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CANADA
DEPARTMENT OF MINES
HON. LOUIS CODERRE, MINISTER; R. W. BROCK, DEPUTY MINISTER.
GEOLOGICAL SURVEY

MEMOIR 68

No. 59, GEOLOGICAL SERIES

A Geological Reconnaissance between Golden and Kamloops, B.C., along the Canadian Pacific Railway

BY

Reginald Aldworth Daly

OTTAWA
GOVERNMENT PRINTING BUREAU
1915

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PREFACE.

The following report gives the more important results of a survey along the Canadian Pacific railway between Golden and Kamloops, B.C., a distance of 224 miles. The writer was commissioned to work on the general geology of this long section during the summers of 1911 and 1912. A principal aim was to collect data for the guide book to be used in the 1913 session of the International Geological Congress. The actual area thus covered in reconnaissance is about 1,400 square miles. For certain problems connected with stratigraphy and structure it was found necessary to travel considerable distances from the railway. Adams lake, the northern arm of the Shuswap lakes, and the heights of the Dogtooth mountains and Prairie hills between Donald and Bear Creek, were thus for special reasons explored.

Efficient assistance in the field was given by Dr. N. L. Bowen during the first season, and by Mr. F. J. Alcock during the second. Special thanks are due to Mr. Howard Palmer for the use of many of his valuable photographs taken in the Selkirks; to Dr. E. Deville for permission to publish the Wheeler photographs; and to the Canadian Pacific Railway company for the gift of a number of their official photographs.

The base maps used in the field were: the Kamloops and Shuswap sheets of this Survey, respectively published in 1895 and 1898, on the scale of 1: 253,440; A. O. Wheeler's map of the Selkirks, published by the Interior Department of Canada, 1904, on the scale of 1: 60,000 (four sheets); and his topographical map of part of the Rocky mountains, in four sheets (scale 1: 160,000), kindly furnished in blue print form, prior to publication, by the Surveyor General, Dr. E. Deville.

Preliminary statements of the results have been given in the Summary Reports of the Survey for 1911 and 1912, and in Guide book No. 8 referring to the Transcontinental Excursion C1 of the Congrès Géologique Internationale (issued by this Survey in August, 1913).

Nearly nine-tenths of the area traversed shows outcrops older than the Olenellus zone of the Cambrian. Younger rocks appear at the extreme eastern end and extreme western end of the section. The Cambrian sediments forming the highest summits of the Selkirks, and the Cambrian-Ordovician beds flooring the Rocky Mountain trench, are outliers of the great group of Palæozoic strata which largely composes the Rocky mountains. That geological province is now being energetically studied by Dr. J. A. Allan and Dr. C. D. Walcott, who follow the pioneers in this field, Mr. R. G. McConnell and Dr. G. M. Dawson. The Cenozoic, Mesozoic, and younger Palæozoic formations at and east of Kamloops represent the eastern part of a totally different complex which has recently been attacked by Dr. C. W. Drysdale, Mr. B. Rose, Mr. C. Camsell, and the writer, all having the advantage of Dawson's published account of his reconnaissance of south-central British Columbia.

The broad intermediate band of Pre-Cambrian rocks was also covered by Dawson and McEvoy in their laborious explorations. Since Dawson published their joint results on the country west of Revelstoke, twenty years ago, no geologist has carried on serious work in the railway belt between Golden and Kamloops. Until quite recently this stretch had been wholly traversed by no other geologist except Dawson, and practically no other name appears in the bibliography of a section twice as long as the average cross-section of the European Alps. In many essential points the present writer has come to the same conclusions as Dawson. In others the agreement is only partial, while a few important conclusions of this second reconnaissance differ completely from those of Dawson. These divergences are chiefly due to the writer's access to many new facts discovered, since Dawson's death, in the railway belt itself and in the detailed survey along the International Boundary, where the same great Cordilleran zones are crossed. Such differences of view have had but little effect on the writer's increasingly high admiration of Dawson's intense spirit, which carried him, in spite of enormous physical difficulties, through one of the longest and most arduous explorations on record. It is safe to say that his general statement of British Columbia geology will stand as essentially true; his details could not all be correct. In occasionally emphasizing differences of interpretation, one must not forget that Dawson's task was to outline the general geology of an area as large as Germany and France combined.

A Geological Reconnaissance between Golden and Kamloops, B.C., along the Canadian Pacific Railway.

CHAPTER I.

GENERAL TOPOGRAPHY.

The Canadian Cordillera is divisible into four major provinces: (*a*) the Coastal Mountain system, including the Vancouver range and the Coast range; (*b*) the Belt of Interior Plateaus; (*c*) the Middle or Interior Mountain group, including the Columbia, Selkirk, and Purcell ranges; and (*d*) the Rocky Mountain system (Map No. 1458). The basis of this subdivision and naming is described in Chapter III of Memoir No. 38 of this Survey. Dawson's pioneer statement was there enlarged and otherwise changed in order to meet the necessities of systematic work along the 49th parallel section. The constituent mountain systems are separated from one another, with some rigour, by structural depressions and erosion troughs. In the area covered by this reconnaissance the systems concerned are the Rocky, Purcell, Selkirk, and Columbia mountains, and the Belt of Interior Plateaus. The dividing depressions are: the Rocky Mountain trench, the Purcell trench, and the "Selkirk Valley" (namely, that part of the Columbia valley that lies west of the Selkirk range).

In general the Rocky mountains are separated from the northern Purcells and Selkirks by the Rocky Mountain trench, which is drained by the Columbia river (Plate I). On a very small scale map of the Cordillera there would be difficulty in showing any deviation of that river from the main axis of the trench. However, the river does leave that axis at a point near Donald and runs for a distance of nearly 20 miles behind the long, narrow mountain block overlooking Beavermouth on the northeast. In a sense, this "Beavermouth block" is really part of the Dogtooth range, from which it has become separated by a late-Glacial or post-Glacial diversion of the Columbia from the main axis of the Rocky Mountain trench. South of Donald the width of the trench, measured from crest to crest of the bounding mountains, is about 8 miles. Northwestward from Donald it preserves its trend as a great trough, 5 miles in width, now drained southeastwardly by Blackwater creek. The "Beavermouth block" thus cut off between the river and the principal trough is stratigraphically and structurally a continuation of the Purcell Mountain system. According to an alternative view, the "Beavermouth block" might be considered as a mass isolated in the Rocky Mountain trench, which thus includes both the wide trough at Blackwater creek and the local, canyon-like part of the Columbia valley to the southwest of the "Beavermouth block." Probably the latter conception offers the fewest complications in a treatment of the local topography in terms of a systematic scheme for the whole Cordillera. So far as known to the writer, the Columbia has been diverted from the main axis of the trench at no other point in its course between the Columbia-Kootenay divide and the Big Bend, where the river finally leaves the trench.

Scenically this trench is very impressive. Approaching it by railway from either side, the observer has followed a tortuous way through closely set mountains, famous for their ruggedness. At Golden he suddenly emerges from the Kicking Horse canyon and finds himself in a wide trough stretching northwest and southeast, as far as the eye can reach. Its real majesty becomes apparent when he reflects that the eye takes in only a minute section of a feature which extends nearly a thousand miles, from Montana to Yukon, a distance greater than the whole length of British Columbia. From the Columbia river, here about 2,550 feet above the sea, the slopes ascend on either side over strong benches of gravel and glacial drift to the cliffy scarps of mountains ranging from 7,000 to 9,000 feet in height (Plate II). The topographic relief is thus considerable, but the Rocky Mountain trench cannot be appreciated at its true orographic value unless its unique length is kept in mind. As a comparatively straight, through-going depression it appears to have no rival in any other mountain chain. Its origin is considered at page 113.

The northern end of the Purcell Mountain system is found at the junction of the Beaver and Columbia rivers. The system is locally divided by the valley of Quartz creek into two parts, the Dogtooth mountains and the Prairie hills. The former are the higher and more rugged, though few peaks exceed 9,000 feet in elevation. Because of their structure and comparative lack of thick, massive rock formations, the Purcells are much less imposing than the cliffy and horned ranges to east and west (Plates XLIV and III).

At page 30 of Memoir No. 38 of this Survey (1912) will be found a statement as to the grounds for excluding the mountains east of Beaver river from the Selkirk system. This is contrary to common, though by no means universal, usage, which is not founded on a systematic, comprehensive principle of orographic subdivision, but on a mistake in Palliser's sketch map of 1860. The map indicates the "Selkirk Mountains" as a long, unbroken ridge extending across the area now known to be occupied by the deep valley of Beaver river. In 1860 the existence of this major trough was unsuspected and Palliser's "Selkirk Mountains," though occupying all the space within the northern loop of the Columbia, are represented as of only about half their actual width. The Duncan appears on this map far out of its proper latitude and longitude, and it is noteworthy that the Selkirks are not shown as extending across the Duncan. Kootenay lake, Duncan river, and Beaver river all lie in the same through-going depression, the Purcell trench. That strongly marked feature is best regarded as a necessary line of primary orographic subdivision (Plates IV to VII). Hence, according to the new definition, the Purcell trench separates the Selkirk system of mountains from the Purcell system. A careful study of Palliser's maps, the earliest showing the "Selkirk Mountains," proves that the new definition does little violence to that explorer's own statement as to a natural eastern limit for the range. It was not until 1905, when Wheeler published his fine map, that a cartographer could be convinced of the necessity of recognizing a great system east of Beaver river as distinct from the Selkirk system. The reasons for giving the name "Purcell range or system" to that mountain group are given in Memoir No. 38 and need not be repeated.

The Purcell trench is not much over 200 miles in length. At the International Boundary and for scores of miles northward it is almost as impressive in depth and width as the Rocky Mountain trench. In the portion drained by Beaver river, the Purcell trench is only from 3 to 5 miles broad, measured from crest to crest of its mountain walls, and its floor is correspondingly narrow. The general form is that of a fiord-like, heavily glaciated valley (Plate IV). Opposite the hanging valley of Bear creek the trench floor is 3,000 feet above sea; the Prairie hills range from 7,000 feet to 8,000 feet or more in height (Plate V), and the opposing Selkirk peaks are of various heights, culminating at 10,808 feet in Mount Sir Donald.

The strength of relief in the Selkirks at the railway belt is further given by the altitude of the Columbia river at Revelstoke, which is approximately 1,450 feet above sea-level. For details concerning the topography of these splendid mountains the reader is referred to Wheeler's excellent map and its accompanying text[1] (Plate VIII).

Within the railway zone covered during the reconnaissance, the highest peak of the Columbia range is Mount Begbie, 8,946 feet above sea (Plate IX). Though not so high as the Selkirks, this range is one of the roughest in the Cordillera. North of the Arrow lakes no part of it has ever been properly mapped and a chief reason is the truly great difficulty of travel in most of the range. Much more forbidding than the general steepness of slopes is the density of the forest cover, and especially of the overwhelming thickets that have grown up in fire-swept areas.

The Selkirk valley (Plate X), sharply delimits the Columbia range on its eastern side, except at the north, where it is obliquely truncated by the Rocky Mountain trench. The western limit cannot be closely fixed since the range merges

[1]A. O. Wheeler, The Selkirk Range, Department of the Interior, Ottawa, 1905, 2 vols.

insensibly into the Belt of Interior Plateaus. In the railway zone the plateau form first becomes marked in the vicinity of Sicamous. At the extreme northwest the range is probably best considered as terminating at the master valley occupied by the headwaters of the North Thompson river.

Dawson and several later authors have used the name "Interior Plateau" for the broad region between the Columbia and Coast ranges. The present writer prefers to use the plural form "plateaus." The region is obviously not a plateau in its present form and topographic relations; on the other hand, there is no certainty that it ever was a plateau unit, since dissected. Large areas of its pre-Palæozoic, Palæozoic, and Triassic rocks were clearly baselevelled and remnants of the resulting peneplain now form local plateaus (Plates XI and XII). Other large areas underlain by Tertiary lavas similarly form plateau elements separated by comparatively young valleys. In many places these lavas lie nearly or quite horizontal. They have everywhere suffered erosion, but as yet there is no proof that these plateau facets are parts of the same general peneplain which still remains in the areas of truncated pre-Jurassic terranes. Throughout most or all of Jurassic, Cretaceous, and Eocene times this Cordilleran belt was being denuded, and reduction to the peneplain form would be the result, at least locally, by the beginning of the Oligocene, when the principal lava floods of the belt were poured out. One may well doubt that the succeeding time has been long enough for a general peneplanation of the new volcanic relief and the older rock complexes in the belt. To describe the belt as the Interior plateau implies more or less definitely that it is a physiographic unit; more concretely, that it is a dissected peneplain. In view of many unsolved problems, as, for example, the fixing of a distinction between constructional lava plateaus and two-cycle plateaus in this region, that simple conception of the belt has not been justified by proof. Its simplicity may be as dangerous as it is alluring.

The individual plateaus vary in altitude, as here illustrated:

	Approximate elevation in feet.
Green Timber plateau	3,800
Bonaparte plateau	4,000
Arrowstone hills	5,000—5,500
Porcupine plateau	4,800
Kukwaus plateau	4,500
Red plateau	4,000
Timbered hills	5,000—5,500
Little Timbered hills	4,500—5,000
Douglas plateau	3,500—4,500
Adams plateau	6,000

The strength of the relief in the belt is further indicated by the water levels in the chief drainage system:

	Feet above sea-level (approximate).
Shuswap lake	1,140
Kamloops lake	1,120
Thompson river at Ashcroft	900

CHAPTER II.

GEOLOGY: INTRODUCTORY REMARKS.

GENERAL STRATIGRAPHIC COLUMN.

The rock formations encountered during the reconnaissance, range from the Pre-Cambrian (pre-Beltian) to the Pleistocene. They are listed in the following table, which shows the existence of several long breaks in the stratigraphic succession. No rocks clearly referable to the Ordovician, Silurian, Devonian, Lower Carboniferous (Mississippian), Permian, Cretaceous, Eocene, Miocene, or Pliocene have been found in the area to be considered. The region is not specially favourable to the study of Cambrian or later rocks, but it is extraordinarily important for the student of the Pre-Cambrian.

TABLE OF FORMATIONS.

System	*Formation*	*Thickness in feet*	
Recent and Pleistocene	Fluviatile, lacustrine, glacial	..	
	Unconformity		
Oligocene	Kamloops group (volcanics and interbedded sediments)	1,500+	
			1,500
	Unconformity		
Triassic (and Jurassic ?)	Nicola series:		
	Sandstone, argillite, and breccias (1,000 feet)		
	Massive basic volcanics (4,000+ feet)		
	Basal conglomerate and breccia (300 feet)		
			5,300

	Unconformity		
Carboniferous (Pennsylvanian)	Cache Creek series:		
	Limestone, quartzite, argillite, and some volcanic ash (7,700 feet)		
	Quartzites with lava flows and ash-beds (3,000 feet)		
	Cherty quartzite, siliceous argillite, and greywacke (2,500 feet)		
	Basaltic ash-beds (500 feet)		
		———	13,700
	Base concealed (probable unconformity with Shuswap terrane)		
Lower Cambrian	Sir Donald quartzite	5,000+	
Beltian	Ross quartzite (upper part)......	2,750	
	Ross quartzite (lower part).......	2,500	
	Nakimu limestones.	350	
	Cougar formation (quartzite with metargillitic beds)............	10,800	
	Laurie formation (metargillite, limestone, quartzite)...........	15,000	
	Illecillewaet quartzite...........	1,500	
	Moose metargillite..............	2,150	
	Limestone (marble).............	170	
	Basal quartzite.................	280	
		———	40,500
	Erosion unconformity with Shuswap terrane		
Pre-Beltian (Shuswap terrane)	Intrusive granites................	...	
	Shuswap series:		
	Adams Lake volcanics...........	10,000+	
	Tshinakin limestone-metargillite..	3,900	
	Bastion schists (phyllites, etc.)...	5,000	
	Sicamous limestone.............	3,200	
	Salmon Arm mica schists........	1,800	
	Chase quartzite................	3,000	
	Tonkawatla paragneiss (?).......	1,500+	
		———	28,400
	Base concealed		
	Grand total of thickness..........		89,400

MAJOR GEOLOGICAL PROVINCES.

The statement of the geology naturally falls into three parts. The oldest rocks belong to the Shuswap terrane, which forms a broad middle belt in the area (Map No. 1458) This will be first treated. Resting upon it on the east is an enormous mass of bedded rocks belonging to the Beltian system and the conformably overlying Cambrian system. These formations constitute practically the whole of the Purcell and Selkirk mountains east of Albert Canyon; their description occupies a second part of this report. A third part is concerned with a much younger complex of formations ranging in age from the Carboniferous to the mid-Tertiary and outcropping only in the Belt of Interior Plateaus, west of the Shuswap terrane. Discussing these three geological provinces in turn, the treatment is not only in the chronological order, but is also fairly simple in a geographical sense.

CHAPTER III.

THE SHUSWAP TERRANE.

GENERAL DESCRIPTION.

Perhaps nowhere else in the Cordillera is there so complete a section of the formations antedating the Olenellus zone. Because of its strong topographic relief, this mountainous land gives the geologist a certain advantage over his colleague who is working in the comparatively flat country so characteristic of the Pre-Cambrian areas in eastern Canada and northwestern Europe. The geologist in British Columbia can often follow important contacts through vertical distances measurable in thousands of feet; he can observe in three dimensions (Plate XIII). Thus, great rock diversity, large area, enormous thicknesses, intrinsic importance, and the conditions of exposure make it necessary to lay special stress on the pre-Olenellus formations. These are divisible into two groups, here called the Shuswap terrane, and the Beltian system.

The exposed basement rocks of British Columbia were grouped by Dawson under the name "Shuswap series," taken from that of the lake which has long borne the canoes of the Shuswap Indians (Map 143, A). In the legend of his 1898 map Dawson described the complex as follows:

> "This series, where typically developed, consists of greyish gneisses, occasionally hornblendic or garnetiferous, glittering mica-schists, with beds of crystalline limestones and quartzite. The gneisses, when in association with the last-mentioned beds, are often highly calcareous or siliceous and generally rusty on weathering, and graphite is often present in these gneisses as well as in the quartzite and limestones. The rocks described undoubtedly represent parts of a bedded series, but are associated with a much greater mass of mica-schists, gneisses and granitoid gneisses,

many parts of which are evidently foliated granites, from which it is impossible to separate them. The frequent occurrence of quartzites among these latter rocks, however, appears to show that they are at least in part the result of a further alteration of the same bedded series. On the other hand, these gneisses often pass gradually into unfoliated granites from which they are also inseparable on the map. The actually observed outcrops of limestone are noted on the map, as well as the general direction of foliation or bedding wherever this has been determined with approximate accuracy. Elsewhere, the gneissic and associated granitic rocks are merely indicated by a general tint.

The Shuswap series proper is evidently referable to the Archæan, and is much like the Grenville series of the Laurentian of Eastern Canada. This resemblance extends to its manner of association with the foliated rocks that resemble the 'Fundamental Gneiss' of the same region."
In his last summary of Cordilleran geology Dawson wrote:

"The Shuswap series has been made to include this entire complex mass of crystalline rocks, although it might be more appropriately restricted to the originally bedded members. These, it will be observed, now very closely resemble those of the Grenville series of the province of Quebec, the resemblance extending to the nature of their association with the foliated rocks, which in turn closely resemble the so-called "Fundamental Gneiss' of the same region."[1]

The writer follows Dawson's own suggestion and designates the sediments and associated volcanics of the complex under the name "Shuswap series," which excludes the plainly intrusive granites, pegmatites, and orthogneisses. The whole assemblage of sedimentary, volcanic, and plutonic rocks is here, for convenience, called the "Shuswap terrane."

During the field season it became convincingly clear that the Shuswap series includes also two great formations which had been referred by Dawson to the Cambrian; these are the "Nisconlith"

[1]G. M. Dawson, Bull. Geol. Soc. America, Vol. 12, 1901, p. 63.

limestone with the associated rocks, and the Adams Lake series. The evidences that these rocks are not only Pre-Cambrian but also pre-Beltian were given in the Summary Report for 1911 (See also page 59).

The Shuswap terrane thus comprises a gigantic group of rocks, here listed in tabular form, from youngest to oldest.

	Formation	Approximate thickness in feet.
	Unconformity with Beltian System	
Intrusive	Batholiths, laccoliths, sills, dykes, and chonoliths of granite, aplite, and pegmatite, generally metamorphosed....................	——
Shuswap series	Adams Lake basic volcanics (with contemporaneous basic intrusives)	10,000+
	Tshinakin limestone-metargillite..	3,900
	Bastion schists (phyllites, etc.)....	5,000
	Sicamous limestone (representative of Dawson's "Nisconlith" series)	3,200
	Salmon Arm mica schists.........	1,800
	Chase quartzite.................	3,000
	Tonkawatla paragneiss (?).......	1,500+
	Base concealed	
		28,400

It needs no emphasis that the foregoing table gives merely a tentative statement of sequence and thicknesses for the Shuswap series. A rigorous description of the stratigraphy is still impossible in this difficult terrane, which has much of the complexity usually found in the Pre-Cambrian areas. The succession of the bedded formations has been deduced from widely separated localities and is based on purely lithological correlations. According to the actual experience of two field seasons the Sicamous limestone is the best horizon marker, and its relations to the Bastion schists above and the Salmon Arm schists below is definitely ascertained. The type section showing these relations is that at Bastion mountain (Plate XV; Map 143,A). That the Tshinakin formation overlies the Bastion schists is by no means as clear. The only full section of the

Tshinakin formation was found on Adams lake, where it is underlain by phyllites lithologically correlated with the Bastion schists.

The Adams Lake volcanics of that section undoubtedly overlie the upper Tshinakin limestone and there is no indication of overturning. At Shuswap village the Chase quartzite underlies a thick mass of mica schists which have been correlated with the Salmon Arm formation on a purely lithological basis, and the Tonkawatla formation holds a still lower place in the series, if the writer is correct in regarding the massive quartzi es at the summit of the Columbia range as equivalent to the highly similar Chase format: 1 at Shuswap village, 58 miles distant (Map 143,A).

In spite of the doubts accompanying such correlations, the ter has compiled the foregoing table which will at least il-.ustrate the various types of rock composing the Shuswap series. The estimates of (maximum) thicknesses are obviously also subject to uncertainty. Those given for the Sicamous and Tshinakin formations are fairly trustworthy. The thickness assigned to the Bastion schists may be too great even for a maximum. Dawson estimated the Adams Lake volcanics as 25,000 feet thick in the Adams Lake section. Some of the basic rocks there measured may really represent intrusive sills and, for the present, it is safer to assume for the volcanics themselves a maximum thickness no greater than 10,000 feet.

TONKAWATLA FORMATION.

At the point where the Tonkawatla valley joins the Columbia River valley, just west of Revelstoke, a great group of bedded crystalline schists crops out on the north side of the railway. These rocks are among the oldest in the Columbia range and have been tentatively placed at the base of the Shuswap series as exposed in the railway section.

These schists are massive and relatively homogeneous. In both respects they have the superficial appearance of orthogneisses. In greater part they are dark or medium grey to greenish grey, strongly micaceous, and visibly feldspathic as well as quartzose. Such dominant, gneissic beds, ranging from a few inches to a hundred feet or more in thickness, are generally separated by thin, still more micaceous beds or by thin lenses of metamorphosed limestone. The limestone layers are locally very numerous, but, where seen, never of thickness greater than a few inches. In and near the railway cuttings the limestone beds are characteristically interrupted so that each now forms a number of thin lenses arranged in the plane of bedding. In spite of this effect of metamorphism, the carbonate rock cannot be regarded as merely of the nature of a vein formation; it is a true calcareous sediment.

The abundance of the limestone beds suggested in the field that the associated schists are paragneisses rather than the metamorphic equivalents of igneous intrusives. On the whole, that conclusion seems to be supported by microscopic study, though the thin sections have not yielded absolute proof. The essential constituents are quartz, biotite, plagioclase (averaging labradorite), and subordinate orthoclase or microcline. In one thin section a diopsidic mineral is abundant. Garnets, calcite, and tremolite are common accessories. The feldspars are strikingly poikilitic and, like the other essentials, show strain phenomena. The mineralogy and structure of the rock are appropriate to a recrystallized calcareo-argillaceous rock, e.g., "Kalkthonschiefer."[1]

The limestone beds are pale grey to white in colour and medium-grained. They too are strongly charged with quartz, biotite, and diopsidic grains. Muscovite, talc, and chlorite are locally developed in large quantity, and in thin section titanite is seen to be surprisingly abundant. The carbonate base effervesces freely and seems to be quite low in magnesia. Within the beds the silicates tend to be more or less segregated in sub-layers which project on the weathered surface. These lie parallel to the general bedding of the formation.

For more than a mile this Tonkawatla formation is continuous along the railway. It dips northerly at angles varying from 8° to 30°, with an average of about 18°. At the 3-mile

[1] See H. Rosenbusch, Elemente der Gesteinslehre, 3d edition, 1910, Analysis No. 13, p. 599.

railway post the exposures give an apparent thickness of at least 3,000 feet; it may be considerably greater.[1]

Farther west the formation is cut by many sills of granite and aplite, which obscure the stratigraphic relations. At the 9-mile post, on the summit, the Tonkawatla schists appear in the core of a west-pitching anticline and show a continuous thickness of fully 1,000 feet. The schists are here charged with occasional thin beds of grey quartzite. At the 9·5 mile-post they are overlain by massive quartzites, which are provisionally referred to the Chase formation; these in turn pitch under a thick mica-schist (Salmon Arm) formation which has participated in the same anticlinal folding.

The Tonkawatla formation has been positively identified at no other section in the area covered by the reconnaissance.

CHASE FORMATION.

This is a series of banded though massive calcareous quartzites, admirably exposed in the ridge immediately east of Shuswap village and southeast of the town of Chase (Map 143,A). Nearly the whole western slope of the ridge is underlain by these rocks with an average dip of about 52° to the northwest. The upper contact with the Salmon Arm schists is well shown, but the actual base of the formation was not found. A thickness of at least 3,000 feet is represented in the visible quartzites.

The dominant rock is white to pale grey or light bluish-grey quartzite, generally charged with grains of calcite and of various silicates. The latter include diopside (salite ?), tremolite, microcline, titanite, and muscovite. Pyrite and magnetite are common accessories. The disseminated calcite grains are in some phases so abundant as to induce a sugary habit for the weathered surface of the rock. The silicates are of metamorphic origin. They are commonly aggregated in layers parallel to the obvious bedding of the formation. As in the Tonkawatla strata, the titanite is a noteworthy constituent. The quartz grains themselves seldom reach 1 mm. in diameter and in three thin sections average

[1] From Revelstoke to Kamloops the mile-post numbers begin at Revelstoke.

about 0·2 mm. One specimen which is rather poor in silicates was estimated to be 85 per cent quartz and 10 per cent carbonate. From the general abundance of diopside and tremolite, it is probable that the original carbonate material was strongly magnesian. At some horizons it formed distinct, thin beds, now largely composed of silicates. On weathering, these depressions and the resulting ribbed appearance of the otherwise strikingly massive quartzite is so characteristic that it was used as a means of preliminary correlation.

Rocks of the same general character and associations were found at the southern end of Mara Arm; at the Columbia River bank, 4 miles north of Revelstoke; and near Summit lake at the divide of the Columbia range, as already noted (Plate XIV). At all four localities the formation is rather strongly injected by granitic dykes and sills and the metamorphism of the sediments is at least partly magmatic in origin. The abundance of titanic acid, as represented in the titanite formed in the calcareous beds, and the feldspathization of the beds find explanation on this view of the metamorphic process.

SALMON ARM FORMATION.

Intense metamorphism, largely controlled by granitic heat, is still more conspicuous in all the observed exposures of the Salmon Arm schists (Map 143,A). Their relation to the underlying Chase quartzite is very clear in the type section of Shuswap village. The formation is there composed of coarse-grained mica schists which are often highly garnetiferous and are interrupted by occasional beds of micaceous quartzite. In this section the top of the formation does not appear, but at least 1,500 feet of beds appear to be present. On the shores of the Salmon Arm of Shuswap lake, the visible thickness is greater—at least 1,800 feet—but in this case the lower contact, with the Chase quartzite, was not identified At no other section was the whole thickness represented.

The principal rock type in the formation is a garnetiferous muscovite-biotite-quartz schist, of silvery to greenish-grey colours. The micas often form parallel growths; muscovite is usually the more important of the two, but some types are true biotite-quartz schists. The garnets are, as usual, poikilitic, and they form the nuclei of knots developed in the schist. Orthoclase or other alkaline feldspar and plagioclase in small grains are relatively rare accessories. In a more quartzitic phase, orthoclase becomes important and muscovite is practically absent; titanite and epidote are accessory minerals. Among the numerous sills and dykes satellitic from the Little Shuswap granite body, two other rock types were observed in the formation, a biotite-epidote-quartz schist and a hornblende-quartz schist. The amphibole is of acicular habit.

The whole assemblage of coarse, glittering schists is strikingly similar in field habit to those forming the contact aureole about the granite stocks at Monk creek in the southern Selkirks, and here also the intense metamorphism is best explained as due to the thermal action of neighbouring or directly associated intrusive granite.[1] Throughout the Chase-Shuswap section, this thermal metamorphism has notably transcended and quite obliterated the effects of the older regional metamorphism, which has affected the entire Shuswap series.

In the section on the north shore of Salmon arm, granitic injections become quite rare as the upper contact of this schist formation is approached. Accordingly, its beds are much finer in grain and are to be classed as true phyllites. The mica is of sericitic habit and the quartz grains are generally less than 0·1 mm. in diameter, as contrasted with those in the thermally metamorphosed phases, with diameters reaching 2 mm. As one passes downward in the section well exposed on Bastion mountain, the phyllites gradually become coarser in grain, while granitic sills are seen to increase in number; until, near the foot of the mountain, the schists rival in their coarse crystallinity those at Shuswap village. In both sections orthoclase becomes locally so abundant a constituent of the schists as to suggest that they have been somewhat feldspathized by the intrusive sills.

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[1] Cf. Memoir No. 38 of this Survey, 1912, p. 299 and Pl. 27.

SICAMOUS FORMATION.

In the uppermost hundred feet the Salmon Arm schists become increasingly charged with limestone beds, thus indicating a transition to the conformably overlying Sicamous formation. This member has three principal outcrops in the area traversed. That at Sicamous itself probably represents the eastern end of the band which follows the southern slope of Bastion mountain where a complete section of the formation is well shown (Plate XV; Map 143,A). North of Canoe point its average dip is about 45° to the north-northwest. At the high bluff 9 miles to the southeast, the dip averages 25° to the northwest. The mean calculated thickness is here 3,200 feet. Much greater thickness was calculated from the section at Blind bay but the difference is likely to be due to fault-duplication in the latter section. Rocks tentatively referred to this formation crop out on the shores of Shuswap lake opposite Quartzite point and in Dyke bay. Those outcrops apparently form a continuous band, but it cannot represent a complete section.

The dominant rock of the formation is an impure, schistose limestone of characteristic bluish grey to dark grey colour. Most of the specimens effervesce violently with dilute acid; in them the carbonate material must be calcitic and low in magnesia. It is believed, however, that some beds are strongly magnesian. The grain varies from fine to medium, the carbonate individuals seldom surpassing 3 mm. in length. Generally a few quartz and pyrite granules are accessory, but the chief impurities are carbon and sericite (or talc ?). The characteristic dark colour is given by disseminated carbon dust which appears in practically all of the limestone. The concentration of this substance in thin layers parallel to the bedding planes is partly responsible for the marked fissility of the rock. It was observed that where the carbonaceous matter is specially abundant the rock is notably friable in all directions, a property likewise characteristic of the carbonaceous limestones of the Beltian system and clearly due to the poor cementing quality of the impurity. For the rest, this property is explained by a similar, filmy development of the sericitic mineral. This is often so abundant that the rock merits the name, calc-schist. Throughout, the formation has been recrystallized but in no case was the schistosity seen to cross the bedding at an appreciable angle.

The attitude of the bedding was generally clear, either because of original variations in the limestone itself (carbon content, etc.), or because of the common intercalation of thin, more siliceous layers. Many of these are true phyllites or sericite-quartz schists; more rarely they are talc schists or talc-chlorite schists. At the foot of the bluff about 1 mile east-north-east of Sicamous, a lens of impure graphite, one-half inch in thickness, was found in a bedding plane.

Comparatively few granitic sills or dykes were discovered in the Sicamous formation and those actually seen are all quite thin. The limestone has evidently been little affected by the thermal metamorphism which has so conspicuously affected the underlying formations. Yet it is certain that the limestone *is* cut by some of the granitic injections which swarm so wonderfully in the Salmon Arm schists and older members of the series. The fissility of the Sicamous formation implies its easy injection and it seems probable that, for some reason, the granitic magma locally had difficulty in rising to this level in the Shuswap series.

Bastion Formation.

Toward its upper contact the Sicamous limestone becomes generally more charged with interbeds of phyllite. These mark a transition into the conformably overlying Bastion formation. Though this is one of the thickest members of the Shuswap series, it was nowhere found in good exposure and its thorough description is still impossible. It is named from the long ridge called Bastion mountain, which is capped by the formation.

The lower part of the formation is chiefly composed of phyllites of habit like that of the Sicamous phyllite. Interbedded with them are several beds of white to dark grey or blackish limestone, which is generally more massive than the Sicamous limestone but in other characteristics very similar. In the upper part of the formation, beds of sericitic quartzite and of dolomitic metargillite also interrupt the phyllites. At several horizons, ranging from near the base upward, thick zones of talc schist, chlorite schist, and epidotic or zoisitic schists bearing quartz and chlorite were also observed. At least some of the latter beds are to be regarded as of igneous origin but whether they are intrusive sills or extrusive lava flows or tuff beds could not be determined. As in the still younger Adams Lake formation, the basic eruptives have been regionally metamorphosed with a thoroughness never before matched in the writer's experience. Neither in the outcrops nor in thin sections has a single trace of the original rock structures been preserved. With singular monotony each of these basic zones exhibits perfect fissility which is the external sign of complete alteration.

Inasmuch as a large part, if not all, of these basic materials may represent intrusive sills, the true thickness of the Bastion sediments cannot be stated. The total apparent thickness of over 5,000 feet may be considerably too great for this member of the Shuswap series.

Schistose rocks provisionally referred to this formation were mapped on the eastern shore of Shuswap lake, south of Quartzite point (Map 143, A); in a small area east of Notch Hill station; and about the southern end of Adams lake, as well as along the outletting Adams river. In all these cases the exposures are poor and the structural obscurity great. None of the sections is complete, so that the writer was baffled at each attempt to define the Bastion formation in terms of the exact succession and composition of its beds. The most favourable locality for future study of its stratigraphy is probably the area north of the band of Sicamous limestone in Bastion mountain.

Tshinakin Formation.

On the Shuswap map sheet Dawson coloured, as of Carboniferous date, two areas of limestone, one crossing Adams lake and the other situated near the Cinnemousun narrows of Shuswap lake. In the legend he expresses doubt as to this correlation and adds: "If correctly referred, it is probable that the beds immediately underlying them [the limestones] at these places also belong to the Cache Creek [Carboniferous] rather than to the Adams Lake series, from which, however, it is now impossible to separate them on account of the great metamorphism they have suffered."

The present writer is convinced that these limestones are pre-Beltian in age and regards them as forming an important member of the Shuswap series. The limestone itself has a distinctly different habit from the equally metamorphosed Carboniferous limestones. None of the sediments regularly associated with the Cache Creek limestone, dark-coloured quartzites, and argillites are found in either of the lake sections. And, lastly, the bedded rocks conformably underlying and overlying the older limestone as well as the limestone itself (Cinnemousun locality) are cut by intrusive aplite, pegmatite, and typical orthogneisses of exactly the same character as those now proved to belong to a pre-Beltian date of eruption. This older limestone, together with intercalations, has been named the *Tshinakin formation*, from a creek running along its strike and emptying into Adams lake (Map 143, A).

The only known complete section of the formation is that on Adams lake. There Dawson's mapping was confirmed, but time failed for a retracing of the limestone throughout its 15 miles of outcrop. On the western shore of the lake the exposures are good and the following section was constructed.

Top conformable with Adams Lake greenstones.

	Thickness in feet.
Upper limestone	1,500
Phyllitic metargillite	800
Lower limestone	1,600
	3,900

Base conformable with schists of the Bastion type.

The strike here averages N. 75° W. and the dip about 48° northward; at the lake shore the total width of the outcrop is somewhat more than a mile.

The lower limestone is generally massive, but at intervals of 20 feet or more is interrupted by schistose zones. On the fresh fracture the rock—a true marble—is cream-coloured, yellowish white, or bluish grey, rarely pure white. It weathers to a buff tint or, where affected by soil or moss solutions, to a bluish grey. Different specimens effervesce freely to moderately with dilute acids, indicating variation in the magnesian content; the rock seems to carry some magnesium carbonate at all horizons. The grain is fine, with average diameters ranging from 0·15 mm. to 0·25 mm. Unlike the Sicamous limestone, this rock ca··ies little impurity. In one thin section a few quartz granules, about 0·05 mm. in diameter, were observed. Carbonaceous material is nearly or quite absent throughout the formation. Micaceous impurities, so characteristic of the Sicamous formation, were seen only in very rare intercalations of chloritic calc-schist and in the thin phyllitic beds which are more numerous near the upper contact of this lower limestone. The phyllites undoubtedly represent siliceous sediments and their presence, together with the other field facts, made the position of the original bedding in the marble quite clear. A few veins of calcite crystals, reaching 5 cm. or more in diameter, were seen to cut across the stratification. These crystals are strongly bent and fractured, indicating deformation after the veins were developed, presumably at the time when the strata were upturned. The metamorphism of the original beds into marble is, however, to be credited to antecedent simple burial, in a region then characterized by a steep thermal gradient (See page 42).

Conformably overlying the lower limestone is a band of grey phyllite, estimated to be 800 feet in thickness. It is calcareous, becoming a true calc-schist in a phase which passes into the upper limestone. The rock is similar to that forming interbeds in the limestone proper.

The upper limestone is essentially like the lower one, the only difference noted in the field being a possibly greater proportion of schistose beds interrupting the massive marbles.

The exact place of the Tshinakin formation in the Shuswap series cannot be definitely stated. Owing to bad weather and other conditions it was impossible to make a thorough study of the adjacent bedded rocks. Conformably beneath the lower limestone is a great series of phyllites, with thin interbeds of dark, carbonaceous limestone, the whole assemblage being extremely like that in the Bastion formation. During the time offered in the field these schists could not be traced into relation with any other recognized member of the series, and their correlation with the Bastion schists rests on a purely lithological basis. Here, as at other points, the table showing succession in the Shuswap series needs revision after much additional field work.

The limestone occurring 2 miles southwest of Cinnemonsun narrows (Plate XVI) is more massive than the average Tshinakin rock, but is otherwise so similar that it has been provisionally referred to the same formation, corresponding more nearly to the lower limestone on Adams lake. The grain is here decidedly coarser, with diameters reaching 3 mm. Wherever tested, the magnesia content is quite low and commercial experiments have shown that the rock makes excellent lime and plaster. The microscope shows an extreme freedom from siliceous or other impurities in the carbonate rock, except in the lowest exposed beds, which carry disseminated quartz and carbonaceous granules.

At least 700 feet of limestone is represented in this section. The failure of the upper two members of the formation is explained by postulating a fault, as shown in the map (Map 143, A).

Adams Lake Formation.

On Adams lake the upper Tshinakin limestone is directly and conformably overlain by an assemblage of bedded rocks which in part represent those included by Dawson in his "Adams Lake series." His description of the series, given in the legend of the Shuswap map sheet, may be quoted:

> "This and the underlying Nisconlith series are classed as Cambrian. Their stratigraphical relations are well seen within the limits of this map-sheet, but they have yielded no fossils, the age assigned depending upon the fossiliferous

series in the Rocky Mountains, with which sections in the Selkirk Range form an intermediate and connecting link. (Kamloops Report, p. 30 B). The Adams Lake series consists almost entirely of altered volcanic materials. Where best displayed, on Adams and Shuswap Lakes, it comprises a great thickness of chloritic, feldspathic, sericitic, and sometimes nacreous schists, with occasional argillites. In the lower part of the series the schists are generally grey, in the upper usually green. The northern edge of the grey schists, crossing Adams Lake north of Skwa-am Bay, runs to the forks of Scotch Creek and reappears in the east part of Shuswap Lake nearly opposite Quartzite Point; but it is not everywhere well defined. Irregular beds of limestone occur in the upper part of the series, but no attempt has been made to define these on the map. The schists have resulted from the dynamic metamorphism of more massive volcanic rocks, into which they can be traced. The same rocks are seen in a partially altered condition, as schistose diabases and schistose diabase-agglomerates, in the belt which follows Louis Creek and reaches the South Thompson. The grey schists appear to be derived chiefly from the agglomerates. The rocks near Adams River are notably massive and show little evidence of pressure. Between Seymour and Anesty Arms of Shuswap Lake, the rocks assigned to this series (not without doubt) are very greatly altered and consist largely of micaceous, hornblendic and gneissic schists."

The recent field work has led to important changes in interpretation. The present writer regards as of pre-Beltian age the whole group mapped by Dawson with the colour of the "Adams Lake series." That part of it which conformably underlies the Tshinakin formation on Adams lake is here tentatively considered as belonging to the Bastion schists. The part conformably overlying the Tshinakin limestones on Adams lake is separated under the name "Adams Lake formation." A third part, outcropping on the shores of Shuswap lake and elsewhere, is coloured on Map 143, A as greenstone schist of uncertain origin and relation.

The Adams Lake formation includes the youngest recognized bedded rocks of the Shuswap series. It consists chiefly of green schists derived by metamorphism from basic eruptives. At several horizons these schists carry thin intercalations of limestone and quartzitic schists. The sediments clearly indicate the position of original bedding, which, where observed, is parallel to the well-marked schistosity of them and of the adjacent greenstones. For more than 5 miles along the northwest shore of Adams lake, from the Tshinakin limestone band northeastward, these rocks are continuous. Throughout this section the strike averages nearly N. 55°W. and the average dip is at least 45° to the northeastward. Though the top of the formation is not exposed, the apparent total thickness represented in the section is at least 20,000 feet. About 1 mile southwest of the mouth of Spapilem creek, the dip changes to the southwest and, in spite of local complexities, remains in that direction all the way to the contact of the great body of intrusive granite mapped at the head of the lake. This synclinal arrangement of dips probably means repetition and the youngest exposed bed of the Adams Lake formation is probably represented in the axis of the syncline. Dawson estimated his Adams Lake series to be 25,000 feet in thickness. On account of imperfect exposure and the relative homogeneity of the formation in the long section, it was impossible to determine the actual thickness of the rocks comprising it, but it is certain that it must be very great. A minimum estimate of 10,000 feet is assumed.

The most striking characteristic of the greenstones is their advanced metamorphism. Whether the dip is very low or as much as 70° or 80°, the schistosity is generally very perfect. The fissility is so great as often to cause real embarrassment as one attempts to reduce a piece of the rock to the standard shape and size for a hand-specimen. Nevertheless, the writer was not prepared, in the field, for belief in such complete metamorphism as is proved by the study of many thin sections under the microscope. In none of these was a single primary feature identifiable. Though the green schists are clearly derivatives of basaltic or allied basic eruptive material, neither field relations nor the facts learned from thin sections gave absolute proof as to the original structures of the primary rocks. It is probable, however, that Dawson was quite correct when he referred the latter to a volcanic origin. The grain of the schists is never coarse but it varies from bed to bed in just the manner expected in an intensely metamorphosed pile of volcanic ejecta. Dawson was more fortunate in being able to trace some of the schists into distinctly extrusive phases. In view of Dawson's wide experience with the formation, the writer believes it wisest to adopt his interpretation of these baffling rocks. However, some of them may be metamorphosed injections, sills, or even laccoliths.

The basic schists are lithologically very similar to standard phases of the Keewatin in eastern Canada. They are generally chloritic. Uralite, epidote, zoisite, and secondary quartz in ever-varying proportions are regular associates of the chlorite. Comparatively abundant crystals or granules of dolomite or calcite, titanite, leucoxene, and pyrite are the normal accessories. Not a certain trace of feldspar was observed in any of the thin sections—a fact which tends to suggest the extrusive, chilled character of the original igneous rocks. According to mineralogical constitution the metamorphic types actually found are: chlorite-quartz schist, uralite-chlorite-quartz schist, uralite-chlorite-epidote-quartz schist, dolomitic chlorite schist, and true amphibolite. Zoisite generally accompanies the epidote.

The prolific secondary quartz disseminated through the schists has a possible bearing on the origin of the dense quartzites of the Beltian and Cambrian systems, as noted on a later page. The quartz granules vary in diameter from 0·005 mm., to 0·1 mm., rarely to 0·2 mm. Generally the diameters average less than 0·05 mm.

Many quartz veins and lenses parallel to bedding cut the green schists. Some of these are powerfully sheared and otherwise deformed in a manner like that of the coarse calcite veins in the underlying Tshinakin formation.

The thin limestones interbedded with green schists are light to dark grey and fine grained, with an average grain diameter of about 0·5 mm. Wherever collected they seem to be magnesian but never ideal dolomite. In habit they recall the less carbonaceous phases of the Sicamous limestone. Thin layers of fine-grained mica schist and sericite schist, in the former case associated with such limestone, similarly recalled a common phase of the Bastion formation. Moreover, the green schists of the Bastion and Adams Lake formations are lithologically identical. Such repeated resemblances between the rock types tend to corroborate the structural evidence that the Adams Lake formation is truly a conformable part of the Shuswap series. The great similarity of this formation to the Keewatin rocks of the east is enhanced by the discovery of dolomitic chert interstratified with the limestone at one horizon. This chert carries thoroughly idiomorphic rhombs of dolomite.

Greenstones of Uncertain Age.

Highly schistose rocks of the same general quality as those composing the Adams Lake formation cover large tracts in the mountains surrounding the main lakes. Among the occurrences may be specially mentioned: those mapped at the lower end of Adams lake; an area touching Little Shuswap lake at its northern end; an area, the largest of all, extending 20 miles along Shuswap lake, from Adams river nearly to Cinnemousun narrows; and small areas mapped south of the narrows (Map 143,A).

Dawson mapped all o[illegible] with the same colour as that used for the Adams Lake [illegible]n, and it is indeed possible that his correlation is entirely just. Yet the present writer has been able to adopt it only by assuming enormously complicated effects of faulting or thrusting, whereby this youngest member of the Shuswap series could be brought into the observed relations with the Bastion, Sicamous, and still older members. In general these greenstones are conformable with the adjacent limestones, quartzites, or phyllitic schists, as if representing as many horizons of contemporaneous basic lavas. Some of them may have this origin, and it has been seen that the greenstones of the Bastion formation seem to be the results of volcanic action which later piled up the enormous mass of the Adams Lake formation. Prolonged study of these debatable green schists has, however, shown that their origin and correlation cannot now be stated, and it has seemed safer to map and review them under a separate caption indicating an important, unsolved problem.

Greenstones North of Little Shuswap Lake.

