut by a low-angle fault (*See* Figure 1). These major structural elements are complicated by minor folds, drag-folds, and faults. The following is a table of the formations encountered:

TABLE II

TABLE OF FORMATIONS EXPOSED IN THE SELKIRK MOUNTAINS ALONG THE CANADIAN PACIFIC RAILWAY

Palæozoic (?)	Carboniferous (?)	Milford group (?)	Slate, limestone
		Unconformity	
Proterozoic	Windermere	Lardeau series (Laurie formation)	Argillite and limestone; 12,000 feet
		Badshot formation	Limestone; 60 feet
		Hamill series	Quartzite and quartzitic phyllite; 4,000 to 10,000 feet
		Disconformity (?)	
		Horsethief Creek series	Member C: quartzite and phyllite; 100 to 400 feet Member B (Nakimu formation): limestone; 10 to 600 feet Member A: phyllite, limestone, quartzite; 1,000 feet
		Base not exposed	

HORSETHIEF CREEK SERIES[1]

The oldest exposed member of the Windermere system is the Horsethief Creek series. The series was originally described by Walker (1926, p. 14) in the Windermere area. It has been recognized in the Dogtooth Mountains by Evans (1933), and in the Nelson map-area (east half) by Rice (1941).

The best exposures of the series are along the eastern and western slopes of Beaver River Valley. Evans (1932) described the occurrences on the eastern side of the valley and the Prairie Hills. The present writer recognized the series on the western side of the valley, exposed in several localities along the Stoney Creek-Rogers Pass road, the railway cuts, and the lower part of Bear Creek. The series is divisible into at least three members, as follows:

[1] Named Horsethief formation in 1926; changed to Horsethief series in 1929 (Walker, 1929), and later (Evans, 1933) to Horsethief Creek formation because the original name was preoccupied; and, finally, to the Horsethief Creek series (Rice, 1941).

Horsethief Creek series	Member C	Thickness (approximate) 100 to 400 feet
	Member B (Nakimu formation)	10 to 600 feet
	Member A	1,000 feet
	Base not exposed	

The members correspond respectively with the upper shale, limestone, and lower slate members as described by Evans (1933, p. 117) in the Dogtooth Mountains.

Member A is equivalent to Evans' lower slate member of the Horsethief Creek formation. Daly regarded these rocks as equivalent to his Cougar formation, and explained the drastically different lithology by appeal to rapid lateral gradation from quartzites to argillites and phyllites. The writer feels that this correlation is untenable.

Member A. This member consists of pale grey to silvery phyllites and shales interbedded with thin, sandy, and quartzitic layers and some limy bands. Its total thickness could not be determined, but is at least 1,000 feet, which is also that of the lower slate member of the Horsethief Creek in the Dogtooth Mountains. The formation is easily identified from its stratigraphic position below the Nakimu limestone and by its dominant light-coloured phyllites. Its best exposures are in Bear Creek Valley, east of the Connaught tunnel, and in railway cuts near Stoney Creek. Presumably the member underlies Beaver River Valley. Dawson, Daly, and Evans regarded the rocks underlying that valley as forming a broken or crumpled anticline, with a fault paralleling the valley. The writer has no additional information to contribute.

Member B (Nakimu formation). The Nakimu limestone of Daly is one of the most prominent horizon markers within the Horsethief Creek series (*See* Plates I and II). Although relatively thin, it underlies a large area and fairly well maintains its lithological characteristics. The most typical exposures of the Nakimu are on Cougar Mountain near Nakimu Caves. There, due to drag-folding and slicing in the vicinity of the Cougar fault, the member appears to be very thick (1,200 feet). Its average thickness elsewhere is about 300 feet, but in places the formation thins, or possibly the visible thickness is reduced by faulting, to a mere 10 feet or so. Mostly, it is a bluish grey, compact, and massive limestone with irregular sandy nodules and lenses.

Daly (1915, p. 76) gives a detailed description of the lithology of the Nakimu limestone. The rock is not appreciably metamorphosed, but the most painstaking search failed to reveal any fossils beyond some doubtful worm burrows, which have been noted in several beds. They are small, calcite-filled tubes, elliptical or circular in cross-section, 2 to 4 mm. in diameter, and from 4 to 10 cm. long. Some are slightly wavy and some are straight. Their presence gives some surfaces of the limestone the "bird's-eye" appearance common in the Palæozoic limestone. These structures, quite definitely, cannot be regarded as diagnostic fossils.

At the Cougar Mountain fault (*See* Figure 1B) the Nakimu limestone is drag-folded, crushed, and very possibly faulted. The shattering is apparently the result of a tightly overturned anticlinal fold cut by a major, east-dipping fault. It permitted the seepage of water, whose solvent action is responsible for the formation of the caverns. Elsewhere the rock is quite compact and massive, and only limited solution took place.

On the eastern limb of the Summit syncline (*See* Figure 1B), facing Beaver River Valley, the Nakimu limestone is less massive and is interbedded with phyllite, schist, and sandy layers. The limestone is probably magnesian, as it weathers buff. Its eastern exposures are largely hidden by forest growth, and access to them is difficult.

Member C. Overlying the Nakimu formation is a variable thickness of rocks consisting of thin-bedded, sandy limestone, beds of phyllite and quartzite, and more or less strongly metamorphosed argillite. These rocks seem to grade from the Nakimu limestone below to the Hamill quartzite above.

In the Dogtooth Mountains, the same stratigraphic position is occupied by varicoloured slates and phyllites, with interbands of quartzite and limestone. Their aggregate thickness is 1,140 feet (Evans, 1932, p. 117). Farther west the member is poorly exposed, and appears to be much thinner, possibly not more than 300 or 400 feet thick. In these exposures it consists of thin beds of limestone, quartzite, and phyllite or schist, and can only be recognized because of its proximity to the Nakimu limestone. On the eastern limb of the Summit syncline (*See* Figure 1B), northeast of Tupper Glacier, Daly (1915, p. 77) reported that the Nakimu is overlain by 150 feet of dolomitic sandstone, schist, and dolomite. On the west slope of Mount Cheops, some of the sandy beds of Member C show crossbedding and channel-fill structures, indicating shallow water conditions of sedimentation. The thickness there is about 300 feet.

