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DEPARTMENT OF MINES
HON. CHARLES STEWART, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

GEOLOGICAL SURVEY
W. H. COLLINS, DIRECTOR

MEMOIR 153

No. 134, GEOLOGICAL SERIES

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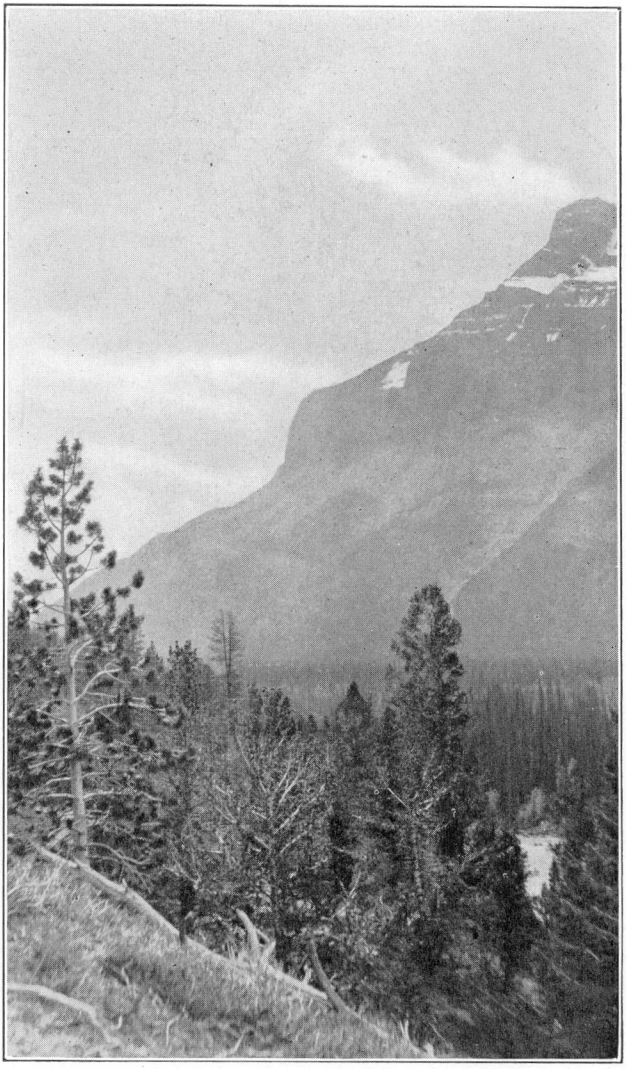

Profile of Rundle mountain. The two sharp cliffs are formed by, respectively, the Minnewanka (upper part) limestone and the Rundle limestone. (Page 4.)

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Banff Area, Alberta

CHAPTER I

INTRODUCTION

INTRODUCTORY STATEMENT

The summer of the year 1923 was spent by the writer in making a geological survey, including an investigation of the well-known thermal springs, of the area in the immediate vicinity of Banff, Alberta. The investigation was undertaken at the instance of the Parks Branch, Department of the Interior, and was occasioned by the fact that during the winter of 1922-23 one of the springs, known as the Upper Hot spring, ceased to flow for a period of two months. As the water of this spring especially is used by patients visiting Banff for therapeutic treatment, it is desirable that the flow should not be interrupted. An investigation of the cause of the cessation of flow necessitated a study of the origin of the springs; this led naturally to a detailed examination of the geology of the region. On this account an area was chosen which included Sulphur and Rundle mountains to the south of Bow river and Cascade and Norquay mountains to the north of the river. The results of these investigations are embodied in the following report.

