CANADA

DEPARTMENT OF MINES

HON. LOUIS CODERRE, MINISTER; R. W. BROCK, DEPUTY MINISTER.

GEOLOGICAL SURVEY

MEMOIR 55

No. 46, GEOLOGICAL SERIES

Geology of Field Map-area, B.C. and Alberta

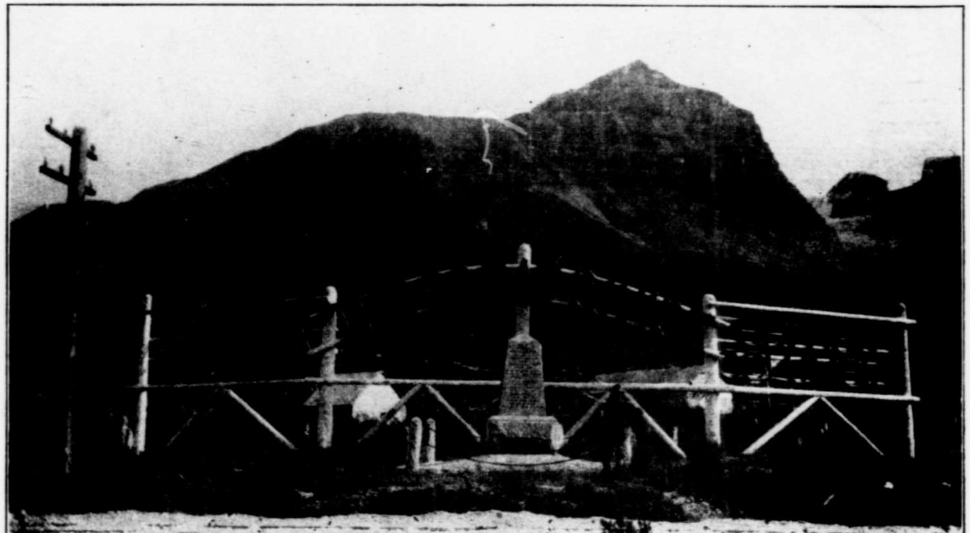
BY

John A. Allan

OTTAWA
GOVERNMENT PRINTING BUREAU
1914

No. 1370

PLATE I.



The Great Divide.

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Geology of Field Map-Area, B.C. and Alta.

CHAPTER I.

INTRODUCTION.

GENERAL STATEMENT AND OBJECT OF INVESTIGATION.

The district in the vicinity of Field and Ice river, British Columbia, was chosen for geological research principally for two reasons: firstly, there is a complete section of the Cambrian series exposed in the various parts of the district. This proves to be the thickest Cambrian section yet studied in Canada, and is well exposed throughout its whole thickness. Attention has been drawn and special interest has been given to the district about Field during the last three years, on account of the remarkable and unique fossiliferous Cambrian horizons discovered by Dr. C. D. Walcott, Secretary Smithsonian Institution, Washington. These fossils are abundant in certain strata, and include many new genera and species.

Secondly, an alkaline intrusive complex in the Ice River district offers an important subject of research. This igneous complex adds another occurrence to the list of very interesting groups of alkaline rocks, which have been studied in great detail in many parts of the world, and which are quite important on account of their variation in mineral composition. This occurrence was also considered worthy of special study, since, with one exception, it is the only large intrusive mass yet known to occur in the Rocky Mountain system between the International Boundary at the 49th parallel, and at least as far north as the 54th parallel of latitude.

This report deals with a part of the section which is being worked out along the main line of the Canadian Pacific railway across the entire North American Cordillera from the Great Plains on the east to the Pacific ocean on the west.

FIELD WORK AND ACKNOWLEDGMENTS.

The data upon which this report is based is the result of about eight months' work in the field during the summers of 1910, 1911, and a part of 1912. Mr. F. J. Barlow efficiently assisted the writer during the first two years of field work. In 1912 assistance was received from Mr. A. E. Cameron and Mr. C. R. Woodward.

The writer wishes to acknowledge the generous assistance rendered by the members of the geological department at the Massachusetts Institute of Technology. Most of the office work has been carried on at this institution, and a portion of this report has been presented as a thesis for the degree of Doctor of Philosophy.

Acknowledgments are especially due Dr. C. D. Walcott, Secretary of the Smithsonian Institution, Washington, D. C., for his untiring interest in problems dealing with stratigraphy and palæontology, also for his helpful suggestions and kind criticism of the stratigraphic section, and of the results obtained both in the field and in the laboratory; the writer's best thanks are due him also for the determination of all the fossils collected in the field. The writer gratefully acknowledges the loan of thin-sections and microphotographs of certain Ice River rocks from Dr. A. E. Barlow; and also his helpful discussion of certain petrographic problems; he thanks Prof. W. M. Davis of Harvard University for kindly criticizing some of the physiographic results; and also Prof. J. E. Wolff of Harvard for placing certain petrographic collections, including those of Alnö, Sweden, and Brögger's petrographic series of the Christiania district, at the disposal of the writer for comparative study.

LOCATION AND EXTENT OF AREA.

The area which is included on the accompanying geological map and discussed in this paper, lies on the western slope of the Rocky mountains in the vicinity of, and especially to the south of the main line of the Canadian Pacific railway in British Columbia. The map area includes over 400 square miles. The limits are 51° 05′ and 51° 28′ north latitude, and 116° 15′ and 116° 35′ west longtitude. The district studied in the field begins at the continental watershed and extends westward to the Beaverfoot range, the most westerly range of the Rocky Mountain system. It lies largely within Yoho park, which is reserved by the Dominion Government, and is located within East Kootenay district and Golden mining division. Field is the only town on the west slope of the Rocky mountains along the railway line. Ice River valley, in which is exposed the alkaline igneous complex, is readily reached by a good pack trail from Field, or from Leanchoil, which is 17 miles west of Field on the railway. From Leanchoil, the trail follows up the northwest side of the Beaverfoot valley for a distance of 12 miles, where it crosses Ice river. This trail has been in use for almost three-quarters of a century; it was originally used by the Stony and Kootenay Indians, and is known as the "Kootenay trail." It continues southward up the Beaverfoot valley and down the Kootenay valley to Fort Steele.

HISTORY AND PREVIOUS WORK.

The earliest published account of exploratory work in this part of the Rocky mountains is that contained in the account of Sir George Simpson's travels.[1] In August, 1814, he crossed the pass now called Kicking Horse pass, and went down the river of the same name on his way to the Pacific coast. He travelled down the Kootenay and probably over the Kootenay trail from Leanchoil.

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[1] Simpson, Sir George, "Narrative of an Overland Journey Round the World," London, 1847.

In 1858 the Palliser expedition explored the Rocky mountains at various latitudes. Dr. James Hector,[1] geologist to the expedition, crossed the Vermilion pass, followed down the Vermilion river, and up the Kootenay, down the Beaverfoot and up the Kicking Horse river to the continental watershed.

The main line of the Canadian Pacific railway was constructed in the early eighties when further exploratory work was done.

The first geological report of this part of the Rockies was made by G. M. Dawson in 1885. His observations are included in a preliminary report which appeared in the annual volume of the Geological Survey for that year. He made a hasty trip to the mouth of Ice river,[2] and noted the intrusive mass and the occurrence of sodalite.

During the following year R. G. McConnell worked out a geological section across the Rocky Mountain belt in the vicinity of the 51st parallel.[3]

The specimens of igneous rock collected by Dawson in the Ice River valley were later examined, in 1902, by A. E. Barlow, who published a short description of the diverse types represented.[4]

In the same year Prof. T. G. Bonney examined and described sodalite syenite, which had been collected in 1901 by Mr. E. Whymper from the same locality.[5]

In 1903, Bonney described certain peculiar markings which occurred in specimens of quartzite collected by Prof. Collie, from the Canadian Rockies, near Field.[6]

In 1907, C. D. Walcott began his studies of the Cambrian in British Columbia. He found the best exposed section to be in

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[1] Hector, James, Quart. Jour. Geol. Soc. London, Vol. 17, 1860; p. 388.

[2] Dawson, G. M., Annual Report, Geol. Survey, Canada, Vol. I, Part B, 1885.

[3] McConnell, R. G., Annual Report, Geol. Survey, Canada, Part D, 1886.

[4] Barlow, A. E., "Nepheline Rocks of the Ice River, B. C." Ottawa Naturalist, Vol. 16, 1902, p. 70.

[5] Bonney, T. G., "On a Sodalite Syenite (Ditroite) from Ice River, B. C." Geol. Mag. Vol. 9, 1902, p. 199.

[6] Bonney, T. G., "Markings on Quartzite Slabs," Geol. Mag. Vol. 10, 1903, p. 291.

Mt. Bosworth at the Continental Divide, on the Canadian Pacific railway. He subdivided the series into ten formations, and accurately measured sections in various localities east of Field. He continued his studies in 1909-1912 (inclusive) in the vicinity of Field, giving special attention to the palæontology. He has discovered many remarkable fossils, and has greatly extended our knowledge of the fauna that lived in the Cambrian seas. The results of his studies on the Cambrian of this district are published in the Smithsonian Miscellaneous Collections.[1]

The writer spent the field seasons of 1910 and 1911 in this district; the preliminary reports have been printed in the summary reports for the same years.

[1] Walcott, C. D., Cambrian Geology and Palæontology, Smithsonian Misc. Coll., Vol. 53, Nos. 1, 5, 1908; No. 7, 1910; Vol. 57, No. 1, 1910; Nos. 2, 3, 5, 1911; Nos. 6, 7, 8, 1912.

CHAPTER II.

SUMMARY.

PHYSIOGRAPHY.

The Kicking Horse river forms the main transverse westward drainage of this portion of the Rocky mountains. It has its source in a broad saddle of the Kicking Horse pass with an elevation of 5329 feet. The westward slope from the pass is much steeper than that to the east. In a distance of about 8 miles the river drops 1300 feet to an elevation of 4064 feet at Field, and 1100 feet of this drop occurs within 5 miles. The river is about 42 miles long and has a total fall of 2750 feet. Several of the larger tributaries, such as the Ottertail and Beaverfoot, are subsequent to the soft structure of the rocks. The valleys are all of pre-Glacial origin, but they have become rounded, deepened, and widened by the action of the valley glaciers. Basins have been gouged out of the floor of the valleys by the concentrated action of the ice erosion, at the junction of the two or more valley glaciers. These basins have since become aggraded with gravel and sand, on the surface of which the present streams have a meandering course. One of the largest and finest is seen between the mouth of Yoho river and the town of Field in the Kicking Horse valley. The outlet of the drainage was originally to the southeast through the valleys of Beaverfoot and Kootenay rivers. The change of drainage was caused by the obstruction of Beaverfoot valley, probably accompanied by a slight uparching of the floor. The drainage was changed after the ice had melted out of the valleys and had left morainal débris behind, which obstructed the former grade of the valley.

The topography is extremely rugged and mountainous. The relief is distinct. The whole district is maturely dissected, and the interstream areas have been worn down to very narrow knife-like ridges which in many places are not a foot in width. The intervening ridges rise from 8000 to 11,500 feet above sea-level. The interstream divides have a fairly uniform elevation of

8000 to 8300 feet. In explaining the cause of this accordance of interstream divides, it has been suggested that they represent the elevation of the surface of the ice sheet, the projecting portion of the ridges having been eroded to the surface of the ice.

The greatest average elevation, which is over 10,000 feet, is reached in the Bow range which forms the Continental watershed. There is a gradual downward slope in the whole system to the Columbia valley, with the exception of a few peaks in the Ottertail range, of which Mt. Goodsir (11,676 feet) is the highest in this part of the Rocky mountains. The general appearance of the Bow range is quite distinct from those to the southwest. It is made up chiefly of heavy bedded quartzites, limestones, and dolomites, chiefly of Lower and Middle Cambrian age. The beds are lying nearly horizontal and weather in large part into precipitous castellated cliffs, which show up an "alcove" form of erosion in certain cliff-forming limestones and dolomites.

In contrast with the general appearance of the Bow range there is the broad drainage area of the Ottertail valley to the southwest. It is floored by slates, shales, and argillites, all of which are soft, highly cleaved, and weather readily into rounded topped ridges and broad talus slopes.

The Ottertail range contains a band of limestone which forms a precipitous cliff, frequently 2000 feet high, along the southeast of Ottertail valley. The broad Beaverfoot valley, with a northwest-southeast trend, underlain by soft slates and argillites, separates the Beaverfoot range, which is the last range to the west, from the rest of the mountain system. The Beaverfoot range has a very irregular zigzag summit made up of harder Ordovician and Silurian sedimentary rocks.

The Van Horne range is the northwest continuation of the Beaverfoot and Ottertail ranges across the Kicking Horse valley.

Cirques, hanging and U-shaped valleys are numerous in many of the smaller tributary valleys. The suggestion has been offered by the writer that some of these hanging valleys have been initiated by cliff glaciers. All stages in the development of such a valley are represented in this district. One of the best and most noted examples of a hanging valley is that represented by Takakkaw falls in the Yoho valley, where the water falls over

1200 feet from the lip of the depression. Erosion by rain, wind, and frost is going on at an enormous rate, with the result that the higher mountain peaks are capped by precipitous slopes, and are typically alpine.

STRATIGRAPHICAL GEOLOGY.

The rocks in Ice River district are sedimentary, metamorphic, and igneous. The sedimentary rocks range in age from Pre-Cambrian to Silurian, inclusive. They are divided into various ages on palæontological and lithological evidence, and for the same reasons are further subdivided into several formations. The table on page 60 gives the succession of these formations and the distinguishing lithological characters of each.

The general succession of formations from the lowest to the highest or from the oldest to the youngest, is from the northeast to the southwest, since the trend of the mountain ranges is northwest and southeast. Two structure sections are given across the strike of the beds in a northeast-southwest direction.

The Pre-Cambrian is exposed in the extreme northeastern corner of the district studied. Dr. Walcott notes that there is a break between the Pre-Cambrian and the Cambrian beds. This break is in the main an unconformable one, but appears conformable in places.

The total thickness of the section worked out between the base of the Cambrian and the top of the Halysites beds (Silurian), is over 29,418 feet. In this section the Cambrian makes a conformable series over 16,500 feet thick, resting unconformably upon the Pre-Cambrian and transitional above into conformable Ordovician.

The Lower Cambrian beds are largely quartzitic. Certain of these beds contain numerous annelid borings, others contain well rounded argillaceous concretions, and others show cross-bedding. These features suggest a close point of origin of the material composing the beds.

In contrast with the highly siliceous Lower Cambrian beds, the Middle Cambrian formations are essentially calcareous or dolomitic in character. The Stephen formation is important palæontologically, since it contains two highly fossiliferous lentils, the "Ogygopsis shale," on Mt. Stephen, containing the famous trilobite "fossil bed," and the "Burgess shale," on Mt. Field, containing another rich fossil bed. From the latter Walcott has determined merostomata, branchiopoda, malacostraca, trilobita, annelids, medusæ, and (probable) holothurians. Even the soft part of these animals are well preserved, so that they add much to our knowledge of the variety of life present in the Middle Cambrian sea.

The massive beds of the Eldon formation make a good horizon marker because they form steep cliffs and castellated crags. This erosion feature makes it possible to distinguish the Middle Cambrian from a distance.

The Upper Cambrian was previously subdivided into three formations (Bosworth, Paget, and Sherbrooke), with a total thickness of over 3590 feet. In the Ottertail range in the vicinity of Ice river, the writer found that the sedimentary series could not be correlated with those in the Bow range. This series has been subdivided, on lithological basis, into three formations, the *Chancellor* below, the *Ottertail* in the middle, and the *Goodsir* at the top. The Ottertail formation consists essentially of beds of massive blue limestone; it is over 1700 feet thick and is a good horizon marker. Only two fossils have been found in it, and these are Upper Cambrian in age. The underlying formation consists of red weathering shales and meta-argillites, which also are of Upper Cambrian age. The lower limit of this formation is not well defined since the lower beds become more highly crushed and sheared and finally the cleavage predominates over the plane of stratification. These beds are mapped in the sheared zone. This zone is 5 to 6 miles wide, has a northwest and southeast trend, and underlies the greater part of the Ottertail valley. The eastern limit of this zone is bounded by a fault, "the Stephen-Dennis fault." The writer is of the opinion that this zone represents the highly sheared and contorted beds of the Chancellor formation. In some localities where the plane of stratification can be determined, the beds are lying almost horizontal, and in others they are more or less tightly folded.

Above the Ottertail formation there is a thick conformable series of thin-bedded cherts, cherty and dolomitic limestones, and siliceous and calcareous shales, which the writer has called the *Goodsir* formation, since they are best developed in Mt. Goodsir. This formation is over 6000 feet thick. The lower 3000 feet are remarkably well banded, and in the ridge to the east of Moose creek, where the beds are best exposed, there are 64 alternating hard and soft bands. These bands vary from 8 to 200 feet in thickness.

Several species of fossils were found in the lowest beds of this formation, of which four are new.

On lithological evidence and from the fauna represented, the writer places the boundary between the Cambrian and the Ordovician, at least tentatively, at the top of the Ottertail limestone and the base of the Goodsir formation.

In the Beaverfoot range there is a band of black fissile shale rich in graptolites of Ordovician age. This formation is defined on the east side by a fault which passes along the northeast slope of the Beaverfoot range.

The Silurian is represented by the Halysites beds in the Beaverfoot range, consisting of white quartzite and massive bedded dolomite. The formation is apparently conformable upon the graptolite beds and is found within a synclinal fold in the latter. Certain layers are rich in corals as the name indicates.

IGNEOUS GEOLOGY.

This Ice River alkaline intrusive mass is not only irregular in outline as shown on the map, but it is irregular in its relations to the surrounding sediments. It can not be grouped as regards form, with any of the typical forms of igneous bodies as they are defined, and yet it is closely related in various ways to several types.

The writer proposes to regard this complex as an asymmetrical laccolith with a probable stock-like feeder which connects this chamber with a much larger reservoir beneath. In this respect the Ice River complex as exposed is satellitic to a larger and deeper parent mass.

This complex comprises an area of about 12 square miles and is best exposed in the southern portion of the Ice River valley. The outline of the exposure of this igneous rock is shaped somewhat like a retort, with its greatest development towards the south and two arms extending from the corners and narrowing towards the north.

The form of this igneous complex has been determined as an asymmetrical laccolith, thinning out towards the north. It has a stock-like conduit through which the molten material was forced from a deeper intercrustal reservoir, that has not yet been exposed by erosion. It agrees with the mechanics of laccolithic intrusion, in the fact that the cover has been lifted to a certain degree by the pressure behind the magma.

Lithologically, the rock series comprising the laccolith are alkaline in composition. The material in this laccolithic chamber has been brought in by a single intrusion; the separation of the magma into the diverse types has resulted from various processes of differentiation.

For convenience in the description of the petrology of the rock types, the series has been subdivided into three groups according to mineralogical composition. The first group includes the leucocratic types which make up the larger part of the complex. Nephelite syenite is the most important member, and at the same time the more highly alkaline. With it are included many minor types, all variation facies of the nephelite syenite.

Within the second group are included ijolites, urtites, and other varieties essentially mesocratic, but varying towards both leucocratic and melanocratic types.

The third group includes jacupirangites, alkalic pyroxenites, and associated melanocratic varieties.

The texture of the rock varies greatly, not only within the complex as a whole, but also within the groups, and even within the diverse types.

It is a characteristic feature that the rocks vary both in appearance and in mineralogical composition sometimes within a few feet. Irregular patches or schlieren, consisting of material richer in dark coloured constituents, are present in many of the types.

Mineralogically, the groups are characterized by the presence or absence of certain essential minerals. In the first group alkali feldspar, nephelite, ægirite, and sometimes sodalite are the essential minerals. Several varieties of feldspar are represented, but orthoclase or microcline and albite, often perthitically intergrown, are the most abundant. In the leucocratic rocks, nephelite is always subordinate in amount to the feldspar, and in some types is almost accessory. With the characteristic ægirite-augite is sometimes found accessory amphibole determined as basaltic and barkevikitic hornblende. Sodalite becomes an essential constituent in some of the material which has been concentrated along the roof of the laccolith. This mineral has a deep blue colour, so that when it occurs as one of the constituents, it makes a decorative stone of economic importance. Sodalite also occurs in veins of almost pure material.

In the second group, the transition types, represented by ijolites and urtites, the essential minerals are nephelite, ægirite-augite, and barkevikite. Feldspar is either absent or accessory. In some varieties of ijolite, hornblende predominates over pyroxene, so that it gives a new type, "barkevikite-ijolite." In the transition types from nephelite syenite to ijolite, there is a gradual decrease in the amount of nephelite present.

In the jacupirangite and associated types of the third group, there is but little light coloured material. Pyroxene, magnetite, ilmenite, schorlomite, and sphene are the essential minerals. In one type of rock sphene makes up about 30 per cent of the whole.

There is a remarkable absence of dykes in and about the complex. Only twelve were found in the field. These are narrow and most of them have a general east-west trend.

Structurally, the diverse types of the complex are transitional into one another and represent a single period of intrusion. In every case the leucocratic types remained in a molten condition after some of the darker coloured material had frozen. This material was broken and the cracks filled with the still fluid nephelite syenite. These dyke-like masses of light coloured rock in the melanocratic material form a striking feature in certain parts of the complex, as they stand out as irregular sheets on the eroded surfaces.

The hypothesis offered for the explanation of the diverse types within this complex, which are transitional into one another, is a combination of the result of separation by gravitative adjustment, and the rapid cooling of a portion of the original heterogeneous magma in the thinner and cooler portions of the chamber. There has been a sinking of the heavier minerals and a rising of the lighter ones. This explains the occurrence of sodalite-rich rocks always at the upper contact.

It has been shown that a laccolith, besides arching up the cover, is able to shatter the contact and enclose zenoliths, and even to assimilate a certain amount of rock on the contact. The main evidence at hand for assimilation is the frequent presence of calcite as a pyrogenetic mineral. Limestone on the contact has been fused, and the calcite has crystallized out like any of the other constituents.

The zone of metamorphism is very irregular and poorly defined. In some places it is only a few feet wide, while in other parts the rock is distinctly metamorphosed for 500 to 700 feet from the contact. The most striking contact rock is a dense, reddish-brown hornfels, which lies between the igneous rock and the limestone in the upper contact. This band was originally a calcareous shale which has become highly baked by the intrusion.

The age of intrusion, as near as can be determined from the evidence at hand, is probably Post-Cretaceous. It is older than the main period of deformation, which is connected with the revolution at the close of the Laramie. There was a period of folding earlier than the main shearing, and the intrusion is younger than this folding.

In the eastern part of the Rocky mountains the Cretaceous lies conformably upon the older strata, so the assumption is made that the folding occurred after the deposition of the Cretaceous, and is, therefore, late or Post-Cretaceous in age. The period of faulting has followed the main deformation of strata. The

Ice River complex has not been strongly affected by the Laramide revolution. The igneous rocks are so much more resistant than the surrounding sediments, that the latter have been intensely squeezed about the igneous mass.

CHAPTER III.

PHYSIOGRAPHY: THE WESTWARD DRAINAGE SYSTEM.

The drainage system of the westward slope of the Rocky mountains in the vicinity of the 51st parallel, consists of a main transverse stem called the Kicking Horse river,[1] and a number of tributaries entering from both the north and the south. Some of these tributaries are equally as large as, and at least two of them are larger than, the main stem. The smallest members of the drainage system are represented by a large number of small streamlets, most of which are intermittent. These represent the twigs of the system and occur upon the steep mountain slopes bordering the larger valleys, and are finely displayed in the canyon-cut portions of the main trunk.

KICKING HORSE RIVER.

It is proposed to first give a description of the main transverse valley occupied in part by the Kicking Horse river. This river is a tributary of the Columbia river, which flows in the broad north and south trough, the "Rocky Mountain trench" or the "Columbia-Kootenay trough," forming the westerly limit of the mountain system. The length of Kicking Horse river is almost 40 miles and in this distance it has a difference in elevation of almost 2700 feet. The summit of the valley has an elevation of 5329 feet, while the mouth of the river is 2580 feet above sea-level.

A glance at the map, or a trip over the railway at this point, makes it evident that the so-called source of the Kicking Horse

[1] This river was originally called the "Wapta" by the Stony and Kootenay Indians, but the name was changed to "Kicking Horse" after the expedition of Sir James Hector in 1858, when his party extended their exploration up this valley and found the Kicking Horse pass. The river was so called on account of a mishap which befell Dr. Hector on this expedition, and which in later years proved serious to him.

river, at the pass of the same name, does not represent the head of the main branch of the westward drainage. A much larger stream, the Yoho, entering the transverse valley from the northwest at a point about 4 miles from its head, might be rightly considered as more deserving of being called the source of the westward drainage. At the point of junction of the Yoho river with the Kicking Horse river, the former carries about four times the volume of water that the latter does. It must, however, be noted that for a distance of more than 10 miles from its source, the Kicking Horse river follows a distinctly transverse course, whereas the Yoho river is subsequent upon the trend of the structure in the mountain ranges and, therefore, if the origins of the depressions occupied by these two streams are considered in determining which should be called the source of the main drainage, then it would seem that the source of the Kicking Horse river rightly deserves this name.

The Kicking Horse river has its source in a rather broad, somewhat flat-floored, saddle-like depression, rather steeply sided to the north and south, and very gently sloping towards the east and west. This gentle slope continues for a distance of about 2 miles on the west side and 1 mile on the east side of the low crest which in this part of the mountains forms the Continental Divide (Frontispiece).

On the summit of the pass the grade is almost imperceptible. A small stream gathers its trifling volume from the south side of the depression, and where it reaches the lowest level divides into two small streamlets which flow in opposite directions. The water which deviates from this point eastward "eventually mingles with the ice cold tides of Hudson bay," while that which is drained to the west finally reaches the Pacific ocean. This broad-seated, saddle-like depression or elevated "through-valley," has been carved out of thick-bedded quartzites, transversely to the strike of the strata, and is believed to have been deepened by glacial overflow. The ice coming from the mountains, especially to the immediate south, accumulated in this depression, then overflowed to the east down a gentle slope into the valley now occupied in part by the Bow river, and to the west down a very steep slope into the deeply cut valley of the Kicking Horse river. The valley glacier in this stage would be a "through glacier." The floor of this ancient ice saddle is thinly veneered with ground moraine, including numerous large boulders, many of which appear to be of local origin. Within a few hundred yards of the low crest, on the westward slope there is a small pond of water called "Sink" lake because it has no visible outlet. A small streamlet enters it on the south side and is the outlet of a small lake, Ross lake, with emerald coloured water, which is situated in the bottom of a cirque, 400 feet above the summit of the saddle.

Almost 2½ miles from the summit and about 100 feet below the highest part of the crest, there is a larger lake, almost half a mile long and a quarter of a mile wide. It seems as if this lake occupies a depression in the bed-rock, and not one entirely in the ground moraine. This lake is known by the name of "Wapta" lake, since it virtually represents the main source of the Kicking Horse river which was formerly called the Wapta river by the Indians.

At the precise head of this lake a small stream enters from the south, the waters of which, though small in volume, cataract over rock ledges with the roar of a mighty mountain torrent. It has most fittingly been called "Cataract" brook. This brook flows in a north and south depression which parallels the course of a sharp down-flexure in the sediments to the west. The brook is fed almost entirely by glaciers on the ridge in which Mt. Victoria and Lefroy are situated, and on the mountains to the west. One branch has its source in Lake Oesa and Lake O'Hara. The former lake lies in a rock basin at an elevation of 7398 feet, and is connected with the latter by a chain of two smaller lakes and a cataracting stream which through much of its course runs underground. Lake O'Hara lies at an elevation of 6664 feet. It is surrounded, at its upper end, by precipitous quartzitic cliffs over 100 feet high. The water from the upper lakes comes from under a thick veneer of rock talus and cascades, in a fall of almost 100 feet, into the upper end of Lake O'Hara. This lake lies in a cirque-like depression, the outlet of which is formed by morainal detritus. These lakes lie in a series of "tandem cirques." The glacier in the cirque between Mt. Yukness and Mt. Schaffer also supplies a stream to Lake O'Hara.

The second main branch of Cataract brook gets its supply from a large amphitheatre-cirque between Mts. Odaray, Duchesnay, and Stephen. Below the junction of these two main branches the floor of the valley is comparatively flat and broad. The brook meanders over the floor and in some places the channel broadens to form small lakes. In the last three-quarters of a mile, the grade of the brook changes to that of a cataract, thus giving the valley a hanging character. There is a fall in the stream of almost 400 feet in this distance. It is worthy of note, that the north-south depression occupied by Cataract brook is a feature more or less continuous for 25 miles to the south and is occupied in part by McArthur creek, Goodsir creek, and Moose creek.

In the Kicking Horse valley a few hundred yards below the outlet of Wapta lake, a small creek enters from the north. This stream, although insignificant in size, is the outlet of Sherbrooke lake, which lies in a north-south depression between Mt. Ogden and Paget peak. The lake is about 1 mile long, lies 700 feet above Wapta lake, and is fed directly from the glaciers about Mt. Niles and Mt. Daly. The water shows varying shades of green; the part of lake near inflowing streams is emerald green, while the rest of the lake is a lighter green and may be better described as a nile green. This depression is an excellent example of a hanging valley. From the outlet of the lake the stream cascades down 800 feet in less than a mile, where it joins the Kicking Horse river. The photograph (Plate II, B) shows the cirque-like nature of the lake basin, with steep mountain slopes on either side and also the steep drop into the Kicking Horse valley lying between the lip of the lake and Cathedral mountain on the other side of the valley.

Sherbrooke lake is a very beautiful resort and a trail has been built up to it from Hector station. This easy mode of access will soon make the lake another of the many spots of superb natural beauty which are afforded to the traveller in the Canadian Rocky mountains.

Both Cataract and Sherbrooke valleys, although of subsequent and of pre-Glacial age, have been rounded and deepened by valley glaciers which moved to the north and south respectively and finally spread out to the east and the west in the transverse valleys of the Bow and the Kicking Horse rivers.

Below the outlet of Wapta Lake basin, which has formed in relatively hard, siliceous and argillaceous limestone, the waters of the Kicking Horse occupy a young canyon, in places 200 to 300 feet deep between almost vertical walls. This canyon cuts into the west side of the saddle-like continental divide, and extends transversely across the strike of thick- and thin-bedded limestones, siliceous slates, and shales which dip towards the east. This is the upper canyon of the Kicking Horse river, the lower canyon being near its mouth. The grade of the Kicking Horse river in the upper canyon is very steep and in a distance of 2½ miles from the lower end of Wapta lake, there is a difference in elevation of 900 feet. At the lower end of the canyon the valley of the Kicking Horse rapidly broadens into an immature glacial trough, in the floor of which are basins gouged out by the action of the valley glaciers, with corresponding protruding sills of harder rock forming the lips of the basins. The basins are now, for the most part, aggraded, and they will be discussed later.

In order to overcome the rapid descent of the valley floor, the Canadian Pacific Railway Company have constructed two spiral tunnels, one on the western slope of the Rockies between Hector, near the summit, and the other at Field at the southwest base of Mt. Stephen. The upper tunnel is in the base of Cathedral mountain and is 3200 feet long; the lower tunnel is in Mt. Ogden and is 2910 feet long. By this means the line has been lengthened in this distance 4¼ miles and the grade has been reduced from 4·5 per cent to 2·2 per cent.[1]

[1] Note.—The upper tunnel (No. 1), in the base of the Cathedral mountain makes a pear-shaped loop and the lower track runs back parallel with the upper one for several hundred yards. The vertical distance between the rails at the ends of the tunnel is 60 feet. After crossing the Kicking Horse river it is necessary to make another spiral in order to get down the valley. This is done by the No. 2 tunnel in Mt. Ogden, which is 300 feet shorter than the No. 1 tunnel. It makes an elliptical curve and the lower track emerges at

At the lower end of the canyon the Kicking Horse river is greatly increased in volume by a much larger branch from the northwest; this is the Yoho river. The valley of the Yoho is famous for its U-shaped character and its wonderful hanging valleys, giving rise to waterfalls which have become world known (Takakkaw and Twin falls). The Yoho takes its rise from the still existing glaciers at its head, the Yoho, Habel, Wapta, and Daly glaciers. The general direction of the valley is determined by a fault plane, which on the south side of the Kicking Horse valley passes between Cathedral mountain and Mt. Stephen. Plate III, A, shows Takakkaw falls, on the valley side about 2 miles north of the limit of the accompanying map. Takakkaw falls is the highest cataract on the American continent. The water cascades 1248 feet over massive-bedded Middle Cambrian limestones. The water comes from the front of the Daly glacier which lies in a cirque-like depression and cannot be seen from the valley floor. The stream has cut a narrow channel for itself through the hard limestone rim of the cirque.

It may be well to state here, as was mentioned before, that the size of the Yoho valley and its relations with the main valley of the Kicking Horse below the junction, seem to suggest that this valley should be regarded as the main branch of the westward drainage system. The grade in the valley floor of the Yoho is much more gradual throughout its extent than that of the upper portion of the Kicking Horse valley, which also tends to support the suggestion that it is the prominent stem in the westward drainage. Another reason for considering the Yoho river as the main trunk in the drainage system is the fact that at the point of junction of these two rivers the Yoho is at grade with the Kicking Horse river, whereas the upper part of the latter is not at grade with the mouth of the Yoho river, but enters

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right angles to the upper track. Again there is 60 feet between the two rails at the ends of the tunnel. After recrossing the Kicking Horse river, the railway gradually drops into the bottom of the valley at Field. The total length of tunnelling is over 1¼ miles, the length of track has been lengthened from 4 to 8⅛ miles, and the grade has been reduced more than half, from 4·5 per cent to 2·2 per cent. The cost of construction was about $1,500,000. It took 20 months to construct the tunnels and they were opened in July, 1909.

over a small fall. In a distance of 15 miles the Yoho only falls 1500 feet, while the Kicking Horse river drops as much as 900 feet in the 2½ miles above the mouth of the Yoho river.

The water in the Yoho river is always very murky on account of the large amount of silt which it carries from the glaciers, while that of the comparatively small stream of the Kicking Horse is clear and crystal-like, with a bluish green tint while running in its course. Both the Yoho and Kicking Horse valleys were at one time occupied by streams of ice having a thickness of at least several thousand feet. Very distinct glacial striations were formed on the base of Mt. Stephen, and it is estimated that the ice extended at least 4000 feet above the site of Field on the north side of Mt. Stephen. The great North shoulder of Mt. Stephen, shown in Plate III, B, was shaped by the valley ice so that the glacier extended over the top of this shoulder, but the top of Mt. Stephen remained as a nunatak above the ice. Lunoid furrows on a glaciated surface show that the ice was moving to the west. The two branches of ice on coming together from the Kicking Horse pass and from the Yoho valley, by their combined action had sufficient force to greatly deepen and widen the depression down which the ice continued to flow towards the west. By their combined action the ground plucking was great enough to gorge out deep basins, in places accounted for by the relatively soft nature of the underlying strata and in other places by the increased concentration of the erosive forces of the ice at the bottom of the glacier. These basins are in some places separated by distinct rock ridges crossing the floor of the valley as noted in the further description of the Kicking Horse valley. After the ice left the valley, the basins in the valley floor became aggraded with the abundant gravels and sands carried down from the front of the glaciers, and farther up the valleys it is believed there is at least 100 feet of sand and gravel. The U-shaped character of the Kicking Horse valley between Mt. Stephen and Mt. Field, and also the aggraded basin flooring the valley, are well shown in Plate II, A.

The portion of the valley just described is an excellent example of an aggraded basin. The level, gravelly floor broadens in places to a width of 1 mile, and throughout the distance, the river, frequently changing its courses, meanders about in a most picturesque manner. The channels anastomose with one another in such a way that the river has a distinctly braided appearance. The river has a broad flood-plain which it covers only when the water is very high.

On the south side of this broad, aggraded basin towards its western end is situated the town of Field, lying at the base of Mt. Stephen. On both sides of this portion of the valley the walls rise abruptly for several thousand feet into stately mountains. On the north side Mts. Field and Burgess rise 4400 and 4600 feet respectively above the valley floor, while to the south Mt. Stephen towers 6420 feet above the river.

One and a half miles below Field, although the contour of the bed of the valley has become little changed, the river channel narrows to a few feet and in one place is spanned by a natural bridge which has been formed in a band of thin-bedded limestones. This part of the valley floor, where the bed-rock outcrops, forms the rock lip to the aggraded basin just described; at this point, which is about 6 miles from the mouth of the Yoho, the power of corrasion of the old valley glacier greatly decreased.

On the two sides of the natural bridge, referred to above, there is a difference in level of the water of 20 feet. The origin of the bridge seems to the writer to have been due to the formation of two pot holes, which at depth became united. These continued to be deepened, the one having an open inlet for water the other a narrow outlet. This enlargement is still going on, so that it has become necessary to strengthen this natural feature with cement. The addition of a bridge railing has greatly marred the natural beauty.

After numerous small falls, rapids, and canyons, in which the floor of the channel falls 100 feet in 1½ miles, the river is joined at grade by two tributaries from the north, Emerald creek, and the Amiskwi river. The former is only about 10 miles long and takes its rise from the glaciers in the President range, with Emerald lake as a reservoir for the supply. Amiskwi river is over 20 miles long and receives many tributaries along its extent. Cirques are numerous at the heads of several of the subtributaries.

Below the mouth of these tributaries the floor of the main valley of the Kicking Horse broadens rapidly and attains a maximum width of 2 miles. The river channel is extremely tortuous and the stream meanders about with an anastomosing character over the aggraded gravel floor, changing its courses with the least provocation, especially after heavy rains.

About 1 mile below the mouth of Amiskwi river, Boulder creek enters from the east; it has a very steep gradient. It rises between Dennis and Duchesnay passes and in a distance of 3 miles has a fall of 2100 feet.

Three miles below the mouth of the Amiskwi, the main valley is joined from the southeast by a large one, in which flows the Ottertail river. This river heads almost 15 miles from its mouth and is enlarged by several large sub-tributaries from Ottertail range on the southwest and the mountains flanking the Bow range on the northeast. So flat is the floor of the main valley at the mouth of the Ottertail that its channel, after coming out on this flood-plain, turns sharply to the south, and running almost parallel to the Kicking Horse river, enters the latter 3 miles farther down stream.

Ottertail creek, which enters from the northwest, its valley being subsequent to the structure, divides about half a mile from the channel of the Kicking Horse: one branch turns down stream and after flowing sub-parallel for 1½ miles, enters the Kicking Horse river. The other branch, which is the smaller, comes out straight to the main river, the two channels thus forming a delta. This obstruction is an alluvial fan which has been built up gradually by the stream and also by numerous snowslides.

Below the mouth of the Amiskwi, the course of the main Kicking Horse river runs almost due south, thus cutting obliquely across the highly sheared band of soft rock flooring the Ottertail valley and forming the base of the Ottertail mountains and the Van Horne range. The broad flood-plain of this part of the Kicking Horse valley represents a second aggraded basin similar to the one noted at Field and the mouth of the Yoho river. This basin is about 8 miles long and extends from the mouth of the Amiskwi to a point 3 miles below Ottertail railway station. There the channel narrows to a few yards in width and the floors and walls of the valley consist of soft shales and argillites, thus representing a rock lip similar to that at the natural bridge. The origin of this basin is also similar to the one farther up the valley. It is a glacial erosion basin, formed by the gouging out of the softer rock in the floor by the valley glacier. Glacial corrasion was especially intense along this stretch on account of the combined action of the tributary valley glaciers from Emerald creek and the Amiskwi river. The regular flow of the ice stream in the main valley was further interrupted by the ice from the Ottertail valley which, as the map shows, tends to point up stream. There may have been another small ice flow from the Otterhead valley. All these factors tended to increase the erosive action of the ice and to gouge out the soft underlying rocks.

Almost 1 mile below the mouth of the basin just described, a youthful, V-shaped, subsequent valley enters from the northwest, and this is occupied by Porcupine creek; in no part does this valley show signs of maturity, not even early maturity. The valley is about 12 miles long and heads in the centre of the Van Horne range.

The main Kicking Horse river now turns a little east of south, becoming subsequent to the structure for a distance of about 6 miles, cutting in part obliquely across the steeply tilted, thin-bedded limestones, shales, and argillites. At this point the river is joined from the southeast by its largest tributary, the Beaverfoot river. The valley of this tributary is subsequent to the structure, but the sides have become rounded and the floor broadened by the passage of the ice to the southeast. It seems quite evident that the water from the main transverse stream, the Kicking Horse, was drained to the southeast through the Beaverfoot valley in pre-Glacial time, but a discussion of this point as well as a description of the Beaverfoot valley, will be given later.

Within a few feet of the junction of the crystal-like water of the Beaverfoot and the grey, muddy water of the Kicking Horse, the water falls over a precipice 40 feet high, called Wapta falls.

Below the falls the course of the river swings round rapidly to the northwest through an angle of about 130 degrees. This acute bend in the drainage will in this report be referred to as the "Leanchoil bend." For about 9 miles below this bend, down almost to Palliser station, the course of the Kicking Horse river is subsequent upon the tightly folded and highly cleaved soft argillites and slates of the Van Horne range, thus corresponding in direction to the trend of the Beaverfoot valley referred to above.

Below Palliser station the trend of the river turns westward, and in the remaining 15 miles of its course, the valley is again transverse. The water has cut a narrow canyon diagonally across the thin-bedded, much distorted slates and carbonaceous shales, and the steeply dipping massive quartzites and dolomites of the Beaverfoot range. This part of its course is known as the lower Kicking Horse canyon, to distinguish it from the upper canyon through which the stream descends from the summit to the flood-plain at the mouth of Yoho river.

In the lower canyon the water cascades over many waterfalls and rapids between vertical walls in some places less than 100 feet apart, until it emerges into the Columbia valley, and meets the Columbia river at grade at the town of Golden. The Columbia valley forms a part of the Rocky Mountain trench,[1] which separates the Rocky Mountain system from the Purcell and Selkirk ranges. This trench is continued to the southeast by the Kootenay valley and the headwaters of the Flathead, and to the northwest by the Canoe, Parsnip, Finlay, and Kachika rivers. It has a total length of about 800 miles and a width of from 2 to 15 miles.

In the last 15 miles the floor of the Kicking Horse channel drops 700 feet. This portion of the valley cuts across the Beaverfoot range and may be regarded as a youthful, antecedent, trans-

[1] Name proposed by R. A. Daly for this "Long, narrow, intermontane depression occupied by two or more streams (whether expanded into lakes or not) alternately draining the depression in opposite directions"; "Nomenclature of the North American Cordillera between the 47th and 53rd Parallels of Latitude." Geog. Jour., June 1906, p. 596.

verse valley. Youthful in the sense that the canyon has been entirely cut in post-Glacial time and is yet far from reaching a base-level.

CHANGE OF DRAINAGE.

Although the drainage of this part of the Rocky mountains is now to the west, yet the writer feels convinced that the present drainage was initiated with the melting out of the valley glaciers, and that in pre-Glacial time the drainage was to the southeast through the Beaverfoot valley. It is probable that before the ice filled the valleys, the eastern part of the Beaverfoot range was drained by a valley extending southeasterly, the upper main part of the stream being represented to-day by the upper part of Glenogle creek. This ancient stream flowed to the southeastward, and at Leanchoil bend it united with the pre-Glacial Kicking Horse river and flowed down the Beaverfoot-Kootenay valley. A stream draining the westward slope of the Beaverfoot range most likely occupied a valley, now represented by the lower portion of Kicking Horse valley, from a point between Glenogle and Golden. Presumably the head of this valley was separated by a comparatively low divide from the larger valley on the eastern side of the Beaverfoot range. It is impossible to say just how the "through valley" was cut across the Beaverfoot range, but there seems to be sufficient evidence to indicate that with the change of climate and the accumulation of ice in the valley east of the Beaverfoot range, there was an overflow of ice through the depression into the Columbia valley. The saddle-like summit was presumably so deepened by the glacial overflow as to allow a westward outlet for the water after the drainage had been checked to the southeast. The supposed causes of obstruction to the southeastward drainage through the Beaverfoot valley will be considered more fully on a later page.

As soon as the ice melted out of this saddle-like summit of the pass across the Beaverfoot range and as soon as the surface of the water occupying the depressions to the east, whether as a stream on the aggraded floors of the valleys or as a temporary lake formed at the front of the ice, reached the level of the summit of this pass across the range, there was initiated an outflow of water into the Columbia river. The volume of water was sufficient to cut through the underlying rocks of the Beaverfoot range and to form the canyon which now exists and is known as the lower Kicking Horse canyon.

The evidence at hand seems to warrant the above conclusions. The higher part of this transverse valley through the Beaverfoot range is rounded and ice-worn, and extends with these characters down to about the 4000-foot contour, whereas the lower part is water worn and post-Glacial in origin. Furthermore, well marked terraces in the Beaverfoot and Kicking Horse valleys above Palliser, are sufficiently high to indicate the overflow through this trough to the Columbia valley or Rocky Mountain trench. In the Beaverfoot valley there is a marked 4400-foot terrace and in the Kicking Horse the terraces extend up to at least 4650 feet. The elevation of the present summit of the Beaverfoot valley is a little over 4000 feet.

As to the origin of the Kicking Horse and other V-shaped valleys, Dawson stated that they are not due to the action of ice but to stream erosion. Glacial striations and smoothing were found near the bottom of the Kicking Horse valley at the base of Mt. Stephen. Although the valleys long antedate the Glacial epoch, yet, many of them have been deepened and given their present rounded contours and broad floors by the corrasive action of the ice. The aggraded basins, such as are seen in the floor of the Kicking Horse valley, have been formed in this way.

The westward drainage, especially that of a transverse character, probably began with the primary uplift of the mountain system, which was towards the close of the Mesozoic, when the system was outlined as a series of low ridges. At that time, Dawson thinks that the general elevation over most of the Cordillera was 3000 to 4000 feet lower than it is to-day. The drainage in the Rocky mountains at that time may have been largely consequent. The post-Laramie deformation brought about the beginning of the great valley system, and Dawson has noted as one example, the Columbia-Kootenay valley which was eroded in the Eocene. Later uplift in the Pliocene caused a rejuvenescence in stream erosion.

OTTERTAIL RIVER.

Ottertail river flows in a strike valley which is about 15 miles long and is subsequent to the structure of the soft shales, slates, and argillites through which it cuts. In these respects the valley is similar to that of the Beaverfoot. The river has its source in a broad, nearly flat meadow, forming part of Ottertail pass. The pass, and the depression which is continuous with it to the southeast, is occupied in part by the source of the Vermilion river, which, after flowing in a southeasterly direction for about 20 miles, makes a right angled turn to the southwest, and, passing through a gorge between the Vermilion and Mitchell ranges, enters the Kootenay river 15 miles southeast of its head, in the Beaverfoot-Kootenay trough.

Ottertail pass, with an elevation of 6900 feet above sea-level, shows good evidence of having been carved out by the action of a valley glacier. It has low rounded slopes on either side and its floor is not only broad, but also about a mile in length, is thickly veneered with detritus, and studded by several small lakes which are formed in "glacial drift-basins."[1] It may here be noted that several similar but larger lakes in obstruction basins are scattered about the summit, in the Beaverfoot-Kootenay trough, and two have also been noted in the Kicking Horse pass.

From the pass, Ottertail river drops about 1500 feet in the first 3 miles. At this point it is joined by a much larger stream from the north, Misko creek. The map shows that the valley of this tributary has a north-northwest trend. It, therefore, points almost up-stream and makes a very sharp angle with the valley of the main trunk. Later it will be shown that the valleys of Moose creek, Ice river, and numerous smaller valleys on both sides of that part of the Beaverfoot-Kootenay trough drained by the Beaverfoot river, also present this barbed appearance with reference to the main valley. Three miles farther down the main trunk, or about 6 miles from the pass, another large branch, Goodsir creek, enters at grade from the south. This creek, which is 3 miles long, has its source in the three small

[1] Davis, W. M., "Classification of Lake Basins." Boston Soc. Nat. Hist., Vol. 21, Jan. 1882, p. 315.

glaciers on the north slopes of Mt. Goodsir and Mt. Sharp. From the gravel-covered end of the largest of these glaciers the main stream emerges from a sub-glacial channel, not as a small brooklet of insignificant size, but as a large, powerful mountain torrent which roars as it cascades over the morainal boulders. Plate IV, A, shows the stream as it emerges from an inverted cone-shaped depression. More will be said about these glaciers in another chapter, but it may be well to note, in passing, that this tongue of ice, for a width of one mile and a length of half that distance, is covered with morainal material varying from a fraction of a foot to more than 3 feet in thickness. Along the front edge, where the rock débris is thick and the ice thin, vegetation of a scrubby nature grows. In one place, a small gully, cut in the ice by a super-glacial stream, exposed the greenish blue ice enclosing many small boulders at the base, a veneer of about 3 feet of gravel and silty material above, with scrubby spruce 1 to 2 feet high, and certain alpine flowers growing on the surface. This feature of super-glacial vegetation is common in the Arctic regions, but not so common as far south as the fifty-first parallel of latitude.

This small tongue of ice offered many interesting features in stream erosion. There are many streams cut into the surface of this broad, fan-shaped tongue of ice; some carry a large volume of water in the middle of the day, some are consequent on the slope of the ice, while others are in part consequent and in part subsequent along fractures which carry the stream in a different direction. So important are some of these super-glacial streams that they have cut youthful V-shaped valleys in the ice as much as 30 or 40 feet deep and upwards of 100 feet in width across the top of the gully. The larger streams follow meandering courses in the clear, bluish green ice. The up-valley sides of the lobes have steep bluffs, while the down-valley slopes are much gentler, just as is the case in river meanders. In a few cases the necks of the lobes in the meanders had been cut across and the stream was carving a new meander for itself.

In comparing the erosion features of these glacial streams with those of a normal river, the reader will at once remark that there is a vast difference between normal stream meanders and those just described in these super-glacial streams. In the former a meandering course is a distinct sign of old age, whereas in the case in question the stream shows every sign of youthfulness, with a drop in the bed of its channel of 100 feet within a quarter of a mile.

The writer offers the following explanation of the formation of meanders in these super-glacial streams with such a steep gradient. It may be said with considerable certainty that no streams running over the surface of a glacier are following a straight course unless they are following a joint crack in the ice. If there is a large amount of sand and gravel in the ice, as these are melted out they are hurled along in the stream with the result that they strike against any projecting irregularities on the sides of the channel. Their impetus is sufficient to gouge out the ice which they strike against, and they are then washed out of that 'harbour' only to repeat their effect on the opposite side of this groove through which the streamlet, or at first a threadlet of water, is rushing. As this process continues, the outside of the curve is rapidly worn back and the meanders become more pronounced. The ice is worn out very rapidly by the continuous grating of the detrital load carried in the stream. The broadening of the trench does not take place by simply melting of the ice on its slopes, but by the rapid undermining on the outside of the curves, which results in a caving in of a large block of ice. The channel of the stream may be very readily blocked up by a large fragment of ice, or perchance a large boulder which has been melted out of the ice. In this case the water rushes over a new surface of ice and soon forms a new channel for itself. The curves in the meanders are as a rule simple and not convoluted. Furthermore, as the neck of a lobe becomes narrow a slight obstruction in the main stream will turn the water over this neck and a cut-off will result. All these changes necessarily go on very rapidly, because not only is the annual season very short, but also the daily active life of the stream, for the carrying power and the load are very ineffective after the middle of the afternoon.

The head branches of Goodsir creek are heavily loaded with silty material from the glaciers. The stream in the lower two-thirds of its length has a broad flood-plain which has been formed by aggradational processes.

The map shows that this north-south valley is continuous with that of McArthur creek, on the north side of Ottertail river. These valleys, together with that of Moose creek to the south, and Cataract brook to the north, form a discontinuous erosion depression throughout the entire length of the map-area. The northern part of this depression has been developed along a north-south fault line.

McArthur creek is about 7 miles long and is bifurcated towards its upper end. One branch begins at McArthur pass, being intermittent in its upper part, and derives much of its water by underground channels from McArthur lake (elev. 7359 feet). This lake lies in a rock basin, the lip of which is over 50 feet above the present surface of the water. At the eastern end of the lake (Plate IV, B) stands Mt. Biddle, with a glacier of the same name lying in a well formed cirque and extending into the lake. The other branch of McArthur creek begins between Mt. Duchesnay and Mt. Odaray and is subsequent to the structure, having a northwest and southeast trend. This valley is mentioned here because towards its head the talus débris from Mt. Duchesnay is rapidly encroaching upon the stream and driving it farther into the slope of the ridge which lies to the north of Odaray pass. Below the junction of the two branches, McArthur creek presents a stage of adolescence. The grade is uniform, there are no falls, and the stream twists about over its aggraded flood-plain. Within the last mile of its course the stream bends round towards the southeast to meet the Ottertail river at grade. This deflection of the course near its mouth is also seen in Miske creek, and it occurs as soon as the branch valley enters the side of the trunk valley.

Below the mouth of McArthur creek the valley of the Ottertail is prominently V-shaped, and the stream is in a youthful stage of its cycle. The diagram (Figure 1) shows this V-shaped character of the valley along the base of Mt. Owen which is shown on the map as roughly triangular in outline.

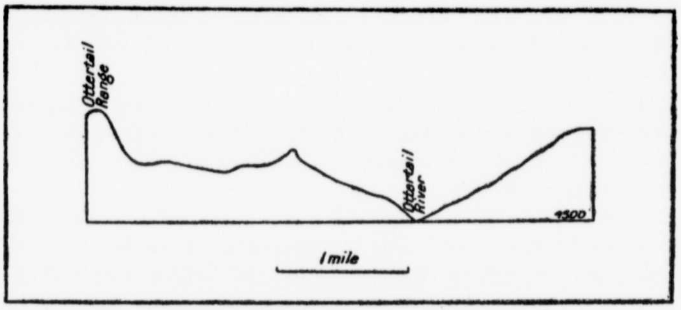

Fig. 1. Cross-section of Ottertail valley.

The Ottertail is joined from the south side by three small branches, Silver Slope, Haskins, and Quebec creeks. All of these streams get their water from the Hanbury glacier and small cliff glaciers in the Ottertail range.

On the north side of the valley, Float creek is especially worthy of mention. It lies between Mt. Owen and Mt. Duchesnay and is only 3½ miles long. Figure 2 gives a profile of this

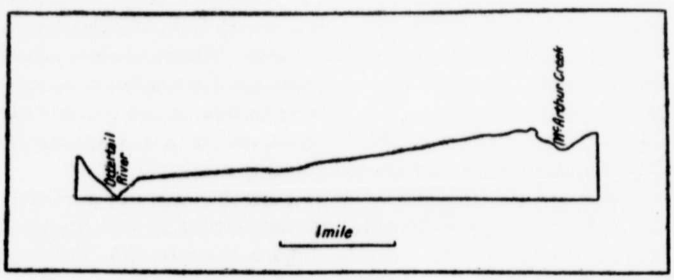

Fig. 2. Profile of Float creek.

stream. The mouth of Float Creek valley hangs 800 feet above the stream bed of the Ottertail. Furthermore the profile and the map show that the head of this valley cuts in at right angles to that of the northwest fork of McArthur creek. It is also hanging 1000 feet above the channel of the latter. Float creek is a lateral, consequent stream, whose valley by headward erosion has cut into the side of the valley of McArthur creek.

Below the mouth of Float creek, the Ottertail has cut a V-shaped gorge into recent glacial gravels and this gorge is 300 feet deep towards the mouth of the valley. It is joined near its mouth by Haygarth creek, the last small lateral branch from the north.

As soon as the flood-plain of the Kicking Horse river is reached the channel of the Ottertail swings round to the south, and instead of joining the main river at once, it runs sub-parallel with the Kicking Horse for 2 miles on the flood-plain of the latter before uniting with it.

The whole drainage area of the Ottertail valley is underlain by very soft, highly sheared rocks which crumble down readily under the action of degradational processes, forming rounded or gentle slopes such as are so well shown in the south side of Mt. Owen. It has been mentioned that the lower part of the valley is sharply V-shaped. Between the top of the V-shaped, recent valley and the base of the prominent escarpment (shown in Plate V, A), the average slope is gentle, and in some places there is even a depression along the base of the cliffs. This feature is continuous to the southeast for over 20 miles. The profile in Figure 1 shows the relation of this gentle slope to the steeper slope; the former is sometimes nearly 2 miles wide. These features seem to suggest that when the ice filled the valley its slopes were gently rounded by the ice, and as the ice moved from the more massive rocks in the Ottertail mountains on to the very soft rocks below, the latter were eroded more rapidly near the base of the high escarpment than towards the centre of the valley. After the ice melted out of the valley, the stream cut its present V-shaped notch in the floor of the broad valley that had been rounded out by the ice.

BEAVERFOOT VALLEY AND ITS TRIBUTARIES.

It has been previously stated that the Kicking Horse river at Leanchoil bend, the point where it turns sharply northeastward after having flowed almost due south for several miles, is joined by a large tributary from the southeast, the Beaverfoot. A glance at the map shows that the Beaverfoot valley has a northwest and southeast trend. It may thus be called a "strike valley," since it is parallel to, and subsequent to the general structure of the mountain ranges. This valley may be described as a broad, flat-bottomed trough, the sides of which at first slope gently and are followed above by steeper slopes. It is continued to the southeast by the valley of the Kootenay river, thus forming an intermontane trough, which, for convenience, will be called the "Beaverfoot-Kootenay trough." The upper portion of the trough is about 2 miles wide, but it broadens towards the southeast to a maximum width of about 4 miles. This trough is very much smaller than the Columbia-Kootenay trough to the west.

For a distance of 14 miles from the Kicking Horse river, the trough is occupied in part by the Beaverfoot river draining northwestward, and for 50 miles below this point it is occupied by the Kootenay river flowing southeastward. The valley then turns at right angles to the west, and crossing the Beaverfoot range, enters the larger Columbia-Kootenay trough a short distance south of the upper Columbia lakes.

The summit between the northwestward and southeastward drainage is so very little above the floor of the trough that it can not be recognized when traversing the valley. The summit may be regarded as extending for about 4 miles along the valley, in which distance the streams, draining in opposite directions, interlock with one another in an intricate manner. The elevation of this divide is about 4000 feet.

The Beaverfoot river has its main source in the mountains to the northeast of the wide valley. The main branch is called Moose creek, which heads in the slopes of mountains over 10,000 feet high and flows from a large glacier, the Washmawapta snowfield, lying in the Ottertail range to the east and south of

Helmet mountain and covering about 7 square miles. Moose Creek valley has a north and south trend and is in line with the valleys of Goodsir and McArthur creeks, and Cataract brook. It has a rounded outline, which shows that it has been shaped by the action of a valley glacier. Much of the outline of the sides of this valley has been modified by degradational processes. The valley is only 6 miles long. In the upper 3 miles of the valley the course of the creek is still very young and contains many rapids. Below this point at certain places in the valley floor, the stream has a flood-plain several hundred yards wide. There is so much loose talus on the slopes of this valley that large masses of this loose detritus are carried down in the springtime by snow slides and heavy rains. The only large tributary of this stream is Dainard creek, which has a northeast and southwest trend.

At the point where Moose Creek valley opens out into the large Beaverfoot-Kootenay trough, the course of Moose creek turns sharply through 90 degrees to the southwest, and within a mile makes another right angled turn and continues for over 2 miles on the northeast side of the valley with a northwest trend. After bending sharply to the southwest for a mile, it again turns abruptly to the northwest and continues on the southwest side of the trough as the Beaverfoot river.

There can be no doubt that Moose creek at one time drained to the southeast, and the small stream entering Moose creek at its first sharp bend is supposed to mark the old course of this creek to one of the branches of the Kootenay river. There are now only about 300 yards between these two streams. Moose Creek valley makes an angle of 40 degrees with that of the Beaverfoot, so that in order to reach the general trend of the Beaverfoot it has been necessary for the course of Moose creek to turn round 140 degrees.