The variability of thickness, and evidence of local erosion surfaces, suggest that Member C was at least partly eroded before the deposition of the more massive Hamill quartzites. The evidence of the erosion is not sufficiently clear, however, to consider it as anything more important than a local disconformity. Evans (1932, p. 118) mentions that: "a gently undulating erosion surface at the Horsethief Creek-Fort Mountain contact occurs at the top of the upper slate member at Twelvemile Creek. In other sections, Horsethief Creek and Fort Mountain strata showed no measurable difference in attitude, though Fort Mountain strata rest on different horizons of the underlying Horsethief Creek at different localities." There is, therefore, a possibility that an erosional unconformity separates the Horsethief Creek from the overlying Hamill series. The former is probably a Precambrian series, whereas the Hamill, although largely unfossiliferous, may be of Cambrian age. The unconformity may, therefore, be of greater significance than previously thought.

HAMILL SERIES

(*See* Plates III and IV)

The name Hamill series was proposed by Walker and Bancroft (1929, p. 9) for a succession of strata varying from quartzite to schist and limestone in the Lardeau area. Three belts of predominantly quartzitic rocks cross the Canadian Pacific railway within the section studied. Similarity of lithology, thickness, and structural and stratigraphic relationships strongly indicate that the rocks exposed in these belts are parts of a single series, which is thought to be equivalent to the Illecillewaet and Moose, Ross and Sir Donald, and Cougar formations previously described by Daly. The Hamill series rests on the Horsethief Creek series and underlies the Badshot limestone.

A very careful examination of the series was made at various localities, and although gradational changes in it are readily apparent, the lithology is so similar throughout that no serious doubt can exist that the three belts are part of one great sheet of sandy sediment, folded and metamorphosed into quartzites, phyllitic quartzites, and schists. The westernmost parts of the western belt exposed near Albert Canyon station look different only because of a higher grade of metamorphism than the central and eastern belts. The central and eastern belts are identical even in the minor elements of mineralogy and lithology.

The most westerly belt of quartzite and quartzitic argillite crosses Illecillewaet Valley east of Albert Canyon station on the Canadian Pacific railway. The quartzites and the gneissic phyllites outcropping in this vicinity were named by Daly (1915, p. 66) the Moose and Illecillewaet formations. By extending the trend of the belt southward for about 2 miles, it connects with the western belt of the Hamill series as mapped by Walker and Bancroft (1929, Map 235A). There is, therefore, no doubt that the Illecillewaet and Moose formations are parts of this series.

Farther east another belt of quartzites crosses Illecillewaet Valley on either side of Ross Peak station. These quartzites were named by Daly (1915, p. 70) the Cougar formation. The trend of this belt if continued southward would connect with the eastern belt of the Hamill, as shown by Walker and Bancroft on Map 235A. The gap in this instance amounts to nearly 20 miles, and is in part occupied by a large area of granite. However, the stratigraphic position of the quartzites above the Horsethief Creek series, and below a thick argillaceous series (Laurie or Lardeau), leaves little doubt of its identity with the Hamill.

Still farther east, occupying a wide area between Cougar Brook and the western slopes of Beaver River Valley, is the third belt, consisting of massive quarzites, placed by Daly (1915, pp. 78-83) in his Ross and Sir Donald formations. These formations rest on Member C of the Horsethief Creek series and are practically identical lithologically with the Cougar, and, to a lesser extent, with the Illecillewaet and Moose formations. The thickness of the Cougar and the combined Ross and Sir Donald is almost exactly the same, namely, about 10,000 feet. It is, therefore, difficult to avoid the conclusion that the Ross and Sir Donald are equivalent to the

Illecillewaet and Moose and to the Cougar formations and, therefore, to the Hamill series. Furthermore, the structural relationships, as determined in the field, support this conclusion.

It is the opinion of the writer that all three belts are formed of the same thick series of quartzitic rocks folded into two major synclines and an intervening broken anticline (*See* Figure 1B). This conclusion is inescapable, both on lithological and structural grounds. The position of these quartzite belts largely determines the location of the highest peaks in the Selkirk Mountains.

There appears to be no adequate reason for separating the Ross and the Sir Donald formations, as was done by Daly. Throughout the entire section, the rock consists of quartzites, sandstones, ferruginous sandstones, arkoses, and conglomerates interbedded with phyllitic quartzites, phyllites, and minor amounts of argillite. Near the middle of the series is a band of phyllite about 300 feet thick, and near the top is another band of phyllite at least 1,000 feet thick. Until future, more detailed work permits separate mapping of the finer lithological units, the entire assemblage may, for convenience, be identified with the Hamill series.

The Hamill series consists predominantly of quartzitic rocks. Some of the strata are arkoses or feldspathic grits, others are pure, compact, siliceous quartzites or sandstones. The quartzites are interbedded with phyllites and schists and layers of quartz-conglomerates. Some layers are thinly laminated, due to the concentration of grains of magnetite and biotite along bedding planes. The quartz grains are commonly blue or iridescent.

Observations of the Glacier quartzites on the flanks of Sir Donald Range, Glacier Ridge, Mount Abbott, and Mount Cheops show that the bulk of the series, with the exception of the most massive layers, is a quartzitic phyllite. The flaky mineral is probably sericite. Some of these beds grade into true, bright green to light grey schist. Thin bands of slate occur in places. It is estimated that at least 50 per cent of the formation consists of the quartzitic phyllite. The first impression gained is that quartzite is entirely dominant, and only a closer study reveals the vast amount of quartzitic phyllite and schist. The reason for this is that the more resistant quartzites outcrop on the surface in bold cliffs and escarpments, whereas the phyllitic rock is likely to form more gentle slopes, which are covered with vegetation and mantle. This observation is greatly strengthened by the examination of rock removed from the Connaught tunnel, which to a large extent is either schist or quartzitic phyllite.