From the shore of this lake northward to Adams river, the new wagon road crosses an apparently continuous mass of greenstone cut by dykes apophysal from the Little Shuswap granite injection. The basic rock is comparatively massive but has many schistose phases. The planes of schistosity dip 20°-45° in a northwesterly direction, conforming with the bedding planes of an overlying group of phyllites, quartzites, and schistose, carbonaceous limestones mapped as belonging to the Bastion formation.

This thick mass of greenstone is conceivably of extrusive origin and contemporaneous with the Bastion sediments, but several facts rather point to its being intrusive. Wherever it outcrops the rock is nearly uniform in grain and it is generally massive. No sign of a distinct lava-flow or of a pyroclastic bed could be und. In several thin sections relicts of primary plagioclase were discovered and the rock certainly has the look of having been originally a diabase or fine-grained gabbro. At present it is a felted aggregate of chlorite, quartz, and epidote, in which feldspar, uralite, zoisite, green biotite, dolomite, secondary magnetite, and abundant titanite are locally concentrated in varying proportions.

In conclusion, it seems probable that all, or nearly all, of this greenstone is not volcanic but represents an altered injection or series of injections, of the sill or laccolith type. A similar origin may be tentatively postulated for the pod-like bodies of greenstone mapped about the outlet of Adams lake.

Greenstones on Shuswap Lake.

As shown on the map (Map 143, A), both shores of Shuswap lake, from the outlet to the narrows and beyond, are chiefly underlain by greenstones. In part these may be effusive lavas of the Bastion formation, but at several localities they are so massive and homogeneous as again to suggest an injected origin. This is particularly the case with large masses exposed at Notch hill; on the lake shore opposite Quartzite point; at lake shore exposures about 1 mile south and southwest of Cinnemousun narrows; at the shore 1 mile north of Canoe point; at different points on the shore east of Blind bay; and near the mouth of Manson creek. At these localities the usual perfection of fissility is not shown and the rock in large respective volumes has the habit of uralitized diabase or gabbro. As always in these pre-Beltian greenstones, the study of thin sections yielded no definite results in the matter of origin. The igneous rock has, in every case, gone over to the same felty aggregates as those above described. Though great care was exercised to secure the freshest possible material, not a single fragment of undoubted primary material, except very rare plagioclase, was found in the two score of thin sections prepared from the greenstones. Judging rather from the field impression, the writer is inclined to regard a considerable part of these obscure bodies of basic schists as derived from numerous sills and other true injections.

The dominant rock types are chlorite and talc schists, wi h or without large amounts of epidote, uralite, and zoisite. The list of accessories is also such as to show derivation of the greenstone from rocks chemically of basaltic composition.

Relation to the Adams Lake Formation.

Except in their more massive character locally, these undated greenstones are identical in field habit and microscopic characters with the Adams Lake schists. In neither rock group was an eruptive species demonstrated which originally could have been more acid than basalt or basic andesite. In both groups the astounding degree of metamorphism and its mineralogical products are the same. The one striking difference is found in stratigraphic position. Generally the greenstones of Shuswap lake are interbedded with sed'ments which appear to belong to the Bastion, Sicamous, or Salmon Arm formations.

While some of the basic masses may represent lava flows, it is possible that a large proportion of them are sills which were injected at these lower horizons during the long period of vulcanism which developed the Adams Lake formation. This conception is but a working hypothesis; its final testing must await further and very detailed work in the field.

Granites and Orthogneisses of the Shuswap Terrane.

The youngest pre-Beltian rocks found in the area traversed are intrusive granites and their gneissic derivatives. While these plutonic types are not all of the same age, there is no indication that any of them is older than the Adams Lake formation, and it is clear that all members of the Shuswap bedded series are cut by pre-Beltian granite. The area and volume of the plutonics are very great, so that they compose a large part of the visible Shuswap terrane. They form thousands of bodies, most of which are too small to be shown on the scale of an ordinary geological map. A half-dozen of the more extensive, well-individualized bodies are indicated on Map 143 A, and Map No. 1448. Much of the terrane is, however, composed of a complex of dominant granitic injections, generally thick sills separated by thin beds of metamorphosed sediments. Areas underlain by this kind of complex are shown with a special colour; in these it is the sedimentary bands which are too thin and too irregular to be adequately mapped on a small-scale reconnaissance map.

The chief mode of intrusion is that of sill or *lit par lit* injection (Plate XVII). The sills are literally countless. Some similar injections, while preserving concordant contacts, have swollen to the thickness of ordinary laccoliths and, in a few cases, they have also the moderate lengths and breadths of true laccoliths. Dykes of identical material are numerous; some of them visibly locate the channels through which the sill magmas flowed. On Adams lake, on Seymour arm, and along the railway between Craigellachie to Sicamous, three major bodies of continuous granite were encountered. These are all of batholithic dimensions and may be of batholithic origin, though as yet one cannot exclude the possibility that all three are due to laccolithic or chonolithic injection on a gigantic scale. The description of the plutonic rocks will begin with these greater masses.

Granitic Mass at the Seymour and Anesty Arms of Shuswap Lake.

This body was studied only along the lake shores, where it is known to cover more than 100 square miles. Judging from Dawson's map and from distant field-glass views it is probable that the actual area is several hundreds of square miles.

The mass is composite. The older and larger part of it is a gneiss, originally a common biotite granite often bearing hornblende; local phases approach quartz diorite. It is clearly intrusive. It encloses many blocks of the adjacent sediments and penetrates them in the form of numerous sills and dykes. The metamorphic aureole, along the southern contact at least, has a width of more than a quarter of a mile and perhaps more than half a mile. There the invaded phyllites become massive, hornfelsy, garnetiferous mica schists and paragneisses; the interbedded limestones are strongly silicated; diopside, orthoclase, microcline, and a mineral with the optical properties of olivine being abundantly generated. The feldspathization of the limestone extends more than 600 feet from the contact. The intensity of the contact metamorphism is as striking as that about many typical batholiths and in general the dominant rock appears to have batholithic relations. However, the available time for field work did not suffice to prove its essential cross-cutting nature, and it is safer to call it simply a "mass."

The rock varies in the perfection of its schistose structure, which is usually conspicuous and is apparently never quite absent. Regional metamorphism has developed abundant secondary biotite (rarely muscovite), epidote, zoisite, and secondary quartz, at the expense of the feldspar and hornblende. Orthoclase and medium to acid plagioclase are the original feldspars. The nature and proportions of the other original constituents, biotite, green hornblende, and quartz, are those of a most common type of granite.

This main body is cut by multitudes of aplite and pegmatite injections, generally dykes running in all azimuths. At Beach bay, on Seymour arm, and across the lake are exposures of a long body of white aplite, bearing a little biotite, but devoid of hornblende. It is stock-like in plan and it covers at least 3 square miles. This is of nature identical with the aplite of the dykes and it presumably also cuts the hornblendic orthogneiss. The aplites are intimately associated with the pegmatites and both are doubtless late differentiates from the magma from which the slightly older hornblendic granite crystallized. As usual, these salic differentiates show a greater abundance of more alkaline feldspars than that characterizing the main granite. Orthoclase is an essential in all these rocks, but the aplites, and yet more notably the pegmatites are rich in microperthite, microcline, albite, and acid oligoclase; the microperthite is specially prominent and in the pegmatites often forms crystals several inches in diameter. Muscovite is not as abundant as biotite, even in the pegmatite dykes. Considering their great number, the banality of the pegmatite masses here, as indeed throughout the Shuswap terrane, is noteworthy and certainly has petrogenic significance.

Granitic Mass at the Northern End of Adams Lake.

Owing to bad weather it was impossible to secure data sufficient for a comprehensive account of the still larger body of granite in which the upper part of Adams Lake valley has been cut. Dawson's map shows only the southern border of the mass, in an area measuring roughly 16 miles by 10 miles. After merely a very hasty examination, carried on with a small, open motorboat during a storm, the writer has but few notes concerning the mass. It appeared to be a common biotitic orthogneiss, with the same types of aplitic and pegmatitic associates as those just described in the body farther east. This old granite is surely intrusive, here cutting and heavily metamorphosing the Adams Lake greenstones and interbedded sediments for a distance of at least 1,000 feet from the contact. The aureole includes a massive, very tough, strongly garnetiferous hornfels derived from a basic (sedimentary?) schist, and enclosing a bed of garnet-bearing pyroxenite which was doubtless originally a limestone.

The southern contact runs roughly parallel to the strike o the invaded formation, suggesting that this granite is possibly a huge laccolith, but no more than a guess as to its structural relation is now possible.

Granitic Mass in the Sicamous-Craigellachie Section.

Poor exposure of the rocks and the ferocity of the locally famous mosquitoes of the Eagle River valley are responsible for incomplete information regarding the third principal body of orthogneiss, that crossed by the railway for 14 miles west of Craigellachie. Though nearly all the outcrops along that section are clearly those of originally granitic rocks, there are a few sedimentary beds which have the appearance of dividing the granites rather systematically, as if the latter were thick sills, homologous with those so clearly exposed east of Craigellachie. Again, more field work is required to test that hypothesis and compare it with the view that the granites represent a true batholith, either simple or composite.

The granites of this section, though unusually massive for the Shuswap terrane, are generally schistose and have clearly undergone regional metamorphism. Area for area, they are the most basic of all the Shuswap granites met with. Hornblende is usually an abundant mineral, sometimes being more conspicuous than the universal biotite. The ruling species are hornblende-biotite gneiss and biotite gneiss. In the more hornblendic phases quartz loses its importance and the rocks tend towards granodioritic (and even syenitic?) composition. All these rocks are cut by common aplites and coarse pegmatites in both sill and dyke form. The sills follow the schistosity of the invaded gneisses.

The sediments locally interrupting the plutonic rocks are always in thin beds or lenses; they include rusty paragneisses, crystalline limestone, and calcareous quartzite. The last is somewhat like the Chase quartzite.

Granite Laccolith (?) at Little Shuswap Lake.

This lake lies in a body of biotite orthogneiss which is intrusive into stratified rocks of the Shuswap series. Its apophyses were observed in the Salmon Arm schists and the Chase quartzite, as well as in the (intrusive?) greenstone north of the lake. On all sides the contacts of this old granite, which measures 8 miles by 3 miles, are roughly concordant and it appears to form a true laccolith. The prevailing strike of the body and of the enclosing schists is about N. 55°-60°E. The gneissic structure of the plutonic rock is regularly parallel to the bedding of the sediments and dips about 45° in a northwesterly direction. The orthogneiss on the northwest shore of the lake is continuous but the lower part of the body, exposed on the steep slopes southeast of the lake, carries many thin lenses of muscovite schist, muscovite-biotite schist, and biotite schist, typical of the Salmon Arm formation. These lenses preserve the gene[illegible]rike and dip and seem to separate sill-like portions of the intrusive which, perhaps, may best be described as a "divided laccolith.[1]"

The orthogneiss is itself cut by many intrusive sills of normal aplite, thick and thin. These lie in the planes of schistosity of the orthogneiss which must ha[illegible] been well foliated before their injection. On the northwestern shore of the lake, a 40-foot sill of coarse, non-schistose granite porphyry has a similar relation.

The rock species of the whole composite mass are those most common in the Shuswap terrane; the biotitic orthogneiss, itself almost aplitic, is unusually rich in microcline and microperthite.

Sill-sediment Complex.

The foregoing partial sketch of the Shuswap terrane shows that it is composed of many individual formations which may be separately mapped. Their exact order of age is known only in part, but the individuality of the recognized members is not to

[1] Cf. R. A. Daly, Igneous Rocks and Their Origin, New York, 1914, p. 74.

be doubted. There remains for discussion an important group of pre-Beltian rocks, forming a composite mass which cannot be mapped as either sedimentary or igneous. Granitic sills constitute the larger part of its volume but the intervening sediments or problematical schists are also essential. The whole forms a gigantic example of *lit par lit* injection and it has been coloured on Maps 143 A and No. 1450, as the "sill-sediment complex."

The largest area of this complex, where crossed by the railway, is that between Albert Canyon station and the Columbia river, a distance of 22 miles (Plate XVIII). The next largest area is that sectioned by the railway between Clan William and Craigellachie, a distance of about 18 miles. Smaller areas are mapped at intervals along the shores of Shuswap lake. Reconnaissance journeys to Arrowhead, up the Columbia, to Frog lake, to Vernon, and field-glass studies from commanding points suggest that the complex makes up more than 50 per cent of the entire Shuswap terrane. In many cases its boundaries are mapped quite arbitrarily, as it there passes insensibly either into the mapped "granitic masses" or into one or another of the mapped sedimentary formations of the terrane. The latter transition simply means that the granitic sills and dykes have so increased in number and volume as compared with the injections in the mapped sediments that a colour distinction is imperative.

The sills and dykes of the complex are exactly similar in kind to those which are found in the dominantly sedimentary areas. Their rock types include: white granitic aplite, aplitic biotite granite, granitic pegmatite, hornblende-biotite granite, hornblende g[illegible], two-mica granite, and their gneissic equivalents. This list names the species roughly in the order of decreasing volumetric importance. Aplites or strongly aplitic granite form more than half of the igneous rock, and coarse pegmatites are extremely abundant. The dykes are many but are completely overshadowed both in number and volume by the sills. The latter range in size from microscopic films to masses more than 3,000 feet in thickness and are exposed for miles along the strike. One of the largest examples is shown on Map No. 1448, just west of Albert Canyon station. In a 30-foot cliff southeast of Notch Hill station the writer counted thirty aplite and pegmatite sills, ranging from 6 inches to 2 feet in thickness (Figure 1). South of Mitikan siding, 6 miles west of Three Valley station, about 200 similar sills were counted in a cliffy bluff some 2,000 feet in

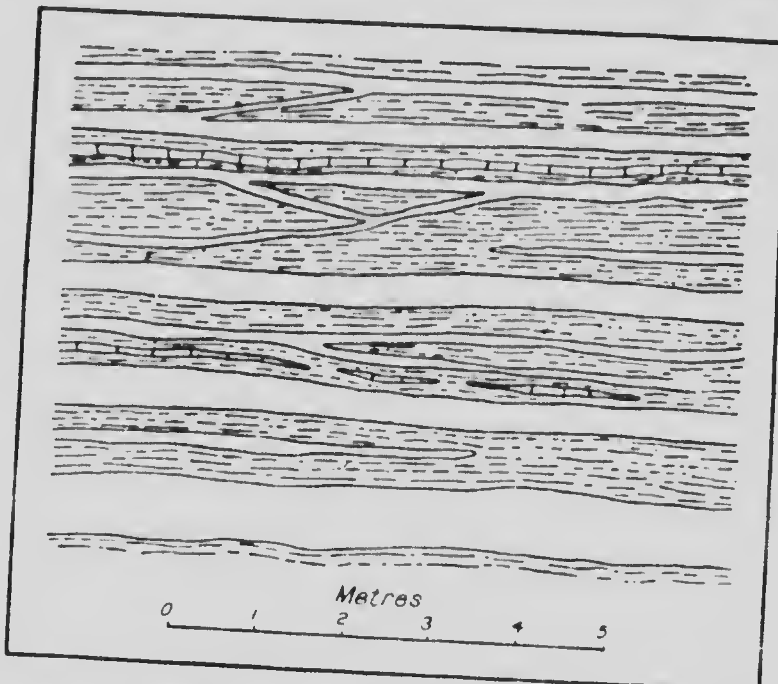

Figure 1. Diagram showing metasedimentary schists and limestone beds cut by aplitic sills; near Carlin siding.

height; they were of all thicknesses up to nearly 300 feet. These figures show typically the degree of granitic saturation characterizing broad stretches of the Shuswap terrane. The phenomenon, though not adequately illustrated, is suggested in Plate XVII.

The injections show systematic differences of age. It was observed that the oldest injections are generally hornblendic and comparatively femic. They are now hornblende-biotite orthogneisses identical in habit with the more schistose phases of the greater "masses" above described. A few, always thin, layers of amphibolite may represent still older injections, but, on the other hand, may be metamorphosed sediments. Nearly or quite contemporaneous with the hornblendic gneisses, in a few instances somewhat younger, are yet more abundant sills and dykes of biotitic orthogneisses, rich in epidote but free from hornblende. These two gneissic types are almost always highly schistose, with the schistosity planes parallel to the bedding of the adjacent limestone, quartzite, or micaceous sediments. The metamorphic structure must have antedated the injection of the aplite and pegmatite sills which, by countless thousands, follow such planes of schistosity. As a rule these younger rocks are quite massive or are far less schistose than their hosts.

The mineralogical content of the intrusives is like that of the composite "masses" already described. In the scores of type specimens and many hundreds of outcrops examined, no mineral aggregates but those of the commonest kinds of granites, aplites, and pegmatites were found. Garnets are very common in the aplite and pegmatite. Tourmaline and muscovite are rather uncommon in the pegmatites, which like the other rocks are remarkably monotonous in showing an essential content of quartz and alkaline feldspar, with a little biotite. This constancy of composition is like that of the dominant intrusives of "Laurentian" facies the world over. Here, as elsewhere in the Shuswap terrane, the more salic intrusives are rich in microperthite, microcline, and highly sodic plagioclase. The quartz of the pegmatites is very often bluish and iridescent. These colour phenomena are clearly due to a strongly cataclastic structure in the crystals. As we shall see, the quartz pebbles of the Beltian grits and conglomerates are similarly blue and iridescent, while their abundant feldspars are alkaline, including much microperthite and microcline. The inference is that the material of those sediments h s been partly derived from the Shuswap dykes and sills and that the cataclastic structure now seen in aplite and pegmatite was largely developed in pre-Beltian time.

The sediments of the complex have all been extremely metamorphosed and are now represented by coarse, glittering mica schists and paragneisses with thin, white, crystalline limestones (usually silicated and often feldspathized) and occasional quartzitic beds of considerable thickness. The micaceous types predominate. When feldspathic, they offer the familiar problem of distinction from orthogneiss. This distinction has been made in several instances and it appears to be a rule that the rusty gneisses of the complex are of sedimentary origin. The nearest allies of these sediments as a whole are, among the recognized bedded formations, the Salmon Arm schists and Tonkawatla paragneiss; and, as a provisional hypothesis, it is held that the sediments of the complex in the Columbia and Selkirk ranges date from horizons at least as low as the Salmon Arm schists. Yet some of the smaller areas of the complex adjoin extensive bodies of the Bastion and Adams Lake schists, and may be simply heavily injected equivalents of these. Observation shows that, where the granitic sills are greatly multiplied in the younger Shuswap schists, thermal metamorphism has converted those sediments or volcanics into as coarsely crystalline schists as those characterizing the sill complex elsewhere. Thus, as usual, high crystallinity cannot be used as a safe criterion in assigning a general date to the sediments of the complex.

Two bands of quartzite deserve special mention. They seem to have no equivalents in the Tonkawatla or younger formations. One of these is exposed on the steep slope north of Clan William station. It is a white, notably tough, glassy, very coarse-grained quartzite, bearing accessory orthoclase and biotite. More than 80 per cent of the rock is clear quartz, in large, intimately interlocked grains. At first this body, nearly 800 feet in apparent thickness, was taken for a very acid aplite, but a microscopic examination suggests that it is more probably of sedimentary origin.

The other band, outcropping at Quartzite point on Shuswap lake, is more clearly stratified and its sedimentary nature is unquestioned. It is a banded, white to grey, highly vitreous rock, extraordinarily hard and brittle. A thickness of at least 80 feet is exposed. It is underlain by tough, grey paragneiss of phyllitic habit, cut by many injections of aplite and pegmatite.

Origin of the Siliceous Sediments of the Shuswap Terrane.

As yet no one has found, in the Canadian Cordillera, rock formations definitely proved to be older than the Shuswap series, which itself appears to be a perfectly conformable group of rocks. These sediments originally rested on an extensive terrane, now not known in exposure. Its nature cannot, of course, be fully described, but at least one of its characteristics is to be read out of the constitution of the Shuswap series which, at many horizons, carries quartzitic beds. In spite of their advanced metamorphism, these were largely derived from normal sandstones, though some may conceivably be of chemical origin. In one bed from the Bastion formation the writer detected the structure of a true sandstone, with indication of the secondary enlargement of the original sand grains. A fine-grained, schistose conglomerate, with quartz pebbles, was seen in the schists at the lower end of Adams lake. The abundant phyllites and sericite-quartz schists of the series are derivatives of a potassic, feldspathic terrane. Taking all the facts together, it seems necessary to believe that the old land mass, from which the clastic Shuswap sediments were derived, was in part, at least, of granitic or gneissic character. We thus arrive at a conclusion which is like that already deduced by the students of the older Pre-Cambrian clastic rocks on other parts of the world. The earliest land surface of which we have knowledge, indirect as it is in each instance, was underlain by both quartzose and feldspathic rock. It is a justifiable inference that this rock had the composition of ordinary granite.

General Conclusions Regarding the Shuswap Granites.

Although no direct chemical study has been made of the acidic intrusives, their mineralogy shows certain facts which would simply be confirmed by many costly analyses. The older, more femic phase of the Shuswap granite (and its gneissic equivalents) is distinctly potassic and thus corresponds to the most abundant type of granite throughout the world. Just as clearly the aplites and pegmatities are more sodic, though always rich in potash. The contrast is shown by the very much greater abundance of typical microperthite and of sodiferous microcline and orthoclase in the younger, salic injections. Yet there is no reason to doubt the syngenesis of all, or nearly all, of these types. The hornblendic gneisses pass gradually into biotitic gneisses and both pass into aplites and pegmatites identical with those forming separate dykes and sills. The latter are younger than the dominant orthogneisses, but owe their origin to a concentration of certain elements from the orthogneissic rock or magma. Soda has thus been specially concentrated and, as so generally the case, its vehicle was the volatile matter "sweated" out of the older rock or magma. This higher alkalinity of aplite and pegmatite illustrates a law of widespread application in Pre-Cambrian terranes.

The Shuswap intrusives are, in other essential respects, of typical "Laurentian" habit. The tremendous development of aplites and pegmatites, the constant recurrence of the sill and *lit par lit* forms of injection, and the monotony of composition are all characteristics of the classic Laurentian of eastern Canada and of the older granites in Fennoscandia, etc. The conditions which led to the generation of highly salic granite and to its injection in sill form were special to the early Pre-Cambrian and have never been repeated on anything like the same scale in the later periods.

Metamorphism of the Shuswap Rocks.

The Shuswap terrane is essentially a very large mass of ideal crystalline schists, only partly exposed. On all sides it runs under younger formations and it is typical of Pre-Cambrian complexes generally. For the most part the original nature of each formation, whether sedimentary or igneous, has been determined, but the exact nature of the processes by which each has been completely recrystallized remains a matter of debate. Nevertheless, this terrane has certain elements of structure and conditions of exposure which are rarely elsewhere so favourable for the discussion of the metamorphic problem. The deep dissection of the terrane enables the geologist to observe in the three dimensions of space to a degree not matched in the Pre-Cambrian shields of eastern Canada and Fennoscandia. The relatively small amount of strong upturning and folding in the British Columbia pre-Beltian makes it possible to evaluate, better here than in any equal area known to the writer, the real importance of dynamic metamorphism in the development of crystalline schists. Another special advantage of this field is the presence of numerous limestone horizons which, at many critical localities, enable one to locate original bedding planes with practical certainty.

All authorities agree that elevated temperature and differential pressure (stress) are necessary conditions for the formation of crystalline schists.

Both conditions are obviously met at many igneous contacts, where true crystalline schists have been developed, though only on a comparatively small scale. Such alteration is well called *contact* metamorphism; sometimes it is called *thermal* metamorphism, to emphasize the dominant control of temperature, though no one using this expression would mean to deny the co-operation of heat in true dynamic action, that is, the shifting of one rock mass against another. It is sometimes called *hydrothermal* metamorphism, obviously without implying that water and heat are not actively engaged in other types of metamorphism.

Dynamic metamorphism has long been recognized as that set up by the movement of rock *masses* in the earth's crust, as in regions of strong deformation. That definition also emphasizes simply one out of several co-operating causes for recrystallization, among which are elevation of temperature, the activity of interstitial water, and mere burial under a heavy rock-mantle. In dynamic metamorphism the required raising of temperature is due to rock-crushing and depression of the rock by folding or faulting; the stress is usually developed tangentially with respect to the earth's curvature. It is essential that this stress is due to the shifting in relative position of large bodies of solid rock. If "dynamic metamorphism" also be used as the name for *all* recrystallization where movement is implied, as, for example, the movement of the molecules of intensely localized solutions, that expression includes all types of metamorphism and becomes useless. Since very strong crustal deformation at one locality generally means similar disturbance for a considerable area round about, dynamic metamorphism is also commonly called *regional*.

Some authors use the term "regional" in order not to take a definite position as to the cause of the large-scale metamorphism. Others use it expressly to signify that widespread metamorphism may be dynamic, or *static*, or both. Of late years "static metamorphism" has been coming into its own and an increasing number of field observers emphasize its real importance. Nevertheless, it is singularly ignored in text-books and in most memoirs on the basement complexes.[1]

Its essential idea is that recrystallizing stress is developed by burial and dead weight. This stress is vertical, radial, and not tangential with respect to the curved surface of the earth. The weighting may be due to sedimentation in a geosyncline, or to the accumulation of a volcanic cover, or to overthrusting. In all three cases there is movement of rock matter, so that, in a strict sense, the resulting metamorphism of the buried rock is also dynamic. But here the movement of rock masses is *preliminary* to recrystallization and not *pari passu* with it, as in true dynamic metamorphism. In the one case the rock movement is an *indirect* cause of metamorphism; in the other it is a *direct* cause. In the one case recrystallization is chiefly accomplished after the movement of rock masses has ceased and may continue during several major geological periods; in the other case recrystallization is chiefly accomplished during the movement of rock masses under tangential thrust, and seldom continues for more than a fraction of a major geological period.

Since, then, it is generally agreed that the term "dynamic metamorphism" is to be arbitrarily defined and is restricted in

[1] G. M. Dawson was one of the earliest writers to recognize static metamorphism. He was led to it while studying the Shuswap crystalline schists and he clearly anticipated the writer in an independent recognition of the principle. (See G. M. Dawson, Bull. Geol. Soc. America, Vol. 12, 1901, p. 64.)

meaning to that type where orogenic movement is in direct control, it is proper to use the term "static metamorphism" to designate the process of recrystallization under the quite different condition of simple deep burial. A synonym is "load metamorphism," which is a literal translation of Milch's "Belastungs-metamorphismus," which he introduced in 1894.[1]

Judd used the expression "statical metamorphism" to denote a type which has some of the features of load metamorphism. He pointed out the tendency to exaggerate the importance of "dynamic" metamorphism and showed that drastic recrystallization may take place through the application of high pressure without shearing. "The most potent agency

> by which change is effected consists in the penetration of the whole mass of the rock by various liquid or gaseous solvents. It is for the whole group of such changes—of which 'schillerization' is a conspicuous example—that I propose to employ the term *statical* metamorphism."[2]

Its effects show the operation of "chemical and crystallizing

> processes which certainly go on at great depths, and under enormous pressures, even when the rock-masses do not yield to the pressures and thus become subjected to the movements which result in dynamometamorphic action. Such changes, resulting from pressures that do not effect movements in the rock-masses, may be appropriately called 'statical metamorphism'."[3]

Judd, like Milch, emphasized the essential role of water in making these changes, and Termier, in vigorous criticism of the extreme position of many advocates of dynamic metamorphism, has sought to explain the crystalline schists of the Alps as due to recrystallization under the influence of gaseous "colonnes filtrantes" from magmatic depths. Termier goes so far as to hold that dynamic metamorphism "does not exist."[4] Such an extreme conclusion suggests that, as so commonly, a formal,

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[1] L. Milch. Neu. Jahrb. für Miner. etc., B.B. 9, 1894, p. 121.

[2] J. W. Judd, Geol. Mag., Vol. 6, 1889, p. 246.

[3] J. W. Judd, ibid., p. 243.

[4] P. Termier, Compte Rendu du Congrès Géologique Internationale, Vienna, 1903, p. 581, and Stockholm, 1910, p. 588.

sweeping difference of opinion may arise largely as a matter of the definition of terms. It is quite justifiable to hold that *pure* dynamic action, that is, mere mechanical shearing, cannot form typical crystalline schists, but few authors have seriously held that it could. This adjective "dynamic" is still highly useful as it indicates the *controlling* factor among the many which are involved in this type of regional metamorphism. Water and other volatile substances are certainly important reagents in all types of metamorphism on the large scale. Such fluids may be just as abundant in the roots of a crumpled mountain mass as in the beds of a geosynclinal prism or in the contact aureole of an igneous intrusion. The special abundance of these reagents cannot be used as a necessary feature of static or load metamorphism.

In summary, dynamic metamorphism has two necessary features. It is *directly* due to orogenic movement and the stress involved is dominantly tangential with reference to the earth's surface shell. Static metamorphism has two necessary features. It is *directly* due to burial and the stress involved is radial. Obviously both may affect the same body of rock and the resulting complication may be further enhanced by the altering action of intrusive magma.

Such complication is so general in mountain cores and basements that it is highly important to have recorded those areas of the globe where pure types of metamorphism are illustrated. In eminent degree the Shuswap terrane and the adjacent Beltian rocks show the overwhelming dominance of load metamorphism.

Static Metamorphism.

Several facts of field observation prove conclusively that dynamic metamorphism, as above defined, cannot be held responsible for the existing crystallinity of the Shuswap bedded rocks in general, nor for the prevalent gneissic structure of the many sills, laccoliths, and larger "masses" (Plates XIX and XX).

Though these rocks are perfect types of the crystalline schists, their secondary planes, in metasedimentary and orthogneiss alike, nearly always lie rigorously parallel to original bedding. As already noted, the abundance of limestone horizons, from the Salmon Arm formation and sill-complex upward to the Adams Lake formation itself, makes it specially easy to discern the true bedding. When, in addition, layers of quartzite, sericite schist, phyllite, biotite schists, muscovitic schists, calc-schist, dolomitic schist, or even fine-grained conglomerate and graphitic lenses occur in regular alternation with one another or with limestone, this concordance is yet more clearly demonstrated. It was observed not only at all stratigraphic horizons, but also in practically all parts of the terrane, from Adams lake and the Thompson river to Albert canyon in the Selkirks.

A second principal fact is that the Shuswap rocks have been relatively little disturbed from their original position. Over broad individual areas the dips seldom surpass 15° or 20°. Numerous blocks, each several square miles in area, have dips less than 10°, with truly tabular habit. Good examples may be seen in the high cliffs at the summit of the Columbia range, along the section from Revelstoke to Arrowhead (27 miles), and in smaller areas on Shuswap lake. The average of the dips read in the terrane is about 35° and this is not likely to be the true average, since no special record was made in many sections showing much lower dips. Of special import is the fact that usually the crystallinity of the flat-lying beds is just as pronounced as in adjacent vertical or nearly vertical beds of the same horizon.

Again, the terrane shows a remarkable rarity of ordinary folds, such as are normal in orogenic belts. With the present field data it is not possible to declare the exact mode of deformation, but in general it seems to be that due to normal faulting with moderate tilting of the crust blocks. Conceivably, overthrusting was also a factor but no notable evidence of it could be secured. In short, the terrane is quite unlike the younger terranes, east and west, which illustrate enormous tangential compression on a first-class scale.

This reason alone makes it incredible that the existing crystallinity of the Shuswap series can be due to dynamic metamorphism, but yet more compelling is the nearly universal parallelism of bedding and schistosity in flat or gently dipping strata. As Milch and others have pointed out, such intense recrystallization must have occurred before the beds were upturned, even to the extent actually observed.

The problem is partly solved when it is recalled that there is no difference in physico-chemical principle between dynamic and static metamorphism. In both cases, stress and the influence of Riecke's principle are essential. It makes no difference to a feldspar grain whether the stress is directed radially or tangentially in the earth; if the temperature and other conditions are right, it will go over to quartz and mica, with the development of micaceous fissility at right angles to the direction of stress. If schistosity and true bedding are parallel over thousands of square miles, it becomes infinitely probable that the altering stress was vertical and antedates massive deformation of the schists.

To explain the intensity of this load metamorphism, special conditions must be assumed.

In spite of the fact that sills and intrusions are, in general, most abundant in the lower part of the Shuswap series, and have there added the effects of true contact action, it seems clear that the lower formations are somewhat coarser-grained than the upper. This is to be expected if their recrystallization has been due to static metamorphism, increasing with the load. Yet that the latter process is responsible for the complete recrystallization of even the youngest beds of the Adams Lake formation is as evident as in the case of any other member of the Shuswap series. To produce the effect one cannot assume an indefinitely thick cover on the Adams Lake formation at the time it was so altered. The lowest Cretaceous beds of the Cascade mountains or of northern California, though at one time covered by 30,000 feet of rock, are not crystalline schists. In general, Cambrian and later strata have not been completely recrystallized though buried more than 30,000 feet. On the other hand, nearly all flat-lying Pre-Cambrian sediments the world over have been metamorphosed, and it is practically certain that many of them were never buried 20,000 feet nor yet injected by igneous magma. A leading condition for the advanced recrystallization in Pre-Cambrian terranes seems to have been a Pre-Cambrian thermal gradient for the earth which was notably . eeper than the gradient ruling in Palæozoic and later times.

Another condition was unquestionably the water and other volatile solvents originally present in the Shuswap rocks. In part these were "connate" waters, trapped in the original deposits. In other part they were of magmatic origin, forming an integral part of each granitic, aplitic, or pegmatitic sill. These magmatic fluids entered the sediments and locally added the effects of contact metamorphism to those of static metamorphism. Yet great volumes of the gases must have remained in the igneous bodies themselves after consolidation and aided in their slow recrystallization, which was also hastened by the solvents diffusing into the sills and dykes from the sediments.

We have seen that the recrystallization of the granites is usually thorough and the marked schistosity of the orthogneisses very generally lies parallel to bedding. This structure is best exhibited in the sills but it was seen also in the wider dykes. Though such dykes are nearly or quite vertical, their schistosity is still parallel to the bedding of the adjacent sediments. Figure 2 is a copy of a field sketch showing both structures lying nearly horizontal. It is an illustration of a leading fact on which the belief in static metamorphism is founded. No other explanation seems possible. The schistosity of the dyke is clearly not of dynamic origin.

Whatever additional factors might be considered, there can be no doubt as to the profound influence of static metamorphism in the Shuswap terrane. In the writer's opinion, it is often dominant in large areas of the Pre-Cambrian shield of eastern Canada. Arnold Heim describes the tabular structu of the orthogneisses of Greenland, suggesting another example on a large scale.[1] It is probable, in fact, that the Pre-Cambrian complexes are so highly crystalline not merely because of a specially steep thermal gradient in early times. In the very long period during which a post-Cambrian batholith cooled after crystallization, its temperature was still high and its minerals were

[1] A. Heim, Medd. om Grönland, Vol. 47, 1911, p. 180.

subject to vertical stress. Yet most of these younger masses are massive and not seriously affected by the static metamorphism which is so manifest in the orthogneiss sills of eastern and western Canada. The contrast may in part be due to the failure of sufficiently deep erosion in the post-Cambrian batholiths, but

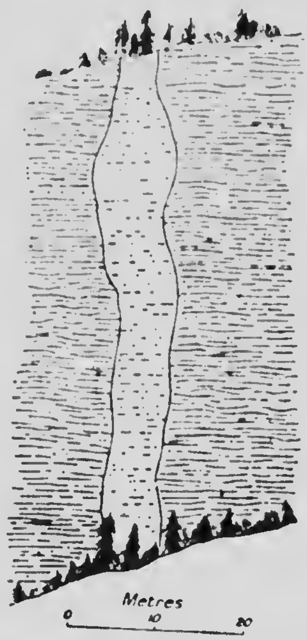

Figure 2.—Cliff section of aplitic dyke cutting paragneiss (?) at Clan William. The dyke shows nearly horizontal schistosity, parallel to that in its country rocks. All the rocks have undergone static metamorphism since the intrusion of the dyke.

this is not likely to be a sufficiently general explanation. The enormous development of pegmatite and aplite in the Pre-Cambrian complexes directly suggests that the early granitic magmas were specially rich in volatile components. Though these partly escaped in the formation of sill, dyke, and batholith, the gases remaining in the crystallizing bodies must have been comparatively abundant. Under the combined influence of crustal load and a high thermal gradient, these residual gases functioned as the solvents leading to thorough recrystallization, with schistose orthogneiss as the final product. On the other hand, the younger batholiths are largely re-fusions of Pre-Cambrian granite and orthogneiss and should necessarily have a lower content of volatile matter, since each re-fusion means a new opportunity for the escape of juvenile gases.

In conclusion, the hypothesis that the early Pre-Cambrian granite magma was hydrous to a degree never again reached on such a scale, seems to account for principal features of the Shuswap and similar terranes. These are: (1) the strongly salic quality of the granitic injections; (2) the unrivalled abundance of pegmatite; (3) the common transformation of the intrusives into orthogneisses, especially those intrusives which carried enough iron oxide and magnesia to form biotite; and (4) the prevalence of sill and *lit par lit* injection, which is aided both by preliminary static metamorphism and by high gas-tension in the injected magma.

In passing, it may be remarked that many of the aplite and pegmatite injections may not be phases of primary magma but rather the products of local "selective solution" at levels characterized by much occluded water and by temperatures moderately high but too low for anhydrous fusion.

This whole matter is affected by a leading consideration which cannot be quantitatively stated but is worthy of attention. The "freezing" of a batholith is *progressive*, beginning at the roof and wall. The new, solid shell of granitic rock more or less perfectly retains the gases slowly concentrating beneath as crystallization of the magma goes on and diffusion of the gases to the upper levels (loci of low pressures) continues. The same principle would apply to the history of the earth's primitive crust. Does a foliated structure characterize the staple rocks of the early Pre-Cambrian because of such primitive subsurface concentration of gases from a "sweating" planet? In the presence of the gases, either occluded or in solid solution, the mineral aggregates, which were in equilibrium under uniform pressure immediately after original crystallization, were not in equilibrium under the new, vertical stress, and slowly changed to the stable combinations of orthogneisses.

Dynamic Metamorphism.

The static alteration of the Shuswap rocks appears to have been essentially completed before they were anywhere strongly deformed. The only ascertained pre-Beltian movements of importance were the secular deepening of the Shuswap geosyncline and the changes of level suffered [illegible] strata during sill injection. In post-Cambrian time t[illegible] [illegible]lex terrane was locally broken and its blocks were [illegible] [illegible]ositions showing approximately the Cordilleran n[illegible] [illegible]utheast strike. During this deformation, narrow zones [illegible] [illegible]nd granite were sheared and partially recrystallized und[illegible] [illegible]ol of tangential stress. At many localities, though b[illegible] [illegible] gene[illegible] [illegible]er the terrane, this second schistosity d[illegible] [illegible]mor-phism is superposed on the older schi[illegible]

The best examples were seen in [illegible] tal[illegible] [illegible]oritic schists so abundantly exposed on Shuswap lak[illegible] [illegible]XXI is a photograph of talc schist at Blind bay illustrating "strain-slip cleavage" dipping 70°–80° north-northeast and crossing an older schistosity (typical of static metamorphism) dipping 25° in the direction N. 20° W. On the western shore of the lake, 2·5 miles north of Quartzite point, a large outcrop of very fissile chlorite schist shows a similar crossing of two schistosities; in this case abundant talc and magnetite have been generated in the planes of the younger schistosity, while chlorite and biotite are essential in the parts outside the zones of shearing. A similar phenomenon is repeatedly illustrated in the phyllites and sericite schists.

The orthogneisses have also been doubly metamorphosed, with occasionally remarkable results Two illustrations may suffice.

One hundred yards west of Victor lake, near the divide of the Columbia range, a small injection of biotite granite, apparently part of a 600-foot sill exposed north of the railway, has been energetically gripped in the Cordilleran mountain building and changed to a very conspicuous banded gneiss. The sill dips 10°-15° in the direction N.80°W., thus conforming with underlying limestone and quartzite. Where it has not been sheared, its schistosity conforms with the sill contacts. At the railway shear-zones appear, dipping at high angles to the southwest. Parallel to these zones or in them are thick schistose aggregates of mafic minerals, chiefly biotite. The glittering black bands reach 4 inches in thickness and were exposed more than 20 feet along their strike. Between them are much thicker, light coloured, more massive bands, composed essentially of quartz and feldspar, with a little biotite visible in the hand specimen. A rough measurement of volume percentages for typical bands gave the following result:

	Dark band.	*Light band.*
Biotite	65	8
Orthoclase	15	30
Oligoclase	—	20
Quartz	5	40
Titanite	5	—
Apatite	2	—
Uralite	5	—
Sericite, zircon, and magnetite	3	2
	100	100

Unfortunately, no specimen of the unsheared granite was collected for comparison, but it is a normal type of biotite granite. It was estimated that the black bands represent about 10 per cent of the total volume of the visible banded phase. Their minerals are almost entirely devoid of strain phenomena and they have evidently crystallized after the shearing. On the other hand, all, or nearly all, of the mineral grains in the light bands are cataclastically affected, with abundant "strain shadows" in the polarized light.

The origin of this banded gneiss seems clear. The light bands represent the original granite, thoroughly crushed and then deprived of most of its femic material which, with some of the orthoclase, migrated into the major shear-zones and there formed a new rock. The whole process is an effect of dynamic metamorphism.

A similar case was found in a banded gneiss outcropping along the eastern shore of Frog lake, again with a Cordilleran strike for the bands. Several examples in post-Cambrian batholiths were found during the 49th Parallel survey.[1]

Contact Metamorphism.

The alteration of the Shuswap series by pre-Beltian intrusives presents two phases, reference to which has been made on earlier pages.

The large "masses" (batholiths?) of granite and orthogneiss have developed broad aureoles of normal contact metamorphism. In these the schists have become more or less massive, tough, and hornfelsy; the limestones are silicated, sometimes to a remarkable degree; and feldspathization is common. The phyllites become garnetiferous, often coarse, mica schists. The greenstones, chlorite schists, and uralite schists become amphibolites and hornblende gneisses.

In the second phase of contact action the original schistosity (due to static metamorphism) is not so much obliterated, and the hornfelsy habit does not characterize the affected formations. Yet, recrystallization is here just as manifest, with a resulting coarseness of grain distinctly greater than that in the aureoles just noted. This phase is best illustrated in the "sill-sediment complex" and in the lower recognized formations of the Shuswap series where penetrated by many granitic sills. These injections did not seriously disturb the conditions of vertically-directed stress which characterized the bedded rocks. On account of their number they did affect the general thermal gradient over wide areas; hence the chief reason for the existing high crystallinity of the inter-sill strata. Magmatic emanation co-operated with this purely thermal change, but throughout vertical stress controlled the recrystallization. Coarse, glittering mica schists, well developed paragneisses, and relatively coarse and crystalline limestones, schistose to massive, were the chief products. It is this phase of the terrane, with its abundant

[1] Memoir No. 38, Geol. Surv., Canada, 1912, pp. 380, 441, and 524, where this type of metamorphism is discussed.

sills and *lit par lit* injections, which most insistently recalls the standard crystalline-schist complexes elsewhere.

Thus, static and contact metamorphism, here as so often, pass into each other—a transition naturally to be expected, since each is partly thermal in origin.

Structural Features.

As above detailed, the recrystallization of the Shuswap series took place when its strata lay flat. That attitude was not essentially disturbed by the injection of the countless sills, which themselves were statically metamorphosed to a great extent. Some of the later aplites and pegmatites are quite massive; these have escaped recrystallization partly because of their chemical composition, for they do not carry the materials necessary to the formation of abundant biotite.

Since this metamorphism under the vertical stress of load, sediment, volcanic layer, and sill have been more or less deformed. With tabular blocks are now associated, in the terrane, numerous "homoclines" whose mutual relations are not yet thoroughly understood.[1] By the best working hypothesis, they are tilted blocks separated by normal faults. Excepting minute crumples, folds are very rare, indicating a primary structural contrast of this terrane with the Beltian-Cambrian terrane of the Selkirks and Purcells, or with the Palæozoic-Mesozoic terranes west of the Shuswap lakes.

A further strong contrast with the younger elements of the

[1] For convenience the word "homocline" will here be used as a general name for any block of bedded rocks all dipping in the same direction. The writer is inclined to follow the general, though not universal, usage which defines "monocline" as a one-limbed flexure in strata, which are usually flat-lying except in the flexure itself. A "homocline" may be a monocline, an isocline, a tilted fault-block, or one limb of anticline or syncline. The field data in hand are often insufficient to show which of these categories is represented in a given orographic block, the only ascertained element of structure being a dip persisting in one direction. Until further, conclusive observations are made, it is well to have a non-committal name, such as "homocline." This term can also be advantageously used to refer to one limb of an anticline or syncline, even when the complete form of the fold has been determined.

Canadian part of the mountain chain is found in the strike directions. Both east and west of the Shuswap terrane, the strike runs systematically from S.25°-50°E. to N.25°-50°W.—in the general Cordilleran trend. The strikes recorded in the basement terranes generally range from east-west to northeast-southwest. Excepting for certain narrow zones the average strike runs from N.70°E. to S.70°W., and thus almost at right angles to the Cordilleran trend. In the exceptional zones, which usually illustrate dynamic metamorphism, the strike is clearly Cordilleran.

It will later be shown that the upturning of the Shuswap beds in part dates from post-Beltian time. Whether the transverse strikes of the basement rocks were then developed or represent a pre-Beltian, post-Shuswap period of true orogenic movement cannot be declared.[1] *A priori* some of the visible deformation should be referred to the late Mesozoic and Tertiary revolutions which have affected the Beltian and younger formations. During these periods of strong compression, most of the visible Shuswap terrane escaped the folding so powerfully affecting the younger rock systems. Only in the above-mentioned narrow zones was the Cordilleran trend imposed on the basement rocks. Yet each post-Palæozoic revolution was certainly closed by a stage of normal faulting, and it is possible that the prevailing structure of the basement terrane is due to such secondary collapse after the strong compression of its now folded cover. This possibility suggests an important question in the dynamics of mountain-building: in the secondary collapse and final gravitative adjustment of a folded mountain chain, are transverse faults and transverse, tilted fault-blocks normally developed as dominant structural features? If so, the basement, along with the overlying folded shell of the earth's crust, should be thus faulted. Herein is perhaps the chief ground on which the leading trends in the Shuswap terrane are to be explained.

The failure of strong folding and other evidences of intense tangential compression in the basement rocks is one of the most

[1] Dawson was inclined to believe that the Shuswap rocks were not seriously deformed until post-Cambrian time (Bull. Geol. Soc. America, Vol. 12, 1901, p. 64).

significant facts won during the reconnaissance. In this respect the contrast with the younger formations is remarkable. The extent of the contrast is mirrored in the statistic of average dips. The average recorded dip in the Shuswap terrane is less than 35°. The averages for large typical areas of the Albert Canyon division and Glacier division of the Selkirk series (Beltian-Cambrian), for the Carboniferous, and for the Triassic series—all in the area here described—are respectively about 38°, 59°, 73°, and 64° The comparatively slight deformation of the basement rocks is not to be attributed to their greater rigidity, which might be conceived as a cause for their refusing to buckle under orogenic pressure of the same order as that applied in the folding of the Beltian and younger formations. As a matter of fact, the bedded Shuswap rocks are exceptionally fissile and weak; over large areas they are but little strengthened by sill injections. The only just conclusion seems to be that the earth-shell engaged in the post-Shuswap orogeny was only a few miles, perhaps 6 or 8 miles, in depth. *Over* the Shuswap terrane this shell was thrust and crumpled; its underlying basement could not, however, escape the normal faulting incidental to the secondary collapse of the mountain chain.