After reaching the main valley the river follows a narrow but tortuous channel "in a trough-like depression in the centre of the valley about three-quarters of a mile in width and bordered by gravelly terraces which run back to the bases of the mountains on either sides."[1] Although it is only about 14 miles in a

[1] Dawson, G. M., Annual Report Geol. Survey, Canada, 1886, Part B, p. 121.

straight line from the summit of the valley to the mouth of the Beaverfoot, yet the water course is about twice that length. The gravelly terraces mentioned can best be recognized from the tops of some of the ridges on either side a few hundred or a thousand feet above the bottom of the valley, the view at lower altitudes being obstructed because of the thickly wooded nature of the valley. About 10 miles from its mouth, the Beaverfoot is joined from the north by a second equally large river, Ice river. Throughout the rest of its course the Beaverfoot is joined by numerous small obsequent or consequent streamlets and brooks from the steep slopes of the mountains on either side of the valley. Many of these are intermittent, but their youthful valleys or gullies are being continuously widened and deepened by erosion, so that the spring torrents bring down enormous volumes of rock débris, which, when it reaches the gentler slope of the broad trough, spreads out at random from the channels of the streamlet. This detritus in some places forms a fan-shaped mass covering up the roots and 2 to 3 feet of the trunks of the trees which thickly wood the floor and sides of the trough. Steep creek furnishes an example of this feature.

The valley of Ice river extends northward for about 8 miles from where it joins the Beaverfoot, and heads in the slopes of lofty mountains of the Ottertail range, varying in height from 10,000 to over 11,600 feet. The mountains at the extreme end of the valley are covered in part by Hanbury glacier, which occupies about 8 square miles and has an estimated thickness, in one part, of 1500 feet. This ice field can be regarded as a "through glacier," as defined by Tarr, since it drains from a low divide into the Ottertail valley as well as into that of Ice river. The valley of Ice river is narrow and deep, with very steep sides that are notched by several side tributaries, all of which head in glacial cirques. Some of these cirques hang high above the main valley. Numerous consequent and obsequent streamlets groove the sides of the valley. About 2 miles from its head, the valley floor broadens to half a mile in width and the river quietly meanders over this aggraded basin which has been gouged out by the movement of a valley glacier. This basin is followed by a narrow lip to the west of Mt. Mollison, through which the river passes in a long, continuous series of rapids, to join the Beaverfoot river 3 miles below.

It will be noticed that the courses of both Ice river and Moose creek trend almost due south until their respective valleys emerge from the high mountains and approach the side of the Beaverfoot valley. When within 2 miles of their points of junction with the river running in the bottom of the broad trough, their courses suddenly and sharply turn to the west, almost at right angles, to join the Beaverfoot which runs northwest. These two examples, together with many similar cases of small streamlets, tend to show, or at least seem to suggest, that the entire drainage in this trough was at one time, probably quite remote, carried in a southward direction. In the case of Ice river, the writer did not find any old channel continuing to the south, but the sharp, right-angled turn in the Beaverfoot about 3 miles above where Ice river now joins it, suggests that there may have been a connexion through this way.

ORIGIN OF THE BEAVERFOOT-KOOTENAY TROUGH.

It is believed that this trough, although rounded out by a valley glacier, had its origin at a "remote period of great or very long continued erosion subsequent" to the building of the mountains (at the close of the Laramie). The entire drainage in this valley was formerly southward and then westward into the Columbia-Kootenay trough. The drainage of the Kicking Horse river, above Leanchoil bend, may also have had its outlet to the south through the same trough, together with at least a portion of the eastward drainage of the Beaverfoot range through which the Kicking Horse now runs in a deep gorge. It seems altogether probable that the valley glacier, which filled the upper end of the Kicking Horse valley, also moved out by this southward course.

It has been suggested by Dawson that post-Glacial drainage was for a time to the south, and that a slight lowering of the land to the northward, probably accompanied by a slight arching of the floor of the trough, arrested the southward drainage and caused the waters to find an outlet in the opposite direction. This outlet was afforded by the pre-Glacial transverse depression through the Beaverfoot range, which had been deepened by the ice and through which the Kicking Horse has now cut its lower canyon. Another suggestion can be offered to explain the change in the direction of the drainage. As the front of the ice retreated up the Kicking Horse valley from this trough, there seems to have been a ponding of the water in front of the ice. Evidence of the former existence of such a lake is seen in the silts which are found towards the centre of the valley, a very good exposure of which occurs in the banks of the present channel between Palliser and Leanchoil. This lake was possibly caused by detritus washed down from the slopes on either side of the valley and built up in delta-like masses or in the form of alluvial fans, at or about the present position of the Beaverfoot-Kootenay divide. The encroachment of this material towards the centre of the valley gradually arrested the southeastward drainage which probably had a very slight grade. As soon as the surface of this lake was high enough to spill over the low summit of the depression across the upper end of the Beaverfoot range, into the Columbia valley, this obstruction about the summit of the Beaverfoot-Kootenay trough became more effective, and with the increase in volume of the stream discharging through the old valley across the Beaverfoot mountains, a channel was cut into the steeply dipping sediments of the Beaverfoot range. Since that time the present canyon has been cut, and it is still being deepened.

CHAPTER IV.

PHYSIOGRAPHY: GENERAL CHARACTER OF THE DISTRICT.

The area described in the report lies on the western slope of the Rocky Mountain system, beginning at the continental watershed and continuing westward to within a few miles of the Rocky Mountain trench which separates the Rocky mountains from the Selkirks. The topography is very rugged and alpine in nature. The district is maturely dissected and the interstream areas are worn down to very narrow, knife-like ridges. The mountain peaks present true erosion forms of an alpine type and everywhere erosion is still going on very rapidly so that talus débris covers all the gentler slopes. Glaciers have modified the outlines of the valleys, both large and small, and some of the valleys have a depth of 4000 feet.

DRAINAGE.

Since the drainage system has been described in detail in the previous chapter, a brief mention here will be sufficient. The district includes most of the drainage area of the Kicking Horse river which forms the main trunk of the transverse drainage. The main trunk, the branch valleys, and most of the subbranches are of pre-Glacial age, but have been broadened and rounded by the action of valley glaciers, and have become deepened in a few places, in post-Glacial time. On the whole, the U-shaped valley form predominates in all the larger tributaries.

The V-shaped type is best seen in the lateral, consequent, and obsequent valleys cut in the steep sides of the larger, rounded valleys. Besides these smaller valleys, the upper and lower canyons of the Kicking Horse are also of post-Glacial origin.

The U-shaped outline of the Kicking Horse valley is well shown in the photograph (Plate II, A) taken near Field between Mt. Stephen and Mt. Field. The sides of the valley at the town of Field extend 3100 to 3500 feet above the valley floor.

There has been a greater deepening of the valleys where the ice was thickest. Concentration of the ice in the main valley after it had come from tributaries would greatly intensify differential erosion, so that not only some valleys but even some parts of a single valley would be cut down faster than others.

GRADES.

There is much variation from place to place, in the grades of the main trunk streams as well as of the lateral consequents. It has been pointed out that in the case of the Kicking Horse river there is a drop of 1100 feet in a distance of 5 miles from its source, and of only 1600 feet in the remaining 38 miles. The following table gives the grades of all the main streams included in the district:—

Kicking Horse river	(first 5 miles)	1100	feet—average,	220	feet per mile
" " "	(last 38 miles)	1600	" "	42·2	" " "
Yoho river (bet. source and mouth)		1200	" "	80	" " "
Ottertail river	(first 3 miles)	1400	" "	466·6	" " "
" "	(last 13 miles)	1700	" "	130·6	" " "
Boulder creek	(6 miles)	3000	" "	500	" " "
Emerald creek	(5 miles)	400	" "	80	" " "
Cataract brook	(first 8 miles)	1100	" "	137·5	" " "
" "	(last mile)	475	" "	475	" " "
Sherbrooke lake (Ck)	(last mile)	700	" "	700	" " "
McArthur creek	(7 miles)	1700	" "	242·8	" " "
Misko creek	(7 miles)	1700	" "	242·8	" " "
Float creek	(first 3 miles)	2070	" "	690	" " "
" "	(last half mile)	600	" "	1200	" " "
Silver Slope creek	(4½ miles)	2400	" "	533	" " "
Haskins creek	(3 miles)	1800	" "	600	" " "
Quebec creek	(2 miles)	2000	" "	1000	" " "
Beaverfoot river	(25 miles)	850	" "	34	" " "
Moose creek	(7 miles)	1800	" "	257	" " "
Dainard creek	(5 miles)	1800	" "	360	" " "
Ice river	(12 miles)	1500	" "	125	" " "
Zinc creek	(2 miles)	2000	" "	1000	" " "
Sodalite creek	(2 miles)	2400	" "	1200	" " "
Shining Beauty creek	(1½ miles)	3000	" "	2000	" " "
Mollison creek	(2 miles)	2400	" "	1200	" " "
First creek S. of Garnet Mt.	(last half)	1200	" "	2400	" " "
Second creek S. of Garnet Mt.	(last half)	1200	" "	2400	" " "

This table shows that the tributaries of Ice river, especially, are hanging high above the main valley floor. There are many smaller streams which would show an even greater average grade per mile.

HANGING VALLEYS.

The hanging valley is a very common topographic feature in the Rocky mountains and there are many of them in the district mapped. The mouths of many of the lateral valleys are "hung up" 700 to 1200 feet above the floor of the main valley. One appropriate definition of a hanging valley is that given by I. C. Russell, who states that this term applies to "any valley or valley-like depression the bottom of which is not in even adjustment with the bottom of the lower depression with which it unites and into which it drains, the passage from one to the other being by means of a slope of greater declivity than the gradient of the tributary valley, and in most instances precipitous."[1] This definition does not state by what process the hanging lateral valley has been formed. Russell also points out the fact that all hanging valleys are not formed by glacial erosion but classifies them into four "species," (1) stream-formed, (2) ocean-formed, (3) diastrophic, and (4) glacial-formed. It is only this last "species" that is important in the Ice River district.

The origin of glacial-formed hanging valleys is still a debated question. Many hold that they are formed by a more rapid deepening of the main valley by a glacier, with the result that the tributaries are unable to cut down their valleys at an equal rate, so that when the ice melts out of the main valley, the mouth of the tributary hangs high on its side. Others hold that hanging, tributary valleys result from glacial widening of the main valley, rather than from glacial deepening. This point of view has been offered and very well discussed by Johnson, and illustrated with diagrams.[2]

The writer has found that in the district being described, differential glacial erosion by the combined results of glacial deepening and widening of the main valley at points where the ice was thickest and with strongest motion, has caused the formation of the hanging valleys.

The writer wishes to present another form of hanging valley whose origin is not to be explained by differential glacial erosion in the valley beneath. There are many small, cliff glaciers which originate in slight depressions in the steep face of a mountain slope. Plate V, B, shows some of these patches of ice on

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[1]Russell, I. C., "Hanging Valleys," Bull. G. S. A.; Vol. 16, 1905, p. 76.

[2]Johnson, D. W., "Hanging Valleys." American Geog. Soc., Vol. 41, 1909, p. 665.

the north slope of Mt. Goodsir overlooking Ottertail valley. One of these glaciers is 2000 feet above the foot of the cliff. To this type of hanging glacier Russell has given the name "mountain-side glacier." These cliff glaciers gradually excavate their own depressions in the side of the mountain and sometimes as a result of a variation in climatic conditions, such as a very warm summer, the ice melts away, and the depression may be seen to have a cirque-like outline. Frequently the cirque is slowly extended inwards by bergschrund or headwall erosion by the ice until the final form is a U-shaped valley with precipitous walls, terminating in a cirque-like head or corrie. Plate VI, A, shows a hanging valley believed to have been developed as explained above. This photograph shows the third hanging valley south of Helmet mountain, opening into the east side of Moose Creek valley. This depression overlooking the deep valley of Moose creek is not more than a mile in length. According to this method of formation of hanging valleys, differential glacial erosion in the main valley is not a determining factor in the development of a hanging valley. A valley formed by the action of cliff glaciers (mountain-side glaciers) differs from one formed by normal valley-forming agencies, in that it is practically entirely lacking in side tributaries. The one shown in Plate VI, A, is typical in this respect. The depth to which a mountain-side glacier will excavate the bed of its basin will be determined in part by the rate of melting of the ice, and probably in a greater degree, by the hardness of the underlying rock. In the example just cited a band of massive blue limestone (Ottertail formation) forms the lip of the valley and much of the floor. The lip of this valley "hangs" about 2000 feet above the floor of the main valley. Other similar cases are to be found in the first and second depressions to the south of Helmet mountain, both of which are hanging valleys.

Owing to the lack of detail in the topographic map, many of the finest hanging valleys in the region are not indicated by the contouring of the map. A glance at the map shows that one of the most pronounced hanging valleys and cirque basins is in the Bow range to the west of Mt. Niblock. There are really two basins, the higher being 1200 feet above the lower which encloses Ross lake.

There are certain other lateral valleys which, although not now possessing a hanging relation, yet had their origin as hanging valleys, the lip having been cut away, due to the softness of the rocks, since the melting of the ice from the main valley. Zinc valley is an example of this type.

In conclusion it may be said that most of the valleys have been deeply carved by stream erosion in pre-Glacial time, but have been greatly modified by glacial degradational and aggradational processes. The valleys were widened and deepened, some were left "hanging" above the main valley, while others have been formed by the action of cliff glaciers independently of differential glacial erosion in the main valley.

RELIEF.

This area is typical of the westward slope of the Rocky mountains. The topography is still in the first cycle of erosion. It is rugged, mountainous, and in the main, maturely dissected, giving rise to a landscape typically alpine in outline. The erosion forms, as they now appear, produce a mountain scenery which equals, and in some respects surpasses, anything on the continent, and even on the globe. The contrast of lofty rugged peaks, glaciers and snowfields, deep rounded valleys with rivers and lakes filled with water of varying shades of green, are features which to be thoroughly appreciated must be seen.

There is a gradual westward slope of the top of the ranges and ridges from the Continental Divide to the westward limit of the Rocky Mountain system. In general, it may be said that to the south of the Canadian Pacific railway the western part of the Rocky Mountain system consists of three ranges—the Bow range to the east, forming the continental watershed; the Ottertail towards the centre, and the Beaverfoot range to the west, the last one forming the eastern limit of the Rocky Mountain trench.

The greatest average elevation, which is over 10,000 feet, is attained in the Bow range, where several peaks are over 11,000 feet high. In the Ottertail range there are only a few peaks over 10,000 feet high and only one over 11,000 feet, that one being

Mt. Goodsir. The south tower of this mountain, 11,676 feet, is the highest in this part of the Rocky Mountain system.[1]

In the Beaverfoot range the average elevation is about 8500 feet. Between these ranges are intermontane depressions, or valleys of erosion, modified by glacial action. The broad valley of Ottertail river separates the Bow from the Ottertail range. This depression is continued to the southeast by the valley of the Vermilion river. The Beaverfoot valley separates the Ottertail and the Beaverfoot ranges. This depression is an excellent example of a "through valley" since it is drained by the Beaverfoot river flowing to the northwest, and by the Kootenay river to the southeast. The summit of the Beaverfoot-Kootenay trough has an elevation of 4000 feet, and the divide between these two streams is so gradual or flat that it is not apparent to the traveller. The head branches of the two streams interlock on the broad summit and a few small lakes and swamps mark the watershed. The sides of this trough are rounded and faintly terraced. There is a difference in elevation of 850 feet between the source and mouth of the Beaverfoot river, a distance of about 25 miles. The origin of this valley has been previously discussed. Both Ottertail and Beaverfoot valleys are dependent in origin upon the underlying structure, and correspond to the major axis of folding in the mountain system.

The Beaverfoot and Ottertail ranges are continued to the north of the railway by the Van Horne range. The former is continued to the southeast by the Brisco range and the latter by the Vermilion range. Bow range to the northeast is continued north of the railway by the President range.

The portion of the mountain system within the map area may, in general, be said to be maturely dissected; the interstream areas have been worn down, frequently to very narrow, even to knife-like ridges that in many places are not a foot in width. Headwall erosion of the interstream ridges is especially

[1]A complete ascent of this peak was made by the writer and his assistant, F. J. Barlow, in July, 1910. It was the third ascent of the south tower. The climb proved most difficult and dangerous. It required 45 hours to make the ascent and return from Ice River valley. The first ascent of this lofty peak was made by Professor Fay of Tufts College, Boston, in 1906.

evident in those valleys which terminate in cirque basins or corries, or in what originally was a basin formed in this manner but which has since become partly filled with rock débris. On account of the rapidity with which erosion is going on, the lateral tributaries are frequently bordered by large fan-shaped talus slopes, some of which are 1½ miles long with slopes from 20 degrees to 40 degrees. Many of the small lateral streams have built up broad, fan-shaped alluvial cones at the point where they enter the main valley. Those of Zinc creek, Steep creek, and Hoodoo creek are a few good examples.

At the extreme southeastern corner of the map-area there are, at an elevation of 6200 feet, two small lakes, called Dainard lakes. Above these there is another small lake at an elevation of 7850 feet. This lake is the highest in this part of the Rocky mountains. It is 450 feet above Lake Oesa and almost 1000 feet above Lake Agnes (Lake of the Clouds), near Lake Louise. It is about 500 yards long and 200 yards wide, and lies in a cup-shaped depression in the side of the mountain. It is fed from the cliff glaciers above and has no visible outlet. The surface of the water is now 75 feet below the lip, but there is an old outlet shown 50 feet above its surface. The water is a milky green and has the appearance of being very deep. A fault crosses the side of the lip and the inner side has dropped down. This structural break allowed the ice to deeply scoop out the basin on the inside of the fault. According to the classification of lake basins by Davis, this lake occupies an orographic glacially eroded basin.

GLACIATION.

Only a few of the more salient features of this vast problem can be mentioned.

Remnants of the ice sheet are to be found in numerous local glaciers in the Bow and the Ottertail ranges. In the Bow range, the Victoria, Lefroy, Horseshoe, and Wenkchemna glaciers are the largest and best known. To the north of the railway, the Daly glacier in the Waputik mountains feeds a part of Sherbrooke lake and Takakkaw falls. In the Ottertail range, the Washmawapta snowfield and Hanbury glacier are the largest, while the glacier on the southeast slope of Mt. Sharp and three others on the northeastern slope of Mt. Goodsir overlooking the Ottertail valley, in a manner connect these two larger ones.

The Washmawapta snowfield covers an area of less than 7 square miles (Plate VI, B). The surface is not level but gently undulating, and conforms in a certain degree with the folds in the underlying massive blue limestone. The limestone outcrops in places at the surface of the ice so that the maximum thickness of the ice is believed to be less than 500 feet. The surface of the ice is fissured by crevasses wherever there is tension within the mass, such as where there is a sudden change of gradient in the floor on which the ice rests. Wherever there is an ice-fall the crevasses are numerous, forming seracs; these appear as narrow, wedge-shaped pinnacles of ice. In projecting tongues of ice, crevasses are numerous, due to the more rapid movement of the centre of the tongue. Plate VII, A, shows numerous longitudinal crevasses which have become deepened by super-glacial streams. The bergschrund is not a common feature of this snowfield since the glacier almost caps the ridge, but it is very well shown in many of the smaller patches of ice. Travel on the surface of this glacier is dangerous as the firn covers up many large crevasses.

Small ponds are sometimes formed between the rock and the edge of the glacier. One of these was about 20 feet square. This shows that the glacier sits close to the bed-rock, and on account of the moderate thickness of the ice at this place, all loose sub-glacial débris and cracks in the rock are frozen so as to prevent any outlet of the water which collects at the upper contact with the exposed rock.

Hanbury glacier covers about 5 square miles. It is situated at the head of Ice River valley and extends to the summit of Mt. Vaux. The drainage is largely to Ice river, but there is a broad, low divide on the surface of the glacier with a large tongue forming a northern outlet of the glacier to the Ottertail valley. In this respect it is a "through glacier" on a small scale. Tongues of ice extend down to 6000 feet; this is about the lowest limit of the ice in this district with the exception of a moraine-covered tongue of ice at the head of Goodsir creek, which extends down to 5200 feet. A line drawn from Hanbury peak to the ridge dividing the head of Ice river, practically divides the glacier in half; along this line there is an abrupt declivity which is marked on the surface by long sub-parallel crevasses. East of this line, judging from the surrounding slopes, the glacier must be nearly 1500 feet thick unless the rock floor is unusually uneven.

There is very little super-glacial débris on either of these two large glaciers; some is found along the edge only. The freshly exposed ice is also practically free from englacial detritus, but the abrasive action is very great. Ice river is at all times heavily laden with rock flour washed out from the end of the glacier; the water is almost milk coloured towards the middle of the day. This material is silting up the floor of the valley lower down the stream. The river gets most of its water from this source, and it has been very appropriately named on account of the extreme coldness of its water.

There is evidence about the edges of the ice that the glaciers are decreasing in size. Depressions, which have been occupied by the ice so recently that their morainal material has not yet been disfigured by subaërial erosion, are now empty. At the end of many of the ice tongues it is common to find a boulder-wall, or Geschiebe-wall, made up of the ground moraine or basal débris which has been shoved out by the moving ice. Furthermore, during the latter half of July and first half of the month of August, large blocks of ice are occasionally displaced from the front of the moving sheet, which, thundering down the mountain side, are crushed to a powder.

The banding or stratification in the ice is particularly well shown in Plate VII, B. This is a photograph of the glacier extending northward from Opabin pass. The layer between the dark concentric bands represents the annual snowfall on the névé. Similar bandings are exposed in the Biddle glacier which extends beneath the surface of Lake McArthur at its northern end.

On the erosion surface of the ice "glacial tables" are a common feature; some of these are 4 feet high. The surface is frequently pitted with "dust-wells," each of which is occupied by a small fragment of rock. Since the rock absorbs heat more rapidly than the ice, it melts a pocket for itself in the ice.

The glaciers in the Bow range cannot be discussed here. They have been studied in detail by Sherzer, and are described in his treatise on the glaciers.[1]

It has been previously stated that the valley sculpture has been modified to a large degree by the movement of the ice sheet. The upper limit of the ice is not so clearly defined, for degradational processes have obliterated all direct evidence of the extent of the ice sheet. From observations of the slopes and contours of the higher mountain peaks, the writer is convinced that the ice sheet did not cover all the peaks, but that many of them projected nunatak-like. The ragged, sharp, serrate peaks of Mt. Stephen, Cathedral crags, Mt. Goodsir, and others, have been sculptured by the combined action of frost, rain, and wind, and not by ice. The peaks are composed of fresh rock, whereas lower slopes present a typical "Felsenmeer"[2] down to the tree line, which is about 7000 feet above sea level, and corresponds in general with the lower limit of cirque basins. In the case of Mt. Stephen the ice extended above the great north shoulder (Plate III, B) to at least an elevation of 8500 feet.

ACCORDANCE OF INTERSTREAM DIVIDES.

In the Ice River district especially, there is a remarkable uniformity of levels in the interstream or intervalley divides. This elevation varies from 8200 to 8600 feet. This was found to be the case irrespective of the kind of rock which forms the divide. Daly has shown that the accordance in many summit levels in Alpine mountains can be accounted for by a variety of processes.[3]

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[1] Sherzer, William H., "Glaciers of the Canadian Rockies and Selkirks." Smithsonian Contributions to Knowledge; Part of Vol. 34, No. 1692, 1907, pp. 19-80.

[2] Felsenmeer is a German word for the veneer of broken rock débris on the slopes of a mountain above timber line.

[3] Daly, R. A., "The Accordance of Summit Levels among Alpine Mountains: The Fact and its Significance." Jour. of Geo., Vol. 13, No. 2, 1905, p. 105.

In this part of the Rocky mountains, wind erosion has undoubtedly been a prominent factor in producing this accordance, but another possible explanation may be offered. When the ice cap covered a large part of the mountains, those portions of the ridges projecting above the ice, between the highest protruding mountain peaks, would be worn down to the surface of the ice. This accordant level need not be that of the divides of the present day, but probably much higher. After the ice melted away these divides would be subjected to the same degradational process, with the result that they would be worn down to a subequal level by the action of wind, frost, rain, and snow. Tarr has noted a similar feature in the glaciers of Alaska.[1]

The only glacial markings found in the region are exposed in the northwest base of Mt. Stephen, near the town of Field. The chatter marks and lunoid furrows with concave side to the east, show that the ice in that part of the Kicking Horse valley moved westwards.

EROSION.

Subaërial erosion is a marked feature in these mountains. The lower slopes are deeply mantled with rock waste. This is especially evident above the tree line, which in this region is about 7000 feet above sea-level. Degradational processes do not go on as fast below timber line, due to the protection afforded by the prolific floral growth. It must, however, be remembered that the tree-covered zone is also underlain by rock waste from higher levels.

The enormous rate at which erosion is proceeding in these regions can only be appreciated by one who has worked in these mountains and has seen it going on.

It is a matter of considerable risk to attempt work on the steep slopes of these mountains during or immediately after a rainstorm. The effect which a severe mountain rainstorm can have on the rock can best be appreciated by the observer who experiences one of these above timber line.

[1] Tarr, R. S., "The Yakutat Bay Region, Alaska," U. S. G. S. Prof. Paper, No. 64, 1909.

Wind is also an important degrading process. The summits of ridges and mountains are always being swept by a terrific gale, no matter how quiet the atmosphere may be in the valley below. Not only sand fragments but rock débris an inch in diameter cannot resist the force of these winds.

As an example of the rate of erosion the following is given. During the summer of 1910, on the divide at the head of Mollison creek, a block of basic igneous rock 2 feet high was projecting from the smooth wind- and rain-swept saddle. This block, for certain reasons, was remembered and was visited again in 1911. It was then a crumbled knoll of débris about 8 inches high, the rest having been carried away. Many other cases could also be cited.

The long, even talus slopes tell the same story of the effect of rain, frost, wind, and snow upon these mountains. In many places the only bed-rock to be seen projects as knobs from the thick veneer of rock waste.

In some of the higher peaks, erosion shows itself in another form. Cathedral crags may be taken as an example. Instead of the rock crumbling, large blocks, sometimes scores of feet in diameter, are dislodged and roll down to the more gently sloped shoulder below. In these crags there are vertical walls 500 to 1000 feet high on all sides, so that it is one of the few peaks that has not been climbed by the aspiring mountaineer.

The erosion forms produced depend quite largely on the nature of the underlying rock.

There is also a certain amount of rock waste carried down by the avalanches, both glacial and snow, and especially by the mountain streams possessing very high gradients, many of which are intermittent. The result of the last is to build up broad cones on the valley floor below. By this material the underbrush and finally the forests are crushed down. The gravels at the mouth of Steep creek extend up 3 feet on the trunks of the trees. The same is true with Zinc creek, and scores of other smaller streams.

Rock waste is also transported to the lower levels by a gradual gravitative movement. This goes on faster above the tree line.

To summarize. Erosion in these alpine mountains is going on at an almost inconceivably rapid rate. The chief factors which bring about the disintegration of the rock and the transport of the rock débris to a lower level are: rain, frost, wind, snow avalanches, streams, and the pull of gravity. The rate of erosion is much greater above timber line. The flora tends to protect the underlying surface. It has also been previously stated that the streams coming from beneath a glacier are heavily laden with rock flour and sand. This feature indicates the effect of abrasion along the floor of the ice.

CHAPTER V.

CLIMATE, FLORA, AND FAUNA.

CLIMATE.

The field season is very short and atmospheric conditions vary. Snow storms may come at any time of the year, and the winter snow begins to fall about the middle of August, but field work can be carried on for a longer season on the lower levels. The upper part of the ridges retain snow until the first of July, while many slopes and canyons retain patches of perennial snow. The mean atmospheric temperature in summer is moderate and it is only in the valley bottom that a high temperature may occasionally be recorded. The winters are severe and long; during the winter of 1911 the mercury reached a minimum of -44 degrees at Field. The snowfall varies, but according to reports the snowfall in the Kicking Horse valley is between 15 and 20 feet. The rainfall varies from year to year. No record has been kept in the vicinity of Field, but the table given below gives the monthly precipitation at Banff since 1906. These results were obtained from Mr. Sanson at the meteorological station at Banff, Alta. They show that the annual precipitation varied from 14·58 inches in 1906 to a maximum of 24·48 in 1907. This excessive rainfall was caused by very heavy rainstorms in the early spring.

PRECIPITATION IN INCHES PER MONTH AT BANFF, ALBERTA.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total inches.
1906	0·77	0·40	0·19	0·32	2·98	1·91	0·89	2·26	0·54	1·95	0·87	1·50	14·58
1907	1·64	0·56	1·55	1·63	3·33	2·80	2·80	4·26	2·62	0·96	1·22	1·11	24·48
1908	1·10	1·03	1·58	1·66	4·14	2·61	1·06	1·74	1·41	1·87	1·18	1·71	21·09
1909	3·94	1·38	0·78	0·92	1·49	1·81	2·68	0·99	1·18	0·70	4·67	1·02	21·56
1910	0·46	1·88	1·59	1·19	0·65	2·77	0·46	2·97	1·06	1·36	0·98	0·90	16·27
1911	3·12	0·65	0·56	1·14	1·35	2·84	1·38	3·76	1·14	0·56	1·64	0·04	18·18
1912	0·94	0·21	0·32	1·35	1·06	3·02	5·03	3·94	1·03	0·48	1·40	0·37	19·15
1913	1·22	0·45	1·43	1·56	1·34	2·29	0·91	2·85	2·24	1·22	2·35	0·02*	17·88

*December, 1913, was the mildest month for the last eight years. The precipitation was practically nil.

FLORA AND FAUNA.

Timber line is between 6500 and 7000 feet above sea-level, and in many places is quite sharply marked, especially on the south and west slopes. This is a very distinct feature on the south slope of Mt. Odaray and is shown in Plate VIII, A. The lower levels are heavily wooded with a second growth of spruce, balsam, fir (*Pseudotsuga douglasii*), aspen (*Populus tremuloides*), small yellow pine (*Pinus ponderosa*), and scrub pine (*Pinus murrayana*). A mountain birch (probably *Betula occidentalis*), occurs towards the watershed range, and a larch, Lyall's larch (*Larix lyallii*)[1] is frequently seen at the upper limit of tree line.

Underbrush of many kinds abounds in the bottoms of the valleys. Devil's club (*Fatsia horrida*) was encountered in at least three of the valleys.

Some of the timber in the west slope of Beaverfoot valley has been milled, but as a rule it is small. Two feet in diameter is about the maximum size. Fires have not occurred for many years and they are now closely watched as this region is within the park limits. The beauty of the young pine, spruce, and fir forest is best shown on the wagon road from Field to Emerald lake, where the drive has been cut for almost a mile in a straight line through these straight, unidimensional trees, principally jack pine. There is a marked absence of all kinds of green-leafed trees other than aspen. This feature is characteristic of the Rocky mountains in general.

Game is becoming abundant, as it is protected within the limits of the Yoho park. Large game consists of goats, deer, moose, cariboo, and grizzly, cinnamon, and black bears. Of these the goat is especially abundant, and may be seen at almost any time in large flocks on rocky slopes above timber line in Moose Creek valley.[2]

Small game includes beaver, lynx, coyote, wolverine, martin, mink, marmot, and porcupine. Beavers are abundant in the

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[1]Technical names given by G. M. Dawson in Annual Report, Geol. Survey, Canada, 1885, p. 33 B.

[2]A flock of 61 was seen by the writer at one time in Moose Creek valley, and rarely a day passed without seeing a dozen or more.

Beaverfoot valley. They have dammed up the watercourses in many places, forming swamps and lakes. One of these lakes is within half a mile of the Ice River bridge, near the edge of the trail.

CHAPTER VI.

STRATIGRAPHICAL GEOLOGY.

GENERAL INTRODUCTION.

REGIONAL.

The geology of the district treated in this memoir was first described in 1885, by Dawson, and the only geological map of the region is that which accompanies his report for that year.[1] On this map the sedimentary rocks are grouped under only three headings, the Cretaceous, the Carboniferous and Devonian, and the Cambrian. It has since been necessary to make changes in these last two groups.

The following year, 1886, Mr. McConnell[2] completed a geological structure section across the system, in which he showed the faulted nature of the beds, especially in the eastern slope of the Rockies. He subdivided the section into the Cretaceous; Banff limestone, Devono-Carboniferous; Intermediate limestone, Devonian; Halysites beds, Silurian; Graptolite shales, Ordovician; Castle Mountain group, Cambrian; and Bow River group, Cambrian. The Cretaceous was found to be, in the main, confined to the foothills as far west as Kananaskis on the railway, but also outcropped in the Cascade basin in the vicinity of Banff. The Bankhead coal mines are located in this basin. The western limit of the Carboniferous and the Devonian was given as being about halfway between this basin and the Continental Divide. The remainder of the section, as shown by McConnell, consisted of Cambrian beds, except in the last range of the system, in which the Halysites beds and Graptolite shales are exposed.

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[1]Dawson, G. M., "Physical and Geological Features of that Portion of the Rocky Mountains between Latitudes 49° and 51° 30′." Annual Report, Geol. Survey, Canada, Vol. I, 1885, Part B, pp. 37-169.

[2]McConnell, R. G., "Geological Structure of a Portion of the Rocky Mountains, Accompained by a Section Measured near the 51st Parallel," Annual Report, Geol. Survey, Canada, Vol. II, 1886, Part D.

In 1910, Dr. C. D. Walcott placed a part of the Bow River group in the Pre-Cambrian.[1]

The rocks on the westward slope of the Rockies are, in the main, older than those on the eastward slope. The strike of the formations corresponds with the major axis of folding in the Rocky mountains, which is northwest and southeast. In the eastern slope of the mountain system the general dip is towards the west and the successive ridges appear as tilted orographic fault blocks, while in the westward slope the general succession of beds also have a westward dip, but are folded instead of being faulted.

The formations which occur within the Ice River district have not yet been traced over 20 miles on either side of the railway.

The Ice River intrusive mass is the only igneous body thus far located in this part of the Rocky Mountain system. G. M. Dawson has shown on his map, referred to above, a small patch of "diorite" in the southern end of the Mitchell range, on the edge of Cross river, about 40 miles southeast of the summit of Beaverfoot river, while the next nearest exposures of igneous rocks are those of the Cretaceous agglomerate and ash beds near Crowsnest pass, still farther to the south.

LOCAL.

The rocks of the area included on the map are sedimentary, metamorphic, and igneous. The igneous rocks occur as an irregularly shaped intrusive mass, occupying about 12 square miles and exposed in Ice River and Moose Creek valleys. The igneous body is alkaline in nature and amongst the rock types present nephelite and sodalite syenites predominate, but these grade into numerous varieties in which the iron-magnesium content increases, with a proportional decrease of the light coloured constituents, until the final type is one free from all light coloured minerals. This extreme phase is represented by

[1] Walcott, C. D., "Pre-Cambrian Rocks of the Bow River Valley, Alberta, Canada," Smithsonian Miscellaneous Collection, Vol. 53, No. 7, 1910, p. 423.

such types as urtite, ijolite, and jacupirangite. Schlieren effect is very common, giving numerous alkaline types.

The age of the intrusion can not be definitely fixed from field evidence. It is later than the lower Palæozoic, and the writer is inclined to place it at the close of the Mesozoic or early Tertiary. This intrusive body is one of the very few occurrences of igneous rock in the Rocky mountains of Canada. It is one of the few localities in which sodalite occurs.

The sediments range in age from Pre-Cambrian to Silurian. Of these the Cambrian series covers much the larger area. The general succession of sediments is from east to west. The Pre-Cambrian is exposed just east of the summit of the mountain system. The Lower and Middle Cambrian formations contain numerous massive beds, frequently forming cliffs and castellated peaks, and are characteristically shown in the Bow range. The Upper Cambrian formations are exposed west of the Bow range, in the Ottertail and Van Horne ranges. The Ordovician and Silurian are exposed in the Beaverfoot range, and one formation in the Ottertail range is now placed in the Ordovician. These sediments on the whole are predominantly calcareous and dolomitic, with the exception of the Lower Cambrian, which is almost entirely quartzitic. The Cambrian sediments lie fairly flat, with a general dip to the west except in a zone of sheared rocks in the Ottertail valley where the beds are steeply dipping or contorted into open and closed folds.

DETAILED DESCRIPTION OF FORMATIONS.

GENERAL STATEMENT.

The sedimentary rocks of the district range in age from Pre-Cambrian to Silurian, and are subdivided into a number of formations as seen in the accompanying table. The Cambrian gives a thick conformable series over 16,500 feet thick, resting unconformably in some places upon a Pre-Cambrian base and transitional above into conformable Ordovician.

The first subdivision of the rocks in the west slope of the Rocky mountains was made by Mr. R. G. McConnell in 1886.[1]

[1]Annual Report, Geol. Survey, Canada, Vol. II, 1886, Part D, p. 15.

In this section he divided them in ascending order into the Bow River group, Castle Mountain group, Graptolite shales, and Halysites beds. Of these he placed the Bow River and most of the Castle Mountain groups as Cambrian; the remainder of the latter and the Graptolite shales, as Ordovician, and the Halysites beds as Silurian.

In 1907, Dr. C. D. Walcott extended his studies of the Cambrian into the Rocky mountains in the vicinity of Field, and later published an account of the Cambrian section of Mt. Bosworth and vicinity at the Continental Divide, where there is exposed a complete section from the lowest Cambrian up to the base of the Ordovician, as he then considered the upper strata, and on detailed palæontologic evidence subdivided the Cambrian into ten formations.[1] The top of this section on Mt. Bosworth is capped by a "massive bedded, gray and bluish gray arenaceous limestone, with thin layers, irregular stringers, and nodules of dark chert" 110 feet thick. Regarding these highest beds Walcott writes that "from their lithologic character and the finding of obscure fossils that suggest *Ophileta* of the lower Ordovician, the upper 110 feet of strata are tentatively referred to the Ordovician system." At the close of the field season of 1911, Mr. L. D. Burling, then assistant to Dr. Walcott, and the writer went over the Bosworth sections and in this capping strata some fossil fragments were found that proved to be Upper Cambrian in age, so, therefore, the top of the Cambrian is not represented in this section, or at least, the highest beds are lower than the Ordovician.

The field season of 1910 was spent by the writer in Ice River and Moose Creek valleys, where it was found that the sediments were lithologically divisible into three distinct formations, but the few fossils then found were not sufficient to determine the horizon of these beds. An attempt was made to correlate the beds with those occurring in the Bow range in the Mt. Bosworth section, but this was found impossible as the rocks of the Ottertail valley, which intervene, are highly metamorphosed

[1] Walcott, C. D., Nomenclature of some Cambrian Cordilleran Formations." Smithsonian Miscellaneous Collections, Vol. 53, No. 1, 1908, p. 1.

and contorted, and besides there is a slip with undetermined throw bounding the eastern side of this sheared zone.

In a further study, in 1911, several fossils were found in various localities, but chiefly from the base of the "*Goodsir formation*," and a few from the underlying Ottertail limestone. This material has been determined by Dr. Walcott. He found six species represented in the collection from the Goodsir formation. Of these, four, including the trilobite, *Ceratopyge canadensis*, are new. The finding of these fossils places this formation at the base of the Ordovician, so that it is an addition to the Ordovician column in the Canadian Rocky mountains. Very few fossils were found in the underlying "*Ottertail*" and "*Chancellor*" formations, but those determined belong to the Upper Cambrian. The upper limit of the Cambrian can now be regarded as the top of the Ottertail formation, and in this section the transition from the Cambrian to Ordovician can be studied.

The thickness of the Ottertail and Chancellor formations when added to that of the Mt. Bosworth section represents the total thickness of the Cambrian in this district, and makes a total of over 16,500 feet. This is a minimum estimate.

TABLE OF FORMATIONS.

System	Formation	Approximate Thickness. Feet	Approximate Thickness. Metres	Lithological characters
Recent and Pleistocene.	Fluviatile...	....	....	Gravel, sand.
	Lacustrine..	....	....	Gravel, sand, clay, silt, and conglomerate.
	Glacial.....	....	....	Till.
	Erosion surface.			
Post-Cretaceous	Igneous complex		....	Nephelite syenite, ijolite, urtite, jacupirangite, etc., with dykes.
Silurian	Halysites beds.	1,850+	563 +	Dolomites and quartzites weathering light grey to white, with shale interbedded.
Ordovician	Graptolite shales	1,700+	518+	Black, brown, and grey, fissile shales.
	Goodsir shales	6,040+	1,842+	Cherts, cherty limestones, banded cherts, thin-bedded siliceous dolomites, grey dolomitic limestones, siliceous and calcareous slates and shales; weathering black brown, purplish grey, light yellow, and buff.
Upper Cambrian	Ottertail limestone	1,725+	526+	Massive blue limestones with cherty and shaly bands.
	Chancellor	4,500+	1,372+	Thinly laminated grey argillaceous and calcareous meta-argillites and shales; weathering reddish, yellowish, and fawn; underlain by highly sheared grey shales, slates, argillites, and phyllites in Ottertail valley.
	Sherbrooke	1,375	419	Thin-bedded oolitic, cherty, arenaceous or dolomitic limestones.
	Paget	360+	110+	Massive, bluish grey limestones with oolitic bands of dolomitic limestones.
	Bosworth	1,855+	565+	Massive, grey, arenaceous and dolomitic limestone; weathering yellowish buff; underlain by thin-bedded dolomitic limestone with interbedded bands of greenish, siliceous shale; weathering buff, greenish, yellowish, deep red, and purplish.
Middle Cambrian	Eldon	2,728	831	Massive-bedded arenaceous limestones forming cliffs and castellated crags.
	Stephen	640	196	Thin-bedded limestone, and shale; includes 150 feet of "Ogygopsis shale" in Mt. Stephen, and "Burgess shale" in Mt. Field.
	Cathedral	1,595	486	Thin-bedded arenaceous and dolomitic limestones, weathering grey and buff.
Lower Cambrian	Mt. Whyte	390	119	Siliceous shale, sandstone, and thin-bedded limestone.
	St. Piran	2,705	824+	Ferruginous quartzitic sandstone.
	Lake Louise	105	32	Compact greyish siliceous shale.
	Fairview	600+	183	Ferruginous quartzitic sandstone. Local basal conglomerate and coarse-grained sandstone.
	Conformable in some places			
Pre-Cambrian	Hector	4,590+	1,399+	Grey, green, and purple siliceous shale with conglomerate interbedded.
Base not exposed.	Corral creek	1,320(+)	403+	Quartzitic and coarse-grained sandstone with shale interbedded.
Total thickness		34,078+	10,390+	

Résumé of Section.

Silurian	1,850+ feet.
Ordovician	7,740+ "
Upper Cambrian	9,815+ "
Middle Cambrian	4,963+ "
Lower Cambrian	3,800+ "
Pre-Cambrian	5,910+ "
Total	34,078 feet.
Total Cambrian	18,578+ feet.
Limestone (calcareous and dolomitic)	10,278 feet.
Thin-bedded strata (mostly shale)	10,540 "
Quartzites and sandstones	3,800 "
Total	24,618 feet.[1]

PRE-CAMBRIAN.

The rocks which underlie the Cambrian and are especially well developed in the upper part of the Bow River valley above Laggan, Alberta, have been placed in the Pre-Cambrian by Dr. Walcott.[2] Only a very small area in the northeast corner of the map-area is occupied by these rocks. It is situated east of Stephen station on the Canadian Pacific railway and on the eastward slope of the Continental watershed. These rocks had been previously referred to by Mr. McConnell[3] as the lower part of the Bow River group.

Dr. Walcott regards as Pre-Cambrian all the strata below a conglomerate bed regarded as forming the basal member of the Cambrian. This conglomerate consists of white, semi-transparent quartz pebbles two millimetres to ten centimetres in diameter and, towards its base, of "rounded and angular pebbles (fragments) of dark siliceous shales of the subjacent

[1]Total thickness of continuous conformable series from the base of the Fairview to the top of the Goodsir formations.

[2]Walcott, C. D., Pre-Cambrian Rocks of the Bow River Valley, Alberta, Canada." Smithsonian Miscellaneous Collections, Vol. 53, No. 7, 1910, p. 423.

[3]McConnell, R. G., Annual Report, Geol. Survey, Canada, 1886, Part D, p. 29.

Hector formation." There is a possibility, not mentioned by Walcott, that these shale fragments may have been derived from Cambrian beds to the west. Dawson[1] mentions small pieces of feldspar and abundant pale mica in the matrix of the same conglomerate. Its constituents seem to point to a near-by source of origin. In thickness it varies from 100 feet at Lake Louise to 200 feet at Vermilion pass, and 300 feet at Fort mountain to the north. These points are outside the map-area. Walcott explains this varying thickness as being due to the fact that the Pre-Cambrian surface on which the conglomerates were laid down was broadly irregular, so that in the depressions a greater thickness of conglomerate accumulated than elsewhere. He places these beds in the "Algonkian," and subdivides the series into the Hector formation at the top and the Corral Creek formation below. The estimated thickness given in the table for each of these formations was obtained by the writer outside the limit of this map-area. The beds of the upper formation consist of siliceous or arenaceous shale, varied in colour, grey, black, green, purple, and red being represented; while those of the lower formation are coarse sandstone, fine grained quartz conglomerate, and quartzitic sandstone. The base of these sediments is nowhere exposed. These sediments are non-fossiliferous, and Walcott regards them as non-marine in origin,[2] having been deposited in an inland, fresh-water sea. This deposition was abruptly interrupted by a sudden ingression of the Cambrian marine sea, which brought with it a highly developed Cambrian fauna which had been developed under littoral conditions during the "Lipalian sedimentation."[3]

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[1] Dawson, G. M., Annual Report, Geol. Survey, Canada, 1885, p. 159 B.

[2] Walcott, C. D., "Pre-Cambrian Rocks of the Bow River Valley, Alberta, Canada," Smithsonian Miscellaneous Collections, Vol. 53, No. 7, 1910, p. 427.

[3] Walcott, C. D., "Abrupt Appearance of Cambrian Fauna on the North American Continent," Smithsonian Miscellaneous Collections, Vol. 57, No. 1, 1910, p. 14.

CAMBRIAN.

Lower Cambrian.

The Lower Cambrian rocks have been subdivided by Dr. Walcott, in 1907, into four formations—the Fairview at the base, Lake Louise, St. Piran, and Mt. Whyte.[1] This division was made chiefly on the abundant fossil evidence which he obtained.

The writer did not attempt to separate these formations, but only distinguished the Lower Cambrian as a whole. A brief note will be made on each of these four formations.

Distribution and Thickness.

The Lower Cambrian is developed largely in the Bow range, and, in the area shown by the accompanying map, it occurs on the westward slope of the range. Almost the entire valley of Cataract brook is underlain by the Lower Cambrian. The western limit of these beds is in part marked by a fault, the "Stephen-Cathedral fault[2]" which brings the Lower Cambrian beds up sharply against the Middle Cambrian, between Mt. Stephen and Cathedral mountain.

A small anticline in Middle Cambrian strata west of the fault exposes the uppermost Lower Cambrian beds in the valley of the Kicking Horse at the northwest base of Mt. Stephen and, across the valley, in the south base of Mt. Field.

The total thickness of Lower Cambrian is 3800 feet.

Lithological Characters.

The lithology of the beds is fairly uniform. They are essentially quartzitic sandstone, siliceous shale, and thin-bedded, arenaceous limestone. About thirty-five different species of fossils

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[1] Walcott, C. D., "Nomenclature of some Cambrian Cordilleran Formations." Smithsonian Miscellaneous Collections, Vol. 53, No. 1, 1908, p. 4.

[2] So called since it is prominently seen between Mt. Stephen and Cathedral mountain.

have been determined by Walcott. A detailed list of these may be found in his paper on the Cambrian sections already mentioned.[1] Above the surface of Lake O'Hara 3000 feet of quartzitic beds are exposed. The uppermost beds are well exposed above Lake Oesa in Mt. Lefroy, as shown in the photograph (Plate VIII, B). Most of these beds are massive and form steep cliffs; they are ferruginous in large part, with occasional massive beds of pure white quartzite containing numerous annelid borings. Some of the layers of siliceous shale are about ½ inch thick and the annelid borings are perpendicular to the bedding. There are also pure quartzite layers in which there are annelid borings 4 inches long. The numerous borings present in these beds indicate that this sand-loving animal was abundantly represented. Annelid trails are also numerous and were made by the same animal, probably *Scolithus*. Walcott has noted the similarity of such borings and tracks in both the lower part of the Olenellus zone and in the uppermost Lower Cambrian.[2]

The ferruginous varieties of quartzite consist of semitransparent quartz grains, with decomposed feldspar grains, calcite, and light-coloured mica. The recrystallization is probably due largely to the effect of static metamorphism, caused by the weight alone of the overlying beds. Microscopically, this rock is a finely granular, ferruginous quartzite with a calcareous cement. It consists of colourless, well rounded grains of quartz with a seriate, homoid fabric. The largest grain noted was 1·25 millimetres in diameter; many are less than 0·25 millimetres in diameter. The cement is calcite, often darkened with enclosed particles. There are many grains of black iron ore in the interstices, but no feldspar or mica was present in the slide examined, although they are visible in the hand specimen.

In Mt. Odaray to the west of McArthur pass, the Mt. Whyte formation, the highest division of the Lower Cambrian, extends up to an elevation of 8200 feet. The uppermost beds consist of thin-bedded, siliceous limestone, interbedded with greenish, siliceous shale and thin beds of sandstone. From the siliceous

[1] Smithsonian Miscellaneous Collections, Vol. 53, No. 5, 1908, p. 212.
[2] Walcott, C. D., U. S. G. S., 10th Annual Report, 1888-89, p. 603.

shale the fossil *Micromitra (paterina) wapta*, Walcott, has been determined, which places it in the Mt. Whyte formation.

On the east side of Lake McArthur there are reddish, concretionary beds, boulders of which are readily noticed on the talus slopes. The concretions appear as well rounded, sometimes almost spherical nodules, $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter, and consist of a cryptocrystalline aggregate of quartz grains. The matrix is finely granular and is made up essentially of calcite grains, also kaolinized feldspar fragments and mica flakes.

Another peculiar type appears as a greenish siliceous shale, usually about 1 inch thick, which contains numerous concretion-like nodules. These concretions are all about the same size and range from 0·8 to 1·3 inches in diameter. On the weathered surface these "bosses" show up best; they are dome-like in form, but are not quite hemispherical owing to a slight flattening on the upper tip. Most of them have a "dimple" at the top, so that in vertical section they represent slightly flattened "hemidomes." Professor Bonney[1] has studied these bosses and states that they resemble concretionary "globulars" in a magnesium limestone of Durham, which also show slightly flattened hemidomes. He says that these bosses are not true concretions. They consist of "angular and subangular quartz enlarged by a secondary deposit, of crystalline silica, optically continuous." The presence of tourmaline, zircon, sphene, limonite, rutile, chlorite, and epidote in them disproves their concretionary origin. He believes them to be casts of pits made by an annelid, *Planolithes* (a sand-liver), which usually moves horizontally, while *Scolithus* moves vertically. He concludes that they "represent 'pit-holes' formed by retreat into the mud of *Planolithes* or some annelid of similar habits and that the pits were already filled, perhaps a little stiffened, when *Planolithes* moved among them."

Certain other layers of thin-bedded sandstone contain numerous concretions, well rounded in outline and made up of a calcareous clay. The matrix consists of well rounded quartz grains, decomposed feldspar fragments, and other constituents, which suggests that the material has not been transported far

[1] Bonney, T. G., "Markings on Quartzite Slabs—Canadian Rocky Mountains," Geol. Mag., Vol. 10, 1903, p. 291.

before being deposited. Cross-bedding is well shown in certain beds in the St. Piran and Mt. Whyte formations. This indicates that at least the Lower Cambrian beds were laid down in a shallow sea. The walls of fractures and joint planes are frequently encrusted with hexagonal crystals of colourless quartz and plates of specular hematite.

Middle Cambrian.

Names of Formations.

The Middle Cambrian has been divided, largely on faunal evidence, into the Cathedral, Stephen, and Eldon formations,[1] each of which is well developed in a mountain by the same name. These were formerly referred to by McConnell as part of the Castle Mountain group.[2]

They can be readily distinguished from one another by their lithological characters and by the contrasting topographic forms developed by them. The massive beds of arenaceous limestone of the Eldon, for example, form prominent cliffs that weather into numerous castellated crags; in contrast to this, the underlying Stephen formation is a series of thin-bedded limestones and shales which are less resistant to the action of erosion agencies and form gentle slopes. The Cathedral, at the base, is another massive-bedded formation forming steep cliffs. Besides the form of weathering as a means of distinction between these formations, the colour of the weathered surface is also an important distinguishing factor.

Distribution and Thickness.

The Middle Cambrian is well developed in the upper part of the Bow range, above the quartzitic beds of the Lower Cambrian and also in several mountains to the southwest. The three formations have a characteristic development in Mt. Biddle

[1] Walcott, C. D., Smithsonian Miscellaneous Collections, Vol. 53, No. 1, 1908, p. 3.

[2] Annual Report, Geol. Survey, Canada, 1886, p. 15 D.

(Plate IV, B), Park mountain, Mt. Odaray, Mt. Stephen, and Cathedral mountain, and to the north of Kicking Horse valley in Mt. Field and Mt. Bosworth. The section was first worked out by Walcott in Mt. Bosworth, where he found a thickness of 4963 feet of Middle Cambrian, capped by beds lithologically like the Bosworth formation of Upper Cambrian age.

The southwestward limit of these Middle Cambrian beds is defined by a fault called the "Stephen-Dennis fault," since it crosses the ridge connecting these two mountains. To the south of this break the strata are intensely metamorphosed, as will be seen later. This break was traced for 15 miles southeast of the Kicking Horse valley, but to the north of the valley it has not been followed.

Character.

The series is largely calcareous and dolomitic. The Cathedral formation consists essentially of thin-bedded, arenaceous and dolomitic limestones which weather light or dark grey and buff. Certain beds weather into thin slabs which on the surface become pitted, giving the rock a very gritty or lava-like feel.

A band of white marble, weathering yellowish grey, about 200 feet thick, occurs in Mt. Odaray. A similar band is found in Cathedral mountain at about the same horizon, and also in Mt. Field. This band of marble is exposed in the bottom of the Yoho valley about 2 miles from its mouth. It is highly dolomitic and varies in colour from white to grey, sometimes banded. Some of it has been staked out for quarrying purposes and may in the future prove to be of economic value.

The following section was measured in this band of marble, where it is exposed at the switchbacks on the Yoho wagon road, beginning at the top of the bluffs where it becomes covered up, and continuing down to the river:—

25 feet white and grey dolomitic marble (massive).
35 feet white and grey dolomitic marble (shattered).
55 feet best variety of white dolomitic marble.
100 feet white marble with many grey spots and containing cavities formed as a result of dolomitization.

40 feet coarsely crystalline, grey to white dolomitic marble.
15 feet mottled grey marble with white bands.
6 feet mottled white marble with dark grey bands.
20 feet dark grey, badly shattered.
15 feet dark grey, with white stringers.
4 feet dark grey, coarse.
5 feet light grey to white.
7 feet bluish, siliceous limestone.
13 feet mottled and banded with white dolomite.
10 feet arenaceous limestone containing pyrite crystals.

350 feet. Total thickness measured.

It is in this formation that the ore body worked in the Monarch mine on Mt. Stephen is located, as is also the Black Prince prospect on the opposite side of the valley, on the slope of Mt. Field.[1]

On both sides of the Yoho valley, over 500 feet above the floor and near its mouth, caves have been weathered and dissolved out of this formation along the fracture zones. The waters percolating through the rock are heavily loaded with carbonates in solution, so that on the floor of these caves a hard calcareous tufa has been formed. One of the caves is about 100 feet deep. On the north slope of Mt. Stephen, overlooking the railway, there is a cave in the same formation. It is well known locally as "Crystal cave," since in it, along a fracture, were found numerous well-formed quartz crystals.

The Stephen formation is much thinner than the Cathedral; on Mt. Bosworth it is 640 feet thick, and on Mt. Stephen, 562 feet in the section given by Dr. Walcott. It consists of thin-bedded, dark grey or bluish limestone interbedded with siliceous shale. This formation is especially important because in Mt. Stephen it includes a lentil of shale, about 150 feet thick, known as the Ogygopsis shale[2] in which is found the famous

[1] This ore body has been described by the writer, with assays, in the Summary Report, Geol. Survey Canada, 1911, p. 182.

[2] Walcott, C. D., Smithsonian Miscellaneous Collections, Vol. 53, No. 5, 1908, p. 210.

Walcott, C. D., "Mt. Stephen Rocks and Fossils." Canadian Alpine Journal, Vol. 1, No. 2, p. 292, 1908.

"fossil bed" of Mt. Stephen. From this bed Walcott has determined thirty-two species of fossils, many of which are trilobita.

This formation contains another lentil called by Walcott "Burgess shale," developed on the opposite side of the valley, on Burgess pass. This shale corresponds in horizon to the Ogygopsis shale on Mt. Stephen. In this band of shale Dr. Walcott, in the summer of 1910, made the discovery of a new fossil bed which has furnished a unique Cambrian fauna. He enlarged his collection in the summer of 1911. Not only have new families, genera, and species been made, but from this material Dr. Walcott has made wonderful discoveries of the relations of the hard and soft parts of these animals, being enabled to do so because of the remarkably fine state of preservation of the structures of the soft parts. These discoveries have changed, to a certain degree, some of the previous ideas as to the variety of life in Cambrian fauna. Full descriptions of the fossils found in this bed have been published in four papers,[1] with numerous plates showing details of structure. In the preliminary study of the fauna Dr. Walcott has "distinguished 56 genera in collections from a block of shale not over 6 by 40 feet in area and 7 feet in thickness." In the last of these papers is included a description of the character of the Burgess shale which has been studied microscopically by Mr. E. S. Larsen, Jr., of the U.S. Geological Survey.

Macroscopically, the Burgess shale is a dense dark grey, calcareous shale which breaks into layers $\frac{3}{5}$ inch or even less in thickness. The surface of the layers is traversed by numerous, minute, parallel veinlets less than a millimetre in width; these are described below. So important is this shale that its characters as described by Mr. Larsen are here given:—

"The microscopic examination of the thin section of the rock shows that it is very fine-textured—so fine that much of the mineral shows aggregate polarization. It is made up largely of white mica, which occurs in minute shreds or scales arranged

[1] Walcott, C. D., "Middle Cambrian; Merostomata; Holothurians and Medusae; Annelids; Branchiopoda, Malacostraca, Trilobita, and Merostomata." Smithsonian Miscellaneous Collections, Vol. 57, Nos. 2, 3, 5, 1911, and No. 6, 1912.

parallel to the cleavage of the rock. Kaolinite is rather abundant and a very few minute grains of quartz, small prisms of apatite, and a few crystals of pyrite can be recognized. Numerous dark brown to black streaks arranged parallel to the cleavage represent carbonaceous matter. There is a system of parallel veinlets less than a millimetre across, which are normal to the slaty cleavage; fractures through the centers of these veins show small grains of calcite and blotches of cupriferous pyrite. The surfaces of a system of later fractures are irregular and are coated with carbonates. Sections of the veinlets mentioned are made up in large part of an isotropic mineral which is nearly colourless in the thin section. In the hand specimen it is pale green. It has an index of refraction of about 1·62 and preliminary chemical tests indicate that it is near the chlorates in composition. A further study of the mineral is being made. In the center of the veinlets are irregular crystals of calcite and a little pyrite.

"A chemical analysis of the slate was made by Mr. George Steiger in the laboratory of the United States Geological Survey and is given under No. 1 of the following table. Analyses of several somewhat similar rocks and of a sericite are also given."

	1	2	3	4	5
SiO_2	54·49	55·80	60·28	57·96	55·00—67·00
Al_2O_3	25·60	27·72	22·61	24·70	11·00—23·00
Fe_2O_3	0·89	3·07	2·53	1·27	0·52— 7·00
FeO	2·00		0·45	0·62	0·46— 9·00
MgO	1·18	0·53	1·35	2·16	0·88— 4·57
CaO	1·90	0·14	0·13	2·30	0·33— 5·20
Na_2O	0·28	1·51	0·54	6·95	0·50— 3·97
K_2O	6·67	5·62	5·73	2·56	1·76— 5·27
$H_2O(-)$	0·33		0·60	0·04	
$H_2O(+)$	3·91	4·03	3·62	1·06	2·82— 4·09
TiO_2	0·72		0·69	0·88	
CO	1·54				
C			0·97		
P_2O_5	0·08		0·03		
S	0·24				
BaO			0·04		
	99·83	98·42	99·57	100·50	
Less O	0·09				
	99·74				

1. Middle Cambrian shale from British Columbia.

2. Sericite. Durrberg. Quoted by Dana, System of Mineralogy, 6th edition, page 618, analyses 41.

3. Mansfield slate (lower Huronian). Crystal Falls district, Michigan, U.S. Geological Survey Monograph 36, p. 59.

4. Kata-biotite-orthoclase gneiss. Corundum-bearing. Waldheim, Saxony. Quoted from Grubemnan, "Die Kristallinem Schiefer," 2nd edition, 1910, p. 158.