The thickness of individual beds varies greatly. In some parts of the section the rock is so massive that it is impossible to determine the bedding (*See* Plate IV). Crossbedding, ripple-marks, channel-fill lenses, and minor erosional surfaces are common throughout the series. No doubt these beds were laid down close to shore, probably as components of a vast delta or a series of interlocking deltas, for which the palæogeographic name of 'Selkirk delta' might be appropriate. The vast areal extent of the series leaves little doubt that it was deposited along the shores of an advancing sea. As this advance was slow, different parts of the 'Selkirk delta', although generally uniform lithologically, are not contemporaneous. It is, therefore, quite possible that the same continuous sheet of sand was being deposited in Precambrian times in the Selkirks and in Lower Cambrian times in the Rocky Mountains.

The top of the Hamill series exposed in the summit syncline at Glacier is somewhat more argillaceous. Phyllites and argillites interbedded with beds of quartzites are exposed at several points near this station, on the western side of Illecillewaet Glacier, on the lower slopes of Glacier Ridge, and on Mount Abbott. These more muddy sediments mark the transition from the Hamill to the succeeding Laurie (Lardeau) series. There is a gradual but noticeable change in the lithology of the rock from east to west. Quartz conglomerates and feldspathic sandstones are most common in the Sir Donald Range; within 3 miles to the west, on Mount Abbott, and almost continuously exposed in the intervening distance, the rocks become finer grained and more phyllitic; still farther west, on Ross Peak and Cougar Mountain, the rock is largely a rather fine-grained white quartzite or sandstone, with subordinate amounts of the quartz-conglomerates; and near Albert Canyon, about 8 miles west of the last preceding outcrop, the rock is largely a fine-grained quartzite interbedded with much argillite, and is commonly metamorphosed to finely laminated paragneiss and gneissic phyllite.

A similar, east to west gradation marks the change from prevailingly thick-bedded quartzite on Sir Donald Range to a platy and fissile rock near Albert Canyon. The total thickness follows the same pattern, diminishing from about 10,000 feet in the east to about 4,000 feet in the west.

The Hamill quartzitic rocks are the youngest exposed within the boundaries of the Summit syncline; farther west, in the region occupied by the Laurie syncline, they are overlain by the Badshot limestone formation and the Lardeau series (Laurie formation).

BADSHOT FORMATION

Overlying the Hamill series, and exposed in the western limb of the Laurie syncline, is a band of metamorphosed limestone about 60 feet thick. The limestone is grey to bluish grey, and in places is well banded. It is the lowest of several other limestone beds occurring higher in the succeeding series. Geographically, it is on the strike of, and within 4 to 5 miles northwest from the last outcrop of, the Badshot formation as mapped by Walker and Bancroft (1929), and in banding, colour, and texture resembles that formation. It separates the Hamill series, as already described, from the Lardeau series (Laurie formation), whose description follows. Stratigraphically, it occupies an identical position between two thick series of rocks, the quartzitic Hamill series and the argillaceous and calcareous Laurie formation (or Lardeau series). The writer is, therefore, confident that his identification of the limestone as the Badshot formation is correct.

The Badshot was not seen along the eastern limb of the Laurie syncline, but Gunning (1929) reports a broad band of crystalline limestone at the head of Caribou (Bostock) Creek and east of the summit of Flat Creek. It is quite possible that the writer missed the limestone on the lower timbered slopes facing the railway. Where observed, no fossils were found in the limestone.

The Lardeau series is developed typically in Lardeau map-area, south of the section under present consideration, where the series lies in a great synclinal trough. It consists of a heterogeneous assemblage of partly metamorphosed sediments, the dominant types being argillites and limestones. The original definition (Walker and Bancroft, 1929, p. 11) includes all strata from the top of the Badshot formation to the unconformity at the base of the Carboniferous (?) Milford group. The age of the series is supposed to be latest Windermere. The Badshot formation is the lowest prominent bed of limestone appearing above the dominantly quartzitic Hamill series, and logically, in the writer's opinion, should be included in the Lardeau series. In the present section, rocks of Lardeau type appear to cross Illecillewaet Valley between Albert Canyon and a point approximately 1 mile east of Bostock Creek.

LARDEAU SERIES

Overlying the Badshot formation is a great thickness of black argillites, dark limestones, and several beds of quartzite. Estimates made in the field suggest a total thickness of between 15,000 and 20,000 feet. Taking into account the great deal of crumbling, drag-folding, and possible, but hidden, faulting, the thickness can possibly be reduced to a minimum of about 10,000 or 12,000 feet. The black argillites and dark limestones constitute the most characteristic members of the formation. Daly (1915) called this series the Laurie formation, and gave an adequate description of it. Unfortunately, not being aware that he was dealing with an overturned synclinal structure, he described it as a single homocline. Consequently, his lithological units are repeated. Walker and Bancroft (1929, p. 11) give a description of the Lardeau series of the Lardeau map-area, which can be applied to the Laurie almost word for word. Further, the writer had occasion to examine the Lardeau of the Kootenay Lake district in the summer of 1947, and has no doubt of its identity with the Laurie. Gunning (1929) included the sedimentary rocks of the Laurie formation in his member 2 of the Precambrian group, and his description of this 'member' fully agrees with observations made by the writer. As an additional proof for the equivalence of the Lardeau and the Laurie, the examination of the map of Lardeau area (235A) will show that the regional trend of the Lardeau series would bring it into the position occupied by the Laurie only a few miles north of the last outcrops mapped by Walker and Bancroft. The principle of priority may, indeed, eventually require that the term Laurie be used instead of the Lardeau.

Most of the limestones in the Laurie formations are black to dark grey, very fine grained, and in places banded. The argillites are commonly coal black; some are massive and others fissile, shaly, or slaty. Large crystals of pyrite are quite commonly present. Some layers show a peculiar porous texture, which at first glance resembles the texture of vesicular basalt. Walker (1929, p. 11) mentions this type of rock in the Lardeau, and states that microscopic examination shows conclusively that the rock is sedimentary. Schists and quartzites occur throughout the formation, but are usually inconspicuous because of the dominant dark colour and fissile nature of the formation as a whole. Care must be exercised in distinguishing between bedding and cleavage; in places the two seem to be parallel, but at several localities, especially near Flat Creek station, the bedding and cleavage are distinct, and give a clear clue to the overturned position of the eastern limb of the Laurie syncline.