Age and Correlation.

The distribution of the Shuswap rocks, as shown in Map No. 1458, was chiefly determined by Dawson, who states that they extend northward to the Finlay river, between the 56th and 57th parallels of latitude. They do not appear anywhere in the Rocky Mountain system, nor are they known in the Coast range, though it is quite possible that some of its crystalline rocks belong to the pre-Beltian. So far as known, then, this terrane forms an elongated dome in the heart of the Cordillera, surrounded on all sides by the eroded edges of younger, overlapping strata. South of Upper Arrow lake it has been so covered or else replaced by post-Palæozoic batholiths, and no pre-Beltian rocks have been demonstrated in the Cordillera on the line of the 50th parallel.

Ten miles north of the International Boundary, at the

Purcell trench, pre-Beltian rocks reappear. They have been grouped under the name, Priest River terrane. Though its details of stratigraphy and structure are very obscure (owing partly to poor exposure in a region of specially continuous forest), the writer believes that this rock group is to be best correlated with the Shuswap terrane. As in the Canadian Pacific section, the basal formation of the Beltian system has been turned up to view, but here it is a heavy conglomerate bearing pebbles of the Priest River rocks. In both regions the angular discordance between the Beltian and pre-Beltian terranes is very slight. The Priest River terrane shows no outcrop of the Adams Lake greenstones, but its schists, quartzites, and limestones are lithologically very similar to those of the Shuswap. An important contrast is seen in the failure of numerous granitic sills and dykes in the southern area, which is cut by the Rykert batholith of possible post-Palæozoic age. However, considerable areas of the Shuswap terrane itself are free from intrusive orthogneisses, etc., and the Priest River terrane might display them if its exposure were more extensive. The likelihood that the two pre-Beltian areas really represent outcrops of the same terrane is enhanced by the fact that the one is on the Cordilleran strike from the other.[1]

From descriptions of the "Archæan" rocks on the west shore of Coeur d'Alene lake, it is probable that the Shuswap terrane is typically exposed another degree of latitude farther south.[2]

It is unsafe to carry definite correlation into the greater Pre-Cambrian areas of the United States portion of the Cordillera, but it is noteworthy that their "Archæan" phases also show prevalence of aplitic and pegmatitic intrusions on a scale seldom if ever matched in Beltian or later time. The writer agrees with Dawson as to the great resemblance between the Grenville-Laurentian complex of eastern Canada and the Shuswap sediment-orthogneiss terrane, but their precise correlation is still clearly impossible.[3] Nevertheless, the *quality*

[1] See Memoir No. 38, Geol. Survey, Canada, 1912, p. 270, where the correlation of the Priest River terrane is briefly discussed.

[2] D. F. MacDonald, Bull. 285, U. S. Geol. Survey, 1906, p. 42; F. C. Calkins, Bull. 384, U. S. Geol. Survey, 1909, p. 33.

[3] Cf. G. M. Dawson, Bull. Geol. Soc. America, Vol. 12, 1901, p. 63.

of the early Pre-Cambrian events in these widely separated regions is the same. The writer has been recently impressed in the field with the dominance of sill and laccolithic injection in the Ontario field to an extent for which he was by no means prepared by published descriptions of the Laurentian terrane. In that regard and with respect to the abundance of pegmatites and other evidences of gigantic pneumatolysis, the British Columbia and Ontario complexes illustrate a world-wide eruptive condition which was strongly developed only in the early Pre-Cambrian stage of the earth's history.

CHAPTER IV.

THE STRATA OF THE PURCELL AND HIGHER SELKIRK MOUNTAINS.

Between Albert Canyon and the Rocky Mountain trench, the area of reconnaissance exhibits no sedimentary formations younger than the Cambrian, and the only other formations are a few thin, igneous injections, a small lava flow, and sporadic volcanic projectiles at one horizon. By far the greatest volume of the rock exposed belongs to the Beltian system. The rest of the sediments are of Cambrian age.

BELTIAN SYSTEM.

DEFINITION.

While sectioning the Cordillera at the 49th parallel of latitude, the writer felt the need of a systemic name for the huge series of Cordilleran rocks lying conformably below the Olenellus zone. In the report on that section (Memoir 38 of the Survey) the name chosen was "Beltian," which was derived from "Belt series" or "Belt terrane." In one of his publications Walcott used the term without definition other than that implied in its derivation and in Walcott's well known ideas concerning the relation of the Cambrian beds to the Belt series.[1] He considers that these rock groups, where carefully studied, are always separated by a pronounced disconformity or by a true unconformity. As suspected in the 49th parallel section and corroborated in the Canadian Pacific section, the two groups are essentially conformable in the Canadian Rocky mountains. The writer, therefore, adheres to his original definition of the Beltian system as that including all the Cordilleran strata lying conformably below the Olenellus zone, as well as the rocks which are

[1] See C. D. Walcott, Smithsonian Misc. Coll. Vol. 53, 1908, p. 169.

synchronous with those strata, though not in proved conformity with the *Olenellus* zone.[1]

The Beltian does not comprise all of Dawson's "Selkirk series," the upper beds of which are probably of Lower Cambrian age. On the other hand, it includes rocks grouped by him under the name, "Nisconlith series." In the summary report for 1911 (page 170) the writer gave reasons for the discontinuance of the term "Nisconlith" as a designation for any rocks in the railway section. It was pointed out that the "Nisconlith" mapped in the Shuswap Lake region is really part of the pre-Beltian terrane and that the "Nisconlith" of the Selkirk range belongs to a horizon far below the Lower Cambrian. Dawson's "Selkirk series" may, for convenience, be used as the name of the entire Beltian-Cambrian conformable group in the Selkirk range.

Lithologically the Selkirk series is divisible into two strongly contrasted parts (Map No. 1450). The lower part is the Albert Canyon division, composed chiefly of argillaceous types; the upper part is the Glacier division, dominantly quartzitic.

These definitions may be more readily reviewed as summarized in the following table, which gives a like statement of Dawson's definitions.

It should be noted that the term "Beltian" is intended primarily for local, Cordilleran use. Some day a general name will be needed for all the sediments of the world which were deposited in strict conformity beneath the Olenellus zone, and it is likely that this Selkirk section will be specially considered in making that invention, but it would be disastrous if "Beltian" should be hastily expanded so as to have such a continental or world meaning. It is in no sense a name competing with "Algonkian." In none of its chameleon changes has the definition of "Algonkian" ever involved conformity with the Olenellus zone as a necessary element. As shown in the 1911 summary, the use of "Algonkian" in describing the older rocks of British Columbia is impossible without running foul of one or another of its attempted definitions.

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[1] Memoir 38, Geol. Survey of Canada, 1912, p. 189.

	Shuswap Lakes Region.	Selkirk Range.	
NEW CORRELATION.			
Beltian with subordinate *Cambrian.*	Not known.	Glacier division.	Selkirk series.
Beltian.	Not known.	Albert Canyon division ("Nisconlith" of Dawson's Selkirk section).	Selkirk series.
		Unconformity.	
Pre-Beltian.	Intrusive granites. Shuswap series (including rocks mapped on the Shuswap sheet as "Nisconlith" and "Adams Lake" series).	Intrusive granites. Shuswap series.	

CORRELATION BY DAWSON.

Cambrian.	Adams Lake series.	Selkirk series.
Cambrian.	Nisconlith series.	Nisconlith series.
	Unconformity.	*Unconformity.*
Pre-Cambrian ("Archæan").	Intrusive granites. Shuswap series.	Intrusive granites. Shuswap series.

GENERAL STRATIGRAPHY.

The Canadian Pacific section across the Selkirks exhibits the Beltian system with unrivalled completeness. At its summit there is visible conformity with rocks clearly assignable to the Olenellus zone; its base is at a plane of unconformity. From the highest bed to the lowest the system is a practically unbroken succession of unfossiliferous beds, showing a total thickness greater than any other yet measured in the Cordillera.

Between Albert Canyon station and the summit, the general stratigraphic column was worked out; it is shown in the accompanying table.

COLUMNAR SECTION OF THE BELTIAN SYSTEM IN THE SELKIRK MOUNTAINS.

	Top, erosion surface.	*Approximate thickness in feet*
GLACIER DIVISION ("*Selkirk series*" *of Dawson*).	Ross, quartzite (in part)	2,500
	Nakimu limestone	350
	Cougar formation (quartzite with metargillitic beds)	10,800
ALBERT CANYON DIVISION ("*Nisconlith series*" *of Dawson*).	Laurie formation (metargillite, often calcareous; with subordinate interbeds of limestone and quartzite; basal bed, limestone 50 feet thick)	15,000
	Illecillewaet quartzite	1,500
	Moose metargillite	2,150
	Limestone (marble)	170
	Basal quartzite	280
		32,750
	Base, unconformity with Shuswap terrane.	

The Cougar and Laurie formations may be considerably thicker than as shown in the table. Dawson assigned a minimum thickness of 40,000 feet to the whole conformable group above the Shuswap terrane, thus indicating a minimum of about 33,000 feet for the Beltian portion. The true total for the Beltian may be well over 40,000 feet, but the writer has preferred to give underestimates except for those formations whose exposures permitted certain results in measurement. At the International Boundary the Beltian-Cambrian (?) series showed a minimum thickness of 32,050 feet, including 6,000 feet of volcanic beds.[1] Walcott states that the "Algonkian" (Belt) rocks in northwestern Montana and northern Idaho have a total thickness

[1] Memoir 38, Geol. Survey of Canada, 1912, p. 162.

of 37,000 feet.[1] These estimates are all of the same order of magnitude and tend somewhat to corroborate one another.

Basal Quartzite.

As shown on Map No. 1448, the oldest visible formation of the Beltian system is a quartzitic sandstone resting unconformably on the Shuswap terrane. This bed is known to extend 4 miles along the strike and keeps its lithological character and stratigraphic position to the limit of the area accessible during the reconnaissance. At the 49th parallel the basal formation of the Beltian is the well exposed, coarse Irene conglomerate, which locally exceeds 5,000 feet in thickness. In the railway section no pebbly bed was anywhere found at the corresponding horizon and the microscope was required to prove the derivation of the oldest Beltian sediment from weathered Shuswap rocks.

The quartzite rests directly on one of the thickest sills or laccoliths in the "sill-sediment complex" of the pre-Beltian. Part of this sill is shown on Map No. 1450. It is a highly foliated orthogneiss of a type very abundant in the Shuswap terrane, a metamorphosed biotite-hornblende granite. The foliation planes lie nearly or quite parallel to bedding in the quartzite, which dips at about 45° to the northeast. The strike is thus in the Cordilleran trend and the upturning is clearly of post-Beltian date. Though the sill has lost some of its volume by the pre-quartzite erosion, it is still more than 3,000 feet in thickness. Its lower contact is well exposed and one can see that the mass was injected along a plane in a series of dark-coloured, micaceous and hornblendic schists which are in part probably of sedimentary origin.

The orthogneissic sill is riven by numerous dykes of aplite and pegmatite of typical Shuswap habit. These are somewhat less conspicuous in the upper part of the sill than below, as if the salic magmas had difficulty in penetrating this once massive granite. Nevertheless, there are many aplitic dykes cutting the orthogneiss just below the quartzite; in fact, their presence is the best field evidence as to the position of the contact between sill and overlying quartzite. Their injection entirely ante-

[1] C. D. Walcott, Bull. Geol. Soc. America, Vol. 17, 1906, p. 18.

dated the Beltian system, in which neither sill nor dyke of granite, aplite, or pegmatite was found at any horizon, within the area covered. The salic injections cutting the orthogneiss are truncated by the old erosion surface limiting that great body above.

This field observation alone suffices to prove the existence of a long erosion interval immediately preceding the deposition of the lowest Beltian stratum. Microscopic study confirms the deduction in spite of the advanced (static) metamorphism of the rocks both above and below the unconformity. The basal sandstone is feldspathic and has been changed into a schistose, micaceous rock which resembles the underlying orthogneiss rather closely. Though they can usually be distinguished in the thin sections, there is a debatable zone about 10 feet in thickness which cannot easily be assigned to orthogneiss or quartzite. The cause of the uncertainty is quite natural. The quartzite is in reality an arkose formed out of, and merging into, the granitic rock as it underwent disintegration at the beginning of the local Beltian sedimentation. Farther up from the orthogneiss the sand is more quartzose and better bedded, indicating more thorough washing by water currents.

To show the relation more concretely, a suite of specimens, collected at the point where Albert (Moose) creek crosses the unconformity, may be briefly described (Plate XXII).

About 200 feet stratigraphically below the eroded top of the sill, the orthogneiss has essential components regularly found in many Shuswap sills—biotite, hornblende, medium to acid plagioclase, orthoclase, and quartz (specimen *a*). The accessories are the equally banal magnetite, apatite, and titanite. Epidote is a subordinate product of metamorphism.

Fifteen feet below the plane arbitrarily taken to represent the true contact within the debatable zone just mentioned, the rock (specimen *b*) is macroscopically much like the first, but the microscope shows a great increase in epidote, the entrance of considerable zoisite, and an apparently complete alteration of the original plagioclase; hornblende is present in abundant light green blades. The internal structure of the rock is confused and quite unlike that normal to orthogneiss.

A third specimen (*c*), taken at a point about 2 feet above the contact, shows the same type of structure, but is entirely free from hornblende, which characterizes the orthogneiss. The composition, in rough weight percentages, is:

Quartz	45 per cent
Orthoclase	20 "
Biotite	15 "
Epidote	15 "
Titanite, magnetite, and apatite	5 "
	100

Specimen *d*, taken about 2 feet stratigraphically above *c*, has a different composition:

Quartz	55 per cent.
Plagioclase	18 "
Orthoclase	15 "
Biotite	8 "
Epidote, titanite, and apatite	4 "
	100

Its plagioclase is developed as porphyroblasts.

Specimen *e*, taken about 50 feet above the contact, has a composition almost identical with that of *d*.

Specimens *f*, *g*, and *h*, taken at different points 150 feet above the contact, gave the following approximate percentages by weight:

	f	*g*	*h*
Quartz	80	82	63
Feldspar (chiefly orthoclase)	13	10	25
Biotite	5	5	10
Zircon, titanite, magnetite, sericite, garnet, etc.	2	3	2
	100	100	100

Another specimen of a similar quartzite overlying the adjacent limestone, gave measurements of the same order as those for *f*, *g*, and *h*.

The arkosic nature of the basal quartzite is evident. The materials of its lowest beds could not have travelled far from their parent ledges where the Shuswap granite had undergone secular weathering. The purely mechanical process of disintegration was accompanied by some chemical decay, for there was some leaching of the femic elements now represented in the hornblende of the orthogneiss. The younger part of the basal member represents washing of the residual sands with strong concentration of quartz—a foreshadowing of the enormous, almost unrivalled, development of quartzose sediments in late-Beltian and Cambrian time. One is reminded of a parallel case in the Crystal Falls district of Michigan, described by Clements. There the "Archæan" granite is transitional upward into "recomposed granite" (now sericite-quartz schist), which passes gradually into true quartzite at the base of the lower Huronian.[1]

Lowest Limestone.

The uppermost 10 feet of the basal quartzite is interleaved with thin beds of limestone, showing a passage into a bed of variegated limestone, which, at Albert creek, is about 170 feet in thickness. This oldest carbonate rock of the exposed Beltian is a true marble and of different habit from the limestones higher in the series. Its colour varies from white to bluish-grey and pale brown, generally weathering to a buff tint. All specimens of it effervesce more or less violently with dilute acid, but some layers are notably magnesian. The grain varies capriciously from very fine to decidedly coarse. The coarse phases all show cataclastic structure and the marble has been squeezed into cracks of the adjoining quartzites. The effects of moderate dynamic metamorphism have been added to those of general recrystallization under an extremely thick cover.

The limestone is generally free from impurities; a few quartz granules are interspersed in the carbonate and chert lenses locally occur in bedding planes, but no other mineral is to be

[1] J. M. Clements, Monograph 36, U. S. Geol. Survey, 1899, p. 51. Compare C. R. Van Hise, in Monograph 28 of the same Survey (1897), p. 226, for another instance, found where the feldspathic quartzite near the base of the Lower Marquette series closely simulates the immediately underlying granite.

seen in the thin sections. Like all the other Beltian limestones in the Selkirks, it enclose no fossil remains.

Moose Metargillite.

This formation has been named from Moose, now Albert, creek, which runs over it at Albert Canyon station (Map No. 1448). The formation is very poorly exposed in the area traversed, but it is certainly thick (total thickness estimated at 2,150 feet) and seems to be composed of fairly homogeneous material. As a whole the formation is the recrystallized product of argillaceous material The metamorphism has not generally gone to the length of developing a true mica schist and the term, metargillite, is chosen as a truer designation.

The best outcrops studied are those forming a broad hill just east of Albert Canyon station. The metargillite is there chiefly a comparatively massive, dark grey, carbonaceous rock strongly charged with an obscure mineral which appears to be cordierite. Quartz in minute granules is a subordinate essential; a little biotite and magnetite are accessory. About 10 per cent of the formation here consists of films or thin beds of true phyllite and still rarer, silvery mica schist; these interrupt the dominant cordieritic (?) rock at intervals.

Illecillewaet Quartzite.

Overlying the Moose metargillite in perfect conformity is the Illecillewaet quartzite, named from the river, which has sunk a transverse valley, now followed by the railway, and has thus prepared a natural section through the entire series (Map No. 1448). This formation also was not seen in satisfactory exposure and its columnar section cannot yet be described in detail. Where actually seen, it is a comparatively homogeneous, hard, grey, rarely white, massive to fissile quartzite, with thin interbeds of dark-coloured metargillite or phyllite. The original sediment may have been somewhat feldspathic, but no feldspar now appears in the thin sections, which are those of a quartz-sericite rock essentially. Chlorite, pyrite, and carbonaceous dust are present in small amounts. Where more abundant the pyrite gives a rusty habit to the weathered rock.

Laurie Formation.

Three-fourths of the Albert Canyon division is included in the colossal Laurie formation, which is named after the mining camp near Illecillewaet. It is of very great thickness and should certainly be subdivided in a detailed survey of the Selkirks; this could not be accomplished during the reconnaissance, partly for lack of sufficient time in the field and partly for lack of satisfactory exposures. Between "Albert Canyon" gorge and Ross Peak station, for a distance of 10 miles, the railway crosses the strike of the formation, which is exposed in the long cuttings and in the heights north of the railway (Plate XXIII). Measurement on the actual outcrops gave the following succession:

Columnar Section of the Laurie Formation.

Base of the Cougar formation.	*Approximate thickness in feet.*
8. Grey, phyllitic metargillite	4,000
7. Quartzite	650
6. Black to dark grey metargillite	500
5. Alternating beds of phyllite and quartzite	750
4. Black to dark grey, carbonaceous, often pyritous metargillite, with interbeds of blackish limestone	9,300
3. Grey quartzite	400
2. Black to dark grey, strongly carbonaceous metargillite, with numerous interbeds of blackish limestone	3,500
1. Massive, light grey limestone	50
Top of Illecillewaet quartzite.	19,150

The structure is homoclinal (see page 53), with dip varying from 10° to 70° but steadily to the northeastward. The prevalence of a uniform dark grey colour and of a metargillitic composition and the general absence of good horizon-markers make it difficult to determine how much of the apparent thickness is due to duplication by fold and fault. That there is some duplication is obvious in the contorted zone shown at Laurie on the structure-section plate (in map-pocket). Yet in spite of all care to use any field hint of repetition of beds, the writer cannot assume the net thickness to be less than 15,000 feet. This estimate accords with that of Dawson for his "Nisconlith series" of the Selkirks and a comparison with his section shows that that series and the Laurie formation are nearly identical.[1]

The lowest member (*1*) of the formation is a 50-foot bed of light bluish-grey banded limestone, outcropping at the western end of the well known gorge of the Illecillewaet, 2 miles east of Albert Canyon station. Some of the bands are coarse-grained; alternating with them are others with grain diameters reaching 0·15 mm. and averaging 0·05 mm. or less. Rare granules of quartz, a few talc or sericite films, and, in one thin section, rounded grains of diopside were seen to be accessory constituents in this nearly pure carbonate rock. Tests showed that it is highly magnesian; some phases may be true dolomite.

Member *2* is a composite of alternating metargillite and impure limestone beds. The former is often phyllitic, a strong fissility being imparted by abundant sericite, so developed that the resulting schistosity is always parallel to the stratification planes. The generally marked friability of the metargillites is partly due to an unusual content of carbonaceous material, which is rather uniformly disseminated in clouds of non-cementing grains. This ingredient explains the prevailing black to graphite grey colour of most members of the entire formation. Small crystals or formless grains of pyrite seldom fail in the thin sections and hematite or limonite are common constituents in small amounts. At many horizons carbonate material is an important component of the metargillite, which is then transitional into the impure limestones and calc-schists of member *2*. These also are of black or deep grey colour because richly charged with carbon dust. Many interbedded films of phyllite, or else sericite more disseminated through the limestones, make the beds

[1] G. M. Dawson, Bull. Geol. Soc. America, Vol. 2, 1891, p. 174.

highly fissile. Quartz granules represent another common impurity. At some horizons metacrysts of a brownish carbonate, probably ankerite, were observed. Silicates other than sericite are rare, but small amounts of serpentine, talc, and tremolite were observed in some thin sections. The limestones appear to be magnesian; no true dolomite has been observed.

Member *3* is well exposed on the top of the ridge west of Illecillewaet, between the 5,600-foot and 6,000-foot contours. Elsewhere in the area traversed it is almost wholly covered by forest. It is a homogeneous, light greenish-grey, sericitic quartzite. Some chlorite aids the sericite in making the rock more or less fissile in planes parallel to bedding. Grains of plagioclase, orthoclase (?), and microperthite are accessories. They have average diameters of about 0·05 mm., which is also nearly the average for the quartz grains. This is the lowest horizon where microperthite has been proved in the Beltian sediments. The importance of microperthite and allied feldspars in suggesting the origin of these sediments will be emphasized on a later page.

Member *4* may be quantitatively described in almost the same terms as *2*. Its dominant rock is a remarkably homogeneous, black to dark grey, carbonaceous metargillite. This may be typically seen in several long cuttings on the railway between Illecillewaet station and Flat creek. At many horizons the rock is charged with numerous cubical crystals of pyrite, very perfectly developed and reaching diameters of an inch or more. Quartz, sericite, and carbon dust are the usual components. Chlorite is a subordinate companion of the sericite in a few specimens. Magnesian calcite is a common accessory and all gradations exist between metargillite on the one hand and impure, blackish magnesian limestone or calcareous quartzite on the other. The limestone beds are numerous and are of habit identical with those in member *2*, but the grain is exceptionally fine. In one thin section the carbonate grains average 0·02—0·04 mm. in diameter, thus recalling the chemically precipitated limestones of younger rock systems. The carbon content rises in some beds to the point where analysis would suggest an impure coal or graphite. Quartzitic interbeds are rare in member *4*; those microscopically examined are both calcareous and tremolitic. Zones of crinkled phyllites were found at many horizons among the metargillites with plane-parallel bedding.

One-half mile southeast of Illecillewaet station, a poorly exposed but apparently thick bed of talc-chlorite-quartz schist is intercalated in the phyllite-metargillite mass. No certain field evidence of the origin of the schist was forthcoming, but its microscopic study suggests that it may be a bed of basic volcanic material, statically metamorphosed.

By a rapid transition, member *4* passes upward into a variegated zone (member *5*) dominated by light-grey, calcareous, quartzitic sandstone interbedded with grey phyllites. A greenish cast is given by disseminated sericite. In the only thin section of the sandstone examined microscopically, the quartz grains, 1 mm. to 0·7 mm. in diameter, were seen to be rounded, having preserved their clastic form. This is the lowest horizon where such original outlines are seen to have survived the wholesale metamorphism which has affected the Beltian rocks.

Above *5* comes 500 feet of the normal, black to dark grey metargillite, which has not been specially studied (member *6*).

That zone is succeeded by about 650 feet of light grey, slightly calcareous, quartzitic sandstone (*7*), very similar to that in member *5*. Again, original forms of the rolled sand grains are visible in thin section and also evidences of their secondary enlargement.

Member *8*, the top of the Laurie formation, is very thick, but poorly exposed along the sides of Caribou Creek and Flat Creek valleys (Plate XXIV). Wherever seen it is a dark grey, calcareous, often crinkled metargillite. It generally resembles very closely the phyllites of the lower members. In one thin section chlorite and a staurolite-like mineral in small amount were observed. Otherwise the mineralogy is as monotonously typical as in the other Beltian metargillites.

Cougar Formation.

The top of the Laurie formation is also the top of the Albert Canyon division of the Selkirk series (Map No. 1450). In the railway belt this great division crops out only in the section on the western slope of the Selkirks. Just east of Flat Creek siding the upper contact of the Laurie dips northeastward under the Cougar quartzites and, so far as known, never reappears in the Cordillera farther east. In the eastern Selkirks and in the Purcell and Rocky mountains, orogenic uplift has been insufficient to bring the Laurie and older rocks up to a level where erosion might have exposed them. It is different with the Cougar formation, the lowest member of the Glacier division, for it reappears in all the mountain systems, east of the water divide of the Selkirk range. Partly because of more numerous outcrops and also because of widespread exposure above tree-line, the stratigraphy of the Glacier division is better understood than that of the older division.

The locality best qualified to give a complete columnar section of the Cougar formation is the group of ridges and peaks surrounding the head of Cougar brook, including Cougar mountain, from which the formation has been named (Map No. 1449 and Plate XLV). These heights are situated in the same marvellous homoclinal section which has been ascended all the way from Albert Canyon station. At that section was worked out, with approximate accuracy, the following:

COLUMNAR SECTION OF THE COUGAR FORMATION.

Conformable base of the Nakimu limestone.

		Thickness in feet.
6.	Grey, thin-bedded to thick-bedded quartzite, weathering rusty; with thin interbeds of phyllite and white quartzite; a few seamlets of crystalline limestone in the uppermost quartzite	5,500
5.	Conspicuous band of white, homogeneous, massive quartzite	300
4.	Massive, light grey quartzite, interrupted by many bands of grey, quartzitic grit and coarse sandstone and by beds of dark grey, siliceous metargillite, about 1,000 feet from the top, a thick band of massive white quartzite	3,000
3.	Quartzitic and phyllitic, grey sandstone, and fine conglomerate with metargillite. Near the middle of this zone, angular fragments of altered basaltic rock (bombs?) enclosed in an argillaceous (?) base were found	900

2.	Altered basaltic lava	50
1.	Thick-platy to flaggy, sometimes phyllitic, grey quartzite	1,050
		10,800

Conformable top of Laurie formation.

East of the Selkirk divide the Cougar rocks have been much sheared and both statically and dynamically metamorphosed, so that even that part of the formation there actually exposed does not give a satisfactory columnar section. It is clear, moreover, that the formation notably and systematically changes character as it is followed eastward, and the foregoing statement applies only to the phase exposed west of Rogers pass.

The total thickness stated is enormous but it is a minimum. The width of outcrop in the Illecillewaet homocline is 18,000 feet and the average dip is at least 45°. The gross apparent thickness is about 13,000 feet. There are, however, local duplications (Plate XXV) and liberal allowance for these has brought the total down to 10,800 feet. Its magnitude naturally suggested the advisability of subdivision for purposes of mapping, but the quartzite mass is relatively so homogeneous that this could not be done during the reconnaissance.

In member *1* a thick bed of white to pale pink, massive quartzite was collected for microscopic study. It was seen to be essentially composed of flattened, interlocking quartz grains with major diameters ranging from less than 0·1 mm. to 1 mm. A little sericite occurs in the bedding planes but no feldspar whatever was found.

The basaltic member (*2*) has been so greatly altered that its original nature is somewhat obscure. It is a grey, massive to slightly schistose eruptive, with field suggestion of a volcanic ash. The only thin section prepared shows relics of basic plagioclase in phenocrysts. For the rest, the rock is a confused mass of epidote, uralite, and chlorite. Further study is needed to tell whether this specimen typifies the whole 50-foot bed, in which case the bed is probably a porphyritic lava flow. On the other hand, the rather vague field impression that it is a basaltic or basic-andesitic breccia may have been correct. The essential point is that the bed appears to be truly volcanic and not intrusive in origin.

From the heterogeneous member *3* a specimen of fine-grained grit was specially studied. Its longest grains reach 4 mm. in diameter. Most of them are composed of bluish, opalescent quartz, identical with that so very abundant in many overlying strata of the series. This is the lowest horizon where such blue quartz was discovered. Its colour and iridescence are explained by the thorough fracturing of each grain showing those properties. From the fact that they characterize well-rounded, uncrushed grains, it seems highly probable that the fracturing had been accomplished before the grain was washed from its parent, pre-Beltian ledge. Each of many of the larger grains is composed of a single crystal of quartz, indicating an original source in a decidedly coarse rock. Similar large, rounded, grains of microperthitic feldspar are also abundant; it will be seen that similar material is a steady companion of the iridescent quartz grains and pebbles in the still younger sediments of Beltian and Cambrian age. These small pebbles are embedded in a cement of sericite, secondary quartz, and carbonate (dolomite or highly magnesian calcite). A little chlorite and pyrite are accessory. This rock may thus be called a feldspathic grit with a calcareo-phyllitic base.

The gritty beds are interleaved with the dominant grey, compact quartzites, which also carry intercalations of soft, friable schist, regarded in the field as phyllite. At one horizon near the middle of this member, massive, angular bodies of a rather intense green colour are embedded in the schist. These masses are elongated in the bedding plane and range from a few inches to 6 feet in length. Their nature was first suggested in the laboratory, where the microscope showed them to have, approximately at least, the composition of basalt. Again basic plagioclase is the only original mineral discernible. Its crystals have parallel arrangement, as if due to flow in the original magmatic state. Green epidote composes the rest, more than half, of the rock. Since, unfortunately, no specimen of the phyllitic base was collected, the exact mode of origin cannot be stated. The writer's best guess is that these epidotic masses are greatly altered volcanic projectiles.

Member *4* was sampled at three horizons for microscopic examination. One specimen, showing quartz pebbles reaching nearly 1 cm. in diameter, was found to be free of feldspar and to be essentially a pebbly quartz-sericite schist, with some disseminated grains of dolomite and carbon. A second specimen, also of grey colour, has the same general composition but lacks accessory dolomite. It shows some secondary enlargement of the quartz grains, many of which are bluish and iridescent. This rock is a true quartzitic sandstone. The third specimen is a pinkish-white quartzite bearing sericitic films parallel to bedding. Its grain is comparatively even, diameters ranging from 0·05 mm. to 1 mm., and averaging about 0·2 mm. A little typical microperthite occurs in small grains through the quartz.

Member *5* is a notably massive and homogeneous body of almost perfectly pure quartz. No feldspar and but traces of sericite were seen in the thin section. The diameters of the thoroughly interlocked quartz grains reach 0·5 mm., averaging about 0·08 mm. They are generally lenticular and arranged parallel to bedding.

Member *6* is also quartzitic in general, but, on the whole, is more ferruginous and more thin-bedded than the rest of the Cougar formation (Plates XXVI and XXVII). Only two specimens were collected for study and these showed no persistent features not characterizing the quartzites and phyllitic schists of the lower members, except the introduction of a greenish pleochroic mica which here joins the almost ubiquitous sericite (also paragonite ?) in lending fissility to the rocks. The limestone beds noted in the columnar section represent transition to the conformably overlying Nakimu formation.

East of the Selkirk divide, the Cougar formation crops out liberally, but, as already noted, its base is not there exposed, nor has any horizon below member *4* been identified. The contact with the Nakimu limestone, always in perfect conformity, may be followed for miles on each side of the Beaver River valley and in the escarpment of the Dogtooth mountains

(Maps No. 1447 and Structural section). Repeated by strong folds, the Cougar is, in fact, the most extensive formation cropping out between the Selkirk divide and the Rocky Mountain trench.

Though a distance of only 8 miles separates the nearest outcrop of the formation in the two limbs of the great summit syncline, it shows decidedly different characters in these outcrops. Along Beaver river and to the eastward, the quartzites have become more fissile because more charged with sericite along the bedding planes; and interbeds of metargillites have also increased in number (Plate XLVI). The sediments are here less quartzose and more argillaceous than those simultaneously laid down farther west. A second field contrast is seen in a stronger development of true slaty cleavage in the rock east of the Selkirk divide, where deformation has been much more intense than on the western slope. During this folding, the local increase of temperature, aided by the original nature of the more argillaceous sediments, has developed many zones of true mica schists bearing well-developed muscovite in the bedding planes and, more locally, large tabular metacrysts of lustrous biotite, which are arranged at all angles to those planes. Small garnets are also developed in many beds.

However, highly siliceous beds appear also on the eastern side of the Selkirk divide. Feldspathic sandstones and grits are still abundant and their characteristics are always the same as those above described. The most massive member is a feldspathic quartzite well seen at Beavermouth, north and south of the Columbia. This is at least 300 feet thick and rivals the Sir Donald quartzite in strength and homogeneity. The structural relations are not clear, but the writer suspects that this body of quartzite belongs to member *4* of the general section. In contact with it is a thick band of extremely friable talcose schist, the equivalent of which was not observed west of the divide, though it may be found there after a more detailed search is made. As at Cougar creek, the quartzites become charged with calcareous or dolomitic phases and with thin beds of magnesian limestone as the Nakimu limestone itself is approached.

Nakimu Formation.

The Nakimu limestone is the key to the stratigraphy and structure of the Selkirk and Purcell mountains in the railway belt. It is named from the Caves of Nakimu (Caves of Cheops) which have been opened in the limestone by the erosion of Cougar brook in its subterranean course northeast of Cougar mountain (Plate XXVIII). The stratigraphic importance of the limestone is obvious from the fact that it is the only member of the Glacier division which contrasts greatly with the dominant siliceous beds (Plate XXIX). The distribution of its outcrops is shown on Maps No. 1449 and No. 1447. As these were plotted the folded structure of the mountains became clear. On account of its importance the Nakimu formation will be described in terms of a half-dozen sections run through it at widely separated localities.

The formation has its greatest observed thickness at the Caves of Cheops (Nakimu), where it appears in the western limb of the summit syncline. Local warping of its easterly-dipping rocks here broadens the outcrop, which reaches a width of about 1,200 feet. A bluish-grey crystalline limestone is the principal constituent. A few beds are composed wholly of carbonate, ranging from nearly pure calcite to dolomite. The majority are more or less charged with detrital grains of quartz and with shreds of sericite or talc lying in the bedding planes. Near the top the limestone is interrupted by phyllitic and quartzitic laminæ. The limestone generally weathers grey but is often mottled with irregular buff-coloured surfaces. It is usually fine-grained, with diameters of the grains averaging about 0·2 mm. These are characteristically flattened parallel to the plane of bedding. After years of search Mr. Charles Deutschman, guide to the caves, has entirely failed to discover fossils, in spite of the favourable appearance of the limestone. The total thickness at this section is at least 350 feet and may be as much as 500 feet.

On a traverse from Bear Creek station westward toward Hermit Crest, the formation was again encountered, this time in the eastern limb of the summit syncline and 8 miles from the Caves of Cheops. Already the lithology is seen to differ from that of the western section. Here the principal member is a 275-foot zone of grey crystalline, magnesian limestone of the type already described, but charged with numerous lenses of interbedded sericitic schist and with abundant small sand grains (diameters 0·1 to 0·3 mm.) disseminated through some beds of the limestone itself. The latter recall common phases of the Beltian Altyn limestone of Montana. The weather tints vary from grey to buff, the latter being more common than at the caves. Above the limestone is a 150-foot zone of dark buff, dolomitic sandstone with numerous intercalations of rusty quartzitic schist and of dolomite. This upper zone represents a slow transition to the Ross formation and it is here impossible to mark the exact contact. Thus, in the short distance of 8 miles, the Nakimu formation has become thinner and also more siliceous. The disseminated sand grains seem to be wholly quartz and no feldspar was observed in the thin sections.

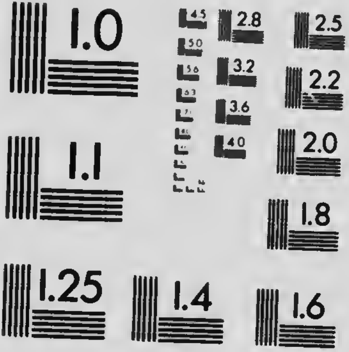
Two miles north-northeast of Sixmile Creek station the formation was again studied, in the eastern limb of the Beaver River anticline. In that section the rocks have been severely compressed and it is possible that some of the Nakimu formation has been sliced and faulted out of sight. It consists of several thin beds of the normal, grey magnesian limestone, with others of brown-weathering dolomitic habit, all intercalated in a series of fissile sericite schists, dolomitic sandstones, and quartzite. The total thickness is about 200 feet and of that the limestone beds total not more than 75 feet.

In the Beaver River canyon, 1·5 miles to the eastward, orogenic slicing has reduced the thickness of the exposed Nakimu limestone to about 5 feet. There the rock is carbonaceous, dark grey, and unlike the standard limestone at the Caves of Cheops, but identical with a phase occurring in the typical Nakimu of the Dogtooths and Prairie hills.

Following along the strike 10 miles to the south-southeast, a good section of the formation is found in the western limb of the Quartz Creek anticline and west of the main forks of the creek. It is here at least 600 feet thick. At the base, for a thickness of 400 feet or more, the rock is a massive, homogeneous, light grey dolomite or magnesian limestone extremely similar to that at

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



the Caves of Cheops. A thin section of the only specimen collected from the outcrop showed typical oolitic structure. The "eggs" are of normal size. Their component granules average about 0·015 mm. in diameter, rising to a maximum of 0·03 mm., thus corresponding in size to the granules of oolites generally. This rock has evidently preserved its original texture. The field observations do not suffice to tell how much of the limestone is oolitic. It is overlain by at least 200 feet of a highly heterogeneous calcareous member, composed, in rapid alternation, of: dark grey, fetid limestone; buff-weathering, compact, siliceous dolomite; sandy and pebbly dolomite; and ferruginous sandstone and grit. Some of these phases also resemble the Altyn formation at the Alberta-Montana boundary line.[1] Only a few of the upper limestone beds are exposed on the opposite slope of Quartz Creek valley, 3 miles to the northeast. In a 4-foot layer traces of oolitic structure were observed.

These different sections show the rapid changes affecting the Nakimu formation as it is followed across the mountains. It is made up of a number of dovetailed lenses which thin out and thicken in short distances, while the whole preserves a general calcareous composition. The grey limestone remains the dominant member in nearly all sections and has a habit that makes it almost unmistakable in the field. Its intimate association with several strongly contrasted types of magnesian sediments, an association repeated in practically all of the local sections, is a further aid to correlation. Finally, the fact that typical Ross and Cougar rocks lie respectively above and below the limestone at any one of the sections removes any doubt as to its identification. The Nakimu formation is, by long odds, the best horizon-marker in the Selkirk and Purcell mountains where crossed by the railway. The marked individuality of its beds as lithological types and their special association promise to make this formation useful in long-distance correlation (See pages 86 and 94).

Ross Formation.

The youngest member of the Beltian system is the Ross formation, named from Ross Peak (Map No. 1449). As noted

[1] See Memoir 38, Geol. Survey of Canada, 1912, p. 56.

on page 86, the Olenellus zone is probably located about mid-way in this formation but it is conveniently described as a whole in the present connexion. Good, complete sections were found on both slopes of the Selkirk range. Other good ones, though lacking the uppermost beds, are abundantly displayed on the higher peaks of the Purcell ranges. The type section selected is that shown in the superb exposures west of Rogers Pass, at the head of Bear creek. The dip averages about 60° to the northeastward, illustrating its gradual steepening in the giant homocline which has been crossed all the way from the basal unconformity at Albert Canyon, 16 miles distant. Along the trail from Rogers Pass to the Caves of Cheops, the Ross formation has the following constitution:

COLUMNAR SECTION OF THE ROSS FORMATION.

Conformable base of Sir Donald quartzite.

	Thickness, in feet.
Grey, rarely rusty, thick-bedded, compact quartzite, with interbeds of grey and brownish quartzitic sandstone and grit................	1,200
Pale rusty-brown dolomitic phyllite and highly sericitic quartzite, carrying in the middle a 50-foot bed of grey quartzite................	350
Grey quartzite, thick-platy and homogeneous, weathering grey and rusty; with interbeds of hard quartzitic grit and sandstone...........	3,700
Conformable top of the Nakimu limestone.	5,250

Leading characteristics of the formation in this western phase are: its thick bedding; its highly siliceous (quartzitic) composition; its relative homogeneity; and its habit of weathering with brown-rusty surfaces. All of these features, except the last, it shares with the overlying, grey-weathering Sir Donald quartzite, and it is difficult to indicate any exact plane of demarcation between them.

The dominant quartzites of this section are represented in a half-dozen specimens which have been microscopically examined. Much additional collection and study are needed before a detailed account of them can be given. With the exception of one specimen showing accessory grains of plagioclase and orthoclase, all are essentially non-feldspathic. Quartz and sericitic, white to greenish mica, in ever varying proportions, with occasionally a few epidotic grains, recur with the same monotony as in the Cougar formation. Many beds are gritty, exhibiting rounded pebbles of bluish, iridescent (strained or granulated) quartz from 2 mm. to 8 mm. or more in diameter. Some of the well-rounded quartz grains show secondary enlargement.

The Ross formation was not closely studied in the bold escarpments of the Selkirks overlooking Beaver river, where are found exposures of admirable completeness, but, because of the ruggedness of the mountains, to be worked out only with abundance of time for slow, arduous climbing. The massiveness and relative homogeneity of the formation are well preserved, but it seems to be here yet more ferruginous than in the type section across the divide.

At least half of its beds remain in the Dogtooth mountains, where the upper ones, together with the entire Sir Donald quartzite, have been eroded away (Map No. 1447 and Structural section). These Ross beds of the eastern sections, like the underlying Cougar beds, are extensively affected by orogenic pressure (Plate XXX). The resulting cleavage is occasionally seen to cross the bedding planes very clearly, but, as a rule, cleavage and bedding are sensibly parallel. The secondary structure tends to obscure the original habit of the strata, but there are good indications that the Ross formation, like the Cougar, was originally more ferruginous, more argillaceous, and more thin-bedded in the Purcells than it is at the west slope of the Selkirks. Indeed, the change is already marked in the outcrops of the east slopes of Mount Tupper and Mount Macdonald, only 7 or 8 miles from the type section at the head of Bear creek. Judging from the specimens collected, the eastern phase is also more charged with sandy and gritty beds carrying disseminated dolomite in the cement. On the summit of the Prairie hills, 2 miles west-southwest of the forks of Quartz creek, the basal member of the Ross formation is a 150-foot bed of massive conglomerate, with pebbles of blue quartz reaching one inch in diameter.

Its cement is largely dolomite. In the northeastern limb of the same syncline, only a mile distant, this same horizon is represented by about 200 feet of true quartzitic sandstone, again directly and conformably overlying the Nakimu formation. Since the syncline is tightly closed, the original distance of these sediments from each other was certainly much more than a mile, but their sharp lithological contrast illustrates the lenticular character of the Ross strata in general. No two of the sections, run in the Ross outcropping in the Dogtooths or Prairie hills, agree in lithological succession with each other or with that so accessible and so well exposed in the Beaver River canyon. Yet the persistence of the same general, massive and ferruginous habit and of a constant relation to the Nakimu limestone makes it easy to map the Ross formation in practically all parts of the area covered.

CAMBRIAN SYSTEM.

Sir Donald Formation.

The Ross quartzite passes gradually upward into the Sir Donald formation, which composes the horn of Mount Sir Donald; hence the name (Plate XXXI). In the area traversed, this formation is entirely confined to the great summit syncline of the Selkirks (Map No. 1449). It is the youngest member of the Selkirk series and, with the upper part of the Ross formation, has been correlated with the Lower Cambrian of the Rocky mountains. On account of their superior stratigraphic position in the broad, wrinkled syncline and yet more because of great massiveness and strength, the Sir Donald rocks constitute most of the finest mountains in this part of the Selkirks (Plate XXXII). Erosion has removed an unknown, probably small, thickness of beds which once formed a continuous whole with the 5,000 feet of Sir Donald sediments now visible in the railway section.

For a thickness of about 4,000 feet this formation is, on the whole, a markedly homogeneous body of siliceous deposits, principally normal quartzites carrying abundant interbeds of very hard quartz grits and fine conglomerates. These are white to rather light bluish grey, seldom dark grey on the fresh fracture. On weathering, most phases tend to assume a grey tint. The massiveness is notably greater than even that of the Ross quartzite and resembles the habit of certain thick members of the Cougar formation west of the summit. Many beds are from 5 to 30 or more feet in thickness, giving the effect of cyclopean masonry (Plate XXXIII, A). At several horizons near the base of the formation, more fissile, micaceous quartzites or quartz schists are intercalated. These weather like many beds of the Ross and Cougar formations.

At the Illecillewaet glacier, on the east and north of Glacier House, at the eastern foot of Ross peak, and elsewhere, rusty quartz-mica schists, sericitic schists approaching true slates, with interleaved quartzites, crop out rather abundantly. In some of these cases the schistose rocks follow zones of powerful shearing and the fissility is in part due to the dynamic metamorphism of originally massive, though impure, quartzites. Yet it is clear that, along the floor of the valley between Glacier House and Rogers Pass, there is a considerable thickness of silicious argillite with subordinate interbeds of true quartzite. From their position in the main axis of the summit syncline, this group of originally muddy sediments is inferred to be the upper part of the Sir Donald formation, and thus to represent the youngest bed-rocks in the region. These beds are crumpled, faulted, and greatly cleaved; hence their thickness could not be accurately determined. It is probably more than 500 feet and may be 1,000 feet. In the formation as a whole no single bed of the schist nor any of the staple quartzites, grits, or conglomerates could be followed far, and as yet no systematic subdivision of this great mass is possible.

The microscope shows that the Sir Donald sandstones, grits, and conglomerates are generally feldspathic, often to a high degree. Microperthite, microcline, orthoclase, and acid plagioclase are all well represented. Single crystals, particularly of the alkaline feldspars, constitute entire pebbles in the conglomerates and grits. The same is true of quartz pebbles and it is clear that these clastic materials were derived from very coarse granitic rocks or pegmatites. The quartz grains and pebbles are commonly bluish and iridescent. Thus in all essential respects the leading Sir Donald types resemble some of the older Cougar and Ross sandstones and grits.

Upper Cambrian Beds in the Columbia Valley.

Eastward from Beavermouth for a distance of about 2 miles, the railway runs over the Cougar quartzites, which are suddenly replaced in the rock-cuttings by shales with subordinate interbeds of limestones (Structure section in map-pocket). These have entirely different habit from any of the formations so far described, recalling the Ordovician Goodsir beds of the Rocky mountains across the valley. The shales, often calcareous, vary in colour from grey to black. They are friable, heavily jointed, and locally well cleaved across the bedding planes. The limestones weather to a buff-grey and seem to be generally magnesian.