5. Range of composition of commercial slate of aqueous sedimentary origin according to Dale, U.S. Geological Survey Bulletin 275, p. 36.

"The analysis shows a remarkable similarity to analysis 2, which is of the mineral sericite from Durrberg; after deducting the calcite and pyrite from the slate analysis the similarity is still more striking. Analysis 3, which represents the Mansfield slate of lower Huronian age from the Crystal Falls district, Michigan, is somewhat higher in silica and lower in aluminum, but is otherwise very similar. Analysis 4 represents a kata-biotite-orthoclase gneiss, corundum-bearing, from Saxony, and differs from analysis 1 chiefly in its lower water content and in the relation between the soda and the potash. The fifth column gives the range of composition of commercial slates of aqueous sedimentary origin as given by Dale. The slate from British Columbia is outside of these limits in many respects; the silica is a little lower, the aluminum is high, the soda low, and the potash high. In general, this rock, as compared with other slates, phyllites, and related schists, is noteworthy for its low content in silica, its high aluminum and potash, and its poverty in all other oxides except water. The excess of potash over soda is especially remarkable.

"The composition of the slate and its microscopic texture show that it was derived from a very fine, highly aluminous sediment, whose material must have consisted of the very finest suspended matter which had been leached unusually free from iron, magnesia, lime, etc., and which consisted largely of kaolinite and quartz."

At Biddle pass the Middle Cambrian is faulted down against the Lower Cambrian quartzites. At this point, on the east side of Park mountain, a thin-bedded black limestone about 150 feet thick, weathering in small lens-shaped fragments, contains the two fossils:—

Lingulella mcconelli Walcott.
Neolenus serratus (Rominger).

These fossils belong to the Stephen formation. Other fossils were found on the west slope of Park mountain in the bottom of the first small draw which enters McArthur creek on the south side of the pass. The beds which are lying comparatively horizontal in Park mountain are in this draw turned down steeply, but they are not broken off. On one side of the draw is a grey-weathering, dolomitic limestone, massive-bedded and badly crushed, belonging to the Cathedral formation, while on the other side is a siliceous shale with interbedded oolitic layers, ½ to 3 inches thick, belonging to the Stephen formation. This shale weathers brownish and contains many fossils. From the material collected, Dr. Walcott has determined the following species.

Micromitra (*Iphidella*) *pannula* (White).
Micromitra (*Paterina*) sp. undt.
Orthotheca major, Walcott.
Nisusia alberta, Walcott.
Neolenus serratus (Rominger).
Ptychoparia cordillaera Rominger.

The Eldon formation has its known maximum development in Mt. Bosworth where Walcott has measured a thickness of 2728 feet. It consists essentially of massive-bedded, arenaceous limestone having a creamy yellow colour on the weathered surface, overlain by less massive siliceous and dolomitic limestone beds.

The Eldon is characterized by its cliff forming nature, the cliffs usually weathering into a series of castellated crags, such as seen in the Mt. Stephen amphitheatre. This crag feature makes the formation readily recognizable though miles distant.

In the amphitheatre between Cathedral, Stephen, and Odaray mountains, the Eldon limestone is well exposed, lying almost flat with a slight dip to the southwest. The limestone is traversed by two series of joint cracks at right angles to each other. The surface waters have dissolved out channels along these planes, so that it is common to hear the sounds of the rushing waters of these underground streams, far below the present surface.

Upper Cambrian.

The Upper Cambrian in this map-area has been subdivided into five formations. The lower three formations (Bosworth, Paget, and Sherbrooke) were recognized by Dr. Walcott in 1908 when he studied in detail a section exposed on the south slope of Mt. Bosworth. At this time the uppermost beds in the Sherbrooke formation were considered to represent the top of the Cambrian section in this area. In 1910 the writer found that the beds underlying Ottertail valley and forming much of the Ottertail range to the west, could not be correlated with the Cambrian formations then recognized in Mt. Bosworth, but represented a younger series of beds. These were subdivided by the writer into the *Chancellor* formation below and the *Ottertail* formation above. The latter was found to represent the highest series in the Cambrian in this section of the Rocky mountains and was overlain by a thin-bedded series of rocks, the lower beds of which contained certain Ordovician fauna.

The Ottertail consists of massive limestone beds which clearly define the limits of this formation.

The Chancellor formation consists almost entirely of shales. The lower half of this formation consists of very highly sheared and metamorphosed shales which underlie the Ottertail valley. For a time the relation of these beds to the Sherbrooke formation could not be obtained, so that in the Summary Report for 1911 the writer refers to these beds as the "sheared zone" of the Chancellor formation.[1]

In the following season further field study showed that a complete section of the Chancellor formation was exposed in the Van Horne range outside of this present map-area. The approximate thickness of the series is 4500 feet. Those beds in the Ottertail valley which have been referred to as the sheared zone, represent the lower portion of the Chancellor formation, and that series overlies the Sherbrooke formation.

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[1]Summary Report, 1911, Geol. Survey, Canada, p. 180.

Formations in Mt. Bosworth.

In the Bosworth section the Upper Cambrian has been subdivided by Dr. Walcott into three formations, Bosworth at the base, Paget above, and Sherbrooke at the top. These formations have a total thickness of 3600 feet in this section. As mentioned previously, the uppermost 110 feet of strata were tentatively placed in the Ordovician, partly from the finding of an obscure fossil that suggested *Ophileta*, a lower Ordovician form,[1] but during the summer of 1911, definite Upper Cambrian fossils were found in this strata by Mr. Burling and the writer, so that the uppermost beds on Mt. Bosworth are at least lower than the Ordovician.

DISTRIBUTION AND CHARACTER.—Brief mention may here be made of these three formations before the uppermost Cambrian formations are discussed.

The Bosworth, Paget, and Sherbrooke formations[2] are typically exposed in the northeast corner of this sheet in Mt. Bosworth and vicinity. There is probably some of the Bosworth formation capping Mt. Stephen. Similar measures also occur on both sides of Kicking Horse valley a short distance below Field, and again, farther west, over an area stretching northward from Otterhead creek.

The Bosworth formation is conformable upon the Middle Cambrian; it has a thickness of 1855 feet in Mt. Bosworth and consists of arenaceous shales, greenish, reddish, buff, yellow, or grey in colour, with numerous mud cracks and ripple marks; thin-bedded, shaly, dolomitic limestone weathering light grey and buff, interbedded with greenish siliceous shale, and overlain by 600 feet of massive-bedded, dark grey, arenaceous, dolomitic limestone weathering yellowish buff.

Determinable fossils have not been found in this formation, and Dr. Walcott states that this 1855 feet of strata in the Bosworth formation remind him in lithologic character and appear-

[1] Walcott, C. D., "Cambrian Sections of the Cordilleran Area." Smithsonian Miscellaneous Collections, Vol. 53, No. 5, 1908, p. 204.

[2] First named by C. D. Walcott, 1908, since the beds are well exposed in Mt. Bosworth, Paget peak, and about Sherbrooke lake: Smithsonian Miscellaneous Collections, Vol. 53, No. 1, 1908, pages 2-3.

ance, of strata of the upper portions of the Cambrian Belt Terrane of Montana. No traces of life were observed and the shaly, banded character of the beds is very striking.[1]

The Paget formation is 360 feet thick in the Bosworth section. It consists of 300 feet of massive beds of oolitic limestone irregularly interbedded with green, siliceous shale and overlain by massive-bedded greyish dolomitic limestone. *Hyolithes*, *Agnostus*, and *Crepicephalus* are the only fossils which Walcott has determined in this formation.

The Sherbrooke formation lies conformably on the Paget, and in the Bosworth section is 1375 feet thick. At the base of this formation there are over 600 feet of grey, dolomitic, arenaceous limestone. The line of demarcation between these beds and the underlying formation is not sharp and is often difficult to recognize. The upper half of this formation consists of grey, oolitic limestone, some layers of which have a nodular character; greenish siliceous shales that frequently have a purplish tint to their flat surfaces; and, capping the preceding, a massive, blue limestone with cherty nodules. The oolitic layers are perhaps the best distinguishing feature of this formation since fossils are rare. The genera noted in this formation are *Illaenurus*, *Agnostus*, *Crepicephalus*, and *Ptychoparia*.

This succession of Cambrian formations holds good in the Bow range and as far west as the Stephen-Dennis fault, which is shown on the map to pass between Mt. Stephen and Mt. Dennis, and to the southwest of Mt. Odaray and Park mountain.

Chancellor Formation.

NAME.—The name given this formation was chosen because beds of this division are especially well exposed on the east and north slopes of Chancellor peak. The name was first used by the writer in the Summary Report of 1911; in the report of the previous year, the upper part of the formation was included under No. 1 in the table of formations.[2]

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[1] Smithsonian Miscellaneous Collections, Vol. 53, No. 5, 1908, p. 208.

[2] Summary Report, Geol. Survey, Canada, 1910, p. 137.

The upper half of this formation consists of unaltered shales or beds that have not been greatly disturbed, while the lower half consists of very highly sheared and metamorphosed shales. Since the extent of this sheared zone has been distinguished on the accompanying map, the lithological characters of these beds will be considered after the general features of the unaltered portion of the Chancellor formation has been mentioned. The upper limit of this formation in the original locality is sharply defined by the overlying limestone of the succeeding formation, but the lower limit is not definite. In the unaltered portion of the Chancellor formation, at the type locality, has been included the red-weathering shales and meta-argillites, beginning at their uppermost extent where they are in contact with a massive, blue limestone, and extending downwards into the underlying rocks included in the sheared zone as far as the lowest point where the bedding planes remain unobscured by the secondary structures developed in the sheared zone; that is to say, down to where the beds are so metamorphosed, contorted, and sheared, that their true thickness in this map-area becomes doubtful. In one section the thickness of the beds in this portion of the formation was found to be over 2500 feet.

From the above remarks it will be seen that there is no sharp line of demarcation between the less unaltered upper portion of the Chancellor and the underlying sheared rocks.

DISTRIBUTION AND THICKNESS.—The Chancellor formation is well exposed in the upper part of the Ice River valley, also along the base of the Ottertail range on the south slope of the Ottertail valley, and on the higher slopes of the Ottertail range, below the massive-bedded limestone of the overlying formation. It is exposed around the base of Mt. Hurd and Mt. Vaux at the north end of Ottertail range and is developed on the opposite side of the Kicking Horse valley on the southeastern end of the Van Horne range, where it forms the deep red weathering slopes of Mt. King.

This is the lowest formation exposed in the Ice River basin, and in Zinc valley there is exposed a measured section 1160 feet thick.[1] On the northeast slope of the Ottertail range there is a

[1] Geology of Ice River district, Summary Report, Geol. Survey, Canada, 1910, p. 137.

much greater thickness of these beds exposed, and on the slope between Syncline peak and the Ottertail river, the writer made a section, partly measured, partly estimated, with a thickness of over 2500 feet.

The beds below this point were too highly contorted and altered and the bedding plane too much obscured by secondary cleavage, to permit the making of a reliable estimate of the thickness of the lower portion of the formation. An estimate which was made of the total thickness of the Chancellor formation, as exposed in the Van Horne range northwest from Mt. Hunter, showed that this formation is at least 4500 feet thick.

CHARACTER.—The formation is characterized throughout its thickness by its remarkable lithological uniformity and by the reddish colour of the weathered outcrops of its upper portion. In general the unaltered portion of the series of beds is thin-bedded with a slaty cleavage parallel with the stratification plane.

The upper 1000 feet of the formation consist of thin-bedded, grey and blue, argillaceous and calcareous meta-argillites, with some thin interbedded layers of more highly carbonaceous material. A partial analysis made of these shales gave:—

Insoluble residue............74·4%
Carbonates.................22·6%

The soluble material consisted essentially of alumina, silica, and ferric oxide. The percentage of magnesia was greater than that of lime. The rock is a calcareous and dolomitic shale high in iron. These beds weather red, brown, yellow, fawn, and buff, the colour depending upon the varying ferruginous content of the beds.

The lower members of the formation are greyish, calcareous shales, meta-argillites and argillites, sometimes even phyllitic in character towards the bottom of the section, weathering greenish, greyish, reddish, yellowish, and buff. An analysis shows that the underlying beds contain more carbonates than the upper beds of the formation. There is more magnesia than lime in the carbonates. The analysis gave:—

Insoluble residue............63·6%
Carbonates.................36·4%

In respect of colour alone, on fresh or weathered surfaces, it would be impossible to separate the beds included in the Chancellor formation proper from the underlying phyllitic beds in the sheared zone of this formation.

A section was measured with a steel tape on the face of the ridge dividing the upper part of Zinc valley. The following beds were recognized beginning at the top of the series:—

Thinly laminated shales with silken lustre; some layers are so thin that they can be bent like cardboard	67 feet
Grey-weathering, sericitized shale............	42 feet
Dark grey shale and meta-argillite, weathering fawn to red, interbedded with thin layers from 4 to 8 feet thick of harder, grey dolomitic limestone which weathers in shaly fragments................	208 feet
Massive, argillaceous, shaly limestone with a band 15 feet thick of siliceous limestone in which the ore pocket at the Zinc Valley prospect occurs.......	44 feet
Thinly laminated, grey to bluish meta-argillite weathering red, yellow, fawn, and brown. The cleavage face is finely crumpled giving it a wavy, silken lustre. Average thickness of laminæ less than half an inch; contains numerous pyrite segregations frequently surrounded by white tremolite; leaf-like impression of pyrite often common on the cleavage planes......................................	329 feet
Dark grey, meta-argillite with silky lustre on cleavage faces; weathering dark yellow; pyrite concretions......................................	117 feet
Soft, dark grey, strongly argillaceous shales and meta-argillites, weathering readily into a dark grey talus; some layers are almost black. They are badly crumpled but break almost parallel to the bedding...	200 feet
Light grey to brown calcareous shales with massive layers of argillaceous limestone 8 to 10 feet thick; weathers to a very dark or black talus. The material making up these beds is loosely held together even in the fresh rock. These are the lowest beds exposed in the Ice River valley.........................	155 feet
Total thickness for Chancellor in the Ice River valley..	1162 feet

There are, however, thicker and better exposed sections on the southwest slope of the Ottertail valley, at the base of the limestone cliffs which cap the Ottertail range. One of the best exposures occurs on the shoulder between Haskins creek and Silver Slope creek and is shown on Plate V, A. The upper 600 feet are exposed in an inaccessible cliff, with a general dip of between 25 degrees and 30 degrees into the mountain. In many respects the beds are similar to those in the section in Zinc valley; all have a distinctly red-weathering nature and are comparatively uniformly stratified. There are several narrow bands, 3 to 8 feet thick, of siliceous limestone and cherty limestone. Two sheets of igneous material are interbedded, one about 2 feet thick and the other more irregular of form and varying in thickness between 3 and 10 feet. In some places this material cuts across the stratification. The partly measured, partly estimated thickness of the beds at this locality is over 2500 feet; but as already mentioned, it is not possible to draw any sharp line between the beds at the base of the section and those of the sheared zone to the northeast and, therefore, the measured thickness does not represent the whole of the Chancellor formation. In the above section, the beds in the lower 1000 feet are quite uniform in composition being thinly laminated shales and meta-argillites, weathering readily to a fawn and light yellowish clayey talus. This formation forms a comparatively gentle, frequently talus-covered slope in contrast with the cliff-forming limestones above. Plate V, A, shows the gentle slope underlain by the Chancellor formation at the base of the limestone cliffs, with the rounded slopes of the ridges underlain by the sheared rocks to the right of the picture.

In the section in Zinc valley there are certain bands of siliceous limestone which are much harder than the associated strata and stand out on the weathered surfaces. One of these bands is about 15 feet wide; it is highly siliceous and the quartz has been recrystallized. On account of the greater resistance of this particular band of rock it has been sheared into rounded, lenticular, boulder-like masses. The softer meta-argillites and shales have been squeezed about these harder bosses. Some of these blocks are strongly mineralized with lead, zinc, and iron sulphides.

In the upper half of this formation it is especially true that the major cleavage is always parallel with the plane of stratification, thus giving a meta-argillite. So perfect is the lamination that some beds can be broken into layers of from 1 inch down to even less than $\frac{1}{8}$ inch in thickness. The thinner layers are sometimes quite flexible. This rock breaks up readily and forms long gentle talus slopes. In some places about the head of the Ice River valley, broad fan-shaped talus slopes are as much as $1\frac{1}{2}$ miles long, with an average slope of about 30 degrees. It is common to find large fragments of meta-argillite on these slopes; some are 4 feet long, 2 or 3 feet wide, and less than 1 inch in thickness. The carbonate content of these rocks is too high, and they weather too readily to various hues of red, to make them of any economic importance as roofing slates.

The cleavage faces of the shales frequently show a silken lustre and are often traversed by very minute parallel crumples, resembling the creases in a piece of crepe paper. There are also numerous nodules or concretions of pyrite surrounded by lens-shaped masses of white tremolite; sometimes the fibres of tremolite are perpendicular to the pyrite nodule. Granular calcite also occurs in some of the concretions. In certain layers, pyrite occurs with good crystal outlines, and sometimes as thin, leafy aggregates along the cleavage planes. Between the layers of meta-argillite, especially in the upper half of the formation, numerous long, narrow markings are noticeable, caused by needle-like bodies having a silvery lustre and made up of minute plates of a fibrous mineral which is probably tremolite, although the microscopic determination of the powder was indefinite. Fibrolite has also been suggested. These fibrous inclusions have always a parallel arrangement. The largest are less than 1 millimetre wide and 6 to 10 millimetres long. This mineral as indicated by the parallel arrangement was evidently formed while the shearing was going on. Jointing in this formation is common, and is usually nearly perpendicular to the bedding.

AGE AND CORRELATION.—This formation belongs to the Upper Cambrian. The only fossils determined were found in the beds in the Van Horne range, These were:—

Lingulella isse, Walcott (?)
Agnostus sp.

Although the strata seemed suitable for the preservation of fossils, yet none have been found in any of the beds belonging to this formation either in the Ice River valley or elsewhere in the Ottertail range.

SHEARED ZONE: DISTRIBUTION AND CHARACTER.—This sheared zone has been mapped separately. In width the zone varies from 5 to 6 miles. It is limited on the northeast by the Stephen-Dennis fault, and its southwest limit is at the east base of the Ottertail range. In general the larger part of the area drained by the Ottertail river is floored by these rocks. Reference to the accompanying map will show the general limitations of these rocks. They also form the base of the Van Horne range. In the Ottertail zone the beds are highly contorted and closely folded along the northeastern side of the zone. The folds open out in places, the beds becoming gently undulating and even nearly horizontal in certain localities. Towards the southwest the dip steepens to the south and the beds dip under the Ottertail range.

The most intense contortion of the beds was noted in the ridge between Mt. Duchesnay and Duchesnay pass, on the south side of Boulder creek. The beds there are so closely folded that the thickness cannot even be estimated. The general strike of these sheared rocks is northwest and southeast. The sediments were folded previous to the crushing and shearing. This feature is best seen along the valley walls of the side tributaries, cut into the northeast slope of Ottertail valley; in such places wherever the folding could be determined it was found to be gentle, while the shearing planes were almost vertical and evidently had formed without reference to the folding. The cleavage planes are, as a rule, nearly vertical and strike north 35 degrees to 65 degrees west, though in some places they correspond with the strike of the bedding planes. The cleavage is in every case the predominant parting, and often it is very difficult to determine the original bedding. The folding seems to have been contemporaneous with the major faulting, while the shearing is younger than the folding and faulting. It is only in certain softer bands that there is any evidence of recrystallization resulting from metamorphism.

The rocks of this sheared zone are in general highly calcareous. They include shales and calcareous slates, argillites, and phyllites.

McConnell gives the results of a chemical test of these sheared rocks from the Ottertail valley made by F. D. Adams.[1] The test gave:—

Carbonates..............57·476%
Insoluble residue..........42·524%

The insoluble portion is argillaceous with an admixture of quartzose material. The soluble portion contained a trace of alumina and ferric oxide as well as lime magnesia. Besides the more argillaceous rock varieties there are some beds of massive, blue limestone, usually less than 20 feet thick, and bands of thin-bedded blue limestone that may be several hundred feet thick. In the top of Mt. Dennis a thick band of the thin-bedded limestone is especially prominent and forms a good horizon marker. In this ridge it dips to the west at varying angles of over 30 degrees; it was traced to the west down Boulder creek where it flattens out and in places assumes a horizontal position. A similar band of thin-bedded, blue limestone outcrops at the Ottertail falls, 12 miles up the valley (Plate IX).

The highly cleaved character of the strata is especially well displayed in Mt. Duchesnay and Mt. Owen. The cleavage faces frequently have a silken lustre and glisten with a silvery appearance due to the development of sericitic mica and chlorites. The rocks in the zone, on account of their crushed and sheared character, are less resistant to weathering than they otherwise would be, and form rounded or even slopes to the mountains and ridges. Plate XI, A, shows the smooth slopes of Mt. Owen contrasted with the bolder topography developed by the Middle and Upper Cambrian beds in the distance to the right.

Some of the phyllites contain numerous leaf-like particles, lenticular in shape, sometimes less than 1 millimetre wide and about three times as long as wide. These particles suggest chiastolite or andalusite. They lie parallel with one another on the cleavage faces of the rocks, thus indicating that they probably developed during the period of shearing.

[1] Annual Report, Geol. Survey, Canada, 1886, p. 26 D.

In places, the shearing has been so intense that the argillites cleave along faces so smooth as to appear polished. In many slates there are two planes of cleavage, but one is always dominant. The bedding is sometimes obliterated or appears only as minute bands of lines crossing the cleavage faces.

The colour of the sheared rocks varies very widely, being grey, greenish blue, drab, or purple on fresh surfaces and steel grey, buff, fawn, brown-red, or scarlet on weathered surfaces.

Rapid alternations of very thin layers or beds are very common. In some places, as on Mt. Duchesnay, the slates are grey in colour and the bedding is indicated by dark or black carbonaceous layers, or bands of layers; sometimes an individual layer may be less than 1 millimetre thick. Similar beds are exposed in the southeast end of the Van Horne mountains. A chemical test on these gave[1]:—

Insoluble residue....................82·719%
Carbonates.........................17·281%

The insoluble residue was found to be argillaceous material, the rock being a dolomitic argillite.

A characteristic feature of these rocks is their banded character as developed on weathered surfaces. A rock may be dark grey on the fresh surface, but where weathered it appears to be composed of bands of grey, alternating with others of red, yellow, or brown colour. In other examples the fresh rock may be a blue limestone or calcareous slate, and yet where weathered it shows a distinct banding due to alternating bluish and buff coloured layers, or bluish and yellowish layers. Again, as it frequently happens, certain bands resist the action of the atmosphere and stand out as ridges on the weathered surface. It was found that in some cases these harder layers were siliceous, while the softer ones were calcareous. In other instances the harder layers were dolomitic, and the softer, calcareous, or the harder might be calcareous and the softer argillaceous. At different localities several hundred feet of sediments were found displaying the results of such differential weathering.

One of these localities is the southeast slope of Mt. Owen. The alternating layers vary from the fraction of an inch to 1½

[1]McConnell, R. G., Annual Report, Geol. Survey, 1886, p. 26 D.

inches in thickness. When the thickness of the alternating hard and soft bands is about the same, the weathered surface has a very striking appearance. Certain of these banded beds break up into long narrow fragments.

It is somewhat difficult to realize under what conditions these sediments were laid down in order to produce their banded structures. It seems to the writer that these alternating bands, with their different qualities so prominently developed under the influence of weathering, indicate seasonal variations of atmospheric conditions during the period of deposition. That is to say, the harder and more siliceous layers may each represent the amount of sedimentation during the annual season of heavy rainfall, when relatively coarse material would be washed down into the inland sea, while the softer layers may represent the product of the dry season when only the finer material would be washed out from the shore. It would seem that only some such regularly recurring annual change of conditions would account for this alternation of layers of fairly uniform thickness.

SHEARED ZONE: AGE AND CORRELATION.—The relation which exists between the lower portion of the Chancellor formation and the Sherbrooke formation could not be found in this map-area; but to the northwest of Mt. Hunter in the Van Horne range these relations were observed. The Chancellor formation there is about 4500 feet thick; it is overlain by the massive limestone of the Ottertail formation and underlain by the massive limestone of the Sherbrooke formation, which is exposed on this map-area 2 miles east of Leanchoil station.

Ottertail Formation.

NAME.—This formation, which consists of limestone, is exposed in the map-area entirely within the Ottertail range, and for this reason has been called the Ottertail formation. It forms prominent escarpments wherever it outcrops. This cliff-forming feature is especially well developed along the northeast side of the Ottertail mountains from Mt. Hurd southeast to the limit of the map south of the Washmawapta glacier, a distance of almost 20 miles.

DISTRIBUTION AND THICKNESS.—The formation is exposed in the upper part of the Ottertail mountains lying between the Ottertail and Beaverfoot valleys, to the south of the valley of the Kicking Horse river. It forms the upper part of Mt. Hurd, with the exception of a few feet at the tip belonging to the overlying formation, and the upper cliffs in Mt. Vaux and Chancellor peak. It forms the steep escarpment just mentioned above, which extends from Mt. Hurd 20 miles to the southeast. It floors nearly the whole of Moose Creek valley, and wherever well exposed it is an excellent horizon marker.

This feature is well seen in the Ice River valley. Since this valley is of anticlinal structure the beds are dipping away on both sides. On the east side of the valley, the limestone is exposed between Sodalite valley and Zinc valley, the band encircles the head of Zinc valley, along the base of Mt. Goodsir, where it is dipping to the east, then, extending around the head of Ice River valley, it forms the upper part of Chancellor peak, where it dips towards the west. There it is split apart by a sill-like projection from the intrusive mass. This feature is shown in section (I-J). These two bands of limestone quickly diverge; the lower one forms the lower part of Garnet mountain, then disappears below the talus in the floor of the valley. The upper band forms the top of the ridge extending southeast from Chancellor peak, and also forms the roof of the igneous mass. It continues across the valley about 1 mile above the lower bridge and is well exposed in the north—facing cliffs of Mt. Mollison. The outcrop narrows in this mountain and disappears before the summit of the ridge between Ice river and Moose creek is reached, but this is due to a down folding of the limestone beneath the overlying formation. It outcrops again on the Moose Creek slope and floors almost the entire valley. In this valley its lower contact is not exposed, but its upper limit can be traced almost around the valley sides, except where covered by talus.

To the east of Moose Creek valley the Washmawapta snowfield lies directly on this limestone. The southeastern portion of the map-area is occupied largely by this formation, with the exception of a small patch of the underlying red-weathering shales and meta-argillites of the Chancellor formation, which outcrop in the bottom of the valley of Dainard creek. This limestone formation can be readily traced by aid of field glasses for many miles down the range to the southeast.

The thickness of this formation does not vary widely. In Mollison creek, on the east side of Ice River valley, the limestone has a measured thickness of 1550 feet, but at this point it is in contact with the igneous rock, so that the total thickness of the limestone is not exposed, some of it having been cut away by the intrusion of the igneous mass.

Another section was made on the precipitous escarpment on the south slope of Ottertail valley, and on the shoulder dividing the slopes towards Silver Slope creek and Goodsir creek. At this point the total thickness of the limestone is well exposed. In this section, which was partly measured and partly estimated, the formation is 1640 feet thick. About 3 miles farther east, in the cliff between Goodsir glacier and the first glacier to the northwest, a trigonometrical estimate gave 1575 feet for the total thickness of the formation, but at this point a small amount at the base may be covered by the ice moraine. There is, however, apparently a thickening of the limestone to the southeast, for although no measured sections could readily be made in Moose Creek valley, yet by rough estimation there is a greater thickness exposed in this valley than in any of the sections named above. This thickening or apparent thickening of the formations is better illustrated in the case of Limestone peak to the north of Washmawapta snowfield. As will be seen in the photograph (Plate X), this cliff is almost vertical and quite inaccessible. The lower contact of the limestone formation is represented by the top of the talus slope at an elevation of about 7000 feet, while the top of Limestone peak is 9442 feet high. Since the beds are nearly horizontal there is apparently an approximate thickness of over 2450 feet of limestone contained in this section. If this entire thickness belongs to the same limestone formation as it appears to do in the field, it indicates a thickening of over 800 feet in the limestone in a distance of less than 5 miles.

CHARACTER.—This formation is, in general, a lithological unit, being composed essentially of limestone, massive and thin-bedded, with intercalated layers of calcareous shale. The shaly character of the beds is more evident towards the base of the formation. On a fresh surface the rock composing the whole band is characterized by its grey or bluish colour, while on weathered faces it is light grey to black. The shale bands are so distributed between the more massive beds that they do not greatly affect the steepness of the slope on the exposed face. The upper and lower contacts of the formation are everywhere sharply marked and can be located, especially when viewed from a short distance, within a few feet. At the lower contact are the red weathering beds of the Chancellor formation, while at the upper contact is another thin-bedded slaty series very distinct in character from the more resistant blue limestone of the Ottertail formation. This formation is, therefore, a unit, and can almost always be readily distinguished from the overlying and underlying formations and forms a good horizon marker. The following partial analysis shows that the typical member of the formation is a pure limestone. The soluble material gave a trace of alumina and silica and about 2 per cent magnesia, the rest being lime:—

Carbonates..................	98%
Insoluble residue.............	2%

The limestone is more or less metamorphosed where it is in contact with the intrusive igneous mass. This phenomena is especially well displayed in the band of the upper part of the formation forming the roof to the igneous body in the ridge to the southeast of Chancellor peak. There the limestone has been highly recrystallized, with a variable texture. At some places the rock consists of small, white calcite rhombs loosely held together; in others the texture may be so fine as to appear almost aphanitic. Frequently the marmarosis is not complete. In such cases much of the original limestone forms the matrix of the rock and is held together by calcite. Where the limestone was quite impure, the resulting metamorphosed rock contains other minerals, especially green actinolite needles.

Along a greater part of the contact of the igneous rock with the overlying limestone there is an irregular band of hornfels which varies in width from a few feet to a maximum of about 300 feet. The bedding in the hornfels when visible is always parallel with that of the limestone, but is very irregular at the igneous contact. This hornfels is a compact and even aphanitic, dark reddish, drab, greenish, or grey rock having a flinty fracture. Microscopically the hornfels consists of biotite, muscovite, clinozoisite, diopside, quartz, epidote, perovskite, magnetite, and some small feldspar laths. Numerous dark patches are a constant feature in this hornfels. These patches are about 25 mm in diameter. They apparently consist of knots of minute grains of clinozoisite, which are frequently surrounded by a border of minute muscovite flakes. Some of the patches consist of a cluster of rounded grains of epidote. This hornfels band was originally a cherty or siliceous bed of argillaceous limestone, which has been recrystallized by the heat and vapours emanating from the intruding rock.

Fragments of the hornfels are enclosed in the syenitic rock near the upper contact, as well as large blocks of the purer limestone. The limestone fragments have been metamorphosed to a dense rock consisting essentially of vesuvianite, lime-garnet, diopside, and calcite, with as accessories, wollastonite, forsterite, zoisite, clinozoisite, and possibly some brucite and cancrinite.

Some alteration has taken place in the beds underlying a part of the igneous body, but the extent of this marmarosis is much less than that of the metamorphism at the upper contact.

At various horizons in the formation, the beds consist of alternating bands from ½ inch to 2 inches thick, of varying hardness, so that on the weathered surface the rock has a distinctly furrowed appearance. Although in such cases the fresh surface of the rock may appear to be uniform in composition, yet in reality the harder bands are dolomitic or siliceous, while the softer bands are calcareous. Cherty layers are very common in this formation; they usually are less than 1 inch thick, but their greater hardness causes them to form ridges on the weathered surfaces. This banded or furrowed character is well exposed in the limestone on the east slope of Garnet mountain.

Another characteristic feature of the banded part of this formation is seen where the beds have been crumpled and folded into miniature folds. The harder, dolomitic, siliceous or cherty layers being more resistant, in most cases have been shattered into angular fragments, while the crevices between the fragments have been filled in by the material of the soft, intervening limestone bands, which in many cases has apparently acted as a semiplastic mass. Sometimes the limestone is partly recrystallized. Where the movements have been stronger the harder angular fragments are scattered at random throughout the rock, and are held together by the crystallized limestone. Very little evidence can be seen of these structures on fresh surfaces, but on a weathered face the hard fragments stand out in relief and give the rock a very rough surface (Plate XII). In some cases the nodular fragments stand out as much as $\frac{3}{4}$ inch above the rest of the rock.

All stages of the features just described are exposed on the west and east slopes of Zinc mountain. Excellent examples of folds of miniature size can be studied in some of these beds. Synclinal, anticlinal, open, close, symmetric, and asymmetric folds are represented even within a block of rock one yard square. There are occasional layers of a compact, greenish argillaceous limestone. It is common to find certain of these greenish layers crumpled into small folds, with successive laminæ about $\frac{1}{4}$ inch thick shoved slightly past each other and overlapping like shingles on a roof.

Another characteristic form of weathering is shown by certain bands of limestone which are blue on fresh surfaces but on weathering become mottled with very irregular, blue or very dark patches, surrounded by buff or light grey-weathering materials. Both the light and dark weathering materials are calcareous and weather evenly, but that part which weathers lighter in colour is argillaceous, hence softer and less resistant to pressure. The original more calcareous layers have evidently broken under pressure and their fragments become more or less rounded. There is also some evidence of flow in the argillaceous material of the softer layers which offered the least resistance to the movements.

Since this limestone formation generally outcrops in precipitous cliffs, the best exposed and most complete sections are usually at least in part inaccessible, so that accurate measurements of the thickness can not be made. However, on account of the thin-bedded less resistant character of certain bands within the formation, there are places where less abrupt though still steep slopes have developed and partial sections are exposed. Where more gentle slopes have formed, since erosion is going on very rapidly, the outcropping beds become covered with talus to such an extent that no measurements of value can be obtained. The dip slopes and basset slopes, usually gentle and ledgy, are exposed about the heads of valleys or along the floors of the valleys, as in Moose Creek valley, but in such places the talus obliterates a great part of the actual thickness. There is an almost complete section exposed in the bottom of Mollison Creek valley, half a mile above where it joins Ice river. This section has been measured in detail, but the lower divisions of the formation are wanting and the section ends at a contact with nephelite and sodalite syenite. The details of the section, arranged in descending order, are given below:—

Section of Ottertail Formation in Mollison Creek.

Thin-bedded, grey limestone, interbedded with numerous bands of grey, siliceous and calcareous shales	264 feet
Reddish weathering, compact, siliceous shale......	73 "
Dark grey, compact, thin-bedded dolomitic limestone...	85 "
Thin layers of siliceous shale with calcareous layers ¼ to ½ inch thick.................................	25 "
Black dyke, with large biotite phenocrysts.........	5 "
Limestone and dolomite interbedded in thin layers.	95 "
Thin-bedded limestone with a few thin dolomite layers interbedded.................................	180 "
Blue-grey limestone; some bands weather shaly,..	290 "
Blue, fine-grained limestone, with a few leaf-like layers of dolomitic limestone........................	30 "

Massive, blue limestone weathering grey; contains much granular calcite as a result of contact metamorphism.................................. 188 feet

Shaly limestone weathering dark grey............ 60 feet

Massive limestone, highly recrystallized and twisted.. 250 "

(Contact with nephelite syenite)

Total thickness exposed in section.........1545+"

A number of partial sections were measured in Ice River and Moose Creek valleys. The complete thickness of the formation is, however, best exposed in the escarpment on the southwest side of Ottertail valley. These cliffs are shown in the picture in Plate V, A. A section was made up this escarpment between the heads of the valleys of Goodsir creek and Silver Slope creek. An attempt was made to actually measure the whole thickness of the formation at this point, but it was found that the upper 800 feet was inaccessible, so that the thickness of this part was estimated. The total section gave 892 feet as measured and 833 feet as estimated. The details of the various beds in descending order are given below. The overlying formation does not occur at this point, so that the formation may be 50 feet thicker than that given.

Section of the Ottertail Formation in the Ottertail Escarpment.

Massive blue limestone weathering grey...... 425 feet

Massive blue limestone with a few shaly bands. 408 "

Thickness estimated............... 833 "

Massive limestone, some beds 15 feet thick........ 100 feet

Massive limestone with a few interbedded dolomitic bands....................................... 99 "

Blue limestone, thinly bedded, with oolitic layers 6 to 10 feet thick................................. 26 "

Massive bed of blue limestone, shows irregular lentils on weathered surface......................... 112 "

Concretionary, bluish limestone, weathers dark grey	62 feet
Shaly blue limestone, weathers into lens-like fragments	90 "
Massive blue limestone in thick beds	100 "
Arenaceous limestone with calcite stringers	6 "
Limestone beds about 5 feet thick, some grey lentils on weathered surface	25 "
Thin, alternating layers of calcareous and dolomitic limestone weathering grey and black	10 "
Massive beds of blue limestone weathering grey, and showing bluish, irregular lentils; interbedded with beds of shaly limestone and calcareous shale. Other bands are thin-bedded limestone	150 "
(The relative amounts of the various types in the above 150 feet could not be distinguished. A dark green dyke cuts vertically through these lower beds, and pinches out in a distance of a few yards.)	
Thin-bedded limestone weathering into grey and blue bands, the former are more argillaceous	52 "
Exposed to west of section: cherty limestone weathering with hard nodules, and interbedded limestones weathering into roughly pitted shaly fragments with a graty feel. In contact with slates and shales of the overlying formation	160 "
Total thickness measured	892 "
Total thickness for Ottertail formation	1725 "

By comparing this section with the one measured in Mollison creek it will be noticed that the strata are more shaly and thin-bedded in character. This is due to the effects of contact metamorphism by the adjoining igneous rock, and also to the severe crushing to which the strata have been subjected since the intrusion of the igneous mass which acted as a resistant block while the weaker, overlying limestone was intensely sheared.

In the section measured trigonometrically at the head of Goodsir creek, between the cliff glaciers of Mt. Goodsir, the details of the beds were not determined. Here the beds form a precipitous escarpment. The thickness obtained was 1575 feet, but the base is covered by morainal detritus. The character of the beds in the vertical escarpment to the north of Washmawapta snowfield in Limestone peak, shown in Plate X, was not determined. However, several hundred feet in the upper part of the formation consists of massive beds of blue limestone, some of the beds of which are 50 feet thick and form a perpendicular face. The formation seems to have a thickness of about 2450 feet in Limestone peak, which means a considerable thickening of the formation to the southeast.

AGE AND CORRELATION.—The palæontological evidence of the age of the Ottertail formation is meagre. Many fragments of fossils were found, but from this material only two genera could be determined:—

Ptychoparia sp.?
Lingulella sp.?

These fossils were found in the amphitheatre at the head of Hoodoo creek between Mt. Vaux and Chancellor peak, and on the north slope of the latter. This formation has been examined closely in many localities, but except at the one place no trace of fossils has been found, although the nature of the beds is such that if life were abundant in the sea when these limestones were deposited some evidence of their remains should be preserved.

The age of the formation is, therefore, not definitely known. Lithologically, the formation can not be correlated with any of the Upper Cambrian formations in the Bow range. Its upper limit is determined by the overlying formation, which from palæontological evidence is definitely proved to be lower Ordovician. The faunal horizon is only a few feet above the top of the Ottertail limestone. Until better evidence can be found, the Ottertail limestone must be regarded as uppermost Cambrian or the transition from the Cambrian to the Ordovician.

ORDOVICIAN.

Goodsir Formation.

NAME.—The Goodsir formation was named by the writer, in 1911, after Mt. Goodsir where the best section of the formation is exposed. The highest beds of the formation are exposed on the top of the south tower of Mt. Goodsir at elevation 11,676 feet (Section E-F).

DISTRIBUTION AND THICKNESS.—This formation caps the Ottertail mountains. There are a few square yards exposed on the extreme top of Mt. Hurd; it caps Mt. Vaux and underlies Hanbury glacier at the head of Ice River valley. The valley of the northeast fork of Ice river has been cut through this formation into the underlying Cambrian. It continues in Mt. Goodsir where it has the greatest development, but is again cut off at the divide between Moose Creek and Goodsir Creek valleys. On the east side of Moose creek this formation is again exposed on Helmet mountain on the tops of the interstream ridges and over the greater part of the ridge terminating in Striped mountain. On account of the southward dip of the beds away from the igneous rock of Ice river, the formation forms the top of Mt. Mollison and its southward slope; it continues northwest on the slope overlooking the Beaverfoot valley until it pinches out in a synclinal fold on the south slope of Chancellor peak. It presumably floors the upper part of Beaverfoot valley and is developed on the east slopes of the Beaverfoot range. The area of this formation exposed in the Beaverfoot range is bounded on the southeast by a fault, and towards the north another fault defines the northeastern limit of the same area, the fault passing between Leanchoil station and the ridge of Mt. Hunter.

The greatest thickness is exposed in the south tower of Mt. Goodsir, but even there the highest beds do not represent the top of the formation as developed elsewhere outside of this district. Plate XI, B, shows the total thickness of the Goodsir formation in Mt. Goodsir and also the underlying Ottertail formation. An attempt was made to accurately measure the thickness of these beds, but on account of the long talus slopes and the inaccessible cliffs, especially in the upper 2000 feet, the attempt was unsuccessful. Since at this locality the average dip of the beds is 20 degrees and the upper and lower limits are observable, it was possible to estimate the thickness of the formation in Mt. Goodsir and this was found to be 6040 feet.

At Striped mountain at the southerly end of the ridge on the east side of Moose creek, a partial section was measured of the lower 3000 feet which are there especially well exposed. It was at first thought that these beds were different from those exposed in Mt. Goodsir[1] but later they were found to be the same although their lithological character has changed.

CHARACTER.—This formation is in large part made up of thin beds. It lies conformably on the limestone of the Ottertail formation, with at the base, a band of soft, calcareous red-weathering shales overlain by a band of greenish, dense, siliceous shale. These two bands are together about 75 feet thick. It is from these shales that most of the fossils found in this formation have been recovered. They form an excellent horizon marker whereby to determine the position of the boundary between the two formations. The limestone of the underlying formation, in contact with these shales and slates is cherty, weathering into cherty nodules, and interbedded with a shaly limestone which weathers into harsh, gritty fragments (Plate XII).

In general the lower half of the Goodsir formation consists at the base of alternating bands of—(1) soft argillaceous and calcareous slate, grey and buff coloured, and forming gentle slopes; and (2) harder bands of siliceous and dolomitic, siliceous slate weathering fawn and light yellow, and forming steep ledges. This character only holds true in Striped mountain and Beaverfoot valley where the measures though more highly cleaved are less affected by contact metamorphism. In the section on Mt. Goodsir this distinction of alternating hard and soft bands can not be made and the formation consists of cherts, cherty limestone, banded cherts, shales, thin-bedded limestones siliceous and dolomitic, interbedded with siliceous shale. The dense

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[1]Geology of Ice River district, Summary Report, Geol. Survey, Canada, 1910, p. 137, Nos. 3 and 4; and p. 138.

compact nature of all the beds and their thin-bedded character are features especially characteristic of the formation in this locality. The colour on weathered surfaces is dark brown, chocolate brown, reddish, purplish, olive, buff, drab, and grey. The general colour of the whole when viewed from a distance is dark brown. On account of their dense, hard character, most of the beds break up into sharp, rectangular fragments, which on further decomposition form sharp edged, rock débris. The uppermost 500 feet of the formation in Striped mountain consists of alternating beds like those at the base, but the strata do not tend to outcrop in ledges since the beds in the different bands are of nearly equal hardness. The highest bed is a greenish purple, hard, dense, siliceous limestone that contains numerous lenticular concretions of pyrrhotite with some chalcopyrite.

The formation as developed in the south base of Mt. Goodsir and at the head of Zinc valley, is intensely metamorphosed by a sill-like arm from the igneous body. Highly silicified, dense limestones and banded cherts are abundant in this contact metamorphosed zone. The banded cherts consist of dark and light bands, the former are black or dark brown, while the latter are grey, pinkish, or purplish. The specific gravity of this type of rock is 2·887. Microscopically this rock consists of a cryptocrystalline mass of granular mineral aggregates, the constituents of which could not all be determined. Those minerals which were determined are, quartz, feldspar, biotite, muscovite, and clinozoisite.

In the case of a bed of reddish brown, aphanitic shale with a conchoidal fracture, which lies within 100 feet of the contact of this formation with the igneous body near the mouth of Mollison Creek valley, the microscope shows that the rock consists of a cryptocrystalline mass of biotite, calcite, clinozoisite, some quartz and an indigo-blue, doubly refracting chlorotoid which has been determined as penninite (pinite). Sometimes this mineral surrounds magnetite grains. A striking feature of many of these aphanitic rocks as seen under the microscope is the presence of numerous dark patches or spots. The material in these segregations could not be determined.

The green, aphanitic, calcareous shale on the top of the south tower of Mt. Goodsir contains lenticular patches of pyrrhotite. Some of these segregations are 1 inch long and ¼ inch wide; they often resemble impressions of fossil remains. The specific gravity of this rock is 3,068; this abnormal density is probably due to the iron content. In the table of densities given in the latter part of this paper, another specimen from this formation in Mt. Goodsir has a specific gravity of 2·951.

The beds of the section in Striped mountain have been subjected to shearing. The cleavage planes dip nearly vertically and the strike is almost east and west. The strata were originally fossiliferous, as evidenced by numerous sheared fossil fragments found in some of the beds, but the intensity of the metamorphism suffered by the strata renders it improbable that determinable fossils will be found in these beds. Some of the fossil fragments were found to be lying parallel with the cleavage plane rather than with the bedding.

The section developed on Striped mountain is the only portion of the formation which has been measured. There are 32 distinct hard, and as many soft, bands exposed in this mountain from the top of the underlying Ottertail formation to the summit of the mountain at 9250 feet. Only the lower 18 pairs of bands were directly measured, the thickness of the remaining 14 was estimated. The character of these beds was mentioned above; it is quite similar throughout, the harder beds consisting of more siliceous or dolomitic slate, and the softer of argillaceous and calcareous slate, weathering greyish or greenish. On account of their highly cleaved character and because of the development of chlorite and other alteration products, the surfaces of these slaty fragments are smooth and are slippery when wet.

A partial analysis of a sample of shale from the soft beds gave:—

Insoluble residue...........	54·7%
Soluble.....................	45·3%

The latter contained very little iron, alumina, or lime, but a large amount of magnesia. In the following section the numerals refer to the numbers of the hard bands beginning at the top of the mountain, while the letter S refers to the corresponding softer bands. The thicknesses of numbers 1 to 13, inclusive, were estimated, and of numbers 14 to 32 inclusive were measured.

Section in Striped Mountain to East of Moose Creek Valley.

Bands Nos. 1 to 13 inclusive (estimated)	1600 + feet
Band No. 14 (hard	56 feet
" " S (soft)	100 "
" " 15	50 "
" " S	50 "
" " 16	25 "
" " S	50 "
" " 17	10 "
" " S	18 "
" " 18	90 "
" " S	10 "
" " 19	12 "
" " S	12 "
" " 20	25 "
" " S	15 "
" " 21	10 "
" " S	12 "
" " 22	100 "
" " S	130 "
" " 23	6 "
" " S	20 "
" " 24	40 "
" " S	10 "
" " 25	50 "
" " S	15 "
" " 26	30 "
" " S	10 "
" " 27	40 "
" " S	20 "
" " 28	15 "
" " S	40 "
" " 29	45 "
" " S	15 "

Band No. 30	....	45 feet
" " S	....	10 "
" " 31	....	30 "
" " S	....	10 "
" " 32	....	50 "
" " S	....	24 "

Total thickness measured... 1300 feet
Total thickness of banded series.......2900 feet

AGE AND CORRELATION.—This formation, as determined by faunal evidence, belongs to the lower Ordovician. It is conformable with the Upper Cambrian beds and on account of the lack of fossils in the upper part of the Ottertail limestone, the lower limit of the Ordovician cannot be clearly defined. Fossil horizons were found at four localities, but in each case near the base of the formation. In Ice River valley fossils were found on the west side of the amphitheatre at the head of the east fork; also on the north side of Mollison Creek valley about ½ mile above its junction with Ice river. At both of these localities, the fossil-bearing beds are in the same horizon and consist of a greenish, calcareous and siliceous shale. The beds occur about 30 feet from the base of the formation as there developed. The other two localities in which fossils were found occur in Moose Creek valley on the northeast slope of Mt. Mollison, about 1000 feet above the bottom of the valley. The beds there consist of a dense, greenish, siliceous shale, weathering light grey and buff, and occur within 300 feet of the base of the formation.

The fossils collected have been determined by Dr. Walcott. He found four new species; of these the trilobite *Ceratopyge* has not been described before from this country. This genus has been described as occurring at the base of the Ordovician in Sweden. The presence of this fauna in these beds is the chief evidence for placing the beds of the Goodsir formation at the base of the Ordovician. The following fossils have been determined from this formation:—

Ceratopyge canadensis Walcott.
Lingulella allani Walcott.

Lingulella moosensis n. sp.
Obolus mollisonensis n. sp.
Obulus (very small species—undt.)
Agnostus sp.

On lithological and faunal evidence the boundary between the Upper Cambrian and the Ordovician is placed, at least tentatively, at the top of the Ottertail limestone and at the base of the Goodsir formation. This boundary is best exposed on the north slope of Mt. Goodsir and is shown in Plate XI, B.

The Goodsir formation conformably underlies the Graptolite shales which are exposed only in the Beaverfoot range and are also of Ordovician age.

Graptolite Shales.

These beds have been so named by Mr. McConnell on account of the richness of certain layers in graptolites. The presence of this fauna determines the age of the formation as Ordovician. It is exposed in the Beaverfoot range in the southwest corner of the map-area and in the continuation of this range to the north of the railway. The best section is exposed along the main line of the Canadian Pacific railway, in the lower Kicking Horse canyon, at Glenogle. In Glenogle creek and in the small creek to the west, this formation was found to be about 1700 feet thick. The beds are steeply dipping to the northeast, and form part of an overturned fold, so that they appear to be overlain conformably by the uppermost beds of the Goodsir formation. The Graptolite shales consist of black, carbonaceous, and brown, fissile shale at the top, underlain by grey shales with another band of black shales near the base. Underlying these shales are more massive, calcareous beds which are lithologically similar to some of those in the Goodsir formation, and which for this reason have been placed in the Goodsir formation.

Some of the uppermost beds are highly fossiliferous. The best exposure of this fossiliferous, black, thinly laminated shale is in a small creek a few hundred yards west of Glenogle station. Some of the graptolites obtained were almost a foot long. The following species have been collected from this shale by McConnell and determined by Professor Lapworth:—

Didymograptus enodus, Lapworth.
Glossograptus tricornis, Emmons.
Glossograptus spinulosis, Hall.
Cryptograptus tricornis, Carruthers.
Diplograptus angustifolius, Hall.
Diplograptus rugosus, Emmons.
Climacograptus coelatus, Lapworth.[1]

Since this formation occupies a very small part of this map-area and since the relation existing between the Ordovician formations is not clearly exposed in this part of the Beaverfoot range on account of the highly sheared and broken character of the beds, a brief note can only be made in this paper. Field observations show that in the Beaverfoot range the Graptolite beds are lying conformably on the Goodsir shales.[2] There is a transition from one formation into the other.

SILURIAN.

Halysites Beds.

These beds were first named and described by McConnell along the main line of the Canadian Pacific railway where the Kicking Horse cuts across the Beaverfoot range. This formation consists of white and brown quartzites, brown siliceous shale, and massive beds of grey dolomite. On account of the hardness of these beds they form the top of the Beaverfoot range. The white quartzite is a good horizon marker and has been mapped separately from the rest of the formation. This bed is very white and has a measured thickness of 800 feet where examined 15 miles to the southeast of the railway. Microscopically, the rock is quite free from all impurities and consists

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[1]McConnell, R. G., Annual Report, Geol. Survey, Canada, 1886, Part D, p. 24.

[2]This conformable relation is shown in a section across the Rocky mountains given in the International Geological Congress Guide Book, No. 8, Part 2, 1913 (in pocket); and also on the Route map opposite page 189.

of a mosaic of angular colourless quartz grains. The quartzites are overlain by massive-bedded, grey dolomites which weather to buff and almost white. The microscope shows that this rock was originally a pure magnesium limestone which has become recrystallized by regional metamorphism.

The age of these beds is definitely Silurian as determined by the fauna. Corals are abundant in certain layers, especially *Favosites*, *Halysites*, and a *Zaphrentis*, but the fossil material has not yet been determined specifically. One specimen collected of a part of a Favosites colony is 8 inches in diameter. Crinoid stems and a few brachiopods have also been noted.

This formation apparently lies conformably on the Graptolite shales, but since the two formations form part of an overturned fold in which the strata dip steeply to the northeast, the Silurian beds appear to underlie those of Ordovician age.

During the season of 1912 the writer found that the thickness of this formation to the southeast in the Beaverfoot range is much greater than that given by McConnell along the railway. The section where examined had an approximate thickness of 1700 feet as measured and estimated.

This is the youngest formation which occurs on the west slope of the Rocky mountains in this latitude. A reconnaissance has been made of the last range of the system for 30 miles south of the railway and almost as far north of the Canadian Pacific railway, and no younger formations have been recognized.

PLEISTOCENE AND RECENT.

The broad floors of the Kicking Horse and Beaverfoot valleys are thickly veneered with stratified gravel, sand, and silt. This detritus is, at least in part, of glacio-lacustrine origin. It was washed down the slopes and smaller valleys into a lake that formed at the front of the ice sheet after the glacier had retreated from these valleys. The finest material has been carried farthest from the old shore, so that near the mouth of the Ottertail valley, in the Kicking Horse valley below Leanchoil, and in the Beaverfoot valley, silty material is found about the centre of the valleys. This material is best exposed in the lowest parts of the present river channels.

These stratified deposits now appear in distinct terraces along the sides of the valleys up to an elevation of 4650 feet. At Emerald, 3 miles west of Field, and again, between Leanchoil and Palliser, there are at least five terraces noticeable. In the Beaverfoot valley and also at the mouth of the Ottertail valley, the 4650-foot and 4600-foot terraces are well marked. The greatest width noted between the two shores marked by the upper terrace was about 3½ miles. The pebbles in the gravel are rounded or faceted, and large glacial boulders, some 3 feet in diameter, were found in some of the gravels. Irregular lenses of sand in the gravel are common, and are well exposed in the cut-bank ½ mile west of Emerald station. These may have been formed by the melting of blocks of ice heavily laden with sand.

The gravels carry a large amount of clayey or silty material which acts as a cement when the detritus becomes compressed. In the upper part of Porcupine creek this consolidation has ac-

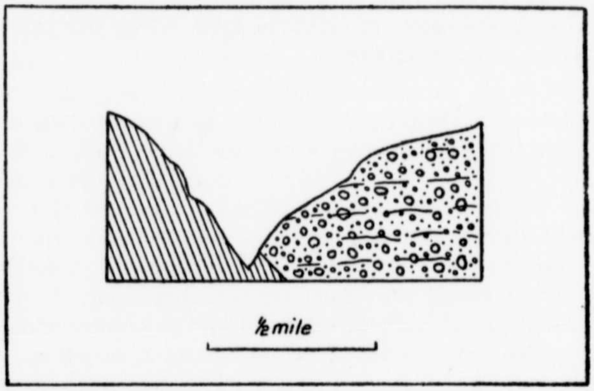

Fig. 3. Cross-section of recent conglomerate in Porcupine valley.

tually taken place. The gravels and sands, roughly stratified, have become cemented into a firm conglomerate. This conglomerate is so hard that in one place the present stream has preferred to cut its channel through the slates at the side of the old valley (Fig. 3). Much of the present course has been cut into the south slope of the old valley. In one place the hard conglomerate has been undermined by the stream to form a gallery 15 feet high and 30 feet deep, and here a side stream enters the main stream by a waterfall.

Fluviatile deposits thickly cover the valley floors at the widest places and where the streams are at or near grade. In some places in the Kicking Horse valley, they form a flood-plain 2 miles wide. In several places, depressions gouged out of the valley floor by the action of the ice have been aggraded by sand and gravel carried down by the streams and in times of flood. These features have already been discussed in Chapter III.

The lower parts of the more gentle slopes of the mountains are deeply covered with talus. In Hoodoo creek between Chancellor peak and Mt. Vaux, the talus contains many large boulders which, when the rock débris is eroded away, act as protecting caps and thus form peculiar-shaped pillars. These are called "hoodoos" and several are found in this creek. A few of them are shown in Plate XIII, A. In this photograph a rough banding is shown in the partly consolidated talus, which represents the inclination of the talus slope.

CHAPTER VII.

ICE RIVER IGNEOUS COMPLEX: GENERAL INTRODUCTION.

GENERAL STATEMENT.

The Ice River igneous complex is an excellent example of how a rock magma, while in a molten, or viscous condition, has differentiated into parts which are chemically and mineralogically different, and which, on cooling, gave rise to diverse types of rock. This igneous complex is made up of a variety of rock types which have a broad range in mineralogical composition, but since all the various rock types are highly alkaline in composition, the whole complex forms a unit. Macroscopically the rocks vary from a light grey nephelite syenite in which dark coloured constituents are almost entirely lacking or are present only in subordinate amounts, through types with increasing amounts of dark coloured minerals, to a final end type consisting essentially of pyroxene and magnetite or ilmenite. The rock types range from sodalite syenite and nephelite syenite, through urtites and ijolites, to a jacupirangite. These types are, in the main, contemporaneous in age, and, at least in some places, grade into one another.

The igneous rocks which make up this complex represent a continuous intrusion in which the melanocratic types crystallized and cooled first. In places these earlier cooled rocks were shattered and into the cracks the lighter coloured more alkaline magma was forced, so that breccias and dyke-like masses of the nephelite syenite in the darker coloured rocks are noteworthy features.

Besides the normal rock types there is a marked pegmatitic development in the complex. These pegmatites are made up essentially of nephelite and sodalite syenites. They appear as irregular dykes and schlieren, irregular masses or "flammen." These pegmatites may be regarded as contemporaneous, and as differentiates from the same magma, and as filling up the cracks formed in the previously cooled magma. They cut the complex in all directions, but are more abundant in those areas made up of the melanocratic rock types which represent the earliest cooled portions of the magma.

An attempt is made in colouring the geological map to distinguish the areas occupied by various types, but this must not be considered as thoroughly accurate, since the varied nature of the types and the transitional varieties present did not permit of this drawing of definite boundaries.

DISTRIBUTION.

Exposed Extent.

The igneous rocks in the area are entirely intrusive and are exposed in the southwest portion of the map-area within the limits of Ice River and Moose Creek valleys. The exposed igneous rock covers about 12 square miles. With the exception of a small portion of the mass at the head of Moose Creek valley, to the north of Helmet mountain, the complex forms a single mass centred in Ice River valley. In outline the irregular main portion of the mass is shaped, somewhat roughly, like a retort, with the large portion of the retort extending from the north slope of Mt. Mollison northwards to Sodalite valley, and the two narrower extensions respectively projecting northward beyond Zinc mountain and northwestward to Chancellor peak. The main mass is about 4 miles across at its widest portion in an east-west direction, and 3 miles in a north-south section; while including one of the extensions the body is, from Mt. Mollison to Chancellor peak, over 7 miles in length. A glance at the map shows that the northwestward projection from the main part of the mass extends along the west side of Ice River valley from opposite the mouth of Sodalite valley up to Chancellor peak, a distance of 5 miles, where this sill-like projection pinches out beneath a small cliff-glacier. This arm of the mass is sill-like since it splits apart a band of limestone; its lower and upper contacts are well exposed in and about Garnet mountain, and at this point the igneous rock has a calculated thickness of 1·1 miles or 5800 feet. The other projection from the main complex extends through Zinc mountain and ends abruptly in Sentry peak. The roof of this portion of the mass has been eroded. There are about 2 square miles of rock belonging to the same intrusion, exposed at the head of Moose Creek valley, between Helmet mountain and Mt. Sharp. This mass was formerly connected with that in Ice River valley and has become detached by the erosion of Moose Creek valley. There is no evidence that this igneous complex extends beyond the limiting ridges of Moose Creek valley.