EARLY EXPLORERS IN THE REGION

So far as is known, the first white men to enter this part of the mountains were David Thompson and Duncan McGillivray who, in November, 1800, ascended Bow river to "the Gap" but did not proceed as far as the present site of Banff.[1] In 1840 the Rev. R. T. Rundle journeyed into the mountains to do mission work among the Stoney Indians and camped with them from the early part of June to the middle of July in front of the mountain since named in his honour.[2] Later in the same year Sir George Simpson passed through this area and reached Columbia valley by way of what is now known as Simpson pass.[3] In 1845 Father P. J. De Smet crossed the summit of White Man pass, camped where Canmore now stands, and traversed the mountain trail to Rocky Mountain House.[4] Several years later Sir James Hector of Capt. John Palliser's expedition made a reconnaissance of this part of the mountains. He was the only one of the early explorers

1 Tyrrell, J. B.: "Journeys of David Thompson in North Western America," Toronto, 1888.
2 Wesleyan Missionary Notices, 1841-2-3.
3 Simpson, Sir George: "A Journey Round the World," London, 1847.
4 De Smet, P. J.: "Oregon Missions," New York, 1847.

who made a contribution to the geology of the area.[1] In 1859 the Earl of Southesk, bent more on hunting than on scientific exploration, traversed Pipestone pass and thence descended Bow river.[2] The writer was informed by Mr. Tom Wilson of Enderby, B.C., that a party of Americans whom Southesk encountered at the old Bow fort had traversed White Man pass. In 1880 the first party of surveyors connected with the location of the Canadian Pacific railway camped in the vicinity of Banff and were responsible for the actual discovery of the thermal springs.

PREVIOUS GEOLOGICAL WORK

Many of the geological features in the neighbourhood of Banff have become well known through the work of several geologists who have conducted surveys in this area. In 1885 Dr. G. M. Dawson completed a reconnaissance of the geological and physiographic features of this part of the mountains.[3] In 1886, R. G. McConnell completed his section across the Rocky mountains near the 51st parallel.[4] The succession of strata established by him has been little changed to the present time. Since that date geology of this region has been further investigated, notably by J. A. Allan,[5] D. B. Dowling,[6] H. W. Shimer,[7] and E. M. Kindle,[8] who have added considerably to the knowledge of the district.

A special investigation of the chemical constituents of the waters of the thermal springs was undertaken by J. Satterly and R. T. Elworthy.[9] This is the only work of importance on the thermal springs that has hitherto been attempted. Reports on the phosphate deposits that occur in this area have been made by Dr. F. D. Adams and W. J. Dick[10] and by Hugh S. de Schmid.[11] The results obtained by these investigations are, in part, embodied in this report.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the many courtesies received from the officers of Rocky Mountains park during the progress of the investigation. Thanks are due especially to Dr. J. A. Allan of the University of Alberta whose long experience in geological work in the mountains was of great assistance to the writer. To E. M. Kindle, Geological Survey,

1 Palliser's Journals, 1857-8-9-60.
2 Southesk, Earl of: "Saskatchewan and the Rocky Mountains," Edinburgh, 1875.
3 Geol. Surv., Canada, Ann. Rept., vol. I, pt. B (1886).
4 Geol. Surv., Canada, Ann. Rept., vol. II, pt. D (1887).
5 Geol. Surv., Canada, Sum. Repts. 1912-14-15, also Guide Book No. 8, pt. II.
6 Geol. Surv., Canada, Publication No. 949, 1907.
7 Geol. Surv., Canada, Sum. Rept. 1910.
Bull. Geol. Soc. Am., vol. 24, pp. 233-240, 112-113 (1913).
Geol. Surv., Canada, Bull. 42, pp. 1-84 (1926).
8 Pan.-Am. Geol., vol. 42, pp. 113-124, 217-218 (1924).
9 Mines Branch, Dept. of Mines, Canada, Bulls. Nos. 16 and 20.
10 Commission of Conservation of Canada, Rept. 1915.
11 Mines Branch, Dept. of Mines, Canada, Bull. 12, 1916.