Minor folding is superimposed on the main overturned synclinal structure. The most noticeable effects of drag-folding and crumpling can be seen in the vicinity of Laurie tunnel and on the southeast slope of Fidelity Mountain, particularly north of Illecillewaet River. The writer's conclusion is that this disturbed zone is the result of intense deformation and flowage close to the axial plane of the overturned major syncline.

CARBONIFEROUS (?)

Milford Group (?). Drysdale (Burling, 1918, p. 146) reported finding crinoid stems near the Laurie (Lanark) mine on the southwest slope of Fidelity Mountain, north of Illecillewaet River. This locality is within the outcrop area of the Laurie formation. Gunning (1929, p. 142A) reported on the locality in the following terms: "These fossils which Drysdale collected are too poorly preserved to warrant any statement other than that they may be sections of crinoid stems. Similar material was found by the writer at the Lanark mine in grey, impure limestones. It may be said then, that at the Lanark mine and for considerable distances both east and west of it, sediments that may be of Upper Palæozoic age are found. If they are Palæozoic they almost surely constitute an infolded syncline in member 2, similar to several of the areas of the Milford group in Lardeau map-area."

The locality was visited by the writer during the field season, and a careful search for the fossils was made, but nothing resembling recognizable remains was found. The country rock near the Lanark mine is black slate interbedded with limestone, and intensely contorted. It lies almost exactly in the centre of the Laurie syncline, and the beds exposed are, therefore, the youngest found in the mapped section. Because of the intensity of deformation it would be very difficult to distinguish the slates and limestones of the Milford, should they be present, from the argillites and limestones of the Lardeau series (or Laurie formation).

Walker and Bancroft (1929, p. 12) report that rocks of probable Mississippian age, called the Milford group, occur "in small infolds on the northwest side of Trout Lake, on Mount Thompson, and on Sprout Mountain. On the east side of the mapped area a small infold was found on the ridge east from Mount Abbot."

It is, therefore, quite possible that the crinoid stems seen by Drysdale, Burling, and Gunning came not from the Laurie formation but from a small infold of Milford rocks, and the fact that this locality is near the central part of the Laurie syncline strengthens this possibility. The Milford fauna, as described by Walker, is restricted to non-diagnostic crinoid stems and a few poorly preserved Upper Palæozoic corals.

CORRELATIONS

Close correlation is possible with previously described rocks both east and southwest of the section studied (*See* Figure 4).

The Horsethief Creek series can be traced without much difficulty across Beaver River Valley and is the obvious equivalent of similar rocks in the Prairie Hills and Dogtooth Mountains described by Evans (1933) as parts of this series. Overlying these strata west of Beaver River are the thick, predominantly quartzitic and phyllitic rocks of the Hamill series. In the Dogtooth Mountains, the Horsethief Creek series is overlain by strata lithologically similar to the Lower Cambrian Fort Mountain, Lake Louise, and St. Piran formations of the Rocky Mountains. It is, therefore, at least strongly probable that the Hamill series and the Fort Mountain, Lake Louise, and St. Piran strata are stratigraphically equivalent, although they may differ somewhat in age.

In the western part of the section examined, the beds of the Hamill series are on strike with, and only a few miles from, the Hamill outcrops as mapped by Walker and Bancroft (1929, Map 235A). Lithologically they are very similar. The westernmost outcrops, because of increasing grade of metamorphism, may be more difficult to correlate. The Hamill series then seems to be correlative with the Fort Mountain, Lake Louise, and St. Piran formations in the Purcell Range, and with the Hamill series of the Lardeau Selkirks.

Overlying the quartzites and the phyllitic quartzites of the Hamill series, and underlying the black argillites, limestones, and quartzites of the Laurie formation is a narrow belt of bluish grey, banded, semi-crystalline limestone. In the Lardeau area, separating the quartzitic Hamill and the argillaceous and calcareous Lardeau series, is a similar band of limestone, the Badshot formation. The limestone exposed near Albert Canyon is in the identical stratigraphic position with the Badshot, and is almost on strike with, and within a few miles of, the last recorded outcrop of that formation. It is, therefore, concluded that the Albert Canyon limestone is equivalent to the Badshot formation.

In the Dogtooth Mountains, the predominantly arenaceous Fort Mountain, Lake Louise, and St. Piran strata are overlain by the Donald limestone. The Donald formation carries a Lower Cambrian fauna of mesonacid trilobites and pleosponges. Stratigraphically it appears to be equivalent to the Badshot formation. Similarly, the southern extension of the Badshot formation, exposed in the Pend-d'Orielle River area, contains a rich pleospongian fauna indicative of Lower Cambrian age.

The Laurie formation is both lithologically and stratigraphically equivalent to the Lardeau. The two series of rock are so alike that no doubt whatsoever can exist of their identity.

STRUCTURAL GEOLOGY

The geological structure of the Selkirk Mountains along the main line of the Canadian Pacific railway, from Albert Canyon station in the west to Beaver River Valley in the east, is shown diagrammatically in Figures 1B and 3, and differs considerably from that given by Daly (1915) and Figure 2 of the present report. No attempt was made in the field to work out the minor elements of structure, as this would have required a large-scale systematic mapping of exposures along the railway, a task that could not be undertaken in the time available.

Difficult as the work in the high mountains may be physically, there is a compensation; in the absence of vegetation at higher altitudes, many structural elements of the region can be observed directly without recourse to numerous dip and strike observations.

At Albert Canyon station the series of sedimentary rocks is interrupted by an igneous-metamorphic complex consisting of granite-gneiss, paragneiss, quartzite, and schist, cut by granite and pegmatite. Just west of the station, the Hamill quartzite grades almost imperceptibly into the paragneisses of the Clachnacudainn Range. It is, therefore, highly probable that the igneous-metamorphic complex extending from Albert Canyon station west to Columbia River at Revelstoke contains additional members of the Windermere series, metamorphosed beyond recognition. For a fuller discussion of this the reader is referred to Gunning's report (1929) on this area.