Beds of the same general character crop out along the line for the next 6 miles, to the eastern end of the local canyon of the Columbia. Throughout this section, strike and dip change very rapidly, indicating structural turmoil. So great is the disorder that no measurement of the true thickness represented is possible nor was the attempt to work out the exact sequence of strata any more successful. Between Donald and Golden, a distance of 16 miles, bed-rock is exposed at only two localities on the railway. At the crossing of Blaeberry river the outcrop is large, showing shales of the Goodsir type. No other notable outcrops were seen, during this reconnaissance, in the floor of the Rocky Mountain trench between Donald and Golden, but it is likely that most or all of it is underlain by the shale-limestone series actually seen along the railway. Without borings it will remain impossible to map in detail the bed-rocks underlying the trench, for they are covered by a remarkably thick and continuous mantle of glacial debris and terrace gravels.

Fossils were found in the cuttings at and immediately east of the tunnel at the 54·6 mile-post, nearly 3 miles west of Donald. They occur in the cores of small calcareous nodules which have been abundantly segregated in grey shale. On breaking the nodules open longitudinally, fragments of trilobites were found in fair abundance. This material was sent to Dr. C. D. Walcott who kindly examined it and reported as follows: "The fossils indicate the upper portion of the Upper Cambrian and possibly would be placed in the base of the 'Ozarkian' by Ulrich. Two genera are clearly defined. The larger specimens belong to a genus closely allied to *Dicello-cephalus* and there is one specimen of *Illenurus*. There is also another form not yet clearly identified." At least 1,000 feet of beds are represented at this fossil-bearing locality.

It thus appears likely that the trench is floored by Upper Cambrian and Ordovician sediments, which have been faulted into contact with the Beltian Cougar formation (See Structural section).

Correlation With the Rocky Mountain Cambrian.

No fossils were found in either the Sir Donald or the Ross formation, but their relation to the Cambrian of the Bow River valley, 50 miles to the eastward, seems clear from lithological resemblances. These are quite specialized and become most significant when the respective *successions* of beds are compared. The correlation adopted is as follows:

	SELKIRK MOUNTAINS		ROCKY MOUNTAINS	
	Erosion surface.		*Conformable base of the Middle Cambrian.*	
		Thickness in feet.		*Thickness in feet.*
Lower Cambrian	Sir Donald quartzite	5,000+	Mt. Whyte formation.....	390
			St. Piran formation.......	2,705
			Lake Louise formation....	105
	Ross quartzite (upper part)...........	2,750	Fairview formation.......	600
Beltian	Ross quartzite (lower part)...........	2,500	Hector formation (upper part)..................	630
	Nakimu limestone...	350+		
	Cougar formation (in part)...........	10,800	Hector formation (lower part)..................	3,960
			Corral Creek formation....	1,320
			Base concealed.	

There can be little doubt that the St. Piran formation is the eastward continuation of the Sir Donald. In the Lake Louise section the St. Piran "consists of massive-bedded, ferruginous, quartzitic sandstone, with a total measured thickness of 2,705 feet."[1] Its higher content of iron oxide is to be expected from a general rule affecting the Rocky Mountain geosynclinal. Most of its siliceous beds become more ferruginous as they are followed from west to east. As already noted, this is the case with the enormous Cougar and Ross formations. The rule is again illustrated on a grand scale in the 49th parallel section.[2] Allowing for that change, the lithological similarity of the St. Piran and Sir Donald rocks is most striking. All important phases of the Sir Donald are found in the Lake Louise section. These include fine conglomerates, grits, and quartzites, charged with abundant grains of blue, iridescent quartz and of feldspars belonging to species identical with those already listed for the Sir Donald sediments. A score of leading rock types, differing among themselves and each showing distinctly individual habit, are thus to be parallelled in the two formations. The resemblance is further evident in their thick-bedded, massive nature, which, for so great, continuous masses of sandstone, is unmatched in the Selkirk and Rocky Mountain sections. Annelide borings, locally forming "pipe-rock" like that in the Scottish Cambrian, are found in the St. Piran quartzite, but as yet are [illegible] in the Sir Donald, where, however, they may be dis[illegible] special search. Toward the top of the St. Piran, [illegible]r lake, a thick member of white to grey, compact [illegible] was found to be composed of well rounded quartz grains which have been thoroughly cemented by secondary enlargement. The rounding is perfect in grains only 0·2 mm. or less in diameter as well as in the average grain which, in different specimens, ranges from 0·3 mm. to 0·5 mm. in diameter. The rock is ideally pure quartzite, lacking feldspathic or sericitic ingredients. It appears, in fact, to be a lithified

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[1] J. A. Allan, Guide-book No. 8, 12e Congrès Géologique Internationale, Ottawa, 1913, p. 175; cf. C. D. Walcott, Smithsonian Misc. Coll., Vol. 53, 1908, p. 215.

[2] Memoir 38, Geol. Survey of Canada, 1912, p. 170.

dune sand. No such phase was discovered in the Sir Donald formation but the reason may be simply the difficulty of distinguishing, in the field, quartzite of eolian origin from the normal, clearly water-laid quartzite of the formation.

The lithology of the Fairview and upper Hector beds corresponds well with that of the Ross formation, allowance again being made for an increase in argillaceous material in the eastern part of the geosynclinal. It is possible that the Nakimu limestone is represented in the dove-coloured to pinkish limestone found by Walcott about 630 feet below the top of the Hector formation.[1] Greater certainty attaches to the correlation of the lower and thicker part of the Hector with the Cougar formation of the Purcell and Selkirk mountains. The grey, greenish, and purplish metargillites ("shales") of the Rocky Mountain formation, with the interbeds of grits and conglomerates, are exactly duplicated in quality at the Beaver River canyon and other sections in the Purcells. Roughly speaking, the Cougar formation is the western equivalent of most of McConnell's Bow River group.

Thus, in details and in the general succession, the correlation of these sediments seems as justified as it well can be on a lithological basis. It should obviously be tested by further search for fossils in the Sir Donald and upper Ross beds. Annelide borings and "pipe-rock" should be specially sought for, since these are the most abundant traces of life in the Lower Cambrian of the Rockies. However much the suggested correlation may be affected by such future discoveries, there is no possible question that the lower two-thirds, at least, of the Selkirk series is of Pre-Cambrian age, belonging to the Beltian system.[2]

In the great section at Mount Robson, 180 miles northwest of Laggan and 150 miles north of Glacier, Walcott has found the Lower Cambrian developed, with facies very similar to

[1] C. D. Walcott, Smithsonian Misc. Coll., Vol. 53, 1910, pp. 428 and 429.

[2] The equivalence of strata expresses itself in the present topography. In quality the Bow River valley is a replica of the Beaver River valley. Each is overlooked by high massive cliffs composed of the massive Lower Cambrian quartzites, while beneath, in the valley floor itself, are the softened profiles due to the weakness of the thin-bedded Beltian beds.

those exhibited in the Laggan-Mount Bosworth district.[1] His correlation for the Lower Cambrian is summarized as follows:

ROBSON DISTRICT.

Formations	*Thickness, in feet*
Hota	800
Mahto	1,800
Tah	800
McNaughton	500+
	3,900+

MOUNT BOSWORTH SECTION.

Formations	*Thickness, in feet*
Mount Whyte	390
St. Piran	2,705
Lake Louise	105
Fairview	600
	3,800+

The lithological resemblance is specially striking between the McNaughton and Fairview formations and between the Mahto and St. Piran formations. It is to be noted that so expert a collector as Walcott has not succeeded in finding fossils in the Mahto, Tah, and McNaughton beds which total at least 3,100 feet in thickness. Presumably, their correlation has been based on lithological likeness to their equivalents in the Laggan-Lake Louise district as well as on their stratigraphic relation to the fossiliferous Hota formation. Walcott states that "it is difficult to determine the line of demarcation between the sandstone of Cambrian and pre-Cambrian (Belt) age."[2] In this respect, in its as yet unfossiliferous character, and doubtless in essential lithology, the Sir Donald formation of the Selkirks is like the bulk of the Lower Cambrian strata at Mount Robson. Its correlation with the Lower Cambrian of the Laggan-Lake Louise district is thus rendered the more probable.

RELATION OF CAMBRIAN AND BELTIAN IN THE CANADIAN CORDILLERA.

Throughout the North American Cordillera, where he has done systematic field work, Walcott considers that the Cambrian and "Algonkian" (latest Pre-Cambrian) strata are separated by an unconformity. He writes: "During the past ten years, as

incidental to my Cambrian work, I have been studying the contact between the Cambrian and pre-Cambrian in the Cordillera area. From British Columbia and Alberta, on

[1] C. D. Walcott, Smithsonian Misc. Coll., Vol. 57, 1913, p 343.
[2] C. D. Walcott, op. cit., p. 339.

the main line of the Canadian Pacific Railway, to Arizona and southern California, a distance of over 1,000 miles I have found evidence of a transgressing Cambrian sea and consequent unconformity between the Cambrian and pre-Cambrian. It may have been the advancing, overlapping Lower Cambrian sea as in southwestern Nevada, the Middle Cambrian sea as in Utah and Idaho, or the Upper Cambrian sea as in Colorado.

"The Cambrian rocks may be abruptly unconformable upon the Algonkian, or practically conformable as in areas where there has been very little disturbance of the subjacent Algonkian beds. Over the interior of the continent the late Middle Cambrian and Upper Cambrian strata unconformably overlap the Algonkian and Archean, and clearly could not have recorded any part of the history of the period indicated by the absence of Lower Cambrian strata or of the sediments deposited in the period represented by the unconformity between the Lower Cambrian and Algonkian strata. I do not know of a case of proven conformity between Cambrian and pre-Cambrian Algonkian rocks on the North American continent. In all localities where the contact is sufficiently extensive, or where fossils have been found in the basal Cambrian beds or above the basal conglomerate and coarser sandstones, an unconformity has been found to exist. Stated in another way, the pre-Cambrian land surface was formed of sedimentary, eruptive, and crystalline rocks that did not in any known instance immediately precede in deposition or origin the Cambrian sediments. Everywhere there is a stratigraphic and time break between the known pre-Cambrian rocks and Cambrian sediments of the North American continent."[1]

While there is unquestionably an unconformity at the base of the demonstrated Middle Cambrian in Arizona and other states of the Union, no proof has yet been given that all the sediments underlying that surface of unconformity are of pre-Olenellus age. The recent work of Walcott and Allan in the Canadian Rockies has shown, more clearly than ever before, the

[1] C. D. Walcott, Smithsonian Misc. Collections, Vol. 57, 1910, p. 11.

enormous length of Middle and Lower Cambrian time. It appears to have been long enough to allow of sedimentation, followed by moderate orogenic movement with considerable erosion, and then overlapping sedimentation, all within the Cambrian period. The Middle Cambrian (Flathead sandstone) marine transgression in Montana and Wyoming is a phase of crustal uneasiness which affected most or all of the whole eastern half of the Cordillera. That general movement of sea-level may have been associated with local, moderate upturnings of the order described for the visible Grand Canyon series at the Colorado river and for some other so-called "pre-Cambrian" series in the United States part of the mountain chain.

The officers of the United States Geological Survey have held for the last thirteen years that the "Belt series" of Montana and Idaho is entirely of Pre-Cambrian age. Two reasons are given for this view. One is the unfossiliferous character of the Belt sediments. The other is the "unconformable" position of the Belt series beneath the transgressive (Flathead) sandstone bearing Middle Cambrian fossils.

The first argument is obviously inconclusive, as illustrated anew in the unfossiliferons character of most of the demonstrated Cambrian beds of the Mount Robson district. The second argument has value only after the time interval represented in the so-called general unconformity has been evaluated. In another place the writer has expressed doubt that the time break preceding the deposition of the Middle Cambrian Flathead sandstone or its equivalents in Montana and Idaho is of any considerable magnitude.[1] In Utah and in Alberta the Flathead transgression is represented by a widening of the geosynclinal sea, whereby thick limestones, quite conformable with the underlying Middle and Lower Cambrian beds, were centrally deposited while sands were being laid down along the transgressing margins of that sea.

The writer is yet more sceptical as to the existence of an unconformity between the Lower Cambrian and the Beltian in the Canadian Pacific section.

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[1] Memoir 38, Geol. Survey of Canada, 1912, p. 189.

Walcott holds that there is such an unconformity in the Bow valley, and states the evidence in the following words:

"Viewed in a restricted way, much of the pre-Cambrian surface was regular and the Cambrian rocks appear to be conformable to the subjacent pre-Cambrian strata. All about the sides of the valley the strata of the two formations, Fairview of the Cambrian and Hector of the Algonkian, dip away at about the same angle, but, when we apply the test of the varying thickness of the basal Cambrian conglomerate and the difference in the character of the upper beds of the Algonkian in different places, we at once become aware that the pre-Cambrian surface is more or less irregular, and that when the Cambrian sea trangressed over the area now included in the Bow Valley it found a broadly irregular surface with low hills and broad level spaces covered with a deep mantle of disintegrated rock. It washed out the muds and carried them away and deposited the sand and pebbles of its advancing beaches over and around the irregularities of the pre-Cambrian surface.

"The unconformity is well shown at Fort Mountain, where the basal Cambrian is formed of massive layers 4–10 feet thick, which usually rest directly on the Hector shale (pre-Cambrian). In places, however, slight hollows in the shale are filled with thin layers of a more or less ferruginous sandstone that was deposited by gentle currents prior to the deposition of the massive conglomerate layers. The lower 10–20 feet of this conglomerate contains rounded and angular fragments of the subjacent pre-Cambrian formations. The Cambrian sea was evidently transgressing across the dark siliceous shales of the pre-Cambrian land and reducing them to rolled pebbles, angular fragments, and mud. The mud gave origin to small lentiles of shale similar in character to the shale below the unconformity, while lentiles of sandstone of greenish tint indicate that fine material was being derived from still older pre-Cambrian formations than the shale.

"On the southwest side of the Bow Valley the Fairview formation extends well down on the wooded slopes, but

I know of no exposure showing the contact of its basal conglomerate with the underlying Hector shale north of Mount Temple. East of Mount Bosworth the contact of the Cambrian and pre-Cambrian appears to be in the valley just north of Stephen on the Continental Divide.

"Of greater importance is the evidence that the sediments of the two periods were deposited under different physical conditions. The Cambrian sandstones are composed of clean, well-washed grains, and the Cambrian calcareous and argillaceous shales were deposited as muds offshore along with the remains of an abundant marine life. The Hector shales of the pre-Cambrian are siliceous and without traces of life; the sandstones are impure and dirty, with the quartz grains a dead milky white, or glassy and iron stained. The sediments forming them were evidently deposited in relatively quiet muddy waters, and I think in fresh or brackish waters."[1]

The present writer has spent some time in studying the relations in the Bow valley and finds Walcott's arguments unconvincing.

(1. Angular fragments derived from the Hector shales evidently do not prove a significant time break. On the other hand, the writer has found in the Lower Cambrian conglomerate no rounded pebbles which have surely been derived from the Hector formation after its lithifaction.

(2.) The Fairview conglomerate is practically identical in composition and habit with many beds of conglomerate far down in the Pre-Cambrian of the Rockies and closely resembles still older beds in the Beltian Cougar formation of the Selkirks. In the writer's opinion, no one of these conglomerates in preference to any other can be selected as marking an unconformity.

(3.) Variations of thickness in the Fairview conglomerate and in the underlying formation are features to be expected on either hypothesis. Close study of the Cambrian-Beltian strata, both in this railway section and in the 49th parallel section, has shown that the siliceous beds are all lenses. A given lithological

[1] C. D. Walcott, Smithsonian Misc. Collections, Vol. 53, 1910, p. 426.

type is seldom continuous for more than a few miles, especially when measured across the geosynclinal axis. Examples may be seen in the Gateway, Hefty, Wolf, and Ripple formations at the 49th parallel. The remarkable differences in the character of the Cougar formation, the Nakimu formation, and the Ross formation, where these respectively emerge in the two limbs of the Selkirk summit syncline at points separated by only 8 or 10 miles of distance, are further illustrations. On a still larger scale the quartzites of the Cougar largely peter out eastward, to be replaced in the Rockies by the metargillites and siliceous "shales" of the Hector formation. At once so general and so local is this development of lenses in the Rocky Mountain geosynclinal that variations in thickness at any one horizon cannot be taken as evidence of an unconformity until it is clear that these variations are not due to the original conditions of deposition in the geosyncline.

(4.) All observers in the Bow River district agree that the Fairview conglomerate is locally concordant in dip with the underlying Hector. Allan has published an excellent photograph in illustration.[1] Summarizing his detailed work in the region he writes:

"The contact between the Pre-Cambrian and the Cambrian is seldom exposed. It was examined at three localities. At one exposure in Bath Creek valley, near the summit of the Rocky mountains, the contact is a conformable one, while in two other localities in which the contact was exposed, there is a noticeable unconformity between the beds of the two systems. In one case the Pre-Cambrian shales were dipping 31 degrees S. 55° W., and the Lower Cambrian quartzites had a dip of 35 degrees S. 5° W."[2]

At the last-mentioned locality there is a quite moderate discordance of dip between the two formations but it is not obvious that this means an erosion interval. The observed difference of dip is no greater than that often observed in successive beds of a continuous sedimentary series, deposited by

[1] J. A. Allan, Guide-book No. 8, 12e Congrès Géologique Internationale, Ottawa, 1913, p. 173.

[2] Ibid, p. 172.

shifting currents of either air or water. Here again the distinction between an original structure and a true unconformity is extremely delicate. Moreover, the actual amount of discordance is of an order which might be locally produced during the uplifting of perfectly conformable sandstone and shale which yielded in different ways to the deforming force.

In conclusion, the writer believes that it is not justifiable to assume either a general unconformity or an important disconformity at the base of the Fairview formation, nor at any other horizon of the Bow River district between the oldest exposed Beltian and the Carboniferous.

Walcott states, without giving the evidence, that in the Robson district, 180 miles to the northwest, the Lower Cambrian rests unconformably on the Beltian Miette formation. This conclusion is difficult to reconcile with his statement already quoted that there is no obvious plane of separation between the sandstone of Cambrian and Pre-Cambrian age.[1]

Assuming that the Sir Donald and St. Piran formations represent equivalent horizons, the conformity of the Cambrian and Beltian sediments in the Selkirks is quite clear. The exposures at many different sections are practically ideal and at none of them is there the slightest indication of a time break in the sedimentation.

Reviewing the evidence, it seems highly probable that in the heart of the Rocky Mountain geosynclinal prism there is one of the rare localities where the time-interval indicated in the basal unconformity of the Cambrian elsewhere was occupied with the uninterrupted deposition of sediments. Other cases are found in southern Sweden and southern Norway, where the Lower Cambrian passes gradually downward into the Pre-Cambrian within the limits of the sparagmite formation.[2]

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[1] C. D. Walcott, Smithsonian Misc. Collections, Vol. 57, 1913, p. 339.

[2] See A. Tornquist, Grundzüge der geologischen Formations- und Gebirgskunde, Berlin, 1913, p. 53; J. J. Sederholm, in "Different Types of Pre-Cambrian Unconformities," a paper read at the 12e Congrès Géologique Internationale, Toronto, 1913.

CORRELATION WITH CAMBRIAN-BELTIAN ROCKS AT THE 49TH PARALLEL.

In 1910 the writer sent to press a statement of the inter-relations of the pre-Ordovician rocks traversed along the International Boundary and indicated their subdivision into Cambrian and Beltian groups in the present meaning of those terms. Owing to poor exposures and physical difficulties of travel, the stratigraphic results in the boundary belt, where it crosses the Purcell mountains, were unsatisfactory. Fortunately the Director of this Survey detailed Dr. S. J. Schofield to study the stratigraphy of this range in the more open country just to the north of the international line, and the succession has been much better determined. Schofield's results have been published in summary form. Combining them with the writer's original observations in the boundary belt, it is now possible to improve on the stratigraphic description of the Purcell series as given in the Boundary Survey report. The succession shown in the fifth column of the following table is thus to be understood as applying to the western half of the Purcell range at the 49th parallel, rather than to the area studied by Schofield to the north and northeast. Any difference in the respective stratigraphic columns is largely due to the usual variability of the geosynclinal sediments as they are followed across country. Schofield's recognition of the important Aldridge formation is a decided step toward a final understanding of the Purcell series. It is probable that a considerable area of the quartzites shown in the boundary map as belonging to the Kitchener formation really underlies the Creston quartzite and belongs to the Aldridge.

The writer's more recent work on the Canadian Pacific (main line) section has suggested another, but this time minor, change in the correlation table of the boundary report. This consists in the assignment of the whole, instead of merely a part, of the Wolf formation to the Lower Cambrian.

The probable correlations important in the present connexion are noted in the accompanying table. The Summit, Purcell, and Lewis series include equivalent parts of the Rocky Mountain

CORRELATIONS IN THE ROC

	Castle Mountain—Bow River Series (Bow river, Canadian Pacific Ry.)	Selkirk Series (Selkirk range, Canadian Pacific Ry.)	(
Middle Cambrian	Eldon limestone, 2,728 feet Stephen limestone, 640 feet Cathedral limestone, 1,595 feet		B
Lower Cambrian	Mt. Whyte metargillite, 390 feet St. Piran quartzite, etc., 2,705 feet Lake Louise metargillite, 105 feet Fairview quartzite, etc., 600 feet	Sir Donald quartzite, 5,000 feet Ross quartzite (upper part), 2,750 feet ±	Ri Do W
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.*	Mo Ire Ire

...E ROCKY MOUNTAIN GEOSYNCLINAL.

...dian	SUMMIT SERIES (Selkirk range, 49th Parallel.)	PURCELL SERIES (Western part of Purcell range, 49th parallel.)	LEWIS SERIES (Clarke and Lewis ranges, 49th parallel.)
	Beehive quartzite, 7,000+ feet	Kitchener quartzite (upper part), 5,000± feet	Kintla metargillite, 820+ feet Sheppard dolomite, 600 feet Siyeh limestone, 4,100 feet
...00 feet ...part),	Ripple quartzite, 1,650 feet Dewdney quartzite, 2,000 feet Wolf grit, 2,900 feet	Kitchener quartzite, (lower part), 1,000+ feet Creston quartzite, 5,000 feet	Grinnell metargillite, 1,600 feet Appekunny metargillite, 2,600 feet
...part) ...et ...feet ...eet ...5,000 ...1,500 ...feet	Monk metargillite, etc., 5,500 feet Irene volcanics, 6,000 feet Irene conglomerate, 5,000 feet *Unconformity.*	Aldridge quartzite, 6,000 + feet *Base concealed.*	Altyn siliceous dolomite, 3,500 feet Waterton dolomite, 200 feet *Base concealed.*

geosynclinal at the 49th parallel; they have been given special names because of their great lithological contrasts.[1]

Excepting *Beltina*, abundant in the upper part of the Altyn formation, no useful fossils were discovered in the Summit, Purcell, or Lewis series. Nor has anyone yet traced these rocks northward so as to show their relation to the fossiliferous Cambrian of the Field-Laggan district. The correlation is, thus, based purely on lithological resemblance and on general stratigraphic succession. Tentative as such a correlation must be, it has value in suggesting lines of future investigation in the field. The detailed features on which some of the equivalents have been matched are recorded in Memoir No. 38 of this Survey and need not here be described.

The recent study of the Sir Donald formation shows that it has a remarkably close parallel in the equally massive quartzites and grits of the Ripple-Dewdney-Wolf group in the Summit series. In massiveness and great thicknesses, in colours, in degree of lithification and metamorphism, and in quite specialized composition, the matching is extremely close. The abundance of blue, opalescent quartz grains and pebbles and of the alkaline feldspars (microperthite, microcline, etc.) among the clastic ingredients is repeated in both groups. All of these characteristics are found in the fossiliferous St. Piran-Fairview group, with the exception that the latter is somewhat thinner and more ferruginous, as expected from its position in the Rocky Mountain geosyncline. These resemblances, coupled with the fact that the Selkirk and Summit series form part of one mountain range and are found on the same axial line of the Cordillera, compel the writer to emphasize the probability of their equivalent age.

The very massive, grey Creston quartzite of the Purcell series represents the finer-grained, offshore equivalent of the

[1]Schofield considers that the entire Purcell series is of Pre-Cambrian age, though he has found the fossiliferous Middle Cambrian Burton formation to rest "with no discordance of dip" ("conformably") on the recognized beds of the Purcell series (S. J. Schofield, Museum Bulletin, No. 2, Geol. Survey of Canada, 1914, reprint, p. 4; and Summary Report of the same Survey for 1913, p. 131). This important discovery seems to warrant continued scrutiny of the thesis that the entire "Belt series" of Montana, Idaho, and southern British Columbia is Pre-Cambrian in age.

Dewdney-Wolf group, and the Creston has been clearly traced into the Appekunny formation of the Lewis series.

In a similar way the Monk formation thoroughly matches the equally composite Cougar formation. The reader has already noted that the prevailing quartzites and grits of the Cougar, on the west slope of the Selkirks, are largely replaced by metargillites in the Dogtooth mountains and the eastern Selkirks. In the Bow valley of the Rocky mountains this formation is clearly represented in part of the Hector and Corral Creek formations. In the 49th parallel section the Monk formation appears to pass into the finer-grained, more argillaceous Aldridge formation of the Purcell range, and then into the impure Altyn dolomite, 100 miles farther east. The evidence for these transitions is not as full as could be desired, but it is worthy of remark that the Altyn dolomite is, at certain horizons, strongly charged with grains and small pebbles of quartz and of microperthite and other alkaline feldspars with precisely the same habit as those in the gritty and conglomeratic beds in the Monk and Cougar formations.

It is possible that the huge mass of the Irene volcanic (basaltic) formation is contemporaneous with the thin basaltic layer near the base of the Cougar.

The equivalent of the very thick Irene conglomerate at the base of the Summit series has not been identified in any other of the series. In the 49th parallel section the writer found no rock that could be definitely correlated with any part of the Albert Canyon division of the Selkirk series. Some beds of the lower Monk formation recall the dominant, carbonaceous Laurie metargillites of the railway section; yet it is clear that the latter formation cannot have more than a few hundred feet of thickness at the international line, if it is there present at all. The four lowest members of the Selkirk series seem, yet more surely, not to be represented in the boundary section.

The downwarping of the Rocky Mountain geosyncline, with consequent sedimentation, evidently began in the Albert Canyon district much sooner than it did 200 miles farther south. The sedimentation continued in the northern Selkirks until the pre-Ordovician deposits accumulated to their maximum known thickness in the Cordillera. At an epoch comparatively late in the Beltian period, the widening of the geosyncline developed the conditions of sedimentation in the region of the present southern Selkirks and in the whole region to the east as far as the Great plains.

The sedimentation was accompanied by occasional extrusions of basic lavas. At the 49th parallel these have formed the Beltian Irene volcanic formation of the Selkirks, a thin basaltic flow in the Lower Cambrian (?) Grinnell formation of the Rockies, and the extensive Middle Cambrian (?) Purcell lava formation of the Purcell and Rocky mountains. So far as known, similar contemporaneous vulcanism occurred in the Canadian Pacific section only during lower-Cougar time.

CONDITIONS OF SEDIMENTATION IN THE ROCKY MOUNTAIN GEOSYNCLINAL.

SOURCES OF THE CLASTIC MATERIAL.

During the 49th parallel survey it became clear that the mechanical debris there constituting the Rocky Mountain geosynclinal was chiefly derived from a pre-Beltian terrane lying to the west of the present Columbia River valley. The Beltian-Cambrian conglomerates, grits, and quartzitic sandstones of the southern Selkirks have their stratigraphic equivalents in the fine-grained quartzites of the Purcell range and, still farther east, in the argillaceous and calcareous sediments of the Rocky mountains. This systematic change in grain and composition was observed at many horizons in the geosynclinal.[1]

Nowhere in Canada has the eastern limit of this geosyncline been found. However, in Montana not far south of the International Boundary, there is clear evidence that a small percentage of the geosynclinal sediment was derived from an eastern landmass. Walcott states the case in the following words:

> "A more or less shallow open sea extended eastward of the Kootenay valley 300 miles or more. In the vicinity

[1] See Memoir 38, Geol. Survey of Canada, 1912, p. 166.

of Neihart, Montana, there is a trace of the eastern shore-line in the uplift of Archean gneiss and schist, with the basal conglomerate resting upon it. Occasional beds of conglomerate also occur in higher formations of the Algonkian 20 miles and more away from the Neihart Archean. It seems probable that the latter exposure is of an area that was soon buried by the Algonkian sediments, and that the main eastern shoreline, or land area, was still farther eastward during most of Algonkian time. From the character of the Algonkian sediments of the Little Belt mountains it also appears that the eastern land area afforded very little coarse material. It may have been low, sending only muds and solutions of lime and silica to the Algonkian sea, along with an occasional rush of sand and fine gravels."[2]

Thus, not only the increasing fineness of grain of the Beltian-Cambrian clastics as they are followed eastward along the boundary line, but also an inspection of the eastern shore-line, where visible, shows the main source of the material.

The Canadian Pacific section thoroughly corroborates that conclusion, which has been supported also by the studies of Calkins and MacDonald south of the boundary and of Schofield north of the boundary. In the foregoing pages are given several illustrations of the principle used at the 49th parallel. The massive, often sandy or gritty, quartzites of the Cougar formation, outcropping west of the Selkirk divide, become argillaceous quartzites in the Dogtooths and true metargillites in the Bow River valley (Hector and Corral Creek formations). Transitions in the same sense have been described in connexion with the Lower Cambrian of the Selkirks and Rockies. Hence, for all the members which are exposed both in the east and in the west, the rule is followed. Owing to unequal upturning and erosion, most of the pre-Beltian members of the geosynclinal are not exposed in the Rockies, and none of the Middle Cambrian or younger members is exposed in the Selkirks of the railway belt. The comparison of facies cannot be as full as at the In-

[2] C. D. Walcott, Bull. Geol. Soc. America, Vol. 17, 1906, p. 27.

ternational Boundary but, such as it is, it leads to the same generalization.

On the other hand, the railway section is more instructive since it passes through a broad area of rocks actually representing the nature of the land mass whence the geosynclinal clastic sediments were chiefly derived. The basal quartzite at Albert Canyon is definitely shown to have originated in the deeply weathered, older Shuswap orthogneiss. There is no reason to doubt that the fine-grained sandstones throughout the Selkirk series have a similar origin in the Shuswap terrane. The probability of this is specially indicated by the lithology of the conglomerates and grits forming the abundant lenses in the quartzites of the Cougar, Ross, and Sir Donald formations of the Selkirk-Purcell mountains and their equivalents in the Rockies (Corral creek to St. Piran). The pebbles of the coarser fragmentals are chiefly composed of glassy, white to bluish, often opalescent quartz, and of white to pink or red, alkaline feldspars. Microperthite and microcline are particularly abundant. Though measuring a centimetre or more in diameter, pebble after pebble of quartz or feldspar was seen to be a piece of a single crystal. Both in size and in rather specialized composition this coarser debris exactly matches thousands of the pegmatite sills and dykes in the Shuswap terrane. The writer has observed the blue colour and iridescence of the quartz pebbles repeated in the quartz of the pegmatitic injections. In both cases the special optical behaviour is due to straining and granulation of the crystals and has probably been intensified in the metamorphism of the Selkirk series.

In view of all the facts there can be no doubt that the Shuswap terrane has furnished the gravels and coarser sands of the geosynclinal. The fine-grained sands, as shown merely by their intimate, interbedded relation to the pebbly layers, must be credited to the same general source. That conclusion is upheld by the common abundance of clastic, alkaline feldspars in the quartzitic sandstones.

However, at least half of the quartzite in the Rocky Mountain geosynclinal was originally not true sandstone at all, but a highly siliceous mud. The microscope shows that this mud was composed of minute grains of clastic quartz forming 60 to 90 per cent of its weight. The enormous volume of such material in the compact quartzites of the Beltian-Cambrian series at the 49th parallel first became understood after the recent study of the Shuswap terrane.

Many thin sections have been prepared from typical specimens of the thick, extensive Adams Lake and other greenstones. These were found to carry a high percentage of secondary quartz, in grains varying in diameter from 0·005 mm. or less to 0·3 mm., with an average of 0·01 mm. to 0·04 mm. in the different specimens. The micaceous, chloritic, and calcareous schists of the Salmon Arm, Bastion, and Adams Lake formations carry much quartz in grains with diameters ranging up to 2 mm., but averaging not more than 0·1 mm. The micas, carbonates, chlorite, talc, epidote, zoisite, pyrite, and other minerals enclosing these quartz granules, are all liable to complete decomposition during secular weathering. The quartz, more resistant to solution, would thus be free and ultimately concentrated in basins of deposition. The mode of transportation and concentration will be discussed in the next section, where also a statement as to the grain of the siliceous Beltian-Cambrian muds will be found. Meanwhile it suffices to note that the Shuswap terrane as a whole was specially adapted, by its richness in fine-grained schists of the right kinds, to furnish great volumes of quartz dust or quartz silt.

DUNE-SAND QUARTZITES.

While local coarseness of grain, and, more generally, highly developed stratification show that the geosynclinal sediments were in largest part laid down under water, there are good proofs that the wind was also a powerful factor. The evidence is threefold. Some of the quartzites are typical dune deposits; much of the more compact homogeneous quartzite has the character of modern, siliceous loess; and, thirdly, the magnesian limestones of the Rockies contain abundant grains of quartz and feldspar which, judging from their size and form, were clearly driven far by the wind.

The dune sands already noted in the St. Piran formation are composed of exceedingly well rounded grains of quartz, varying in diameter from 0·2 mm. to 1 mm., with averages of 0·3 mm. to 0·5 mm. in different specimens. No other mineral appears in thin section and the sand was lithified by the deposition of infiltrated quartz, giving ideal examples of secondary enlargement of clastic grains. Since many of the grains have a mean volume only one-fiftieth of the smallest grain which can be rounded by running water, their transportation by the wind seems quite clear.[1]

The fact that this St. Piran sand is massive and constituted of pure quartz, practically free from other substances is another strong evidence of an eolian origin.

Similar beds of dune sand were found in the Fairview and Hector formations, though in neither case is the sand as purely quartzose as in the St. Piran. The writer suspects still another horizon in the Ross formation, outcropping at the head of Bear creek; the full evidence is here obscured through metamorphism. The wonderfully massive and pure quartzites of the Cougar formation, west of the Selkirk divide, may also be partly due to the eolian concentration of quartz, but again thorough recrystallization forbids a definite judgment. A similar suspicion attaches to the yet more spectacular Ripple quartzite of the 49th parallel section.[2]

Eolian transportation is shown in the well rounded forms of the quartz and feldspar grains, so abundantly distributed through the thick Altyn limestone of the 49th parallel section. Many of these grains are far too small to have been rounded by water action. They were blown out to sea and sank to the bottom of clear water, from which the magnesian limestone was being chemically precipitated on a great scale.[3] The feldspar grains are largely microperthite and microcline, of the same habit as that in the grits and conglomerates of the Selkirks. It is highly probable that the grains were derived from the Shuswap

[1] Cf. W. H. Sherzer, Bull. Geol. Soc. America, Vol. 21, 1910, p. 625; V. Ziegler, Jour. of Geology, Vol. 19, 1911, p. 654.

[2] Memoir No. 38, Geol. Survey of Canada, 1912, p. 155.

[3] Memoir No. 38, Geol. Survey of Canada, 1912, pp. 56, 64, and Fig. 8.

terrane and that they were carried to their final resting place by the westerly winds which, in Beltian times as now, were the dominant air currents in these latitudes.

LOESSIC QUARTZITES.

In both the 49th parallel and Canadian Pacific sections, at least half of the geosynclinal quartzites are much too fine in grain to be considered as lithified sandstones, of either aqueous or eolian origin. They represent colossal accumulations of quartz and subordinate feldspar, with varying amounts of muddy and calcareous impurities. The quartz and feldspar grains are angular and vary from 0·02 mm. or less to 0·3 mm. in diameter, averaging 0·05 mm. to 0·1 mm. Such beds are common in the Sir Donald, Ross, and Cougar formations, but for purposes of discussion it will be well to consider some of the most remarkable examples in the quartzites of the 49th parallel, since chemical analyses of these are in hand.

The western phase of the Creston formation in the Purcell range is an extraordinarily massive quartzite, a mile or more in maximum thickness. Its homogeneity is likewise striking; in the type exposures no interbeds of conglomerate or grit could be found and true sandstone seems to be very rare; the occasional argillaceous layers were thin in all cases. "Already in the hand specimens numerous glints of light from non-micaceous particles suggest that the rock is highly feldspathic. At the same time it is seen that the general greenish tint of the quartzite is due to disseminated minute plates and shreddy foils of mica. These observations are confirmed by microscopic examination. Interlocking quartz, feldspar, and mica are seen to be the essential constituents. Each of these minerals is glass-clear in the fresh specimens. Orthoclase, microcline, microperthite, oligoclase, and probably albite make up the list of feldspars. Of these orthoclase and microperthite are the most abundant, though it is not certain that in any specimen the other feldspars of the list are absent. The mica includes both highly pleochroic biotite and muscovite, the latter being either well developed in plates or in the typical shreds of sericite. In some specimens the biotite is the more abundant of the two micas but in others it becomes subordinate to muscovite and may disappear altogether.

"Other constituents are very subordinate; they include rare anhedra of titanite, titaniferous magnetite, pyrite, epidote, and zoisite.

"The quartz and feldspar grains vary from 0·02 mm. to 0·2 mm. in diameter, averaging perhaps 0·06 or 0·08 mm. The lengths of the mica scales are usually not much greater. Though few direct traces of clastic form are left among the minerals, it is probable that these dimensions represent approximately the size of the original grains. The texture of the quartzite is thus quite fine in the type specimens as, indeed, throughout all the exposures; in all the thousands of feet of thickness no conglomeratic, gritty, or even very coarse sandy bed was seen."[1]

The chemical analysis of this rock is given in column 1 of the following table of analyses. The weight percentages of the constituents were calculated to be, roughly:

Quartz	58
Albite molecule	21
Orthoclase molecule	9
Anorthite molecule	2
Micas	7
Accessories	3
	100

[1] Memoir No. 38, Geol. Survey of Canada, 1912, p. 123.

Analyses of Quartzites and Loess.

	1	2	3	4	5	6	7	8
SiO_2	82·10	76·90	68·37	51·65	60·01	62·40	76·91	74·46
TiO_2	0·40	0·35	....	....	....	0·43	0·52	0·14
Al_2O_3	8·86	11·25	7·02	7·85	7·44	10·14	12·50	12·26
Fe_2O_3	0·49	0·69	4·41	1·74	3·07	3·47	4·28	3·25
FeO	1·38	3·04	3·99	0·98	2·49	0·57	0·70	0·12
MnO	0·03	0·02	....	....	....	0·07	0·09	0·02
MgO	0·56	1·01	4·41	3·67	4·04	2·07	0·89	1·12
CaO	0·82	0·88	3·89	15·02	9·46	7·30	0·27	1·69
Na_2O	2·51	3·28	0·87	2·69	1·78	1·13	1·39	1·43
K_2O	2·41	1·36	1·34	1·38	1·36	1·83	2·25	1·83
H_2O	0·42	1·40	3·85	1·90	2·87	3·37	....	2·70
P_2O_5	0·04	0·15	....	....	....	0·16	0·20	0·09
CO_2	....	tr.	1·91	13·05	7·48	6·86	....	0·49
SO_3	....	....	....	....	....	0·20	....	0·06
	100·02	100·33	100·06	99·93	100·00	100·00	100·00	99·66

Column 2 of the same table gives the analysis of a type specimen of the overlying Kitchener quartzite, in which the weight percentages of the constituents are, approximately:

Quartz	52·0
Albite molecule	23·0
Orthoclase molecule	5·5
Anorthite molecule	3·0
Paragonite	7·0
Sericite	4·0
Epidote	1·0
Magnetite, titanite, etc	4·5
	100·0

The Kitchener quartzite is clearly similar to the Creston in grain, homogeneity, and essential mineralogy, but is somewhat more ferruginous and, as a rule, distinctly less massive.

Columns 3 and 4 of the table state the analyses of the more calcareous equivalents of the Creston beds in the eastern Purcells and western Rockies, at the international line. Column 5 gives the mean of these two analyses and column 6 gives the average of the analyses of seven American specimens of typical loess and five German specimens. Column 7 states the calculated composition of the insoluble and non-volatile portion of this average leess. Column 8 gives the analysis of a loess sample taken at Kansas City, Missouri.[1]

None of the published analyses of loess shows the upper limit of its possible quartz content. Mr. E. W. Shaw of the United States Geological Survey states, by letter, that quartz constitutes as much as 80 to 90 per cent of certain samples collected on Crowleys Ridge, Arkansas. There are all transitions from such nearly pure quartz dust or quartz flour to the highly calcareous types of Germany. Evidently too much stress should not be laid upon exact chemical composition in attempting to declare the origin of the compact quartzites under discussion. Yet the accompanying table of analyses permits the suggestion that the materials of these quartzites have been largely concentrated by the wind.

Perhaps more compelling is the fact that these geosynclinal sediments are quite unlike any water-transported deposit of similar grain and areal magnitude, known to be forming now on the sea-floor. The mineralogical and chemical contrasts with the muds at present accumulating in the sea are not wholly to be explained by the siliceous character of the landmass (Shuswap terrane) which supplied the clastic material. If that material were transported by marine wave and current only, it is incredible that the aphanitic quartzites should so often carry only traces of argillaceous matter. The observed concentration of minute quartz and feldspar grains represents a decided selection by the transporting agent, such as is not known offshore from granitic terranes at the present day. On the other hand, recent studies of desert regions and the areas to leeward of them show that winnowing by the wind can segregate vast deposits of quartz

[1] Sources in Memoir 38, Geol. Survey of Canada, 1912, pp. 102, 127, 799; F. W. Clarke, Bull. 491 U. S. Geol. Survey, 1911, p. 486; G. P. Merrill, Rocks and Rock Weathering, New York, 1897, p. 330; H. Rosenbusch, Elemente der Gesteinslehre, 3rd ed., Stuttgart, 1910, p. 536.

dust more or less mixed with feldspar dust and quite subordinate grains of other minerals.

This argument by exclusion, the chemical and mineralogical constitution of the compact quartzites, their extraordinary homogeneity and thick bedding (occasionally rivalling the loess of China), and their intimate association with contemporaneous dune sands have prompted the writer to emphasize eolian concentration.

Some of the quartzites may represent deposits of true loess formed on the temporarily dry surface of the geosynclinal as it slowly thickened during the crustal downwarping. Yet many of the compact quartzites are well laminated, as if re-assorted by water, at the bottom of which the dust finally came to rest. It appears probable, in fact, that much of the dust was blown eastward, out to sea, there to accumulate; just as the wind is now carrying Saharan dust to the Atlantic and Mediterranean basins. Similar action best explains the minute, isolated quartz sherds and feldspar granules observed in the Nakimu, Sheppard, Siyeh, Altyn, and Waterton limestones of the geosynclinal, all of which are offshore deposits.[1]

FLOOD-PLAIN AND PLAYA DEPOSITS.

Barrell has shown excellent reasons for belief that certain sedimentary formations in the Rocky Mountain geosynclinal were formed subaërially. That origin is to be ascribed to the Kintla and Grinnell formations of the Clarke and Lewis ranges; probably to the respectively equivalent Gateway-Moyie and Wigwam formations in the same section along the 49th parallel; and to the Spokane formation of Montana.[2] Deep red colour, abundant sun-cracks and ripple-marks at many horizons, and salt-crystal casts are among the features of these sediments which enforce Barrell's interpretation. Walcott has adopted

[1] See Memoir No. 38, Geol. Survey of Canada, 1912, pp. 53, 58, 75, 78, 98, and 105.

[2] J. Barrell, Jour. of Geology, Vol. 14, 1906, p. 553; R. A. Daly, Memoir No. 38, Geol. Survey of Canada, 1912, p. 83; W. H. Emmons and F. C. Calkins, Prof. Paper No. 78, U. S. Geol. Survey, 1913, p. 29.

it and favours the view that most of the Belt series in northern Montana is of non-marine origin.[1] He suggests that even the Beltian limestones were deposited in one or more fresh-water lakes. When, however, the great thicknesses and areas of the Altyn, Siyeh, Sheppard, and Nakimu limestones, as well as their comparative homogeneity in vertical sections are considered, this hypothesis is difficult to accept. It was offered in explanation of the general absence of fossil remains in the Beltian rocks; but their failure may be attributed, with at least as much probability, to the poverty of the Beltian ocean itself in the salts important for the secretion of shell or skeletons. It should be noted that the Beltian limestones, in field habit, order of thickness, grain, structure, and chemical composition, are very similar to the massive Rocky Mountain Cambrian limestones which carry infrequent, though remarkably rich zones of chitinous marine fossils. For these reasons the writer is inclined to believe that most of the Beltian-Cambrian beds outcropping in the Rocky Mountain geosynclinal area were laid down in an open sea.

In spite of careful search, carried on during two field seasons in a region of good exposures, not a single horizon of playa or flood-plain sediment was identified in the Selkirk series. No sun-cracks nor any evidences of saline basins were to be found, and the practically complete absence of ripple-marks in such an enormous body of sands and muds is truly remarkable. It is unlikely that metamorphism is responsible for their failure to appear in the outcrops; the Selkirk series is altered little, if any, more than the Beltian-Cambrian rocks at the Montana boundary, which are very abundantly supplied with ripple-marks at many horizons. It seems necessary to conclude that most of the Beltian-Cambrian sediments in the railway section are offshore deposits.

ORIGIN OF THE PRE-ORDOVICIAN LIMESTONES.

The Shuswap series contains at least 6,000 feet of limestone and dolomite. The Beltian system, at the railway section,

[1] C. D. Walcott, Smithsonian Misc. Collections, Vol. 57, 1910, p. 14.

contains more than 1,000 feet of the same rock types, and in the International Boundary section, at least 3,000 feet. In the Bow River region of the Rocky mountains the Cambrian system includes more than 9,000 feet of carbonate rocks. The origin of the limestones and dolomites which, in merely the pre-Ordovician part of the Rocky Mountain geosynclinal, have a total thickness of 12,000 feet, is manifestly a problem of first-class importance.

A detailed study of the pre-Upper Cambrian limestones and dolomites outcropping in the 49th parallel section showed that only one solution of the problem is acceptable; those rocks are clearly chemical precipitates and not one layer showed the features of a clastic deposit or of a directly organic deposit, such as a coral reef, shell-bank, or foraminiferal ooze. The cause of the precipitation is found in the bacterial decay of animal matter, though Drew recently showed that the precipitation may also be due to the direct action of "de-nitrifying" bacteria.[1]

The pre-Ordovician limestones of the Canadian Pacific section have, as a rule, suffered much more thorough recrystallization than those at the International Boundary. Nevertheless, the writer has found practically unaltered phases of the Cambrian limestones in the Bow River district, and of the Beltian Nakimu limestone in the Purcell mountains. These have the same compactness and general field habit as the Siyeh, Altyn, or Waterton limestones at the 49th parallel. The carbonate granules again range from 0·01 to 0·04 mm. in diameter, with an average for each rock layer of about 0·02 mm. This is the order of size for the carbonate particles precipitated from sea water at ordinary temperatures by ammonium carbonate which has been bacterially generated from animal matter. No other hypothesis of origin can explain the practically entire failure of much larger grains in the unaltered limestones of the geosynclinal, nor the amply proved fact that the same average grain characterizes these rocks throughout thousands of feet

[1] G. H. Drew, Publication No. 182, Carnegie Institution of Washington, 1914, p. 44; cf. Memoir No. 38, Geol. Survey of Canada, 1912, p. 646.

of thickness, in the stratigraphic column from the lower Beltian to the Ordovician, and in field sections 200 miles apart.