Canada, and to Dr. G. H. Girty, United States Geological Survey, the writer expresses his indebtedness for assistance in identifying fossil specimens and for advice in regard to stratigraphic problems. Acknowledgments are due also to Mr. Tom Wilson of Enderby, B.C., for contributions regarding the early history of Banff and to Messrs. R. H. Pegrum and W. A. Lang for the able assistance rendered the writer in the field. Finally, the writer desires to acknowledge the generous assistance received from the staffs of the Departments of Geology and of Mineralogy of the University of Toronto, and especially from Dr. W. A. Parks, Professor of Geology, under whose supervision this report was prepared.

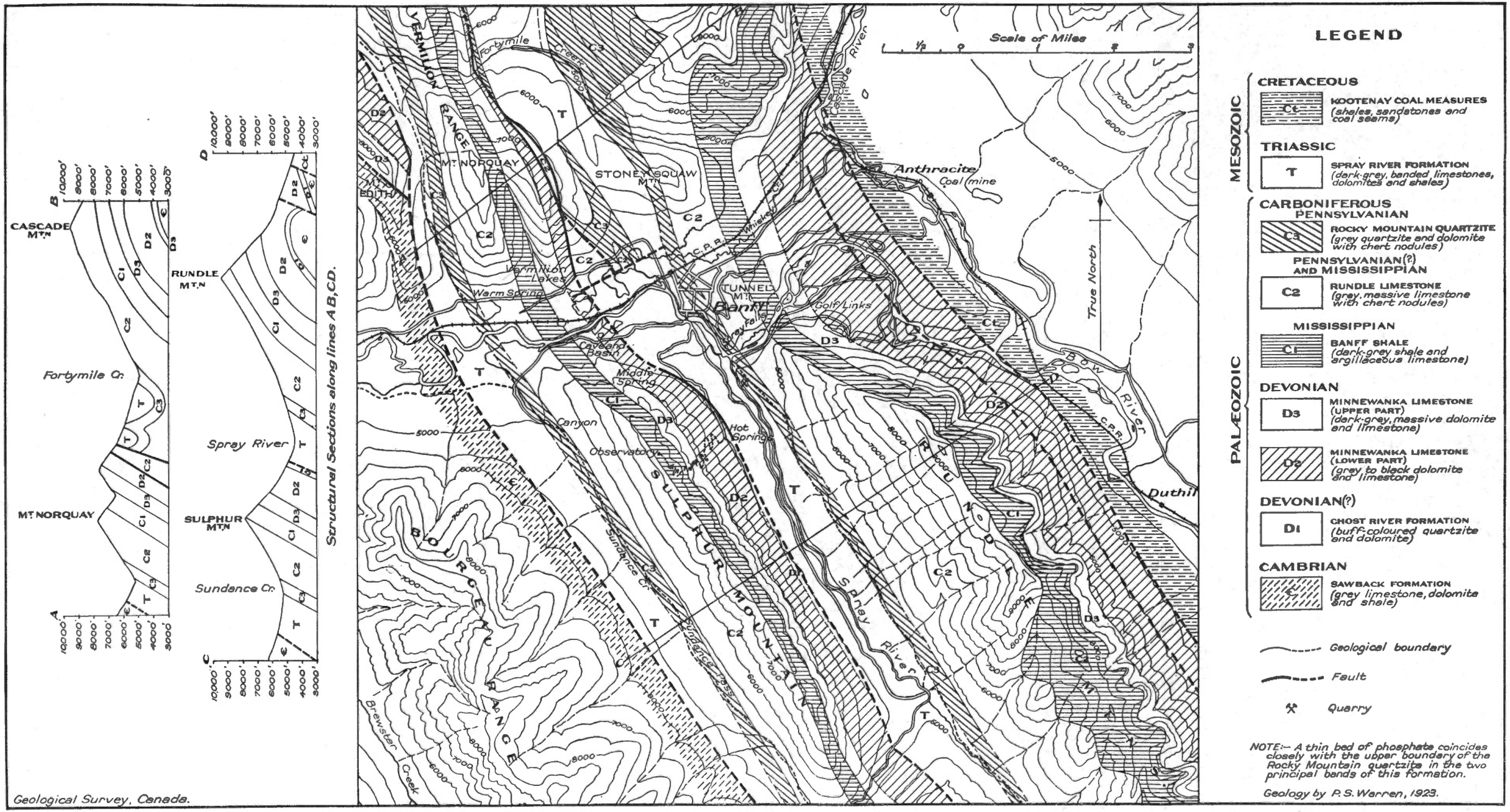


Figure 1. **Banff** and **vicinity**, Alberta.