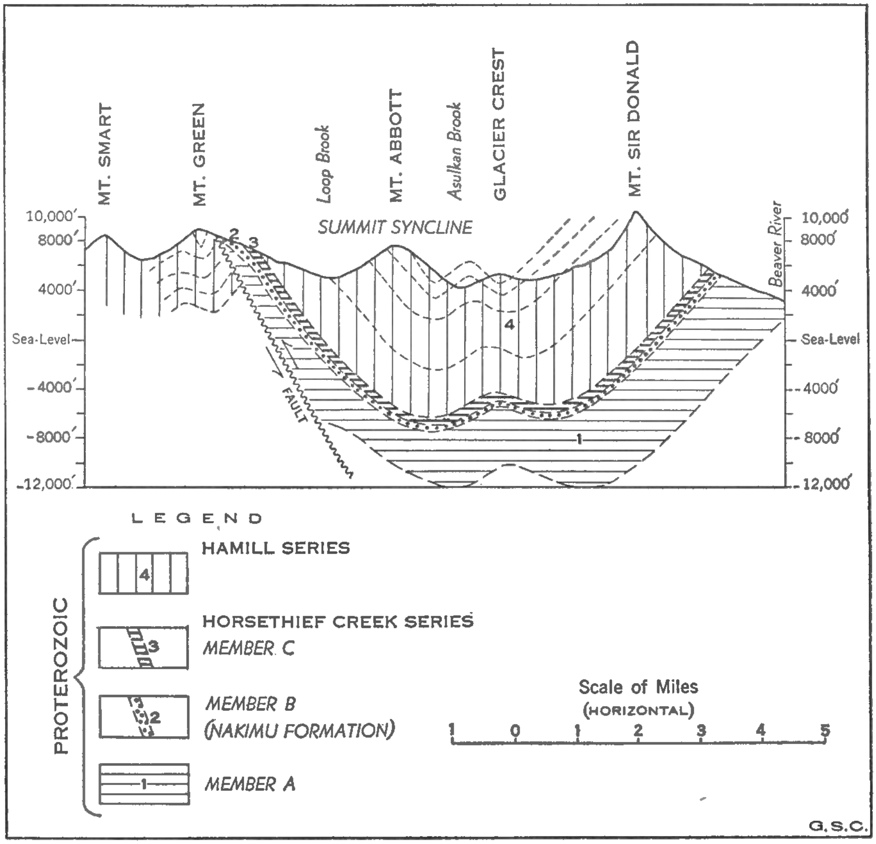

Figure 3. Structure-section from Mount Green to Mount Sir Donald.

East of Albert Canyon the sediments of the Hamill and Lardeau series are folded into a great complex asymmetrical syncline overturned to the west. This structure is referred to in this text as the Laurie syncline (*See* Figure 1 B). Its main axial plane dips easterly at an angle of possibly not more than 20 to 30 degrees, and its position can be determined at several places along the railway by examining the relationship of bedding and cleavage. The strata of the eastern limb generally dip easterly at a higher angle than the corresponding strata of the western limb.

Near the axial plane and the trough of the syncline the predominantly calcareous and argillaceous rocks of the Laurie formation exhibit complex crumpling and flowage. This crumpled zone can be seen at the Laurie tunnel on the railway, and particularly on the heights north of Illecillewaet River. Daly refers to this disturbed zone in the Laurie, but did not attach any special significance to it.

With minor exceptions, the strata repeat themselves on both sides of the axial plane of the Laurie syncline. The overturned eastern limb is well exposed in railway cuts from Flat Creek to Ross Peak stations and in the mountains north of the railway. On Cougar Mountain the Hamill quartzites exhibit the effects of intense drag-folding and crumpling (*See* Plate I), a feature illustrated by Daly (1915, Plate XXV). The drag-folds have been caused by a major fault that separates the Laurie syncline to the west from the Summit syncline to the east. Although no actual fault could be found exposed at the surface, the evidence of drag-folding, occurrence of coarse breccias and quartz veins, and the break in the sequence of formations leave little doubt of the presence of the fault. It is the writer's impression that a tight, westerly overturned anticline formed first and then has been broken by a fault that permitted further displacement of rocks, and, probably, some over-thrusting toward the west. In all probability the fault plane dips easterly at a higher angle than that of the overlying strata.

The main faulting took place in the upper part of the Horsethief Creek series below the Nakimu limestone. Slicing, drag-folding, and flowage combined to increase the normal thickness of the limestone at this locality. Fracturing, in turn, permitted easier percolation of ground water through the limestone and resulted in the formation of the Nakimu caverns.

East of the fault, the strata of the Horsethief Creek and Hamill series are folded into the second or Summit syncline, and several minor reverse faults appear in this part of the section. The eastern limb of the syncline forms the Sir Donald Range, which overlooks Beaver River Valley. No field work was done in Beaver River Valley or in the Prairie Hills farther east, but the impression is unavoidable that Beaver River Valley was eroded in a broken anticlinal structure. Both the Laurie and the Summit synclines and the remnants of the intervening anticline show numerous secondary folds. Such folds are well exhibited in a section from Mount Sir Donald across Illecillewaet Glacier, Glacier Ridge, and Asulkan Valley to Mount Green (Figure 3). Minor folds and faulting are also visible on Mounts Abbott, Cheops, and MacDonald.

No igneous rocks were seen in the entire section, with the possible exception of a bright green schist found both on Mount Abbott and Cougar Mountain, which may be a strongly metamorphosed lava flow.

The general conclusion derived from the structure is, therefore, that the Selkirk Mountains, in the latitude of the main line of the Canadian Pacific railway, consist of Late Precambrian to Cambrian strata, folded into synclines and anticlines overturned to the west. The intense compression was not entirely relieved by folding, and some of the overturned, or even recumbent, anticlines were faulted, resulting in overthrusts directed to the west.