That animal matter was abundant on the pre-Beltian and Beltian sea-floor of the region is manifest from the highly carbonaceous nature of important phases of the Sicamous, Laurie, and Nakimu formations. All such phases are more or less siliceous or argillaceous and it seems likely that complete decomposition of organic debris was here prevented by comparatively rapid burial under mud. Where siliceous mud was not being deposited, putrefaction was generally complete and layers of pure carbonate were continuously formed, as in the enormous formations of the Middle and Upper Cambrian.

Locally the Nakimu limestone is oolitic and oolites occur in the Kintla, Macdonald, Altyn, and Irene (volcanic) formations of the 49th parallel section, as well as in the Upper Cambrian of the Rockies between Field and Golden.[1] These deposits, themselves obviously chemical precipitates, are of very subordinate volume and the pre-Ordovician limestones were initially fine, structureless muds.

The formation of magnesian limestones and of dolomite was discussed in the report on the geology of the 49th parallel, and it is not necessary to restate the conclusions on this well worn theme. Modern researches have largely annulled the mystery which long lay over the subject. It is now clear that, under certain conditions, including the presence of decaying animal matter, magnesiam carbonate is chemically formed on a large scale in the calcareous mud at the sea bottom. This result is facilitated if the calcium salts still in solution are present in small amount—a condition which probably affected the pre-Ordovician ocean.[2]

Assuming on apparently good grounds, that the Pre-

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[1] Memoir No. 38, Geol. Survey of Canada, 1912, pp. 61, 82, 101, and 147; J. A. Allan, Guide-book No. 8, Congrès Géologique Internationale, Ottawa, 1913, p. 179.

[2] See Memoir No. 38, Geol. Survey of Canada, 1912, p. 643. N. Yakowlew (Mémoires du Comité, Géologique, St. Petersburg, Nouv. sér., Livr. 94, 1914, p. 61.) has accepted this hypothesis for the limestones of the Donetz basin, southern Russia.

Cambrian ocean water was nearly limeless, an explanation of the lack of calcareous fossils in the Beltian and still older strata is at hand. This question arises in connexion with the geology of the railway belt. The entire absence of animal remains, other than amorphous carbon, in the Shuswap and Beltian sediments cannot be accounted for by metamorphism. The Laurie beds, for example, have been statically metamorphosed, but their alteration is no greater than that observed in many post-Cambrian formations rich in shells and skeletons. The Nakimu limestone presents a matrix certainly as fit to preserve the hard parts of animals as the Silurian limestone of New York state. The writer is thus impelled to adhere to his explanation of the general failure of Pre-Cambrian fossils, as given in the report just cited.[1]

METAMORPHISM OF THE SELKIRK SERIES.

In general the Beltian-Cambrian sediments of siliceous nature have passed beyond the stage of mere lithifaction and, through recrystallization, have attained some or all of the characteristics of true crystalline schists. Their argillaceous material has almost entirely gone over to sericite or paragonite, secondary quartz, etc., so that true shales are practically wanting; metargillites or fine-grained mica schists represent the original muddy and clayey deposits. The clastic grains of quartz and feldspar have usually lost original form and have become minute, interlocking lenses elongated in the planes of schistosity. In the railway section many beds of the Beltian limestones have been completely recrystallized; the carbonate grains are not only greatly increased in size but are commonly developed with their longer diameters in the planes of schistosity and bedding.

[1] Grave doubt attaches to the reported occurrences of calcareous fossils in the older Pre-Cambrian formations. The Atikokania found in the lower Huronian limestone of Steeprock lake, Ontario, seems to be a form identical with an abundant type of the well known concretions in the Permian limestone at Fulwell Hill, England. (Compare the illustrations in C. D. Walcott's paper in Memoir No. 28 of this Survey and in G. Abbott's paper in "Nature," Vol. 92, 1914, p. 607.) The writer is also sceptical as to the organic nature of some specimens from certain Pre-Cambrian formations, which have been described as *Cryptozoon*.

The fissility produced by these various modes of regional recrystallization is always parallel to the planes of original stratification—a law which, here as in the Shuswap terrane, indicates that load metamorphism has been at work on a great scale. The expectation that metamorphism of this type should slowly increase with depth is matched by the facts. An example is shown in the contrast of the partially recrystallized Nakimu limestone with the typical crystalline limestones underlying the Laurie metargillite. Original outlines are often discernible in the larger clastic grains of quartz in the Ross and upper Cougar sediments, but have been practically obliterated in the entire Albert Canyon division of the Selkirk series. On the average the Laurie metargillites and phyllites are coarser-grained than rocks of the same chemical composition in the Cougar formation. The intense sericitization of the Laurie argillites was accompanied by the generation of extremely abundant lenses of white quartz, which lie in the bedding planes of that formation. Millions of such lenses and associated veinlets illustrate the special extent to which solution and recrystallization have affected the lower part of the Selkirk series. Thus, each of the principal rock types of the series has, in general, suffered metamorphism progressively increasing with the thickness of the rock cover pressing upon it.

Hence the relevant facts of the field agree in showing that most of the observed recrystallization in the series is due to static metamorphism.

Locally superposed are the effects of dynamic metamorphism. These were observed in certain narrow shear zones in the Albert Canyon division, but are much more conspicuous in the closely folded, compressed sediments of the Purcell mountains. A large-scale illustration may be seen at the eastern end of Beaver River canyon, where a secondary schistosity crosses, at high angles, the primary schistosity produced by load metamorphism. The nearly vertical planes of schistosity are plainly due to tangential, orogenic compression and the accompanying shearing.

STRUCTURE OF THE BELTIAN-CAMBRIAN TERRANE (SELKIRK AND PURCELL MOUNTAINS) IN THE RAILWAY BELT.

The sediments of the Purcell range and the high Selkirks together constitute a synclinorium nearly 40 miles broad. As shown in the general cross-section (in map-pocket), this structural unit is unsymmetrical, the lower Cougar beds and the whole Albert Canyon division of the Selkirk series not appearing in the eastern limb, though fully represented in the western limb (Plate XXXIV). The chief subsidiary synclines are three in number, respectively, forming the crests of the Selkirk range (Plate XXXIII, B), the Prairie hills, and the Dogtooth mountains. The corresponding anticlines have been unroofed, forming the valleys of Beaver river and Quartz creek. Minor wrinkles were found in all three mountain groups and some are shown in the accompanying maps and sections. Those affecting the slaty rocks just north of Glacier House are not shown. The folds are open except in the Prairie hills, where the limbs are locally almost vertical. These structures all have the regular, northwest-southeast, Cordilleran trend (Plate XXXV).

A conspicuous contorted zone at Laurie makes the only important, visible break in the Illecillewaet River homocline (see page 53), but small-scale crumples were observed in the Cougar formation (Plate XXV). In 1891 Dawson published a section showing an unsymmetrical syncline in the rocks of the Laurie formation (his "Nisconlith series") with axis outcropping near Illecillewaet station.[1] The writer has not been able to find any field evidence of this synclinal fold. Dawson did not traverse the rugged peaks and ridges just north of the railway, where the structure is best displayed. There, as along the railway itself, the beds are locally wrinkled, but the general northeasterly dip is preserved.

Faulting is not an important structural feature of these mountains. Inspection of Maps Nos. 1447, 1448, and 1449, shows the absence of observed dip-faults on a scale large enough to be mapped. Minor strike-faults were found in the summit

[1] G. M. Dawson, Bull. Geol. Soc. America, Vol. 2, 1891, p. 174.

syncline, as, for example, those outcropping near Glacier station. From Mount Abbott a strike-fault is visible in the steep southern slope of Mount Cheops; another is visible from Glacier House, a few hundred feet above the snow-sheds to the northeast. In spite of the obvious nature of these dislocations, the amounts of their respective displacements could not be determined; in neither case does the movement seem to exceed a few hundred feet in the vertical plane. In the field both dislocations were interpreted as normal faults, but it is possible that they are thrusts; owing to the lack of good horizon markers in the quartzites the decision on that point is difficult.

A normal strike-fault, with vertical displacement of perhaps 1,000 feet was postulated in the axis of the Beaver River anticline (Map No. 1449). Apart from local and apparently unimportant slips, no other fault was located anywhere in the Purcell mountains, though some shearing must be assumed to have taken place during the development of the closed syncline in the eastern part of the Prairie hills and at Beaver River canyon.

The origin of the Rocky Mountain trench is certainly connected with the great strike-fault separating the Beltian sediments from the Upper Cambrian-Ordovician beds of the Columbia valley (Map No. 1450 and Structural section). The sharp contact of these two sets of rocks can only be explained by a fault, with a vertical displacement of about 20,000 feet. Probably the contact has not been established by overthrust. No trace of a thrust-plane could be found at or near the contact. In the Beaverfoot range, across the trench, the Palæozoic (Ordovician and Silurian) strata are strongly overturned to the southwest, that is, in the direction opposite to that expected if the Beltian rocks of the Purcells had been driven upward and eastward over the Cambrian-Ordovician beds of the trench.[1]

It seems more likely that the master fault of the trench is normal, with downthrow on the northeast.

A similar relation between the rocks of the Purcell range and those of the trench has been established at the 49th parallel, where Devonian limestones on the east are dropped down into

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[1] See J. A. Allan, Guide-book No. 8, Congrès Géologique Internationale, Ottawa, 1913, plate showing structure section across the Rocky mountains.

contact with pre-Upper Cambrian volcanics and metargillites on the west.[1] Schofield has recently determined that the same zone of faulting extends at least 35 miles to the north-northwest, where the Lower Carboniferous limestone on the east contacts with the Cambrian (?) Gateway formation on the west.[2]

Thus, for at least 250 miles of its length, the Rocky Mountain trench is probably located on a continuous zone of faulting, which is characterized by very great upthrow on the southwest.

However, it may well be that the trench displacement is not merely that due to normal faulting. This greatest known trench is nearly 1,000 miles in length, stretching from Montana to Yukon Territory, and it lies in rocks of many different ages, though keeping its Cordilleran trend throughout. So far as known it is nowhere a typical graben, with equivalent formations left at the same level on the two sides of the fault-zone. Finally, the trench is very narrow in proportion to its length. All of these features suggest that there has been scission and shifting, causing the horizontal movement of the Rocky Mountain system past the Purcell-Selkirk-Columbia-Cassiar Mountain group or vice versa. An analogy is found in the 600-mile San Andreas rift of California which was the locus of the earth-shaking horizontal shift of 1906.[3] In that shift the crustal block southwest of the line of displacement moved northwestward, relatively to that on the northeast side of the line. It is conceivable that a similar type of crustal scission, accompanied by vertical displacement vastly greater than that demonstrated at the California rift, is the true explanation of this remarkable trench of the Canadian Cordillera.

Reviewing the facts ascertained for the Selkirk, Purcell, and Rocky Mountain groups, one is led to the generalization that all the formations from the Beltian to the upper Palæozoic have suffered strong compressive stress directed from the Pacific basin. The resulting crustal readjustments chiefly took the

[1] Memoir No. 38, Geol. Survey of Canada, 1912, p. 118.

[2] S. J. Schofield, Guide-book No. 9, Congrès Géologique Internationale, Ottawa, 1913, p. 53.

[3] The California Earthquake of April 18, 1906, published by the Carnegie Institution of Washington, 1908, Vol. 1, p. 48.

form of strong folding in the Selkirks and Purcells and of overthrusting, with subordinate folds, in the Rockies. Termier's suggestion that the whole Selkirk range is exotic and has been thrust bodily eastward from an original site west of the Shuswap lakes, is not supported by any known facts.[1] On the contrary the Selkirks are still well anchored to the Shuswap terrane, as indicated in the Albert Canyon section, and they have almost surely not suffered more overthrusting than that necessarily involved in the development of the visible, moderate folds of this range.

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[1] P. Termier, Comptes Rendus, Vol. 157, 1913, p. 753.

CHAPTER V.

INTERIOR PLATEAUS WEST OF THE SHUSWAP TERRANE.

The third of the major geological provinces entered during the reconnaissance is represented in the railway zone between Shuswap lake and the western end of Kamloops lake, a distance of about 60 miles (Map 143, A). Except in the immediate vicinity of Little Shuswap lake, where the most westerly outcrops of the Shuswap terrane appear, this whole region exhibits only upper Palæozoic or younger formations. The nearest exposure of the Selkirk series along the railway lies 100 miles to the eastward. As yet, rock formations dating from the Beltian, Cambrian, Ordovician, Silurian, Devonian, and Mississippian are unknown in the railway zone west of Shuswap lake. Thus, in now considering the bedded rocks of this part of the Interior plateaus, the chronological treatment is clearly preserved.

General Stratigraphy.

Between Sicamous and Savona the railway crosses nearly all the important formations which have been recognized in the entire Belt of Interior Plateaus of British Columbia. The structural complexity is of a high order, generally much surpassing that in the Selkirk, Purcell, and Rocky mountains, and rivalling the disorder of the Shuswap terrane itself. Moreover, many of the principal rock members are singularly massive, homogeneous, and devoid of reliable horizon markers. Hence the writer has been baffled in the attempt to construct a columnar section showing well determined thicknesses for the various formations. Their succession and minimum local thicknesses are noted in the following table, which in principle is similar to that of Dawson for the Kamloops district.[1]

[1] G. M. Dawson, Ann. Rep. Geol. Survey of Canada, Vol. VII, Part B, 1896, p. 26.

	Erosion surface.	Thickness in feet.
Oligocene..................	Kamloops group........	1,500+
	Unconformity.	
Triassic (and Jurassic ?)......	Nicola series...........	5,300
	Unconformity.	
Carboniferous (Pennsylvanian)..................	Cache Creek series......	13,700
	Base concealed.	
		20,500

Absence of Beltian and Lower Palæozoic Rocks.

One of the most notable facts connected with the Interior plateaus is their apparently complete failure to show outcrop of the rock systems which play so great a role in the Selkirk mountains and ranges farther east. Dawson thought that the Boston Bar series of the Fraser valley might possibly be of Cambrian age, but Bowen has recently shown that it belongs to the Mesozoic.[1] No other suggestion that post-Shuswap and pre-Carboniferous sed[illegible] or volcanics occur in the Interior plateaus or Coast r[illegible] British Columbia has yet been well supported by observed facts. It seems highly probable that such rocks cannot have large outcrops in this region; else they would have been suspected by Dawson, whose keen eye was there actively at work for many years.

The oldest known Palæozoic rocks of the Interior plateaus belong to the Cache Creek series, of Pennsylvanian age. At a considerable number of widely separated points, these beds are mapped as in direct contact with rocks of the Shuswap terrane. Illustrations from the Shuswap sheet of this Survey, published in 1898, are to be seen at the following localities:

(*a*) South of Cherry creek;

(*b*) West of Vernon;

[1] G. M. Dawson, Bull. Geol. Soc. America, Vol. 12, 1901, p. 68; N. L. Bowen, Guide-book No. 8, Congrès Géologique Internationale, Ottawa, 1913, p. 266.

(*c*) South of Monte hills; and

(*d*) In the Edwards Creek district.

Unfortunately no special study has been made of these contacts, but it is improbable that every one of them is a faulted contact. The simplest hypothesis is that they represent the unconformable overlap of the Cache Creek beds directly on the Shuswap terrane. The apparently complete lack of Beltian and lower Palæozoic strata at all these localities, and the fact that the clastic materials of the Rocky Mountain geosynclinal were chiefly derived from a large land area not far to the westward of the Selkirk valley, may well have a common explanation.

A similar contrast between the Eastern and Western belts of the Cordillera was established during the survey of the 49th parallel section, and a study of the literature indicates that it exists generally in the mountain chain, from California to Bering sea.[1] Until the close of Mississippian time the Western belt was largely a land surface undergoing erosion, while the Eastern belt was a region of sedimentation. Submergence of the Western belt took place during the Pennsylvanian, a time of widespread marine conditions, for thick limestones and other sediments of this age are found in both Cordilleran belts. The clastic deposits of the Pennsylvanian were derived from islands marking the incompleteness of the submergence, and from volcanic piles thrown up above sea-level at many points in the Western belt.

Much more field work needs to be done before it is assured that the pre-Pennsylvanian sediments did not originally extend to the westward of Shuswap lake. The existing evidence is largely negative and is, therefore, clearly incomplete. Such as it is, that evidence has been greatly strengthened by the recent discovery that Dawson's "Nisconlith" and "Adams Lake" series of the lake region are really parts of the Shuswap terrane, and that the western limit of exposed Beltian or lower Palæozoic strata must be placed 100 miles farther east than the limit implied in Dawson's maps.

In any case the geology of the Interior plateaus is entirely different from either of the two great provinces so far described. In composition and history the plateaus are closely allied to the

[1] See Memoir No. 38, Geol. Survey of Canada, 1912, pp. 203 555, and 567.

Coast and Vancouver ranges, all three orographic divisions lying in the Western Geosynclinal belt of the Cordillera, in which the sedimentary rocks are dominantly of Pennsylvanian or later dates.

CARBONIFEROUS SYSTEM.

The Cache Creek sediments appear only once in the area covered by the present reconnaissance. Their outcrop is continuous between Campbell siding and Kamloops, a distance of about 12 miles (Map 143A). Here the railway crosses the strike of a broad band of Carboniferous rocks which may be followed from Shumway lake and Campbell creek northward for more than 60 miles. On the east these Palæozoic beds are overlain by the Mesozoic Nicola series and the stratigraphic equivalents of the former do not reappear in outcrop until the eastern Rockies, 200 miles distant in an air-line, are reached. On the west the Cache Creek beds disappear under the Nicola and Tertiary formations, emerging first near Ashcroft, 45 miles from Kamloops. Hence all the field observations relating to the Cache Creek series were confined to the one area east of Kamloops. This has great structural complexity and the stratigraphic results are not satisfactory.

The first important notice of this area was published by Dawson in 1879.[1] He added a few notes in his report on the Kamloops map sheet (1896) and in the legend of the Shuswap map sheet (1898), on which no special report has been published.

So far as perfection of exposure is concerned, the section of the Cache Creek series on the north slope of the South Thompson valley east of Kamloops is one of the finest in British Columbia. For several miles the Pauls Peak ridge is remarkably bare of forest growth and of superficial deposits. Nevertheless, the rocks are so greatly deformed that it is very difficult to work out the succession. Dips are high, usually varying from 60° to 90° and the observer cannot be sure in some cases whether or not the beds have been overturned. At some points in the section much

[1] G. M. Dawson, Report of Progress for 1877-78, Geol. Survey of Canada, 1879, Part B, pp. 79-82.

faulting is evident, though the directions and amounts of displacement can rarely be ascertained. The best horizon markers are limestone beds which, however, have been so sliced, squeezed, and podded by the energetic mountain-building that none of them has persistent outcrop for more than a short distance. It will thus be understood that the following statement of the rock succession and thicknesses is wholly tentative.

The field data actually secured seem to show that the oldest members of the series occur only at the western end of Pauls peak ridge; the youngest members occur at the other end of the section, where they are unconformably overlain by Triassic beds. The section between these outcrops shows a small number of compressed folds, locally complicated by faults. Pauls peak itself seems to be a transverse remnant of a syncline with a northwest-southeast axis. In the southwest limb the dips average about 75° to the northeast; in the other limb the dips average about 60° to the southwest. At the eastern extremity of the ridge the dip becomes vertical and farther east becomes again northeasterly, with an average angle of 80°, probably indicating an anticline with an axis roughly parallel to the Pauls Peak syncline. Near the contact with the Triassic the disorder is so great that no simple description of the structure is possible.

So interpreting the general tectonic features, the writer has worked out a provisional statement of the succession, as follows:

Unconformable contact with Nicola series.

	Approximate thickness in feet.
1. Massive fossiliferous limestone, with cherty nodules and lenses	1,000
2. Grey argillite, sandstone, and quartzite, weathering brown	1,500
3. Massive sandstone and argillite, weathering grey	800
4. Massive fossiliferous limestone, with a 90-foot bed of volcanic ash and agglomerate in the middle	500
5. Dark, cherty quartzite with interbeds of sandstone and basic volcanic rock	1,800
6. Massive fossiliferous limestone	100
7. Dark, cherty quartzite, with intercalated ash-beds	1,200

8.	Massive limestone	800
9.	Well bedded, black to dark grey, cherty quartzite with interbeds of massive basaltic ash and some flows of amygdaloidal olivine basalt	3,000
10.	Black cherty quartzite, dark siliceous argillite, and greywacke in alternating beds; one 8-foot bed of grey limestone	2,500
11.	Basaltic ash-beds, with interbeds of cherty quartzite	500+
		13,700

Base concealed.

Fossils were found at various horizons in the limestones. They are most abundant in the uppermost member, in which the shells are locally concentrated in great numbers. Other fossils were collected from members *4* and *5*. The whole collection was submitted to Dr. G. H. Girty of the United States Geological Survey, who very generously determined the species noted in the following lists.

From member *1* were collected:

Zaphrentis sp.
Lophophyllum profundum var. sauridens ?
Camarophoria mutabilis
Camarophoria sella ?
Productus cora (Tsch. non d'Orb.)
Productus sp.
Spirifer ? sp., resembling Spiriferina simensis
Chonetes ? sp. (probably young Productus)
Squamularia lineata (Tsch. non Martin)
Crinoid stems
Fistulipora ? sp.
Endothyra sp.; possibly other Foraminifera

In member *4* shells of Productus cora (Tsch. non d'Orb.) were found. Sections of radiolaria appear in a thin section of the cherty layers which are interbedded in this limestone.

Member *5* carries thick lenses of volcanic ash, doubtless of submarine origin. In one of the lenses these fossils were found:

Zaphrentis sp.
Crinoid stems

Phyllopora ? sp.
Spiriferella arctica ?

The main conclusion reached by Dr. Girty may be given in his own words: "All the collections, at least those which contain sufficient species to afford a basis for an opinion, appear to show about the same type of fauna and to represent about the same geologic age. The geologic age may be Gschelian, but one or two forms, particularly *Spiriferella arctica*, if the imperfect fragment really does belong to that species, suggest the Artinskian, or at least the White River fauna, which Holtedahl thought represented the Artinskian in Alaska."

Further field work is advisable to test the question whether the Permian is actually represented in this section. Meantime, it seems wisest to adhere to the traditional view that the larger part of the Cache Creek series is of Pennsylvanian age. The fossils threw no light on the structural relations in this section. It is possible that members *4*, *6*, and *8* are really parts of member *1* repeated in outcrop, and the foregoing columnar section must be read with that possibility in mind.

Nicola Series (Triassic-Jurassic).

From Campbell siding eastward for a distance of 15 miles, the railway traverses a continuous series of rocks which are referred to the Mesozoic Nicola series of Dawson's classification. The Shuswap map sheet indicates a broad band of Tertiary rocks crossing the railway and river east of Ducks and interrupting this Mesozoic area, but the more detailed study of this reconnaissance has shown that the Tertiary formation of the district is confined to the heights overlooking the South Thompson on either side (See Map 143,A).

The relation of these Nicola rocks to the Carboniferous was determined by Dawson and his statement is corroborated by the more recent study. The contact of the two series is well exposed on the north slope of the river valley, opposite Campbell siding (Plate XXXVI). Their relation is that of an erosion unconformity. The basal member of the Nicola is there a 150-foot bed of coarse conglomerate, passing upward into alternating breccias and sandstones, which in turn are overlain by the thick lavas characteristic of this series. The conglomerate is composed of well rounded pebbles and angular fragments of chert, limestone, dark-coloured argillite, banded quartzite, and white quartz, with many large fragments of dacite porphyry. The chert and limestone pebbles have obviously originated in the underlying Cache Creek series. At their visible contact both series dip at an angle of 50° to the eastward, with a strike of N.10°W. This correspondence suggests that the Carboniferous beds lay nearly or quite horizontal when the Nicola gravels were deposited. The cement of the conglomerate is calcareous and Dawson suggested that this member may be the equivalent of fossiliferous limestone near the base of the Nicola series, farther west.[1]

East of this unconformable contact, for an air-line distance of 10 miles, the Nicola rocks are extraordinarily massive lavas, locally interrupted by lithified breccias and tuffs. The exposures are excellent (Plate XXXVII) for most of this section, but structural analysis gave very unsatisfactory results. The lavas, with the monotonous colour composition, and general habit of altered compact basalts, andesites, and porphyrites, are usually not divisible into distinct flows, nor are they abundantly charged with well-bedded pyroclastics. Hence it is seldom possible to find reliable evidence of the true dips. Not more than a dozen readings of strike and dip were made in the whole area, though considerable time and labour were expended in securing such data. The observed dips were read on the rare, always thin intercalations of basaltic ash, or on aligned gas-pores in the lavas. Nearly everywhere the dips are high. North of Ducks two readings gave 90°, with strike N.30°-40°W.; a third gave a strike of N.40°W. with a northeasterly dip of 75°. Farther east, near the contact with the overlying Nicola sandstones, the greenstone lavas showed average dips of about 65° to the east and northeast. South of the river the lavas are greatly faulted and otherwise disordered; the strikes ranging from N.90°E. to N.40°W. the dips from 25° to 90°. On the whole, however, the strike of

[1] G. M. Dawson, Report of Progress for 1877-78, Geol. Survey of Canada, 1879, Part B, p. 81.

the lava beds seems to average about N.35°W. and thus is roughly parallel to the average strike in the neighbouring Cache Creek sediments.

Near Martin the lavas are conformably overlain by a thick mass of hard sandstones and argillites, which apparently form the local top member of the Nicola series. Here the structural elements are much clearer and again the dips are high, from 60° to 85° to the eastward and northeastward, or even vertical. At Niskonlith lake these sediments are completely cut off by intrusive granite (Map 143,A), and the series is locally incomplete.

On comparing Map 143,A, with the Shuswap sheet, it will be noted that considerable changes have been made in the mapping in the region between Martin and Niskonlith lake. Dawson shows this area is underlain by beds of rock belonging to the "Adams Lake" and "Nisconlith" series. However, the recent reconnaissance has shown that the "Adams Lake" rocks are identical in habit with the demonstrated Nicola volcanics just to the west and are perfectly continuous with them. The massive porphyrite (basaltic and andesitic) flows contain occasional interbeds of volcanic breccia, the angular fragments of which include chert, argillite, and grey limestone closely similar to staple phases of the Cache Creek formations. The field data, therefore, tend to indicate a post-Carboniferous date for this band of "Adams Lake" rocks and strongly suggest their inclusion in the Nicola series.

The "Nisconlith" band seems to be best interpreted as a contact-metamorphosed phase of the top member of the Nicola, in contact with the adjoining post-Palæozoic granite. The exposures are extremely poor, but those actually discovered gave no indication that the Shuswap terrane is here represented; on the contrary, the schists close to the granite appear to pass rapidly into the sandy and argillaceous beds which, a little to the west, conformably overlie the typical massive traps of the Nicola series.

From the various field observations the writer has compiled the following table showing the probable succession of beds in the Nicola series.

		Approximate thickness in feet.
	Top locally truncated by intrusive granite.	
1.	Alternating quartzitic sandstones and argillites, with intercalations of volcanic ash and breccia; at the base, very massive sandstone passing gradually into agglomerate which carries thin basaltic flows and thus itself merges into member *2* below ...	1,000+
2.	Very massive, altered, basaltic and andesitic lava flows, with intercalations of basic breccia and tuff......................	4,000+
3.	Basal conglomerate and breccia............	300+
		5,300+

Erosion Unconformity with the Carboniferous.

The volcanic rocks are chiefly basaltic. They are commonly porphyritic, with phenocrysts of augite and olivine, the former predominating. Olivine-free basalt, olivine basalt, basalt very rich in augite phenocrysts, and andesitic basalt have . recognized. More rarely, hornblende andesite and mica-pyroxene andesite were found. Most of the types, though not crushed, are very badly altered and their diagnosis is, therefore, difficult. It is just possible that sills are represented in the more massive outcrops but none was identified in the field, though a thick layer of porphyrite in member *1* may prove to be a sill. A few, narrow, basaltic dykes were noted; no acid intrusives were found except dykes apophysal from the granite on the east. No definite order of eruption could be determined for the volcanic species; yet it is probable that the andesites were sporadic effusions in a volcanic field which, from beginning to end of its history, was chiefly the scene of basaltic eruption.

During the reconnaissance no fossils were found in the rocks of the Nicola series. The local geology fixes their age within limits, for they unconformably overlie the Pennsylvanian limestones and unconformably underlie the Oligocene. The Nicola rocks are upturned to high angles of dip, faulted, and locally sheared—deformed to a degree never equalled in any large-scale Tertiary terrane of British Columbia. These facts alone indicate the high probability that the series dates from the Mesozoic. A more precise determination of age was made by Dawson nearly forty years ago. At several localities in the Interior Plateaus region he discovered, in the Nicola greenstones, thin limestone beds which bear Triassic and Jurassic fossils. According to his measurement, these two horizons are locally separated by 12,000 feet of beds, chiefly volcanic. He estimated the maximum thickness of the series to be possibly as much as 15,000 feet, the larger part of which he refers to the Triassic.[1]

In view of the close lithological similarity of the great volcanic mass east of Kamloops with the volcanics of the demonstrated Triassic to the westward, it is certainly wise to follow Dawson in referring to the Triassic most of the Nicola rocks mapped in the railway belt around Ducks. The bedded sediments overlying the lavas may be Jurassic, but of that there is no direct evidence. The argillites of this part of the series offer the most hopeful outlook for the discovery of fossils in the future.

KAMLOOPS VOLCANIC GROUP (OLIGOCENE).

The youngest bed-rock formation in the reconnaissance area—that is, the railway zone between Kamloops and Golden—is a thick mass of Tertiary volcanics with local intercalations of well-bedded sediments. This has been called the Kamloops Volcanic group. Dawson mapped it under the name, Upper Volcanic group of the Lower Miocene, the Tranquille beds separating it from the corresponding Lower Volcanic group of the same geological period. Since, however, the Tranquille beds form merely local prisms of fresh-water sediment within a

[1] G. M. Dawson, Ann. Report, Geol. Survey of Canada, Vol. 7, 1896, Part B, pp. 49-62.

single volcanic body, it has proved impossible to map the two igneous groups rigorously. Moreover, at the typical locality (Kamloops lake) the lower volcanics are of almost insignificant thickness or are actually not at all represented in the section.[1] It seems better, for the present, to consider the Tranquille beds as an intercalation in a single group of lavas, which is now known to contain similar thick prisms of sediments at still other horizons. To the whole compound unit the name, Kamloops group, suggested by that of the chief town of the region, may be appropriately given.

East of Kamloops the group is represented only in a few outliers, its principal outcrop occurring north and northwest of Kamloops lake. As Dawson pointed out, it is not always easy to distinguish the Tertiary and Triassic lavas in the field. Considerable time was spent on the problem of their delimitation in the region about Ducks. The result has been to change the local mapping of the Shuswap sheet, as shown by its comparison with Map 143, A, of the present report.

The most easterly outlier in the railway belt is that at Mount Ida, south of Salmon arm. There the Kamloops volcanics consist of amygdaloidal basalt and augite andesite, in beds dipping 25°-30° to southwest and west-southwest. They rest unconformably on probably-Jurassic granite. Opposite Mallard point the granite is cut by a multiple (double) dyke of augite porphyrite, which may have been injected during the volcanic activity.

A second isolated mass forms a prominent ridge just east of Shuswap lake. This is also composed of amygdaloidal basalt

[1] In the Spence Bridge district there is a wide outcrop of rocks mapped by Dawson in the Kamloops sheet as "Lower Volcanic Group." As a result of his recent field studies Drysdale has concluded that this volcanic mass is pre-Tertiary and he tentatively refers it to the Mesozoic. (C. W. Drysdale, Guide-book No. 8, Congrès Géologique Internationale, Ottawa, 1913, pp. 251-253.) If this view is correct, Dawson's Tertiary "Lower Volcanic Group" becomes restricted to the few, very small areas mapped in the vicinity of Kamloops lake. This areal restriction, and the very small thickness of the pre-Tranquille volcanics, seem to render inadvisable the proposed subdivision of the Tertiary rocks; they form a natural lithological and stratigraphical unit which cannot now, if ever, be profitably divided for purposes of mapping.

or basic andesite, in flows now dipping 20°-30° to the west-southwest. They rest, with obvious unconformity, on the schistose greenstones and granitic complex of the Shuswap terrane.

In the Ducks region the South Thompson river has cut completely through the largest outlier, so that the Tertiary volcanics crown most of the heights a few miles back from the river, on either side (Map 143, A). They here unconformably overlie, in turn, the Cache Creek and Nicola rocks and the Mesozoic granites. The Tertiary rocks are distinctly less deformed than the older bedded formations but nevertheless are characterized by sudden changes of dip, caused by considerable faulting and sharp upturning. These, more local, effects are superposed on the broad regional warpings which have affected

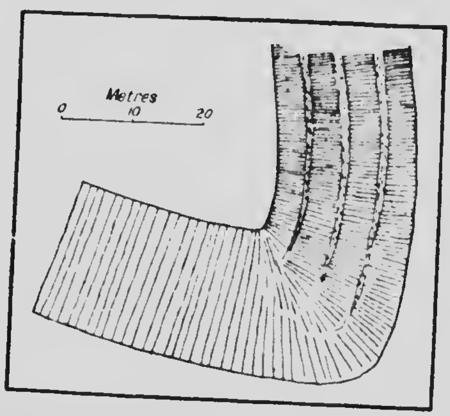

Figure 3. Diagram drawn to scale, showing development of columnar jointing in Tertiary basaltic flow near Ducks station. The gently dipping limb of the syncline is composed of regular columns of great size. The upturned limb is composed of four sets of regular but much smaller columns. The latter seem to have originated through orogenic stresses which were superposed on the normal cooling stresses in the lava long after it had crystallized.

the Kamloops group generally. The rough plateau southwest of Ducks is edged by a retreating escarpment in which greatly decomposed basaltic flows, breccias, and tuffs outcrop, with a southerly dip of 5°. Beneath them is a lens of brown-weathering sandstone with shale and grit phases, showing similar dip. The same series of lavas extends to Monte creek, near which the dips range from 20°-90° (Figure 4) and average perhaps 60°. The strike also shows frequent sharp changes, indicating fault fracturing on a large scale. High angles of dip were also observed in the lavas 4 miles and more northeast of Ducks, where they range from 20° to 60° northeastward.

West of Kamloops the Tertiary volcanics seem to be less deformed and some of the plateaus are reported by Dawson to show nearly horizontal structure.

Within the reconnaissance area there is no section showing a complete section of the Kamloops group. Several localities indicate thicknesses approximating 1,000 feet, and it is likely that a maximum as high as 1,500 feet is locally represented. Dawson found 3,100 feet of lavas and tuffs in his "Upper Volcanic Group" at the Nicoamen plateau.[1] Drysdale states that the average thickness of the group, along the railway, west of Kamloops is about 2,500 feet, and he adopts Dawson's estimate of 1,000 feet for the maximum thickness of the Tranquille beds.

Lithologically the Kamloops volcanics offer no novelty. They are chiefly ordinary basalts, locally rich in olivine phenocrysts but perhaps as commonly olivine-free. The latter type merges, on the one hand, into ultra-femic olivine-free, highly augitic basalt; and, on the other, into augite andesite. No other types were recognized in the areas east of Kamloops, but west of that town Drysdale found some trachytes among the dominant basalts. A few dykes of fresh olivine basalt were the only intrusives seen to cut these volcanics in the railway belt east of Kamloops.

The interbedded sediments found in that belt occur in the scarped mountain overlooking the river, southwest of Ducks. Near the summit the sandstone-shale lens mentioned above is at least 100 feet thick. Lithologically it is very similar to certain phases of the Tranquille beds, but no fossils were here discovered. The base of the brown-tinted lens is covered with talus, at the foot of which is a single large outcrop of pale grey, massive,

[1] G. M. Dawson, Ann. Report, Geol. Survey of Canada, Vol. 7, 1896, Part B, p. 74.

sedimentary rock which appears to be quite unique among the known Tertiary formations of the Interior plateaus. It is locally called "free-stone," but the microscope shows that it is not a sand-rock but a well lithified silt, strikingly similar to the late Pleistocene white silt that forms the conspicuous terraces along the South Thompson. The largest recognizable grains in the rock are angular sherds of quartz not over 0·02 or 0·03 mm. in diameter, material very similar to that in the terrace silt. This peculiar rock seems to be a local lake deposit. It occurs at or very near the base of the Tertiary group and probably not far from the horizon of the Tranquille beds. It carries a few black, carbonized plant stems but no index fossils.

The precise age of the Kamloops group offers a somewhat difficult problem. The volcanics, at least in the lower horizons, are clearly contemporaneous with the Tranquille beds, with which the lavas and tuffs are interstratified. These sediments carry fish remains and a considerable fossil flora. From the former, Lambe has correlated the beds with the *Amyzon*-bearing formations of Colorado and Nevada.[1] Basing his conclusion on a very small collection of the plants, Sir William Dawson suggested that the beds are Miocene; they were accordingly assigned to that date by G. M. Dawson who coloured the Kamloops map sheet. In 1906 Lambe made a much larger collection of plants which have been discussed by Penhallow, who wrote:

> "The conclusion appears justified, to the effect that these beds are of Oligocene age, and possibly not higher than Upper Eocene."[2]

On page 110 of his memoir, Penhallow states that the plants of another collection derived from "beds near Kamloops" (evidently Tranquille) "probably belong to the Oliogcene, certainly not higher, possibly lower." In his general summary (page 144) he concludes that the combined evidence of the fish and plant remains points to an Oligocene age for the Tranquille beds. The Kamloops group has been similarly referred and so coloured on Map 143, A.

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[1] L. M. Lambe, Trans. Roy. Soc. Canada, Vol. 12, 1906, Sect. *iv*, p. 155.

[2] D. P. Penhallow, Report on Tertiary Plants of British Columbia collected by Lawrence M. Lambe in 1906, together with a Discussion of Previously Recorded Tertiary Floras, Dept. of Mines, Geological Survey Branch, Ottawa, 1908, p. 116.

CORRELATIONS WITHIN THE WESTERN GEOSYNCLINAL BELT.

The area which the reconnaissance covered between Shuswap lake and Kamloops is relatively very small, but it shows outcrops of most of the important formations so far recognized and dated, within the Belt of Interior Plateaus. The geological systems represented are largely identical with those that have been demonstrated in the Coast range and Vancouver island. A principal exception is the presence of thick Cretaceous deposits in the western sections, while sediments of that age are unknown in the eastern part of the plateaus region. The still more local, marine Tertiary beds of the coast differ in origin and in age from the Tertiary sediments of the interior. In spite of these and other contrasts in local stratigraphy, it is expedient to regard the Interior plateaus, Coast range, and Vancouver range as being chiefly constituted of a Carboniferous geosynclinal prism, overlain unconformably by a thick, nearly coextensive cover of early Mesozoic volcanics and sediments; both great groups of rocks being locally replaced by batholiths of granodiorite or other granitic types.

In Memoir 38 of this Survey (1912, page 55), the writer has briefly discussed the correlations so far made within this western part of the Cordillera. The agreement of the stratigraphy in standard sections, all the way from Alaska to Oregon, testifies to the general unity of the Western Geosynclinal belt. It is not necessary here to repeat the statement of its ascertained history, which has been summarized still more recently.[1] Since the manuscripts of these publications went to press, Clapp's able volume on the geology of southern Vancouver island has appeared.[2] Of present interest are his conclusions that the island shows: Carboniferous sedimentation (of the Cache Creek type) on a geosynclinal scale; heavy vulcanism in the early Mesozoic (corresponding to the Nicola vulcanism); and extensive batholithic intrusion in post-Triassic, pre-Tertiary time.

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[1] R. A. Daly, Guide-book No. 8, Congrès Géologique Internationale, Ottawa, 1913, p. 157.

[2] C. H. Clapp, Memoir 13, Geol. Survey of Canada, 1912, p. 36.

By these processes most of the important rock bodies composing southern Vancover island were formed. In date and general quality they correspond to the leading formations of the Kamloops-Shuswap area. The local Cretaceous cover of the island has no equivalent in the eastern plateaus region, nor has the volcanic Tertiary cover, the Kamloops group, any known equivalent in the southern part of Vancouver island; otherwise the petrogenic histories of these two distant regions are essentially similar. The work of Dawson, Camsell, Bowen, and Drysdale has shown that, in rock formation and history, the 250-mile section from Kamloops to Vancouver has the same general record.

On the lower course of the Fraser river the railway section enters the mountain zone covered during the survey of the International Boundary. The Cache Creek series can be traced, through Bowen's "Agassiz series," into the "Chilliwack series" which was studied and named at the 49th parallel. Their equivalents on that line of latitude are: (probably) the Leech River formation of Vancouver island, on the west; and, on the east, the Hozomeen series of the Skagit and Hozomeen ranges, the Anarchist and Attwood series of the Interior plateaus, and the Pend D'Oreille series of the Columbia and Selkirk ranges.

Thus, two transverse sections of the Cordillera, sections well separated by distance except on the Pacific coast, agree in showing that the entire region west of the Selkirk valley was the scene of late-Palæozoic sedimentation on a grand scale. That master geosynclinal extended from California to Alaska; in continuity, though not in thickness, rivalling the parallel Rocky Mountain geosynclinal of older date. The post-Pennsylvanian history of the Carboniferous geosynclinal is complex, but the complications have been added in the same general order throughout the length of that great prism. In other words, the Western Geosynclinal belt has acted as a unit through a large part, if not all, of Beltian and later time. Its magnitude and its location at the contact of continental plateau and ocean basin suggests that the major changes in the Western belt were directly controlled by planetary forces.

CHAPTER VI.

INTRUSIVE ROCKS YOUNGER THAN THE SHUSWAP TERRANE.

As in other transverse sections of the Canadian Cordillera, the railway zone shows, as regards non-sedimentary formations, a strong contrast between the Eastern and Western geosynclinal belts. The former belt exhibits few igneous formations of any kind; the latter belt has, in many cross-sections, igneous-rock outcrops that equal or surpass the outcrops of sedimentary rocks in respective areas. In this respect the broad area chiefly occupied by the Shuswap terrane is intermediate in quality, so far as Beltian and later igneous action is concerned. The extrusive formations of the reconnaissance area have been described in connexion with its stratigraphy; incidentally a few basic dykes associated with the volcanic rocks have been mentioned. There remain for discussion a considerable number of intrusive bodies which show no such genetic connexion. In most cases these cannot be closely dated and may well be treated under a separate heading.

Trap Dykes Cutting the Shuswap Terrane.

All members of the pre-Beltian complex are cut by dykes or thin sills of basic composition. These have been noted in the terrane as far east as the Columbia Range divide; as far west as Little Shuswap lake; and in the broad area between Anesty and Seymour arms on the north, and Salmon arm, Mara arm, and Frog lake on the south. Of the scores or hundreds of such intrusions which might be mapped along the usual lines of travel, a number of types were sampled for microscopic examination.

The majority are deep green, steeply dipping dykes of trappean habit, proving to be augite porphyrites or diabase porphyrites, uncrushed but usually so thoroughly altered into uralite, chlorite, carbonate, etc., that a complete diagnosis of the original composition is impossible. From their mineralogical and inferred chemical similarity to the not far distant Nicola traps, it appears possible that these dykes are of Triassic date. Their degree of alteration and greenstone habit render it improbable that these injections are connected with the Tertiary vulcanism.

In the Columbia range trap dykes with the apparent composition of augite camptonite were found. One, with a width of 3 feet, occurs on the lumber company's railway 1,400 yards north of Frog lake; another, 4 feet wide, crops out on Crazy creek about 1 mile above Taft. Like most of the porphyrite dykes, these have the Cordilleran trend, running N. 30°-40° W. About 200 yards south of the dyke first mentioned the Shuswap gneiss is cut by a 1·5-foot dyke of kersantitic rock, also non-sheared, and striking N. 40° W.

The trap dykes are specially numerous in the vicinity of Cinnemousun narrows, where they are chiefly porphyrites of the dominant type. On the east shore of Seymour arm, about 2 miles north of the narrows, a 50-foot, medium-grained dyke was found to be exceptional in containing much free quartz. It is a massive, somewhat schlieric, micropegmatitic quartz-hornblende-biotite-orthoclase-plagioclase rock, recalling a common phase of the great sills of the southern Purcells.

Basic Injections Cutting the Selkirk Series.

At two points in the Selkirk range, igneous rocks of quality very similar to the species last noted were observed.

One of these bodies is a sill outcropping at the 6,700-foot contour on the ridge just south of the mapped lakelet 2 miles northwest of Flat Creek siding. The sill is from 35 to 40 feet in thickness. It is composed of a hornblende-biotite diorite bearing much interstitial quartz and accessory orthoclase. The rock is uncrushed but somewhat epidotized and sericitized. It cuts the upper quartzites of the Laurie formation, a horizon several thousand feet below the volcanic beds in the Cougar quartzite. The relation is thus analogous to that between the Purcell sills and Purcell lava at the 49th parallel section, but there is no evidence that this diorite and the basalt of the Cougar horizon are genetically connected.

The other locality mentioned is near Cutbank siding, where large boulders of a gabbroid rock occur, in such numbers that it is quite likely that the rock forms one or more intrusions in the mountain slope to the north. This occurrence is mentioned specially because of the strong similarity of the rock to the standard phase of the Purcell sills at the International Boundary. The Cutbank locality is on the tectonic strike from that part of the boundary section where the Purcell sills are well developed. The question arises as to whether the Beltian series were simultaneously injected by the gabbro at sections as far removed as that along the Canadian Pacific and those at the 49th parallel and still farther south.

The only other intrusives seen in the railway belt between Albert Canyon station and Golden are two thin injections, both of which are exposed in the celebrated gorge 2 miles east of the former station.

In the walls of the gorge two dykes of lamprophyre appear, dipping 85° due west, and cutting the Laurie metargillite. They are respectively about 3 feet and 1 foot in thickness. The rock is dark, greenish-grey, somewhat porphyritic, medium-grained minette with chilled margins. The phenocrysts include fresh idiomorphic biotites, up to 2 mm. in diameter; prisms of augite up to 1·5 mm.; and talcose pseudomorphs of a mineral which was very probably olivine. The groundmass was diagnosed as orthoclase, with accessory mag.. ·tite. Except for some secondary carbonate and the talc, the rock shows little alteration and is quite uncrushed.

The other injection in the gorge metargillite is a basaltic sill, about 3 feet in thickness, dipping from 30° to 60° to the northeast. The variation of its angle of dip is related to the fact that the sheet locally cross-cuts the sediments. The most remarkable feature of the body is its notable vesicularity. It is strongly charged with typical gas-pores reaching a maximum observed length of three-quarters of an inch and width of one-half inch. The rock is very fresh and is essentially a holocrystalline aggregate of augite and basic plagioclase in the proportions of a normal olivine-free basalt. The structure varies from the diabasic to the panidiomorphic. At least some of the gas-pores are filled with zeolites. In thin section a small, apparently endogenous inclusion composed of intergrown crystals of pure plagioclase was observed. This body has its chief importance in showing pronounced vesicularity, though it was injected under a rock cover presumably hundreds, if not thousands, of feet in depth.