The igneous body is in part conformable with the stratified rocks, and in part cross-cuts the sediments. This feature will be considered in discussing the form of the mass. The most southerly exposure of the complex is in the north face of Mt. Mollison where the upper surface of the igneous rocks dips steeply to the south, and almost conformably under the blue limestone of the Ottertail formation. The upper boundary follows this horizon of blue limestone to Chancellor peak where the igneous mass pinches out. At one place, about 800 feet above this contact and to the southeast of Clauson peak, there is a sill of nephelite syenite, about 100 feet thick, intercalated between the beds of the Goodsir formation. This is only an apophysis from the main mass; it has a limited exposure along the strike and pinches out laterally. Dykes are quite limited in number and extent. They are always very narrow and closely associated with the main mass which they cut in all directions, although a few were found in the Ottertail valley over 5 miles away from the complex. A few sodalite syenite boulders were found at the upper end of Ice River valley, too far north of the igneous mass to have been derived from this complex. These have undoubtedly been derived from dykes or veinlets from the main mass.

The area covered by this intrusive rock is very much smaller than that shown on the geological map by Dawson. He shows about 35 square miles of igneous rock, but this was based on the probable extent of the mass as indicated by boulders of the intrusive rock found in the surrounding valleys. He states that "large pebbles of diorite or nepheline-syenite in the river, appear to indicate, either that the intrusion of rocks of this character, seen on Ice river, extends to some of the sources of the Vermilion, or that another similar intrusion occurs within its drainage area."[1] These boulders came from the nephelite syenite which outcrops on the eastern side of the head of Moose Creek valley, between Helmet mountain and Mt. Sharp. A part of this mass lies on the Vermilion watershed. In the same report, page 124 B, Dawson notes that "small pieces of the same rock were found in the Kicking Horse above the mouth of the Beaverfoot." This material has been carried from the head of Goodsir creek by the Ottertail, and also from the west slope of Chancellor peak. Many fragments were found at the head of Goodsir creek which were brought there by the Goodsir glacier from the interstream divide with Moose creek where the igneous rock is exposed. Some fragments have been derived from veins cutting the sediments in the backbone of the Ottertail range. Plate XIII, B, shows how the upper contact of the igneous rock (black in the photograph) extends a short distance beyond the summit of the ridge, overlooking the Kicking Horse in Butmell peak and the ridge north to Chancellor peak. The northwestern edge of the complex comes within 3 miles of the Canadian Pacific railway directly east of the "Leanchoil-bend," which is 2 miles east of Leanchoil station. On the same page, 124 B, Dawson also states that "a few well-rounded pieces of the same material were found in 1883 in the Columbia-Kootenay valley south of the lakes—the fragments occurred on a terrace at some height above the present stream." He suggests that these may have been carried there by the southward movements of the ice during the Glacial period.

The fact that igneous rocks are so rare in this region makes even a small pebble quickly noticeable to the eye. The writer feels certain that the maximum limits of this exposed mass have been shown on the accompanying geological map, and furthermore that there are no other exposures of igneous rock, of notable size, within a radius of 20 miles.

[1]Dawson, G. M., Annual Report, Geol. Survey, Canada, Vol. I, 1885, p. 120 B.

Extent Suggested by Ore Deposits.

The presence of a number of small vein deposits in the Ottertail valley; in the Kicking Horse between Field and the summit; in Porcupine valley; and the lower canyon of the Kicking Horse, seems to strongly suggest that there is a very much larger lateral extension of igneous material which does not come to the surface, but which is the cause of these ore deposits. The Monarch mine in Mt. Stephen exposes by far the largest of these pockets of ore, and it is 14 miles from the nearest outcrop of the Ice River igneous complex.

FORM OF INTRUSIVE MASS.

Classification of Shape of Ice River Complex.

Not only is the border of the outcrop of this igneous complex irregular in outline, as the map shows, but the shape of the mass is also irregular. It in part bears some resemblance to a laccolith with sill-like projections extending 2 to 5 miles in a northwest and a north direction respectively, from the main centre, while, owing to the removal of a part of the mass by erosion, a portion of the floor of the chamber is exposed on the north side and towards the head of Sodalite valley. There is evidence that the sedimentary roof of the complex has been up-arched to a certain degree. This feature of uplift is shown in sections (E-F) (G-H) in which the overlying sedimentary beds have a much steeper dip than those forming the floor. This feature is especially noticeable in the northwest arm.

If the igneous body be called a laccolith it is clearly asymmetrical in form, as the various cross-sections show. Section K-L shows that it is relatively very thick on the north side of Mt. Mollison and that it rapidly thins towards the north. The profile has a resemblance to that given by Cross of Mt. Marcellina in the Elk mountains of Colorado.[1] The Ice River complex differs from a true laccolith in having marked cross-cutting relations. Even along the comparatively regular upper contact

[1]Cross, W., U. S. G. S., 14th Annual Report, 1892-93, p. 184.

the bedding of the limestone is frequently cut across by the igneous rock.

The northwest arm in the manner of a laccolith or sill, pinches out gradually in the limestone on Chancellor peak; the north arm on the other hand ends abruptly in the sides of Sentry peak and of Mt. Sharp on the west side of Moose Creek valley.

Further evidence of the departure in form of the mass from that of a true laccolith, is furnished by the following facts. The floor of the main body, towards its northern boundary, is exposed in Sodalite valley. The horizontal distance from this exposure of the floor to where the roof of the mass may be seen at its southern limit in Mt. Mollison, is almost 1¾ miles, but the uppermost sediments exposed in the floor in Sodalite valley are stratigraphically higher than those exposed in the roof in Mt. Mollison (Section G-H). In other words, on the northern side of the main part of the complex, in Sodalite valley, the igneous rock is lying on sedimentary beds which also form the cover of the intrusive mass in Mt. Mollison. In this respect it would seem to differ from either a true, or an asymmetric laccolith.

There are about 6 square miles of the complex, between Mt. Mollison on the south, Sodalite valley on the north, Ice river on the west, and the west slope of Moose creek on the east, under which a floor if it does exist is not exposed in the field. There is no evidence at hand which would show that there is a floor beneath a great part of this area. It seems probable that the igneous rock has intruded the sediments and has lifted up the cover to a certain degree. There is a fault of small displacement cutting across the sediments in the cover on the west slope of Mt. Mollison. It has a strike about N. 40° W., which would carry it directly into the igneous body, but it cannot be traced into the igneous complex. It seems probable to the writer that this break initiated the intrusion. The magma worked its way up to the more massive limestone and then spread out slowly to the northwest, lifting up the cover to a small degree. The presence of a softer, more argillaceous layer in the limestone caused the magma to split apart this limestone band, which it did by arching up the cover. To the north and east of the main feeder the magma forced its way between and across the beds. So that for lack of better evidence the assumption is made that in the large part of the "retort," about 6 square miles, the magma has cut across the strata, and that in a greater part of this area there is no bottom to the complex. In this respect this part resembles a stock.

The plane of the upper contact of the mass, from Mt. Mollison to Chancellor peak, is, in a general way, concordant with the stratification of the overlying sediments. In Mollison creek the overlying limestone band is 1540 feet thick, which is almost the maximum thickness of this formation, while in Chancellor ridge the part of the limestone band forming the cover is only 700 feet thick, so that in a distance of about 7 miles the igneous rock cuts across 800 feet. This, however, would not be sufficient to prevent the body from being classed as a laccolith. The angle of dip of the beds in the roof varies from 60 degrees to 85 degrees away from the igneous mass. In some places this dip becomes vertical, or is even overturned and then appears dipping into the irregular mass, but this has been caused entirely by orogenic movement after the mass had become at least partly cold. This will be discussed under structural relations. The metamorphosing effect which the intruding rock has had on the cover is great, and there has been contact metamorphism to some degree for a distance of 700 feet away from this upper concordant contact, at least in some parts of the cover.

The concordant relations of the upper contact as exposed in other parts of the field entirely disappear on the northeast slope of Mt. Mollison. Plate XIV shows how the outcrop of the grey limestone band pinches out in Mt. Mollison and there represents the uncovered upper part of a tight anticlinal fold.

Directly above the limestone band, the reddish weathering, hard, siliceous shales of the Goodsir formation dip southward, away from the igneous rock, and below the lower side of the limestone band the same hard shales appear, badly crumpled, shattered, and broken, against the igneous rock. Beyond the point where the exposure of the limestone pinches out, in Mt. Mollison, dense siliceous, red-weathering shales of the Goodsir formation show the same relations to the igneous mass. Following the line of contact northwards, at a point on the Moose Creek slope, a few hundred feet from the place where the contact crosses the ridge, the Goodsir sediments become less shattered and finally curve round towards Buttress peak where they now underlie (not overlie, as before), the fringing edge of the irregular igneous mass. By means of the above-mentioned very sharp anticlinical fold, almost overturned in profile, the Goodsir beds, which overlie the grey weathering limestone of the Ottertail formation, are curved round to form the floor for the igneous rock which is thinning out at this point. The border from Mt. Mollison to Buttress peak, mentioned above, limits the igneous rock in a southeasterly direction. The contact of this southeasterly corner of the mass could not be definitely located. The bordering sediments are fractured, contorted, and intensely metamorphosed. Numerous short, rapidly ending apophyses of the igneous material extend into this broken-up mass of sediments and form a ragged fringe for the intrusive body.

It has been previously stated that whatever its form may be called, this irregular mass has its greatest thickness on the southern side of the uncovered portion, and thins out towards the north and west. Much of the northward thinning edge has been destroyed by the erosion of Ice River valley and its tributaries, but there still remains a long, northwestern, sill-like extension on the west side of Ice River valley which shows the thickness of this part of the magma chamber. In the case of the northern arm which ends abruptly in Sentry peak, the upper part of it has been eroded away until at present only 300 feet of igneous rock remains on the dividing ridge between Zinc mountain and Mt. Goodsir. Although only about 300 feet of igneous rock is left on this divide at the head of Zinc valley, yet close at hand, a thickness of 1800 feet is exposed in Zinc mountain where the uppermost rock is a nephelite syenite, and the presumption is, that the arm from the main complex may have had a similar thickness. There is another reason for believing that this arm was thick. It has been previously stated, that the isolated body of igneous rock exposed on the east side of Moose Creek valley at its head is a northeasterly extension of the main mass which has become separated by erosion from the main complex by the carving out of Moose Creek valley. The distance between igneous rock on either side of the valley is about 2½ miles, so that it required a fairly thick sheet to extend this distance. It was not possible to determine the thickness of this separate igneous mass between Helmet mountain and Mt. Sharp, but it is at least several hundred feet thick and probably has a thickness of over 1000 feet.

This isolated body bears similar relations to the adjacent sediments as has been mentioned in the case of the main body. On the north side of Helmet mountains the overlying sediments have been up-arched by the intruding mass. The floor on which the igneous rock lies is well exposed to the east of the mass, on the steep side of Vermilion valley.

The irregular outline of the complex and lack of true laccolithic relations suggest the form of a chonolith as defined by Daly.[1] Its asymmetric form, with one steeply dipping contact which in part shows a varying degree of cross-cutting relations, and its thinning out in the opposite direction with general concordant contacts, makes a corresponding similarity with that form of an intrusive body called a "sphenolith." This term has been mentioned by Harker,[2] described by Philippi[3] and named by Burckhardt.[4]

A still wider comparison with other forms of intrusive masses may be made by examining the northeast arm. The sheet at Garnet mountain on the west side of the Ice river is over ¾ mile in thickness, while 1 mile to the south it is over 1 mile thick. Both upper and lower contacts are approximately concordant with the stratification of the Ottertail limestone, which, as has been previously noted, has been split apart by the intrusion. On the opposite side of Ice River valley about 2 miles distant, as the structure of this valley is anticlinal, the limestone forms a continuous band dipping into the base of Mt. Goodsir, and there is no sign of the igneous rock on the east side of the

[1]Daly, R. A., "Classification of Igenous Intrusive Bodies," Jour. of Geol., Vol. 13, No. 6, 1905, p. 499.

[2]Harker, A., "Nat. History of Igneous Rocks," 1909, p. 71.

[3]Philippi, E., "Centralb. fur. min., 1907, p. 456.

[4]Burckhardt, C., "Les masses Eruptives intrusives et la formation des montagnes," Mexico, Mem. Soc. Ant. Alzate, Vol. 21, 1904.

valley (Section I-J). This means that the sheet of igneous rock, which is over 1 mile thick on the west side of Ice River valley, pinches out and disappears within a lateral distance of less than 3 miles. The folding took place before the intrusion so that the igneous rock occupied one limb of the fold and probably the crest. A profile section would in some respects resemble Harker's "phacolite."[1]

GENERAL LITHOLOGICAL CHARACTERS.

Macroscopic.

The various kinds of rocks which go to make up this igneous complex show considerable differences both in their mineralogical composition and in their general appearance. In colour the types vary from a light coloured rock in which the dark coloured constituents are almost lacking, thus giving a leucocratic type, to a black rock in which there are no light coloured minerals present, representing the melanocratic type.

The igneous mass as a whole is alkaline. The various types together with their transitional phases form a complete series between two widely separated extremes. The one end of the series, which is most highly alkaline, is represented by a light grey or greenish grey nephelite syenite. In this normal type the relative amounts of feldspar and nephelite vary, and with the addition of sodalite the rock becomes a light bluish grey sodalite syenite. At the other end of the series is a jacupirangite. This rock is black and lacks all light coloured minerals. The distribution of this type is not as well defined in the field as the nephelite syenite and it passes into a pyroxenite when pyroxene becomes the essential and practically only mineral present. A type intermediate between these two extremes is an ijolite which is made up essentially of nephelite and ægirite-augite.

There is a marked contrast in the field between these three main types, but when the numerous transitional phases are included, no sharp line of division can be made and the complex affords a continuous petrographic series. An attempt has been

[1] Harker, A., "Nat. Hist. of Igneous Rocks," 1909, p. 77.

made to show the areal distribution of the light coloured types represented by the nephelite syenite and associate types; the medium femic types represented by the ijolite, urtites, and other transition types; and the femic types represented by those rocks in which light coloured constituents are accessory or lacking, but the limits of these subdivisions are quite arbitrary.

The texture of the nephelite syenite type varies between wide limits. Normally, the nephelite is coarse-grained and the rock has a greenish tinge due to the vitreous nephelite crystals. The feldspar is orthoclase and microperthite and frequently occurs in long Carlsbad crystals, some of which are ½ inch in length. In some phases of this type, iron-magnesium constituents are almost entirely lacking, but in the series as a whole, both pyroxene and amphibole may be present, and both vary in composition. In places the feldspar shows a sub-parallel arrangement, and the rock is called a foyaite. Towards the contact, sodalite sometimes becomes an essential mineral and the rock is a sodalite syenite or ditroite, while at other parts of the margin the rock is made up essentially of feldspar, which makes it a tönsbergite.

Going down the series, the amount of feldspar decreases, while that of nephelite and the dark coloured constituents increases. In some localities the rock consists chiefly of nephelite with a smaller amount of ægirite, thus giving an urtite.

The ijolite or intermediate type, consists of about equal amounts of nephelite and dark coloured constituents, chiefly ægirite or ægirite-augite. Amphibole becomes an essential constituent in certain varieties. The areal distribution of this type is rather indefinite. The ijolite occurs either in ill-defined areas, or as schlieren in the nephelite syenite. There is a gradual transition between the leucocratic and melanocratic types.

Towards the end of the series and in the more extreme melanocratic types, the light coloured constituents decrease in amount and finally disappear. The rock varieties are made up largely of different combinations of minerals such as pyroxene, magnetite, titanite, and schorlomite in varying amounts.

It is not possible to map in the field the distribution of any one of these rock varieties, for the areas of each are extremely ill defined and grade into one another. There are also numerous "schlieren" among the melanocratic and transition types; biotite frequently forms an essential constituent in such patches, in other cases it is a pyroxene, or the schlieren may be a pegmatite consisting essentially of feldspar, nephelite, and pyroxene.

Pegmatites form a very distinct feature in the complex and are lithologically interesting. They occur throughout the mass in both the leucocratic and the melanocratic types, although seldom in the normal nephelite or the sodalite syenites. This pegmatitic development in some places is dyke-like in form and in such cases usually cuts the melanocratic types or fills well defined cracks in these rocks. More frequently the pegmatites appear as schlieren fading into the surrounding finer grained rocks. In some of these very coarse-grained irregular masses or "flammen," feldspar crystals up to 6 inches in length were noted and ægirite crystals up to 11 inches in length were found in Garnet mountain. The latter frequently occur radiating from a single centre. In other places crystals of nephelite or an amphibole or a pyroxene have grown to several inches in length. It would seem that these pegmatites are of the nature of contemporaneous veins, comparable with those which are so often formed in and around masses of the more acid material.

The numerous rock varieties present in the complex represent a single period of contemporaneous intrusion, but in every case the leucocratic types, and especially the nephelite syenite, are the youngest rocks, that is they have remained fluid longest. Dyke-like apophyses of nephelite syenite cut the melanocratic types, which undoubtedly were the first rocks to solidify. These dykes are usually irregular in width as well as length; they pinch out abruptly or gradually thin out. Their borders sometimes contain the dark coloured minerals of the melanocratic rocks which they cut. On account of resisting erosion better than the enclosing rock, these dykes stand out as hard, light coloured ridges on the talus covered slopes of the mountain sides. Another point of evidence that the leucocratic types were the last to crystallize is seen in the brecciated zones. The fragments are frequently angular and always consist of melanocratic rock; these are cemented together with leucocratic material, usually closely related to a nephelite syenite.

Apophyses are not a common feature in this complex, but those present belong to the nephelite syenite and have thrust themselves into the overlying sediments forming the cover of the intrusive complex. In some places in the north slope of Mt. Mollison, two or more of these apophyses completely surround a large block of the sediments.

At many places along the upper contact of the igneous rock with the sediments, especially in the ridge to the southwest of Chancellor peak, blocks of the sediments have been broken from the cover and have been enclosed in the intruding magma. These xenoliths have been highly metamorphosed by the introduction of silicates from the intruding rock. The mineral composition of these enclosed fragments, of course, depends largely on their original composition. The recrystallization has given these fragments a banded appearance since secondary minerals such as vesuvianite, garnet, and diopside have apparently segregated separately in layers.

The largest xenolith noted in the field, with one exception, was about 100 feet in diameter, others appear to have been larger but have been split apart into smaller fragments by the effect of differential heating produced by the intruding magma. There is, as shown on the map, one abnormally large xenolith on the south slope of Chancellor ridge, to the south of Garnet mountain. The limits of this block cannot be traced on all sides owing to the thick veneer of rock débris. It is at least ¾ mile long, is somewhat lenticular in outline, and in its widest place is 1250 feet (measured) across the outcrop. It was originally a pure limestone block from the cover of the chamber, but has become completely recrystallized to coarse calcite. Other minerals in it are, wollastonite, diopside, a very small proportion of feldspar, and some magnetite. The calcite is highly stained with limonite so that the rock appears red and weathers into a brown talus. Other lithological features of the rocks in the contact zone will be given in discussing the external structural relations of the various rock types.

MICROSCOPIC.

In order to avoid repetition, the detailed microscopic characters will be given under the description of each type. In general, it may be said that the association of certain minerals forms a continuous series from the most alkaline leucocratic type to the least alkaline melanocratic one. In the leucocratic types, feldspar is the predominant mineral constituent. In most cases the feldspar is a perthitic intergrowth of orthoclase and albite or oligoclase-albite, though frequently the potassic member is microcline and less frequently anorthoclase forms the sodipotassic member of the microperthite. The perthitic structure is rarely absent from the feldspars, though in the normal type of nephelite syenite some of the orthoclase is sometimes found separate from the microperthite. The perthitic feldspars are frequently several millimetres long and microscopically show good Carlsbad twinning; sometimes there is a double twinning plane shown. Numerous Carlsbad crystals can be observed megascopically. It is a common feature for these crystals to be sub-parallel with one another and thus give the rock a foyaitic texture.

Nephelite is not abundant in the normal types, while in the more alkalic types some of the feldspar is replaced by sodalite, thus giving a ditroite, which is always found on or near the upper contact of the mass. On the other hand other contact facies of the nephelite syenite are closely similar to a tönsbergite or a theralite, in which case andesine feldspar is present.

In the leucocratic types, the iron-magnesium constituents, which are almost lacking in the most alkaline types, are represented by pyroxene as ægirite and ægirite-augite and in some rocks by basaltic hornblende or accessory barkevikite.

In the transition types, feldspar rapidly decreases and becomes only an accessory constituent in the ijolites; there is a corresponding increase in the amount of nephelite in the rock, so that the urtite contains about 60 per cent nephelite and the rest is chiefly femic material. The type ijolite contains about equal amounts of nephelite and femic minerals. The pyroxene present in the rocks of this group is usually rich in the ægirite molecule, but there is a typical, pale greenish slightly pleochroic pyroxene which is especially characteristic of the ijolite types. Details of these minerals will be given in a later chapter. In the rocks of this second group it is interesting to note that the predominant amphibole, when it is present, is a barkevikite and not basaltic hornblende, which is present in the rocks of the first group.

With a decrease in the amount of nephelite in the rock and an increase in the proportion of pyroxene, amphibole, and iron ore, the rock is classed under the third group. The chief type in this group is jacupirangite, which represents the end of the series and the extreme product of differentiation. There are several intermediate types which will be referred to later.

The microscope shows that as a rule the rocks in this igneous complex are remarkably fresh; this is true even in many of the specimens taken from the immediate surface.

Besides the minerals mentioned as occurring in these rocks, there are many others, but of these the most important is titanite; it is present in all the types and in some rocks is an essential mineral. The name "sphenetite" has been given by the writer to a rock which contains about 30 per cent sphene. Another mineral peculiar to this mass is schorlomite, a black titaniferous garnet; this mineral is not abundant, but it is rarely found in similar alkaline intrusive masses. It is present in the Magnet Cove complex, while a similar variety, iivaarite, occurs in an ijolite from Mt. Iiwaara, Finland.[1]

In comparing the rock of the Ice River complex with those of other alkaline masses, it is noted that garnet, which is a common constituent in the borolanite of the Cnoc-na-Sroine laccolith of Assynt[2], in the alkali syenites of Magnet cove, Arkansas[3], in the foyaite-theralitic rocks of Tasmania[4], in the nephelite syenite

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[1]Ramsey and Berghell, Geol. For. Forh. Stock., Vol. 12, 1891, p. 305.

[2]Shand, S. J., "On Borolanite and its Associates in Assynt," Trans. Edin. Geol. Soc., Vol. 9, Part 3, 1909.

[3]Washington, H. S., "Igneous Complex of Magnet Cove," Bull. G. S. A.,Vol. 11, 1890, p. 400.

[4]Paul, F. P., "Beitrage zur petrographischen kenntris einiger foyaitisch —therelithischen Gesteine aus Tasmanien."

of Ontario,[1] and in the corundum syenites of the Siwamalai series in India,[2] is practically entirely absent in the Ice River types and its place is taken by titanite.

[1]Adams, F. D. and Barlow, A. E., "Geology of the Haliburton and Bancroft Areas, Province of Ontario," Geol. Survey, Canada, Memoir No. 6, 1910, p. 249.

[2]Holland, T. H., "The Siwamalai Series of Eleolite-syenite and Corundum syenites in the Coimbatore District, Madras Presidency," Mem. Geol. Survey, India, Vol. 30, Part 3, 1901, p. 169.

CHAPTER VIII.

ICE RIVER IGNEOUS COMPLEX: PETROLOGY.

DESCRIPTION OF MAIN IGNEOUS TYPES.

METHOD OF SUBDIVIDING PETROGRAPHIC SERIES.

Any attempt to describe in detail all the petrographical variations which are present in this series of alkaline intrusive rocks would prove an almost endless task, for an especially characteristic feature of the complex is the presence of countless variations. The macroscopical appearance of the rock as well as its mineralogical composition frequently changes within a foot or even less in some cases. It can be readily understood that this great diversity of types makes it impossible to map the exact distribution of each rock type. The various rock types are consanguineous with one another and the series forms a "petrological province,"[1] as defined by Judd in his study of the igneous rocks of Hungary and Bohemia.

Although the rocks in this complex show a marked consanguinity[2] yet for the purpose of convenience in description, they may be divided into the following three groups; but it must, however, be understood that there are no arbitrary boundaries

[1]Judd, J. W., Q. J. G. S., London, 1886, Vol. 42, p. 54

He used this term for those regions "within which the rocks erupted during any particular geological period present certain well marked peculiarities in mineralogical composition and microscopical structure, serving at once to distinguish them from the rocks belonging to the same general group which were simultaneously erupted in other petrographical provinces." Previous to this date Vogelsang in 1872 used the term "geognostische Bezirke" to express the mineral and textural distinction between igneous rocks of different regions. H. Vogelsang: Zeitschr. deut. geol. Gesellschaft: Vol. 24, 1872, p. 525.

[2]Iddings, J. P., Bull. Phil. Soc. Washington, Vol. 12, 1892, pp. 128-144. He used the term "consanguinity" to express the fundamental magmatic relationship between rocks of a petrological province.

between these groups or even between the various types within a group. These subdivisions are:—

(1.) Leucocratic types (alkalic types): nephelite syenite, sodalite syenite, etc.

(2.) Transition types: ijolites, urtite, etc., (mesocratic types[1] in part).

(3). Melanocratic types: jacupirangite and other black rock types.

LEUCOCRATIC TYPES.

Distribution.

The general distribution of the three chief groups of rock in this alkaline complex is shown on the geological map. The leucocratic types make up the larger volume of the complex and occupy an area of about 5½ square miles (14·3 km). In general it may be said that the rock types included under this first group compose the southern portion of the complex, where they occupy the whole width of the complex between Mt. Mollison and Sodalite valley, a distance of almost 2 miles. Their eastern limit is marked by the dividing ridge between the head of Mollison creek and Moose Creek valley, while to the northwest this general type extends to a point beyond the mouth of Sodalite valley. Between these limits the rocks essentially belong to the leucocratic type, although even in this area there are several irregular patches ("flammen") of less alkaline rock belonging to the other two groups. In the northern arm of the complex extending towards Mt. Goodsir, there is a patch of nephelite syenite on the top of Zinc mountain; it is most alkaline at the

[1] The term "mesocratic" has been used by Lacroix for those types of rock in which the light and the coloured constituents are present in about equal amounts; in contrast to the "leucocratic" types, so-called by Brögger, in which the light coloured constituents predominate in amount over the dark ones, and to the "melanocratic" types also named by Brögger to include those rocks in which the reverse is true, or the light coloured constituents may be entirely lacking. Reference: M. A. Lacroix, "Les Roches alcalines caracterisant La Province Petrographique d' Ampasindava, Madagascar," Nouvelles Archives du Mus., 4 Serie, Tome 1, 1902.

top and grades downwards into an ijolite, and finally into a jacupirangite at the base. This arrangement with the most basic and heaviest types at the bottom suggests a differentiation due largely to gravity.

It is a noteworthy feature that with but two possible exceptions, the rocks of the first group which are most highly alkaline are situated in the top or upper part of this laccolithic-like chamber.

In Garnet mountain there is in the northwestern prolongation of the main mass, a true nephelite syenite which lies directly on the limestone floor and underneath the less alkaline and melanocratic types. The contact between the igneous rock and the limestone is conformable and it is especially well exposed in the east face of Garnet mountain. At this point there is a thickness of over 200 feet of nephelite syenite exposed between the limestone contact and the top of Garnet mountain. The relation with the melanocratic rock above can not be determined in the field as rock débris covers up the line between these two groups of rock, but the two varieties are only separated by a concealed interval of a few feet and the contrast between the grey nephelite syenite, and the black melanocratic rocks above, is very striking. Apparently the customary intermediate varieties are absent and this suggests that the body of nephelite syenite is an apophysis from the main body of nephelite syenite lying to the south. If this be the case the connexion between these two localities has been destroyed by the erosion of Ice River valley.

East of the main body, in the isolated area between Mt. Sharp and Helmet mountain, there is another small area, of about ½ square mile, belonging to this group. The rock is a nephelite syenite and it lies on top of the Ottertail limestone, while to the west, about the head of Moose Creek valley and to the top of Mt. Sharp, the rocks belong to the second and especially to the third group.

Varieties Present.

Nephelite syenite is by far the most abundant and essential rock type in this first or leucocratic group. A number of other varieties have been determined microscopically, which must be regarded only as variation facies of the nephelite syenite. Those determined are:—

Ditroite (sodalite-syenite).
Tawite.
Cancrinite-syenite.
Hydronephelite syenite (pink-syenite).
Miascite.
Covite.
Borolanite.
Hedrumite.
Theralite.
Laurvikite.
Tönsbergite.

Most of these varieties are in some way associated with the contacts of the complex. Besides the above, pegmatitic bodies, and basic segregations are common.

Macroscopic Characters.

Nephelite Syenite, Sodalite Syenite, etc.

The rock which has been taken as representative of the nephelite syenites is coarse grained and greenish grey, with a mottled appearance from the presence of pyroxene and amphibole. Both of these minerals are very dark and are difficult to distinguish from one another; the hornblende individuals frequently show black, glistening cleavage faces. The dark coloured constituents make up about 10 per cent of the rock. There are two feldspars, perthite and orthoclase, the former predominating. The orthoclase usually occurs as long, rectangular crystals which commonly show Carlsbad twinning. Nephelite appears as greenish grains with a vitreous lustre. Titanite, magnetite, and sometimes biotite, are the only other minerals which can be recognized megascopically. This representative type is exposed on the ridge on the south side of Sodalite valley (Plate XV).

It is a noteworthy feature of the complex and one which must be understood, that the nephelite syenite is not the same over a large area, but varies in texture or mineral composition within a distance of a few feet, so that it is difficult to get two specimens which look just alike.

In the representative type, the long, slender orthoclase crystals sometimes give the rock a porphyritic appearance. Some are 1½ inches long and ¼ inch wide; they are often sub-parallel in their arrangement so that the rock has a foyaitic texture. In other cases where the nephelite syenite is coarser grained, black amphibole crystals, sometimes ½ inch long and idiomorphic in outline, give the rock a peculiar mottled appearance. In some cases, nephelite and feldspar are poikilitically intergrown in large amphibole crystals which are sometimes ½ inch long. Such variations as these seem to be more abundant towards the roof of the complex.

At various places on or near the upper contact of the nephelite syenite with the sediments, sodalite appears as an essential constituent of the rock. One of the best exposures of this sodalite syenite occurs in the bottom of Mollison Creek valley where this stream cuts across the contact of the alkali syenite with the overlying sediments. At this point a small prospect has been opened which shows how intimately the sodalite is associated with the contact. Another locality of sodalite syenite, also at the upper contact of the complex, is about ½ mile south of the first large creek which enters Ice river from the west side of the valley. The sodalite has a beautiful blue colour and appears both as a mineral constituent of the rock and also in veins of almost pure material. Thin veins of this mineral may be found extending for several yards into the alkali syenite, while very thin stringers were found in the overlying sediments at least 20 yards from the contact.

The sodalite syenite is coarse grained and in most cases is free from dark coloured minerals. When present, the ferromagnesium mineral is a green pyroxene. The presence of deep blue sodalite as a mineral constituent, makes the rock a beautiful decorative stone when polished. Some of this material has been exposed to the light in the laboratory for a year and a half and does not show any sign of fading.

The veins of sodalite are irregular in their extent and are frequently sub-parallel, as shown in Plate XVI, B, which is a photograph of a polished specimen. The veins thin out gradually or end abruptly in a number of smaller ones. Four of these veins are shown in the photograph. There are some grains of pyrite and considerable brownish or pinkish cancrinite associated with the veins. The presence of these minerals is rather detrimental to the value of the rock as a decorative stone.

The veins of sodalite along the contact and the thin stringers in the surrounding sediments are of pneumatolytic origin and have formed after the alkaline rock was cool enough to fracture. The sodalite syenite on the other hand represents the extreme alkalic differentiate in the mass. It appears on the upper contact because it is lighter than any of the other rocks and, therefore, was concentrated on the roof of the laccolith. The specific gravity of the sodalite syenite is 2·455, whereas that of the ordinary type of nephelite syenite is from 2·605 to 2·697. In another part of this paper the specific gravities of various types from all three main subdivisions of the complex are tabulated and also those for some of the surrounding sediments.

The extent of these sodalite syenite occurrences could not be determined at either of the localities mentioned. In other parts of the igneous mass, veins of sodalite are found in the syenite, while in Sodalite valley and Moose Creek valley several boulders were found. At one place in Sodalite valley a vein was found in the syenite that consisted of sodalite in a greenish matrix, which proved to be minute ægerite needles with colourless sodalite and cancrinite.

A 6-inch boulder of almost pure sodalite and cancrinite was picked up near the head of Ice River valley. Since this boulder could not have come from the main complex, its occurrence suggests that the sodalite does not always occur directly in contact with the igneous rock. It has evidently been derived from a large vein or segregation. Other smaller fragments of sodalite were found along the south front of the Hanbury glacier and also in the morainal detritus at the front of a glacier at the head of Goodsir creek. The situations of these boulders suggest that they have come from veins cutting the sediments in the backbone of the Ottertail range and have probably been derived from another deeper reservoir not exposed at the surface. The supposed presence of such veins in the Ottertail escarpment, over 5 miles away from the nearest exposure of the alkaline complex, and, also, as already mentioned, the presence of the various ore veins in the Ottertail valley and elsewhere in this district, seems to strengthen the hypothesis that there is an underlying reservoir of much greater lateral extent than the Ice River complex.

The coarser varieties of the alkali syenite weather with a rough pebbly surface, and break down into a sand with coarse, angular grains. When the rock is fractured, as it frequently is, the angular blocks become rounded on the corners and edges, and have a boulder-like appearance. It is often hard to distinguish between the alkali syenite and the overlying sediments in weathered surfaces.

Apophyses from the nephelite syenite have thrust themselves into the cover of the laccolith. There are not many of these and they are chiefly found in the north slope of Mt. Mollison. There are two sheet-like masses cutting the sediments in the cover near the southeastern end of the Chancellor ridge—the larger is about 100 feet thick—but their extent was not traced. In one of these sheets and in a small dyke farther north in the same ridge, long, slender ægirite needles occur. The dyke is 6 inches wide and some of the ægirite needles are 4 inches long and ¼ inch wide. They are arranged perpendicular to the walls of the dyke, which suggests that they were formed while the magma was still quite fluid. Both of these rocks are characterized by a pinkish or rose-coloured mineral which is a monoclinic epidote, piedmontite. This mineral is readily distinguished microscopically by its strong pleochroism which is characteristic of this mineral.

There is another sheet-like apophysis extending from the end of the northern arm of the complex. It cuts through the base of Sentry peak for a distance of at least 1000 feet on the outcrop. This apophysis may be regarded as the thin edge of the laccolithic complex, which originally extended across Moose Creek valley.

It has been previously stated that the whole complex represents a single contemporaneous intrusion, but in every case the more highly alkaline rock was the last to solidify. Much of the nephelite syenite remained in a fluid condition after the mesocratic and melanocratic types had cooled beyond their point of solidification. Orogenic disturbance took place after the bulk of the igneous rock was in a plastic or semi-plastic condition and the already cooled material was shattered and the angular fragments cemented with the remaining still fluid magma. The fragments in the breccia are usually of black or melanocratic rock, while the cementing material is nephelite or other alkali syenite. In every case the facts show that the darker rock varieties solidified first.

In some few cases a mesocratic or lighter coloured rock forms the fragments, but the cementing material is always more highly alkaline and lighter in colour. Plate XVI, A, shows a specimen of this breccia in which the fragments are hornblende-ijolite and the cementing material fine-grained nephelite-syenite. The fragments shown in this plate are portions of a single block which was shattered by differential heating, and it is possible to reconstruct this block from the smaller fragments. In the field it was noticed that many of the rectangular fragments were turned aside from a general axis along which pressure or a slight movement in the magma was strongest. This specimen illustrates the same feature, and it seems possible, at least in some cases, to work out from a study of such breccias, in what direction the magma was moving when the breccia was formed.

The most characteristic feature which proves that the more alkaline part of this magma chamber remained in a molten state longest, is the common occurrence of apophyses or dyke-like masses cutting the darker coloured types. The dykes vary in width from a few inches to 40 or 50 feet. They are irregular in their extent and may thin out within a few feet. They are abundant along the ridge between Mt. Mollison and Mt. Goodsir, and again in the detached portion of the complex on the east side of Moose Creek valley.

Pegmatites.

Intimately associated with the rocks of all three groups, but especially with those of the mesocratic and melanocratic types, are several abnormally coarse phases which are the pegmatitic equivalents of the ordinary types. These phases seem to occur both as dykes, and as "schlieren" of irregular extent. The contact of these pegmatites with the parent rock is sometimes quite sharp, but in other cases the pegmatite grades into the surrounding rock. These pegmatites are most closely related in composition to the more alkaline magma. Those which occur in or near nephelite syenite are lighter in colour and more alkalic than those found in the darker coloured rocks. The composition varies in different localities, but it may be said that the pegmatites consist essentially of ægirite, feldspar (albite and orthoclase), nephelite, and sodalite, while the accessory minerals are schorlomite, hornblende, biotite, corundum, and cyanite.

One of the irregular pegmatite masses occurring near the top of Garnet mountain, consists of long, slender crystals of dark greenish ægirite and orthoclase feldspar. Some crystals are 3 inches long and 1 inch wide. The largest pyroxene crystal noted was 11 inches long and $\frac{1}{3}$ to $\frac{3}{4}$ inch wide, but crystals 3 or 4 inches long and $\frac{1}{2}$ inch wide are very common. The ægirite crystals frequently occur in radiating groups and this is a characteristic feature of the ægirite-rich, nephelite syenite pegmatites. The feldspar shows two perfect cleavages at almost 90 degrees. By examining crushed fragments in liquids of different indices of refraction the feldspar was determined as orthoclase; one ray is lower than 1·523, while the other has a higher index. The feldspar weathers white or slightly pinkish; in some crystals this kaolinization begins at the outer margin, while in others it begins near the centre.

Another variety of pegmatite consists almost entirely of perthitic feldspar. Some of the crystals are at least 8 inches long and show two good cleavages, with one poorer one. These large crystals are sometimes intergrown with each other so as to give irregular forms on the cleavage face. In this pegmatite a few small crystals of corundum are visible, also accessory nephelite and ægirite.

Another type of pegmatite is found on the west slope of Garnet mountain. It consists essentially of nephelite and pyroxene. The nephelite crystals are seldom over 1 inch in diameter. They always have a spotted pink and grey appearance due to incipient alteration. Microscopically, the nephelite is seen to be largely altered to hydro-nephelite and minute brownish segregations which are probably gieseckite. These alteration products give the rock a pinkish tinge. Angular grains of calcite occur interstitial to the other minerals. The possibility of the calcite being a primary constituent of the rock will be discussed in another part of this paper. The pyroxene occurs as stout crystals, the largest seen were 2 inches long and 1 inch wide, but the average is much smaller. It is ægirite-augite with a faint green pleochroism, and shows a good basal parting. The outer edges of these pyroxene crystals sometimes enclose small hypidiomorphic grains of nephelite; this shows that the pyroxene remained molten longer than the nephelite. The nephelite weathers out more readily than the pyroxene so that the surface of the pyroxene appears pitted. Accessory minerals are feldspar, schorlomite, corundum, and cyanite. Vugs of small dimensions are to be found in some of these pegmatites, which are in some cases lined with nephelite crystals.

Basic Segregations.

Basic segregations are not numerous, but may be found irregularly distributed through any part of the nephelite syenite area. These masses are roughly spheroidal or ellipsoidal in shape and vary in size from a fraction of an inch to several feet in diameter. They are much darker in colour than the surrounding rock and are made up largely of ferro-magnesium constituents; sphene, nephelite, and feldspar are seldom found. It is a noteworthy feature that no impoverishment of bisilicates has taken place in the immediately surrounding rock. There are no sharp contacts between the segregations and the syenite, although the transition is frequently abrupt. In many cases these segregations are somewhat angular and may represent foreign basic fragments which have become rounded by the enclosing magma. In such cases the contact is more distinct and frequently the nephelite syenite shows signs of having flowed about the dark-coloured nodule. It is difficult to always distinguish between an enclosed fragment and a segregation.

A few basic nodules were found in the melanocratic type, but are not so common as in the more alkaline rocks. Some of these fragments are bomb-like in outline. One of these from the dividing ridge between Zinc mountain and Sentry peak is 3 inches in diameter, has a specific gravity of 2·919, and consists of biotite and pyroxene.

It seems probable that if the segregations had formed while the magma was still in motion there would be more visible evidence of flow structures. The nodules seem to have segregated from the magma after it had come to rest. Those basic nodules which have flow lines about them are probably enclosed fragments which have been broken from the earlier crystallized melanocratic types.

Microscopic Characters of Essential Constituents.

The mineralogical composition of rocks included under this group varies between wide limits. Some types are much more alkaline than others. In general it may be said that the leucocratic rocks consist essentially of feldspar, nephelite, sodalite, alkali-pyroxene, and aluminous amphiboles.

Feldspar.

The feldspars are represented by several varieties, but in composition they are chiefly alkaline and range from orthoclase to albite-oligoclase (Ab 85—An 15). In a few of the rock types, especially some of those occurring near the margin of the complex, a lime-soda feldspar is present. The most calcic variety found is an andesine, and was determined as Ab 55—An 45; it is present in the theralitic types. The predominant and by far the most abundant member of the feldspar group represented in this complex, is microperthite, made up of an intergrowth of albite and orthoclase or microcline. Much less abundant is an intergrowth of oligoclase-albite, with orthoclase, microcline, or anorthoclase. Commonly some of the feldspar occurs in the rock as separate individual crystals, as well as in perthitic intergrowths. This suggests that when these two feldspars were growing close together they formed an isomorphous mixture. The fact that in the same rock section orthoclase and albite, for example, are found both as individual crystals and as perthitic intergrowths, does not necessarily mean that there were two periods of crystallization.

In one rock, a theralite, the chief feldspar is andesine, (Ab 55—An 45) and occurs in irregular, angular grains well striated, and frequently surrounded by a border of microcline microperthite. This occurrence of a plagioclase centre with a perthitic border of two other feldspars is not uncommon.

Anorthoclase sometimes occurs in clear individual grains, while the rest of the feldspar in the rock is a perthite. No distinction could be made as to which variety was the earlier to form.

The perthitic intergrowths of the feldspar are varied in their appearance. In few cases there is what appears to be an intergrowth of three feldspars. Barlow states that some of the nephelite-syenite pegmatites from this complex consist "chiefly of microperthite (made up often of three feldspars, orthoclase, microcline and albite) with varying amounts of sodalite, nepheline and ægirine."[1] Positive evidence of such a triple intergrowth could not be found. In the thin sections examined in which seemingly such intergrowths occur, it seems probable that it is an intergrowth of microcline and albite alone. It would seem that the microcline does not always show the "gitter-structure," and that in some cases it appears untwinned, or twinned only according to the albite law. Brögger notes the occurrence of microcline in which the gitter-structure is lacking and calls it "moiré-microcline." Dr. Warren has found that moiré-microcline is an abundant feldspar member in the granites of Quincy, Mass.[2] An intergrowth of albite and microcline in part

[1]Barlow, A. E., "Nepheline Rocks of Ice River, B. C.," Ottawa Naturalist, June, 1902, p. 73.

[2] Warren, C. H. and C. Palache., "The pegmatites of the Riebeckite-Ægirite Granite of Quincy, Mass.," Amer. Acad. Arts and Sci., Vol. 47, No. 4, 1911, p. 149.

showing "gitter-structure" and in part lacking this structure, might be mistaken for an intergrowth of three feldspars.

The texture of the perthitic intergrowths varies; it is usually microscopic and seldom macroscopic. The layers of albite are frequently so thin that they become cryptoperthitic. The lenticular layers of albite usually appear parallel with the orthopinacoid zone, but sometimes the intergrowth is across this zone.

In at least one rock there is an intergrowth of orthoclase and nephelite. The latter mineral does not appear in lenticular patches like albite, but as irregular layers. In the same rock there is a peculiar 'finger-print-like' intergrowth (Plate XVII, B). In some cases the centre of the crystal is clear with a shreddy border. This centre is very clear, has a lower index than nephelite, is optically negative, and is probably soda-orthoclase.

Nephelite.

This mineral varies in amount and habit in these rocks. It is not abundant in the normal nephelite syenite, but the amount increases as the rock approaches an ijolite in composition. In the former case it occurs in irregular, more or less rounded grains. When nephelite is abundant or predominates over the feldspar, it forms equant euhedral crystals of angular outline. The form which the nephelite has, and this is also true to a certain degree of the other essential minerals, depends largely upon the percentage of it present in the rock. The mineral in greatest abundance apparently begins to crystallize before the others excepting in the case of certain accessory minerals. The nephelite is usually quite fresh; when altered it most frequently forms hydronephelite and cancrinite; other alteration products are thomsonite, sodalites, and gieseckite.

In the sodic-rich varieties, the nephelite encloses numerous minute needles, sometimes microlite-like in size. They are usually ægirite needles. Other inclusions determined in the nephelite are apatite and rosenbuschite.

Sodalite.

This mineral is fully described under the mineralogy of the rocks, so repetition will be avoided. In the leucocratic types the sodalite usually appears interstitial or vein-like about the other minerals; this suggests that it is of pneumatolytic origin.

Pyroxene.

This mineral varies in composition in the different types in the group but is essentially alkaline. It ranges from ægirite to ægirite-augite, and always has a greenish appearance.

Amphibole.

The essential amphibole is barkevikite. It is black and glossy in the megascopic crystals, and frequently forms large poikilitic crystals. Some of these are nearly an inch in diameter, and the chadacrysts may be nephelite, pyroxene, or any of the other mineral constituents of the rock. Basaltic hornblende is also present in some of the rocks but does not form poikilitic crystals. Fuller description is given in another part of this paper.

Accessory Constituents.

Other minerals that have been determined in the rocks of this group occur only as accessory constituents. They are described in the section of the report devoted to mineralogy, but a list of them may be given here and is as follows: sphene, cancrinite, hydronephelite, noselite, calcite, thomsonite, fluorite, garnet, melanite, zircon, astrophyllite, disthene, apatite, spinel corundum, zoisite, epidote, laumontite, piedmontite, rosenbuschite, ilmenite, perovskite, and magnetite.

Petrography of Type of Nephelite Syenite.

Microscopically the representative nephelite syenite is hypidiomorphic, inequigranular in texture. The rock is quite fresh and consists essentially of orthoclase and albite, and a small amount of nephelite with which are associated subordinate amounts of pyroxene and amphibole as well as magnetite, apatite, sodalite, and other accessory minerals. The orthoclase occurs usually in long, narrow crystals many of which show Carlsbad twinning, or it forms a microperthitic intergrowth with albite. Microcline is present but not in essential amounts. Some of the orthoclase is doubly twinned and is altered around the edge to albitic material. In a few cases large grains of microperthite are bent and in one case an albite crystal is strongly curved.

Nephelite occurs in equant, subhedral grains; its angular or polygonal outline is very characteristic. Sometimes irregular cleavage lines are noticeable. In this rock the nephelite is remarkably free from inclusion although in other varieties ægirite needles are numerous. The mineral is very fresh and its chief alteration product is cancrinite which appears first between the grains of nephelite. In one of the sections a few cubical forms were observed which may be liquid inclusions.

The pyroxene is chiefly a faint green, slightly pleochroic ægirite-augite. The absorption is $\mathbf{a} > \mathbf{b} > \mathbf{c}$, dark green, light yellowish green, and grass green. The extinction on **c** varies from 35 degrees to 45 degrees. In some varieties of the rock the pyroxene is entirely ægirite with an extinction of 5 degrees on **c**.

Amphibole is very subordinate in amount. There are two varieties represented, barkevikite and basaltic hornblende. The former is most abundant; it is deep greenish brown, strongly pleochroic with marked absorption $\mathbf{c} > \mathbf{b} > \mathbf{a}$, dark green to black, dark brownish yellow, and light yellowish brown. This variety is very frequently twinned. Extinction $c \wedge \mathbf{c} = 10$ degrees to 15 degrees. It is usually quite fresh or has a slight greenish border. The barkevikite is frequently twinned.

In some cases the barkevikite forms poikilitic crystals in which the chadacrysts are nephelite and sphene.

Basaltic hornblende is less abundant, it is characterized by a faint greenish colour and less marked pleochroism. The absorption varies from olive green to yellowish green and is determined as $\mathbf{c} > \mathbf{b} > \mathbf{a}$. The extinction of $c \wedge \mathbf{c} = 12$ degrees to 18 degrees.

Sphene is abundant and occurs in euhedral crystals; many of the grains show good prismatic cleavage and have a wedge-shaped outline. This mineral appears colourless, reddish pink, or bronzy brown, and frequently shows a marked absorption determined as **c** > **b** > **a**. Sphene is present in varying amounts in almost every rock type in this complex. In some of the melanocratic types it becomes an essential constituent of the rock.

Apatite is a very subordinate constituent and in many types is entirely lacking. It always tends to form idiomorphic grains. Sodalite when present is always interstitial to the other minerals, which suggests that it is of pneumatolytic origin. Biotite and perovskite are rare or absent. Calcite and cancrinite are secondary. Other accessories are small grains and crystals of zircon, melanite, almandine, corundum, and magnetite.

The following chemical analysis of the normal type of nephelite syenite was made by M. F. Connor in the laboratory of the Mines Branch of the Department of Mines, Ottawa, With it are given analyses from other localities for the purpose of comparision.

	1	2	3	4	5	Average. 6
SiO_2	53·42	53·76	51·58	53·71	53·13	54·63
Al_2O_3	21·04	23·21	19·40	21·82	24·87	19·89
Fe_2O_3	1·74	1·27	4·26	0·78	2·25	3·37
FeO	2·83	3·18	5·25	2·74	1·40	2·20
MgO	0·61	0·23	0·49	0·56	....	0·87
CaO	2·88	2·94	3·64	1·90	2·68	2·51
Na_2O	7·80	6·97	7·49	8·52	5·56	8·26
K_2O	7·48	7·01	4·23	7·07	7·26	5·46
$H_2O(-)$	0·04	1·71	0·27	2·27	0·36	1·35
$H_2O(+)$	0·76				1·05	
CO_2	0·43	....	1·53	....	....	....
TiO_2	0·60	....	0·35	1·03	0·60	0·86
P_2O_5	0·10	tr.	0·15	....	....	0·25
MnO	0·07	....	0·20	0·19	....	0·35
Cl	0·10	....	....	....	....	....
SO_3	0·06	....	....	....	....	....
S	tr.	....	....	....	....	....
	99·96	100·34	99·59	100·59	99·16	100·00
Sp. G.	2·609		2·618			2·600

1. Nephelite syenite, Ice river, British Columbia.
2. Tinguaite porphyry, Magnet cove, Arkansas.[1]
3. Nephelite syenite, Bancroft, Ontario.[2]
4. Pyroxene foyaite, Cerro de Posada, Picota, Monchique.[3]
5. Nephelite syenite, Lake Borolan, Scotland.[4]
6. Average nephelite syenite of 43 analyses, R. A. Daly.[5]

A calculation of the norm according to the method of Cross, Iddings, Washington, and Pirsson, gives the following percentages of the different constituents:—

Orthoclase.........	44·48	per cent.	Salic 87·17
Albite.............	12·05	" "	
Nephelite..........	29·25	" "	
Anorthite..........	1·39	" "	
Diopside..........	7·98	" "	Femic 12·05
Magnetite.........	2·55	" "	
Ilmenite...........	1·22	" "	
Apatite...........	0·30	" "	
Calcite............	0·90	" "	
	100·12	" "	
Water...........	0·80	" "	
	100·92	" "	

[1]H. S. Washington, "Chemical Analyses of Rocks," U. S. G. S., Prof. Paper No. 14, 1903.

[2]F. D. Adams and A. E. Barlow, "Geology of Haliburton and Bancroft Areas, Ontario," Geol. Survey, Canada, Memoir No. 6, 1910, p. 264.

[3]H. Rosenbusch, Elem. der Gesteinlehre, 1910, p. 146.

[4]A. Gemmel, "Chemical Analyses of Borolanite and Related Rocks," Trans. Edin. Geol. Soc., Vol. 9, Part IV, 1910, p. 417.

[5]R. A. Daly, "Average Chemical Composition of Igneous-Rock Types," Proc. Amer. Acad. of Arts and Sci., Vol. 45, No. 7, 1910, p. 222.

$$\frac{Sal}{Fem} = \frac{7 \cdot 1}{1} > \frac{7}{1} \quad \ldots\ldots = \text{Class 1} \ldots\ldots \text{Persalane.}$$

$$\frac{L}{F} = \frac{0 \cdot 5}{1} < \frac{3}{5} > \frac{1}{7} \quad \ldots\ldots = \text{Order 6} \ldots\ldots \text{Russare.}$$

$$\frac{K_2O + Na_2O}{CaO} = \frac{5 \cdot 30}{1} < \frac{7}{1} > \frac{5}{3} \quad \ldots\ldots = \text{Rang 2} \ldots\ldots \text{Viezzenase.}$$

$$\frac{K_2O}{Na_2O} = \frac{0 \cdot 9}{1} < \frac{5}{3} > \frac{3}{5} \quad \ldots\ldots = \text{Sub-rang} \ldots\ldots \text{(Sodipotassic).}$$

The sub-rang has not yet been named although there is one analysis which falls under this sub-rang. This analysis is given in column No. 2 of the table of analyses.

The specific gravity of this nephelite syenite is 2·609.

From a thin-section of the rock the actual mineral composition was determined by the Rosiwal method. On account of the clearness of the various minerals it was possible to distinguish between orthoclase and microperthite. Some basal sections of nephelite may have been calculated as sodalite, which would account for the high percentage of the latter in the Rosiwal determination, and the lack of sodalite in the rock as indicated by the chemical analysis. The result is as follows:—

Orthoclase................	=22·48 per cent
Perthite..................	=22·00 " "
Nephelite.................	=21·78 " "
Fe-Mg constituents........	=13·00 " "
Sodalite..................	= 6·57 " "
Titanite..................	= 2·40 " "
Cancrinite................	= 1·24 " "
Magnetite.................	= 0·45 " "
	99·92 " "

Differentiates of the Nephelite Syenite.

The area in which rocks of the leucocratic type prevail, is not made up of nephelite syenite alone, but includes diverse types all closely related to the nephelite syenite. These types, differentiates from the nephelite syenite, will now be mentioned.

Foyaite.

The feldspar which is abundant in the normal type of nephelite syenite frequently has a sub-parallel arrangement, so that the rock shows a trachyoidal texture and is classed as a *foyaite*. In most cases this fluxional arrangement of the feldspar is visible in the field. It is best exposed on the ridge to the south of Sodalite valley; here the feldspar crystals, many of which are 1 inch long and twinned under the Carlsbad law, are arranged in an approximate east-west direction. Some of the rock when seen under the microscope is allotriomorphic granular, with a hiatal, porphyroid fabric. The porphyritic nature of this rock is sometimes seen in the field, when the feldspar or barkevikitic hornblende, frequently poikilitic, form the phenocrysts.

Ditroite.

The most common differentiate from the nephelite syenite is the rock in which sodalite becomes an essential mineral and may even predominate over the other constituents. This rock is classed a *ditroite*. In almost every occurrence the ditroites are found on or near the upper contact of the complex. The specific gravity of this rock type is 2·455. Since it is lighter than the normal nephelite syenite, which is 2·605 to 2·609, it occupies the uppermost part of the magma chamber. The sodalite occurs both as a mineral constituent of the rock and as veins of almost pure material. In the former case the rock has a beautiful blue colour, because the ditroites are usually coarsely crystalline. This rock type is valuable as a building or decorative stone; it takes an excellent polish and does not fade on exposure. The veins of sodalite vary from a fraction of an inch to 1½ inches in width. They cut the nephelite syenite and also extend as minute veinlets into the surrounding sediments.

The microscope shows that the sodalite in the ditroites and also in some of the nephelite syenites occurs sometimes as irregular grains, but more frequently as irregular veins interstitial to the other minerals in the rock. The sodalite appears to have had a pneumatolytic origin in those cases in which it is vein-like in the rock, but has crystallized out of a cooling magma when it appears as irregular grains and is an accessory constituent of the rock.

Iron-magnesium constituents are very subordinate in amount in the sodalite syenite. When present, ægirite is usually the dark coloured mineral. In one case a rock consists essentially of sodalite and ægirite, of which the former makes up nearly 70 per cent of the rock. Such a rock has been classified as a "tawite" by W. Ramsay; it occurs in the nephelite syenite mass of Kola, Finland.

Cancrinite Syenite.

A 6-inch boulder was found near the head of Ice River valley. It consists of deep blue sodalite and pale yellow cancrinite. This rock was not found in place, but it is believed to have come from a vein or vug in the sediments about the intrusive complex.

Hydronephelite Syenite.

Along the contact of the igneous rock with the sediments there is sometimes found a band of pink syenite. The zone has an irregular width of from a few inches to 6 feet. This rock is best exposed on the lower contact of the northwest arm in Garnet mountain, and again at various places along the upper contact of this same arm of the complex. It has also been found along fractures in the crystalline rock away from the contact, but such an occurrence is the exception.

The colour of this rock varies, and depends on the amount of nephelite present in the unaltered rock. A specimen from the upper contact is a nephelite syenite consisting essentially of perthitic feldspar, ægirite augite, and nephelite which frequently has a pink colour. These pink grains are made up of hydronephelite (ranite), which has been formed from the nephelite by hydration. The specific gravity of this rock is 2·576, while that of a specimen of this pink syenite from the lower contact in Garnet mountain is 2·578. In most cases the pinkish or reddish colour of the rock is intense and readily observable.

Microscopically, the minerals in the pink syenite are more or less altered. The feldspar is orthoclase or microperthite and has always a murky appearance, due to kaolinization and saussuritization. The pyroxene, also altered, is ægirite-augite with extinction up to 35 degrees. There is very little unaltered nephelite. It is replaced by a flaky aggregation of faintly doubly refracting hydronephelite. This mineral is the result of hydration of the nephelite, and since such a reaction would take place more readily along the contact or fractures in the rock, it is in such places that the hydronephelite-syenite is found. Barlow refers to a similar pink or pale-red rock which he calls a "biotite-ægirine-ijolite,"[1] but the amount of biotite is quite subordinate and in several cases is absent from the rock. Those masses which occur in the ijolites or melanocratic types might be called "hydronephelite-ijolites."

Miascite.

One rock agrees in mineral composition with miascite. It is a variation of the nephelite syenite, in which the feldspar is orthoclase and albite, sometimes as microperthite, accompanied by accessory nephelite, while the essential dark coloured constituent is biotite, making up about 20 per cent of the rock. About 4 per cent of the rock consists of a green, isotropic spinel which is probably hercynite ($FeO.\ Al_2O_3$).

Covite.

This rock has a light grey colour, and forms one of the leucocratic, irregular dyke-like apophyses from the nephelite syenite, cutting the melanocratic types. This rock when examined under the microscope is found to consist essentially of alkali-feldspar altered to sericite and kaolin, with nephelite in subordinate amount and altered to cancrinite.

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[1] Barlow, A. E., "Nepheline Rocks of Ice River, B. C.," Ottawa Naturalist, 1902, p. 73.

Borolanite.

This name was proposed by Horne and Teall[1] in 1892, for a special variety of nephelite syenite from Borolan, Scotland, in which orthoclase and melanite were the essential minerals. In the Ice River type the lime appears in sphene instead of in melanite. This type is represented by a nephelite syenite in which the feldspar is essentially orthoclase and is frequently intergrown with nephelite. Ægirite and sphene are accessories in the rock.

Hedrumite.