THE PRECAMBRIAN-PALÆOZOIC BOUNDARY

The problem of where to draw the boundary between Precambrian and Palæozoic strata in the Cordilleran region of Canada is a vexing one. Almost every worker in the field has come to grips with it without finding an entirely satisfactory solution. The writer does not claim to have solved it, but has some suggestions to offer.

The positions of geological boundaries may be determined on the basis of any one or more of several lines of evidence: (1) structural, involving the presence of unconformities due to orogenic movements; (2) lithological or stratigraphical, dependent on changes in conditions of sedimentation, resulting in the accumulation of rocks of contrasting lithology in the same area in successive epochs. Quite commonly such changes may be related to intervals of non-deposition, or local erosion, leading to the presence of diastems and disconformities. No general diastrophic or orogenic movements are necessarily involved; and (3) palæontological, involving the appearance of new genera and species of animals and plants, or at least a marked change in the type of faunal assemblages. The recent papers by H. E. Wheeler (1947, 1948), Wheeler and Beesley (1948), and Schenk and Muller (1941) discuss the principles involved very fully.

Normally, in formations of Palæozoic, Mesozoic, and Cenozoic age, a combination of lithological and palæontological or 'time-rock' basis of subdivision of the strata into mappable units is the most serviceable. In most instances, the appearance of a new fossil genus or species is simultaneous over large areas. Theoretically, there is of course a lag, due to the time it takes a species to disperse from its place of origin; but, practically, it can be assumed that a characteristic faunal zone is contemporaneous over wide areas. This is especially true when an invading sea, or a newly established sea connection, suddenly brings a migrant fauna into a region. Correlation by means of lithology of sedimentary formations alone is the next best method, and for thick, unfossiliferous formations it is the only one possible. However, it has a serious drawback in that the lithology of sedimentary units tends to change both vertically and laterally. Depending on conditions under which the sediments were laid down, these changes may be very gradual and almost imperceptible, or conditions on the sea bottom may be such that the sediments laid down in a relatively limited area and at the same time will be a mosaic of sands, muds, and calcareous precipitates. In cross-section such a deposit will appear as consisting of numerous interlocking lenses of sandstone, shale, and limestone. The lithology of these units will be contrasting, and yet the whole complex will be essentially contemporaneous. A second difficulty is that a transgressing or regressing sea deposits lithologically similar materials in rock-units that transgress time. A layer of sand may, for example, be laid a certain distance off-shore; as the sea advances this layer will be added to from the landward side. The advance may be so slow as to occupy a considerable period of geological time. The result will be a bed of sandstone, essentially uniform lithologically, and perhaps quite unlike the underlying and overlying beds but progressively younger in the direction of the advancing sea. Here, then, will form a distinctive and easily mappable rock unit, whose age is not the same in different parts of the region it occupies.

The presence of a disconformity, because of usually limited areal extent, is not a safe indication of a geological boundary, as conditions of non-deposition, or even local under-water erosion, may exist at different times and in different parts of an area. Even a well-marked disconformity, seen at one locality, may not be contemporaneous with another seen elsewhere.

Correlation by means of orogenic movements, resulting in major unconformities, is a valid generalization, and useful in introducing the concept of subdivisions of time to students of elementary geology, but it can only rarely be applied in the field. Because of the slowness of orogenic movements, their pulsating nature, and the shifting of the locus of disturbance from one geographical area to another, it is the least dependable of the methods mentioned.

Coming to the problem in hand: the conditions in the Cordilleran geosyncline during latest Precambrian and early Cambrian times are particularly difficult to interpret. Throughout a vast area these times saw the deposition of a great thickness of detrital sediments with, at best, a very meagre fossil content. No great and widespread orogenic movements are known to have occurred, and truly regional unconformities, with the exception of one at the base of the Windermere, are lacking. Transgressive overlaps and deltaic deposits have resulted in vast sheets of sandy detritus continuous over large areas, but almost certainly of different ages at different localities. Lateral and vertical gradations from sandstones to shale and back are common. Ripple-marks, crossbedding, channel-fill, and scour attest to shifting currents, and are responsible for the presence of numerous disconformities, and even minor unconformities.

No fossils were found in the Horsethief Creek, Hamill, Badshot, or Lardeau (Laurie) strata exposed in the section examined. The formational subdivisions were established on the basis of lithology and superposition only, and are, therefore, rock-units according to present day stratigraphic usage (Wheeler, 1948). Stratigraphic and structural evidence points to the fact that these rock-units transgress time and are older in the west than they are in the east. The writer subscribes to the principle that the base of the Cambrian is defined by the appearance of fossils characteristic of the *Olenellus* zone. Therefore, on purely negative palæontological evidence all the formations, except the Milford, within the section studied appear to lie below the *Olenellus* zone and may, therefore, be regarded as of Late Precambrian age.

In the Dogtooth Mountains, immediately east of this section, the *Olenellus* zone occurs in the uppermost part of the St. Piran formation and in the overlying Donald formation. Still farther east, in the Field map-area of the Rocky Mountains, Lower Cambrian fossils are found in the Lake Louise, St. Piran, and overlying Mount Whyte formations. As the faunal zones must be regarded as time-units, and, therefore, can be represented as horizontal lines on the time-space diagrams the rock-units appear to transgress them diagonally, rising from west to east. Thus, whereas the Hamill series is apparently Precambrian in the Selkirk Mountains its rock-unit equivalent farther east, the Fort Mountain, Lake Louise, and St. Piran formations, includes Lower Cambrian in the Dogtooth and Rocky Mountains (*See* Figure 4).