Granitic Bodies of Jurassic (?) Age.

Within the reconnaissance area four granitic masses, of date much later than the Shuswap intrusives, have outcrops of considerable area. All of them are located in the Interior plateaus, between Sicamous and Kamloops (Map 143, A). The largest area mapped surrounds Salmon arm and may be called the Salmon Arm body. A much smaller one, to the northwest, is situated near the mouth of Adams river. A third crosses the South Thompson a few miles below Little Shuswap lake; it may be referred to as the Niskonlith body, since it forms the shore of the lake of that name. The fourth, probably the largest mass of all, enters the railway zone at Campbell creek and may be conveniently referred to under the name, Campbell Creek body. South of the railway belt, in the Prairie hills, there is another granitic mass which was not mapped but is here mentioned for the purpose of record. Finally, a word will be added regarding the somewhat remarkable Cherry Bluff intrusive, west of Kamloops, which was examined though it lies outside of the area covered by the present report.

Definite proof that these bodies are of post-Shuswap age has been obtained in only three cases. The Niskonlith granite has strongly metamorphosed rocks of the Nicola series, which are also cut by apophyses of the granite. Dawson demonstrated a similar relation between the Campbell Creek body and the adjacent Nicola traps.[1] The present writer found apophyses of the Cherry Bluff intrusion in the Nicola rocks.

[1] G. M. Dawson, Ann. Report, Geol. Survey of Canada, Vol. VII, 1896, Part B, p. 248.

The probability of a similar date for the Adams River and Salmon Arm bodies is of a high order. Their granitic rocks outcrop at distances of only a few miles from the post-Triassic Niskonlith granite, to which they show strong lithological resemblance. In fact all three areas may be as many outcrops of a single batholith. All three bear traces of orogenic straining, but they are like all the other bodies mentioned in showing a lack of general, strong foliation which is so characteristic of the pre-Triassic (Shuswap) granites. They are further contrasted with the Shuswap granites in not displaying abundant aplitic and pegmatitic phases and apophysal dykes and sills, which are also characteristic of Shuswap granite bodies of large dimensions. Since, between Shuswap time and the Jurassic, no period of granitic intrusion has yet been recognized in the Canadian Cordillera, it seems best to conclude that the Salmon Arm and Adams River granites, as well as the Niskonlith and Campbell Creek granites intruding the Nicola series, are of post-Triassic date.

An inferior limit for the age of these bodies is not obvious from the data derived in this reconnaissance area. The Salmon Arm granite is directly overlain by the Oligocene volcanics of Mount Ida, and, from the failure of apophyses in, and contact metamorphism of, the lavas immediately above the granite, the pre-Oligocene age of the latter is comparatively well assured. That conclusion is supported by the occurrence of numerous parallels in the area covered by the Kamloops sh[illegible]on) and in the Cordillera at the International Boundary and farther south. Since no Cretaceous or Eocene rocks exist in the reconnaissance area, the dating can be made closer only by considering the general history of the Cordillera. So far, the ascertained facts suggest that, in the Canadian portion, only two batholithic periods are represented in the time between the close of the Triassic and the present day. Judging from its colossal results, the one of greater importance is of late Jurassic date; the other is probably late Miocene. It is surprising that no Eocene batholith, intruded in direct consequence of the Laramide revolution, has been demonstrated in Canada; yet this may be accomplished during future field work. Batholiths in California and in Alaska have been assigned to the early Cretaceous, but none of that age has been discovered in Canada. A pre-Tertiary date for the granitic bodies here considered is suggested by the fact that they show evidence of having undergone somewhat severe orogenic compression. Their rocks are locally foliated and, even where quite massive in the field, show strain phenomena under the microscope. Such effects are those to be expected if these bodies had been compressed during the Laramide revolution.

In conclusion, it seems probable that the four granitic masses mapped between Sicamous and Kamloops were intruded in the same general period and that they all date from the late Jurassic. The age of the Prairie Hills and Cherry Bluff bodies will be briefly discussed in the sequel.

The *Salmon Arm mass* covers more than 100 square miles. It has cross-cutting relations to the sediments and greenstones of the Shuswap terrane and appears to be a true batholith. Most of the body is composed of homogeneous, pale grey, medium-grained biotite granite. Of the feldspars, microcline is the most abundant; orthoclase and acid plagioclase (probably oligoclase in average composition) are also essential. In the two thin sections studied the quartz shows undulatory extinction but the rock is little or not at all granulated. A little sericitic muscovite is present, probably as another effect of incipient metamorphism. Near Tappan the granite is cut by several narrow dykes of coarse muscovitic pegmatite bearing large crystals of perthite.

On the south shore of Salmon arm, 10 miles from Sicamous, and again on the point projecting into the lake at the western end of Bastion Mountain ridge, a syenitic rock outcrops which from its position appears to be a contact phase of the Salmon Arm batholith. The syenite lies between the normal granite and the truncated edges of the Bastion and Salmon Arm sediments. Its two outcrops are separated by the lake waters and it is impossible to determine whether they belong to a single continuous zone along the batholithic contact.

The syenite is coarse, porphyritic, and of a light, pinkish colour. It is quite massive and uncrushed. The phenocrysts consist of microperthite and more abundant plagioclase crystals, reaching 1·5 cm. in length and averaging about 1·0 cm. These rest in a groundmass composed of microcline, microperthite, orthoclase, oligoclase, quartz, biotite, and a little green hornblende. Titanite and magnetite are accessory. The rock is a syenite somewhat rich in alkalis. So far as known, it occurs only on that side of the batholith where basic sediments form an important part of the country rock. This association recalls a rule affecting the field relations of syenites in general.[1]

The *Niskonlith body* cross-cuts the Nicola beds on the west and the Shuswap sediments and gneisses on the east; it is overlain, apparently in unconformity, by Oligocene lavas. For a distance of several hundred feet the Mesozoic rocks are metamorphosed. The intensity of the alteration and the general field relations, so far as determined, suggest that this intrusive mass is also of subjacent (batholithic), not merely injected, origin. Where observed, it is uniformly composed of a common type of hornblende-biotite granite, too poor in femic material and plagioclase to be classed as a granodiorite. The granite is fairly fresh on the outcrop. It is massive, with but rare suggestion of a foliated structure, though thin sections show that it is distinctly strained and even locally granulated. Where most affected by orogenic stress, epidote and microcline are specially abundant.

The small *Adams River mass* is stock-like, cross-cutting greenstones and associated schists of the Shuswap terrane. It is a pinkish grey, medium-grained biotite granite, very similar to that forming most of the Salmon Arm batholith.

True granodiorite constitutes the mapped portion of the large *Campbell Creek mass*, which clearly cross-cuts the Carboniferous sediments in batholithic fashion. The width of the metamorphic aureole is, at least locally, to be measured in hundreds of feet. The only observed variation from the normal granodioritic composition was found in a band of grey biotite granite occurring on Campbell creek. This band has the appearance of being a contact phase, merging inwardly into the dominant granodiorite of the batholith. If so, it represents another exception to the general rule that batholithic contact

[1] R. A. Daly, Igneous Rocks and Their Origin, New York, 1914, p. 403.

phases are more femic th[illegible] the principal phases. A thick sill of quartz-hornblende dior[illegible] yards wide on the outcrop and nearly vertical, cuts the [illegible]boniferous sediments at Pauls peak and is probably apo[illegible]om the Campbell Creek batholith. Such associat[illegible] and granodioritic rocks is common throughout th[illegible]lt of the Cordillera.

Owing to its pecul[illegible], the *Cherry Bluff mass* was specially examined, thou[illegible]rop lies outside the area on which the present report [illegible]. The b[illegible]dy outcrops on the north and south shores [illegible] lak[illegible]attle bluff and Cherry bluff respectively [illegible] Its ground plan is that of an ellipse, 5 mi[illegible]iles in greatest width (See Kamloops sheet). T[illegible] Ter[illegible] away from it on all sides except on the sou[illegible]hwest, [illegible]ey have been completely eroded away. Th[illegible] first impression given by the field relations is that the Cherry Bluff mass i[illegible] a laccolith which has domed the Tertiary beds during its intrusion. Closer study tends, however, to throw doubt on that hypothesis.

The mass itself is schlieric and heterogeneous, varying from augite gabbro, through augite diorite, to femic monzonite. One of its apophyses is quite salic, with the composition of monzonite aplite.

The apophyses were found to cut the Nicola volcanics only and none seems to cut the Tertiaries. Both the intrusive mass and the invaded Triassic rocks are greatly altered, sheared, and slickened, while the overlying Tertiary sediments, tuffs, and lavas show none of these features but simply those due to gentle upturning, to angles seldom greater than 15°. Finally, the mass is cut by dykes of fresh olivine basalt which is chemically identical with the overlying Tertiary lavas.

These facts find explanation on the view that the Cherry Bluff body is an injection (laccolithic ?) of pre-Tertiary and late Triassic or post-Triassic date. After its intrusion it was unroofed by erosion and, during the Oligocene, was covered with the lavas and freshwater sediments of the Kamloops group. The latter were afterwards buckled into a roughly domical shell about the extraordinarily strong and tough mass beneath them. This deformation was presumably contemporaneous with that which has deformed the Oligocene formations elsewhere in the plateau region.

However mistaken this explanation may be in details, it is clearly more in accord with the facts than Dawson's suggestion that the Cherry Bluff mass represents a principal vent of the Tertiary lavas.[1]

Simply for record it may be noted that a considerable body of coarse biotite granite is located in the upper part of *Grizzly Creek valley*, in the Prairie hills. This rock was not seen in place but was discovered in the form of very large and numerous boulders along the creek, which have been carried down the valley even as far as its confluence with Beaver river. The granite is porphyritic, with simply twinned phenocrysts of alkaline feldspar reaching 2 inches in length. It is very fresh and free from any evidence of having been strained or crushed by mountain-building forces. That fact suggests a late date for its intrusion, possibly one as late as the Tertiary. It is the most easterly body of granite known to occur near the Canadian Pacific main line. Post-Carboniferous granites of large respective areas have been mapped in the neighbouring Selkirks both north and south of the railway belt.[2]

SUMMARY OF THE IGNEOUS ROCKS.

Reviewing all the igneous formations encountered in the reconnaissance area, one immediately observes the banality of the rock types. Their sequence of eruption is shown in the accompanying table.

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[1] G. M. Dawson, Ann. Report, Geol. Survey of Canada, Vol. VII, 1896, Part B, p. 73.

[2] See this Survey's Geological Map of the Dominion of Canada, on the scale of 50 miles to 1 inch, edition of 1901.

Period	Formation	Forms of bodies	Rock species
Oligocene	Kamloops	Fissure and central eruptions; associated dykes.	Olivine basalt, olivine-free basalt, andesites; porphyrites.
Jurassic (probably)	....	Batholiths, stocks, sills and dykes; (laccolith at Cherry bluff ?)	Granite, granodiorite, quartz diorite, syenite; (monzonite-diorite-gabbro at Cherry bluff.)
Triassic	Nicola	Fissure and central eruptions; associated dykes.	Olivine basalt, olivine-free basalt, andesites; porphyrites.
Carboniferous (Pennsylvanian)	Cache Creek	Central (and fissure ?) eruptions.	Basalt, basic andesite.
Beltian	Cougar	Flows and volcanic projectiles. (Sill.)	Basalt. (Diorite, of sill —date ?)
Shuswap terrane	....	Batholiths, sills, laccoliths, dykes.	Granite, quartz diorite; various orthogneisses; aplite, pegmatite.
Shuswap terrane	Adams Lake	Volcanic (fissure ? and central ?) eruptions; sills and dykes.	Basaltic and andesitic (?) types, now green schists; diabase, porphyrite.
Pre-Shuswap	....	....	Granite or gneiss.

Many porphyrite dykes cutting the Shuswap terrane, the lamprophyric dykes described, and the basaltic sill at Albert canyon (gorge) cannot be closely dated.

The table illustrates certain fundamental rules affecting the igneous rocks of the world.

(1.) Basaltic magma is that one which most steadily recurs in complete eruptive sequences. In this area it was extruded in the pre-Beltian, Beltian, Pennsylvanian, Triassic, and Oligocene periods. During so great a time interval, from the pre-Beltian to the Tertiary, this eruptive product has had practically uniform composition.

(2.) By far the greater part of the intrusive rock of the area is acid (granitic), while all the extrusive magmas have been overwhelmingly basic (basaltic).

(3.) As so often illustrated in other parts of the earth, the basalts are associated with andesites in the most intimate way; they are repeatedly interbedded, and with these types there are numerous lava flows of intermediate composition. As usual, augite andesite (or augite porphyrite) is clearly the most abundant of the andesitic types; hornblende and mica andesites are rare.

(4.) As usual, the Pre-Cambrian granites are somewhat more salic than those of later date, with a quite special development of aplitic and pegmatitic phases. These leucocratic rocks seem to be more sodiferous than the granites, of which they are satellitic differentiates. The writer suspects that this chemical relation generally obtains throughout the larger Pre-Cambrian areas of the Cordillera, if not of the world.

(5.) The extraordinary prevalence of concordant injections (sills and laccoliths) in the Shuswap terrane is a special feature of the Pre-Cambrian, as shown also in the Canadian shield and elsewhere.

(6.) The intrusive relation of the Shuswap orthogneisses and granites to the Adams Lake and other greenstones is strikingly like that between the Laurentian and Keewatin in eastern Canada, or that between the older granites and "metabasites" of Fennoscandia. Such repetition of several specialized features cannot be accidental and must find explanation in a final theory of igneous rocks.

(7.) Although the igneous formations of the region belong to many geological periods, alkaline rocks—that is, those rich in alkalis or others genetically associated with alkali-rich magmas—are almost entirely wanting. The nearest approach to such types are: the syenitic phase of small volume in the Salmon Arm Jurassic batholith; and the few, narrow camptonitic dykes of the Columbia range. This means that most of the rock families recognized in the standard, Rosenbusch classification do not outcrop here at all. The great predominance of the subalkaline types is parallelled in most other large eruptive areas and probably in the average visible terrane of the earth as a whole.

CHAPTER VII.

GLACIATION.

Nearly twenty-five years ago Dawson stated the Pleistocene history of British Columbia, and subsequent investigations have confirmed his views with respect to the broad outlines of that history.[1] This is true of the present reconnaissance, though its chief purpose was rather to collect data on the bed-rock geology.

The vertical and horizontal limits of the great interior ice-cap offered obviously important problems. At the International Boundary the ice was continuous (except for rare nunataks) from the Okanagan range to the Selkirk Range divide. In the railway section the Columbia range is so high that it probably formed an ice-divide even at the time of maximum glaciation. To the eastward of that divide local glaciers fed the mighty sheet which streamed southward, down the Selkirk valley, and finally united with the main ice-cap on lower ground near the Arrow lakes. Yet more effectually the Selkirk range divided the Selkirk Valley glacier from a similar sheet which crept southward, down the Rocky Mountain trench. At the time of maximum glaciation these three principal sheets were undoubtedly connected by "through" glaciers which lay in the mountain cols; yet the trench glacier, the Selkirk Valley sheet, and the main ice-cap were each alimented by two systems of lateral glaciers. A small fraction of these feeders is to-day represented by hundreds of glacierlets in the Rocky, Purcell, Selkirk, Columbia, and Coast ranges.

As shown in the topographic edition of the Shuswap map sheet, McEvoy found on Lichen mountain, on Adams plateau, and on Mount Tod striations which indicate ice-movement *across summits* in the direction, S. 20°-30° E., which is that

[1] See especially G. M. Dawson, Trans. Roy. Soc. Canada, Vol. 8, 1890; Ann. Report Geol. Survey of Can. Vol. VII, 1896, Part B, p. 248.

of the Cordilleran ice-cap in general. The respective heights are about 6,800, 6,100, and 6,800 feet.[1] On the basis of these and other observations, Dawson concluded that the surface of the main ice-cap in Shuswap Lake region was slightly more than 7,000 feet above the present level of the sea. The thickness of ice over the main valleys was, therefore, not far from 6,000 feet. So far as his very limited opportunity for high-level readings permitted, the present writer found reason to endorse Dawson's statement.

The upper limit of the ice in the middle of the Selkirk Valley sheet, when at its maximum, appears to have been slightly lower. On Revelstoke mountain and the adjacent ridges, all signs of general glaciation cease at about 6,500 feet and it seems probable that the limit of the ice was no higher than 6,800 feet. The Columbia river is here about 1,500 feet above sea, so that the local thickness of the ice was no greater than about 5,300 feet. No conclusive observations were made as to the maximum thickness of the ice at the Rocky Mountain trench; it was, however, probably less than 5,000 feet.

A transverse profile of the ice surface at maximum glaciation cannot yet be fully drawn. That it possessed considerable gradients is suggested by observations on the western slope of the Selkirk range. On the summit of the 7,776-foot ridge marked on Wheeler's map, 3 miles north-northeast of Flat Creek siding, good striæ produced by ice moving southward *across* the ridge were discovered. These show that the wide Caribou and Illecillewaet valleys were filled with confluent ice nearly to the 8,000-foot contour. Thus the average slope of the ice surface, between this ridge and Revelstoke, 30 miles distant, was about 40 feet to the mile.

Generally, however, the recorded striæ and grooves were produced by ice which was strictly controlled by the local topography. Obviously each of the countless cirque glaciers had its own system of markings, imitated by the relatively minute glaciers now occupying the valley heads. On the other hand, the deeper troughs of the plateaus region, such as the

[1] Cf. J. McEvoy, Ann. Report, Geol. Survey of Canada, Vol. VI, 1895, Part A, p. 8.

valleys occupied by Adams, Shuswap, and Mabel lakes, caused deflections of the ice currents during the height of glaciation and harboured powerful local glaciers long after the ice-cap had lost its continuity through partial amelioration of the climate. Dawson's report on the Kamloops sheet (1896) sufficiently emphasizes these facts.

The heavy glaciation has effected the normal changes expected in a mountain system of strong relief. Cirques are very abundant in the higher parts of the Purcell, Selkirk, and Columbia ranges, as well as at many localities in the plateaus region (Plates XXXIX and XL). The master valleys have been widened and deepened; the mountain spurs entering them have been largely truncated and trough forms have resulted. Good examples are seen in the Beaver River valley, in the Selkirk valley, and in the valleys occupied by the larger lakes. Oversteepening of the valley walls has led to local land-sliding on a great scale, especially well illustrated along Eagle river, between Three Valley and Taft. Rock basins, large and small, have been excavated. The most remarkable instance is that of Adams lake, 1,200 feet deep and drained over a rocky lip which is covered with only a few feet of drift material.[1]

It is not necessary to review the argument on which is based belief in glacial erosion to the extent implied. The sceptics as to its great efficiency have not sufficiently considered two vital principles. One of these is the power of *concentration.* As at Lake Chelan in Washington state or at the existing Muir glacier, strong topography may so confine glacial currents that the velocity of a trunk stream may be from 10 to 30 times greater than it would be in a corresponding ice-cap which is free to move radially in all directions. As experiments have shown, abrasion is simply proportionate to velocity, under these conditions. Fiords and similar troughs occur only where great concentration of ice has been possible. The amount of their

[1] The arms of Shuswap lake include several long rock basins. Except for its river outlet Mara arm has been cut off from the main lake by the growth of Eagle River delta. Similarly, Little Shuswap lake has been cut off by the Adams River delta. The level of Niskonlith lake is held up by a well-marked moraine left in its valley by a late-Pleistocene local glacier.

widening and deepening in the living rock, measured as excess over that accomplished in pre-Glacial times, is just of the order of magnitude demanded on the assumptions: first, that concentration of ice currents is a primary control; and, secondly, that unconfined ice-caps have eroded solid rock to a depth of 30 to 50 feet.

The other principle, too often neglected in the glacial-erosion controversy, is that *schrund-line action* affects both *sides* of a glaciated valley as well as its head. Practically every geologist agrees that rapid erosion takes place at the valley head, and the explanation is found in sapping or glacial quarrying at the contact of ice and bed-rock. It should be remembered, however, that the same kind of contact exists to right and left of every valley glacier throughout its whole length, except where drift material is temporarily lodged between ice and rock. Sapping at the lateral schrund-lines is clearly an important cause of the widening of troughs, the truncation of mountain spurs, and the peculair relation of the typical hanging valley.

The late-Pleistocene silts of the South Thompson valley belong to a widely spread group of deposits which have been discussed by Dawson in considerable detail.[1] He explained the White Silt formation as the sediment laid down in the main valleys of southern British Columbia at a time when the whole region stood about 2,500 feet lower than now. He wrote:—

> "Following the maximum of this second period of glaciation, came apparently a second subsidence, less in amount than the first, but sufficient to depress the Cordilleran region generally, to a level about 2,500 below that which it holds at the present day. At this stage, and while glaciers of considerable size still occupied the mountain-valleys, and the position of the névé of the former Cordilleran glacier was probably held by an ice-cap of some size, the land remained nearly stationary for a long interval, and remarkable and important silt deposits, well bedded and of con-

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[1] G. M. Dawson, Ann. Report, Geol. Survey of Canada, Vol. VII, 1896, Part B, pp. 252 and 283 FF., where further references to his writings on this subject will be found.

siderable thickness, were tranquilly laid down in different low tracts scattered along the Cordilleran region for a length of some 1,200 miles. These deposits, the writer has in previous publications referred to as the *White Silts*, and as observations accumulated, it at length became evident that these silts possess more than a local significance. They appear, in fact, to constitute a well marked formation, characterizing a definite and long maintained stage of stability in the glacial history. In the various more or less completely separated basins in which they occur, their level is so nearly identical, as apparently to show that this must be referred to a common cause, which it is believed, in consideration of all the circumstances, and particularly in view of the vast area which the observations here referred to cover, can have been no other than the level of the sea at the time. No morainic or other accumulations have been found, such as to account for the production of lakes, in which these silts might be supposed to have been deposited, and had they been formed in separate lakes, held in either in the manner suggested or by glacier dams, they would, in a region of such bold relief as the Cordillera, be expected to occur at very different levels in each basin."[1]

However, Dawson states, in other passages, that some of the high-level silts were deposited in valleys temporarily laked by local glaciers. He did not make clear the field criterion by which those silts could be distinguished from the silts laid down in the long fiords or drowned valleys, the existence of which is implied by the subsidence hypothesis. A late-Glacial or post-Glacial elevation of 2,500 feet should certainly have had many visible effects on British Columbia topography. No such signs of great submergence have yet been discovered and the writer can not believe that Dawson's hypothesis is justified by the known facts. The grounds for this conclusion need not be fully discussed in a report on the present area of reconnaissance, which shows a typical development of the white silts only along the South Thompson river (Plates XLI and XLII).

[1] G. M. Dawson, ibid., p. 252.

In that valley conspicuous terraces have been cut in the silts for a distance of about 30 miles. The elevation of the top of the uppermost bench varies considerably, whether considered in relation to sea-level or in relation to the level of the river. The latter is about 1,150 feet above sea at the outlet of Little Shuswap lake and only about 10 feet lower at Kamloops. The following table shows the approximate heights of the highest silt terraces above the river.

Locality.	*Elevation in feet.*
Chase (outlet of Little Shuswap lake)	75
Shuswap village (terraces irregular)	100
Ducks	275—320
Opposite Campbell siding	420—500
Pauls peak	400—500

Except at its mouth Little Shuswap lake has no silt terraces on its shores, and no notable silt deposit is to be seen at Kamloops. Between the lake and the confluence of the North Thompson and South Thompson rivers, the silt deposit and terraces are continuous. It is believed that the silts are satisfactorily explained as the sediment deposited in a temporary lake flooring the valley of the South Thompson. This lake originated by the damming of the valley—upstream, by a local glacier occupying the Little Shuswap Lake basin; downstream, by a powerful glacier which came southward, down the North Thompson valley, and filled the entire cross-section of the present Kamloops Lake basin up to a level at least 500 feet above the present surface of that body of water. The terracing of this deposit began with the melting of the ice-dams, between which the silt had accumulated to a maximum depth of at least 500 feet and probably more than 600 feet.

The colour of the silt is generally white, tinged with brownish grey. As exposed along the Thompson, the deposit has a remarkably constant, very fine grain. Under the microscope somewhat numerous sherds of quartz, from less than 0·01 mm. to about 0·06 mm. in diameter, are easily identified; but most of the material, of similar grain and likewise colourless or glass-clear, so slightly reacts to polarized light that a direct identification is very difficult. A few of these grains were found to have an apparently perthitic structure and many showed a perfect cleavage. Some appear to be lamellated, suggesting plagioclase. Dark-coloured grains of any kind are very rare.

The conclusion that the silt is chiefly feldspar, largely unaltered, has been confirmed by the following analysis of a typical specimen (No. 1604), taken in the bluff a short distance below Ducks station on the north side of the river. The analysis was made by Mr. M. F. Connor, of the Department of Mines, who made a double check on all the important oxides.

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O
67·38	0·40	15·53	0·96	1·54	0·07	0·90	2·00	5·83
K_2O	H_2O	CO_2						
2·46	3·70	(trace)	(total)	=	100·77			

The oxide ratios correspond to: 49 per cent of albite, 15 per cent of orthoclase, 8·5 per cent of anorthite, and about 18 per cent of quartz. The silt is thus seen to be a very unusual deposit. It approximates a mass which would be produced by the pulverization of a fresh, albite-rich granite or pegmatite. Rocks of that composition are abundant in the adjacent Shuswap terrane, and the silt seems best interpreted as rock-flour, produced by the Glacial grinding of the pre-Beltian granitic intrusives. However, some concentration of the albite feldspar may be represented in the silt actually analysed.

No new evidence was secured as to the multiple nature of the Glacial period in British Columbia. Glacial markings, glacial forms, and glacial deposits throughout the reconnaissance area have so great freshness that none can be definitely referred to an epoch older than the Wisconsin of the east. It is not to be expected that, in a region of such strong relief, the records of an earlier glaciation or of a general interglacial period would be clearly preserved. As elsewhere noted, the local silts along the shore of Kamloops lake have been violently contorted, as if by glacial shove, and, near Cherry Creek station, the silts are overlain by typical boulder clay (Figure 3); yet these phenomena may have been the normal results of oscillation of the large glacier which occupied the Kamloops Lake basin during the last days of the Pleistocene.[1] More positive evidence of a distinctly earlier glaciation may possibly be secured during a study of certain, old-looking, partly cemented gravels conspicuously outcropping on the heights just southeast of Cherry Creek station.

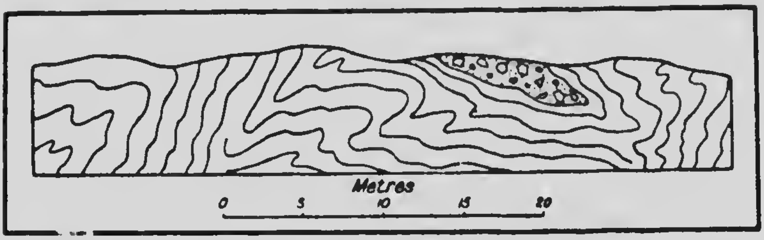

Figure 4. Section illustrating the crumpling of late Glacial silts by an advancing ice-sheet, which deposited typical till (wedge-shaped mass) on the silts. Locality 2.5 miles west of Cherry Creek station on Kamloops lake.

The existing glaciers of the Selkirks and of the neighbouring ranges are very numerous but small; so far as known, their fronts, though oscillating in some cases, have been retreating for at least the last twenty-five years.[2]

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[1] Cf. R. A. Daly, Guide-book No. 8, Congrès Géologique Internationale, Ottawa, 1913, p. 234.

[2] See A. O. Wheeler, "The Selkirk Range," Department of the Interior, Ottawa, 1905, Vol. 1, p. 357; and "The Selkirk Mountains, a Guide for Mountain Climbers and Pilgrims: Information by A. O. Wheeler," Winnipeg, 1912, p. 150. In these works will be found references to the quantitative observations of the Messrs. and Miss Vaux on the Illecillewaet and Asulkan glaciers.

CHAPTER VIII.

GEOLOGICAL HISTORY.

The first demonstrable event in the geological history of British Columbia is recorded in the clastic Shuswap sediments. Their mineralogical composition proves that the region between Albert canyon and Kamloops was long the scene of sedimentation, and was adjoined by a pre-Shuswap terrane of quartzose, granitic or gneissic, character. From that ancient land, muds, sands, and some gravels were washed into a geosyncline which also received accumulations of calcareous and volcanic materials. All of these bedded rocks now constitute the Shuswap series, a very thick, conformable mass which is known only in part, for its base is concealed and its top members have not been identified.

Field observations have not yet given any clue as to the location of the older terrane which furnished the fragmental material, nor as to the extent and axial direction of the Shuswap geosyncline. Provisionally all the pre-Beltian orthogneisses are regarded as belonging to the same general eruptive period as that to which the granitic types definitely intruded into the Shuswap series have been referred. However, this relatively simple correlation may be incorrect, and it is not impossible that some of the rocks mapped as belonging to the "sill-sediment complex" of the Shuswap terrane really belong to the pre-Shuswap terrane.

The notable thicknesses of the Sicamous and Tshinakin limestones indicate that they originated in the sea rather than in freshwater basins. A high content of carbonaceous matter in some of the limestone beds leads to the presumption that the Shuswap ocean was abundantly charged with organisms; the Shuswap limestones themselves are best interpreted as chemical precipitates.

Volcanic action, which seems to have been repeated during the sinking of the geosyncline, reached its culmination in the enormous basaltic extrusions now represented in the Adams Lake greenstones. Other, more massive, greenstones seem to be sills and other injected bodies, perhaps contemporaneous with the volcanics.

During its thickening this composite geosynclinal prism was being slowly recrystallized by load metamorphism. The resulting fissility controlled the mode of intrusion of granitic magmas, which, after the Adams Lake vulcanism, invaded the geosynclinal on a vast scale. These magmas, rich in gases, rose into the now schistose mass and spread along the planes of bedding and along the planes of schistosity that had just been developed parallel to the bedding. The granitic sills and laccoliths crystallized and then themselves underwent static metamorphism. Meantime their own heat and gases had effected widespread contact metamorphism in the bedded rocks.

The granitic injection was not accomplished in a single act but by a succession of eruptions. The whole eruptive period was so long that the earlier sills were statically metamorphosed, at least to some extent, before the latter were injected, for these are seen to have followed planes of schistosity in the older sills. In all parts of the Shuswap terrane the older injections were usually more femic—richer in biotite or hornblende or both—than the younger injections, which are usually aplitic or pegmatitic. The resulting orthogneissic composite is in quality like the standard "Archean" complexes the world over. This similarity suggests that the conditions for the formation of the early Pre-Cambrian complexes were planetary and peculiar to an early epoch in the earth's history. The apparent universality of static metamorphism and of *lit par lit* or sill injection in early Pre-Cambrian terranes leads one to suspect that even the primitive crust of the earth was a composite of orthogneisses.

During the injection of the granitic magmas, the Shuswap sediments must have been deformed to the extent demanded when many sills and laccolithic bodies invade a bedded series, but there is no evidence of strong folding or tilting during pre-Beltian time. In that respect also the conditions were special, since post-Cambrian granites have almost always reached their visible levels in the earth's crust only after a period of strong crustal deformation.

After the granitic invasion, at least part of the Shuswap terrane was lifted above baselevel and was eroded before the lowest Beltian bed was deposited upon the surface of that terrane unconformably.

With that uplift the axial line of the Canadian Cordillera first became definitely outlined. The Western Cordilleran belt became land and in general so remained until the close of the Mississippian period; during the same long era the Eastern belt was a geosynclinal area, its major axis having the same trend as the present Cordillera. The Rocky Mountain geosyncline continued to sink and was filled with sediments in the Beltian (Selkirk series), Cambrian, Ordovician, Silurian, Devonian, and Mississippian periods. Within the railway zone, volcanic action left its mark only in the Beltian Cougar formation; elsewhere the deepening of the vast downwarp was accompanied by vulcanism on the large scale, as represented, for example, in the Purcell, Grinnell, and Irene basalts of the 49th parallel.

Thick and well exposed as they are, the Beltian strata are so far quite unfossiliferous except for the obscure forms found in the upper beds by Weller, Walcott, and the writer. Though most of these sediments have been statically metamorphosed, their alteration is not sufficient to explain the absence of animal remains. The writer is more than ever convinced that their failure is due to the lack of hard parts, especially calcareous tests and skeletons, in the bodies of Pre-Cambrian animals. Chitinous tests were developed during the Cambrian, and rocks of that age, practically as much metamorphosed as many of the Beltian beds, are already famous for their organic enclosures.

Near the close of the Mississippian period, the Western Cordilleran belt, including much of the Shuswap terrane, was downwarped, and Pennsylvanian sedimentation with strong vulcanism affected the whole railway belt from the Shuswap lakes to the Pacific ocean. This Carboniferous geosynclinal (Cache Creek series) had a chief axis roughly parallel to the present shore-line of the Pacific. For part of Pennsylvanian time the Rocky Mountain geosynclinal remained under water, at least locally, but its thickness was increased comparatively little. On the other hand, it is probable that much of the Eastern belt became land at the close of the Mississippian and furnished clastic material to the long trough which was then beginning to deepen in the Western Cordilleran belt.

Permian sediments are possibly represented in the front range of the Canadian Rockies, but in both Cordilleran belts the Permian period seems to have been a time of erosion, the Pennsylvanian sediments of the western geosynclinal having been raised above sea-level. That elevation was probably not accompanied by strong deformation.

The ensuing denudation had removed the upper beds of the Pennsylvanian system before the lowest visible member of the Triassic rock group, a basal conglomerate, was unconformably deposited. The formation of that gravel was immediately followed by the persistent emission of basalts and basic andesites at fissures and central vents (Nicola series). Fossiliferous marine limestones are locally interbedded in these lavas, showing that the Triassic sea extended well into the Cordilleran area from the west. It is probable that these conditions characterized also the early part of the Jurassic period.

The orogenic revolution of the late Jurassic caused much deformation of the Pennsylvanian and early Mesozoic rocks of the Western belt, where batholithic intrusion on a gigantic scale was associated with the intense folding and shearing. It is still a question as to how far the Rocky Mountain geosynclinal sediments were affected by these movements. The structural relation of the Cretaceous beds in the front ranges to the Palæozoic members shows that the Jurassic revolution did not essentially disturb those older rocks. West of the Rocky Mountain divide there is no positive field evidence on the problem, so that no statement is yet possible as to how much of the strong folding in the Purcell and Selkirk mountains is to be credited to the revolution. The area now covered by those mountains was probably raised well above baselevel, for it bears no trace of Cretaceous sedimentation.

After suffering some erosion, the Jurassic mountains were locally downwarped, and remarkably thick prisms of Cretaceous sediments were laid down in the narrow geosynclines thus formed. In the railway zone these were confined to the Fraser valley and coast regions.

Then followed the Laramide revolution, which crumpled the new, Cretaceous sediments and the formations underlying them in the Western belt, and as well the long-resistant Rocky Mountain geosynclinal. During the folding of the front range rocks and their thrusting over the Great plains, the Interior ranges must have been strongly deformed. It is, therefore, possible that the Columbia, Selkirk, and Purcell mountains of the railway section attained their present structure during two different revolutions, the Jurassic and the Laramide. The relative importance of these revolutions in developing the visible folds and faults of the region remains an open problem.

As a result of the Laramide revolution the Canadian Cordillera first reached its full length and breadth. Its constituent ranges were doubtless much higher than those now existing. All Tertiary and Quaternary time has witnessed steady erosion, except in comparatively small areas in the Belt of Interior Plateaus and along the coast, where lavas and sediments locally and temporarily interrupted denudation. Most of the Tertiary sediments of British Columbia are of fresh-water origin and themselves bear witness to the general destructive process. Thus, the Tertiary and later history of the Cordillera must be written in terms of its physiographic development since the beginning of the Eocene.

In Dawson's writings the reader will find a statement of this Tertiary history, which Dawson principally read out of the rocks and topography of the Interior plateaus. As noted in foregoing pages, there are doubts as to the dating of the peneplain facets in that belt, and there is corresponding doubt as to the age of the valleys sunk between them. The difficulty of describing the physiographic evolution of the Interior Mountain ranges, the Rocky mountains, the great trenches, the Selkirk valley, and the thousands of smaller associated valleys is at least as great. Few problems in Cordilleran geology are as important as that offered by the topographic forms and relationships in the Belt of Interior Plateaus, for it is probably there that the Tertiary geology of the Cordillera as a whole will be largely determined. It is now too early to attempt such a statement and the following notes refer primarily to conclusions derived only from the area of the present reconnaissance.

Throughout this region the Eocene was a time of denudation. During the Oligocene a large part of the Belt of Interior Plateaus was deluged by the basaltic and andesitic lavas of the Kamloops group, issuing as fissure eruptions and as composite masses of the Etna type. The necessary disturbance of drainage courses led to local, fresh-water sedimentation, typified by the Tranquille beds.

The Kamloops group is the youngest bed-rock formation in the railway section. Its rocks have been slightly warped practically everywhere and locally upturned to high angles (Figure 3). The date of this moderate diastrophism cannot yet be fixed with absolute certainty, but there is some probability that it should be referred to the late Miocene. At that time the earlier Miocene sediments found in the Snoqualmie quadrangle of Washington state were closely folded. As described in Memoir No. 38 of this Survey, the Miocene (?) beds of the Flathead valley at the International Boundary have also been strongly deformed. It seems reasonable to correlate all these movements and to adopt the prevailing view of Cordilleran geologists that all are of pre-Pliocene date.

The Pliocene continued the general erosion, widening the Miocene valleys. The young valleys or canyons of British Columbia are generally explained on Dawson's assumption that, in the late Pliocene, most of the Cordillera was bodily uplifted to an average amount of about 2,000 feet. Such movement would certainly revive the early Pliocene rivers and produce deep canyons. Yet this hypothesis needs continued scrutiny and matching with field observations. Two-cycle topography is suggested by the high rock-benches in the Rocky Mountain trench and at a considerable number of localities in the Interior Plateaus belt, but there is still no definite proof that the second cycle in each case was begun by uplift in the late Pliocene. The problem is delicate on account of the proved, and apparently widespread, crustal movements during the late Miocene. Distinction between the physiographic effects of late Miocene and Pliocene diastrophism is manifestly difficult.

The Pleistocene history of the reconnaissance area has already been sketched. It is highly probable that the glaciation of this period was intermittent, with one or more periods of deglaciation corresponding to the interglacial epochs recently demonstrated at the western edge of the Great plains and along the Pacific coast; direct evidence of such an interglacial epoch has still to be found in the interior of British Columbia.

Post-Pleistocene time has witnessed the minor changes usually following the intense glaciation of high mountains. The Illecillewaet gorge exemplifies the many cases where bed-rock valley floors have been locally deepened by post-Glacial excavation. That process has been accompanied by degradation in the drift barriers of Glacial lakes. For example, the level of Upper Arrow lake has been lowered by the down-cutting of the Columbia river on the south; in consequence, a post-Glacial delta of the Illecillewaet river stands high and dry above the present level of lake or master river (Plate XLIII). The growth of many deltas, large and small, into the lakes is another conspicuous incident in the post-Glacial gradation of stream courses. At present, hundreds of small glaciers in the Purcell, Selkirk, and Columbia ranges are weakly imitating the grand effects of erosion wrought on the ice-divides and nunataks by the powerful local glaciers of the Pleistocene.

PLATE 1.

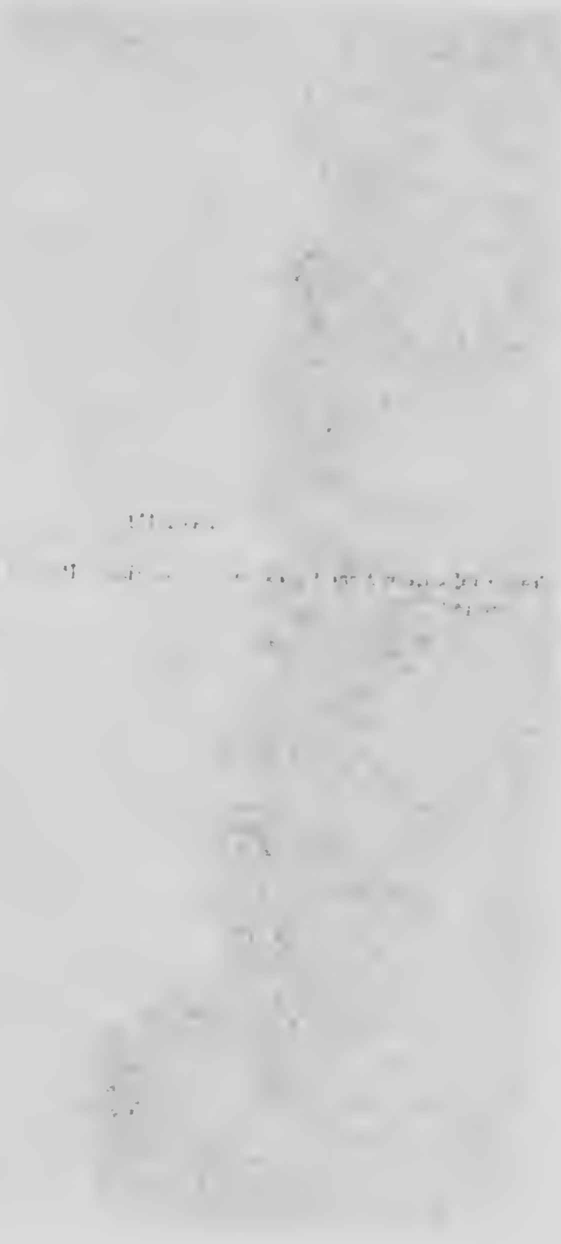
The Rocky Mountain trench from the heights east of Golden, looking south. Across the Columbia river are the Dogtooth mountains. Photograph by Wheeler.

PLATE I

PLATE II.

View in the Rocky Mountain trench, at Donald station, looking northwest. Photograph by Wheeler.

PLATE II.



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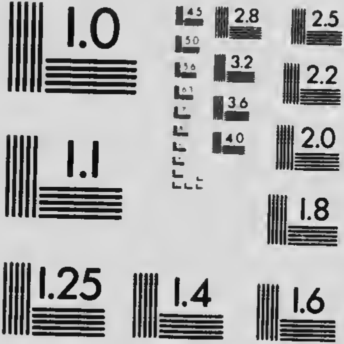


PLATE III.

Prairie hills from Bear Creek railway station. Purcell trench in the middle ground.

Plate III.

[illegible]

[illegible]
[illegible]

PLATE IV.

The Selkirk range and the Purcell trench (Beaver valley). Looking south from Bald mountain (Prairie hills). Photograph by Wheeler.

PLATE IV.

PLATE V

The Purcell trench, Prairie hills (middle ground), and Dogtooth mountains (background). Looking southeast from Mount Macdonald. Photograph by Wheeler.

Plate V.

PLATE VI.

Beaver River escarpment, or western wall of the Purcell trench, looking south along the edge of the Illecillewaet névé (elevation about 9,000 feet). Photograph by Wheeler.

PLATE VI.

PLATE VII.

Looking southwest from Sixmile creek along the Purcell trench (Beaver River valley).

Plate VII.

PLATE VIII.

The summit ridge of the Selkirks from Avalanche mountain (9,387 feet, left) to Mount Sir Donald (10,808 feet, right). Looking northeast from Mt. Abbott. Photograph by Wheeler.

PLATE VIII.

PLATE IX.

Mount Begbie (elevation 8,946 feet), one of the highest peaks of the Columbia range; view from the north. Its rocks belong to the Shuswap terrane. Photograph by the Canadian Pacific railway.

PLATE IX.

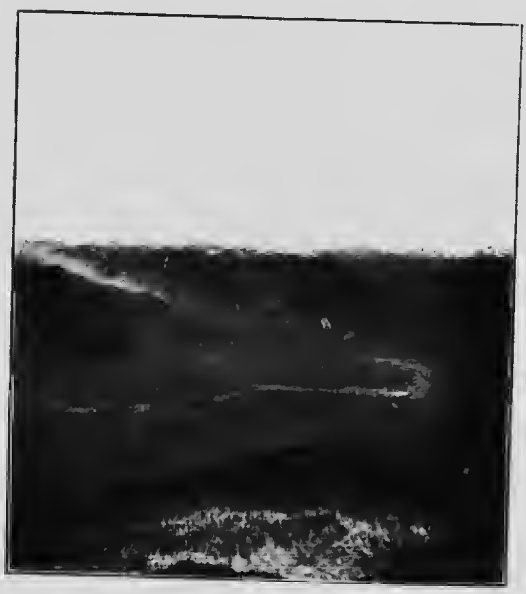
PLATE X.

A. The meeting of the Illecillewaet and Columbia (Selkirk) valleys, seen from Mount Clach-na-Coodin (elevation about 7,500 feet); Columbia range in the background. Looking southwest. Photograph by Wheeler.

B. The Selkirk valley, Revelstoke, the Columbia range, and the Tonkawatla valley. Looking northwest from Mount. Mackenzie. Photograph by Wheeler.

Plate X.

A.



B.

PLATE XI.

View in Belt of Interior Plateaus, looking down Shuswap lake, near Blind bay.

PLATE XI.

Plate XII.

Adams plateau (elevation 6,000 feet); looking east across Adams lake (elevation 1,364 feet).

Plate XII.

PLATE XIII.

The Shuswap terrane in the western Selkirks, looking southeast from Mount Mackenzie (elevation about 8,000 feet). Photograph by Wheeler.

PLATE XIII.

PLATE XIV.

Massive quartzite and paragneiss, referred to the Chase formation; at Summit lake, Colun a range.

PLATE XIV.

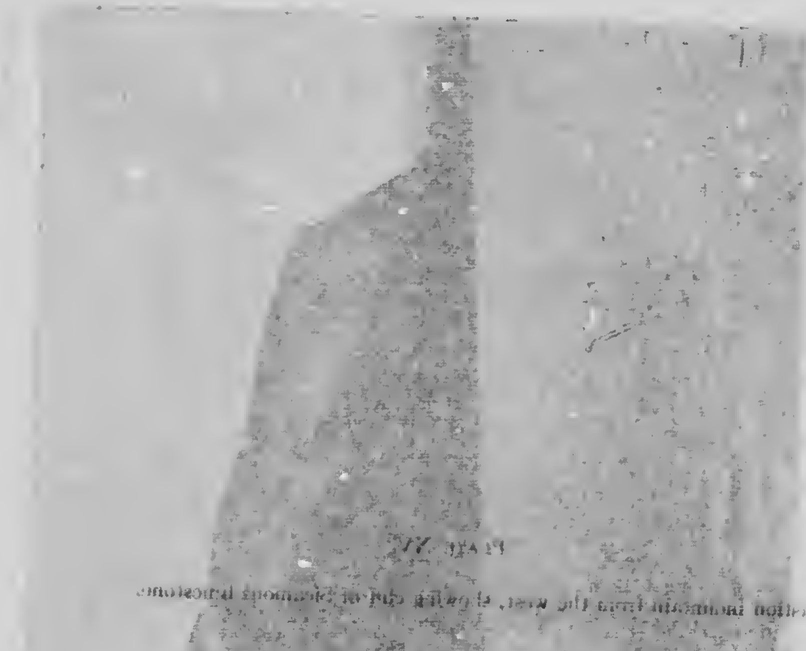


PLATE XV.