In those portions of the nephelite syenite area in which the magma cooled rapidly, the rock has an aplitic appearance. It is a fine grained or aphanitic, holocrystalline rock which consists essentially of orthoclase and albite-oligoclase intergrown as microperthite, with anorthoclase, sodalite, nephelite, and ægirite needles as accessories. This rock is characterized by a trachytoid texture. In one example there are a few grains of well-twinned feldspar which have been determined as Al 55—An 45. This type with increasing amounts of andesine present, grades into a theralite.

Theralite.

Only two specimens belong to this type. They occur in the lower contact zone of the laccolithic mass and consist essentially of sodic and sodicalcic feldspar, determined as Ab 70—An 30, green, pleochroic anhedra of ægirite-augite which are interstitial to the other minerals, and rounded grains of nephelite. All the light coloured minerals are rounded in outline.

Since there is a considerable amount of feldspar which is chiefly andesine in this rock, it agrees with the definition of theralite. Grains of andesine are sometimes surrounded by microperthite. There is an indistinct banding in one of these rocks but no cataclastic structure is shown under the microscope, so

[1] Horne, J. and Teall, J. J. H., Trans. Roy. Soc. of Edinburgh, Vol 37, Part 1, 1892, p. 171.

that the segregation of minerals in bands has taken place while the magma was quite viscous. Another rock has a foliated texture which gives it a gneissoid appearance. The feldspar has a sub-parallel arrangement; and a greenish or yellowish green basaltic hornblende replaces much of the pyroxene.

Laurvikite.

This is a spotted or gneissoid rock with a foliated texture which represents a (lower) contact phase of the nephelite syenite. It consists essentially of microperthite, composed of an intergrowth of what at first sight appears to be three feldspars. This is believed to be an intergrowth of microcline and albite. The gitter-structure of the microcline is well shown in the microperthite. Nephelite and the dark coloured constituents are accessory or are lacking in the rock.

Tönsbergite.

There is another rock in the contact facies of the nephelite syenite with the underlying sediment. On account of its high percentage of alkali feldspar and lack of or quite subordinate amount of nephelite, it corresponds to that group of very feldspathic syenitic rocks from Tönsberg, Norway, to which Brögger has given the name "Tönsbergite."[1]

This phase is transitional to the overlying nephelite syenite. It is a fine grained, leucocratic, holocrystalline, hypidiomorphic rock with a seriate fabric. This rock consists essentially of orthoclase and oligoclase determined as Ab 55—An 45. In one rock, feldspar makes up 75 per cent of the whole. The dark coloured constituents consist of faint-greenish, slightly pleochroic ægirite-augite that is frequently uralitized on the borders of the grains, also a smaller amount of greenish-brown hornblende, which sometimes has pyroxene poikilitically intergrown in it.

[1] Brögger, W. C., Die Eruptivgesteine des Kristianiagebietes, Vol. III, 1899, p. 328.

The accessories appear in small irregular grains and crystals and are, biotite, apatite, sphene, zircon, nephelite, and magnetite.

MESOCRATIC TYPES.

Distribution.

The rocks included under this second group are by no means as common as those which have been described under the first group. The urtites and ijolites have been separated from the more marked melanocratic rock of the third group which contains only accessory or no light coloured constituents. The rocks of this group represent the midway product of differentiation in the complex, between the most alkaline end of the series, represented by the nephelite syenites, and the least alkaline or femic end of the series represented by the jacupirangite. In order to bring out this feature, use has been made of the term "mesocratic type," given by M. A. Lacroix to that group of rocks in the Madagascar alkaline series which contain about equal amounts of light and dark coloured constituents. In the rocks of this second group there are several variation facies which cannot really be called mesocratic rocks. The rock which has been taken as the ijolite type is mesocratic in its mineral composition.

The rocks of the second group are in general very irregularly distributed throughout the northern half of the laccolithic mass. The best development of these rocks is seen in the northwest arm of the complex. They constitute most of this sill-like projection as far as the ridge which connects Garnet mountain with the Chancellor Peak ridge, near Butwell peak. Beyond this point, to the end of the sill in Chancellor peak, the igneous rock is almost entirely lacking in light coloured minerals, and is, therefore, included under the third group.

We have seen in an earlier part of this paper that the top of Zinc mountain is made up of nephelite syenite. In this normal leucocratic rock the feldspar is gradually replaced by nephelite and the rock passes into an ijolite, while at several localities on the floor of this north sill-like extension of the complex, the rock is much more basic, with a very subordinate amount of light coloured minerals. At this point in Zinc mountain, is shown to best advantage the diverse types that have separated from a heterogeneous magma by an adjustment of the minerals by gravitational force.

In the "Moose Creek extension" of the complex, which lies between Helmet mountain and Mt. Sharp, there are ijolites and other transitional types. These occur in irregular patches and intimately associated with the jacupirangite.

Macroscopic Characters.

The rocks in this group vary in colour from a spotted, white and black rock with equal amounts of light and dark coloured constituents, to one which appears very dark, largely due to a darkening of the salic minerals.

In texture they range from a fine grained, phanerocrystalline rock to coarse grained, porphyritic and pegmatitic types; in mineral composition from a rock with equal amounts of nephelite and pyroxene, as seen in the ijolites, or with the nephelite predominant as in the urtites, to other rocks which frequently contain amphibole, biotite, sphene, magnetite, ilmenite or schorlomite as essential constituents.

Some of the characteristic features of the porphyritic and pegmatitic rocks will be mentioned here.

The urtites are usually very coarsely crystalline and are much less abundant than the ijolites. A photograph (Plate XVII, A) shows a polished surface of an urtite. It consists of nephelite and ægirite; the former makes up about 70 per cent of the rock. Some of the ægirite needles are 3 inches long and ¼ inch wide.

There is a porphyritic ijolite, in which some of the poikoicrysts of amphibole are ½ inch in diameter. These large crystals are black and glossy on the cleavage fracture; they are barkevikite as determined by the microscope.

The very coarsely crystalline or pegmatitic varieties are more abundant. One of these rocks appears black since it consists of pyroxene, magnetite, biotite, and a very dark-coloured nephelite whose colour is due to the presence of numerous minute inclusions. Biotite frequently forms crystals 1 inch in diameter, but a few were noted which were 4 inches in diameter. Another rock consists largely of crystals of barkevikite hornblende and nephelite, averaging nearly ½ inch in diameter. Both of these minerals contain numerous minute crystals of pyroxene and much larger idiomorphic crystals of sphene. In one place the rock consists of large idiomorphic grains of greenish nephelite, pyroxene, and black glossy schorlomite. Titanite and calcite crystals are frequently associated with the latter.

Microscopic Characters.

The essential minerals in the rocks of this group are few. Nephelite and pyroxene are present in all the rocks, while amphibole and biotite are common. Sphene, magnetite, and ilmenite are present in nearly all of them, but seldom become essential constituents. The accessories which appear in small grains or well formed crystals are apatite, schorlomite, melanite, zircon, calcite, sodalite, cancrinite, corundum, feldspar, rosenbuschite, and mosandrite.

The nephelite almost always appears with a cubical or polygonal outline and frequently encloses numerous needles of ægirite, apatite, and sometimes rosenbuschite. The angular outline of the nephelite is more evident in those rocks which contain the largest amount of this mineral. It had begun to crystallize earlier than the other essential minerals.

Pyroxene is represented by ægirite or ægirite-augite and a faint greenish variety which is characteristic of many of the less alkaline rocks. Another variety is a pinkish, pleochroic pyroxene which corresponds to a rhombic variety but which has inclined extinction. An analysis has been made of this pyroxene and the results will be given later in this paper.

A noteworthy feature of many of the rocks of the second and third groups is the presence of accessory calcite which forms angular grains interstitial to the other minerals and is not associated with secondary alteration products. This calcite is believed to be of primary origin although possibly formed late in the process of crystallization.

Urtite.

The urtite type is shown in Plate XVII, A. Nephelite makes up 60 to 70 per cent of the rock; it occurs in large subhedral grains 5-7 mm in diameter and free from inclusions. The pyroxene is a faint greenish, non-pleochroic variety, with euhedral outline in the prismatic sections and with a maximum extinction of 33 degrees. Biotite is present in some of these nephelite-rich rocks and is often poikilitic to the pyroxene. Calcite is accessory, but since it appears in angular grains interstitial to the other constituents, and in many cases is not associated with alteration products, it would seem to be of primary origin, or at least of later origin than the other constituents, but not secondary. Other accessories present are sphene, melanite, corundum, schorlomite, iron-ores, and a few grains of a mineral with high index and low double refraction uniaxial, and optically positive. This agrees with the properties of that complex silicate, mosandrite.

A Rosiwal measurement of an urtite gave:—

Nephelite	52·50 per cent.
Pyroxene	20·90 " "
Schorlomite	14·40 " "
Sodalite and haüynite	6·10 " "
Calcite	1·90 " "
Sphene	1·56 " "
Cancrinite	0·60 " "
Iron ore	2·00 " "
	99·96 " "

Ijolite.

There are several varieties of this rare type of rock represented in the Ice River complex. The name ijolite was proposed by Ramsay and Berghell[1] in 1891, for a group of granitoid nephelite rocks exposed on Iijoki river, Finland. So far as the writer is aware this rock is known to occur at only four locali-

[1] Geol. Foren Gorhandl, Stockholm, 1891, Bd. 13, pp. 300-312.

ties, Mt. Iiwaara in Finland[1]; Kaljokthal in Kola peninsula[2]; Nosy bé in northeastern Madagascar,[3] and Magnet cove in Arkansas.[4]

The normal type of ijolite consists essentially of nephelite, pyroxene, and amphibole. Plate XVIII, A, shows the megascopic appearance of a polished specimen of the ijolite. The light and dark coloured constituents are about equal in amount, but in other varieties of this rock the ferro-magnesian minerals make up a larger proportion of the rock. In this respect the Ice River types differ from the occurrences of Kola peninsula and Magnet cove, but are similar to those of Madagascar.

The nephelite in the rock appears in polygonal, frequently equant anhedral forms, sometimes enclosing numerous minute needles of ægirite or apatite; in other cases free from inclusions. Alteration is not a common feature, but cancrinite, thomsonite, hydronephelite, or gieseckite may be present. Nephelite was one of the earliest minerals to begin to crystallize.

Pyroxene is represented by several varieties. Besides ægirite and ægirite-augite, there is a faint greenish variety which is slightly pleochroic. The absorption is determined as $\mathbf{a}$ = grey to colourless, $\mathbf{b}$ = pinkish, and $\mathbf{c}$ = faint reddish pink which gives $\mathbf{c} > \mathbf{b} > \mathfrak{a}$, maximum extinction is 32 degrees to 38 degrees. A chemical analysis of this mineral is given in the chapter on the mineralogy of the rocks.

The Ice River ijolite is an important and special variety, since barkevikite replaces in part the pyroxene of such occurrences as at Kola peninsula and Magnet cove. In this respect this rock is again similar to that of Madagascar. Barkevikite frequently occurs as large poikilitic crystals; in most cases it shows evidence of being a late mineral to crystallize. It is noteworthy that although barkevikite is the essential hornblende in the ijolites and urtites yet we have seen that basaltic hornblende was more abundant in the nephelite syenites. Barkevikite shows strong absorption from light brown, light

[1] Rosenbusch, Elem. Gesteinlehre, 1910, p. 210.
[2] Rosenbusch, Elem. Gesteinlehre, 1910, p. 210.
[3] Lacroix, A. C., Nouvelles Archives du Mus. 4 serie, Tome 5, 1903.
[4] Washington, H. S., Bull. G. S. A., Vol. 11, 1900, p. 399.

yellowish brown to deep brown which has been determined as **b** > **c** > a.

Basaltic hornblende is also present in certain types; it is strongly pleochroic with **c** > **b** > a. The presence of amphibole would give a new variety of ijolites for which Barlow has suggested the name "hornblende (barkevikite) ijolites."[1]

A Rosiwal measurement made on one of the melanocratic ijolites gave:—

Pyroxene	36·58	per cent.
Hornblende	16·25	" "
Nephelite	40·25	" "
Iron ore	3·58	" "
Apatite	1·50	" "
Titanite	1·08	" "
Alteration	0·66	" "
	99·90	" "

Feldspar, which is absent from the European and Madagascar occurrences, is present as an accessory in some of the Ice River rocks. Sphene is a common accessory, but, when absent, the TO_2 appears in ilmenite. Calcite is accessory in amount but appears to be a late primary mineral. There is a common association of sphene and calcite; when together the latter is interstitial to the sphene. This suggests that calcite represents an excess of CaO above that required for titanite. Apatite is sometimes abundant in euhedral grains, while schorlomite and melanite are accessories in the more basic varieties. The former is readily observable in the field but the melanite is not.

The following chemical analysis was made by Mr. M. F. Connor in the laboratory of the Mines Branch, Department of Mines, Ottawa. The result of this analysis is given in column No. 1 of the table and with it are given those from other occurrences for the purpose of comparison.

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[1] Barlow, A. E., "Nepheline Rocks of Ice River, B. C.," Ottawa Naturalist, 1902, p. 73.

	1	[1]	[2]	[3]	[3]	[4]	[5]
SiO_2	41·66	39·25	41·75	42·79	46·63	40·10	43·63
Al_2O_3	22·75	16·01	17·09	19·89	15·03	15·50	19·54
Fe_2O_3	2·33	4·31	6·35	4·39	5·91	6·35	3·77
FeO	6·08	9·64	3·41	2·33	5·09	7·29	3·88
MgO	3·11	4·24	4·71	1·87	3·47	8·41	2·94
CaO	7·76	13·42	14·57	11·76	11·23	12·40	9·89
Na_2O	8·81	4·92	6·17	9·31	8·16	3·37	10·58
K_2O	3·12	2·26	3·98	1·67	1·96	1·67	2·26
$H_2O(-)$	0·03	0·80	0·28	0·99	0·35	0·87	0·86
$H_2O(+)$	1·50		0·62				
CO_2	0·40	....	....	....	....	....	....
TiO_2	1·95	4·02	0·58	1·70	1·12	2·98	1·07
P_2O_5	0·10	0·90	0·09	1·70	....	1·28	1·54
MnO	0·14	0·35	tr.	0·41	tr.	....	0·16
Cl	0·02						
SO_3	0·045						
S	0·03						
*S	0·05						
	99·88	100·12	100·60	98·81	99·57	100·22	
Spec. Gr.	2·892					3·15	

*Evolved by HCl (possibly from Lazurite).

1. Ijolite, Ice river, British Columbia.
2. " " " " " [1]
3. " Magnet cove, Arkansas, U.S.A.[2]
4. " Mt. Iiwaara, Finland. ([3])
5. " Kaljokthal, Umptek, Kola peninsula.[3]
6. " (Bekinkinite) d'Ampasibitika; N.W. Madagascar.[4]
7. " Average composition from 5 analyses.[5]

[1]A. E. Barlow, Ottawa Naturalist, 1902, p. 75.
[2]H. S. Washington, Bull. G.S.A. Vol 11, 1900, p. 399.
[3]H. Rosenbusch, Elem. Gesteinlihre, 1910, p. 210.
[4]M. A. Lacroix, Naur. Arch. du Mus., 4 serie, Tome I, 1902.
[5]R. A. Daly "Average Chemical Composition of Igneous-Rock Types," Proc. Amer. Acad. of Arts and Sci., Vol. 45, No. 7, 1910, p. 229.

Following the methods of the quantitative classification of Cross, Iddings, Pirsson, and Washington, the norm of the rock was calculated. This is as follows:—

Orthoclase	1·11	per cent.
Leucite	13·52	" "
Nephelite	40·33	" "
Anorthite	13·34	" "
Diopside	17·78	" "
Olivine	3·97	" "
Magnetite	3·25	" "
Ilmenite	3·65	" "
Apatite	0·93	" "
Calcite	0·90	" "
	98·58	

This gives the rock the following position in the quantitative classification:—

$$\frac{\text{Sal}}{\text{Fem}} = \frac{2\cdot 3}{1} < \frac{7}{1} > \frac{5}{3} = \text{Class II—Dosalane (near Salfemane)}$$

$$\frac{F}{L} = \frac{3\cdot 73}{1} < \frac{7}{1} > \frac{5}{3} = \text{Order 8—Campanare.}$$

$$\frac{Na_2O+K_2O}{CaO} = \frac{1\cdot 54}{1} < \frac{5}{3} > \frac{3}{5} = \text{Rang 3—(Alkalicalcic).}$$

$$\frac{K_2O}{Na_2O} = \frac{1}{0\cdot 35} < \frac{5}{3} > \frac{3}{5} = \text{Sub-Rang—(Sodipotassic).}$$

No names have yet been given to the rang and sub-rang of this rock, but the writer does not wish to add new names without having another analysis made of a similar rock.

The mode, or actual mineralogical composition of the rock is quite different from the norm. It was calculated from two Rosiwal measurements and is as follows:—

Nephelite	48·00	per	cent.
Sodalite	5·33	"	"
Hydronephelite	3·80	"	"
Cancrinite	0·91	"	"
Feldspar	7·71	"	"
Hornblende (barkevikite)	14·67	"	"
Pyroxene	14·67	"	"
Titanite	3·21	"	"
Apatite	1·30	"	"
Iron	0·30	"	"
	99·95	"	"

MELANOCRATIC TYPES.

Distribution.

The rocks which are included in this group have a limited distribution. The map shows that these femic or ultra-femic rocks occur in the most northerly thin edges of the laccolith. They are exposed in the northwest arm of the complex between Garnet mountain and Chancellor peak; along the floor of the laccolith on the ridge between Mt. Mollison and Sentry peak; and in that part of the mass at the northeast of Moose Creek valley. At other points within the complex irregular patches are found.

In general it nay be said that these melanocratic rocks are found in the northwest arm from the main mass where the magma cooled before differentiation was completed, and are especially abundant along that part of the floor which is exposed in the north and east sides of the complex. Here the most extreme differentiate occurs, and it is one which has separated from a magma by the force of gravity.

Macroscopic Characters.

This group includes all those melanocratic rock types in which the light coloured constituents are accessory or lacking. The most common variety within the group belongs to a rather rare type of rock, for which the name *Jacupirangite* has been proposed by Derby,[1] and applied to a certain femic rock type occurring in a nephelite-bearing series in Brazil. The jacupirangite is a subdivision of a pyroxenite.

In the Ice River series the jacupirangite consists essentially of pyroxene, magnetite or ilmenite, and sphene. The texture of the rock is coarse grained, and the colour black. In some phases of this group, pyroxene makes up almost the entire rock. Irregular patches or schlieren of pegmatite give large crystals of pyroxene, amphibole, or biotite. On the ridge between Mt. Mollison and Zinc mountain one of these schlieren contains large subhedral crystals of a brown hornblende; the largest observed was 4 inches long. There is a similar patch of green pyroxene in the northwest arm above Garnet mountain. A fragment 3 inches in diameter of a single crystal was obtained which is greenish black and shiny, but greenish when crushed. This crystal shows a perfect basal parting. When seen under the microscope crushed fragments show a slight pleochroism; greenish to yellowish, with a maximum extinction of 42 degrees. It appears to be hedenbergite.

At the head of Zinc valley several small segregations were found which weather out in a bomb-like form. These bomb-shaped masses are frequently 3 to 5 inches in diameter. The specific gravity of one of these is 2·919. It is made up largely of biotite, but the crushed fragments show abundant magnetite, some pyroxene, nephelite, and feldspar, besides the biotite. These patches represent segregations which have a spherical form. The exfoliation of these bomb-shaped masses on weathering is caused by the abundant small mica flakes. Another basic schlieren has a specific gravity of 3·146 and consists of large subhedra of hornblende, 1 to 2 cm in diameter, in a matrix of

[1] Derby, O. A., "Magnetite Ore Districts of Jacupiranga, Brazil." A.J.S., Vol. 41, April 1891, p. 314.

nephelite, schorlomite, sphene, olivine, and iron ore. The rock may be classed as a hornblendite or a cortlandite.

Microscopic Characters.

Like the rocks of the second group, the jacupirangite and its associates vary greatly in texture but only slightly in mineralogical composition. The essential minerals are pyroxene, magnetite, ilmenite, and sphene, but of these the first is most abundant. The accessories are sometimes very rare, but frequently form euhedral crystals or subhedral grains. Some of those determined are nephelite, apatite, melanite, schorlomite, corundum, perovskite, and biotite. Calcite, cancrinite, and leucoxene are the chief secondary minerals. The densities of two of these jacupirangites are 3·380 and 3·471.

The essential pyroxenic mineral is a new variety; it has a faint pinkish to greyish colour in thin sections, and is slightly pleochroic. It occurs frequently as euhedral or subhedral grains. It corresponds in many respects to hypersthene, but has a maximum inclined extinction on $c \wedge \mathbf{a}$ of -38 degrees. The optical characters of this rock are given under the mineralogy of the series on a later page. Titaniferous augite and ægirite-augite are also represented.

A Rosiwal determination of a jacupirangite gave:—

Pyroxene	74·28 per cent.
Magnetite	14·95 " "
Nephelite	9·13 " "
	98·36 " "

The minerals are usually quite fresh in these rocks, although the pyroxene grains sometimes have a greenish edge of uralite, or the ilmenite may have a border of leucoxene. Anhedra and minute crystals of magnetite and ilmenite are sometimes quite abundant. In many cases the iron is interstitial to the pyroxene. Nephelite is a rare accessory and is frequently absent. Euhedra of apatite are often present, and in one rock make up 5 per cent of the constituents. Corundum, melanite, schorlomite, perovskite, and olivine are all rare accessories.

One rock contains a few deep reddish, rounded grains which correspond to spessartine.

Euhedra of honey-yellow sphene are abundant, and in some rocks it is an essential mineral. This mineral sometimes appears in crystals ½ inch long and ¼ inch wide, which gives the rock a very striking appearance.

A Rosiwal determination of one of these rocks gave the following results:—

Pyroxene	65	per cent.
Sphene	15	" "
Melanite	5	" "
Iron ore	5	" "
Accessories	10	" "

Another rock contains over 20 per cent sphene. In order to distinguish those rocks rich in sphene from the so-called jacupirangites or pyroxenites, the name "*sphenitite*" is suggested.

DESCRIPTION OF DYKE ROCKS.

It is a noteworthy feature that there is a remarkable absence of dykes connected with this alkaline igneous body. Only twelve have been noted in the field, the widest is 10 feet. In general it may be said that most of them show an east-northeast-west-southwest trend, which is nearly transverse to the axis of folding and shearing. They are all later than the laccolithic intrusion and are all genetically connected with this mass. They may be divided into two groups for convenience of description. These are:—

(1) Bostonite-tinguaite group.

(2) Lamprophyre group.

Bostonite-Tinguaite Series.

A *Bostonite* dyke, 2 to 3 feet wide, cuts vertically through the limestone in the cover of the laccolith. It is a light grey, almost white, aphanitic rock, with a few larger tabular crystals of feldspar. The microscope shows it to consist of a few phenocrysts of perthitic feldspar in a matrix of lath-shaped feldspar crystals, arranged sub-parallel, so that the rock has a trachytic structure.

Tinguaite.—There are two of these dykes, 8 feet and 6 feet respectively, in width. One of these north of Mt. Mollison shows euhedral crystals of ægirite-augite and a pinkish pleochroic variety of pyroxene, in a matrix of microperthite. Hornblende, nephelite, and sphene are accessories.

Phonolite (amphibole-tinguaite).—This dyke is 10 feet wide, runs N. 25° E., and is exposed on the west side of Ice River valley. It consists of alcalic feldspar, nephelite and euhedra of basaltic hornblende and greenish pyroxene. Some of the latter are zonal with augite in centre, ægirite-augite about this centre, and a narrow border of ægirite. Minute apatite euhedra are abundant.

Lamprophyre Series.

Minette.—The occurrence of this rock has the form of an interformational sheet 5 to 7 feet wide. It lies between the Ottertail limestone and the Goodsir formation, and has a strike of S. 65° E. It is a dark grey, fine grained rock, which under the microscope is seen to consist essentially of biotite flakes, some of which are ¾ inch in diameter, feldspar, and secondary calcite. The feldspar is orthoclase.

Vogesite.—This dyke is 3 feet wide and runs almost along the strike of the limestone which it cuts; this trend is N. 65° W. It is a fine grained, almost aphanitic, greenish rock with a few grains of pyrite in it. It consists essentially of pyroxene and hornblende in about equal amounts, in a matrix of untwinned feldspar. Alteration is strongly marked by the presence of muscovite, epidote, and a deep blue chlorite, penninite.

Monchiquite.—A single dyke, 10 feet wide, with strike N. 65° E., cuts the ijolite and overlying sediments in Butwell peak. It is a fine grained, black dyke in which pyroxene and biotite are observable. The microscope shows large, faint greenish subhedra of augite which are often bordered by a darker or lighter coloured band. Deep brown flakes of mica are abundant, as well as several euhedra of strongly pleochroic, brown barkevikitic hornblende. The matrix is feldspar and a colourless isotropic base which may be glass. Small cubes and angular grains of iron ore and small rounded grains of olivine altered to serpentine and magnetite form the accessories.

Fourchite.—A dark grey, cryptocrystalline dyke, 3 feet wide, cuts the upper part of the laccolith. Small phenocrysts of feldspar with angular outline, but kaolinized, are visible megascopically. The microscope shows brown hornblende, greenish ægirite, and abundant rounded grains of pink pleochroic pyroxene which resembles hypersthene but has an inclined extinction. Accessories are perovskite, sphene, apatite, pyrite, and an isotropic colourless base.

Ouachitite.—This dyke is 8 feet wide and has a strike of N. 70° E. It is a fourchite rich in biotite; this mineral makes up 40 per cent of the rock. Hornblende, diopside, nephelite, and feldspar are less abundant. There is a considerable amount of colourless isotropic material interstitial to the other minerals and which is analcite or sodalite. There are many brown irregular subhedra of melanite.

Camptonite.—A fine grained, dark grey cryptocrystalline dyke with small phenocrysts of hornblende, and white patches which are pseudomorphs of feldspar. The matrix consists of feldspar, nephelite, cancrinite, apatite, biotite, muscovite, and zoisite.

Nephelite-basalt.—This dyke, 6 inches to 1 foot wide, cuts the ijolite on the west side of Ice River valley. The rock is porphyritic with a hiatal fabric. Phenocrysts of pyroxene and olivine occur in a fine grained, black matrix of pyroxene, biotite, and nephelite. The accessory minerals are magnetite and sodalite, or analcite. The rock is altered to cancrinite, muscovite, uralite, clinochlore, and pectolite.

VEINS AND DRUSY SEGREGATIONS.

These are not numerous but may be noted on account of the variety of vein-filling material which they contain. The veins are formed along fissures in the igneous rock and are seldom more than 8 inches wide. One of these veins is filled with pure white cancrinite while another contains sodalite. These minerals are pneumatolytically connected with the igneous rock, and represent an after-effect of intrusion. Actinolite in radiating patches with calcite and hydronephelite, and also a drusy pinkish rock with abundant calcite, nephelite, hydronephelite, cancrinite, and zeolitic material, in which pectolite and thomsonite have been determined, form other veins in the igneous rock. A large vein is made up essentially of wollastonite and calcite, but it does not seem to extend very far.

There is a vein at the head of Moose Creek valley, cutting the melanocratic rocks, about 2 feet wide and consisting of white calcite with numerous well formed crystals of biotite. A vein of serpentine was found in another part of the laccolith. Well developed crystals and bunches of crystals have been found in vugs in the igneous rock; of these may be mentioned pectolite, thomsonite, natrolite, black mica (probably lepidomelane), phillipsite, tremolite, and scapolite.

A green mica, anomite, was found in a vein in the limestones of Porcupine creek.

Some of the veins outside of the igneous body have been enriched with ore-bearing solutions which have deposited sulphides of lead, zinc, copper, iron, and silver. The gangue in a few cases is quartz, and in one place calcite and fluorite. On the dividing ridge to the north of Dennis pass, the limestones contain several drusy veins in which were found well-formed quartz crystals.

CHAPTER XI.

MINERALOGY.

The following minerals have been determined from the Ice River igneous, metamorphic, and sedimentary rocks:—

Nephelite.	Forsterite.	Pectolite.
Sodalite.	Brucite.	Actinolite.
Cancrinite.	Epidote.	Tremolite.
Hydronephelite.	Piedmontite.	Hercynite (Spinel).
Feldspar.	Zoisite.	Periclase (MgO).
Pyroxene.	Clinozoisite.	Disthene (Al_2SiO_5).
Amphibole.	Chlorite.	Gieseckite.
Biotite.	Penninite.	Rosenbuschite.
Muscovite.	Clinochlore.	Fluorite.
Anomite.	Prochlorite.	Serpentine.
Calcite.	Zeolite.	Perovskite ($CaTiO_3$).
Sphene.	Thomsonite.	Ilmenite ($FeTiO_3$).
Garnet.	Phillipsite.	Leucoxene.
Schorlomite.	Laumontite.	Magnetite.
Apatite.	Analcite.	Pyrite.
Corundum.	Noselite.	Galena.
Zircon.	Natrolite.	Sphalerite.
Baddeleyite(ZrO_2)	Vesuvianite.	Chalcopyrite.
Scapolite.	Wollastonite.	
Olivine.	Quartz.	

The following tables give a list of the minerals that have been determined in the various groups of igneous rocks in the Ice River complex, also those in the dykes, veins, and sediments:

Nephelite Syenite and Associated Types.

Ægirite.	Andesine.	Barkevikite.
Ægirite-augite.	Anorthoclase.	Basaltic hornblende.
Albite.	Apatite.	
Albite-oligoclase.	Arfvedsonite.	Biotite.
Almandine.	Astrophyllite?	Calcite.

Cancrinite.
Corundum.
Diopside.
Disthene.
Epidote.
Fluorite.
Gieseckite.
Hercynite.
Hornblende.
Hydronephelite.
Ilmenite.
Laumontite.
Microcline.
Microperthite.
Magnetite.
Melanite.
Nephelite.
Noselite.
Orthoclase.
Orthoclase-albite.
Perovskite.
Piedmontite.
Pyrite.
Pyroxene.
Rosenbuschite.
Sodalite.
Thomsonite.
Zircon.
Zoisite.

Ijolite, Urtite, and Associated Types.

Ægirite.
Ægirite-augite.
Analcite.
Apatite.
Barkevikite.
Basaltic hornblende.
Biotite.
Calcite.
Cancrinite.
Clinohypersthene.
Corundum.
Feldspar.
Hydronephelite.
Ilmenite.
Leucoxene.
Magnetite.
Melanite.
Nephelite.
Poikilitic hornblende.
Rosenbuschite.
Schorlomite.
Sodalite.
Sphene.
Thomsonite.
Ti-augite.
Zircon.

Jacupirangite and Other Melanocratic Types.

Ægirite-augite.
Analcite.
Apatite.
Augite.
Barkevikite.
Biotite.
Calcite.
Cancrinite.
Corundum.
Clinohypersthene.
Ilmenite.
Leucoxene.
Magnetite.
Melanite.
Nephelite.
Olivine.
Perovskite.
Schorlomite.
Spessartine?
Sphene.
Uralite.
Zircon.

Dykes.

Ægirite.
Albite.
Alkali-feldspar.
Analcite.
Apatite.
Augite.
Barkevikite.
Biotite.
Calcite.
Cancrinite.
Diopside.
Epidote.
Hornblende.
Magnetite.
Microperthite.
Melanite.
Muscovite.
Nephelite.

Olivine.	Prochlorite.	Zircon.
Pectolite.	Sodalite.	Zoisite.
Penninite.	Sphene.	

Veins.

Actinolite.	Diopside.	Phillipsite.
Anomite.	Glossular garnet.	Prochlorite.
Biotite.	Hydronephelite.	Scapolite.
Calcite.	Muscovite.	Serpentine.
Cancrinite.	Natrolite.	Tremolite.
Clinochlor.	Pectolite.	Wollastonite.
Clinozoisite.	Periclase.	

Sediments and Hornfels.

Ægirite-augite.	Forsterite.	Sodalite.
Analcite.	Garnet.	Sphalerite.
Arfvedsonite.	Magnetite.	Sphene.
Baddeleyite?	Meionite.	Tremolite.
Biotite.	Muscovite.	Vesuvianite.
Brucite.	Nephelite.	Wollastonite.
Calcite.	Penninite.	Zircon.
Cancrinite.	Periclase.	Zoisite.
Clinozoisite.	Perovskite.	
Diopside.	Pyrite.	
Epidote.	Quartz.	
Feldspar.	Scapolite.	

NEPHELITE ($NaAlSiO_4$).—This mineral occurs as an essential, an accessory, or an exceedingly rare constituent in all the rock types in the Ice River complex. The colour varies from almost transparent and vitreous to white, grey, or more commonly greenish, with an oily surface. It sometimes has a pinkish appearance especially when it is altered to hydronephelite. It is frequently very hard to distinguish from feldspar, but is always readily determined by a chemical or microchemical test. This mineral tends to form euhedral or subhedral grains;

this habit is frequently quite noticeable in the field. It breaks with a sub-conchoidal or uneven fracture, but under the microscope often shows one fairly good cleavage. It is usually readily determined from feldspar by its remarkable freshness in most of the rocks, which is a noteworthy characteristic of the mineral in all of the rock types. When it is an essential constituent of the rock, as it is in the urtites and ijolites, it was the first or one of the first minerals to begin to crystallize, and has a rectangular or polygonal outline, but when it is an accessory constituent of the rock as in the nephelite syenite, the feldspar began to crystallize out earlier.

In some of the pegmatitic phases, crystals of nephelite 1½ inches in diameter have been found. It has a hardness about 6·0, fuses readily before the blowpipe to a colourless glass, and the powder dissolves quickly in warm HCl, giving a faint greenish coloured jelly. The specific gravity of the mineral is 2·604; this is considerably lower than that of artificial nephelite, which Dr. Bowen[1] has found to be 2·619. A chemical analysis of an ijolite given on a preceding page, in which nephelite is the essential light coloured mineral, gave 3·12 per cent K_2O. As there is no feldspar visible in the thin sections examined, the potash is probably combined with the nephelite.

The most common alteration products of nephelite are cancrinite and hydronephelite. With an increase in the amount of these decomposition products, the mineral becomes pinkish and even reddish in colour, representing in the case of the latter a complete hydration of the nephelite. The alteration usually begins around the edges of the grain and along the cleavage planes. Other grains show a turbid appearance, due to incipient alteration to a mineral showing rather brilliant aggregate polarization, determined as gieseckite. Other alteration products are thomsonite and seldom sodalite.

Nephelite grains frequently contain minute inclusions, often microlite-like in size. These needles are usually ægirite, or sometimes apatite, but other needles have been determined as a complex silicate, rosenbuschite (Plates XVIII, B, and XIX, A).

[1]Bowen, N. L., "Composition of Nephelite," A.J.S., Vol. 33, 1912, p. 49.

SODALITE.—This mineral occurs especially in those rocks near the roof of the laccolith, as stated before. It becomes an essential mineral in the ditroite or sodalite syenite. It occurs both as a mineral constituent of the rock and as veins of almost pure material. It is principally associated with the upper contact of the igneous rock and represents the extreme product of differentiation, but it has also been found in irregular veinlike patches or vugs of pegmatite.

This mineral has a beautiful blue colour, varying from deep to very light shades and is sometimes almost white. It takes an excellent polish and has a handsome appearance in jewelry. Some of this material has been exposed to the light for two years and it does not show any sign of fading. When it occurs as a mineral constituent of the ditroite, the rock becomes important as a decorative stone, especially for inside ornamentation, since it would readily weather when exposed to the atmosphere, as it has a hardness of a little over 5. The veins of sodalite vary from a fraction of an inch to 2 inches in width. They cut both the ditroite and nephelite syenite and frequently show a subparallel arrangement. Pyrite and sometimes cancrinite are associated with the sodalite, which, although detrimental to the rock for outside use, does not diminish its economic value for inside decorative purposes. The presence of these minerals gives the sodalite a rather brownish shade which adds to its peculiar appearance. A boulder, 6 inches in diameter, found near the head of Ice River valley, consisted almost entirely of blue sodalite and honey-yellow cancrinite. This boulder, since it could not have been derived from any part of the complex now exposed, suggests that veins of this material cut the sediments at the head of Ice River valley not directly in contact with the igneous rock. Minute veinlets or stringers of sodalite are found along joints or fractures in the overlying sediments, several yards from the contact.

Microscopically, this mineral occurs both as irregular rounded grains and more frequently as an interstitial filling about the other grains. It is common to find these grains enclosing numerous minute, doubly refracting inclusions which are sometimes more or less zonally arranged. The mineral is in most cases of pneumatolytic origin, and represents the final residue of the cooling magma. It is sometimes difficult to distinguish sodalite from nephelite even under polarized light. Sodalite can, however, be readily distinguished from basal sections of nephelite by Lemberg's microchemical test,[1] in which a dilute silver nitrate solution is applied to an uncovered portion of the rock section. The grains of sodalite will become coated with white silver chloride, while the nephelite grains are not affected by the acid solution. Fluorite closely resembles sodalite but has a lower index of refraction.

An analysis was made of this mineral from Ice river by Dr. Harrington. It is quite similar to sodalite found in the nephelite syenite of Mt. Royal. The formula of the sodalite as derived from these analyses is $3Na_3O$, Al_2O_2, $2SiO_2$, NaCl. The following analyses of the sodalite from these two localities[2], and also that from Dungannon, Ontario,[3] have been made by Harrington; with these is given for comparison that of the sodalite which occurs in Litchfieldite from Litchfield, Maine.[4]

	Ice river.	Montreal.	Dungannon.	Litchfield.
SiO_2	37·52	37·50	36·58	37·33
Al_2O_3	31·38	31·82	31·05	31·87
Fe_2O_3	.....	0·01	.....	.....
FeO	.....	.....	0·20	.....
CaO	0·35	.....	.....	.....
MgO	.....	.....	.....	.....
Na_2O	19·12	19·34	.....	24·56
Na_2O_3	.....	.....	24·81	.....
Na	4·48	4·61	.....	....
K_2O	0·78	0·27	0·79	0·10
C1	6·91	7·12	6·88	6·83
SO_3	.....	.....	0·12	.....
H_2O	.....	.....	0·27	1·07
Insoluble	.....	.....	0·80	.....
	100·54	100·67	101·50	100·22
Sp. gravity	2·220	2·293	2·295	

[1]Lemberg, J., Zeits, d, d Geol. Gesell, Vol. 42, 1890, p. 738.
[2]Harrington, B. J., Trans. Roy. Soc. Canada, Vol. 4, Sec. III, 1886, p. 81.
[3]Harrington, B. J., Am. Jour. Sc., Vol. 48, 1894, p. 17.
[4]Bayley, W. S., Bull. G.S.A., Vol. 3, 1892, p. 240.

J. Morozewicz[1] produced sodalite artificially, by purely pyrochemical methods. He fused kaolin with sodium carbonate and sodium chloride at about 650° C., and got a mineral with the composition of sodalite. By fusing nephelite with soda and an excess of NaCl he also obtained sodalite richer in chlorine. From these experiments he concludes that two kinds of sodalite exist with the following formulae:—

$$2(NaAl_2\ SiO) + NaCl.$$

$$3(NaAl_2\ SiO) + 2\ NaCl.$$

Sodalite has been produced artificially from several different fusions. Some of these experiments are noted by F. W. Clarke.[2] Lemberg[3] produced sodalite from a fusion of nephelite and common salt.

Professor Bonney[4] has examined specimens of the sodalite syenite from Ice river, which were collected by Mr. E. Whymper in 1901.

He found that this rock consisted essentially of sodalite, nephelite, and albite. In order to explain how the sodalite was formed, he analysed these three minerals. The results are as follows:—

	Sodalite.	Nephelite.	Albite.
SiO_2	37·2	44·0	68·7
Al_2O_3	31·6	33·2	19·5
Na_2O	25·6	15·1	11·8
K_2O	....	7·7	....
Cl	7·3	....	....
Total	101·70	100·00	100·00

[1]Jour. Chem. Soc., Vol. 76, Part 2, 1899, p. 764: or T.M.P.M., Vol. 18, 1898, pp. 128-147.

[2]Data of Geochemistry, U.S.G.S., Bull. 491, 1911, p. 356.

[3]Zeitschrift Deutsch. Geol. Gesell., Vol. 28, 1876, p. 602.

[4]Bonney, Prof. T. G., "On a Sodalite Syenite (Ditroite) from Ice River, B. C.," Geol. Mag., Vol. 9, 1902, p. 199.

For comparison he reduced the Al_2O_3 to unity. This gave:—

	SiO_2	Al_2O_3	Na_2O	K_2O
Sodalite...........	1·17	1	0·80	....
Nephelite..........	1·32	1	0·45	0·23
Albite.............	3·52	1	0·60	....

To quote his conclusions, he states that in order "to get sodalite from nephelite a certain amount of potash and silica must be removed, and 0·35 of soda added with chlorine, an operation not difficult for heated waters with a fair amount of NaCl in solution. To obtain it from albite only 0·20 of soda would have to be added with chlorine, but 2·35 silica removed." He believes that a large part of the sodalite is secondary after nephelite or soda feldspar. The writer has found that very little of the sodalite is secondary after nephelite, but is chiefly primary and of pneumatolytic origin.

Fouque and Levy[1] believe that the formula of sodalite and of nephelite is the same, while Rosenbusch[2] as well as these other two workers state that sodalite may frequently be of secondary origin.

CANCRINITE ($HNaCaAl(SiO_2)(CO_2)$).—This mineral occurs both as a primary and as a secondary constituent of the rock. It is very common near the contact, in which it is an accessory constituent, and is observable only under the microscope. It occurs in angular grains interstitial in most cases to the other constituent of the rock. In some of the sodalite syenites it becomes abundant, and is an essential constituent in one rock. It sometimes forms veins in the igneous mass; one of these is 6 inches wide and is nearly pure cancrinite. In colour the mineral varies from pure white to honey-yellow. It is a common alteration product after nephelite. The occurrence of this mineral suggests that it has crystallized out quite late from the magma, and has probably been affected in some way by the limestone on the contact of the igneous rock. It was first found

[1]Fouque and Levy, Min. Micrograph, Pl. 45, 1879, pp. 447-450.
[2]Elem. der Gesteinlehre, 1899, p. 115.

in Canada by Harrington in the nephelite syenites of Mt. Royal and Beloeil mountain in 1882.[1]

HYDRONEPHELITE ($Na_2HAl_3(SiO_4)_3+3H_2O$).—This mineral is formed by the hydration of nephelite and becomes abundant in certain contact facies, or along fractures in the mass. When this mineral is present in considerable amount the rock has a pinkish or faint reddish appearance. Those rocks in which this mineral becomes an essential constituent have been called *hydronephelite syenites* in this memoir. Under the microscope the mineral appears in small irregular, colourless plates with a flaky appearance. This mineral is abundant in the Port Coldwell nephelite syenites.[2] It is also abundant in nephelite syenite of Litchfield, Maine. In the Norwegian alkaline complex, Brögger has found ranite abundant in certain rocks, and notes that this mineral includes what has passed under the name of spreustein.

This mineral was first recognized in the Ice River rocks and described by Dr. Barlow, in 1902. He separated the hydronephelite from the rock by means of Thoulet's heavy solution. The powder gave a specific gravity of 2·243—2·275. The analysis is given in the following table and with it are others for comparison.

Analyses of Hydronephelite and Ranite.

	I.	II.	III.	IV.	V.
SiO_2	42·80	38·99	39·21	38·72	38·86
Al_2O_3	28·50	33·62	31·79	33·76	33·82
Fe_2O_3	0·34	....	0·57	.....	....
CaO	1·90	0·07	5·07	6·31	6·36
Na_2O	14·33	13·07	11·55	9·56	9·38
K_2O	0·30	1·12	.....	0·16	0·08
H_2O	10·81	12·98	11·71	12·02	11·94
MgO	.....	.....	.....	0·19	0·14
	98·98	99·85	99·90	100·72	100·58
Spec. grav.	2·243–2·275	2·263	2·48	2·34	2·34

[1] Harrington, B. J., Trans. Roy. Soc. Canada, Vol. 1, Sect. 3, 1883, p. 81.

[2] Kerr, H. L., 19th Annual Report, Bureau of Mines, Ontario, Vol. 19, 1910, p. 203.

I. Hydronephelite from Ice river, British Columbia.[1]
II. Hydronephelite from Litchfield, Maine.[2]
III. Ranite from island of Laven, Langesund fiord, Norway.[3]
IV. Hydronephelite from Port Coldwell, Ontario.[4]
V. " " " " [4]

This mineral was named and first described by Clarke, and is referred to above. His formula is $Na_2H, Al_3 (SiO_4)_3 3H_2O$, which requires, silica, 39·29; alumina, 33·41; soda, 13·54; and water, 13·76.

FELDSPAR.—The several varieties of this mineral have been described under the various rock types, and will not be repeated here. Orthoclase, albite, and microcline are the essential varieties. These occur separately, and microperthitically intergrown.

PYROXENE.—This group of minerals is represented by several varieties of which ægirite and ægirite-augite are the most common. Other varieties which are sometimes essential to the rock are augite (titaniferous), diopside, and a pink pleochroic variety with inclined extinction, which may be called *clino-hypersthene* until the results of a more detailed study which is being made are obtained. Other varieties determined, but always accessory to the rock, are hedenbergite, and pectolite. Pectolite occurs in bunches of radiating crystals, filling cavities in the nephelite syenite.

Ægirite and ægirite-augite are characteristic of these sodic intrusives. The ægirite has a deep green colour and is strongly pleochroic. The absorption parallel to the vibration axis is deep green, yellowish green, and faint yellowish green, which has been determined as $\mathbf{a} > \mathbf{b} > \mathbf{c}$. The extinction of $c \wedge \mathbf{a}$ is 5 degrees. With an increase of the augite molecule the maximum extinction grows large, and in many rocks has an angle of 35 degrees to 40 degrees of $c \wedge \mathbf{a}$. On approaching augite the colour of the mineral becomes fainter, and less distinctly pleochroic. In

[1]A. E. Barlow: Ottawa Naturalist, 1902, p. 75.
[2]F. W. Clarke: A. J. S. Vol. 31, 1886, p. 267.
[3]Dana's Mineralogy, 1892, p. 607.
[4]H. L. Kerr: Annual Report Bureau of Mines, Ontario, Vol. 19, 1910, p. 203.

the equigranular rock types the habit of the mineral varies, but it always has a tendency to become sub-hedral and sometimes euhedral in outline. This mineral again shows that its position in the order in which the minerals of the rock crystallized, depends very largely upon the amount in the rock. When it becomes abundant it frequently forms grains with good crystal outline.

The size of the individual grains varies enormously. Ægirite occurs as minute needles in the nephelite or sodalite. These needles are often submicroscopic in size, but frequently 0·001 mm wide. The largest crystal of ægirite observed in the field is 11 inches long and ½ inch wide and occurs in a pegmatite, but needles 4 inches in length are common. All the varieties of pyroxene are remarkably fresh.

Diopside is associated principally with the metamorphosed sediments or igneous rock along the contact.

The pinkish pleochroic variety of pyroxene referred to above is abundant in the jacupirangites or more extreme femic differentiates. In some of the rocks this mineral makes up 80 to 90 per cent of the whole. It occurs in small plate-like grains with a brownish or bronzy lustre. The surfaces of the grains are more or less sub-parallel, so that the rock has a tendency to break in one direction.

Under the microscope in parallel light, thin sections appear fresh and faint pinkish in colour, with a slight pleochroism which has been determined as pinkish or reddish pink, faint pink, and nearly colourless. The absorption is $\mathbf{c} > \mathbf{b} > \mathbf{a}$ with **a** and **b** nearly equal. The grains are subhedral or anhedral, and prismatic sections show good cleavage lines (Plate XIX,B). Those in or near the clinopinacoid zone show an irregular basal parting which is recognized only by the numerous iron ore inclusions along these planes. The prismatic cleavage planes and basal parting makes an angle of 50 degrees, or an obtuse angle of 130 degrees between the 001 and 100 faces. The birefringence is 0·012 to 0·014, but in sections which do not show much cleavage the double refraction is low, and the grain appears dark grey or nearly isotropic. The mineral is optically positive, with (+) elongation so that $\mathbf{c}$=acute bisectrix. Some grains show a deep blue colour between crossed nicols. The dark brush which crosses the field on rotating the section in convergent light shows a deep blue colour on one side and a red on the other, which indicates that the dispersion is strong. The angle for red is greater than that for blue so that the dispersion is expressed by $\rho > \upsilon$. The axial plane lies in the plane of symmetry, so that $b = \mathbf{b}$. In many respects this mineral corresponds to hypersthene, but it has a maximum inclined extinction of 35 degrees to 40 degrees.

On a 010 or clinopinacoidal section showing both cleavage and parting, the angle from c to $\mathbf{a}$ was behind the crystallographic axis so that $c \wedge \mathbf{a} = 38$ degrees, that is to say the acute bisectrix comes out in the upper part of the 100 face or orthopinacoid.

It was difficult to find sections suitable for an accurate measurement of the axial angle, but it is very small, because in sections nearly perpendicular to the bisectrix the dark bands remain very close together. It was found to have an axial angle, $2\,E = 22° \, 22'$.

In order to get the pure material from the other minerals, the rock was crushed to 80 mesh. By means of the "Warren magnetic separater" the dark coloured constituents were first separated from the light coloured minerals, then the strongly magnetic material was separated from other black minerals. This powder was then separated by heavy solution; barium mercuric iodide with a specific gravity of $3 \cdot 5$ was used. The various portions were examined under the microscope and only the purest material was used for an analyses. The mean index of refraction was determined by the immersion method, using thin cleavage fragments which showed least interference. The refractive index of the liquid, which was slowly diluted until it matched as nearly as possible that of the mineral, was determined by means of a hand refractometer. The mean of several measurements gave $1 \cdot 737$ for the refractive index of the intermediate, or β-ray of the mineral.

The following partial analysis was made of this mineral by M. F. Connor in the laboratory of the Mines Branch, Ottawa:—

SiO_2	41·80
Al_2O_3	9·30
Fe_2O_3	5·44
FeO	3·30
MgO	10·82
CaO	22·89
H_20	0·16
$H_2O(+)$	1·10
TiO_2	4·84
MnO	0·10
	99·75
Sp. gravity	3·39

These results show that this mineral is an abnormal hypersthene-like pyroxene, but differs widely from any published analysis. It might be called a clinohypersthene since it has certain optical properties of a rhombic pyroxene but has marked inclined extinction. A further study is being made and the results will be published at a later date.

Another variety of pyroxene common in the Ice river rocks and referred to on a former page has a faint greenish colour and is slightly pleochroic. The absorption is determined as **a**= grey to colourless, **b**=pinkish, and **c** = faint reddish pink. It has a maximum extinction of 32 degrees to 38 degrees. It is soda rich variety and the following partial analysis has been made by M. F. Connor of the Mines Branch, Ottawa:—

SiO_2	45·75
Al_2O_3	4·49
Fe_2O_3	5·09
FeO	11·48
MgO	7·25
CaO	20·50
$H_2O(-)$	0·37
$H_2O(+)$	0·81
TiO	2·18
MnO	0·19
	98·11
Sp. gravity	3·44

AMPHIBOLE.—This mineral is subordinate in amount to pyroxene and is absent from many rocks. The essential amphiboles belong to the basaltic hornblende or barkevikite varieties. The former is more commonly found in the nephelite syenite or leucocratic rocks, while barkevikite is abundant in certain ijolites and other melanocratic rocks. The basaltic hornblende is very black and glossy with good cleavage surfaces showing. Under the microscope this mineral has subhedral outline, is strongly pleochroic, which appears as light yellowish brown, brown, and dark reddish brown. The absorption has been determined as **c** > **b** > **a**. The mineral is negatively elongated with extinction up to 13 degrees. It frequently forms large poikilitic crystals; many are distinctly visible in the hand specimen.

Barkevikite is very common in some of the ijolites. It cannot be distinguished from common hornblende in the field, but the microscope shows it to be a brownish pleochroic mineral, frequently with shades of green. The absorption is pale yellow to colourless, greenish yellow and dark reddish brown, which is determined as **b**>**c**>**a**. It is optically negative and shows good cleavage in the prismatic zones, with maximum extinction 17 degrees to 24 degrees. Some crystals show a deep brown border and faint green centre or vice versa; or the centre of the crystal may be faint green and the border darker green. This hornblende commonly occurs in large poikilitic crystals an inch in diameter.

It is a characteristic feature of the amphibole that when there is much of it present in the rock it tends to form idiomorphic outlines, but if in small amount it is interstitial to those minerals that are present in larger amounts.

The amphiboles of the Ice River rocks are quite similar to those in the Port Coldwell nephelite syenite, and described by Kerr.

Actinolite and tremolite occur principally in veins or in vug-like segregations. Radiating bunches of green fibrous actinolite are abundant in a drusy vein at the head of Zinc valley. Under the microscope it is green, slightly pleochroic, and with good cleavage. The absorption is **a** = yellowish-green, = **b** = **c** =

pale green. It is optically negative, so that **a** = acute bisectrix, negatively elongate and extinction on elongation 0 degrees to 8 degrees.

A few irregular, microscopic grains of greenish and bluish green material have been determined as riebeckite. A few others may be arfvedsonite.

MICA.—Biotite is rare in the Ice River types except as a secondary mineral in the hornfels. It occurs in some of the melanocratic rocks, and especially in porphyritic crystals in the basic ijolites. The largest crystal obtained is 4 inches in diameter and very black on the cleavage flakes. A vein of calcite contains well formed prisms of biotite with hexagonal outline.

Muscovite is rare and usually secondary. It often occurs in the metamorphosed sediments.

A deep green mica occurs in a small vein in the Van Horne range up Porcupine valley. It shows a good biaxial figure which is negative. The axial angle gives 2 E = 54 degrees, and its mean index of refraction is slightly greater than 1·583. Thin flakes are colourless and it is probably magnesia iron mica, *anomite*.

CALCITE.—This mineral is frequently present as an accessory constituent, but is invariably present as a primary constituent in those types which occur on or near the contact with the crystalline limestone. Its mode of occurrence suggests that the mineral is distinctly foreign to the magma, and has been derived from the neighbouring limestones. This mineral occurs as angular grains, sometimes enclosed in other constituents but more frequently interstitial. A microphotograph (Plate XX) shows this relation. In most cases it is not a secondary constituent, as some of the grains are large enough to be easily observed in the hand specimen.

The presence of calcite has been noted in several other occurrences of nephelite syenite. This mineral is believed to be of primary or foreign origin by the investigators in the various regions. It is also found associated with the neighbouring metamorphosed limestone.

The occurrences which will be briefly mentioned are at Bancroft, Ontario[1], in the Siwamalai series of India[2], Island of Alnö in Sweden[3], Kaiserstuhl in Baden[4], at Kussa in the Ural mountains[5], in the nephelite syenites of Zerafschan, Turkestan[6], and in the nephelite syenite of eastern Siberia.[7] Primary calcite has also been found in certain granites. It occurs in a micropegmatite at Sudbury, Ontario[8].

The nephelite syenites of the Bancroft area, Ontario, contain calcite which is believed to be foreign to the magma. Concerning the occurrence of this mineral Adams and Barlow say: "Every stage of the passage from the solid limestone to the separate calcite grains enclosed in the constituent minerals of the nephelite syenite can be distinctly traced, while the latter is at the same time fresh and free from decomposition products. The calcite in the syenites is undoubtedly foreign to the magma and represents inclusions of the surrounding limestones."

In describing the calcite in the Indian occurrence, Holland states: "The calcite occurs in granular crystals with apparently as much right as any of the others to be considered a primary constituent. The crystals form isolated granules and there are no signs of secondary decomposition, the low silica percentage in this group of rocks removes the theoretical difficulty to its

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[1]F. D. Adams and A. E. Barlow, "Geology of Haliburton and Bancroft areas, Ontario," Geol. Survey, Canada, Memoir No. 6, 1910, p. 233.

[2]T. H. H. Holland, "The Siwamalai Series of Elaeolite Syenites and Corundum Syenites in the Coimbatore District, Madras Presidency," Mem. Geol. Survey of India, Vol. 30, Part 3, 1901, p. 197.

[3]A. G. Högbom, "Uber w das Nephelinsyenitgebiet auf der Insel Alnö," Geol. Foren. i, Stockholm Forh., Bd. 17, Heft 2, 1895, S. 118.

[4]Graeff, "Zur Geologie des Kaiserstuhlgebriges," Mitt. d. grossberg, Bad. Geol. Landesanst, Bd II, 1892.

[5]A. Arzruni, "Die Mineralgruben bei Kussa und Miass" (In the Livret Guide for the Ural Excursion of the International Congress of Geologists, St. Petersburg Meeting, 1900.)

[6]J. Preobrajensky, "Die nephelinsyenite vom oberen Zerafschan, Turkestan," Annales del' Inst. Poly., Pierre la Grand a St. Petersbourg, Vol. 15, 1911.

[7]O. Stutzer, "Uber primaren Calcit im Elaeolithsyenit des Botogolsky —Golez in Ostsibirien," Centralbl. Min., Geol. u. Pal., 1910, p. 433.

[8]T. L. Walker, "Geological and Petrographical Studies of the Sudbury Nickel District (Canada)," Q.J.G.S. London, Vol. 53, 1897, p. 55.

crystallization from a molten magma as a normal constituent of an igneous rock."

At Alnö, Högbom believes that the limestone was fused by the magma, and was later, during the solidification of the magma, crystallized out as one of the mineral constituents of the rock. This is precisely the conclusion arrived at by the writer, before he had read the Swedish occurrence, to explain the presence of calcite in the Ice River rocks.

A similar explanation has been offered by Graeff for the Kaiserstuhl occurrence, while Arzruni remarks that the occurrence of calcite in the Kussa nephelite syenite must remain unexplained.

In the Turkestan occurrence, calcite is fresh in a nephelite syenite, and abundant along the contact of the igneous rock with a crystallized limestone.

SPHENE (OR TITANITE) ($CaTiSiO_5$).—This mineral is invariably present in all of the Ice River types, sometimes quite rare or accessory, but frequently abundant in amount, and it even becomes an essential mineral in some of the melanocratic types. One rock contains about 30 per cent sphene, the rest being largely pyroxene. The titanite is remarkably fresh in all of these rocks, and appears in idiomorphic crystals which are frequently well terminated. These crystals are sometimes microscopic in size, but usually macroscopic, and occasionally form crystals 1 cm long and 2 to 5 mm wide. The characteristic colour is honey-yellow, while under the microscope this mineral has a bronze colour, and the darker varieties have a distinct pleochroism. In one type of nephelite syenite the sphene is large and even as phenocrysts which give the rock a conspicuous appearance.

Microscopically, this mineral frequently forms prisms elongated parallel to the vertical axis, while in other sections they have a rhombic habit in cross-section. It quite often shows a good prismatic cleavage so that in many cases the individual grains have a wedge-shaped form (Plate XXI, B). The double refraction is very high, and the interference figure frequently resembles that of a uniaxial mineral.

GARNET (SCHORLOMITE) [$\{Ca_3 (FeTi)_2 \{(SiTi) O_4\}_3\}$.]—This rare mineral is a titaniferous garnet and occurs in some of the coarsely crystalline ijolites of Ice river. In one rock, large angular or euhedral crystals of greenish nephelite and ægirite with long slender habit are held together by schorlomite. Titanite and calcite are also associated with schorlomite. This mineral has a jet black or bluish black colour with vitreous lustre, a brittle texture, and conchoidal fracture. It occurs only in the melanocratic rocks and has been found in the field, at the head of Moose Creek valley, and in the ridge to the west of Garnet mountain. Under the microscope this mineral in parallel light has a faint bluish colour, is isotropic or slightly anomalous under crossed nicols, and appears in rounded grains, which shows that it is of pyrogenetic origin.