CHAPTER II

PHYSIOGRAPHY

TOPOGRAPHY

GENERAL FEATURES

The area described in this report lies on the eastern slope of the main watershed of the Rocky Mountain system. The topography of the whole system is rugged and alpine. Mature dissection has reduced the inter-stream areas to narrow, knife-edge ridges with irregular peaks. These ridges, or mountain ranges, are parallel and follow straight lines for many miles, broken occasionally by the crosscutting of consequent streams. The general strike of the ranges is about 30 degrees west of north. The valleys between the ranges are deep and mostly wide, the mountains rising to a height of from 4,000 to 6,000 feet above the valley floors. Erosion is proceeding at a rapid rate, and small streams are cutting innumerable gullies in the flanks of the mountains. Many of these gullies develop into cirque-like amphitheatres, especially where the beds are soft; on the higher mountains they are as a rule glacier-hung.

The system of drainage is largely subsequent to the general structure. The principal rivers, throughout the greater part of their courses, occupy the large valleys between the ranges and only occasionally do they cut through the main ranges in seeking an exit.

MOUNTAINS

The mountains in the vicinity of Banff are of the type common to the Rocky Mountain system. The two highest, Rundle and Cascade, approach an elevation of 10,000 feet and overlook the broad Cascade valley to the east. They form integral parts of a range which is broken at this point by the easterly traverse of Bow river. Rundle mountain is situated on the south side of the river and Cascade mountain on the north. Both mountains are best designated as ranges as they include several peaks and extend for many miles in a north-south direction. The physiographic features of both are very similar. The eastern face is precipitous, with the slope varying considerably according to the hardness of the rock. The western slope is more gentle and corresponds roughly to the dip of the underlying strata. The peaks are easily accessible from the western side and bridle-paths have been constructed over a considerable part of the route leading to the top.

Tunnel and Stoney Squaw mountains are smaller elevations of the Rundle-Cascade range and are situated on either side of Bow valley between these mountains. Tunnel mountain, by reason of its proximity to the town of Banff, is the better known. It lies to the south of the

original valley of Bow river which, at this point, has been abandoned by the river and is now occupied by a small creek. Tunnel mountain represents an erosional remnant cut off from the northern end of Rundle mountain by a narrow valley now occupied by Bow river. It stands at an elevation of 5,510 feet, which is about 1,000 feet above the level of the valley. The top and sides of the mountain have been well rounded by the action of glaciers.

Stoney Squaw mountain, situated on the north side of Bow valley, is the counterpart of Tunnel mountain. It represents a shoulder cut off from the southern end of Cascade mountain by a narrow gorge formed by Fortymile creek. It reaches a height of 6,130 feet and displays the same characteristic glacial rounding exhibited by Tunnel mountain.

Sulphur and Norquay mountains lie to the west of the Rundle-Cascade range and represent separate units of a parallel range. Sulphur mountain, originally called Terrace mountain, is the better known of the two on account of the thermal springs which are situated along the base of the northeast flank. It lies to the south of Bow river and extends southward for a distance of about 6 miles. Sulphur mountain is separated from Goat mountain to the south by the gorge of Spray river, which is noted for some of the finest scenery in the neighbourhood of Banff. The mountain comprises several peaks, the highest of which attains an altitude of 8,000 feet. The eastern face is not so precipitous as that of Rundle or Cascade mountains and the top is easily accessible either from the front or the rear. A bridle-path has been constructed up the eastern slope to the northern peak where a meteorological observatory with self-recording instruments is situated.