Bastion mountain from the west, showing cliff of Sicamous limestone.

PLATE XV.

PLATE XVI.

Miniature Karst topography on massive (Tshinakin ?) limestone of the Shuswap series; 2 miles south of Cinnemousun narrows.

PLATE XVI.

PLATE XVII.

Aplitic and pegmatitic sills cutting rusty metasedimentary schists and limestone interbeds: western shore of Mara arm.

PLATE XVII.

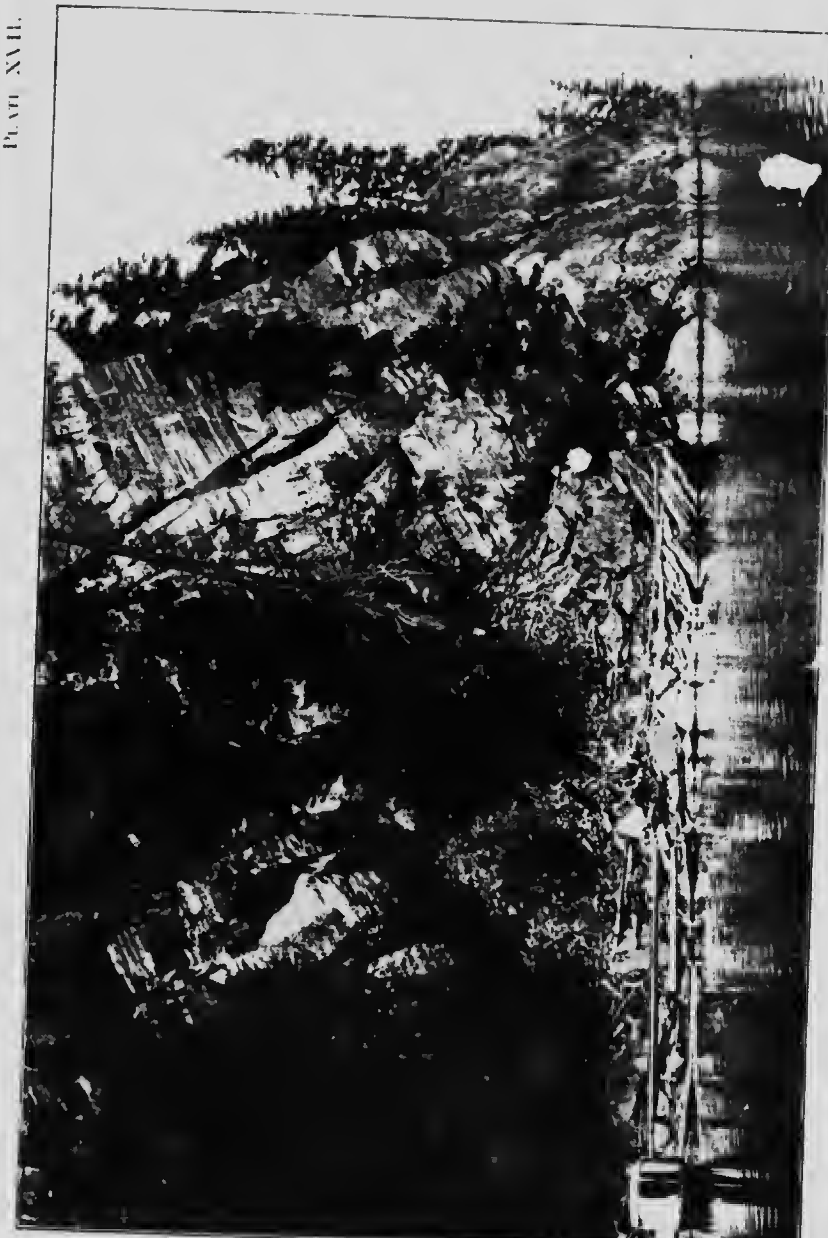


Plate XVIII.

Looking west over the Shuswap terrane, from Mount Clach-na-Coodin, western Selkirks. Photograph by Wheeler.

PLATE XVIII

Plate XIX.

Orthogneiss near Albert Canyon station; schistosity due to static metamorphism.

PLATE XIX

PLATE XX.

Schistosity of typical Shuswap orthogneiss near Albert Canyon station, illustrating static metamorphism. The hammer is 14 inches in length.

Plate XX.

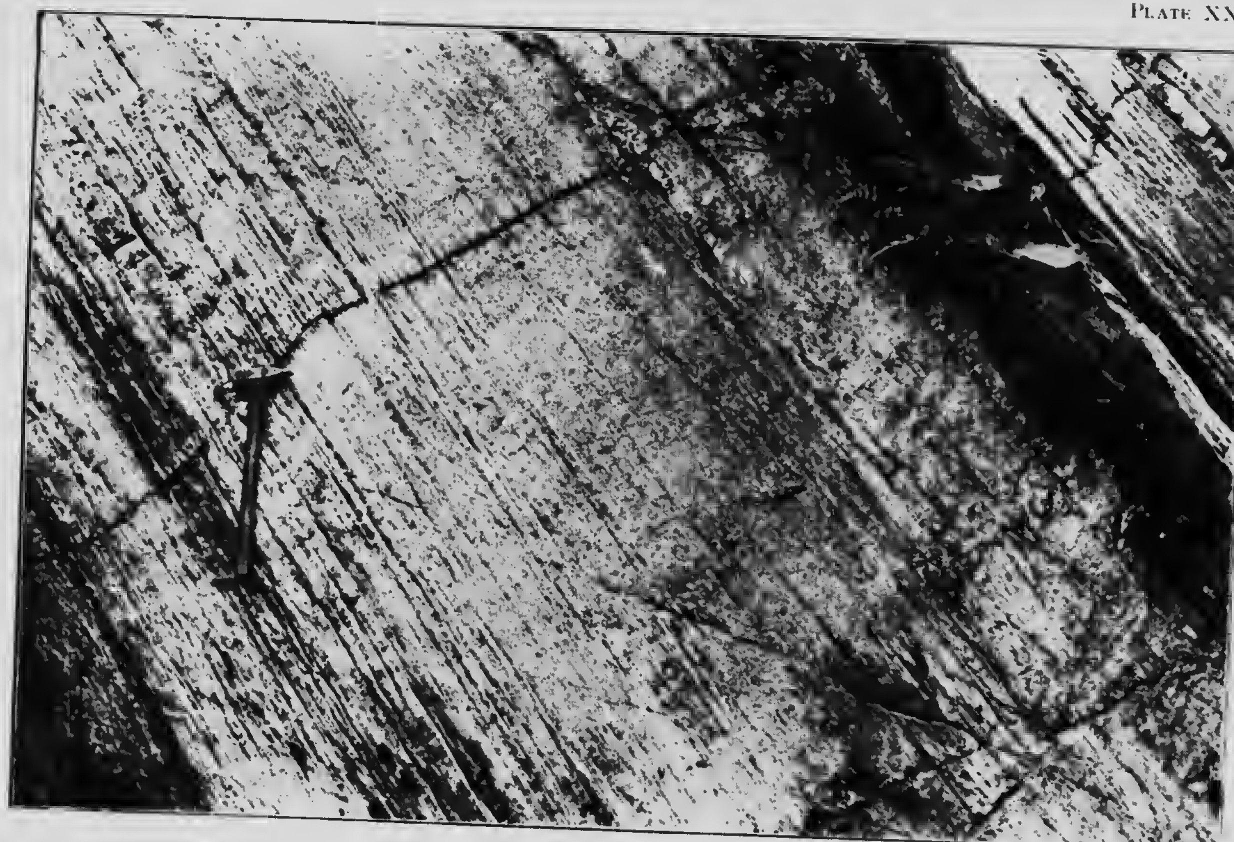


PLATE XXI.

Strain-slip cleavage in talc schist at Blind bay. The well developed low-dipping schistosity is due to earlier, static metamorphism. The camera case is about 2·5 inches thick.

Plate XXI

PLATE XXII

Looking southwest down the Illecillewaet valley at Albert canyon. Foreground underlain by lower beds of the Beltian series. Under the heavy forest of the middle ground is the contact with the Shuswap terrane, which continues to the extreme background. Photograph by Wheeler.

Plate XXII.

PLATE XXIII.

Looking west down the Illecillewaet valley from the ridge (elevation 8,000 feet) just east of Flat creek. The slopes of the middle ground are underlain by the very thick Laurie formation. Photograph by Wheeler.

PLATE XXIII

PLATE XXIV.

Looking east up the Illecillewaet valley from the peak just north of Laurie siding. The foreground and most of the wooded slope on the right are underlain by the Laurie formation, above which are the basal beds of the Cougar formation, in the large outcrop. The mountains of the background, culminating in Mount Sir Donald, are composed of the Selkirk quartzites, dipping east-northeast, away from the camera station. Photograph by Wheeler.

PLATE XXIV

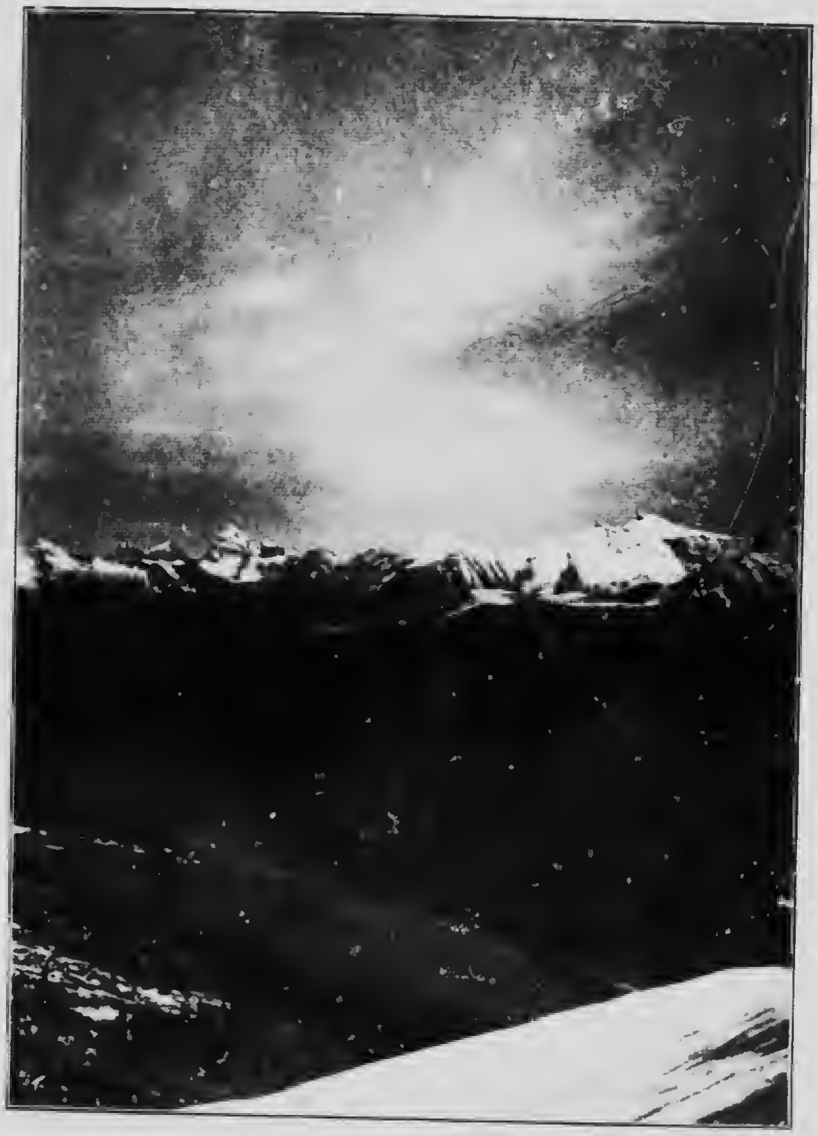


PLATE XXV.

Drag folds in Cougar quartzite near the head of Cougar brook, Selkirk range. The cliff shown is about 50 feet high.

Plate XXV.

PLATE XXVI.

Top of Cougar mountain, looking southeast; showing Cougar quartzite as typically developed in the Selkirk range.

PLATE XXXI

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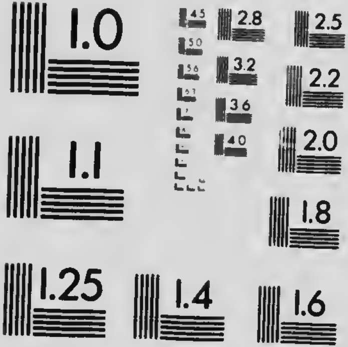

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PLATE XXVII.

Mount Bagheera (left) and Mount Catamount (right), seen from Cougar mountain. The steeply dipping Cougar quartzites are overlain by the light grey Nakimu limestone and lower Ross beds (upper right corner of the picture). Photograph by Wheeler.

Plate XXVII.

PLATE XXVIII.

Cougar mountain and the Illecillewaet valley from Mount Abbott. The light-coloured rock outcropping in the middle ground is the Nakimu limestone overlying the Cougar quartzite of the foreground. Photograph by the Canadian Pacific railway.

Plate XXVIII.

PLATE XXIX.

Looking northeast from the ridge east of Flat creek, across the upper part of the great Illecillewaet River homocline. Cougar quartzite is in the foreground; the light band on the left (middle) is the Nakimu limestone, overlain by Ross quartzite, farther back. Sir Donald quartzite forms the high peaks in the background. Photograph by Wheeler.

PLATE XXIX.

PLATE XXX.

Summit of the Dogtooth range, looking east from a peak near the head of Quartz creek. Slopes underlain by the Ross formation as typically developed in the Purcell mountains.

Plate XXX.

Plate XXXI.

Mount Sir Donald (elevation 10,808 feet) from the side of Mount Abbott. Photograph by the Canadian Pacific railway.

Plate XXXI.

Plate XXXII.

Mount Macdonald (elevation 9,482 feet) from the west. Photograph by the Canadian Pacific railway.

PLATE XXXII

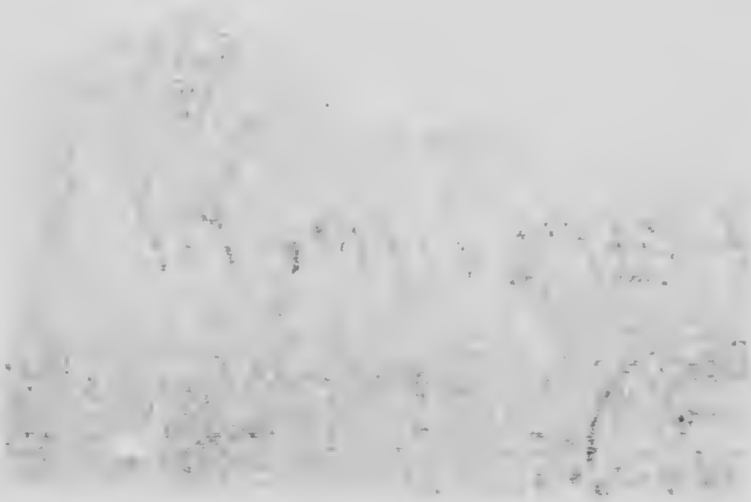
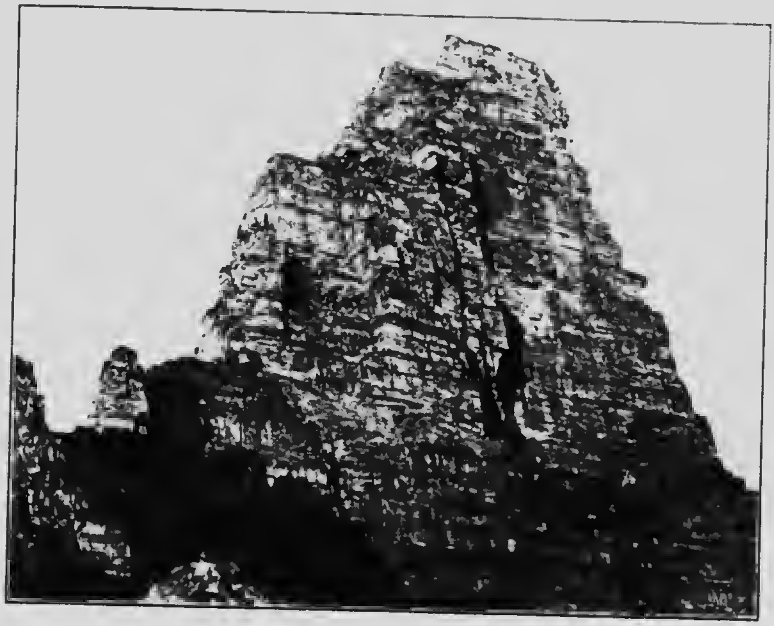


PLATE XXXIII.

A. Summit of Mount Tupper, from Tupper crest; showing characteristic habit of the Sir Donald quartzite. Photograph by Howard Palmer.

B. Looking south from Mount Tupper to Mount Macdonald and Mount Sir Donald (background), showing part of the summit syncline of the Selkirks; the Sir Donald quartzite forms the great escarpment. Photograph by Howard Palmer.

PLATE XXXIII.



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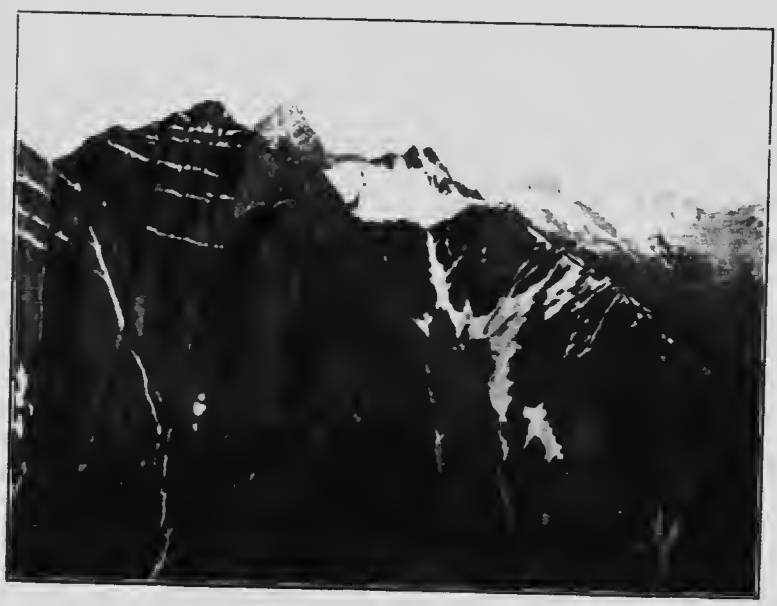

B.

Plate XXXIV.

Cougar quartzites seen from Mount Catamount, across Cougar creek; showing easterly dip. Photograph by Wheeler.

PLATE XXXIV.

PLATE XXXV.

Mount Fox (10,572 feet) from Mount Geikie; view showing the Beltian quartzites continued on their regional strike south of the reconnaissance area. Photograph by Wheeler.

PLATE XXXV

PLATE XXXVI.

Looking north over the South Thompson river, from near Campbell siding, 6 miles west of Ducks. The creek bed in the middle of the view is located on the plane of unconformity between Carboniferous limestone (light coloured outcrops on the left) and the Triassic Nicola formation (dark coloured outcrops on the right.)

Plate XXXVI.

Plate XXXVII.

Characteristic outcrop of Nicola (Triassic) traps near Ducks. The terrace is composed of white silts, here trenched by the Thompson river.

PLATE XXXVII.

Plate XXXVIII.

Battle bluff from the eastern end of Kamloops lake. The foot of Cherry bluff appears on the left.

PLATE XXXVIII.

PLATE XXXIX.

Glacial cirque topography in the western wall of the Purcell trench, just south of Mount Sir Donald. Photograph taken from the Prairie hills, by Wheeler.

PLATE XXXIX.

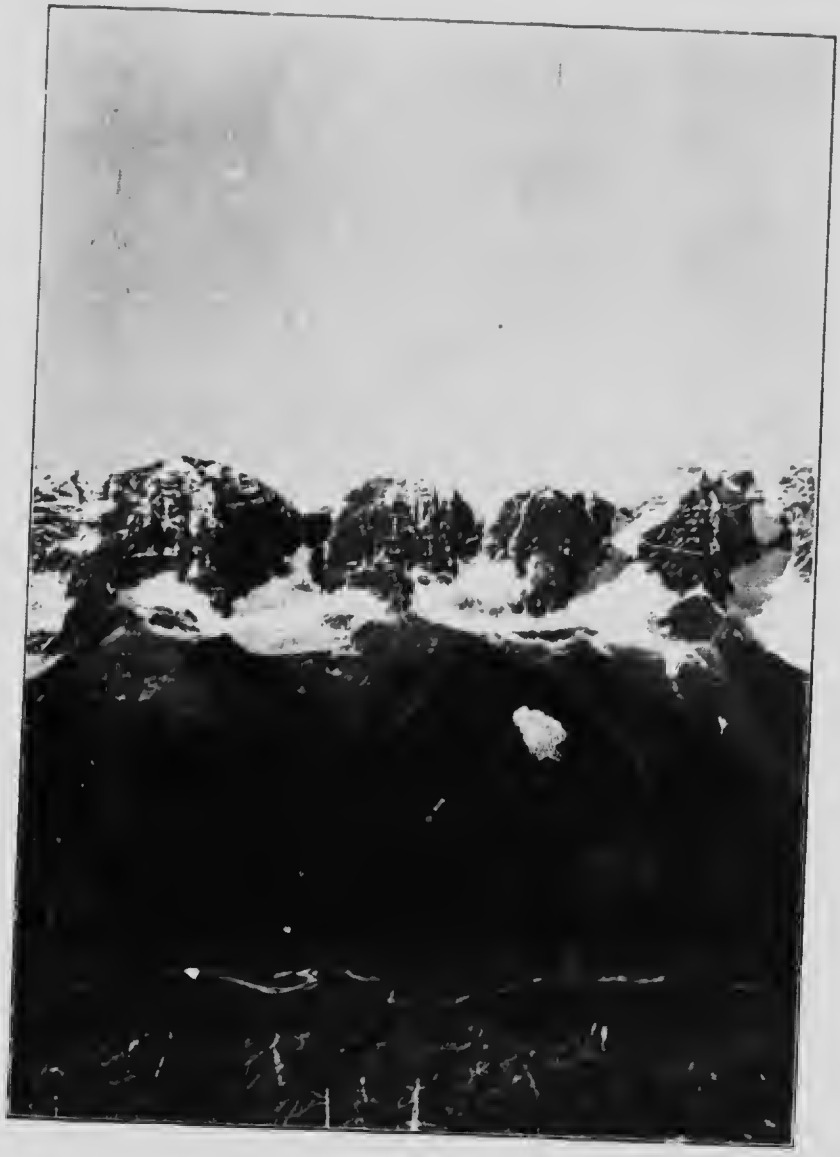

PLATE XL.

Mount Sir Donald and cirque glaciers on its eastern slope; looking across the Purcell trench from the Prairie hills. Photograph by Wheeler.

Plate XL.

PLATE XLI.

Massive Nicola traps and white silt at Ducks. Looking north.

PLATE XLI.

PLATE XLII.

Silt terrace of the South Thompson river, north bank, 4 miles above Ducks.

Plate XLII.

Plate XLIII.

Fore-set beds of sand in the old delta of the Illecillewaet river, 2 miles east of Revelstoke.

PLATE XLIII.

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LIST OF RECENT REPORTS OF GEOLOGICAL SURVEY

Since 1910, reports issued by the Geological Survey have been called memoirs and have been numbered Memoir 1, Memoir 2, etc. Owing to delays incidental to the publishing of reports and their accompanying maps, not all of the reports have been called memoirs, and the memoirs have not been issued in the order of their assigned numbers and, therefore, the following list has been prepared to prevent any misconceptions arising on this account. The titles of all other important publications of the Geological Survey are incorporated in this list.

Memoirs and Reports Published During 1910.

REPORTS.

Report on a geological reconnaissance of the region traversed by the National Transcontinental railway between Lake Nipigon and Clay lake, Ont.—by W. H. Collins. No. 1059.

Report on the geological position and characteristics of the oil-shale deposits of Canada—by R. W. Ells. No. 1107.

A reconnaissance across the Mackenzie mountains on the Pelly, Ross, and Gravel rivers, Yukon and North West Territories—by Joseph Keele. No. 1097.

Summary Report for the calendar year 1909. No. 1120.

MEMOIRS—GEOLOGICAL SERIES.

MEMOIR 1. *No. 1, Geological Series.* Geology of the Nipigon basin, Ontario—by Alfred W. G. Wilson.

MEMOIR 2. *No. 2, Geological Series.* Geology and ore deposits of Hedley mining district, British Columbia—by Charles Camsell.

MEMOIR 3. *No. 3, Geological Series.* Palæoniscid fishes from the Albert shales of New Brunswick—by Lawrence M. Lambe.

MEMOIR 5. *No. 4, Geological Series.* Preliminary memoir on the Lewes and Nordenskiöld Rivers coal district, Yukon Territory—by D. D. Cairnes.

MEMOIR 6. *No. 5, Geological Series.* Geology of the Haliburton and Bancroft areas, Province of Ontario—by Frank D. Adams and Alfred E. Barlow.

MEMOIR 7. *No. 6, Geological Series.* Geology of St. Bruno mountain, province of Quebec—by John A. Dresser.

MEMOIRS—TOPOGRAPHICAL SERIES.

MEMOIR 11. *No. 1, Topographical Series.* Triangulation and spirit levelling of Vancouver island, B.C., 1909—by R. H. Chapman.

Memoirs and Reports Published During 1911.

REPORTS.

Report on a traverse through the southern part of the North West Territories, from Lac Seul to Cat lake, in 1902—by Alfred W. G. Wilson. No. 1006.

Report on a part of the North West Territories drained by the Winisk and Upper Attawapiskat rivers—by W. McInnes. No. 1080.

Report on the geology of an area adjoining the east side of Lake Timiskaming—by Morley E. Wilson. No. 1064.

Summary Report for the calendar year 1910. No. 1170.

MEMOIRS—GEOLOGICAL SERIES.

MEMOIR 4. *No. 7, Geological Series.* Geological reconnaissance along the line of the National Transcontinental railway in western Quebec—by W. J. Wilson.

MEMOIR 8. *No. 8, Geological Series.* The Edmonton coal field, Alberta—by D. B. Dowling.

MEMOIR 9. *No. 9, Geological Series.* Bighorn coal basin, Alberta—by G. S. Malloch.

MEMOIR 10. *No. 10, Geological Series.* An instrumental survey of the shore-lines of the extinct lakes Algonquin and Nipissing in southwestern Ontario—by J. W. Goldthwait.

MEMOIR 12. *No. 11, Geological Series.* Insects from the Tertiary lake deposits of the southern interior of British Columbia, collected by Mr. Lawrence M. Lambe, in 1906—by Anton Handlirsch.

MEMOIR 15. *No. 12, Geological Series.* On a Trenton Echinoderm fauna at Kirkfield, Ontario—by Frank Springer.

MEMOIR 16. *No. 13, Geological Series.* The clay and shale deposits of Nova Scotia and portions of New Brunswick—by Heinrich Ries assisted by Joseph Keele.

MEMOIRS—BIOLOGICAL SERIES.

MEMOIR 14. *No. 1, Biological Series.* New species of shells collected by Mr. John Macoun at Barkley sound, Vancouver island, British Columbia—by William H. Dall and Paul Bartsch.

Memoirs and Reports Published During 1912

REPORTS.

Summary Report for the calendar year 1911. No. 1218.

MEMOIRS—GEOLOGICAL SERIES.

MEMOIR 13. *No. 14, Geological Series.* Southern Vancouver island—by Charles H. Clapp.

MEMOIR 21. *No. 15, Geological Series.* The geology and ore deposits of Phoenix, Boundary district, British Columbia—by O. E. LeRoy.

MEMOIR 24. *No. 16, Geological Series.* Preliminary report on the clay and shale deposits of the western provinces—by Heinrich Ries and Joseph Keele.

MEMOIR 27. *No. 17, Geological Series.* Report of the Commission appointed to investigate Turtle mountain, Frank, Alberta, 1911.

MEMOIR 28. *No. 18, Geological Series.* The Geology of Steeprock lake, Ontario—by Andrew C. Lawson. Notes on fossils from limestone of Steeprock lake, Ontario—by Charles D. Walcott.

Memoirs and Reports Published During 1913.

REPORTS, ETC.

Museum Bulletin No. 1: contains articles Nos. 1 to 12 of the Geological Series of Museum Bulletins, articles Nos. 1 to 3 of the Biological Series of Museum Bulletins, and article No. 1 of the Anthropological Series of Museum Bulletins

Guide Book No. 1. Excursions in eastern Quebec and the Maritime Provinces, parts 1 and 2.

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Guide Book No. 2. Excursions in the Eastern Townships of Quebec and the eastern part of Ontario.

Guide Book No. 3. Excursions in the neighbourhood of Montreal and Ottawa.

Guide Book No. 4. Excursions in southwestern Ontario.

Guide Book No. 5. Excursions in the western peninsula of Ontario and Manitoulin island.

Guide Book No. 8. Toronto to Victoria and return *via* Canadian Pacific and Canadian Northern railways: parts 1, 2, and 3.

Guide Book No. 9. Toronto to Victoria and return *via* Canadian Pacific, Grand Trunk Pacific, and National Transcontinental railways.

Guide Book No. 10. Excursions in Northern British Columbia and Yukon Territory and along the north Pacific coast.

MEMOIRS—GEOLOGICAL SERIES.

MEMOIR 17. *No. 28, Geological Series.* Geology and economic resources of the Larder Lake district, Ont., and adjoining portions of Pontiac county, Que.—by Morley E. Wilson.

MEMOIR 18. *No. 19, Geological Series.* Bathurst district, New Brunswick—by G. A. Young.

MEMOIR 26. *No. 34, Geological Series.* Geology and mineral deposits of the Tulameen district, B.C.—by C. Camsell.

MEMOIR 29. *No. 32, Geological Series.* Oil and gas prospects of the northwest provinces of Canada—by W. Malcolm.

MEMOIR 31. *No. 20, Geological Series.* Wheaton district, Yukon Territory—by D. D. Cairnes.

MEMOIR 33. *No. 30, Geological Series.* The geology of Gowganda Mining Division—by W. H. Collins.

MEMOIR 35. *No. 29, Geological Series.* Reconnaissance along the National Transcontinental railway in southern Quebec—by John A. Dresser.

MEMOIR 37. *No. 22, Geological Series.* Portions of Atlin district, B.C.—by D. D. Cairnes.

MEMOIR 38. *No. 31, Geological Series.* Geology of the North American Cordillera at the forty-ninth parallel, Parts I and II—by Reginald Aldworth Daly.

Memoirs and Reports Published During 1914.

REPORTS, ETC.

Summary Report for the calendar year 1912. No. 1305.

Museum Bulletins Nos. 2, 3, 4, 5, 7, and 8 contain articles Nos. 13 to 22 of the Geological Series of Museum Bulletins, article No. 2 of the Anthropological Series, and article No. 4 of the Biological Series of Museum Bulletins.

Prospector's Handbook No. 1: Notes on radium-bearing minerals—by Wyatt Malcolm.

MUSEUM GUIDE BOOKS.

The archæological collection from the southern interior of British Columbia—by Harlan I. Smith. No. 1290.

MEMOIRS—GEOLOGICAL SERIES.

MEMOIR 23. *No. 23, Geological Series.* Geology of the Coast and islands between the Strait of Georgia and Queen Charlotte sound, B.C.—by J. Austen Bancroft.

MEMOIR 25. *No. 21, Geological Series.* Report on the clay and shale deposits of the western provinces (Part II)—by Heinrich Ries and Joseph Keele.

MEMOIR 30. *No. 40, Geological Series.* The basins of Nelson and Churchill rivers—by William McInnes.

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MEMOIR 36. *No. 33, Geological Series.* Geology of the Victoria and Saanich map-areas, Vancouver island, B.C.—by C. H. Clapp.

MEMOIR 52. *No. 42, Geological Series.* Geological notes to accompany map of Sheep River gas and oil field, Alberta—by D. B. Dowling.

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MEMOIR 51. *No. 43, Geological Series.* Geology of the Nanaimo map-area—by C. H. Clapp.

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MEMOIR 55. *No. 46, Geological Series.* Geology of Field map-area, Alberta and British Columbia—by John A. Allan.

MEMOIRS—ANTHROPOLOGICAL SERIES.

MEMOIR 48. *No. 2, Anthropological Series.* Some myths and tales of the Ojibwa of southeastern Ontario—collected by Paul Radin.

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REPORTS, ETC.

Summary Report for the calendar year 1913, No. 1359.

Report from Anthropological Division. Separate from Summary Report 1913.

Report from Topographical Division. Separate from Summary Report 1913.

Museum Bulletin No. 6. *No. 3, Anthropological Series.* Pre-historic and present commerce among the Arctic Coast Eskimo—N. Stefansson.

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MEMOIR 50. *No. 51, Geological Series.* Upper White River District, Yukon —by D. D. Cairnes.

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MEMOIR 65. *No. 53, Geological Series.* Clay and shale deposits of the western provinces, Part IV—by H. Ries.

MEMOIR 56. *No. 56, Geological Series.* Geology of Franklin mining camp, B. C.—by Chas. W. Drysdale.

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Museum Bulletin No. 11. *No. 23, Geological Series.* Physiography of the Beaverdell map-area and the southern part of the Interior plateaus, B.C.—by Leopold Reinecke.

Museum Bulletin No. 12. *No. 24, Geological Series.* On Eoceratops canadensis, gen. nov., with remarks on other genera of Cretaceous horned dinosaurs—by L. M. Lambe.

Museum Bulletin No. 14. *No. 25, Geological Series.* The occurrence of Glacial drift on the Magdalen islands—by J. W. Goldthwait.

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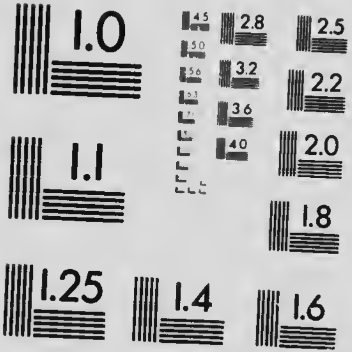

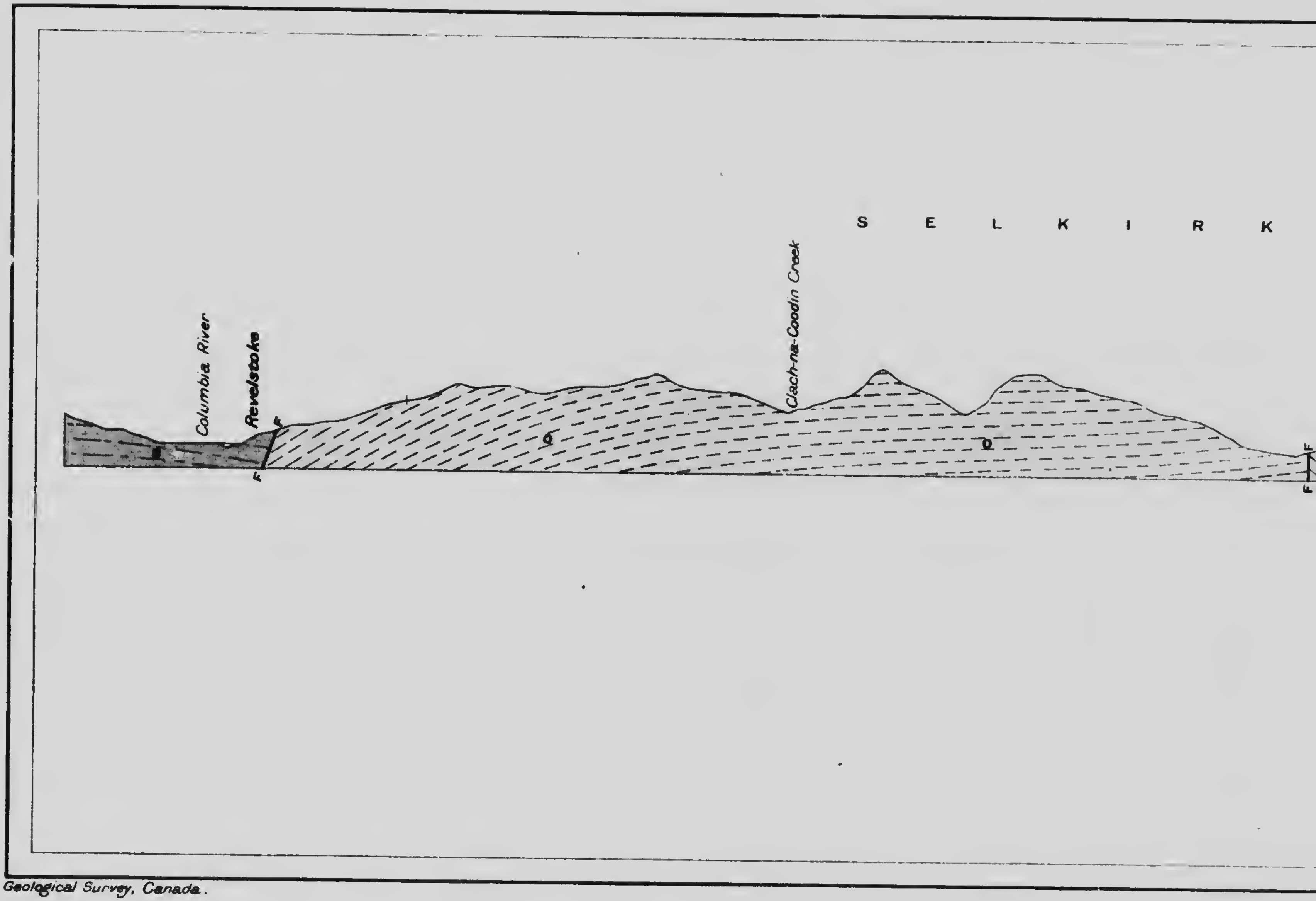

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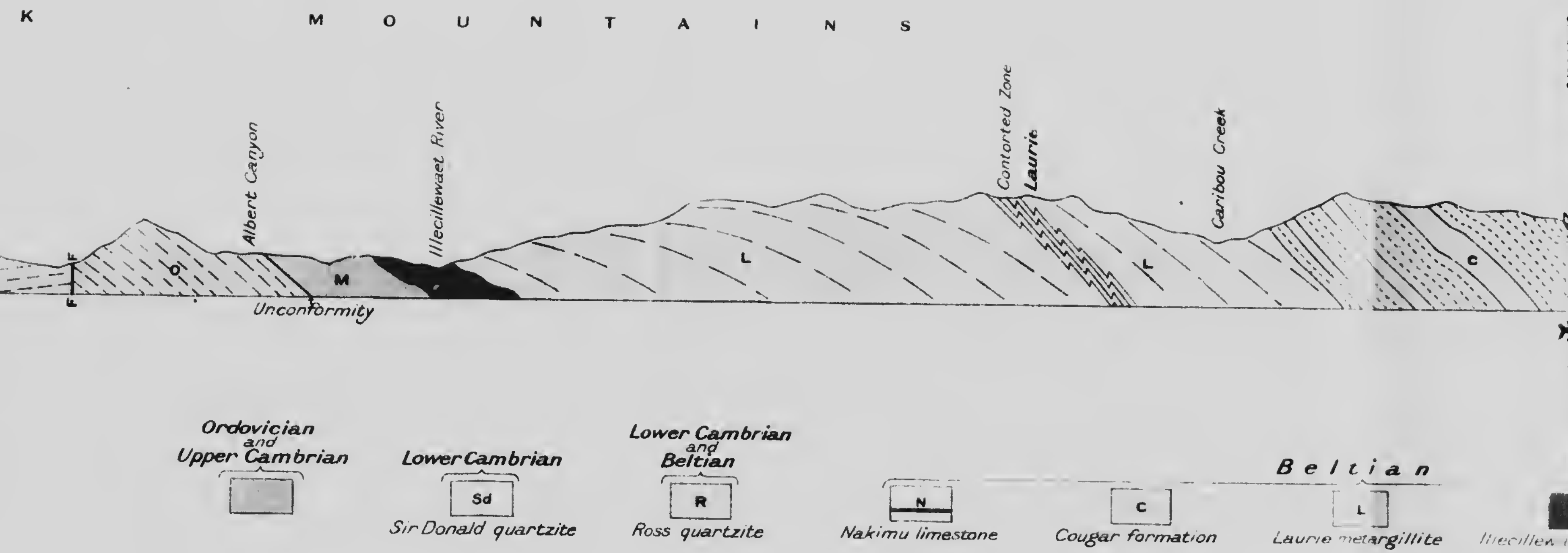
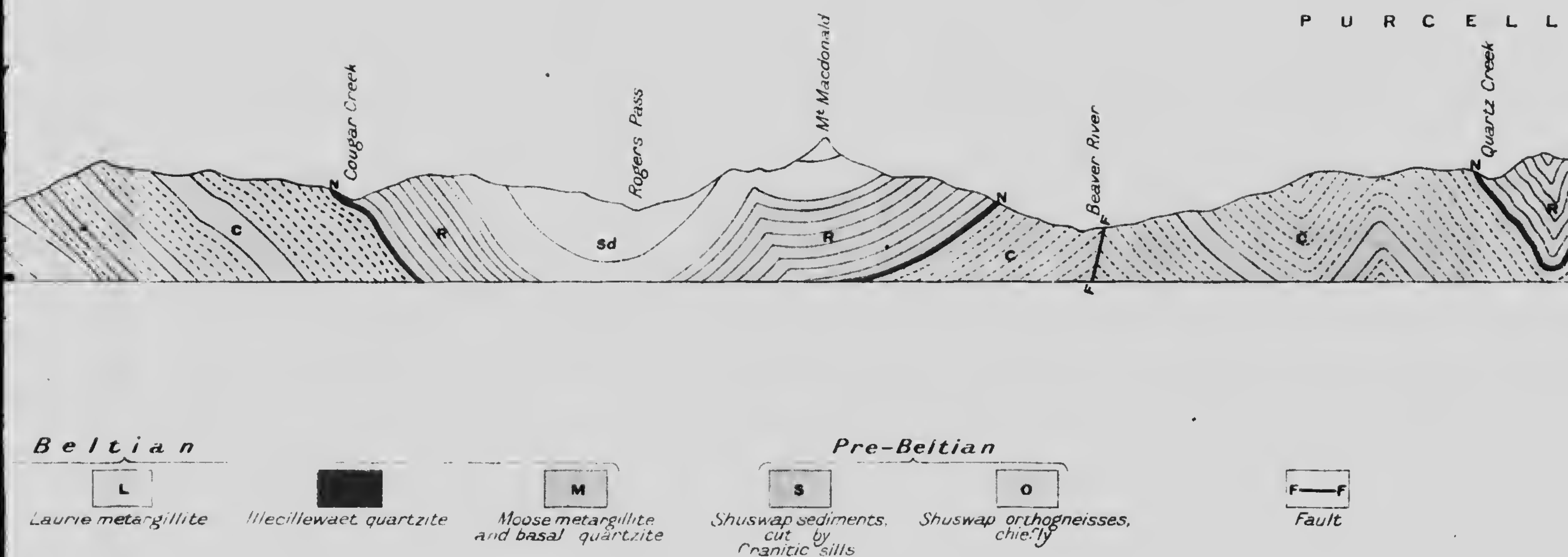


Structure Section of the **Selkirk** and **Purcell Mountains** from

Horizontal and Vertical scale



d **Purcell Mountains** *from* **Moberly Peak** *to* **Revelstoke**

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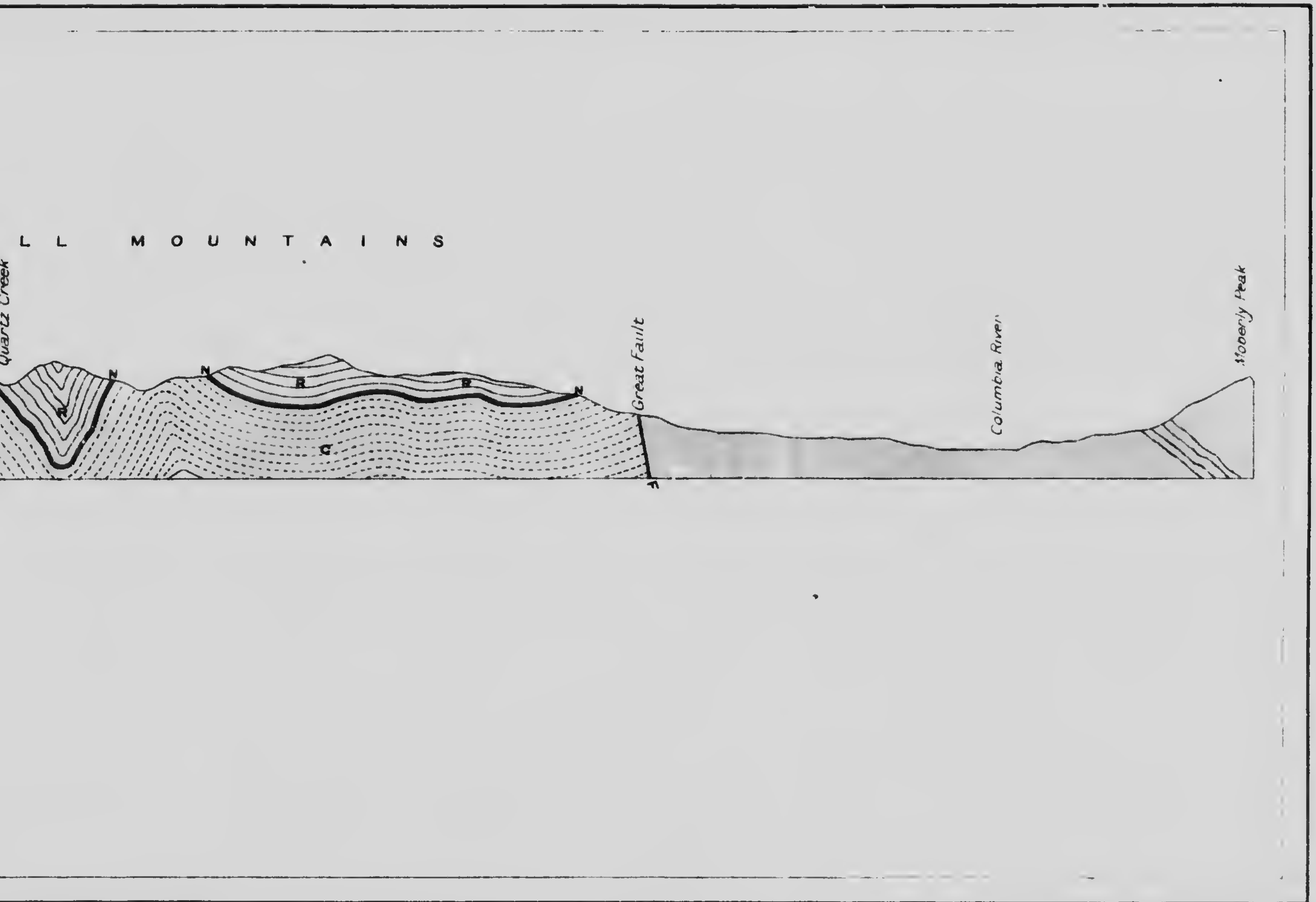
Miles

4 5 6 7 8 9 10

Kilometres

5 10 15



L L MOUNTAINS
Quartz Creek
Great Fault
Columbia River
Moberly Peak
N
R
C

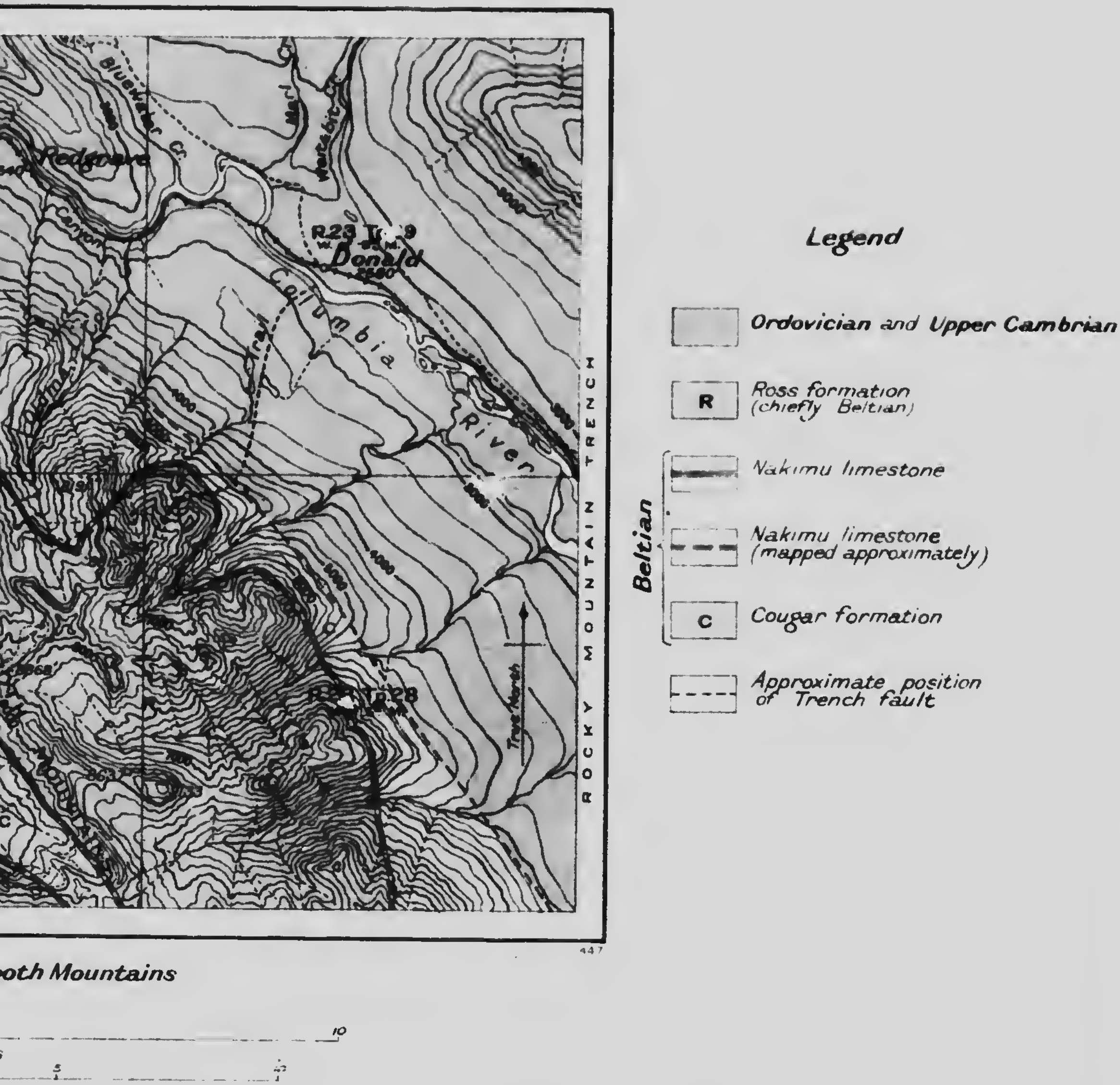
Geological Survey, Canada.