It was named and first described in 1846 by C. U. Shepard, who found this shorl-like mineral in certain rocks from Arkansas.[1]

It is of rare occurrence and is known to the writer to have been found in only two other localities; in the nephelite syenite (Cove type) of Magnet cove, Arkansas, described by J. F. Williams in 1890[2], and in an ijolite from Mt. Iiwaara, Finland, described in 1891, by Ramsey and Berghell.[3]

Schorlomite was found in the Ice River rock by Barlow, and the mineralogy of it was studied by F. G. Wait, chief chemist of the Mines Branch, Ottawa. He states that the mineral "is massive without cleavage, the colour velvet-black, here and there tarnished blue, and occasionally with pavonine tints; that of the streak, is brown; the lustre is vitreous; it is brittle; the fracture is irregular, occasionally subconchoidal; it is opaque; fuses quietly at 3 to a black enamel; has a hardness of 6·5 and a specific gravity at 15·5° C. of 3·802."[4]

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[1] Amer. Jour. Sci., Series 2, Vol. 2, 1846, p. 251.

[2] Ann. Rept. Geol. Survey, Arkansas, Vol. 2, 1890, p. 215.

[3] Geol. For. Forh. Stockholm, Vol. 13, 1891, p. 305.

[4] Quotation given by A. E. Barlow, "Nepheline Rocks Ice River B.C.," Ottawa Naturalist, Vol. 16, 1902, p. 76.

A chemical analysis of this mineral is given in the following table and with it those from other occurrences for comparison:—

	1.	2.	3.	4.	5.
SiO_2	25·77	26·09	25·66	29·24	29·08
Al_2O_3	3·21	.....	.....	1·72	1·44
Fe_2O_3	18·59	20·11	21·58	22·61	22·01
FeO	....	1·57	....	.....	.....
MgO	1·22	1·36	.....	0·46	.....
CaO	31·76	29·38	29·78	26·25	26·79
TiO_2	10·83	21·34	22·10	18·14	18·54
TiO	8·23	.....	.....	.....	.....
MnO	0·76	.....	.....	1·17	0·83
SnO	.....	.....	.....	0·87	0·87
	100·37	99·85	99·12	100·46	99·56
Sp. gravity	3·802	3·783	3·807		

1. Schorlomite, Ice river, British Columbia.[1]
2. " Magnet cove, Arkansas.[2]
3. " " " "[3]
4. and 5. Iiwaarite, from Mt. Iiwaara, Finland.[4]

In the Tasmania, Madagascar, Lake Borlan, and other occurrences of nephelite rock, melanite is a common constituent of certain types. This mineral is closely related to schorlomite, and is found in several of the Ice River types. It is probable that in these rocks there was not enough titanium present to form schorlomite.

Common garnet is abundant as a contact mineral, with such minerals as vesuvianite and wollastonite. Glossular and almandine have been determined, and a few blood red rounded grains which may be spessartine but were too small to be determined.

[1] A. E. Barlow, Ottawa Naturalist, Vol. 16, p. 76.
[2] J. P. Iddings, "Rock Minerals," 1906, p. 360.
[3] J. F. Williams, Ann. Rept. Geol. Survey, Arkansas, Vol. 2, 1890, p. 215.
[4] Ramsay and Berghell, Geol. For. Forh. Stockholm, Vol. 13, 1891, p. 305.

APATITE.—Apatite is a common accessory, especially in the less alkaline types. It frequently forms idiomorphic crystals and often occurs as slender needles in the nephelite.

CORUNDUM.—Corundum is rare in these rocks; it has been determined in some of the pegmatites. There was not an excess of alumina in this magma to form corundum, as is the case in the Ontario and several other occurrences.

ZIRCON.—Zircon occurs sparingly in the nephelite syenite and contact rocks, and has a euhedral habit. In a metamorphosed sediment there are several minute colourless crystals, poorly terminated with high double refraction; they may be zircon but correspond to a description of the oxide of zirconium, baddeleyite, which has been found in the nephelite syenite of Alnö, Sweden.

SCAPOLITE.—This mineral occurs as a metamorphic mineral, and also filling cavities. Meionite variety has been determined in several rocks.

OLIVINE.—The minerals of this group occur principally in the metamorphosed limestones, but in no case are they abundant. Forsterite ($Mg\ SiO_3$) appears in some of the metamorphosed xenoliths in the igneous rock. Under the microscope, it is colourless in parallel light with one good cleavage, parallel extinction, optically positive and biaxial. It has a high index and low double refraction. Brucite has also been determined in the rocks of the metamorphosed zone; in many respects it resembles forsterite in thin-section but is uniaxial.

EPIDOTE.—Piedmontite, the manganese epidote, appears in an apophysis of nephelite syenite. It has a pinkish colour in the rock and under the microscope is seen to be present in irregularly rounded pink grains, strongly pleochroic and nearly isotropic between crossed nicols. It has a high index of refraction, greater than ægirite with which it occurs, and gives a biaxal interference figure which is optically negative.

Zoisite and especially clinozoisite are abundant in the hornfels. The latter occurs as colourless or faintly greenish rounded grains, with a high index of refraction, but less than that of biotite; a low double refraction somtimes shows good cleavage and has an inclined extinction.

CHLORITE GROUP.—The mineral penninite (pennine) is the only variety of this group which has been determined. This mineral is a common constituent in the metamorphosed sediments. Under the microscope it appears as rounded grains, some having a rhombohedral outline. Under crossed nicols it has a low double refraction and shows a deep indigo blue interference colour which distinguishes it from other chlorites.

Clinochlore and prochlorite probably represent the chloritic material present in many of the metamorphic rocks in the area.

ZEOLITES.—Hydronephelite, which is the most important zeolite, has been mentioned earlier in this chapter. Thomsonite appears as an alteration product of nephelite, and also in large cavities in the igneous rock. The largest of these crystals are 3 inches long and have a good prismatic outline. The presence of lime in this mineral distinguishes it from natrolite. Another cavity contained faint greenish white zeolitic material in long radiating prisms. Crushed material when examined under the microscope has a low index and double refraction. It is positively elongated and has maximum extinction of 32 degrees. It closely resembles a potash zeolite, phillipsite. Another zeolite, probably laumontite, occurs in cavities in the nephelite syenite. It is of secondary origin, has an index lower than nephelite but higher than sodalite, and a weak double refraction.

In some of the dyke rocks and in a few of the melanocratic rocks, a colourless isotropic base may be analcite.

VESUVIANITE ($Ca_6(AlOH)\ Al_2(SiO_4)_5$).—This mineral is quite abundant in some of the metamorphosed sediments along the upper contact. It frequently occurs in bands and in the field is hard to distinguish from garnet.

WOLLASTONITE ($CaSiO_3$).—This is one of the most common metamorphic minerals occurring in the sediments on the contact of the igneous body, and also as vein material.

QUARTZ.—Quartz occurs in the hornfels and some of the siliceous sediments. Some fissures and fractures in the sedimentary strata are encrusted with quartz crystals. Well formed crystals have been found in cavities and small caverns on the slopes of Mt. Stephen and Mt. Dennis.

SPINEL (Hercynite) (FeO, Al_2O_3).—This mineral occurs in a mica-bearing nephelite syenite. It makes up about 4 per cent of the rock and occurs in irregular greenish grains, some of which have an octahedral habit.

PERICLASE (MgO).—Periclase occurs in enclosed fragments of metamorphosed limestone. The grains are colourless, isotropic, index greater than Canada balsam, and show an irregular cleavage in one direction.

DISTHENE ($Al_2 SiO_5$).—Disthene is quite rare, but is present in some of the metamorphosed sediments.

PEROVSKITE ($CaTiO_3$).—This mineral is rare or absent. When present it appears as yellowish or brownish isotropic grains, often euhedral in habit. A microphotograph shows some of these octahedral forms (Plate XXI, A). It is invariably associated with rocks which contain sphene and ægirite as two of the mineral constituents.

ILMENITE ($FeTiO_3$).—Ilmenite occurs principally in the melanocratic rocks, while in some of the jacupirangites it becomes an essential mineral. It is difficult to distinguish this mineral from magnetite, but in many cases the grains are characterized by an outer border of leucoxene.

MAGNETITE (Fe_3O_4).—This mineral is invariably present in all the rock types, and sometimes the grains have a good cubical or octahedral habit.

PYRITE.—Pyrite occurs in the sodalite syenite and nephelite syenite near the top of the laccolith. It is more abundant in the sedimentary rocks.

GALENA, SPHALERITE, CHALCOPYRITE, AND PYRRHOTITE.—These minerals are important economically; they form small pockets and mineralized zones in the sedimentary rocks.

To this list might be added other minerals which rarely occur, but those noted are the more important.

CHAPTER X.

ICE RIVER IGNEOUS COMPLEX: STRUCTURE, METAMORPHISM, AGE, ETC.

STRUCTURAL RELATIONS.

INTERNAL.

The internal structural relations of the various types are extremely complex and in so far as they can be referred to differentiation within the chamber, or the relation of one type to another, have been in part discussed under the lithology of the various types. The rocks in the complex represent a continuous petrographic series of consanguineous types, transitional into one another. The series has been subdivided into three groups according to mineralogical composition, and each group is represented by a chief type, nephelite syenite, ijolite, and jacupirangite respectively. The variation facies, which these three principal types present, have been previously discussed.

The series ranges from a sodalite-syenite or foyaite at the alkaline end, to a pyroxenite or jacupirangite at the femic end. The transition from one group, or from one rock type to another, may be so gradual that it is not possible to say where one type begins and the other one ends, or on the other hand, it may be so sudden that within 2 feet a rock with the composition of a nephelite syenite for example, may become an ijolite rich in the dark coloured silicates.

These diverse rock types vary within themselves in both texture and mineralogical composition. For example, the normal nephelite syenite is a medium coarse-grained rock, with accessory dark coloured minerals, but changes to a fine-grained rock on the one hand and on the other to coarse-grained, porphyritic or pegmatitic phases. In composition, the dark coloured constituents may entirely disappear or may become essential in amount.

Porphyritic phases and pegmatitic schlieren are associated principally with the areas occupied by the melanocratic, or dark coloured types. These are situated chiefly in the northwest arm of the laccolith, as well as in the north and northeast thinner parts of the igneous mass, which represent the earlier cooled portions of the laccolithic chamber.

Although the whole petrographic series of rocks represent a continuous intrusion, yet in every case the darker coloured types have cooled first, and before the minerals had a chance to separate out under the influence of gravity. Such has been the case in the northwest arm which runs from the broad part of the mass to Chancellor peak. These rocks represent the original heterogeneous magma before it had a chance to differentiate.

In the broad southern part of this irregularly shaped complex, the field relations, which are usually well exposed, show that there has been a strong tendency for the magma in this part of the chamber to differentiate. The alkalies, silica, and more aqueous portions of the magma have risen to the top in the form of sodalite, nephelite, and alkali feldspar, while the heavier iron-magnesian constituents have settled to the bottom by force of gravity. The sodalite syenite or ditroite is always found on or near the upper contact of the mass. In Zinc mountain there is nephelite syenite at the top, which changes to an ijolite and finally to a jacupirangite or pyroxene on the floor.

Apophyses consisting essentially of leucocratic material penetrate the cover of the laccolith at a few places. In many places, dyke-like masses of nephelite syenite cut the border facies of the complex in all directions, and fill up cracks which have been formed during the cooling of certain earlier crystallized portions of the chamber.

On the south side of Sodalite valley, there is a sub-parallel arrangement of the feldspar crystals in the nephelite syenite, which gives the rock a trachytoid texture. Similar evidence was noticed at other parts within the nephelite syenite area, which suggests that there was a slight movement in certain parts of the magma while it was in a semi-plastic condition.

Cataclastic structure is practically absent from the Ice River complex. Under the microscope, the minerals in a few specimens from the contact facies of the chamber showed some signs of having been crushed. This structure has resulted from the orogenic movements which sheared and regionally metamorphosed the surrounding sediments at a period later than the intrusion.

There is no definite direction of well-marked joint planes, and the fractures in the complex do not seem to have any relation to one another. Some of these fissures have become filled with vein material such as cancrinite, sodalite, wollastonite, and drusy zeolitic material.

External.

It has been previously stated that the Ice River alkaline intrusive has the form of an asymmetrical laccolith with a stock-like feeder. It has been intruded into Upper Cambrian and lower Ordovician sediments which are calcareous and argillaceous. The *upper* contact of the igneous rock with the sediments is in general concordant with the stratification. This contact extends along the northeast slope of the ridge from Mt. Mollison to Chancellor peak, a distance of nearly 9 miles, and is exposed throughout its length with the exception of that portion where it crosses the bottom of Ice River valley. The cover has been eroded from other parts of the laccolith. The lower contact is exposed in Garnet mountain, on the north side of Sodalite valley, at the head of Zinc valley, and between Helmet mountain and Mt. Sharp. This contact is not as concordant with the stratification where exposed, as the upper one, and in some places cuts across the beds at a low angle.

The dip of the upper contact is much steeper than that of the lower. In the former case the angle varies from 70 degrees to 85 degrees, while in the latter, where it is best exposed in Garnet mountain, the dip is 50 degrees to 60 degrees. The difference between the dip of the roof and the floor is due to the up-arching of the former by the intrusion. The beds were folded into the position and attitude still to be seen in the floor, *before* the intrusion, while those forming the cover have been further arched up by the intruding magma.

It has been previously stated that the northwestern limb of the laccolith has split apart the limestone band of the Ottertail formation. This sill-like portion of the laccolith has been intruded along a softer layer near the centre of the formation so that at Butwell peak, west of Garnet mountain, there is about 700 feet of the limestone on the roof, and about 850 feet on the floor. The igneous rock pinches out in Chancellor peak and the two portions of the limestone again join to form a single band about 1600 feet thick. In the northern limb of the laccolith, at the head of Zinc valley, there still remains about 300 feet of the igneous rock on the dividing ridge between Zinc mountain and Sentry peak, but it seems probable that this portion of the laccolith was originally much thicker, since in Zinc mountain there is over 1000 feet of igneous rock exposed. At the end of this northern limb the igneous rock ends abruptly in the base of Sentry peak and a sharp, cross-cutting contact is clearly observable in the field, as is shown in section (K-L).

The intruding rock has had a marked effect on the upper contact, the details of which will be given when discussing contact metamorphism. The effect of contact metamorphism seems to have been much more intense on the roof than on the floor of this laccolith. At various places along the upper contact between the igneous rock and the blue limestone, there is a band of hard, dense, reddish brown hornfels which varies in width from a few feet to a maximum of 350 feet. The upper contact of the hornfels with the limestone, where exposed in the field, is always sharp and conformable, but both conformable and cross-cutting relations are seen between the hornfels and the igneous body. In many places where there is no hornfels band, the igneous body is in contact with the limestone and the latter has been metamorphosed for several hundred feet from the contact.

At various places along the upper contact the overlying sediments have been shattered and large blocks of the hornfels and of the limestone are entirely surrounded by the igneous rock. The largest block separated from the roof, with one exception, is about 100 feet in diameter. Some of these blocks are shattered in situ into smaller angular fragments by the effect of differential heating. There is one large fragment of recrystallized limestone shown on the map to the south of Garnet mountain. It is over 1000 feet thick across the widest portion, thins out towards either end, and is $\frac{3}{4}$ mile long. It has probably been split off from the roof while the magma was being forced into its present position. With this one exception, none of the enclosed sedimentary blocks are more than 200 feet from the upper contact, and at this distance the angular edges of the blocks have been fused off by the enclosing magma. It would seem that the magma must have had a very low viscosity when the cover became shattered or these blocks would have sunk to the bottom of the chamber. The specific gravity of the hornfels on the upper contact is 2·901, whereas that of the ijolite on the upper contact is 2·892, and the densities of diverse types of nephelite syenite are 2·605, 2·609, 2·697, and 2·721.

Although the intense shearing of the surrounding sedimentary series occurred at the close of the intrusion, the igneous body shows very little evidence of having been subjected to orogenic disturbances after its intrusions. This is explained by the fact that the igneous body was much more resistant to the compressional stresses than were the softer sediments about it. In many places about the complex, the soft limestone is crushed against this harder rock. In one place on the roof of the laccolith, in Butwell peak, a boulder-like fragment of nephelite syenite is entirely surrounded by the highly sheared limestone. This "boulder" is now 20 feet from the contact. This evidence shows that the shearing occurred after the close of the intrusion.

The igneous body does not seem to have suffered any faulting. The brecciation of the melanocratic rock types, referred to above, has been caused by the sudden chilling about the walls of the chamber, but these cracks were soon filled with material emanating from the still molten magma in the thicker portion of the laccolith. Some of these cracks extended into the surrounding sediments and became filled with the more alkaline material from the igneous body.

Contact Metamorphism.

Endomorphic.

The internal effect of metamorphism on the igneous body is very slight. There does not seem to have been a rapid or intense radiation from the cooling magma. In the thinner portions of the laccolith towards the north, and especially in the northwest limb of the mass, this effect has been greatest. There seems to be a general tendency for the igneous rock to be more noticeably porphyritic towards the edges of the "sill," while towards the centre, the rock seems to be more coarsely crystalline, and pegmatitic phases occur in greater abundance. Texture such as these would result from a rapid loss of heat in the marginal portions. It must, however, be understood that such an effect is not clearly evidenced in the field, especially since the rock in this part of the mass presents marked heterogeneity in texture and composition.

That part of the igneous body which forms the thinner edges of the chamber was cooled rapidly by its contact with the surrounding sediments, so that it did not have time to differentiate by a sinking of the heavier minerals, and a rising of the lighter ones, as is seen in thicker parts of the chamber.

Microscopically, this endomorphic effect is expressed chiefly by the introduction of lime into the intruding rock. It has been previously stated that the feldspar in the contact facies in some places, especially along the floor of the laccolith, contains much more lime than does the normal type of nephelite syenite. It is believed that much of this lime has been introduced from the limestones at the contact. Calcite frequently occurs in those rocks near the margin of the laccolith. It is not always a secondary mineral, but occurs as well defined rounded or angular grains, sometimes completely enclosed by other constituents but usually interstitial to them. This suggests that the mineral is foreign to the magma, and has been introduced from the enclosing calcareous sediments. The contacts about this complex, where exposed, are usually quite sharp and well defined. In a few cases where fragments of the contact rock have been enclosed and partly fused by the magma it is difficult to tell where the igneous rock ends and the foreign rock begins.

Exomorphic.

The external effect of the intrusion is very much greater than the internal, but it cannot be said that in either case metamorphism is of extreme intensity. The sedimentary rocks on or near the contact have been highly metamorphosed. This alteration is greatest at the contact and becomes less marked a short distance away. The zone of contact metamorphism in the cover of the laccolith is not well defined and cannot be readily recognized. It varies from a few feet to several hundred feet in width, while the maximum width of the zone noticed was about 700 feet. There is only very slight metamorphism shown in the beds on the floor of the laccolith, as compared with that in the cover.

At the upper contact, between the igneous rock and the overlying blue limestone, there is frequently a band of hard, dense, reddish brown hornfels which varies in width from a few feet to 350 feet. This hornfels was originally a band of shale or argillaceous limestone which has become so intensely metamorphosed that the rock has lost all appearance of cleavage, although the original bedding can be recognized as bands in this baked or porcelainized sediment.

The upper contact between the hornfels and limestone is always conformable and sharply defined where exposed, but that between the hornfels and the igneous rock is very irregular. In the field, this band in some places is over 300 feet thick, while in others it may only be 10 feet, or, as is frequently the case, is absent and the igneous rock is in contact with the blue limestone. It is a noteworthy feature that the zone of metamorphism varies in width; in some places the alteration has been intense, while in others close at hand, the amount of metamorphism is almost negligible. These facts seem to show that the more aqueous constituents of the magma were more concentrated in certain areas.

The magma has had a much greater effect on the argillaceous beds of the Goodsir formation than on the limestone of the Ottertail formation. This feature is well shown in Sentry peak and Mt. Goodsir. These shales have been intensely baked to dense hornfels and flinty or cherty banded rocks which break up into rectangular blocks. These beds in the base of Mt. Goodsir are very different in appearance lithologically, from the same beds which are exposed in Striped mountain on the opposite side of the valley and farther away from the igneous mass.

Where the igneous rock is in contact with the limestone, the composition of the resulting marmarosed rock depends upon the original composition of the limestone. If the rock on the contact was a pure limestone, a finely crystalline marble is formed, but, as is frequently the case, where the limestone was quite impure, besides calcite, the metamorphosed rock contains tremolite, diopside, garnet, epidote, and wollastonite. In other places the limestone has been very slightly altered by the intrusion of this alkali-rich magma. The hornfels has a specific gravity of 2·901. Microscopically, the hornfels consists of a cryptocrystalline mass of quartz, feldspar, biotite, and clinozoisite. Biotite is abundant in deep brown, strongly pleochroic flakes that average about 0·01 mm in diameter. Many of the larger flakes are in part or altogether colourless, which suggests a bleaching out of the colouring material. A sub-parallel arrangement of the biotite particles shows that there has been a constant movement of the solutions from the intruding rock. Clinozoisite is abundant, it appears colourless, or faintly greenish with a high index and low double refraction. Quartz and feldspar are very finely granular but are sometimes abundant. Perovskite and epidote are common accessories, indicating the presence of much lime in the original sediment. There are often numerous dark patches in this cryptocrystalline rock which apparently consists of clinozoisite. Other accessory minerals are magnetite, muscovite, zircon, and a colourless, poorly terminated mineral which corresponds to the description of the zirconium oxide, baddeleyite.

Xenoliths.

Along the upper contact of this laccolith there are a few large angular blocks of the hornfels or the limestone of the cover, enclosed in the igneous rock. The largest xenolith seen, with but one exception, was about 100 feet in diameter. Sometimes these blocks are quite close to the parent rock from which they were shattered, or they may be some distance from the contact. All of these blocks, except one, were found within a zone of 200 feet from the contact. There is shown on the map a fragment of limestone which outcrops in the west slope of Ice River valley and south of Garnet mountain. This lenticular block is ¾ mile long, apparently 1000 feet thick at its widest portion, and is exposed over 1000 feet from the upper contact. It would seem that this mass was split from the cover by the magma as it was forced into this part of the laccolithic chamber. The long axis of this block is parallel with the upper contact. The smaller xenoliths have also been torn from the cover by the intruding rock. Some of them have been split up into smaller ones. They are usually angular in outline, but also appear with more or less rounded edges. The contact between the xenolith and the igneous rock is usually quite sharp. The presence of xenoliths in the contact zone of a batholith is common, but this feature is usually lacking around the walls of a laccolithic mass.

The phenomenon of contact shattering and origin of xenoliths is upheld by many geologists. This feature has been strongly emphasized by R. A. Daly in upholding the theory of batholithic intrusion proposed by him.[1] In this paper he has pointed out that xenoliths about a laccolith have more likely been "pulled off from the walls by the friction of the moving magma."

The xenoliths in the Ice River laccolith are entirely metamorphosed and are dense grey or greenish grey on the fresh surface with dark bands of vesuvianite, garnet, or diopside. This banding represents the original bedding of the rock.

Microscopically, the xenoliths consist of a large variety of minerals such as are found in metamorphosed contact rocks. Of these may be mentioned, calcite, scapolite, diopside, vesu-

[1] Mechanics of Igneous Intrusion, A. J. S., Vol. 26, 1908, p. 22.

vianite, garnet, epidote, tremolite, wollastonite, forsterite, penninite, clinozoisite, periclase, brucite, sphene, biotite, muscovite, ægirite, feldspar, nephelite, sodalite, cancrinite, quartz, etc.

Many thin-sections of these metamorphosed sediments were examined under the microscope; they seem to show that the contact rocks were saturated with solutions from the igneous body and that there has been an introduction of material from the enclosing rock. In the case of some of the smaller fragments it is not possible to distinguish between igneous rock and metamorphosed sediment, as the same minerals occur in both. The feldspar in the xenoliths is the same as that in igneous rock. Nephelite and sodalite are present in fragments of the more calcareous rock, and are absent from the more siliceous material. The titanium required for the formation of titanite, which is abundant in some specimens, has been derived from the igneous rock.

In one rock, sphene forms large poikilitic crystals, 8 to 12 mm in diameter. The various detached fragments of a crystal are shown to be similarly orientated under crossed nicols. Vesuvianite always occurs in bands associated with garnet. These two minerals look alike in the field, but under the microscope vesuvianite occurs in subhedra or anhedra, which are slightly double refracting and sometimes show a zonal structure.

Regional Metamorphism.

The sedimentary series in this part of the Rocky Mountain system have been regionally metamorphosed, more intensely in some parts than in others. The chief orogenic disturbances which caused this metamorphism have occurred since or towards the close of the period of intrusion. The igneous rock shows little or no effect from these movements, because it has acted as a resistant "nodule" in the softer sedimentary rocks so that the latter have become crumpled, highly cleaved, and sheared about the laccolithic body.

It has been previously stated in discussing the stratigraphy, that the rocks in the sheared zone though very highly cleaved do not show the presence of many secondary minerals. The shales of the Chancellor formation have been changed to meta-argillites by this regional alteration, part of which may have resulted from static pressure caused by the thick cover.

The Lower Cambrian quartzites have been regionally altered from impure sandstone. On the other hand certain bands of limestone in the Middle and Upper Cambrian have become more or less recrystallized and in some cases the rock has been changed to a grey or white marble.

The effect of this regional alteration is also seen in the Ottertail limestone. It is recrystallized to some degree in almost every part of the formation, but some layers show this more clearly than others. Some layers are saccharoidal in their general texture, while other more impure bands contain recrystallized actinolite or tremolite.

In the thinly bedded limestone in the Ottertail formation, the harder layers have been broken into angular fragments, while the matrix has been partly or wholly recrystallized to calcite or dolomite. This feature is well shown in the limestone underlying the east side of the laccolith in Moose Creek valley. It was at first thought that this rock had been altered by the intrusion, but this alteration is so widespread, reaching beyond the limits of the laccolithic body, that it is now believed to have been regionally metamorphosed.

AGE OF INTRUSION.

Structural Evidence.

The age of the intrusion of the Ice River alkaline rocks cannot be definitely fixed. It cuts the lower Ordovician beds of the Goodsir formation which is the highest member of the sedimentary series represented in the Ottertail range in which the igneous body occurs.

It has been previously stated that the period of folding is older than the period of shearing, while on the other hand the shearing is older than the faulting.

It has been stated elsewhere in this paper that the intrusion occurred after or towards the close of the period of folding and before the principal period of orogenic disturbances, when the rocks were sheared and the mountain ranges elevated. The chief disturbances which caused the principal elevation of the Rocky Mountain system, are believed by Dawson and other workers throughout the Rocky mountains, to have occurred at the close of the Laramie. The folding referred to, which preceded the shearing and also the intrusion, is post-Cretaceous in age. The Cretaceous sediments are well developed in the Cascade basin 35 miles to the northeast; these have also been effected by the folding. The age of the Ice River mass from structural evidences may be regarded as post-Cretaceous.

Correlation Evidence.

Since this is the only igneous complex in this part of the Rocky Mountain system and the only one studied north of the Crowsnest pass, which is about 150 miles to the southeast, a correlation in age can only be made with similar igneous masses in the Rocky mountains, not in the immediate vicinity, but which were probably connected with the same orogenic disturbances.

Dawson shows on his map of 1885, volcanic agglomerates which he places in the Cretaceous of the Crowsnest pass. Knight, who has studied the petrography of these rocks, calls them "analcite trachyte tuffs and breccias."[1]

The famous Montana petrographic province, one of the most important provinces yet studied, has been described by Weed and Pirsson. In the various igneous masses included in this 'province,' in which direct evidence could be obtained, the age of intrusion is always post-Cretaceous. These occurrences referred to are Castle mountain;[2] Little Belt;[3] Judith;[4]

[1] Knight, C. W., Can. Rec. Sci., Vol. 9, No. 5, 1904, p. 265.

[2] W. H. Weed and L. V. Pirsson, U. S. G. S., Bull. 137,1896.

[3] W. H. Weed and L. V. Pirsson, U. S. G. S., 20th Ann. Rept., 1900, p. 271.

[4] W. H. Weed and L. V. Pirsson, U. S. G. S., 18th Ann. Rept., 1897, p. 437.

Highwood;[1] Crazy;[2] Little Rocky;[3] and Bearpaw[4] mountains.

For lack of better evidence the Ice River intrusion may be regarded as Post-Cretaceous in age and earlier than the Laramide revolution.

COMPARISON WITH OTHER OCCURRENCES OF ALKALINE INTRUSIVE ROCK.

The Ice River complex presents certain features that are rare in most occurrences of these alkaline rocks, which havc been described from other parts of the world. It differs from other occurrences in that all the rocks contain nephelite, either essential or accessory, or are alkaline in composition. This complex has an area of 12 square miles, and the rock types are all very closely related to a nephelite syenite or ijolite and thus differ from other occurrences described. Alkali syenite or quartz-bearing rocks are entirely lacking in the Ice River area. Considering the diverse rock types represented in the Ice River, it most closely resembles the foyaite-theralitic rock of Tasmania, described by Paul,[5] and Magnet Cove igneous complex described by H. S. Washington.

It differs from the Bancroft, Ontario, occurrences in that a gneissoid or foliated structure is absent,[6] and essential pyroxene is present more frequently than amphibole or biotite. The last mentioned feature, together with the absence of corundum, causes it to differ from the Siwamalai series in India. The Ice River diverse types represent a single contemporaneous intrusion, while in the Christiania district of Norway, Brögger[7] recognizes a succession of eruptions beginning with the most basic types and forming a continuous series to the most highly alkaline types. He divides the series into six groups of which

[1] W. H. Weed and L. V. Pirsson, U. S. G. S., Bull. 237, 1905.

[2] W. H. Weed and L. V. Pirsson, U. S. G. S., Folio No. 56.

[3] W. H. Weed and L. V. Pirsson, Jour. of Geology, Vol. 4, 1896, p 399.

[4] W. H. Weed and L. V. Pirsson, Amer. Jour. Sci., Ser. 4, Vol. 1, 1896, p. 283.

[5] Paul, F. P., Tschermaks Min. Pet. Mitt, Vol. 25, 1906, p. 269.

[6] Adams F. D. and Barlow, A. E., Geol. Survey, Canada, Memoir No. 6, 1910, p. 329.

[7] Brögger, Zeitschrift fur Kryst. u. Min., Band 16, 1890.

the sub-alkaline basic magma represents the one end of the series and a biotite granite the other end, followed by dyke intrusion.

The closest analogy to the Ice River types is apparently the Magnet Cove occurrence.[1] In both localities the various types represent a contemporaneous intrusion. The complex has the form of an irregular laccolith with a probable stock-like feeder. The types in both range from a foyaite through an ijolite as an intermediate type to a jacupirangite. All types are closely related and are transitional into one another. Nephelite is present in almost all and especially in the intermediate types. Pyroxene is the principal dark constituent and varies from ægirite to ægirite-augite. Amphibole and biotite are most abundant in the more basic types. Although CaO is abundant, especially in the intermediate types, yet there is no anorthite present. There must be some lime in the pyroxene. As SiO_2 increases in the rock, K_2O, Na_2O, and Al_2O_3 increase and MgO and FeO decrease. This shows that the intrusion in both localities is a continuous one. These, however, differ in that the Magnet Cove complex is basic at the centre and acid round the margins, whereas in the Ice River laccolith in that portion of the chamber in which the magma had a chance to differentiate, the more alkaline, lighter portion of the magma has risen to the roof of the chamber and the heavier minerals have settled to the bottom.

Other occurrences which correspond to the Magnet Cove type are the Umptek laccolith of Kola peninsula, Finland, described by Ramsay and Hackmann,[2] the laccolithic mass of Ramnas, Norway, described by Brögger,[3] and the Castle Mountain stock in Montana described by Weed and Pirsson.[4]

A close associate to the Ice River laccolith is that of Cnocna-Sroine near Lake Borolan, Scotland.[5] The lightest rock is at the top of the chamber and is a quartz syenite, while below this

[1] **Washington, H. S.**, Magnet Cove, Igneous Complex, Arkansas, Bull., G. S. A., Vol. 11, 1900, p. 389.

[2] Fennia, Vol. 11, No. 2, Helsingfors, 1894.

[3] Zeitschrift Kryst., Vol. 16, 1890, p. 45.

[4] U. S. G. S., Bull. No. 139, 1896, p. 134.

[5] Shand, S. J., "On Borolanite and its associates in Assynt," Trans. Edin. Geol. Soc., Vol. 9, Part 5, 1910, p. 376.

is a transition rock, which changes into melanite and augite "syenoids" and "borolanite" with depth.

DISTRIBUTION OF NEPHELITE SYENITES AND ASSOCIATED TYPES IN CANADA.

One of the most important areas in Canada is that of the Monteregian petrographic province in the vicinity of Montreal. There are eight "hills" in this province and of these Mt. Royal is the best known. These hills have been described by Adams, Dresser, Young, and others.[1]

One of the largest occurrences in the world yet known is that of Bancroft area, Ontario, described by Adams and Barlow.[2] In this locality the nephelite syenites have a schistose or foliated structure; certain types are rich in corundum. This is the only locality, other than Ice river, in which sodalite is abundant.

A. C. Lawson describes a malignite and other nephelite bearing rocks from Pooh-bah lake, Rainy River district, Ontario.[3]

W. G. Miller refers to other occurrences in the Ottawa valley and at Kipawa river, about 20 miles northeast of the south end of Lake Timiskaming.[4]

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[1]F. D. Adams, "The Monteregian Hills," J. of G., Vol. 11, No. 4, 1903.

F. D. Adams and O. E. LeRoy, Geol. Survey, Canada, Vol. XIV, Part 0, p. 23, 1901.

J. A. Dresser, "Petrography of Shefford Mountain," Amer. Geol., Vol. 28, 1901, p. 205.

J. A. Dresser, "Geology of Brome Mountain," Geol. Survey, Canada, No. 904.

J. A. Dresser, "Geology of St. Bruno Mountain," Geol. Survey, Memoir, No. 7, 1910.

G. A. Young, "Geology of Mt. Yamaska," Geol. Survey, Canada, Vol. XVI, Part H, 1904.

[2]Geol. Survey, Canada, Memoir No. 6, 1910, p. 227.

[3]Univ. of California, Bull. of Dept. of Geology, Vol. 1, p. 337.

[4]Amer. Geol., Vol. 24, 1899, p. 276.

[4]Ontario Bureau of Mines, 7th Annual Report, Part B, 1897, p. 229.

An occurrence of nephelite syenite and associated types at Port Coldwell, Ontario, has been studied and described in detail by H. L. Kerr.[1]

In British Columbia there are two occurrences known, that of Ice river, which is one of the most important in Canada, and an occurrence of nephelite syenite and malignite from Kruger mountain, in the southern part of this Province, near the International Boundary. The latter is described by R. A. Daly in his report for the International Boundary Commission issued by the Department of the Interior, Ottawa.

A useful and extensive table has been made by Daly, which shows the occurrences of alkaline and subalkaline eruptives throughout the world, and their field associations with calcareous sediments.[2]

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[1] 19th Annual Report, Bureau of Mines, Ontario, Vol. 19, Part 1, 1910, p. 194.

[2] "Origin of Alkaline Rocks," Bull. G.S.A., Vol. 21, 1910, p. 92.

CHAPTER XI.

STRUCTURAL GEOLOGY.

GENERAL OROGRAPHIC FEATURES.

The area included in this report and shown on the geological map, lies almost entirely on the westward slope of the Rocky Mountain system, with the exception of the eastern edge of the map-area which extends eastward beyond the Continental watershed.

Taken as a unit it may be said that the structure is monoclinal with a general dip towards the southwest. The lowest beds of the sedimentary series are exposed in the extreme northeastern corner, and the highest or youngest beds are exposed in the Beaverfoot range in the extreme southwestern corner. The area is subdivided orographically into three distinct ranges; these have a northwest and southeast trend which represents the major axis of the mountain folding. These are the Bow, the Ottertail, and the Beaverfoot ranges, the last two unite north of the main line of the Canadian Pacific railway to form the Van Horne range.

The Bow range, on the east, has the highest average elevation, which is over 10,000 feet, and forms the Continental watershed. The Ottertail range occupies the centre of the area, and although the average elevation of this range is less than that of the Bow range, yet it contains the highest mountain in this part of the Rocky Mountain system, and one of the highest in the Canadian portion of the North American Cordillera. This is Mt. Goodsir, which is situated between Ice River, Moose Creek, and Ottertail River valleys. The south tower of this mountain is 11,676 feet high and the north tower is 11,555 feet. In this mountain the beds are lying nearly horizontal or with a maximum dip of 20 degrees to the east or away from Ice River valley.

The Beaverfoot range is the third and most westerly range of the westward slope of the Rocky mountains in this latitude. The strata are very much folded and broken in this range. In this respect it gives a striking contrast with the other two ranges in which the strata are not tightly folded, on account of the more massive bedded strata of which they are formed or by which they are capped.

The Ottertail and Beaverfoot ranges are separated by the broad subsequent erosion "through-valley," which in an earlier part of this report is called the Beaverfoot-Kootenay trough, since it is in part occupied by the Beaverfoot river flowing to the northwest, and the Kootenay river flowing to the southeast. This valley is formed on the very soft, highly cleaved substructure and has been modified in outline by the action of valley glaciers.

The Ottertail and Bow ranges are separated by the valley of the Ottertail which, like the Beaverfoot though less strongly defined, is formed in soft less resistant highly sheared rocks, and is subsequent to the under-structure.

All of the larger valleys are true erosion valleys which in several cases have been widened and deepened by ice action. The typical U-shaped valley formed by a valley glacier is still well preserved in those portions of some of the valleys which cut transversely to the strike of the underlying beds. It has been previously stated that the upper and lower parts of the Kicking Horse river cut across the strata regardless of the structure, while the rest of its course is subsequent on the trend of the softer rocks.

FOLDS.

The major axis of folding has a northwest and southeast trend. In the Bow range, where not modified by faulting, there is a general uniformity of dip to the southwest. This range, as before stated, shows the monoclinal structure of the Rocky Mountain system, which is much better seen east of this area.

Intense folding occurs only in areas underlain by softer rock, such as in the valley of the Ottertail and in that of the

Beaverfoot and in the range by the same name. Anticlinal, synclinal, open, closed, symmetrical, and asymmetrical folds were noted. The latter are as a rule overturned towards the southwest.

In the Kicking Horse valley between Mt. Stephen and Mt. Field, a flat anticline exposes some of the Lower Cambrian beds in the bottom of the valley. The major axis of this fold has a general north and south trend. A similar trend has also been noted in several other open folds with only slight compression; these are not as characteristic as those with the regular northwest and southeast trend. This feature seems to suggest that the period of folding in the Rocky mountains was initiated by compressive stresses which came from the east and west, and that later the major axis of compression became northeast and southwest, resulting in mountain building folds of the first dimension.

In Mt. Ogden and to the east of Cathedral mountain the beds turn down sharply to the northeast but again come up in Mt. Bosworth, thus forming a small syncline.

In the area underlain by the sheared rock in the Ottertail valley and represented in the map by the sheared portion of the Chancellor formation, the beds have been intensely folded. Along the northeastern side of this zone the most intense folding has occurred, while the folds gradually flatten out towards the centre of the valley and assume a gentle undulating or monoclinal dip in the Ottertail range. This close folding is well exposed in the shoulder of Mt. Duchesnay between the top of this mountain and the pass by the same name. The beds are so tightly folded that they present in some places an isoclinal structure. The depth of some of these folds is over 2000 feet.

It is a noteworthy feature of much importance, that in every case where the determination could be made, the folding was always older than the shearing, and earlier than the laccolithic intrusion of the Ice River complex.

The structure in Ice River valley is anticlinal as is shown in section (I-J). This period of folding was before the intrusion. The beds in the cover of the igneous body were further up-arched by the intrusion which, as has been stated before, presents the mechanics of a laccolith.

The sub-structure of the Beaverfoot valley is largely concealed by the surficial deposits, but where observable the beds show evidence of open folding. In the Beaverfoot range the beds are overturned to the southwest and faulted in the several places.

CLEAVAGE.

Evidence of cleavage and intense shearing is found in every part of the area, to some degree depending upon the texture and softness of the rock. Shearing is most intense in the Ottertail and Beaverfoot valleys.

In the more massive-bedded quartzites of the Lower Cambrian formations in the sedimentary series, cleavage is shown only in the interbedded thin layers of siliceous shale or fine-grained argillaceous sandstone. The cleavage lines extend from top to bottom of such layers but do not extend into the massive beds. This feature is well exposed at the side of the railway, 1 mile east of Field.

The strike of the principal cleavage planes is N. 65° to 75° W. and the average dip is 60° to 85° S. W., although frequently the dip may be locally very much less, or vertical, or to the northeast.

In the Ottertail valley the cleavage planes are much more prominent than the bedding. The latter is usually clearly seen on the cleavage faces of the slate, sometimes as distinct bands but more frequently as minute dark lines in the finer textured beds.

There is another but less conspicuous set of cleavage planes which cut across the prominent cleavage at nearly right angles. These are well seen along the railway between Ottertail station and the "Leanchoil bend," and cause the highly cleaved rock to break up into angular fragments. These planes have a general strike of S. 35° W.

There are other cleavage planes shown in the highly cleaved argillites and slates of the area. On the railway near Ottertail station the soft beds break into angular fragments along four distinct planes and one which is less distinct. Three of these are cleavage planes and two are probably jointing planes.

In many places in the Ottertail valley the cleavage planes are distinctly shown cutting across the folds, so that, as stated above, the period of shearing is later than the folding and also later or towards the close of the intrusion. Around the laccolithic mass and especially well exposed in Chancellor ridge, the softer sediments have been tightly squeezed against the more resistant igneous rock, so that in some places the sediments have been shoved over the edge of the laccolith. In one case a block of the igneous rock is found in Butwell peak with the limestone sheared about it, thus showing that the igneous intrusion is prior to the period of shearing. The shearing belongs to the main period of diastrophism, which is Laramie in age in the Rocky mountains, while the folding and intrusion are Post-Cretaceous or at least younger than the deposition of the Cretaceous beds in the eastern part of the Rocky mountains.

JOINTS.

Jointing is not a characteristic feature of the rocks in this area; the best example is exhibited in the thick beds of limestone on the top of Mt. Bosworth. There are two planes of jointing sometimes nearly at right angles, but there does not seem to be any regular trend to these planes, although one set frequently has an east-west bearing. A similar jointing occurs in the flat-lying Eldon limestone in the amphitheatre at the head of Cataract valley, to the east of Mt. Stephen amphitheatre. Here the surface water has dissolved out channels a few inches wide and several feet deep along these joint planes.

FAULTS.

Faulting is an important and prominent structural feature in the area. The faults are normal in character, and in this respect the westward slope of the Rocky Mountain system in this latitude differs from the eastward slope, in which reversed and overthrust faults prevail.

There are two principal systems of faults represented. The one which includes most of the large breaks has a northwest and southeast trend which corresponds to the major axis of the mountain folds. The other system has a north and south trend and the faults are apparently younger than the others. There are numerous minor breaks and slips which are not of significant importance.

The most important fault with a northwest and southeast trend has, in this paper, been called the "Stephen-Dennis" fault. This break passes to the west of Mt. Stephen amphitheatre and turns the strata down deeply at the fossil bed in Mt. Stephen. Its course has not been mapped on the north side of the Kicking Horse valley. It continues to the southeast across Odaray pass and to the south of Park mountain. This break forms in part the eastern border of the sheared zone which is shown on the map as underlying Ottertail valley. The downthrow has been to the west, as is shown in section (C-D). The exact shade and amount of displacement could not be determined on account of the broken character of the rocks to the west.

Another fault with similar trend follows along the west side of the ridge of Mt. Hunter in the Van Horne range. Only the lower end of the ridge to the east of Leanchoil is shown on the map. The higher beds are exposed on the southwest side of the break and the fault plane is nearly vertical.

The northeast slope of the Beaverfoot range is traversed by another fault with northwest and southeast trend.

Of the system of faults which have a north and south trend, the largest fault is the "Stephen-Cathedral" fault (so called in this paper because it is best exposed between the mountains of the same names). By it the Lower Cambrian quartzites in Cathedral mountain are faulted up against the upper Middle Cambrian beds in Mt. Stephen. There is a displacement of more than 3000 feet, with the downthrow to the west, and a hade between 75 and 85 degrees to the west. This break continues up the Yoho valley cutting across the east slope of Mt. Field. To the south it passes over Odaray pass and becomes lost in the sheared zone. This fault is younger than the Stephen-Dennis break, as the latter is displaced over half a mile at Odaray pass. The map shows the trend of this north-south fault. Another fault, with almost vertical dip, is a branch of the Stephen-Cathedral fault. It runs along the north side of Mt. Odaray, across Lake McArthur, and through Biddle pass, where the Lower Cambrian quartzites in Mt. Biddle are faulted up against the Middle Cambrian in Park mountain. This break cannot be traced into the sheared zone. Section A-B shows the steep dip of these fault planes.

On the east shoulder of Cathedral mountain and near the mouth of the valley of Cataract brook, the beds are turned down very steeply to the east, but again turn up in Mt. Bosworth.

There is a normal fault exposed on the ridge connecting Paget peak with Mt. Bosworth; with the downthrow to the west. Walcott states that this fault "brings the base of the Paget formation up about 500 feet" in Buff point.

Another small break is shown on the east shoulder of Mt. Bosworth; the lowest beds are again exposed on the eastern side of the fault.

In the Ottertail range there are several small faults. In Ice River valley, on the ridge west of Mt. Mollison, a fault, with downthrow to the east, cuts the sediments but not the igneous rock, so that it is earlier than the intrusion. It is not connected with the two principal systems of faults.

To generalize as to the age of faulting, it may be said that there was some faulting before the period of intrusion, but the principal northwest and southeast faults were formed after the shearing during a period of tension, as the faults are all normal. These may be regarded as representing a recoil after a period of compression. The north-south breaks are younger than the northwest-southeast ones.

FISSURES.

Fissures are of importance from an economic point of view. Some of these have acted as channels for ore-bearing solutions. Many of these fissures contain small pockets of lead, zinc, copper, and silver ores. There is no general trend to them and they are found in the igneous rocks as well as in the sediments. In the former they are sometimes filled with such minerals as cancrinite, sodalite, wollastonite, calcite, or actinolite. The fissures were probably formed by the same forces that produced faulting.

CHAPTER XII.

HISTORICAL GEOLOGY.

FORM BEFORE MOUNTAIN BUILDING.

The changes in the form of the surface that took place during the period of mountain building of the various ranges in the system have been so varied and so extensive that any statements regarding the character of the surfaces are of conjectural value only. Davis, and possibly a few others, believe that the area now occupied by the Rocky Mountain system, after it ceased to be a basin of deposition had an initial dip towards the east. It became deformed by folding, was base-levelled by erosion, later uplifted during the Laramide revolution, and finally carved by erosion into its present form. There does not seem to be any positive evidence for such wholesale levelling of the primary folds prior to the final deformation. The approximate accordance of summit levels does not necessarily imply an old, base-levelled surface.

SEDIMENTATION.

The old land, from the erosion of which the sedimentary series represented in this area was derived, lay to the west. That part of the North American Cordillera east of the Rocky Mountain trench has been called by Daly the "eastern or Rocky Mountain geosyncline," while that west of this trench is the "western geosyncline." This western portion of the Cordillera was the land area which supplied the material for sedimentation in the eastern basin.

It has been previously stated that the oldest rocks in the map-area are of Pre-Cambrian age, and consist of quartzitic sandstone and siliceous shale. At the top is a basal conglomerate, the composition of which suggests a close point of origin. Walcott believes that these Pre-Cambrian sediments were laid down in an enclosed sea of fresh water, and that the Cambrian sedimentation began with a downsinking and introduction of marine conditions.

The Lower Cambrian sediments, which are almost entirely ferruginous quartzites, have been deposited in a shallow sea although not necessarily very near the shore as the texture of these beds is remarkably uniform and pebbles are absent. The presence of cross-bedding in certain layers also suggests a shallow water origin for these sediments.

Certain facts may here be noted regarding the conditions of sedimentation that prevailed in this area during the Cambrian and at least to the close of the Goodsir epoch in the Ordovician. During this time there were no orogenic movements great enough to produce unconformity in sedimentation, although the very abrupt change from the quartzites of the Lower Cambrian to the limestones of the Middle Cambrian might represent sudden oscillation in the level of the sea floor, with deeper water sedimentation.

The whole of the Middle Cambrian and the Upper Cambrian to the top of the Sherbrooke formation is essentially formed of limestones, calcareous, dolomitic, and arenaceous. This indicates a very long period of stable and quiescent conditions with a few slight oscillations to account for more shaly layers. These formations have a total thickness of 8550 feet, which must represent an extremely long period of clear water conditions.

A gradual change in the levels occurred, resulting in muddy water conditions, which gave rise to the shales of the Chancellor formation. The remarkable uniformity of these shales, over 4500 feet thick, indicates a long period of extreme quiescence. The terrane from which this material was derived contained much iron as is indicated by the persistent red-weathering habit of these beds. It has been suggested that the ribboned character of some of these beds within the sheared zone can be accounted for, not by continuous oscillations of levels, but by seasonal variations.

An abrupt return to clear water conditions initiated the deposition of the Ottertail limestone which is over 1700 feet thick. An equally sudden change brought this form of deposition to a close and opened the period during which the Goodsir formation was deposited. This formation is over 6040 feet thick, and, therefore, much thicker than any of the other formations, but this does not indicate a longer period of deposition, for the rate at which sediments accumulate will depend upon the character of the sediments. Since the beds are not all uniform in composition within this formation, there were frequent oscillations in levels to account for such features.

INTRUSION AND DEFORMATION.

Intrusion, from the evidence at hand, appears to have followed a period of orogenic deformation during which the strata were folded into long ridges. The intrusion was followed by more intense orogenic disturbances which tightly cleaved the strata along planes running directly across the folds, but the strata so affected are mainly confined to an area extending parallel to the axis of folding, i.e., northwest-southeast. The folding was followed by a period of normal faulting, which indicates tensional stresses in the earth's crust and may be regarded as the recoil from a long period of intense compression. In areas where the deforming forces were not so intense, fissures and fractures were formed, many of which later became filled up. Since then erosion agencies have been constantly at work, sculpturing ranges, ridges, and mountain peaks.

The erosion cycle of today is in a young mature stage. There are no interstream areas, the ridges are knife-like, serrate in character, and the streams are still cutting down their channels.

The exact age of the intrusion is not definitely shown, but the evidence at hand makes it probably post-Cretaceous, or about contemporaneous with the Laramide revolutions which caused the main crumpling or distortion of the Rocky mountains. It would seem that the folding began towards the close of the Cretaceous, after the deposition of the Cretaceous beds in the eastern part of the mountain system. There was some faulting of a minor degree accompanying the folding. This was followed by the intrusion of the alkaline complex which was a continuous intrusion of a laccolithic nature, so that the sediments in the cover were further arched up. The closing stage of intrusion is represented by aschistic and diaschistic dykes, which are few in number and quite narrow.

GLACIATION AND RESULTING TOPOGRAPHY.

Since the melting out of the ice, erosion has been both degradational and aggradational in its result. Many of the basins left by the ice on the valley floors have become aggraded, while in other valleys or in other parts of the same valleys that contain aggraded basins, the streams are deepening and widening their channels in the underlying structures.

The action of frost, rain, and wind is rapidly narrowing the interstream ridges, sharpening the higher mountain peaks, and levelling the lower ones.

CHAPTER XIII.

THEORETICAL CONSIDERATIONS.

PROBABLE EXISTENCE OF A DEEPER IGNEOUS BODY.

The Ice River complex is the only igneous rock exposed in this portion of the Rocky Mountain system. Dawson mentions a much smaller igneous mass about 50 miles to the southeast in the Mitchell range. The sediments under the Ice River laccolith are altered more or less, but the same degree of metamorphism is so widespread that it can be accounted for by regional disturbances and not by contact effects produced by a deeper and larger magma reservoir. On the other hand there are numerous mineralized fissures, veins, and beds, within a radius of 10 miles of the Ice River laccolith. The mineralizing solutions have come from below, and probably from a more extensive igneous mass which has not yet been exposed by erosion.

Dawson in his report of 1885 (p. 116 B) states that the limestones to the west of White Man pass, 50 miles to the southeast of Ice river, are locally, intensely metamorphosed and recrystallized. This feature strongly suggested to him the presence of another intrusive mass near the surface, though it has not yet been actually exposed by denudation.

The writer believes that a larger and more extensive intrusive body underlies that of the Ice river. From this larger reservoir it seems probable that the more alkaline and less dense portion occupying the upper part has been forced up into the higher chamber.

METHOD OF INTRUSION.

It has been previously stated that this complex has the form of an asymmetrical laccolith with a stock-like feeder. The presence of a small fault in the sediments of the cover and not extending into the igneous rock, suggests that the intrusion was initiated along this break. The feeder was widened by the breaking away of the limestones about the edges. When the magma reached the horizon between the massive limestone of the Ottertail formation and the underlying soft shales, it spread out, especially towards the north, as the fold was much steeper towards the south in what is now Mt. Mollison ridge. The lowest horizon at which the igneous rock is found is at the base of this limestone formation. Some of the material gradually worked its way up to the centre of the Ottertail limestone where it forced its way along a softer shaly band which has been metamorphosed into a hornfels. The limestone formation was forced apart, and in this way the sill-like, northwestward extension of the complex was formed. As the magma extended northwards from the main feeder it cut gradually across the overlying beds, as might be expected, until in some parts of the complex it occurs in the shales of the Goodsir formation above the Ottertail limestone. It has been noted that the Ottertail limestone forms the cover wherever it is exposed along the southern, steeply dipping contact. This massive rock was most easily acted upon by the hydrostatic pressure accompanying the intrusion, so that it was lifted up by the magma. If the viscosity of the magma was very high, and there is reason to believe that it was, a certain amount of the hydrostatic force would be used up to overcome the internal viscosity of the magma, and the external effect would not be so great as it would if the magma had been less viscous. A magma cannot, theoretically, be regarded as a liquid on account of the viscosity. The complex represents a continuous intrusion which later separated into the diverse types that compose it.

EVIDENCE AND CAUSE OF DIFFERENTIATION.

The rocks of the Ice River complex present an interesting case of a magma which has become differentiated into diverse types. It has been noted that the complex is made up of a series of rock types all of which are transitional into one another. It is not possible to explain this separation of the magma by any single process, but rather by several processes which have been active, probably before, during, and after intrusion.

A comparative study of many of the nephelite syenite and other alkaline rock areas of the world has been made by R. A. Daly.[1] He shows that in 107 out of 155 localities tabulated, the igneous rock is connected with limestones or carbonate rocks. From these facts he has formulated the hypothesis that alkaline rocks have been formed by the absorption of limestone in a molten magma. This carbonate material has acted as a flux and the parent magma has become desilicated into one more highly alkaline.

The Ice River complex is a very strong case in favour of this hypothesis. In order to get to its present position the molten material had to travel through at least 10,000 feet of limestones or highly calcareous sediments of Cambrian age, and 3000 feet of more or less calcareous shales.

The variation into rock types within the complex occurred, essentially, after the intrusion. The magma which first entered the thinner portions of the chamber, cooled before it had time to differentiate completely, but a partial separation had occurred during intrusion. This feature is shown in the northwestern arm from the main part of the igneous mass. In this portion of the complex there is no well-defined distribution of the types, and nephelite syenite or the extreme alkalic differentiate is lacking. Irregular patches or schlieren are abundant in this part of the complex, but it has been previously stated that these schlieren are well crystallized, frequently coarsely granular, porphyritic or pegmatitic. The magma in the thinner edges of the laccolithic chamber would have separated into various portions if it had remained molten long enough or had had a very low viscosity.

The very incomplete separation in this part of the chamber suggests that the viscosity must have been enormously high, and that the diverse variations are due to chemical or physico-chemical forces. A partial segregation of certain groups of minerals, whether in a solid or liquid phase, before the magma

[1] "Origin of Alkaline Rocks," Bull. G.S.A., Vol. 21, 1910, p. 87.

had reached its present position, would account for many of these schlieren. The numerous porphyritic phases within this portion of the mass would suggest that the magma had a very high viscosity.

In the thicker portion of the laccolith which may in part be stock-like in character, the magma remained molten for a very much longer time with the result that physical changes became active. A separation occurred by gravitative differentiation, the alkalies rose to the top of the chamber, while ferromagnesium "cafemic" minerals sank to lower levels. This feature is shown in Zinc mountain where nephelite syenite occurs at the top, ijolites farther down, and the extreme femic differentiates on the floor of the chamber. Fluidity of the magma was probably kept up longer in this deeper portion of the complex, by the fluxing effect of the limestone which had become assimilated in the magma. Field evidence shows that a portion of this highly alkaline magma remained fluid long after the remainder had solidified, because sheets or dykes of the nephelite syenite, and in a few cases, sodalite syenite have filled contraction cracks due to cooling, which were formed in the melanocratic types. It has been shown that although the diverse rock types in the complex represent a contemporaneous intrusion, the dark coloured types have always solidified first.

In the stock-like portion of the complex, where a physical change has caused the magma to separate into diverse types, the result has been that as the heavier minerals sank, the residual upper portion of the magma became most alkaline and lower in silica with an absence of iron-magnesium constituents. Such are the facts shown in the field, as well as in the results of specific gravities of various rock types which are tabulated on a succeeding page. The rock on the extreme roof of the chamber is sodalite syenite which has the least specific gravity of any of those determined. This rock is usually free from coloured constituents. The nephelite syenite also occurs in the upper part of the chamber, whereas those varieties rich in sodic or sodicalcic feldspar are found at lower horizons. There is a foyaitic texture in some parts of the nephelite syenite area. This phenomenon may be explained as the result of convection currents after differentiation and before crystallization had proceeded far. No definite evidence could be found in the field to prove this possible explanation, but it is mentioned here as a suggestion.

The addition of CaO to the parent magma has caused the formation of ægirite-augite and andesine feldspars in some cases. These minerals have sunk to the deeper portions of the chamber. Experimental results show that similar changes can take place in a magma.[1]

A chemical study of the diverse types in this laccolith is a problem for future research.

ASSIMILATION.

Contact.—In discussing the structural relations of the igneous complex, it was mentioned that there are a few blocks of the overlying sediments enclosed in the igneous rock. There has been a small amount of assimilation along the contact. The microscopic study of certain rock types suggests such a chemical change. The dissolved limestone has added CaO and CaO_2 to the magma, thus disturbing its chemical equilibrium. These new components have probably caused the formation of such pyrogenic minerals as calcite, cancrinite, perovskite, and melanite. The calcite is a primary constituent of the rock. The simplest explanation for its presence is that given above. Primary calcite has been found in several other occurrences of nephelite syenite, and even of certain granites.

Adams and Barlow state that the calcite in the Bancroft occurrence of nephelite syenite represents the residual grains of blocks of limestone which have become broken up and fused. In the Ice River occurrence the writer believes that blocks of limestone have become assimilated by the magma to supply the carbonate constituents, and that the calcite crystallized out of the magma similar to and along with the other constituents of the resulting rock.

[1]Vogt, J. H. L., T.M.P.M., Vol. 27, 1908, p. 134.

At a few places near the lower contact the effect of the limestone has been to make the feldspar more calcic than it is in the normal rock.

Abyssal.—There is no visible evidence of absorption of the enclosing sediments, but as suggested, when discussing differentiation, it seems probable that much limestone about the pipe or stock-like feeder of this complex has been dissolved by the intruding mass. The effect of the addition of this carbonate material would be to cause a desilication of the magma, and a more alkaline magma would result, as has been suggested by Daly.

On this hypothesis the deeper sub-crystal reservoir would contain material much less alkaline and nearer the primordial basalt. It is interesting to note that the only other intrusive mass yet recorded in the Rocky mountains, north of the 49th parallel, consists of diorite. This mass is mentioned by Dawson in his 1885 report, and occurs about 50 miles southeast of the Ice River complex. This suggests that there may be a deeper reservoir of more basic material than that represented by the Ice River laccolith.

Table of Specific Gravities.

Specimen No.	*Type.*	*Sp. Gr.*
A 504.	Sodalite syenite	2·455
A 550.	Sodalite (vein material)	2·464
A 400.	Nephelite syenite	2·605
A 400.	Foyaite	2·609
A 511.	Nephelite syenite (coarse grained)	2·612
A 440.	Foyaite with ægirite and sphene	2·657
A 529.	Tönsbergite	2·721
A 445.	Hydronephelite syenite	2·578
A 392.	" " (upper contact)	2·596
A 384a.	Ijolite (analysed) (hornblende-ijolite	2·892
A 385.	"	2·919
A 564.	Ijolite	3·091
A 360.	Jacupirangite (bomb-like schlieren)	2·919
A 538.	"	3·380
A 457.	"	3·471
A 536.	Cortlandite (hornblendite)	3·146
A 543.	Schorlomite	3·809

CHAPTER XIV.