Mount Norquay is situated on the north side of Bow river and resembles Sulphur in its general physiographic features. It extends about 3 miles to the north where it is separated from the Vermilion range by the easterly traverse of Fortymile creek. The double peak, which is characteristic of this mountain, is the result of the unequal erosion of the various strata. The western peak is the higher, attaining an elevation of 8,225 feet; it is easily accessible.

DRAINAGE

The drainage in this area is affected by Bow river and its tributaries. Through most of its course in the mountains the Bow flows southward as a subsequent stream. In the vicinity of Banff, however, its course is directed eastward, making a traverse through the mountain ranges. On entering Cascade valley its course once more assumes a southerly direction.

In its eastward course through the mountains the Bow occupies a broad, U-shaped valley from a half-mile to a mile in width. Its course through this valley is meandering, and its gradient sufficiently low to permit navigation with small boats. The valleys in which the river assumes the southward course are much wider and the gradient is much higher. In Cascade valley, to the east of Rundle and Cascade mountains, the river has cut its course through thick deposits of glacial drift. The drift in

places forms cliffs as much as 200 feet in height along the banks of the river. Owing to the irregular cementation and erosion of this material, many characteristic "hoodoo" forms are produced along the cliffs.

Bow river, at the present time, does not enter the Cascade trough through its original valley to the north of Tunnel mountain; instead, it swings to the south and passes to the west and then south of this mountain. Below a small cataract, known as Bow falls, the river is joined by the Spray and passes out to Cascade valley through a narrow channel between Tunnel and Rundle mountains.

Spray river is the principal tributary on the south side of the Bow. In its upper reaches it flows north in the valley between Goat mountain and the Bourgeau range to the west. About 6 miles south of Banff it traverses the Sulphur-Goat range, enters the valley between Sulphur and Rundle mountains, and flows north to meet the Bow at Banff. As a subsequent stream it flows through a comparatively wide valley with a gradient rather low for a mountain stream. Where it crosses the Sulphur-Goat range, however, it passes through a deep gorge with many rapids and small cascades.

The valley between Sulphur mountain and the Bourgeau range is occupied by a very small stream called Sundance creek. As it leaves the valley it cataracts through a small gorge known as Sundance canyon. The valley is very wide and is still filled with glacial drift.

Cascade river is the principal tributary of the Bow on the north. It flows south through Cascade valley to the east of Cascade mountain, and, after draining lake Minnewanka, joins the Bow.

The only other stream of any importance on the north side of the Bow is Fortymile creek. This stream, after flowing south between the Vermilion range and the Sawback range to the west, changes its course to the east, making a traverse across the Norquay-Vermilion range, and thence cuts its way out to Bow valley between Cascade and Stoney Squaw mountains. The gradient is never very high and the valley is of moderate width except where it passes between Cascade and Stoney Squaw mountains.

Changes in Drainage

A study of the physiographical features of this area tends to demonstrate that various changes have taken place in the drainage system during, or subsequent to, Glacial time. Certain of these changes, as put forward here, are readily discernible, whereas others are not so evident, and definite proofs were not obtainable.

One of the most notable changes is that affected by Bow river in the neighbourhood of Banff. The original valley of the Bow is to the north of Tunnel mountain in line with the general direction of the valley through this part of its course. It now swings to the west and then south of Tunnel mountain to reach Cascade valley. This change was caused by the thick deposits of glacial drift left in Cascade valley. These completely blocked the course of the river and forced it to seek another channel. The old valley of the Bow between Tunnel mountain and Stoney Squaw is now occupied by Fortymile creek and Whisky creek which joins the Bow at

Banff. These two creeks have effectually cleared this part of the valley of glacial debris, but farther to the east in Cascade valley large quantities of glacial drift still occupies the old river course.

The channel between Tunnel and Rundle mountains was formed in pre-Glacial time, as there is considerable evidence that the channel has been occupied by a glacier. This channel was undoubtedly occupied in pre-Glacial time by Spray river which originally joined the Bow in Cascade valley. The slight recession of Bow falls from their original position indicates that Bow river has not occupied this channel for any considerable time.