Prairie Hills and Dogtooth Mou

Miles

Kilometres

To accompany Memoir by R. A. Daly



...ooth Mountains

Geological Survey, Canada

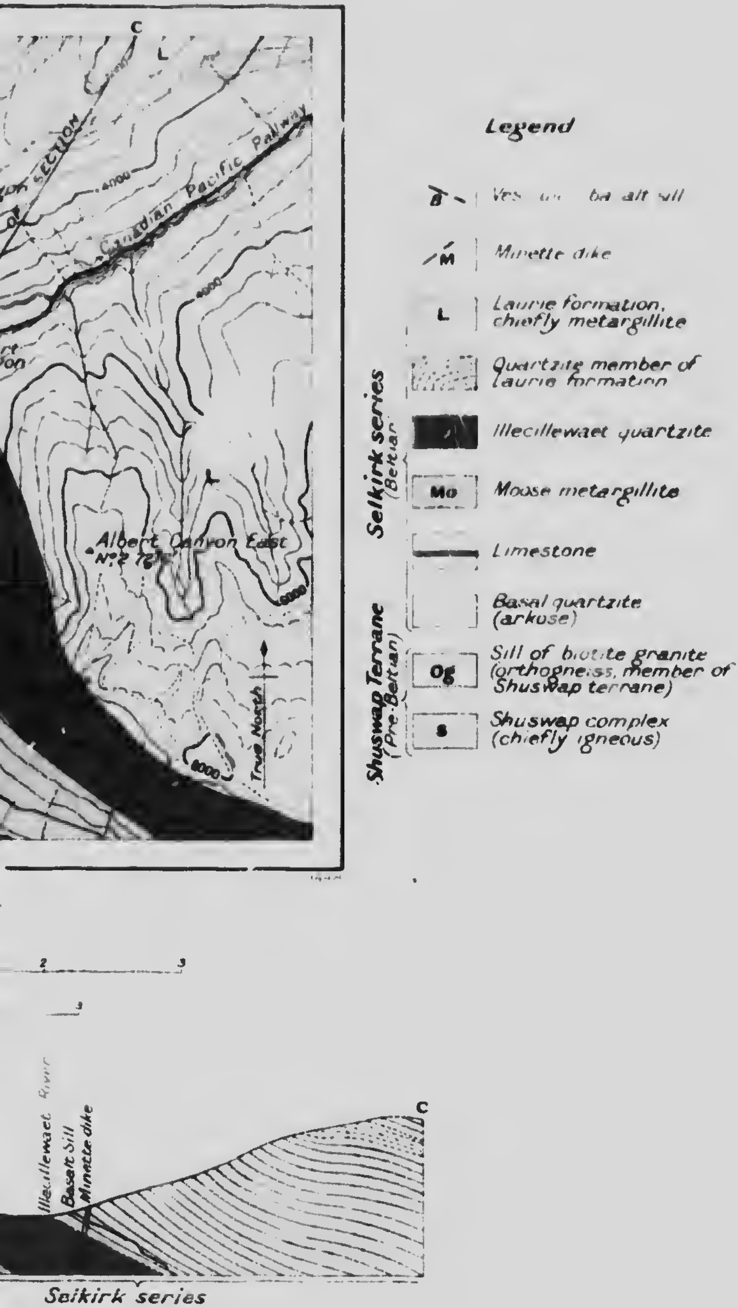
Albert Cany

Miles

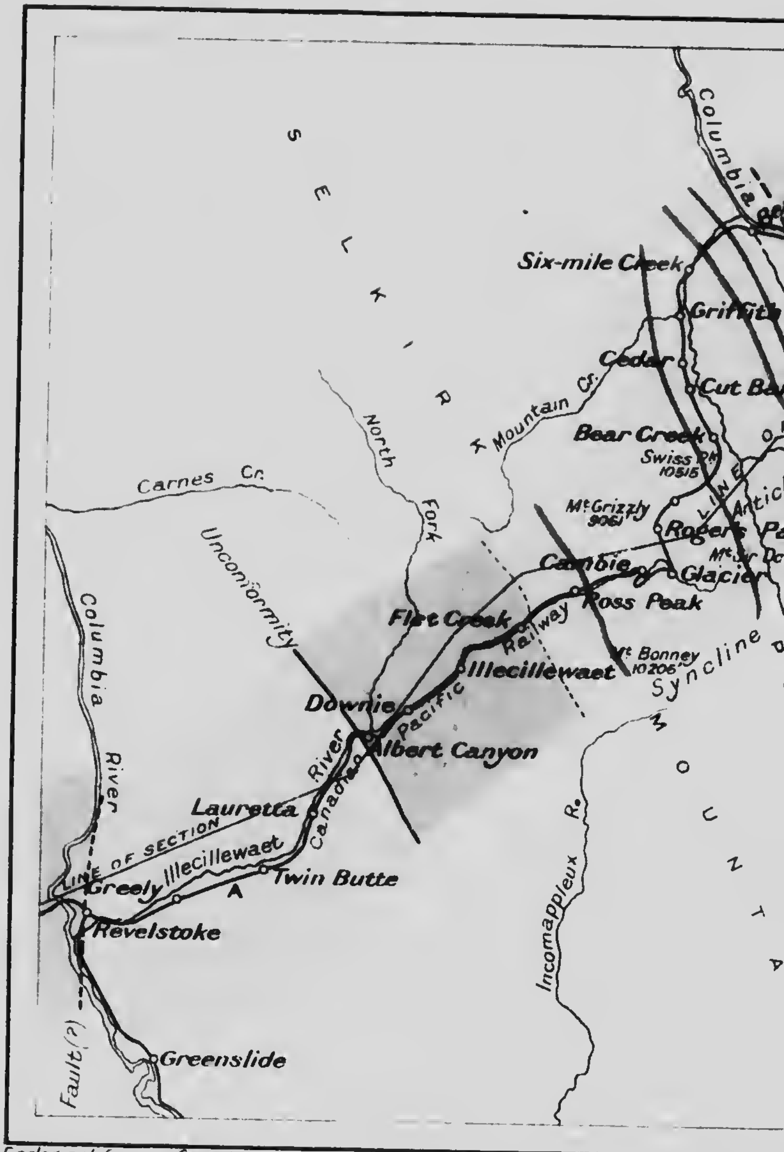
Kilometres

Section along line A·B·C

To accompany Memoir by R.A.Daly


C
L
SECTION
Canadian Pacific Railway
4000
6000
Albert Canyon East
No. 2 76
True North
Legend
M
Minette dike
L
Laurie formation, chiefly metargillite
Quartzite member of Laurie formation
Illecillewaet quartzite
Mo
Moose metargillite
Limestone
Basal quartzite (arkose)
Selkirk series (Beltian)
Og
Sill of biotite granite (orthogneiss, member of Shuswap terrane)
S
Shuswap complex (chiefly igneous)
Shuswap Terrane (Pre-Beltian)
2
3
3
Illecillewaet River
Basalt Sill
Minette dike
C
Selkirk series

A B-C



Geological Survey, Canada.

Geology of the Railway belt between **Golden** a

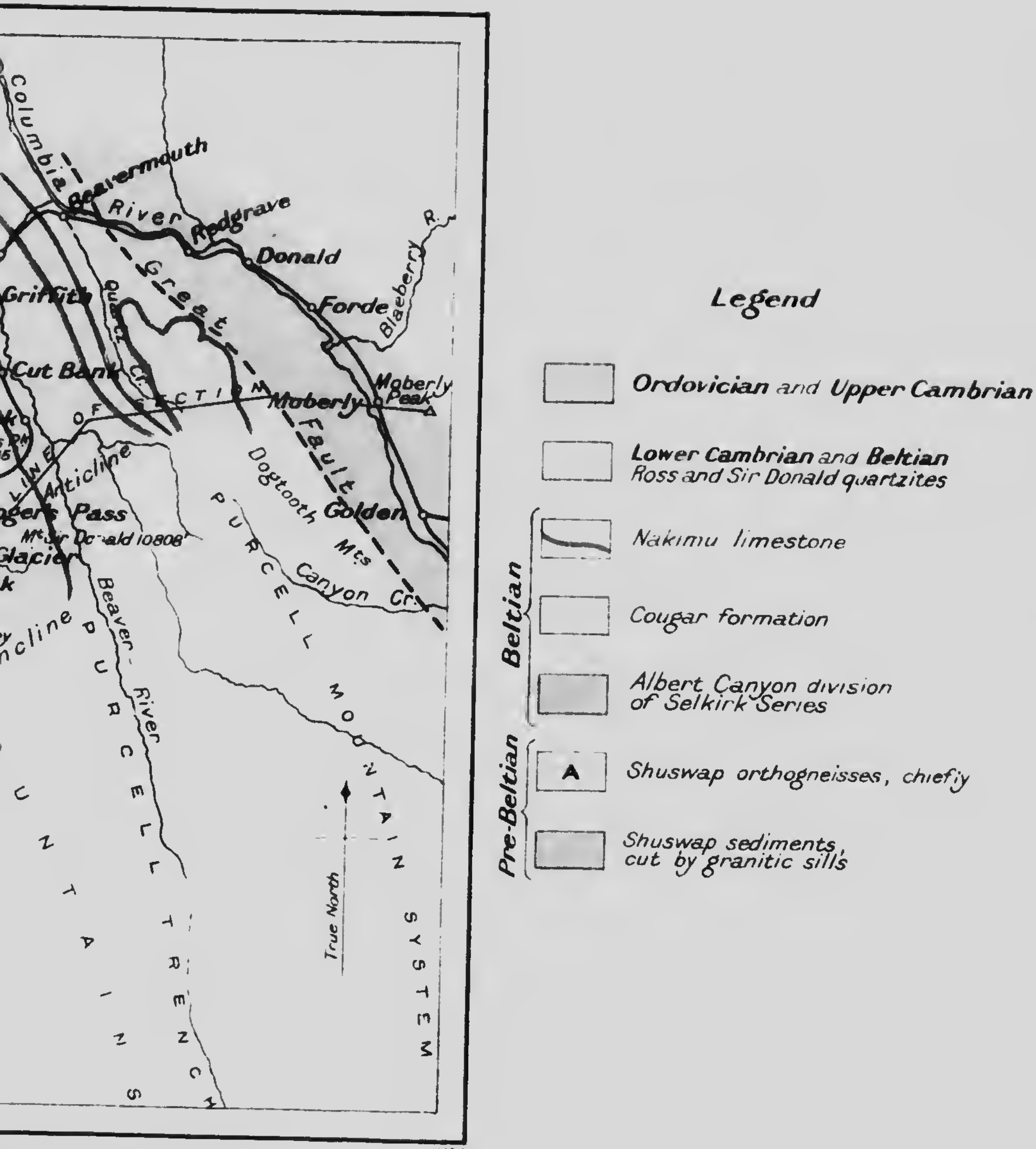
Miles

5 4 3 2 1 0 5 10 15

Kilometres

5 0 5 10 15 20 25

To accompany Memoir by R.A. Daly



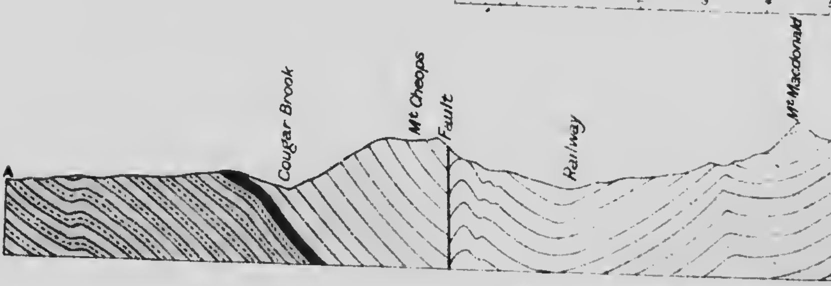
...olden and Revelstoke

Geological Survey, Canada.

Glacier

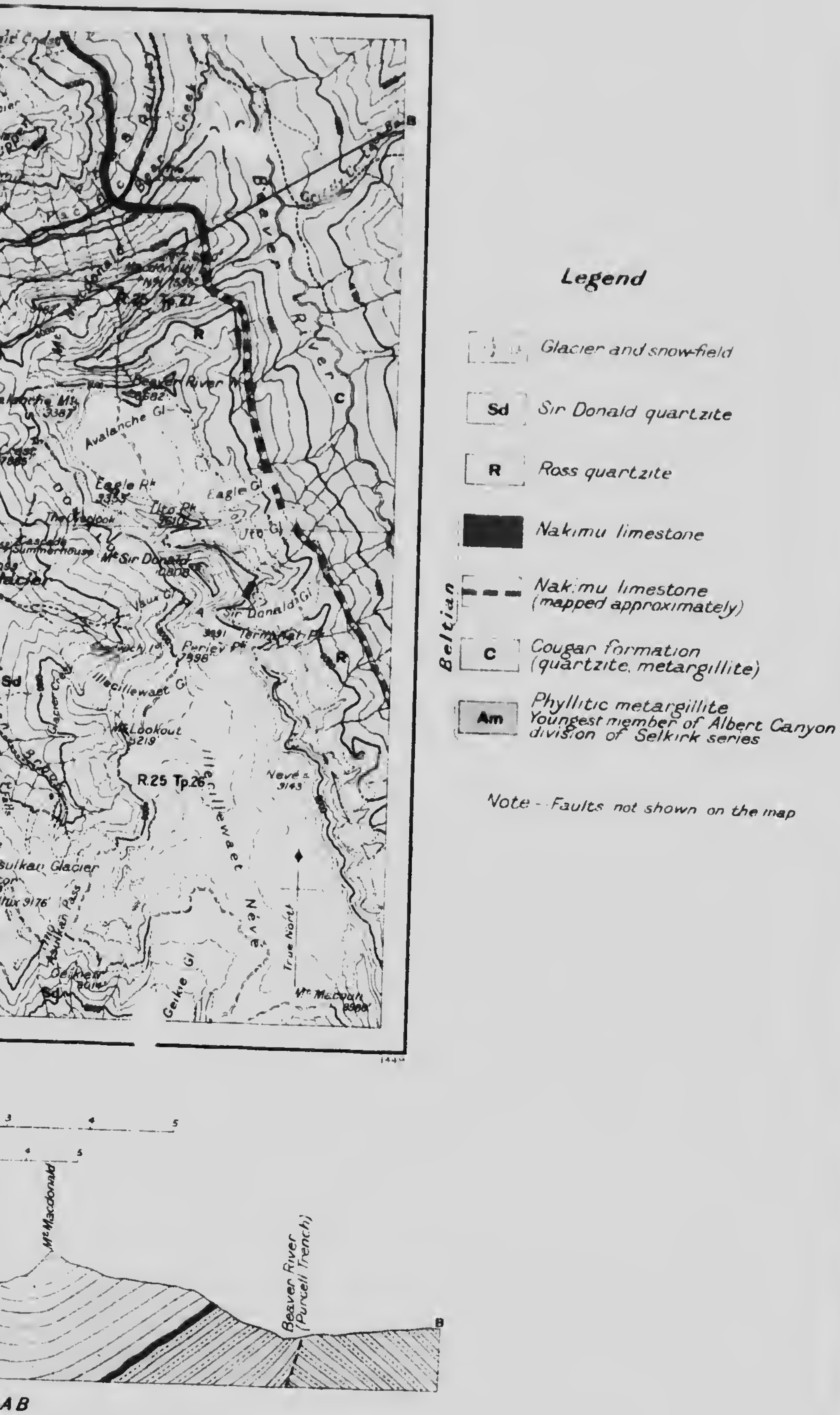
Miles

Kilometres



Section along line AB

To accompany Memoir by R. A. Daly

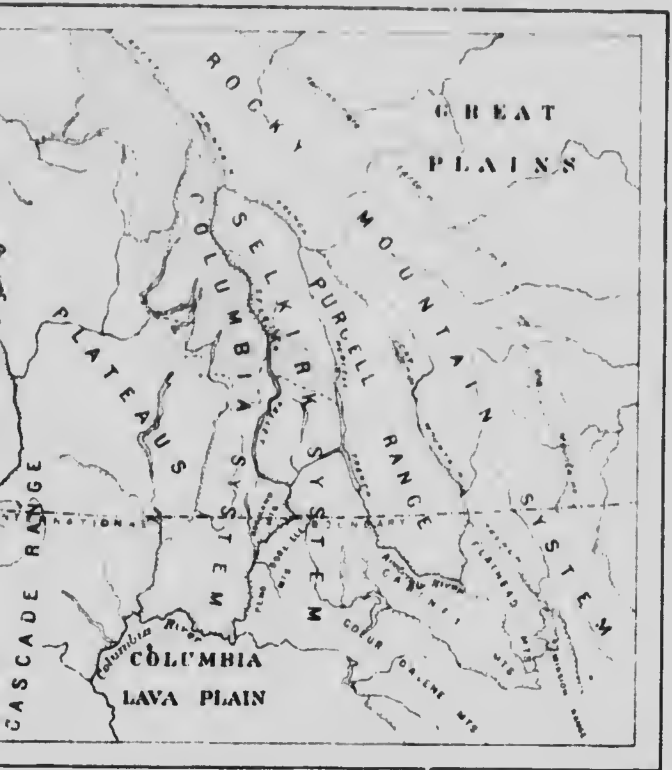

Legend
Glacier and snow-field
Sd Sir Donald quartzite
R Ross quartzite
Nakimu limestone
Nakimu limestone (mapped approximately)
C Cougar formation (quartzite, metargillite)
Beltian
Am Phyllitic metargillite Youngest member of Albert Canyon division of Selkirk series
Note - Faults not shown on the map
R.25 Tp.27
R.25 Tp.26
Avalanche Gl
Eagle Gl
Uto Gl
Sir Donald Gl
Illecillewaet Gl
Illecillewaet
Neve
Geikie Gl
True North
Mt Macdonald
Beaver River (Purcell Trench)
AB

Geological Survey, Canada.

Diagram showing major subdivisions of Co

of **Shuswap Terrane**, Sout

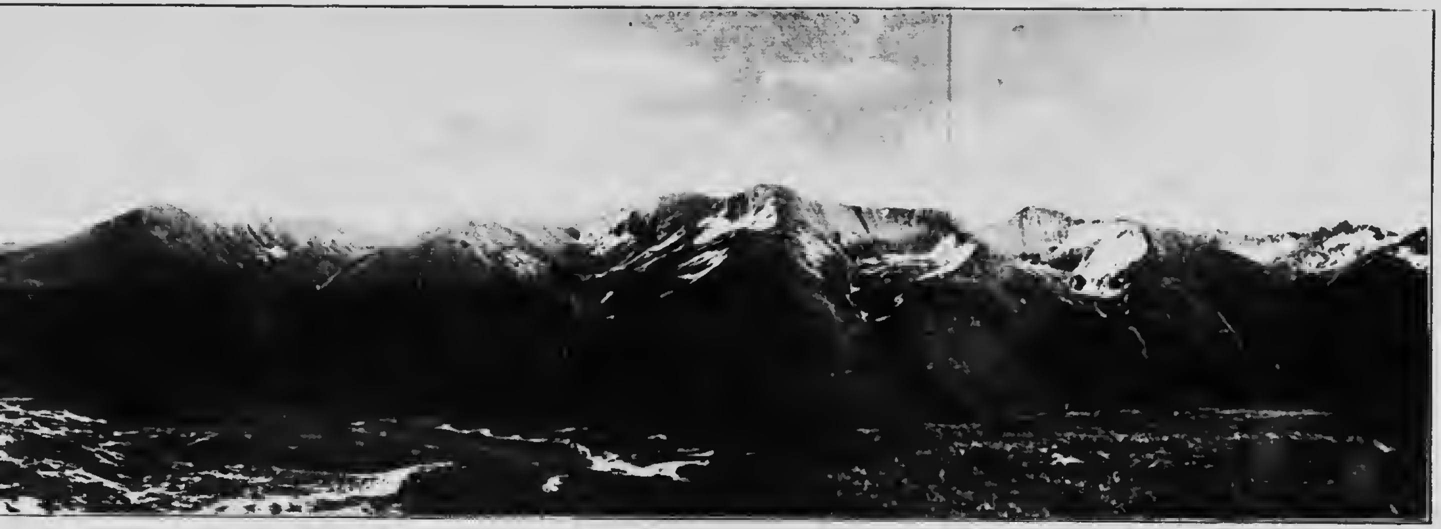
To accompany Memoir by R.A. Daly



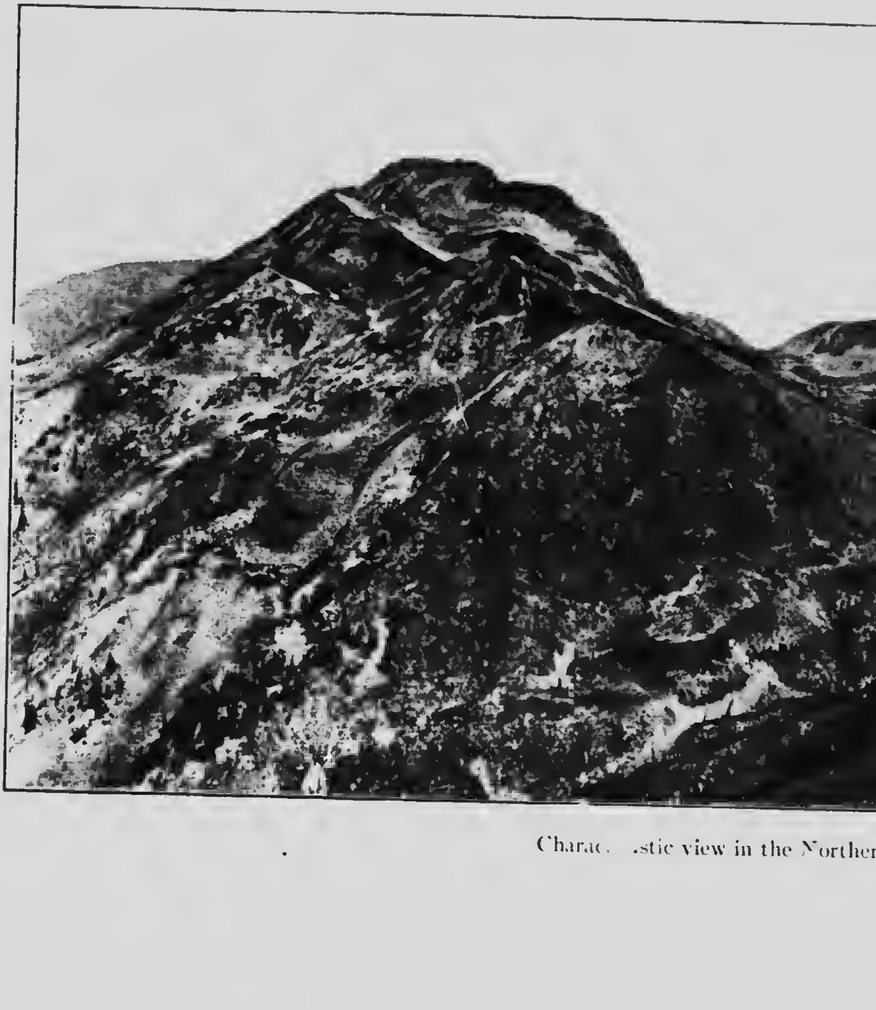
...ions of **Cordillera** and approximate distribution
...**ane,** Southern British Columbia.

Summit topography of the Purcell mountains: Mount

PLATE XLIV.



: Mount Sir Donald on extreme left; Dogtooth range to the right.

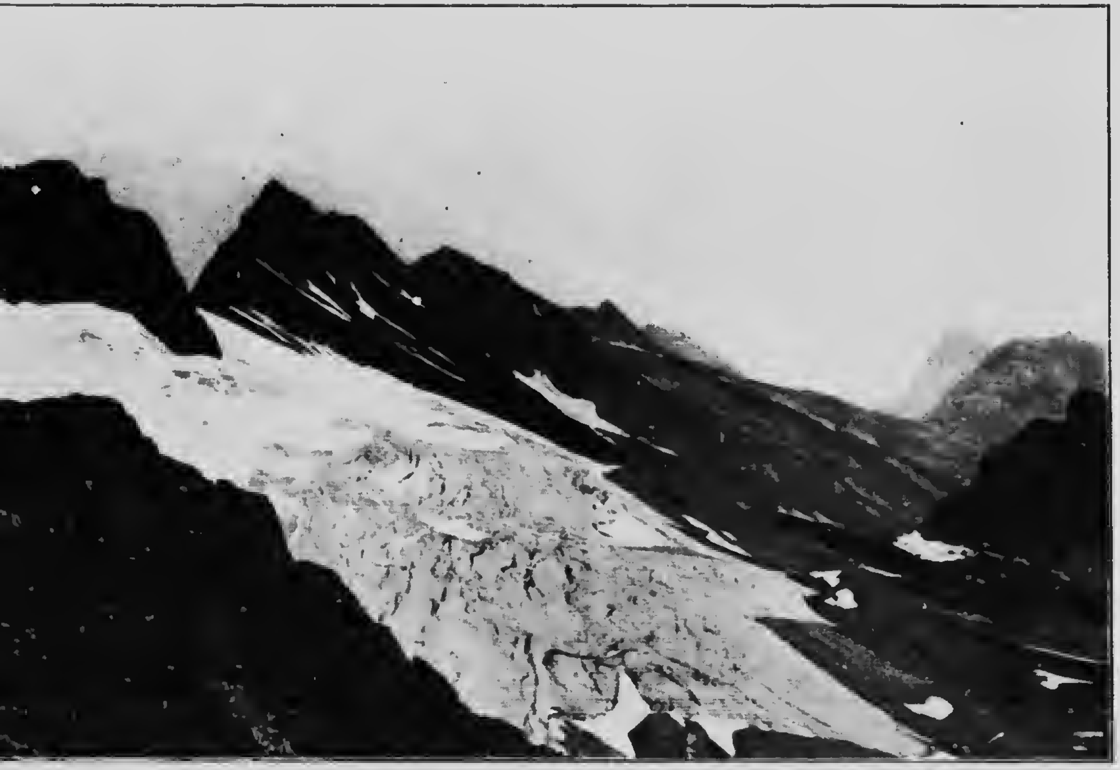


Charac. .stic view in the Norther

PLATE XLVI.

e Northern Purcells, above tree-line.

ugar quartzites at the he



s at the head of Cougar creek.

MAP 143 A
Issued 1915

SHUSWAP LAKE
KAMLOOPS DISTRICT
BRITISH COLUMBIA

Scale, $\frac{1}{253,440}$

Miles

0 5 10 15

Kilometres

1 0 5 10 15 20

4 MILES TO 1 INCH

R A.

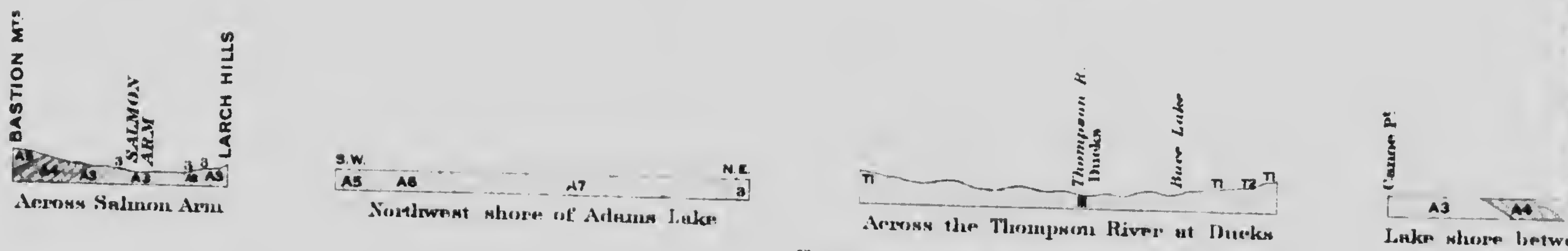
LEGEND

TERTIARY	OLIGOCENE	T2	Kamloops group (sediments)
		T1	Kamloops group (volcanics)
MESOZOIC	JURASSIC	5	Granite and granodiorite
		4	Syenitic contact phase of Salmon Arm batholith
	JURASSIC (?)		Nicola series (sediments)
	TRIASSIC		Nicola series (volcanics)
PALAEOZOIC	CARBONIFEROUS		Cache Creek series (limestone)
		C1	Cache Creek series (quartzite, argillite, etc.)
		3	Orthogneiss granite and aplite
		A7	Adams Lake greenstones (effusive)
		A6	

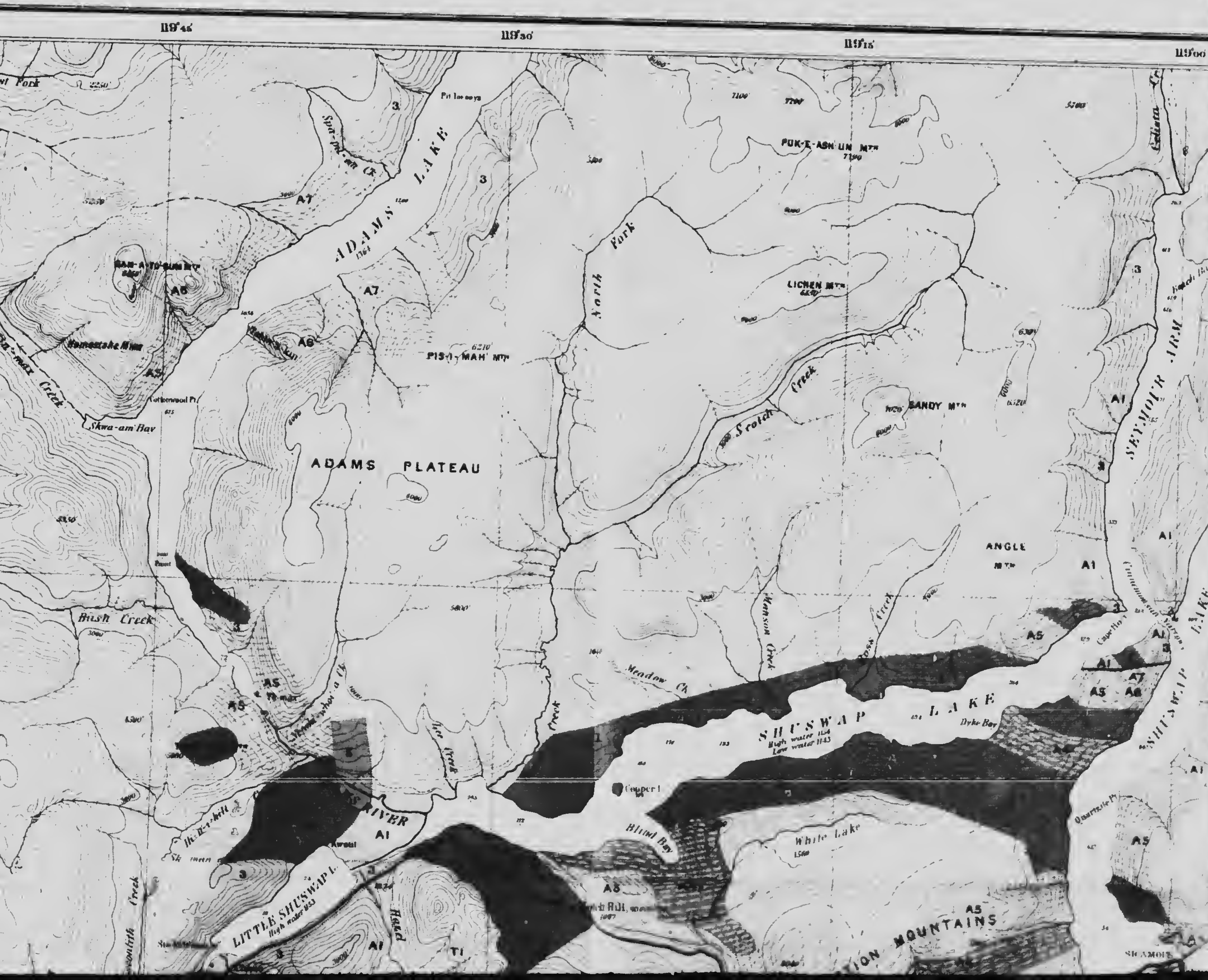
Canada
Department of Mines

HON. L. CODERRE, MINISTER. R.G. McCONNELL, DEPUTY MINISTER

GEOLOGICAL SURVEY



Generalized structure sections
Scale 4 miles to 1 inch



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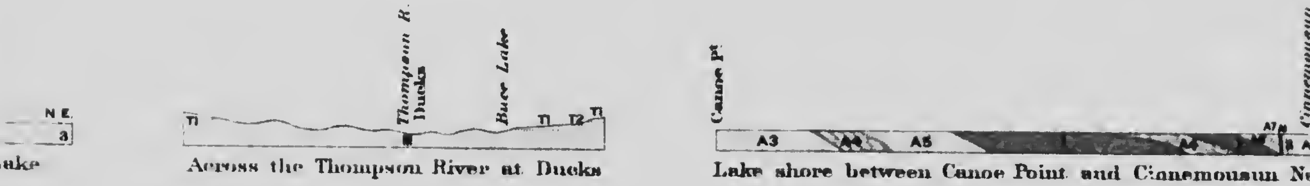
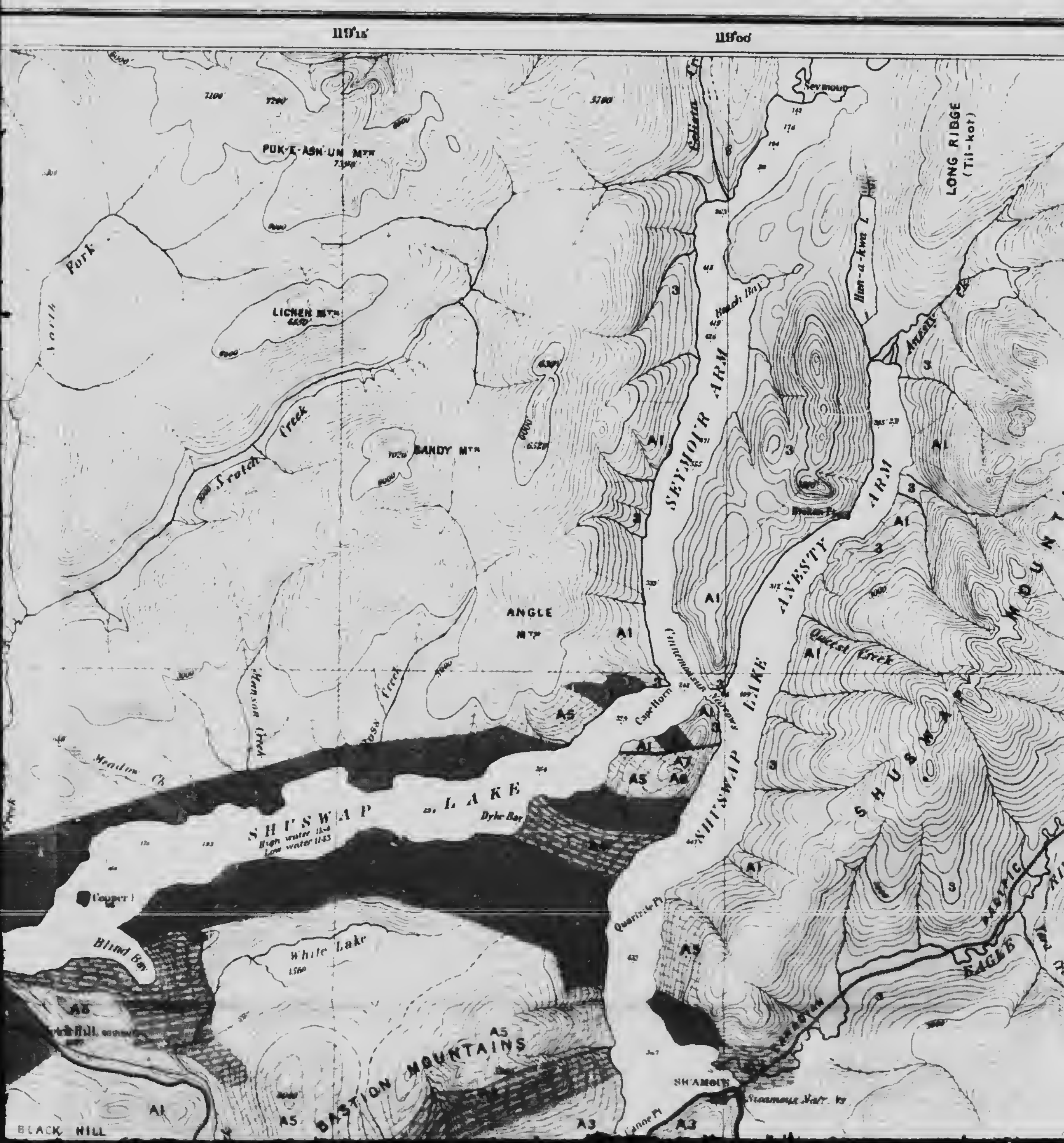
GEOLOGICAL SURVEY



Adams Lake   Across the Thompson River at Ducks   Lake shore between Canoe Point and Cinnemousun N...

Generalized structure sections
Scale 4 miles to 1 inch




Cinnemousun Narrows
ousun Narrows


118°45'
118°30'
51°00'
Jordan River
EAGLE PASS MTS
MOUNTAIN
North Fork
Crazy Creek
Taft
RAILWAY
Craigellachie
Griffin Lake
Griffin L.
Victor L.
Three Valley L.
RIVER
GRIFFIN MTN
Glacier
Yard Creek
Frog L.

PAL[EOZOIC]

C1
Cache Creek series
quartzite, argillite, etc.

3
Orthogneiss granite and aplite

A7
Adams Lake greenstones
(effusive)

A6
Tshinakin limestones and schist

PRE-CAMBRIAN — PRE-BELTIAN

Greenstones
(probably in part intrusive)

A5
Bastion schists

A4
Sicamous limestone

A3
Salmon Arm schist

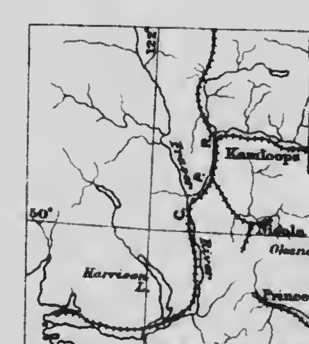
A2
Chase quartzite

A1
Sill-sediment complex

Symbol

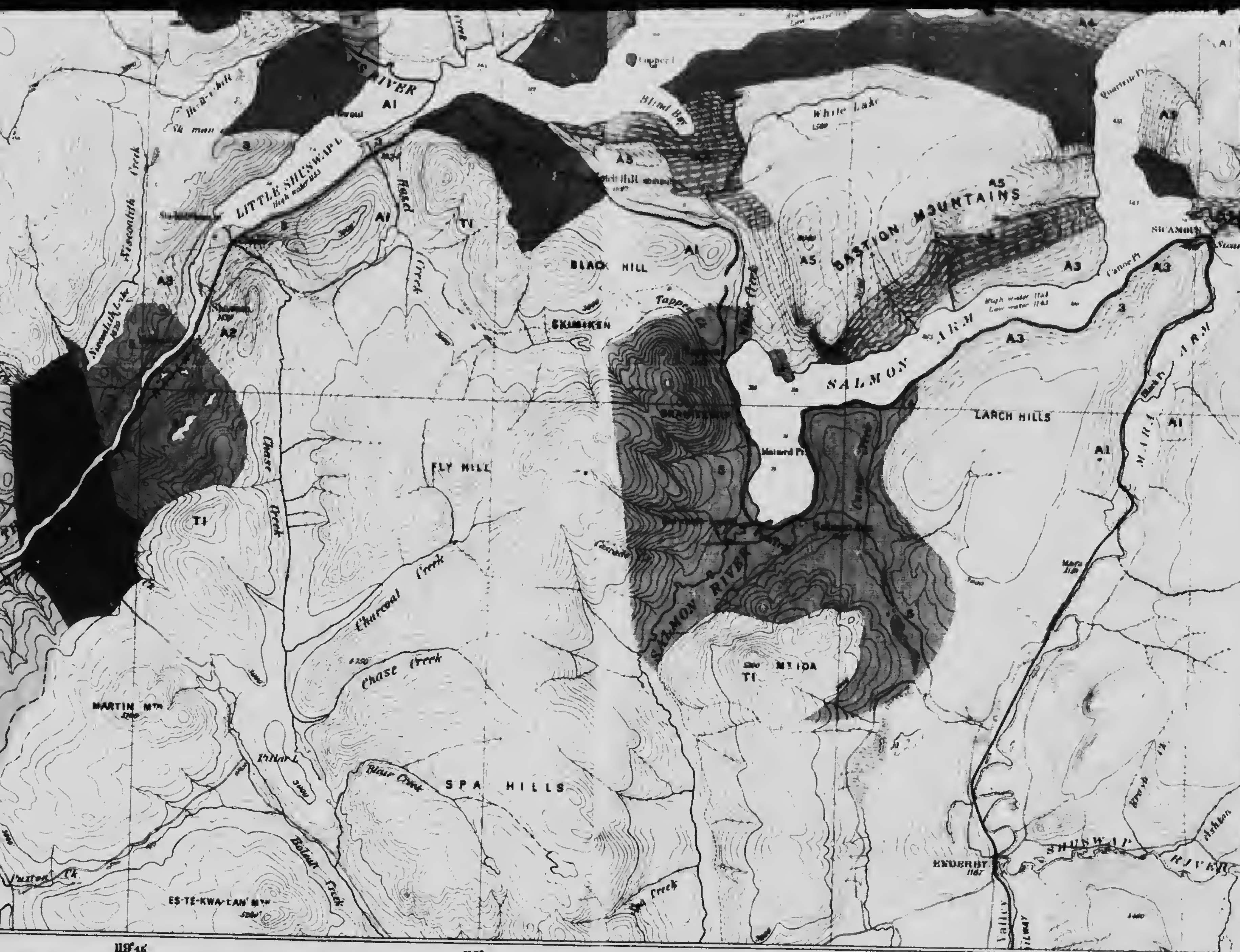
Fault

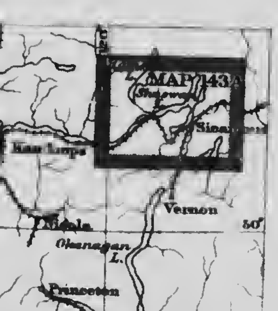
C. O. Senécal, *Geographer and Chief Draughtsman.*
J. J. Carr, *Draughtsman.*



Scale, 100 Miles to

To accompany Memoir by R. A. Daly





0 Miles to 1 inch.

MAP 143 A
(Issued 1915)

SHUSWAP LAKE

KAMLOOPS DISTRICT

BRITISH COLUMBIA

Scale, $\frac{1}{253,440}$

Miles

Kilometres

4 MILES TO 1 INCH

MAP 143 A
(Issued 1915)

SHUSWAP LAKE

KAMLOOPS DISTRICT

BRITISH COLUMBIA

Scale, $\frac{1}{253,440}$

Miles

0 5 10 15

Kilometres

1 0 5 10 15 20

4 MILES TO 1 INCH

R.A.DA

Base map from plate of Shuswap Sheet. No 604, Geological Survey, 1898.

1446

GEOLOGY

R. A. DALY, 1911-1912.