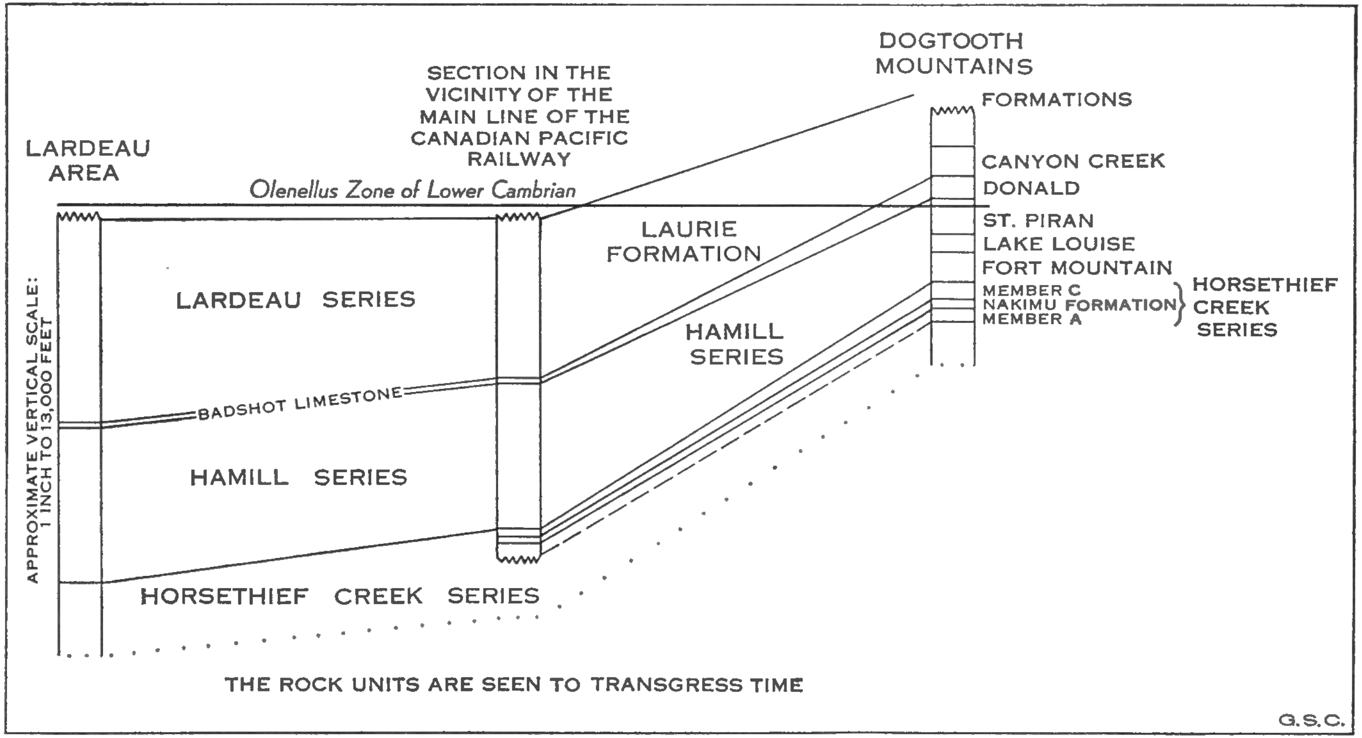

Figure 4. Probable correlation chart of formations in Selkirk and Dogtooth Mountains, using *Olenellus* zone as a reference horizon.

It should, therefore, be kept in mind, that although the Hamill and Fort Mountain-Lake Louise-St. Piran series represent the same rock-unit, there is no certainty that they were laid down contemporaneously. The writer is convinced that deposition of this thick sheet of dominantly sandy material began in the western Selkirks in Late Precambrian time, crossed the Precambrian-Palæozoic time boundary in the eastern Selkirks, and was continued in the Purcell and the Rocky Mountains in Lower Cambrian time.

A parallel situation applies to the overlying calcareo-argillaceous group, involving the Lardeau series, the Laurie formation, and the Canyon Creek formation. In their type areas, the Lardeau and the Laurie are unfossiliferous and presumably lie below the *Olenellus* zone. Eastward from the Selkirk Mountains a clastic series correlated with the Hamill quartzites is overlain by the Donald formation, with Lower Cambrian fossils. If the Donald formation is equivalent to the Badshot formation, and the Canyon Creek formation to the Laurie, the rock-units again transgress time and become younger from west to east.

Although the preceding discussion of the Precambrian-Cambrian relationship appears to be a logical solution of the problem, it is realized that for present practical purposes of geological mapping it may be best to continue mapping rock-units rather than time-rock units, and to select an arbitrary Precambrian-Cambrian boundary. Tentatively, it is suggested that this boundary be placed at the top of the Horsethief Creek series and its equivalents. The reasons for this selection are: no Cambrian fossils were ever found in the Horsethief Creek series in southeastern British Columbia, and a disconformity is indicated between it and the overlying series in the Dogtooth Mountains and the Glacier area.

In the section studied, the lowest exposed rocks are members of an argillaceous series that has been identified as the Horsethief Creek series. This series contains some limestone bands, one of which is the Nakimu formation. Overlying the Horsethief Creek series throughout the section investigated are massive and thick-bedded, predominantly quartzitic rocks variously named the Fort Mountain-Lake Louise-St. Piran in the Dogtooth Mountains, and the Hamill series in the Selkirks. These arenaceous rocks form a vast sheet of sand, rather uniform in appearance, but in all probability deposited at different times in different parts of the region. Above the quartzites is an argillaceous and in part calcareous assemblage of rocks named Mount Whyte in the Rocky Mountains, Donald and Canyon Creek in the Dogtooth Mountains, and the Lardeau (and Laurie) in the Selkirks. These rocks may differ from each other in age, but represent a similar condition of sedimentation. Rice (1941, pp. 22-23) called attention to the apparent cyclical deposition in the Purcell and Windermere series. He pointed out that in the Windermere there is a basal coarse-grained unit, the Toby conglomerate, overlain by the argillaceous Horsethief Creek, and the coarse-grained Hamill overlain by the argillaceous and calcareous Lardeau. So there are two complete depositional cycles, in each instance running from coarse- to fine-grained materials. In the absence of fossils in the type areas of these formations, it was natural to classify them all as Precambrian. However, fossil evidence recently obtained from the Pend-d'Oreille district of the International Boundary section and that previously acquired from the Dogtooth Mountains suggest that the upper division, the Hamill-Lardeau, is at least in part of Palæozoic age. A disconformity was reported by Evans (1933, p. 118) above the Horsethief Creek series separating it from the Fort Mountain in the Dogtooth Mountains at Twelvemile Creek. The writer noted that in the Selkirks the uppermost member of the Horsethief Creek series is variable in thickness, due, possibly, to erosion before the deposition of the Hamill series. This evidence also points to the top of the Horsethief Creek series as a possible arbitrary boundary between the formations of Precambrian and Palæozoic age.