ECONOMIC GEOLOGY.

GENERAL CHARACTER OF ORE DEPOSITS.

There are several localities within the map-area at which ore has been located, but with one exception, very little development has been done on them. In many cases the ore occurs in small pockets of minor importance. In most cases the ore contains argentiferous galena and sphalerite. Copper occurs in some of the smaller prospects.

In almost all the localities noted, the ore occurs in or closely associated with fissures or sheared zones. The ore occurs chiefly in the Middle Cambrian limestones, or in the Chancellor formation of the Upper Cambrian, but small pockets have been found in the Ottertail formation of the Upper Cambrian and also in the Lower Cambrian. The ore-bearing solutions have followed up fissures and replaced or spread out in the softer or more highly shattered beds above. None of the beds can be definitely connected with the igneous complex exposed in the Ice River district, which is the only exposed mass of igneous rock in this portion of the Rocky mountains. It has been suggested that the presence of these widely separated mineralized areas may indicate a broader extension of igneous rock not yet exposed. With the exception of the Monarch mine in Mt. Stephen, no extensive development has been carried on in any of these deposits. All the known occurrences of ore will be mentioned, but those of minor importance only briefly.

MONARCH MINE.

Location.

The Monarch mine is situated about 3 miles east of Field, in the precipitous face of Mt. Stephen, and 1000 feet, almost vertically, above the Canadian Pacific railway. The outcrop of the ore was first located as early as 1885, and it is one of the earliest mines opened and worked in British Columbia. It has not always been called by the same name and the property has changed hands several times. At the time this examination was made the property was owned and mined by the Mt. Stephen Mining Syndicate, of which Mr. J. A. Thomson was managing director with headquarters in Vancouver.

Character of the Deposit.

The ore body occurs in a band of bluish grey limestone about 300 feet thick, which has, on the weathered surface, a slightly pinkish colour. The limestone belongs to the Cathedral formation which is at the base of the Middle Cambrian. The rock is fissured nearly vertically by a major fissure which strikes approximately S. 10° E. There are a series of cross fissures which strike nearly east and west.

There is a well marked zone of sheared rock which can be readily seen from the opposite side of the valley or from the floor of the Kicking Horse river. This zone in its widest portion is approximately 500 feet wide, but it is not possible to examine it close at hand, as it occurs on the vertical face of Mt. Stephen. It cuts diagonally across the bedding of the Cathedral limestones and finally pinches out on the southwest side of the mountain about 800 feet higher up, and close to the base of the Stephen formation. In the mine workings, the zone where exposed, consists of a shattered mass of rock. The fragments are cemented together by calcite or by ore, so that in some places the limestone band appears as a typical shatter breccia. The blocks vary from a few inches in diameter to several feet. The ore minerals, which are essentially galena, sphalerite, and pyrite, occur on and near the major and cross fissures, and also in the cementing material about these shattered blocks.

When the fragments of limestone are small the ore minerals may form the larger part of the cement or may frequently impregnate the blocks themselves. In some cases, but not always, there is an enrichment of ore at the junction of two fissures. In other places there is a replacement of the carbonate rock by the ore minerals, and pockets of almost pure mineral, principally galena, occur. Some of these pockets already opened up are over 10 feet in diameter. It is difficult to outline the form of the deposit as it is now developed, because a large "horse" of the shattered limestone sometimes displaces the ore body several feet in any direction. The main north-south fissure which has been followed for about 250 feet seems to branch into several smaller ones at the inner (south) end. A fault with small apparent displacement has cut off the ore body at this end. The upthrow has been on the south side of this break which strikes nearly east-west. The floor of the ore body consists of a much more massive block of siliceous dolomitic limestone, which has been less shattered about the fissure and which contains very little ore. A zone of pyrite seems to mark the lateral extent of the ore-enriched rock. The sphalerite occurs usually intimately associated with the galena, although it is occasionally found alone in certain parts of the deposit. The sides of the larger fissures are usually highly oxidized and some contain from 2 to 5 inches of gouge clay. Assays show that the galena carries a maximum of 5 ounces of silver to the ton, but the sphalerite does not contain any of this metal.

In general it may be said that the ore occurs along and about a series of cross fissures, sometimes replacing the limestone and cementing together fragments of the shattered rock. The ore solutions have also spread out along the bedding plane on top of the more impervious underlying dolomitic limestone, giving the deposit the general form of a blanket lode.

The ore solutions have come up through the fissures and spread out into and replaced the shattered limestone in the sheared zone. It seems possible that the ore enrichment will continue in the same irregular manner so far as the shattered zone extends both laterally and vertically.

General Development and Equipment.

Until recently the only means of access to the mine was by a trail which leaves the railway about ½ mile farther east in the base of Cathedral Mountain. The trail passes around the cliff, clinging to a slightly projecting harder band of blue siliceous and dolomitic limestone, and supported in places by brackets. It finally reaches an apparently inaccessible point at which the ore body outcrops and from which a tunnel has been driven into the mountain.

The property is now owned and operated by the Mt. Stephen Mining Syndicate with office in Vancouver.

For the last four years development has been carried on during a part of each year. In June, 1911, the company, under the direction of Mr. H. H. Lavery, M.E., began to build a concentrating mill which was completed in February, 1912. Since that date operations in both mine and mill have gone on continuously.

It is a gravity concentrator, 140 by 60 feet in 5 bents, and is situated beside the main line of the Canadian Pacific railway. It has a capacity of 80 tons per day and is being operated near its maximum. The company expects to enlarge it in the near future.

The power is supplied by a 4-foot Pelton wheel with a 2½ inch nozzle under a head of 280 feet, capable of developing 140 horse power of which only about 110 horse-power is required at present. The pipe line is 1706 feet long, is of wood, and is 12 inches in diameter. The water is taken from Thomson creek which flows between Mt. Stephen and Cathedral mountain. A dam 20 feet wide and 10 feet high has been constructed to hold the water supply. Since the creek is glacial fed, the supply of water diminishes in the autumn and finally ceases to flow in the winter. To overcome this difficulty, during the winter of 1911-12, a 100 horse-power slide-valve engine and 100 horse-power boiler with Wainwright feed water heater, were installed to supply the power to the mill and mine. This method has proven unsatisfactory, and it was stated by the management when the writer visited the mine, that it would be changed to an installation with gasoline or oil as fuel. Water power can also be obtained from the Kicking Horse river.

The mill equipment consists of a Blake type jaw crusher, 8 inches by 12 inches, crushing to 1½ inches; one set coarse rolls to $\frac{1}{2}$ inch; one set fine rolls to $\frac{3}{32}$ inch; two sets of trommels $\frac{3}{32}$ and $\frac{1}{16}$ inch respectively; 3 Yeatman hydraulic classifiers; one 4-compartment Hartz Bull jig; two sets of 3-compartment Hartz jigs; 3 Deister No. 2 tables; one Deister No. 3 slime table; one Wilfley table; one Baltic dewatering and settling tank; two set elevators, both belt types; also two bins for lead concentrates and two for zinc concentrates. The light for the mill, mine, and office is furnished by a 10 K.W. generator. An air compressor with a capacity of compressing 250 cubic feet per minute furnishes the power for the mine. The compressor is a single stage, of Canada Foundry Co. make, and delivers air at pressure of about 90 pounds per square inch at the mine.

The ore is brought down from the mine by an aerial tram of the Leschen two-bucket type. The bucket holds about 1500 pounds of ore. The tram is 1000 feet in length and has a drop of 186 feet between terminals. The lower terminal is at the mill and the upper one connects with a tipple in the face of the mountain. From the tipple there is a 300-foot tunnel, and an ore chute 475 feet long with a 60 degree slope. The upper end of this chute is beside the old trail around the cliffs, 1000 feet above the railway. From this point a tunnel 211 feet long has been completed, and a raise 185 feet at a 60 degree slope connects with a central point in the mine. A 12 horse-power gasoline engine is situated at the tipple to run a hoist from the railway below.

Mr. J. J. Crothers is superintendent of the mill and mine and Mr. C. A. McKay is in charge of the mill. The writer wishes to thank these gentlemen for their courtesy while visiting the property, and also Mr. Thomson for much helpful information regarding the operation of the mine and the mill.

Method of Milling.

The ore is dumped in a bin at the lower end of the aerial tramway, goes through the jaw crusher which reduces it to less than 2 inches in diameter, to the coarse rolls, and is elevated to the trommels. The oversize from the first trommel goes to the bull jig and undersize to the second trommel, from which the oversize goes to the jigs, and undersize through the hydraulic classifiers. The spigot from the classifiers goes to the Deister slime table. The Bull jig gives the following products: first compartment gives lead concentrates with lead concentrate hutch; second compartment gives lead concentrate, the hutch going to Deister table; third compartment gives a middle product going to the fine rolls and hutch product to Deister tables; fourth compartment gives zinc concentrates with hutch going to Deister tables. The zinc concentrates are sent to the fine rolls. The 3-compartment Hartz jigs give the following separation: first compartment, lead concentrate with lead concentrate hutch; second compartment, lead concentrate to bins, hutch to Deister tables; third compartment, zinc concentrate to bin, middle product to the fine rolls, hutch to Deister tables. The zinc concentrate is obtained by placing a small ½ inch raise just around the pocket. Tails from all jigs go to waste. The Deister tables give lead concentrates which are sent to bins, middlings which go to Wilfley table, and tails to waste. The Wilfley table treating middlings only has no waste, but gives 3 products, lead concentrates, middlings, which are sent over the table again, and zinc concentrates. The concentrates are run by wheelbarrow from the bins to the cars for shipment.

Production.

The separation of lead and zinc is remarkably clean. The lead concentrates run between 64 and 70 per cent lead, with an average of 67·6 per cent, and less than 9 per cent zinc. The lead contains an average of 5 ounces of silver to the ton, but the zinc does not contain any of this metal. The zinc concentrates average 39-45 per cent zinc, 2 per cent lead, and less than 2 per cent lime. The loss in tailings is always less than 1 per cent; an average assay sample gave approximately 0·6 per cent lead and 0·9 per cent zinc. The Deister slimer saves galena which runs over 55 per cent lead. The mill feed averages 18 to 19 per cent lead and about the same in zinc.

The mill is now handling between 65 and 70 tons of ore per day and is run in 3 shifts. The average production at present is one car (40 tons) lead concentrates in 4 to 5 days. These are shipped to the Trail smelter. The zinc concentrates are being shipped to the United States at present.

Mr. Thomson has made many changes in the mill which have given a cleaner separation and has reduced the cost of production to a minimum. The mill is operated by from 2 to 3 men to a shift.

There are at present about 30 men employed in the mine and mill. The mine also is run on 3 shifts. The mine workings consist of about 1000 feet of tunnelling and overhead stoping. This includes the tunnel and raise which has been completed from the northern face of the mountain and which connect with the ore chute leading down to the tipple at the upper terminal of the aerial tram. There is no timbering in the mine, but occasional pillars of rock are left to support the roof.

A plan of the workings in 1911, before the mill was in operation, is given in the Summary Report of that year.[1] Since that time they have enlarged the workings at the inner end where the fissures are more numerous. There is very little water in the mine.

At the time when visited in 1912, 3 air drills were in use.

There is very little handling of the ore required as it is transported throughout its treatment by gravity.

BLACK PRINCE MINING CLAIM.

This claim is situated at elevation 5050 feet above sea-level in the south slope of Mt. Field. The mode of occurrence of the ore is quite similar to that of the Monarch mine on Mt. Stephen. The ore lies along a fissure which varies in width from a few inches to 6 feet. The rock is a bluish grey siliceous limestone of the Cathedral formation, that has been badly shattered along a zone which cuts across the bedding of the sediment and pinches out in the southwest slope of Mt. Field. This country rock and sheared zone is a continuation of that in which the Monarch ore occurs. The floor is the same hard siliceous dolo-

[1] Geology of Field Map-Area and Vicinity, Summary Report, Geol. Survey, Canada, 1911, p. 182.

mitic limestone band which forms the floor of the Monarch mine. The ore minerals are galena, sphalerite with some pyrite, and a very small amount of reddish coating on weathered surfaces which suggests mimetite. The ore-bearing solutions have replaced some of the country rock and have cemented some of the broken fragments in the sheared zone about the fissure.

The development, which has been done by Mr. W. T. Oke, shows that the ore body is somewhat irregular along the fissure, but the latest work shows up another pocket of galena ore in the end of the tunnel. There is about 70 feet of tunnelling done. The following assay of the ore made by Mr. H. A. Leverin, chemist of the Mines Branch, gives too much zinc for an average of the prospect: lead 16·9 per cent; zinc 21·5 per cent, and silver 0·82 ounces to the ton.

PROSPECTS IN THE OTTERTAIL VALLEY.

There are several small prospects in the valley of the Ottertail and its tributaries, Frenchman, Haskins, and Silver Slope creeks, which are the first three large creeks entering the Ottertail from the west side from its mouth. Some development work has been done on these within the last decade. All the prospects occur in the highly cleaved slates of the Chancellor formation.

There is nothing being done with these various prospects at present. The Canadian Pacific railway crosses the mouth of the valley and a good trail extends 5 miles up Ottertail river.

Each of these prospects will be mentioned briefly.

Silver Slope Creek Group.

This group consists of three claims, the Hercules, the Phoenix, and the Tamarack mining claims. They are situated at the head of the southeast branch of Silver Slope creek. The workings are at elevation 6800 feet, about timber line. On the Hercules claim a tunnel 200 feet long crosses the beds which strike S. 65° E. and dip 40° to 45° S. These beds, dipping into the mountain, consist of reddish weathering slates of the Chancellor formation. The ore occurs as small lenses in a bed of limestone 6 feet thick, interbedded with the slates, partly recrystallized, and seamed with calcite stringers. On account of its hardness this band stands out on the weathered surface. The ore minerals impregnating the limestone in irregular lenses and frequently in calcite stringers, are galena, sphalerite, and pyrite with a small amount of chalcopyrite and probably argentite.

The tunnel was started 75 feet down the slope in order to strike the mineralized band at greater depth, but the end of the tunnel is still a few yards from where the ore will be reached. These claims were originally staked out and assessment work done by Messrs. W. T. Oke, T. Hebson, and Adams. Assays of very large values have been reported from picked samples. An average sample, which the writer collected from the mineralized band of limestone, gave the following results: lead, 15·33 per cent; zinc, 6·87 per cent; copper, 0·35 per cent; silver, 4·50 ounces; gold, a trace.

Haskins Creek Prospect.

A prospect at the head of this creek was first worked several years ago by Messrs. Summers and Bullard. The workings have become filled up. The ore was largely chalcopyrite and pyrite associated with quartz as veins in slates.

Quebec Mining Claim.

This claim is situated in Quebec creek, which is the first large creek entering the Ottertail river from the west, and about 3 miles from the railway. This claim, together with the Ontario and the Empire, formed a group controlled by a syndicate. The workings on the Quebec are at elevation 4625 feet or 900 feet above the railway. There are two tunnels: the lower one is about 200 feet long and has a shaft about 60 feet deep at the inner end; the other one is 175 feet long. The country rock is red weathering calcareous slates highly cleaved and cut by quartz-calcite veinlets. In these veinlets the ore minerals are galena, tetrahedrite, azurite, malachite, pyrite, and some arsenopyrite. No work has been done on the property for over twenty years, but when in operation, a tramway, with wooden rails, about 2 miles long, was built from the workings down to near the railway, where it was intended that a spur should receive the ore. The ore was taken down in a car by gravity and the empty car hauled back by a mule. Only about 20 tons of ore were brought down when a forest fire destroyed a large part of the tramway, and development on the property was discontinued.

A large boulder very rich in similar ore minerals has been found on this slope in the woods, which suggests some other occurrence of the ore in this slope of the range.

Ontario Mining Claim.

This claim lies partly on the opposite side of the Ottertail river. A tunnel has been driven into the soft greenish slates and argillites on the north bank of the river, but has since been covered by talus.

Empire Mining Claim.

Very little development has been done on this claim. The exposure is about ½ mile up the Ottertail river from the railway. The main tunnel has become closed, but two small prospect holes show the greenish, soft argillites and calcareous slates fissured, and these breaks filled with quartz, calcite, and sericite which carry chalcopyrite, tetrahedrite, galena, and some bornite. The ore minerals sometimes occur in small pockets along fracture or between the veins and the highly cleaved slates. A vein 1 to 3 inches wide of pure galena was noted along a joint fracture, in which the galena showed evidences of having been intensely squeezed.

Sunday Mining Claim.

This claim with two others, the Monday fraction and another fraction, form another group. Of these only the Sunday will be mentioned. The workings are situated opposite those of the Empire and consist of a shaft about 100 feet deep, but now filled with water. The main tunnel is about 75 feet long and cuts across the strike of the soft, greenish calcareous slates and argillites. The ore minerals are sphalerite, galena, pyrite, chalcopyrite, with a little tetrahedrite. The gangue minerals are fluorite and calcite, occurring as veins along and across the bedding of the slate, and also in pockets along fractures or small faults. The fluorite varies from a white to greenish blue colour; one pocket of this mineral is 1 foot in diameter. There is not enough of this mineral to give it an economic value. Sphalerite is frequently associated with the fluorite. Ore minerals can be readily separated from the gangue. A small amount of development work was done during the past summer. The following assay was made from an average sample which was collected from the veins containing the ore: lead, 15·66 per cent; zinc, 31·68 per cent; copper, 3·25 per cent; silver, 5·12 ounces; gold, a trace.

The Waterloo Mining Claim.

The Waterloo mineral claim is located near the head of Moose creek on the west side of the valley. It is on the east slope of Zinc mountain, and to the southeast, east of the ridge from the south tower of Mt. Goodsir. This prospect is reached by pack trail from Leanchoil, a distance of about 22 miles. It is about 6½ miles up the Moose Creek valley from the point where this trail leaves the Kootenay trail, that is about 3½ miles farther along the Kootenay trail from the point where the Ice River trail branches off.

The workings of this claim are situated at an elevation of 7100 feet above the sea, or about 200 feet above the timber line.

Owing to the fact that the place is very inaccessible, the project will be of little use unless the ore will produce high values.

Geology and Character of the Deposit.

As this slope of the mountain is thickly covered with talus from the Zinc Mountain ridge, the only exposure on which the deposit could be studied was at the mouth of the workings, which even here is very poorly exposed. The country rocks consist of a dark, thin-bedded, siliceous limestone, dense in texture, with a strike N. 15° E. and dip 42° W. These beds are overlain by more calcareous limestones, corresponding to the limestone band which is traceable about the upper end of Ice River valley and forms the floor of the sill-like projection of the laccolithic mass. The base of the igneous mass is about 500 feet in elevation above the exposed portion of the ore body.

The ore body, so far as the very limited exposure showed, varies in width from 3 to 6 feet, and forms a more or less continuous band, conformable with the bedding of the sediments.

It has the general appearance of a "blanket" deposit. At the mouth of the uppermost tunnel, the mineralized zone has a maximum width of 6 feet and lies directly under a sheet of mica porphyry, a fine-grained, black rock, with a fine-grained groundmass and phenocrysts of biotite, some of which are 1½ inches in diameter. Microscopically this rock is an ouachitite.

The ore minerals are sphalerite, galena, chalcopyrite, pyrrhotite, arsenopyrite, and pyrite. The gangue minerals are calcite and some quartz sparsely disseminated through the ore.

The ore minerals are somewhat peculiar in occurring in individual patches of almost entirely one mineral. This is especially true of the chalcopyrite. The pyrite is well crystallized, and rather coarsely granular. It has associated with it, and enclosed in it, small patches of galena in large cubes. Sometimes a few crystals of pyrite are found within the galena. Irregular streaks and fragments of the dyke material are also impregnated with crystals of pyrite. Quartz grains form the gangue in the specimens examined. Other patches of almost pure sphalerite are associated with the pyrite; other ore minerals are practically absent where the well crystallized pyrite is found. In some of the patches of sphalerite, small, angular fragments of limestones are found, some of which are broken apart in place, the seams being filled with sphalerite, while both the fragments and the sphalerite are veined with chalcopyrite. It is difficult to say which is the youngest mineral, pyrite, galena, or sphalerite, but it seems that they may occur in the order named.

In the lower exposure, which may be slightly lower in horizon than the upper exposure and also slightly farther away from the mica porphyry dyke, the ore is principally pyrrhotite and chalcopyrite, with a very small percentage of galena or sphalerite. Pyrite in the well crystallized form is absent wherever pyrrhotite and chalcopyrite are found. These two minerals are found in irregular patches, of practically pure material. In one specimen some of the limestone of the country rock remained attached and the limestone was thoroughly impregnated with pyrrhotite grains and some chalcopyrite. This probably represents the primary stage of replacement of the country rock. There is, however, in this specimen an extremely sharp contact between a patch of pure chalcopyrite and pyrrhotite and the impregnated country rock. There are also some very small grains of pyrite in the country rock.

The gangue in this part of the deposit seems to have been entirely calcite. The calcite is well crystallized and more or less brownish in colour. Some of the crystals are almost an inch in length and enclose numerous grains of chalcopyrite, irregularly distributed about the calcite crystals.

Calcite crystals which form the gangue are impregnated with chalcopyrite to such an extent as to produce a poikilitic appearance on cleavage surfaces of the latter. Veinlets of chalcopyrite, as shown in one specimen, occasionally cut the sphalerite. On the polished surface the chalcopyrite is irregularly distributed with the grains of calcite and frequently is found enclosing, partially at least, a crystal of calcite. The pyrrhotite on the other hand is more or less bunchy and not nearly so streaky throughout the ore, and is not found impregnating the calcite in the gangue.

Paragenesis of the Ores.

The pyrrhotite is probably the oldest mineral and was the first to precipitate. The calcite was evidently formed very early, probably during the first stages of deposition; it was at least earlier than the chalcopyrite, which, where it separated out, diffused through the gangue material and even sent projections into the pyrrhotite already deposited.

Sphalerite was deposited slightly later than these others and replaced the sediments. Fragments of replaced country rock are yet found lying in the ore pockets of sphalerite. Some of the sphalerite at least had formed pockets before the chalcopyrite was all precipitated, because there are veinlets of chalcopyrite within the sphalerite.

The pyrite occurs well crystallized and is found associated with the basic dyke which overlies the upper exposure. It was the last mineral to remain in solution, and assumed an uppermost position. The galena was formed about the same time as the pyrite and probably slightly before it, since small bunches of pure galena are found in the crystallized pyrite.

The minerals may have been deposited from ascending mineralized solution. As is usually the case, the pyrrhotite is the least soluble and was the first mineral to be deposited, followed by chalcopyrite at a slightly higher level or lower temperature. These were followed in order by sphalerite, galena, and pyrite.

Origin.

It is also highly speculative to say that the solutions were probably hot, and probably directly connected, at some greater depth, with another chamber of igneous material probably similar to the one now exposed above this deposit. However, the country rock in some way has been impregnated and replaced by mineralizing solutions, the minerals being deposited separately to a certain extent.

Development.

As stated before, the workings are located at an elevation of 7100 feet above the sea and about 200 feet above timber line. The development consisted of two tunnels driven along the general strike of the sediments. The one tunnel is 250 feet long and the other about 50 feet long.

The property is now abandoned and while in the field the writer was not able to locate any person familiar with the workings. A first-class cabin is located at timber line and there is good water supply. Mine timbers can be easily obtained. The cost of transportation of ore to railway, however, would be great.

From a representative sample of the ore the following results have been obtained by Mr. H. A. Leverin, chemist of the Mines Branch:—

Lead	3·69 per cent.
Zinc....................	16·10 " "
Copper..................	1·59 " "
Iron....................	27·30 " "
Silver..................	2·90 ounces to ton.
Gold	0·05 " " "

THE SHINING BEAUTY MINE.

Although this property is known locally as a "mine," yet it would more fittingly be termed a prospect. Work has been abandoned on the property for two years. The property was owned and worked by a company under the registered name of the "Laborers' Co-operative Gold, Silver, Lead, Zinc, and Copper Mining Company" of Golden, B.C. The mine was in operation for about 3 years, but as none of the original owners are now in this region, it was impossible to get full particulars about the history of the mine.

The property is located in Ice River valley about 3 miles north of the bridge over the river, and at the head of the first large creek entering the valley from the west, which is known as Shining Beauty gulch. The nearest point on the railway is Leanchoil about 15 miles away. A wagon road was built from Leanchoil to Ice river, up the north side of the Beaverfoot valley, with the intention of extending it up to the workings. The road was never completed and is now used as a pack trail. The workings are readily accessible by a good pack trail up Ice River valley.

Geology and Character of the Deposit.

The workings have been carried on in the massive, blue limestone band of the Ottertail formation, so well developed throughout this valley. At this point the limestone lies directly above the nephelite syenite mass. The limestone band separates the lower calcareous shales of the Chancellor formation from the thick series of siliceous cherty slates of the Goodsir formation. The limestone is bluish grey in colour, and more or less distinctly crystalline.

This formation is fairly massive throughout, but on the weathered surface appears as dark grey and light grey bands from a couple of inches down to a fraction of an inch wide. Some of these bands show minor contortions and minute crumplings. The beds strike N. 35° W. and dip from 68° to 72° S. 55° W. The shearing planes are almost vertical.

The limestone has been fissured, and one of these almost vertical fissures has been filled with a vein which has a general width of about 2 feet. It is in this vein that the ore was found. The vein is constant in width and has sharply defined walls; it follows closely the strike of the limestone, and in vertical extent is readily traceable for about 1000 feet up the almost vertical cliff to the top of the ridge.

The fissure has become filled with white cryptocrystalline quartz, veined with minute stringers of calcite which frequently contains small greenish fibrous aggregations of zeolitic material. The calcite is well crystallized and sometimes encloses irregular pockets of quartz.

Pyrite, galena, and a small amount of chalcopyrite were the only ore minerals recognized in the vein. Of these, pyrite is by far the most abundant. It occurs in well crystallized form, and principally with the cryptocrystalline quartz. Sometimes joints in the vein are coated on either side with pyrite.

There are other minute dark greyish specks and thread-like seamlets in the vein, which may consist of galena and probably some silver, but this material is indeterminable.

There are irregular pockets in the limestone filled with arsenopyrite and quartz, with an intimate granular association. One of these pockets is about 2 feet in diameter, of fairly pure arsenopyrite and some quartz; about it is a zone of a few feet at least, in which pyrite, calcite, and some sphalerite and bornite are intermixed with arsenopyrite and quartz. The surrounding rock is highly stained with limonite from the oxidation of the pyrite. Arsenopyrite is not found elsewhere in the surrounding rock.

General Development.

The workings were carried on between an elevation of 6500 and 7500 feet above sea-level, while the bottom of the Ice River valley at this point has an elevation of 4700 feet.

The development consists of three almost parallel tunnels about 200 feet apart; the one above the other. They all follow the fissure vein which approximately corresponds to the strike of the limestone. The upper tunnel is 375 feet long, the middle one is about 450 feet, and the lower one is only a few feet long.

Production.

The writer was unable to find out just how much ore was actually shipped. The reported value of this ore was $20 per ton, in silver and zinc, but neither were detected in this vein. The ore was found in pockets, but these have apparently become worked out.

The operations were carried on for about three years. On the whole, the property might from its present showing be pronounced worthless, although some returns must have been received to warrant this work. It was suggested that difficulties between management and owners were responsible for discontinuing the work.

ZINC VALLEY PROSPECT.

Location.

This prospect is located on the south side of Zinc valley, a tributary of the Ice River valley, which it enters from the east about 6 miles above the mouth. The prospect is situated at an elevation of 7000 feet or about 1000 feet above the floor of

Zinc valley, and about 14 miles from the junction of Zinc creek with Ice river.

Geology.

This miniature ore body lies in a thick series of thin-bedded calcareous shales of the Chancellor formation. These shales weather readily on the exposed surface to a reddish, yellowish, or buff colour, due to their ferruginous content. Although not readily visible in some layers, pyrite and marcasite occur as minute particles.

These shales or meta-argillites are well cleaved parallel to their bedding plane, to such an extent that flags 4 feet long, 2 to 3 feet broad, and ⅛ to 1 inch thick may frequently be found. These shales where exposed in steep cliffs are readily broken away by the characteristic rapid action of erosion of the region, and fan-shaped talus slopes have resulted, some of them nearly a mile in length.

Interbedded with the shales are narrow bands of siliceous limestone 2 to 3 feet thick. It is in one of these bands that the prospect in question occurs.

Character of the Prospect.

The ore body occurs as a lenticular pocket replacing the lower part of a lens-shaped mass of siliceous limestone. The ore rests conformably on the calcareous shales, which here strike S. 75° E. and dip 30° S. 15° W. The valley is anticlinal in structure, so that here the shales dip away from the valley, into the face of Zinc mountain.

The work consists of a hole 15 feet long, which follows down on the dip of the shales in the foot-wall. In this the entire extent of the ore body is exposed. The exposed portion of the ore body is about 8 feet in maximum thickness, and extends about 30 feet along the strike of the shales. It appears to pinch out in about 12 feet down on the dip of the foot-wall. This is best seen in Figure 4.

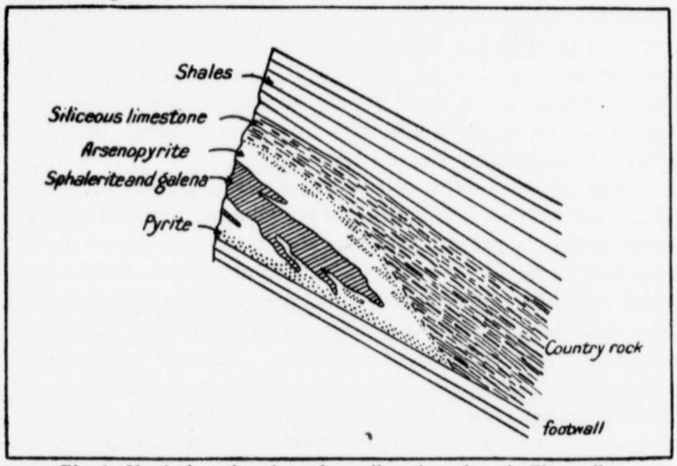

Fig. 4. Vertical section through small pocket of ore in Zinc valley.

The lenticular mass of siliceous limestone which has in part been replaced by the ore is about 75 feet long. Other boulder-like masses or lenses occur along the strike in the same horizon

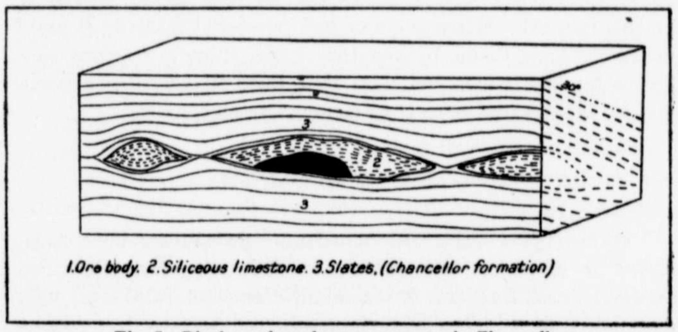

Fig. 5. Block section of ore occurrence in Zinc valley.

(Fig. 5). On account of the hardness of this siliceous band the soft slates have been cleaved about these masses of siliceous limestone.

The gangue minerals are quartz, calcite, indistinct crystals, and fragments of sericite schist. The calcite is in bunches and frequently encloses crystals of pyrite. The sericite schist is secondary and formed by later metamorphism. Irregular grains and cubes of pyrite are enclosed in minute lenses or schist. The quartz occurs in small grains, almost microscopic in size, and is associated especially with arsenopyrite which forms an irregular band within the ore body.

The ore minerals are pyrite, arsenopyrite, galena, and sphalerite. As is shown in Figure 4, the ore minerals tend to form distinct bands. In general, the outer zone consists chiefly of pyrite, especially along the foot-wall where it forms a band almost 1 foot thick. On the upper contact the pyrite forms irregular lenses. The central part of the ore mass consists largely of sphalerite enclosing a few segregations of galena. Stringers and apophysial bands of sphalerite extend into the surrounding zone, especially downwards. The zone about this core of sphalerite and within the rim of pyrite consists of a silvery grey mass of finely granular arsenopyrite and quartz.

The arsenopyrite occurs both as minute grains and also as lenticular crystals. The quartz cannot be readily seen macroscopically, but by examining crushed fragments under the microscope numerous irregular grains can be seen which proved to be this mineral. When some of this powdered material is fused in the reducing flame, besides the arsenic there is a strong sublimate for lead which indicates that there is galena in a finely divided state mixed with the arsenopyrite and quartz.

OTHER PROSPECTS.

In Porcupine creek considerable prospecting has been done. About 3 miles up the valley, at elevation 4300 feet above sea-level, small fractures in a dolomitic slate are filled with vein material, 1 to 6 inches wide, consisting of fluorite, ferruginous dolomite (ankerite), muscovite, and some lepidomelane. The ore minerals are argentiferous galena and pyrite; these occur segregated in the gangue.

In Mt. Field a short tunnel has been driven along a quartz vein 2 to 4 feet wide, which follows the strike of the ferruginous quartzites interbedded with soft, chloritic slates. The ore minerals are chalcopyrite, tetrahedrite, malachite, and azurite. These minerals occur both in the vein and along its sides.

On the south slope of Mt. Stephen at elevation 7200 feet, prospects have been made on quartz veins along fissures in dolomitic limestone. Chalcopyrite and the carbonates are the essential ore minerals.

MERCURY.

Native quicksilver is reported to have been found in the gravels of the Kicking Horse valley in the vicinity of Field. This metal was first found by Mr. Flindt in a water pipe in the Mount Stephen Hotel and must have come from the source of the water supply in the southwest slope of Mt. Stephen. Some of this material was sent to the Geological Survey office. At a later date five samples of gravel were collected by Mr. C. E. Cartwright, consulting engineer, Vancouver, from the flood gravels within 2 miles of Field, and were panned by Mr. C. M. Bryant, Vancouver, with the result that a trace of quicksilver was found in three out of the five samples. Mr. Busteed, General Superintendent, Canadian Pacific railway, in Vancouver, also stated that he obtained quicksilver by panning the gravels "from the edge of the river a few hundred feet below the bridge" —opposite Field station, from a depth of about 2 feet below the surface, "where the high water had cut down about that depth."

These facts seem to show that the quicksilver does occur disseminated through even the surface gravels in the floor of the Kicking Horse valley and that its source must be in some of the surrounding mountains. Two claims have been staked out on the talus on the southwest slope of Mt. Stephen about the intake of the water supply for the hotel. A considerable amount of work was done in an attempt to locate the source of the mercury, but without results.

Some time was spent by the writer at the beginning of the field season of 1912 in examining the rocks in Mts. Stephen, Cathedral, Field, and the Yoho valley. The most likely rock was assayed for mercury, but no trace of this mineral was found. A sample of the sand taken from the Kicking Horse river opposite Field station was panned without results. During the season of 1912 the gravels were panned from the various localities for 4 miles above Field, but no trace of quicksilver could be obtained.

It, however, seems possible that some compounds of this metal may occur even within these mountains, which may have given rise to the native mercury that has been found in the gravels of the Kicking Horse river. Mr. Waldemar Lindgren suggested in conversation that the native metal may have been derived from such a mineral as tetrahedrite which has been found sparingly in some of the small prospects.

Cinnabar is reported to have been found several years ago in a massive Upper Cambrian limestone ridge on the north side of the valley, between Emerald creek and the Amiskwi river.

It has also been found in a calcite vein in the lower Kicking Horse canyon, east of Golden.[1]

STRUCTURAL MATERIALS.

Marble.

Claims have been staked for marble in the Yoho valley in 1911. A cross-section of this band of marble is exposed at the switch-back on the Yoho road, 2 miles from the mouth of this river. At this point the band is between 350-400 feet thick. The rock is a dolomitic marble and varies largely in both colour and texture. In colour it is dark grey, mottled grey with white spots, or vice versa, light grey, white with greyish bands a fraction of an inch in width, and pure white. These last two varieties occur towards the top of the band and are of most economic importance. The rock takes a smooth polish. The grained material can be readily carved and will take a sharp edge. This band of marble extends along the west slope of Mt. Ogden so that the quantity of material is large.

[1] McConnell, R. G., Ann. Rept., Geol. Survey, Canada, 1886, Part D, p. 41.

The exposed surface of the marble is badly fractured so that it would be hard to get large blocks, but this fractured zone may not be very deep. The presence of small cavities in certain layers is also detrimental to the value of the marble. Pyrite is only sparsely scattered through certain layers which might be avoided in quarrying.

During the summer of 1913 diamond drilling was being carried on to find out the extent and quality of the marble.

The beds are lying almost horizontal with a maximum dip of 12 degrees. The railway is less than 2 miles distant at the mouth of the valley and is on the same elevation.

Slates.

The lowermost beds of the thick sedimentary series which are exposed in the Ice River area consist of slates. Although the economic value of these slates cannot yet be definitely foreseen, yet they seem worth the space to describe them, as a possible occurrence for later production.

The slates are the lowest beds exposed in the area, and have a total thickness exposed of over 1100 feet. They are of Upper Cambrian age, and belong to the Chancellor formation. The lowest beds of the formation consist of dark grey to light grey argillaceous and calcareous shales and slates; in some places they are thinly cleaved, but on the whole are very soft, and frequently have a silken lustre on the cleavage planes. These are of very doubtful economic value. These beds are overlain by thin-bedded, grey to black argillaceous slates, which on the whole are much harder than the underlying beds. There is a measured thickness of about 800 feet of the formation which will now be considered. As a whole, these slates weather reddish, brownish to yellowish and buff where the outcropping edges of the beds have been exposed to the atmosphere for some time. The cleavage is developed parallel to the bedding and the beds vary in thickness from a fraction of an inch to several inches.

Where they are exposed on the steep cliffs of a mountain side they readily break apart and form long talus slopes. The weathered fragments frequently occur as large flags; some of those noted were 4 feet long, 2 to three feet broad, and ⅛ to 1 inch thick. Whereas these slates are always discoloured on the exposed surface yet this oxidized layer is very thin and the interior of the layers retains its original grey colour. In most places where these slates are exposed on the valley sides the beds dip into the mountains, thus allowing the waters to penetrate a greater distance along the bedding. Wherever the beds become nearly horizontal or dipping towards the valley, the ends of the beds are covered up by talus, on account of their being readily acted upon by erosive agents.

Some of the beds contain concretions of pyrite and tremolite, the former occurs as nodules, some of which are over an inch in diameter; these concretions are very frequently surrounded by lens-like masses of tremolite. Leaf-like impressions are also common in certain layers along the bedding; some of these are almost microscopic in size.

The development of pyrite and tremolite would, however, seem to be the result of metamorphism on impure beds of shale, which caused the slaty cleavage to be developed, and which folded the rocks in the region.

In no place did the writer find crystals of pyrite disseminated through beds of slate. This would tend to uphold a secondary origin for the pyrite.

Several tests were made on the amount of soluble material in the better variety of this slate. The powder was weighed and then HCl added. There was a strong effervescence, showing a high amount of calcareous material. The residue was washed, dried, and weighed, thus giving the amount of soluble material in the rock.

In tests made with cold acid, the amount of soluble material was found to be between 35 per cent and 36 per cent of the whole. When the solution was boiled for a few minutes, more material was dissolved and the amount which disappeared was 39 per cent.

This shows that the slate, although apparently fairly hard, has a high percentage of calcium carbonate material in it. However, if this soluble material is in so finely divided a state that the rock would weather evenly and not become pitted, the slate would still be of economic value.

The slates are best exposed in the Ice River valley on the east slope of Chancellor peak, and also in Zinc valley. In the former the beds outcrop almost down to the valley floor.

It is necessary to make tests for the weathering properties of these slates, before their value can be ascertained. The shales may be of use in the manufacture of Portland cement. They are also calcareous, which would make the product more desirable for this purpose. This rock may, in certain beds at least, be suitable for the manufacture of brick when crushed.

If these rocks should prove of economic value, the material could be quarried and transported at low cost. There is now a disused wagon road from the railway to Ice river, and these exposures of slate are about 7 miles from the end of the road.

SODALITE.

Sodalite occurs associated with the alkaline syenite intrusive mass of the Ice river. It has a beautiful blue colour which varies from a deep blue to light greyish blue and takes a high polish.

The localities in which this mineral occurs can be most easily reached in Ice river or a little over a mile up the valley on the east side from the point where the main trail crosses the river. A mass of sodalite-bearing rocks has been exposed in the bed of the first large creek about ½ mile from where it enters the Ice river from the east. This prospect has furnished material for many tourists who visit it every summer. Neither the lateral nor vertical extent of this rock has yet been exposed.

Another occurrence of the sodalite syenite is found towards the head of Sodalite valley, which is the second large depression entering Ice River valley from the east. On the west side of the valley another exposure of sodalite syenite occurs about 600 feet above the main valley on the south side of Shining Beauty creek, which is the first large creek entering Ice river from the west. Here the sodalite again occurs on the contact of the igneous mass with the overlying sediments. These three localities are all easily accessible and especially the first described occurrence, as it is only about 1½ miles from the end of the old wagon road and less than ½ mile from the Ice River trail.

A small boulder of pure sodalite and cancrinite was found towards the head of Ice River valley, the occurrence of which suggests that in some locality about the head of the valley sodalite is not directly in contact with the igneous rock.

There is at least one locality in which sodalite occurs on the west side of Moose Creek valley, towards its head, the extent of which is not yet known.

The occurrence of the mineral, as has been previously stated, is found about the border of the igneous mass, usually on the contact between the igneous rock and the sediments. Where it occurs as a mineral constituent of the nephelite syenite, this rock becomes important as a decorative stone.

The sodalite also forms veins of pure mineral in the sodalite syenite, varying from a fraction of an inch to an inch and a half in width. Minute veinlets of sodalite are found along seams in the sediments a few yards from the contact. It would appear as though this mineral has been brought in by pneumatolytic action at the close of the intrusion of nephelite syenite. In most cases the lateral extent of the veins is sharply defined. Although the veins are, as a rule, pure sodalite, yet there are sometimes grains of a brownish mineral which proves to be cancrinite. These grains are in some places scattered throughout, but in others are limited to the middle of the vein. Pyrite and other ferruginous material are also found sometimes sparsely scattered through the veins of sodalite and also through the sodalite syenite. These cause the rock on exposure to assume rusty coloured spots. A greenish coloured pyroxene is also associated with the sodalite, which microscopically is found to be ægirite-augite.

The pure sodalite polishes excellently and assumes a handsome appearance when made into jewelry. In artificial light this mineral looks rather dark in lustre, but not more so than any other blue coloured mineral. Polished specimens of the sodalite retain their appearance much better in artificial light.

An analysis of this mineral was made by Dr. Harrington. It is similar to sodalite found in the nephelite syenite of Mount Royal, where it occurs as a mineral constituent of nephelite syenite. The formula of the sodalite as derived from analysis is: $3\,Na_2O.\ Al_2O_3\ 2SiO_2 + NaCl$.

The following analyses of the sodalite from these two localities,[1] and also that from Dungannon, Ontario[2] have been made by B. J. Harrington.

	Ice river	Montreal	Dungannon
SiO_2	37·52	37·50	36·58
Al_2O_3	31·38	31·82	31·05
Fe_2O_3	tr.	0·01	.....
FeO	.....	.....	0·20
CaO	0·35	.....	.....
MgO	tr.	.....	.....
Na_2O	19·12	19·34	.....
Na_2O_3	.....	.....	24·81
Na	4·48	4·61	.....
K_2O	0·78	0·27	0·79
Cl	6·91	7·12	6·98
SO_3	.....	.....	0·12
H_2O	.....	.....	0·27
Insoluble	.....	.....	0·80
	100·54	100·67	101·50
Sp. gravity.	2·220	2·293	2·295

Before this material can be considered of economic importance it will be necessary to find out its extent, which can only be ascertained by development of the present exposures, because the rock immediately about these exposures is more or less covered up with rock débris.

So far as at present known, the sodalite occurs in poorly defined small irregular masses associated with portions of syenite high in nephelite, and is developed on or near the upper contact of the laccolithic mass with the overlying sediments.

It might be well to note that whereas the vein material is well defined, yet where the sodalite is a mineral constituent of syenite, the line between this mineral and the nephelite is not sharply defined, and the deep bluish coloured sodalite gradually becomes colourless towards the nephelite crystal.

[1]Trans. Royal Society Canada, Vol. 4, Sect. 3, 1886, p. 81.

[2]Amer. Jour. Sci., Vol. 48, 1889, p. 17.

This occurrence is worthy of consideration because the material can be inexpensively worked, and it would seem possible to obtain large blocks of the sodalite syenite. The transportation problem would not be a difficult one as the first described deposit is about 14 miles from the railway and at present a disused wagon road extends to the Ice river and within 2 miles of the exposure. Mr. M. Dainard of Golden located some of the property, but up to the present, no important development has been done.

Syenite.

This rock is light grey in colour, and is a typical nephelite syenite. It varies from a nephelite rich to almost nephelite free rock; the percentage of iron magnesium constituents is very small and biotite is practically absent. The normal syenite, which is comparatively free from fractures, would make a good stone, either for building or ornamental purposes. The amount of this material is unlimited and it occurs along either side of the bottom of Ice River valley. As has been stated before, transportation would not be a difficult problem.

As this is the only large mass of igneous rock of value for building purposes in the vicinity of the main line of the Canadian Pacific railway in the Rocky mountains, a market for the material would soon be established, either in Calgary and eastwards, or if of suitable quality, it might be profitably shipped to Vancouver and the Pacific coast.

Gravel.

There is an extensive deposit of stratified glacial gravels more than 100 feet thick, in the valley of the Kicking Horse river between Field and Ottertail. At Emerald, 3 miles below Field, the Canadian Pacific railway has installed a washing plant, in which the clayey material is washed from the gravels, giving a clean product which is used for ballast.

CLAY.

A small deposit of clay of glacio-lacustrine origin, occurs in the Yoho valley about 3 miles from its mouth. It is of yellowish colour when wet and much lighter in colour when dry. The lime content is high and the finest powder is gritty. This material is of low grade, but might be manufactured into an earthenware or cheaper variety of pottery.

At the town of Field there is a colluvial clay of indefinite extent, washed down from the talus slope of shales and argillites between Mt. Stephen and Mt. Dennis.

Another small lake deposit of glacial clay or silt occurs near the head of Ice River valley at the base of Chancellor peak. The clay is light buff in colour and highly calcareous. Tests on this silt prove it to be of very low grade and of little or no economic importance.

CHAPTER XV.

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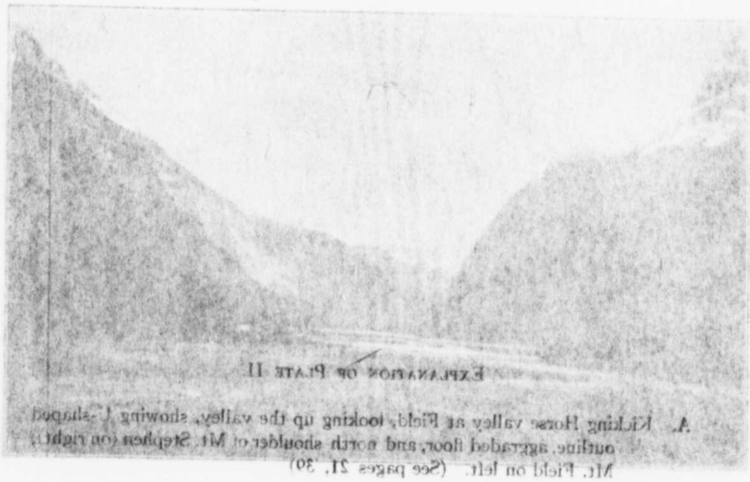

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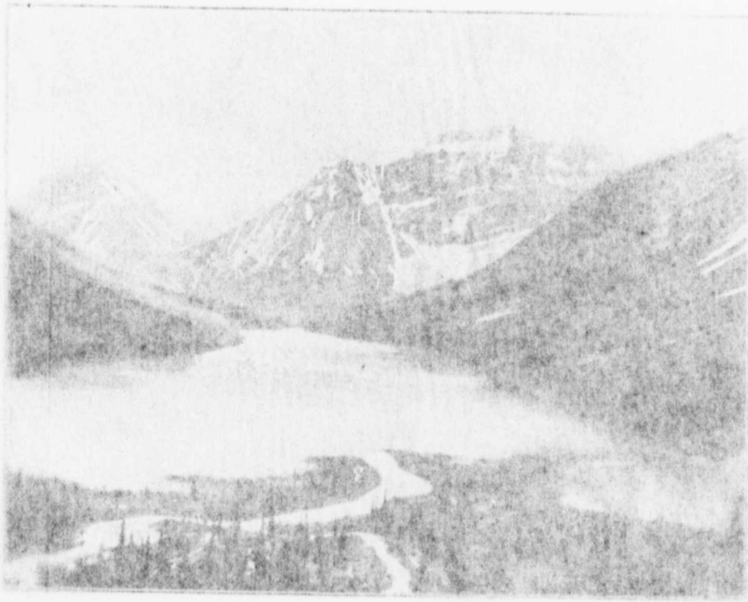


B

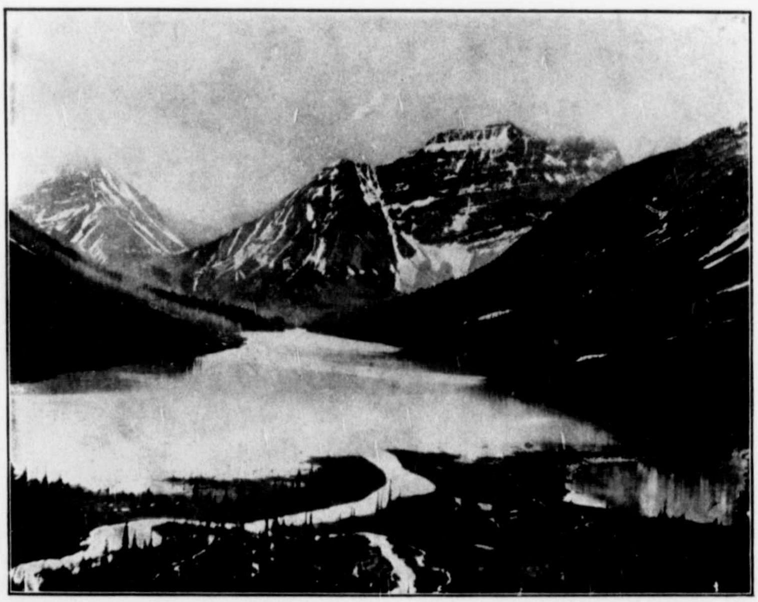
EXPLANATION OF PLATE II.

A. Kicking Horse valley at Field, looking up the valley, showing U-shaped outline, aggraded floor, and north shoulder of Mt. Stephen (on right), Mt. Field on left. (See pages 21, 39)

B. Sherbrooke lake in valley hanging above Kicking Horse valley, showing cirque-like nature of lake basin, steep drop into Kicking Horse valley, Cathedral mountain in centre on opposite side of Kicking Horse valley. (See page 18)

PLATE II.

A



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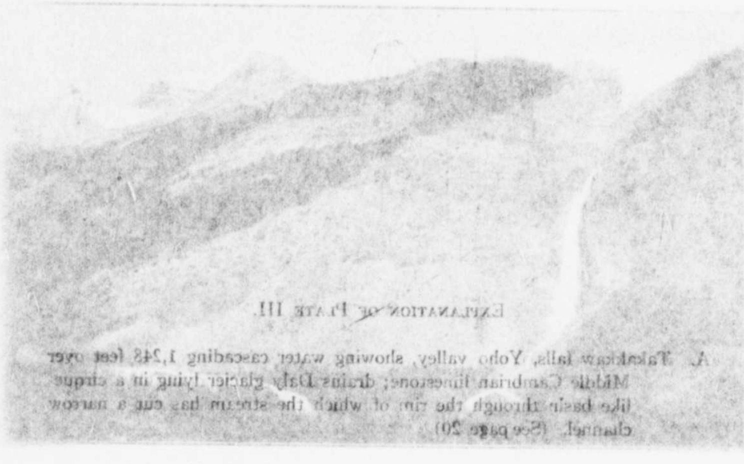
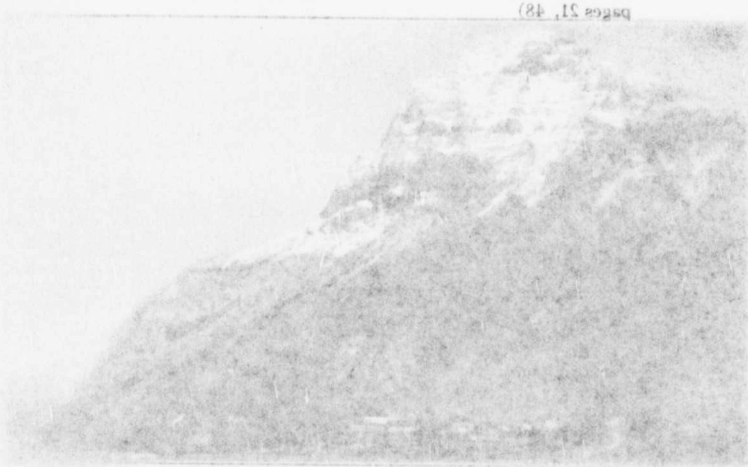




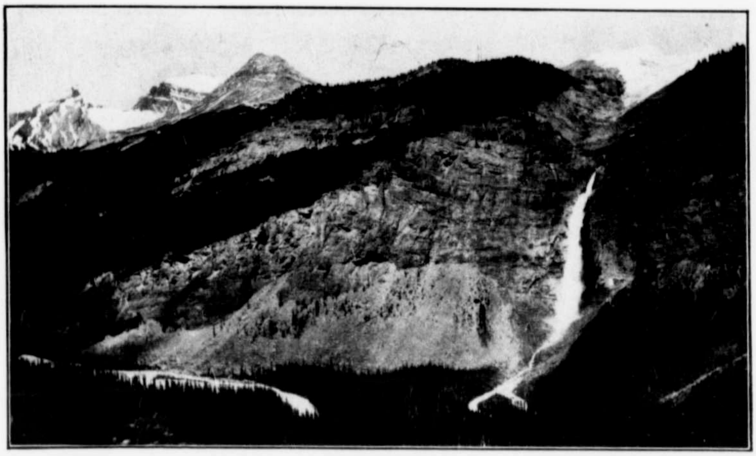
B

Explanation of Plate III.

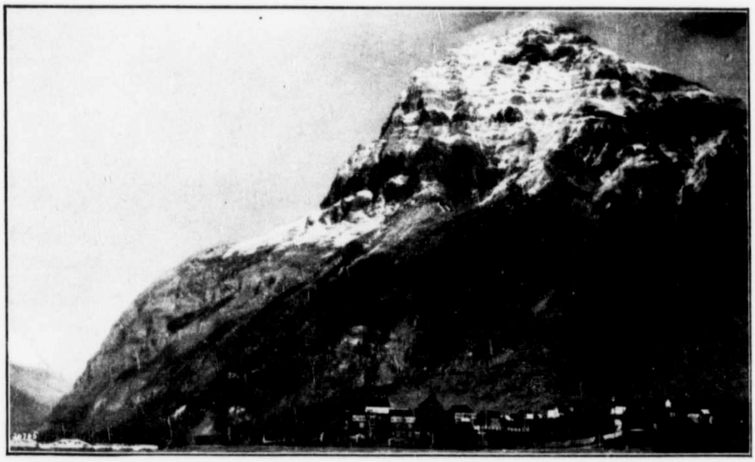
A. Takakkaw falls, Yoho valley, showing water cascading 1,248 feet over Middle Cambrian limestone; drains Daly glacier lying in a cirque-like basin through the rim of which the stream has cut a narrow channel. (See page 20)

B. Mt. Stephen (elev., 10,465 feet), showing north shoulder of the mountain which was overridden and shaped by the valley glacier whereas the top of the mountain remained as a nunatak above the ice. Middle Cambrian formations are exposed in the mountain. (See pages 21, 48)

PLATE III.

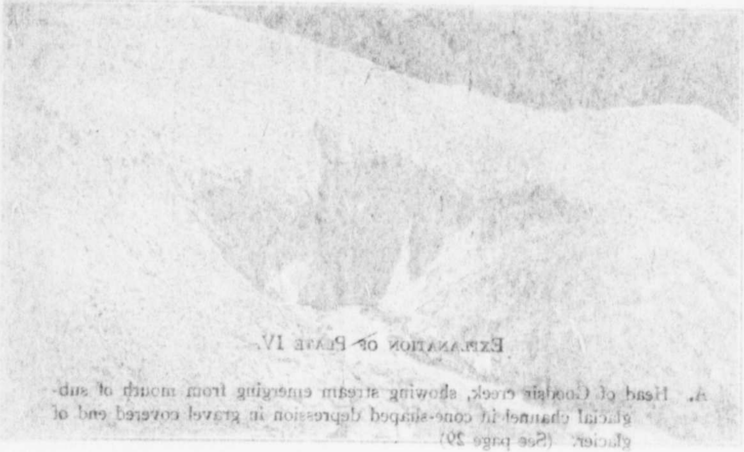


A



B

PLATE IV.

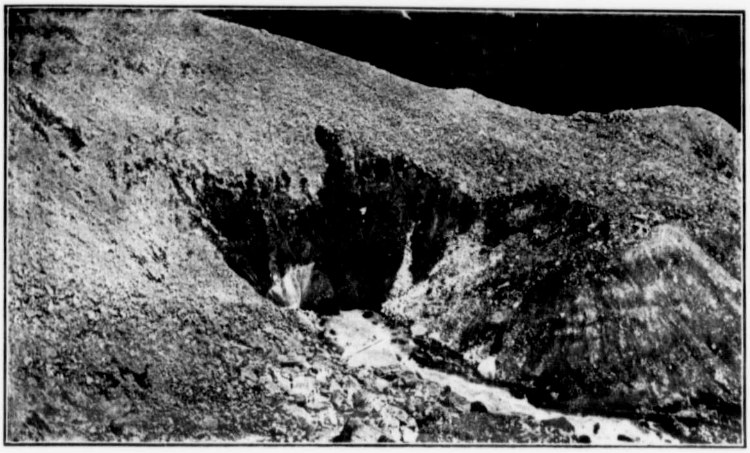


Explanation of Plate IV.

A. Head of Goodsir creek, showing stream emerging from mouth of sub-glacial channel in cone-shaped depression in gravel covered end of glacier. (See page 29)

B. McArthur lake (elev., 7,359 feet), showing Mt. Biddle (elev., 10,867 feet) with Biddle glacier extending to lake and lying in a cirque. The three formations of the Lower Cambrian are characteristically developed in Mt. Biddle. (See page 31)

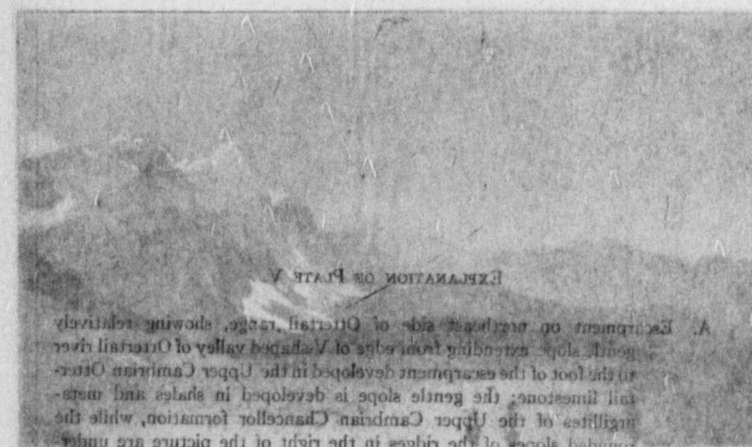
PLATE IV.



A

B

PLATE V.



A

B

Explanation of Plate V.