Our knowledge is too incomplete at present to permit valid generalizations on palæogeographical conditions of late Precambrian and early Cambrian times in the report area. However, certain observations seem to be pertinent. To the west of the area, in the Shuswap region, the Late Precambrian formations consist of great thicknesses of limestones, sandstones, and argillaceous sediments, clearly indicating that a fairly stable sea existed for an unknown, but certainly very long, time. The indicated easterly transgression of this sea began in very late Precambrian (Windermere) times. This transgression was in progress for at least the full duration of the Windermere and Cambrian periods. The coarse-grained arenaceous sediments of the 'Selkirk delta' are, apparently, thickest and coarsest within the Sir Donald Range and thin out westerly. It is, therefore, probable that towards the close of Precambrian time, the eastern shoreline of the sea stood in the position of Beaver River Valley of today. The land to the east of this shoreline had a fairly high relief and well established drainage to supply the conglomerates and coarse grits of the Hamill series. During Cambrian time, the relief was gradually reduced and the shoreline retreated farther east.

It is, perhaps, permissible to speculate on a 'migrating or shifting geosyncline' slowly moving from west to east. The land progressively sank in the east and was elevated in the west. This is indicated by the transgressive relationship of the sediments directed eastward and the apparent lack of Lower Palæozoic sediments in the west. The rising or emerging land in the west was probably low, as most shorelines of emergence are, and did not contribute much sediment. The shoreline of submergence in the east, however, was responsible for most of the sedimentary materials in the section.

A certain distance off-shore from the western margin of the sea, conditions became stable and limestones were deposited. Pleosponges and the mesonacid trilobites occupied such limy bottoms during the Lower Cambrian. By Ordovician time the shifting of the sea probably came to an end; there were no more highlands to the east. The graptolite-bearing Glenogle shales were laid down at this time.

This hypothesis is at variance with the widely held one of G. M. Dawson on the existence of an Archæan axis or geanticline in the present position of the Selkirks, or somewhat west of the Selkirks, which supplied the sediments to the Rocky Mountain (Laramide) geosyncline to the east. The available evidence is not conclusive either way, but the writer's hypothesis of an eastward transgressing sea, and the source of sediments in the Rocky Mountains region is at least a possible alternative that has to be considered.

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PLATE I

Nakimu limestone (N) overthrust over drag-folded Hamill quartzite (H.). F-F possible position of fault. South face of Cougar Mountain. (Pages 6, 15.)

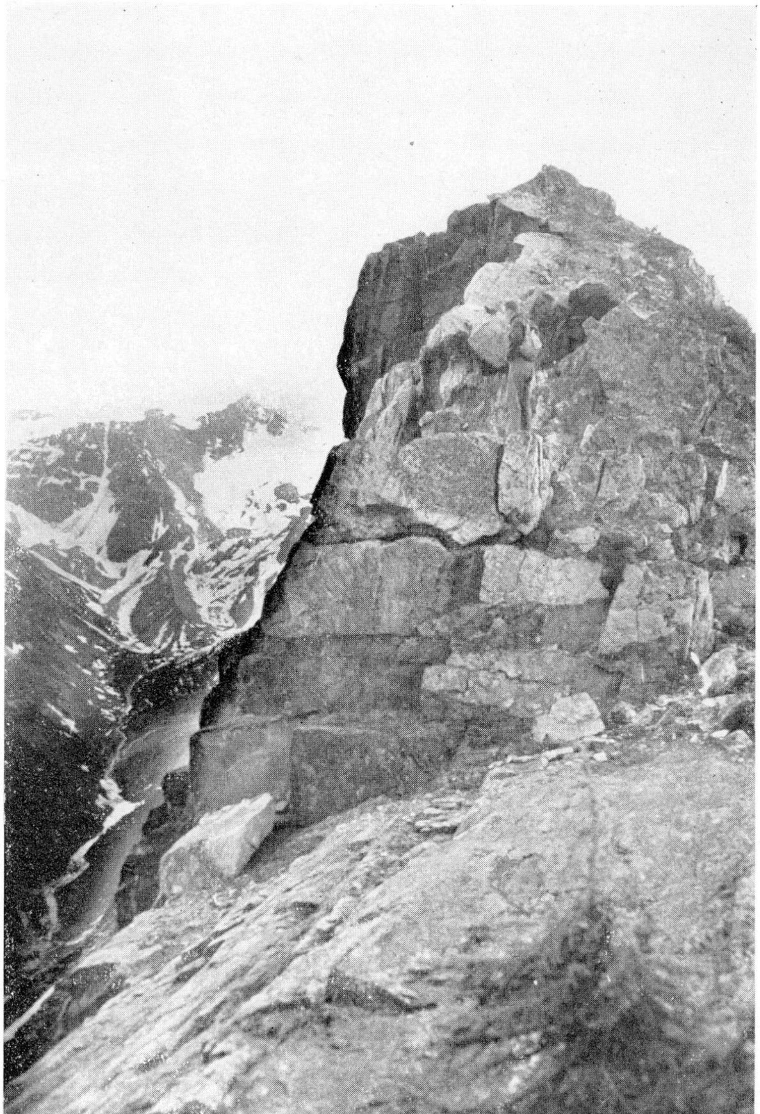
PLATE II

Exposures of Nakimu limestone on east face of Cougar Mountain. (Page 6.)

PLATE III

Thin-bedded Hamill quartzite of the eastern limb of Summit syncline exposed in the bed of Illecillewaet Glacier. (Page 8.)

PLATE IV



The summit of Mount Abbott, made of thick-bedded Hamill quartzite. The dip is almost vertical. (Pages 8, 9.)