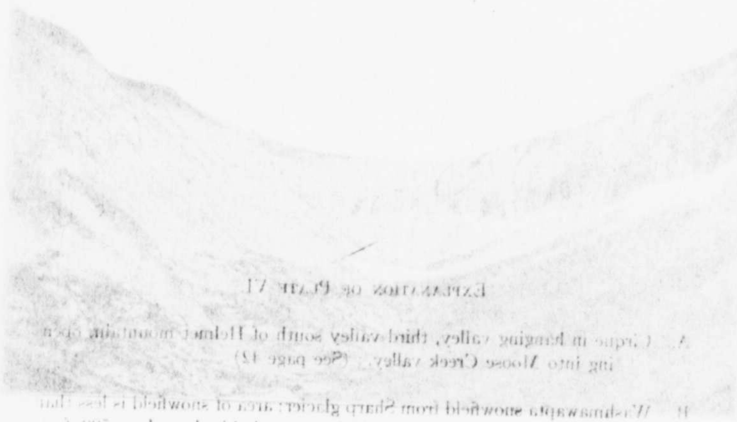
A. Escarpment on northeast side of Ottertail range, showing relatively gentle slope extending from edge of V-shaped valley of Ottertail river to the foot of the escarpment developed in the Upper Cambrian Ottertail limestone; the gentle slope is developed in shales and meta-argillites of the Upper Cambrian Chancellor formation, while the rounded slopes of the ridges in the right of the picture are underlain by the sheared rocks of the Chancellor formation. (See pages 33, 79, 91)

B. Cliff glaciers on northeast side of Mt. Goodsir, overlooking Ottertail valley. (See page 41)

Plate V.

A

B

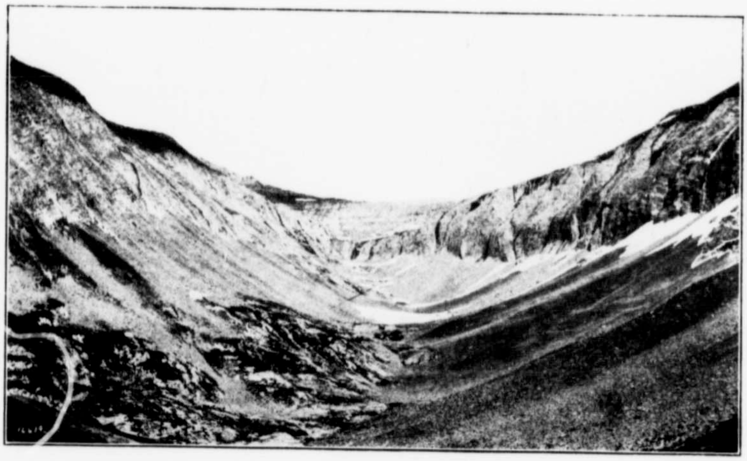


Explanation of Plate VI.

A. Cirque in hanging valley, third valley south of Helmet mountain, opening into Moose Creek valley. (See page 42)

B. Washmawapta snowfield from Sharp glacier; area of snowfield is less than 7 square miles, maximum thickness probably less than 500 feet. (See page 46)

PLATE VI.



A

B

EXPLANATION OF PLATE VII.

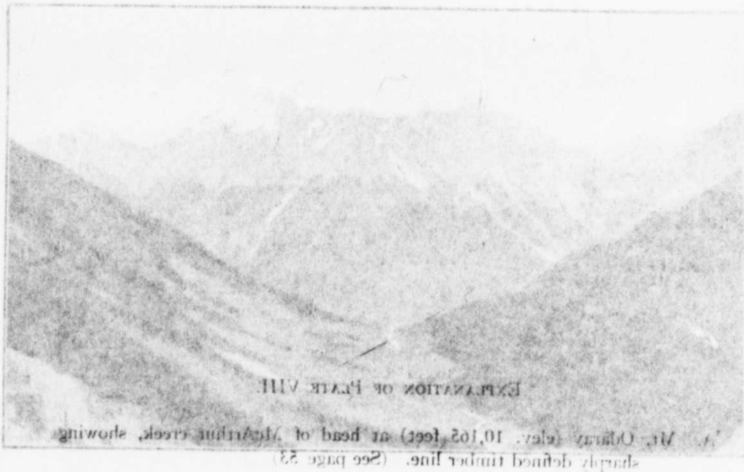
A. Washmawapta snowfield, showing longitudinal crevasses deepened by super-glacial streams. (See page 46)

B. Banding in glacier, representing annual growth. (See page 47)

PLATE VII.

A

B



A

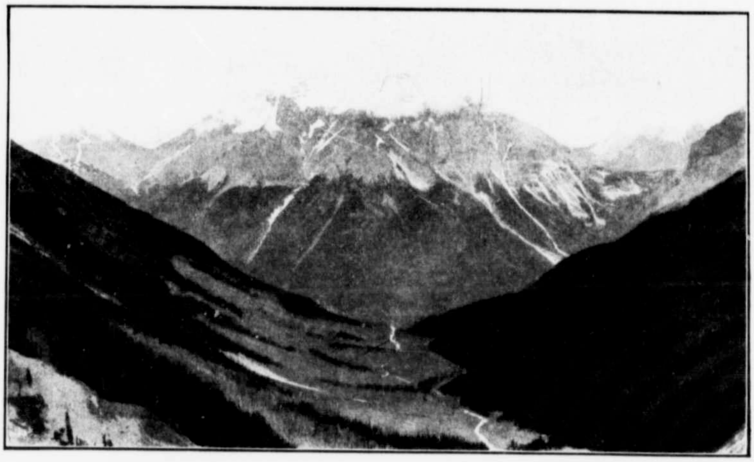
B

Explanation of Plate VIII.

A. Mt. Odaray (elev. 10,165 feet) at head of McArthur creek, showing sharply defined timber line. (See page 53)

B. Lake Oesa and Lefroy ridge; the uppermost beds of the Lower Cambrian occur on the slopes above the lake, overlain by Middle Cambrian. (See page 64)

PLATE VIII.



A

B

Explanation of Plate IX.

Ottertail falls, showing band of thin-bedded limestone in argillaceous strata of Chancellor formation. (See page 82)

PLATE IX.

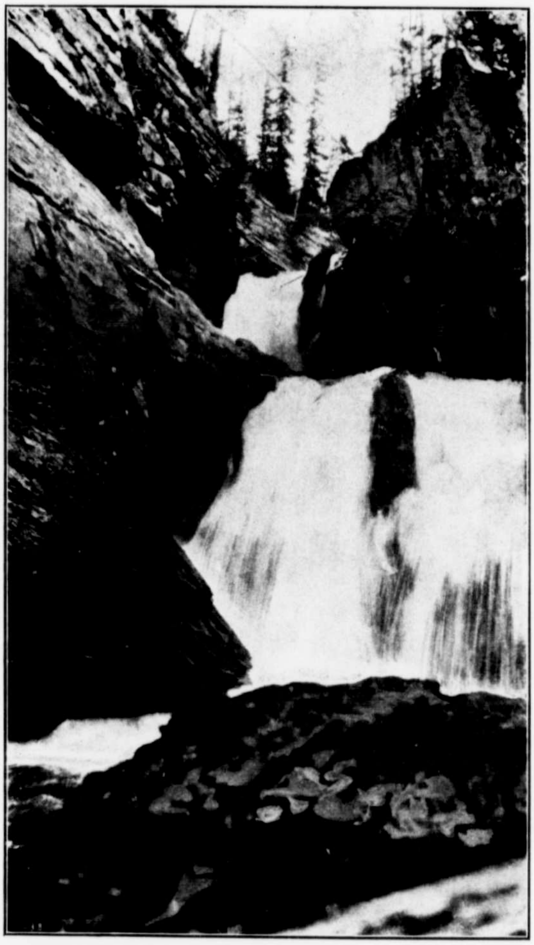
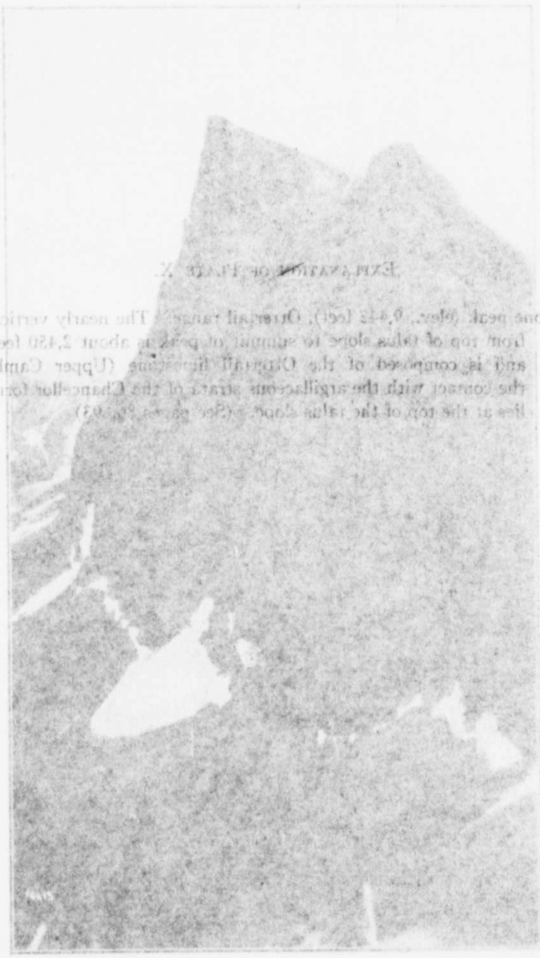


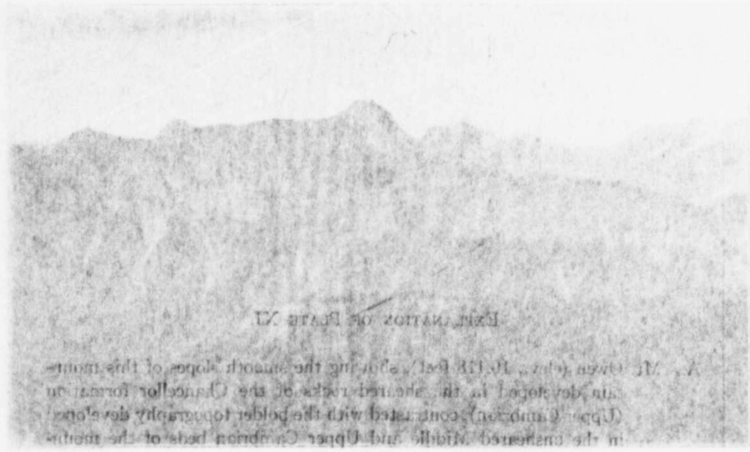
PLATE X.



Explanation of Plate X.

Limestone peak (elev., 9,442 feet), Ottertail range. The nearly vertical face from top of talus slope to summit of peak is about 2,450 feet high and is composed of the Ottertail limestone (Upper Cambrian); the contact with the argillaceous strata of the Chancellor formation lies at the top of the talus slope. (See pages 86, 93)

PLATE X.



Explanation of Plate XI.

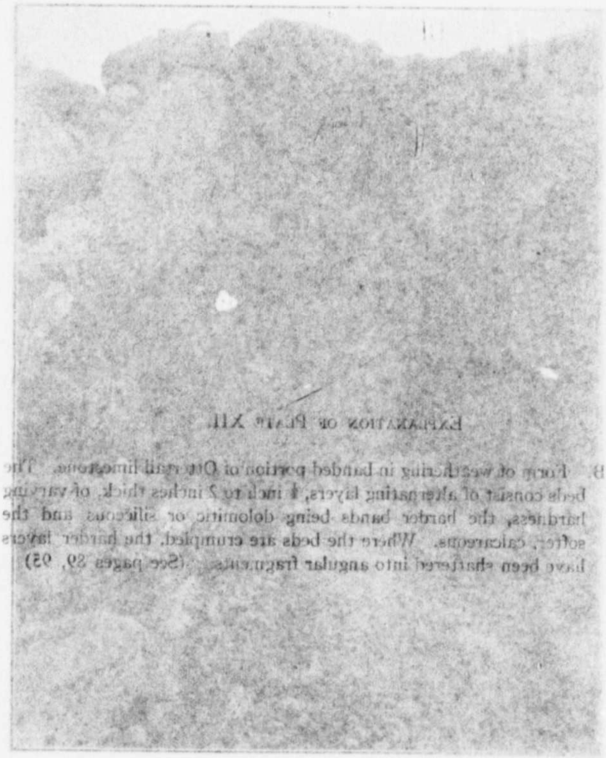
A. Mt. Owen (elev., 10,118 feet), showing the smooth slopes of this mountain developed in the sheared rocks of the Chancellor formation (Upper Cambrian), contrasted with the bolder topography developed in the unsheared Middle and Upper Cambrian beds of the mountains in the distance to the right. (See page 82)

B. Mt. Goodsir from Ice River valley, showing total thickness of Goodsir formation (Ordovician) underlain by the Ottertail formation (Upper Cambrian). (See pages 94, 100)

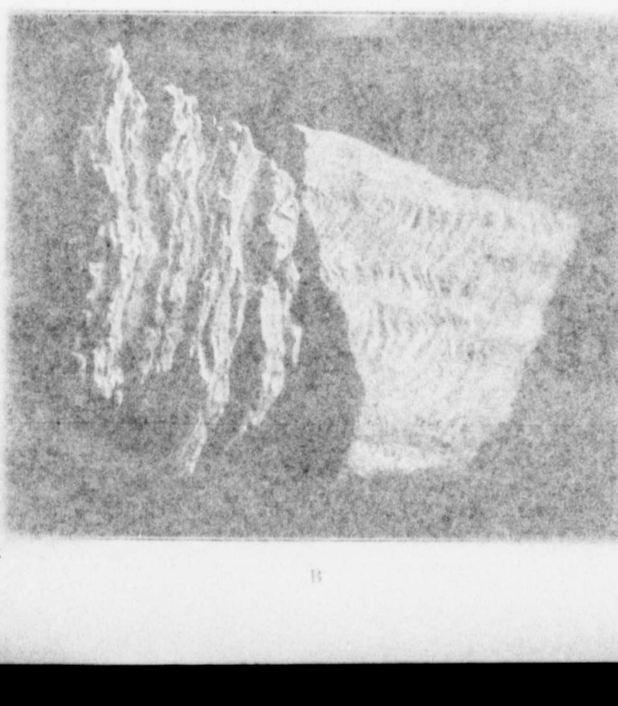
PLATE XI.

A

B



A

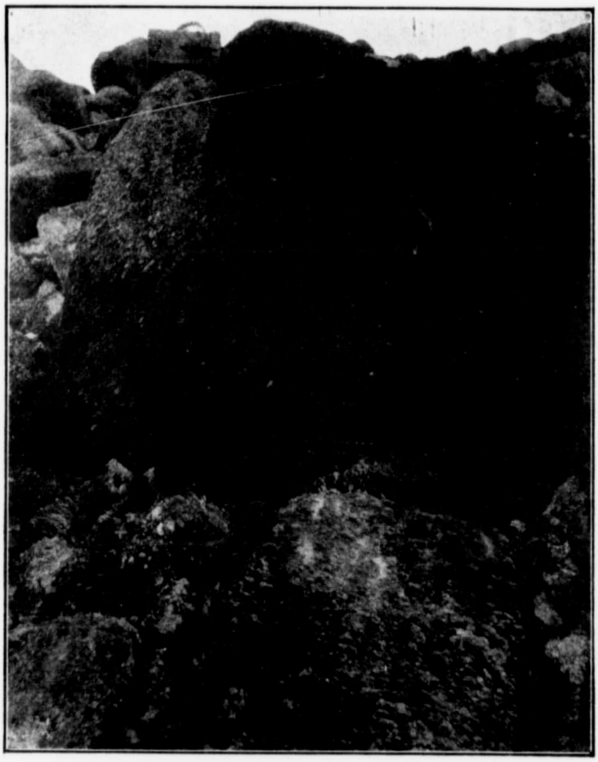


B

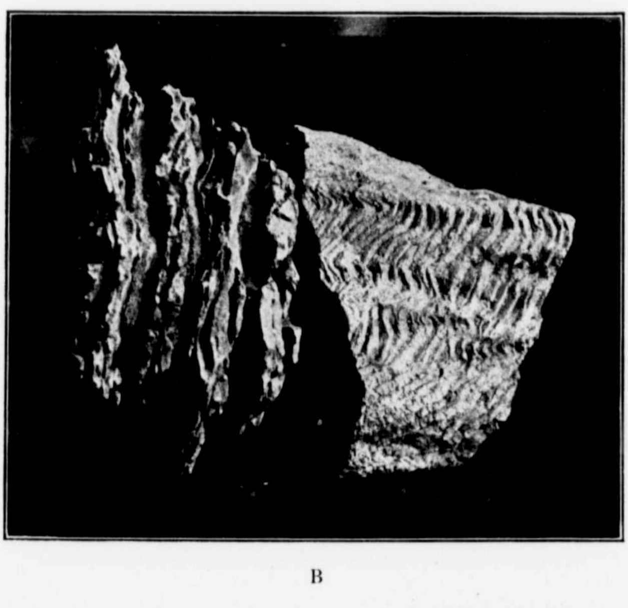
Explanation of Plate XII.

A and B. Form of weathering in banded portion of Ottertail limestone. The beds consist of alternating layers, ¼ inch to 2 inches thick, of varying hardness, the harder bands being dolomitic or siliceous and the softer, calcareous. Where the beds are crumpled, the harder layers have been shattered into angular fragments. (See pages 89, 95)

Plate XII.



A



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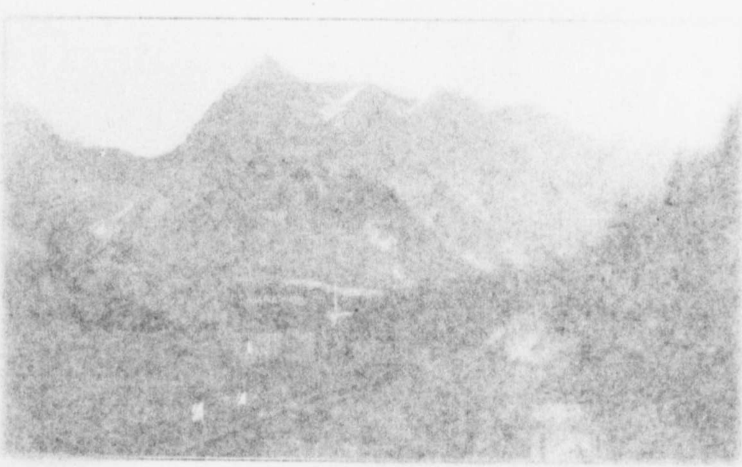


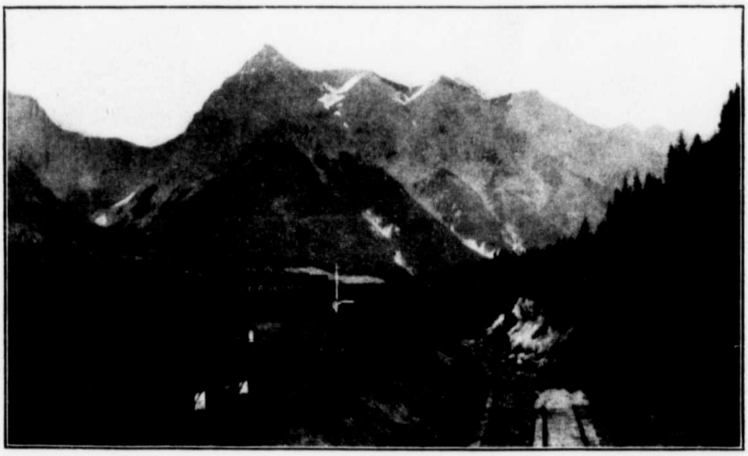
EXPLANATION OF PLATE XIII.

A. "Hoodoos" in Hoodoo creek near Leanchoil, developed in talus which shows a rough banding representing the inclination of the talus slope. (See page 104)

B. Chancellor peak (elev., 10,751 feet), from Leanchoil, showing igneous rock (black) at upper contact with Ottertail limestone. (See page 108)

PLATE XIII.

A



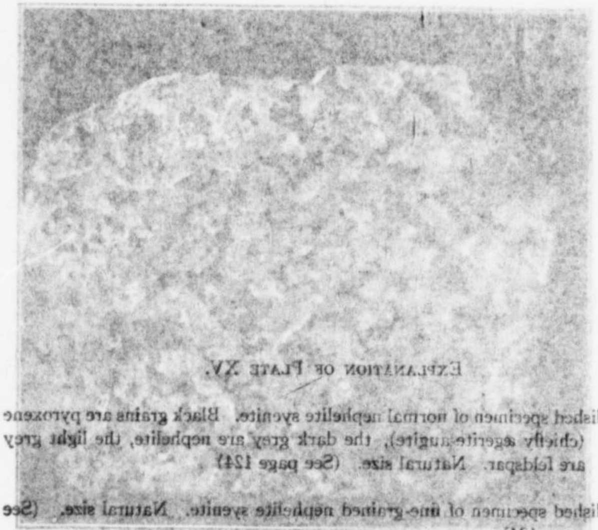
B

Explanation of Plate XIV.

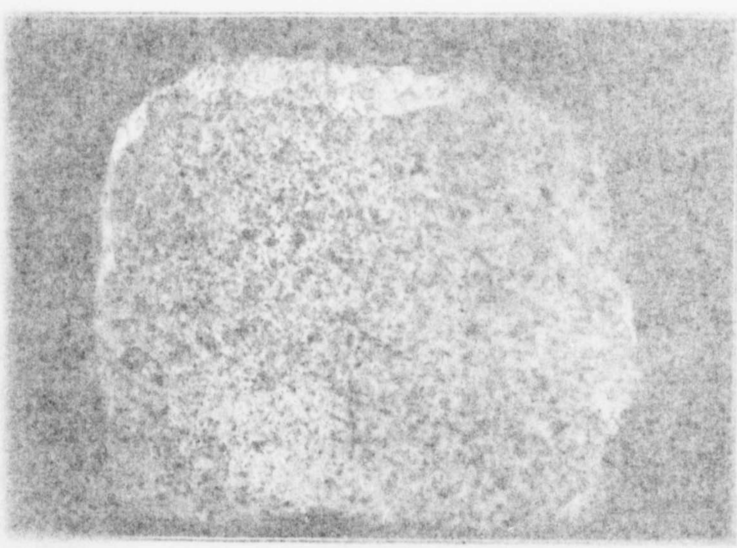
Mt. Mollison (elev., 8,340 feet), showing grey limestone band of the Ottertail formation pinching out to the left, in the argillaceous Goodsir formation along the axis of a tight anticlinical fold. (See page 111)

PLATE XIV.

Plate XV.



A



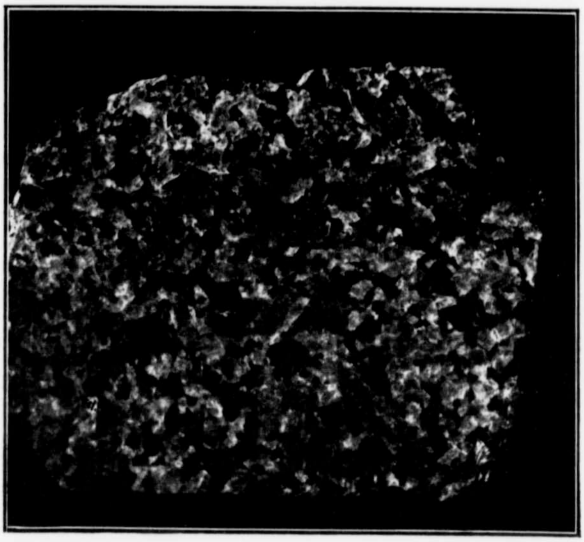
B

EXPLANATION OF PLATE XV.

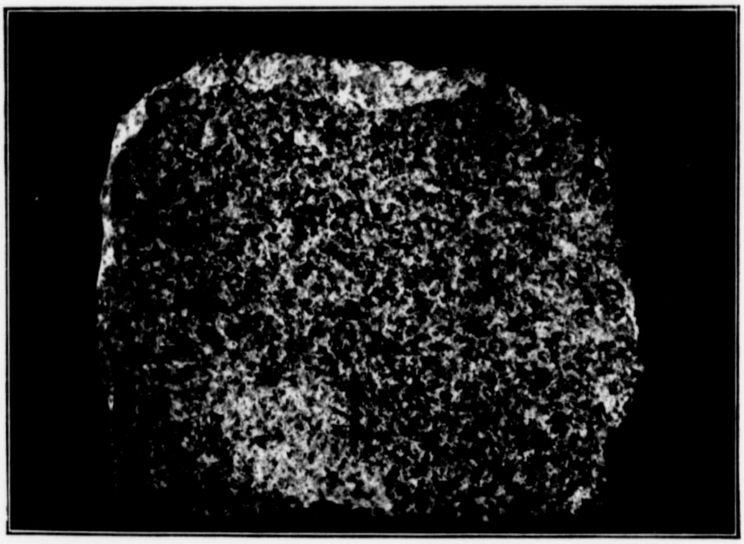
A. Polished specimen of normal nephelite syenite. Black grains are pyroxene (chiefly ægerite-augite), the dark grey are nephelite, the light grey are feldspar. Natural size. (See page 124)

B. Polished specimen of fine-grained nephelite syenite. Natural size. (See page 124)

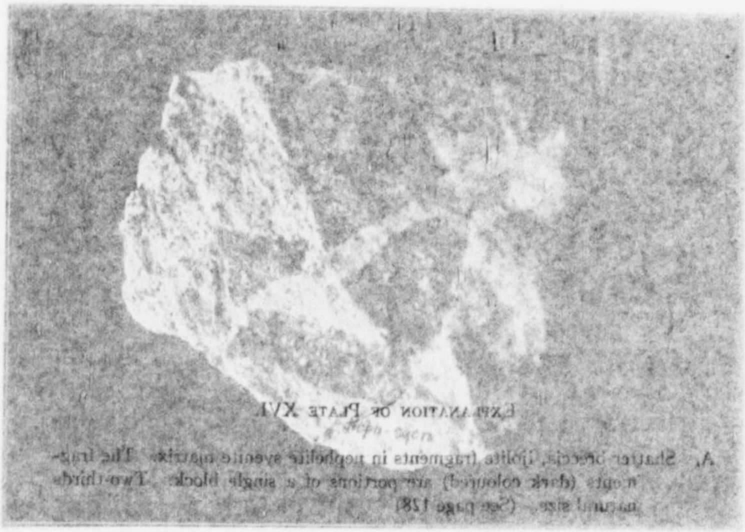
PLATE XV.



A



B



B

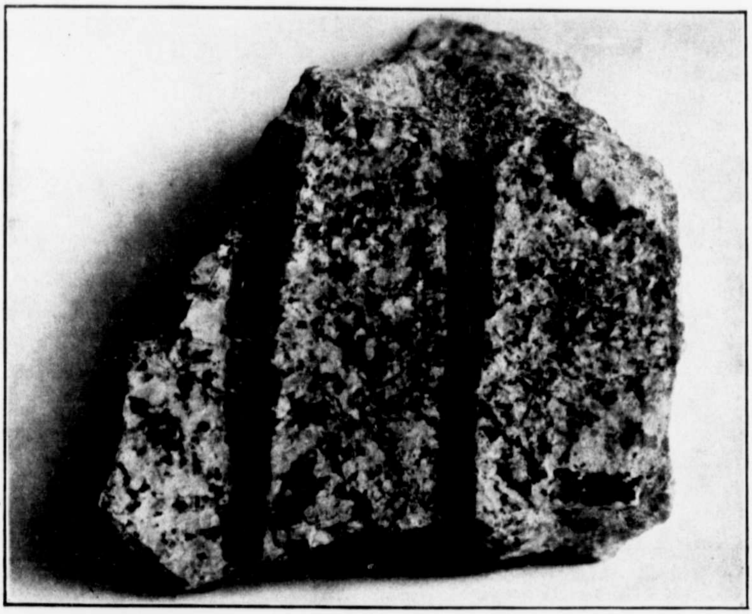
EXPLANATION OF PLATE XVI.

A. Shatter breccia, ijolite fragments in nephelite syenite matrix. The fragments (dark coloured) are portions of a single block. Two-thirds natural size. (See page 128)

B. Polished specimen of sodalite syenite. Shows two well marked and part of a third vein of blue sodalite. One vein shows a fracture in it, filled with cancrinite and thomsonite. One-half natural size. (See page 125)

PLATE XVI.

A



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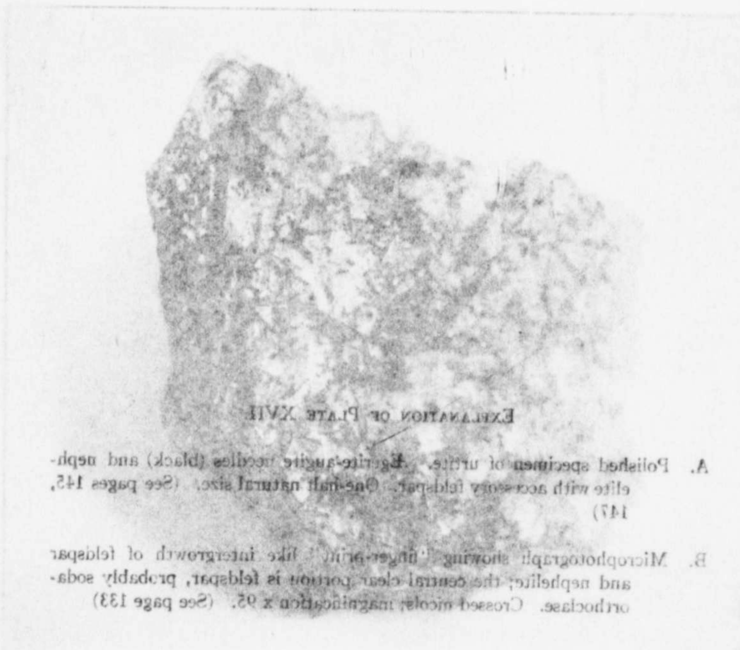
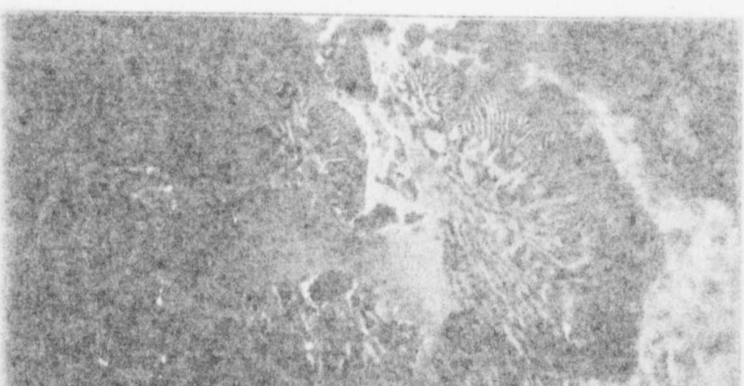


A



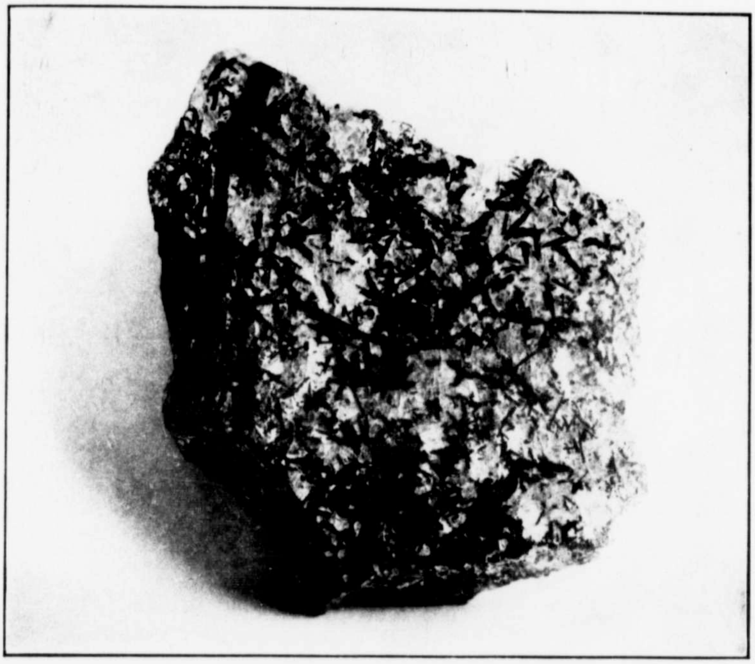
B

EXPLANATION OF PLATE XVII.

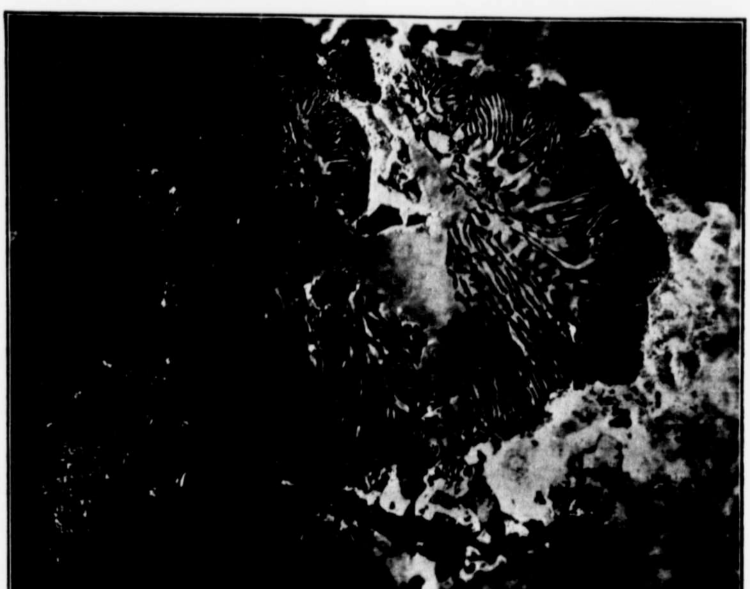
A. Polished specimen of urtite. Ægerite-augite needles (black) and nephelite with accessory feldspar. One-half natural size. (See pages 145, 147)

B. Microphotograph showing "finger-print" like intergrowth of feldspar and nephelite; the central clear portion is feldspar, probably soda-orthoclase. Crossed nicols; magnification x 95. (See page 133)

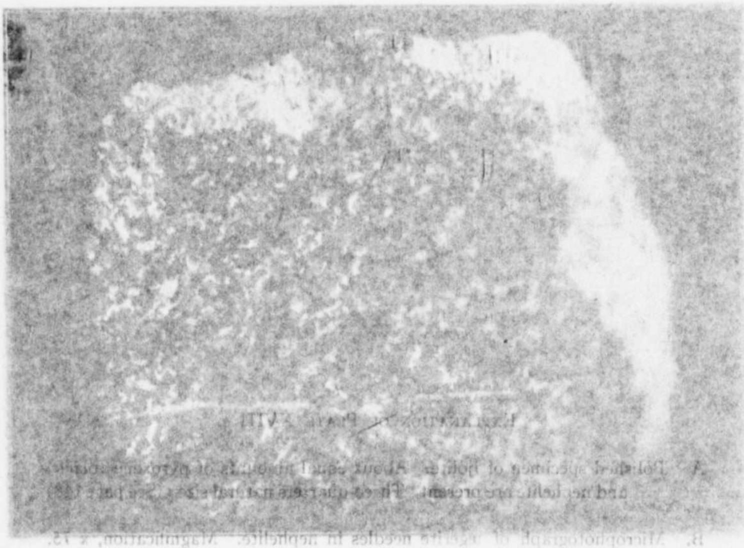
PLATE XVII.



A



B



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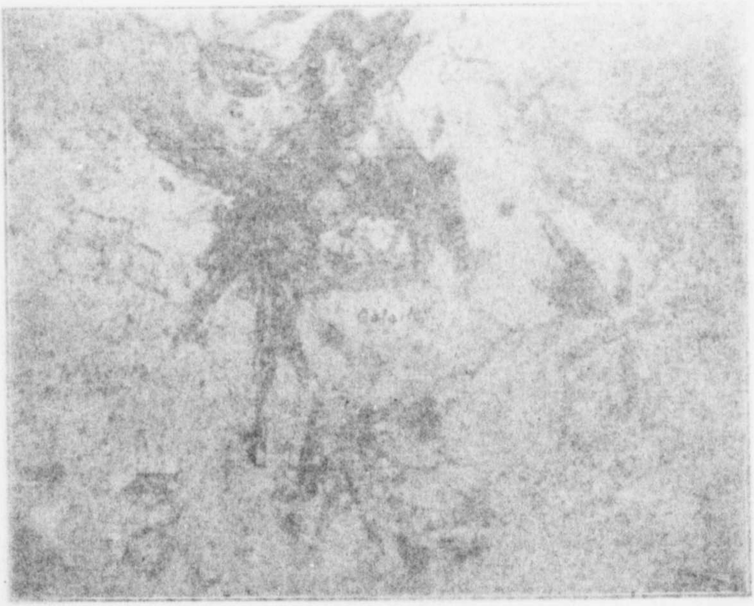


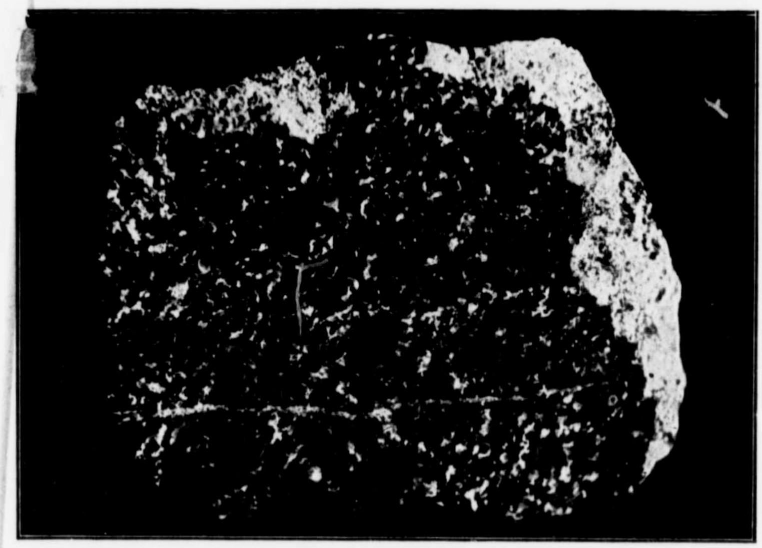
B

EXPLANATION OF PLATE XVIII.

A. Polished specimen of ijolite. About equal amounts of pyroxene (black) and nephelite are present. Three-quarters natural size. (See page 148)

B. Microphotograph of ægerite needles in nephelite. Magnification, x 75. (See page 162)

PLATE XVIII.



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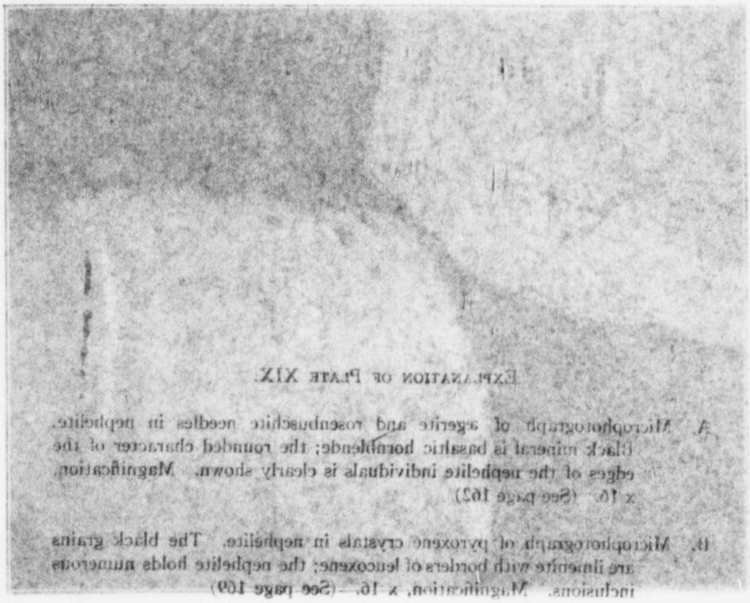

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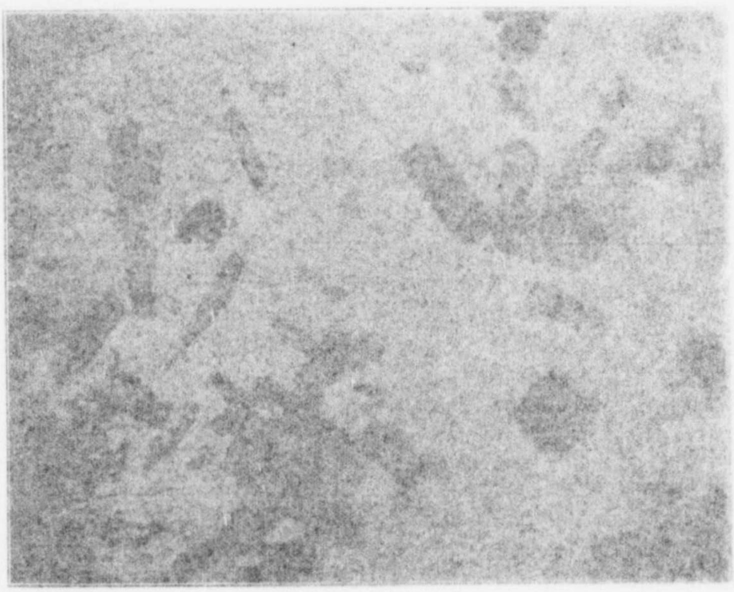


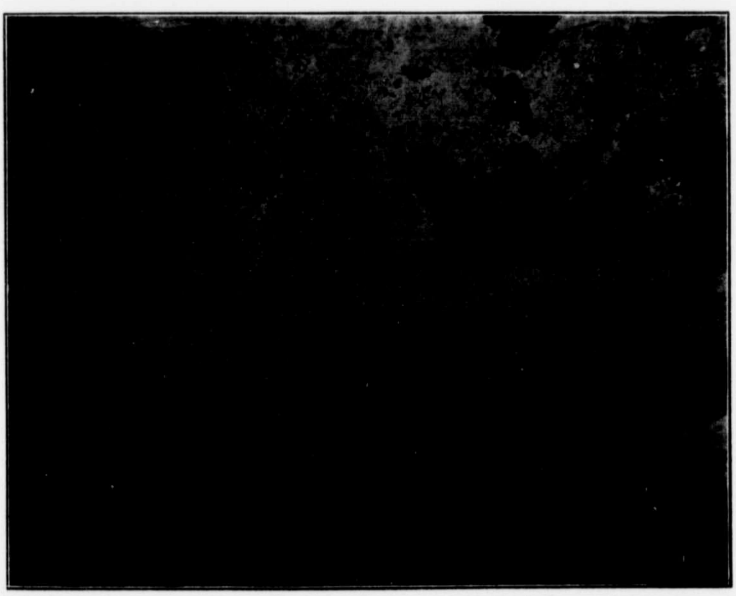
B

Explanation of Plate XIX.

A. Microphotograph of ægerite and rosenbuschite needles in nephelite. Black mineral is basaltic hornblende; the rounded character of the edges of the nephelite individuals is clearly shown. Magnification, x 16. (See page 162)

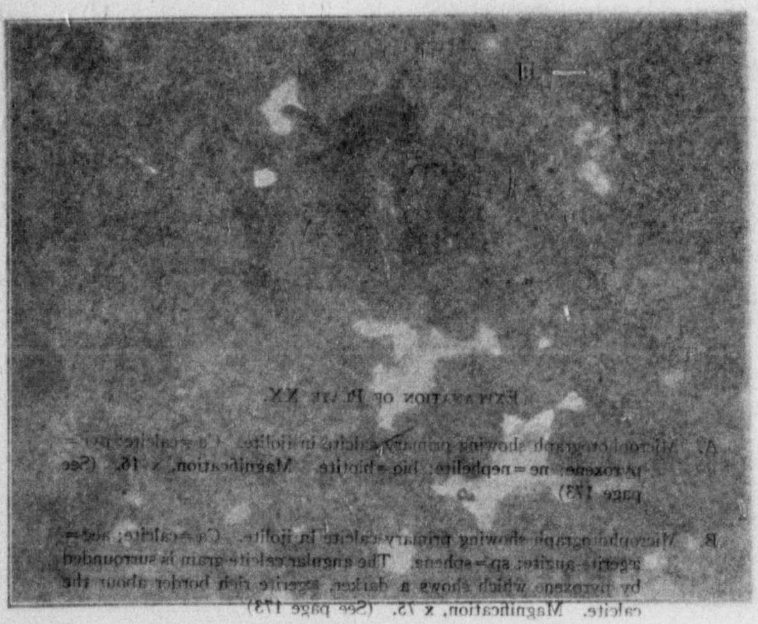
B. Microphotograph of pyroxene crystals in nephelite. The black grains are ilmenite with borders of leucoxene; the nephelite holds numerous inclusions. Magnification, x 16. (See page 169)

A



B

Plate XX.



A

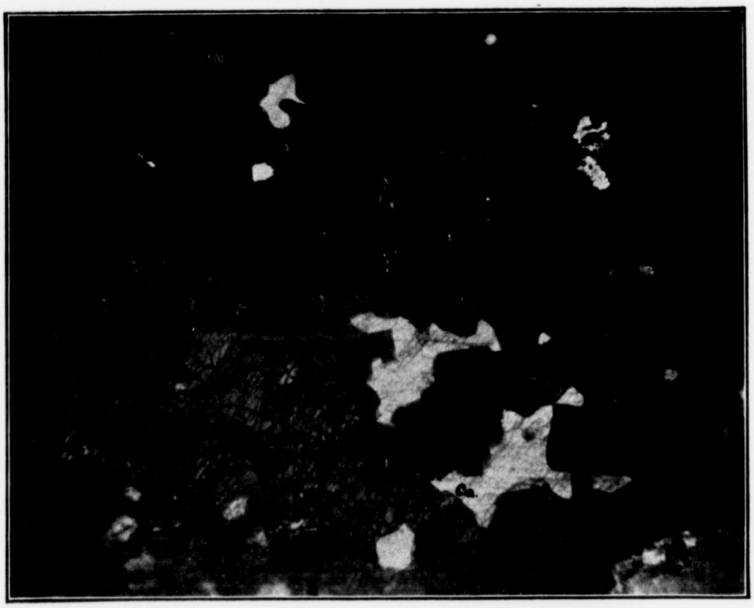
B

Explanation of Plate XX.

A. Microphotograph showing primary calcite in ijolite. Ca = calcite; pyr = pyroxene; ne = nephelite; bio = biotite. Magnification, x 16. (See page 173)

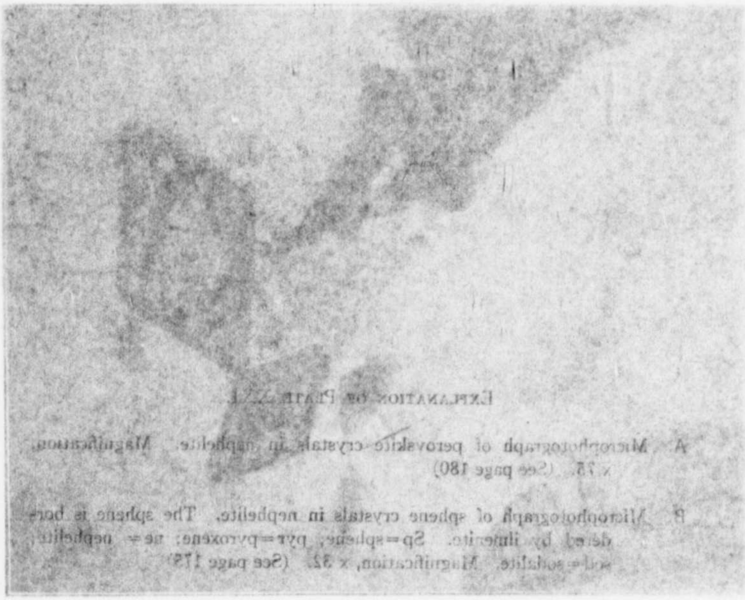
B. Microphotograph showing primary calcite in ijolite. Ca = calcite; aeg = ægerite-augite; sp = sphene. The angular calcite grain is surrounded by pyroxene which shows a darker, ægerite rich border about the calcite. Magnification, x 75. (See page 173)

PLATE XX.



A

B



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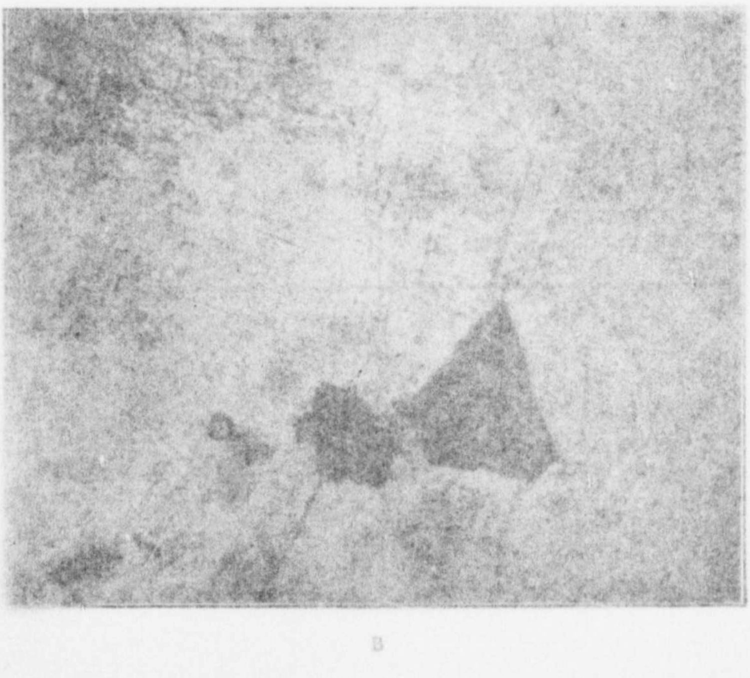


B

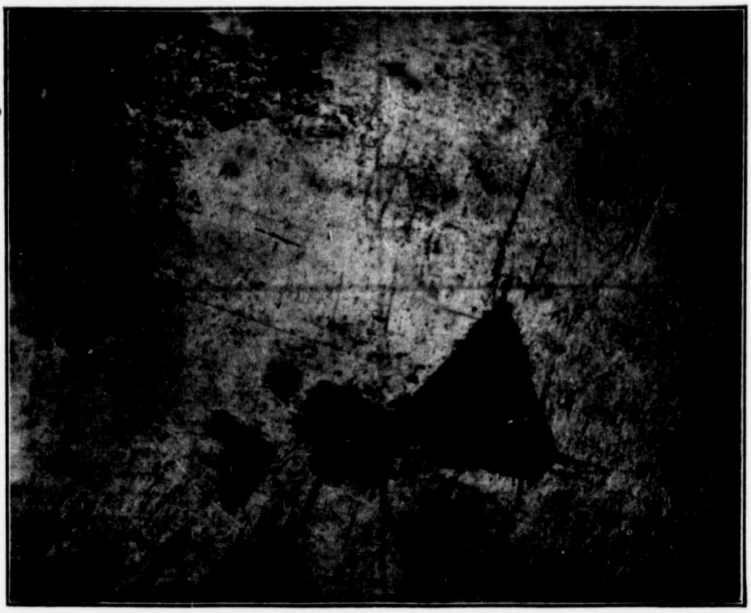
Explanation of Plate XXI.

A. Microphotograph of perovskite crystals in nephelite. Magnification, x 75. (See page 180)

B. Microphotograph of sphene crystals in nephelite. The sphene is bordered by ilmerite. Sp = sphene; pyr = pyroxene; ne = nephelite; sod = sodalite. Magnification, x 32. (See page 175)

PLATE XXI.

A



B

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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.* Palæoniscoid fishes from the Alberta shales of New Brunswick—by Lawrence M. Lambe.

MEMOIR 5. *No. 4, Geological Series.* Preliminary memoir on the Lewes and Nordenskiold 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.

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 north-west 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.

Museum Bulletin No. 2: contains articles Nos. 13 to 18 of the Geological Series of Museum Bulletins, and article No. 2 of the Anthropological Series of Museum Bulletins.

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

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

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 III)—by Heinrich Ries and Joseph Keele.

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

MEMOIR 20. *No. 41, Geological Series.* Gold fields of Nova Scotia—by W. Malcolm.

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.

MEMOIR 43. *No. 36, Geological Series.* St. Hilaire (Beloeil) and Rougemont mountains, Quebec—by J. J. O'Neil.

MEMOIR 44. *No. 37, Geological Series.* Clay and shale deposits of New Brunswick—by J. Keele.

MEMOIR 22. *No. 27, Geological Series.* Preliminary report on the serpentines and associated rocks, in southern Quebec—by J. A. Dresser.

MEMOIR 32. *No. 25, Geological Series.* Portions of Portland Canal and Skeena mining divisions, Skeena district, B.C.—by R. G. McConnell.

MEMOIR 47. *No. 39, Geological Series.* Clay and shale deposits of the western provinces, Part III—by Heinrich Ries.

MEMOIR 19. *No. 26, Geological Series.* Geology of Mother Lode and Sunset mines, Boundary district, B.C.—by O. E. LeRoy.

MEMOIR 40. *No. 24, Geological Series.* The Archæan geology of Rainy lake —by Andrew C. Lawson.

MEMOIR 39. *No. 35, Geological Series.* Kewagama Lake map-area, Quebec —by M. E. Wilson.

MEMOIRS—ANTHROPOLOGICAL SERIES.

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

MEMOIR 45. *No. 3, Anthropological Series.* The inviting-in feast of the Alaska Eskimo—by E. W. Hawkes.

MEMOIR 49. *No. 4, Anthropological Series.* Malecite tales—by W. H. Mechling.

Memoirs and Reports in Press September 10, 1914.

MEMOIR 41. *No. 38, Geological Series.* The "Fern Ledges" Carboniferous flora of St. John, New Brunswick—by Marie C. Stopes.

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

MEMOIR 53. *No. 44, Geological Series.* Coal fields of Manitoba, Saskatchewan, Alberta, and eastern British Columbia (revised edition) —by D. B. Dowling.

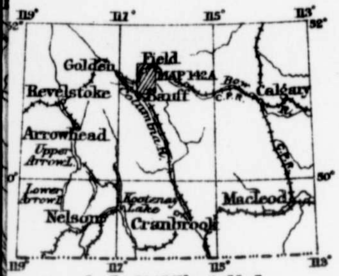
MEMOIR 61. *No. 45, Geological Series.* Moose Mountain district, southern Alberta (second edition)—by D. D. Cairnes.

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

MEMOIR 58. *No. , Geological Series.* Texada island—by R. G. McConnell.
MEMOIR 60. *No. 47, Geological Series.* Arisaig-Antigonish district—by M. Y. Williams.
MEMOIR 50. *No. , Geological Series.* Upper White River district, Yukon —by D. D. Cairnes.
MEMOIR 56. *No. , Geological Series.* Geology of Franklin Mining camp, B.C.—by Chas. W. Drysdale.
MEMOIR 42. *No. 1, Anthropological Series.* The double-curve motive in northeastern Algonkian art—by Frank G. Speck.
MEMOIR 62. *No. 5, Anthropological Series.* Abnormal types of speech in Nootka—by E. Sapir.
MEMOIR 63. *No. 6, Anthropological Series.* Noun reduplication in Comox, a Salish language of Vancouver island—by E. Sapir.
MEMOIR 46. *No. 7, Anthropological Series.* Classification of Iroquoian radicals with subjective pronominal prefixes—by C. M. Barbeau.
MEMOIR 54. *No. 2, Biological Series.* Annotated list of flowering plants and ferns of Point Pelee, Ont., and neighbouring districts—by C. K. Dodge.

Summary Report for the calendar year 1913.

Section along line A-B.



Scale, 200 Miles to 1 Inch

MAP 142 A
(Issued 1915)

FIELD

KOOTENAY DISTRICT

BRITISH COLUMBIA

Scale, $\frac{1}{126,720}$

Miles

1 0 1 2 3 4

Kilometres

1 0 1 2 3 4 5 6

2 MILES TO 1 INCH

GEOLOGY

J. A. ALLAN 1910, 1911.

TOPOGRAPHY

DEPARTMENT OF THE INTERIOR.

PUBLISHED MAPS, 1912.

(TOPOGRAPHICAL SURVEYS BRANCH

Canada
Department of Mines

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

GEOLOGICAL SURVEY

Section along line K-L. Section along line M-N.

Section along line E-F. Section along line G-H. Section along line I-J.

LEGEND

Sedimentary Rocks

QUATERNARY

- Q2 — Alluvial
- Q1 — Glacial

PALÆOZOIC

SILURIAN

- Halysites beds
- S1 — White quartzite

ORDOVICIAN

- O2 — Graptolite shales
- O1 — Goodsir formation

UPPER CAMBRIAN

- C6 — Ottertail formation
- Chancellor formation
- C4 — Chancellor formation (sheared zone)
- C3 — Sherbrooke, Paget and Bosworth formations

MIDDLE CAMBRIAN

- C2 — Eldon, Stephen and Cathedral formations

LOWER CAMBRIAN

- C1 — Whyte, St Piran, Lake Louise and Fairview formations

PRE-CAMBRIAN

- A — Pre-Cambrian

Eldon, Stephen and Cathedral formations

LOWER CAMBRIAN

- C1 — Whyte, St Piran, Lake Louise and Fairview formations

PRE-CAMBRIAN

- A — Pre-Cambrian

Igneous Rocks

POST-CRETACEOUS(?)

- 3 — Leucocratic types (nephelite syenite, etc.)
- 2 — Transition types (ijolite, urtite, etc.)
- 1 — Melanocratic types (jacupirangite, etc.)

Symbols

- Fault (observed)
- Fault (position assumed)
- Geological boundary (position determined)
- Geological boundary (position assumed)
- Ⓕ Fossil locality

LEGEND

Culture

- Railways
- Railway tunnels
- Roads
- Trails
- Aerial tramways
- Bridges
- Mines
- Prospects

Water

- Rivers and lakes

- Prospects

Water

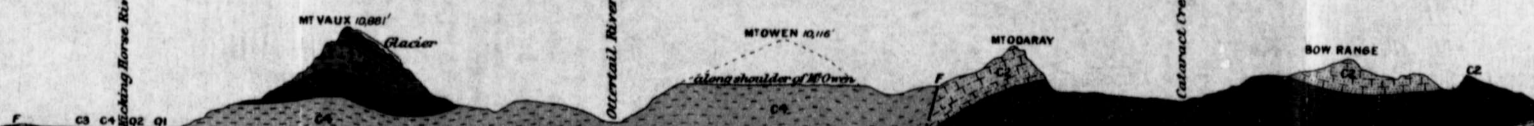
- Rivers and lakes

- Streams
- Watercourses (with intermittent flow)
- Glaciers

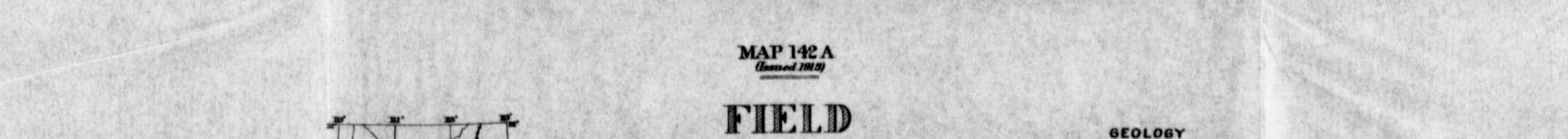
Relief

- Contours (showing land forms and elevations above sea-level) Interval 250 feet

Magnetic declination about 25°15' East.

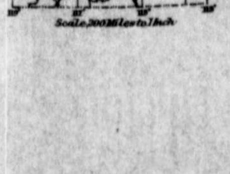


Section along line C-D.



Section along line A-B.

MAP 142 A
(Issued 1913)



FIELD
KOOTENAY DISTRICT
BRITISH COLUMBIA

Scale, $\frac{1}{126,720}$

Miles

Kilometres

2 MILES TO 1 INCH

GEOLOGY

J. A. ALLAN 1910, 1911.

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DEPARTMENT OF THE INTERIOR. PUBLISHED MAPS, 1912. (TOPOGRAPHICAL SURVEYS BRANCH)

To accompany Memoir by J. A. Allan.