Spray river also shows certain changes in its course. The character of its gorge between Sulphur and Goat mountains shows that it has been formed rather recently and that the Spray originally followed some other channel. Its most natural course would be down the valley between Sulphur mountain and the Bourgeau range. This valley is now largely filled with glacial drift and is occupied only by a small stream. The valley is wide and strongly eroded and shows evidence of having been occupied, at one time, by a much stronger stream. This valley is believed by the writer to have been the original outlet of the Spray and he is of opinion that subsequent blockage of the valley by glacial drift forced the river through the gap it now occupies. Previous to this the valley between Rundle and Sulphur mountains was occupied only by the stream now flowing between Goat and Rundle mountains.

The course of Cascade river, from the west end of lake Minnewanka, well into Cascade valley, is through a deep gorge marked by many cataracts. It is quite evident that the river has occupied this course only in recent years. As most of the territory drained by the Cascade lies outside the area studied by the writer, the river was not studied in detail, but it seems evident that its original course was through the valley now occupied by lake Minnewanka.

Dawson[1] suggested that Bow river once occupied the valley of lake Minnewanka. This seems possible, but the Bow must have vacated that course in favour of its present one before Glacial time, for the pre-Glacial valley of the Bow was much lower than lake Minnewanka, as shown now by the glacial drift in Cascade valley.

There seems no reason to believe that the course of Fortymile creek has ever been changed. The height of the pass between mount Norquay and the Sawback range (about 2,000 feet above Bow valley) would preclude any idea of the stream having occupied that passage. The height of the pass between Stoney Squaw and Norquay (about 1,000 feet above the valley) would also be prohibitive.

LAKES

The only bodies of water of any considerable dimensions in this area are the Vermilion lakes. They lie in Bow valley close to the north bank of the river, between it and the foot of mount Norquay. The lakes are

[1] Geol. Surv., Canada, Ann. Rept., pt. B, p. 141 (1886).

four in number, and are connected in a series. They are very shallow and are largely grown up with rushes and algæ. Their margins are marshy and the lakes are best described as open spaces in a large swamp which occupies this part of the valley. Their level is little above that of the river, with which they are connected by a small creek. At the time of low water in the river the level of the lakes falls considerably, exposing mud flats along the shores.

The lakes probably represent the remnants of a much larger body of water which occupied the valley in post-Glacial time before Bow river obtained its new outlet on the west side of Tunnel mountain.

GLACIAL GEOLOGY

INTRODUCTORY STATEMENT

It is impossible to deal fully with a subject as complex as glacial geology with respect to an area so limited as that under discussion. General statements regarding glaciation can be made only as a result of the study of large areas; consequently, remarks on this subject, so far as this area is concerned, must necessarily be very limited.

EXTENT AND CHARACTER OF GLACIATION

Evidence of glacial action is abundant throughout the whole area. The valley of Bow river in its easterly course through the mountains is characteristically U-shaped, signifying that it has been occupied by a glacier. Glacial scouring and rounding are much in evidence on the more exposed points, and glacial debris still remains in the deeper recesses along the valley side. Glacial scouring may also be observed in some of the transverse valleys between the ranges, especially on the lower slopes. The thickness of the ice which filled these valleys may be gauged from the fact that erratic boulders were found to the height of nearly 8,000 feet on Sulphur and Cascade mountains. It is evident, however, from the character of the great peaks of these ranges that the Cordilleran ice-sheet did not pass directly over them, but was confined to the valleys. This statement does not include the less elevated Tunnel and Stoney Squaw mountains, the summits of which have been strongly glaciated.

Glacial drift is very abundant on the lower slopes of the mountains and, in some places, still covers the valley floors. In Bow valley it has been largely removed and may be found only in isolated patches in the more sheltered localities. In Spray River valley glacial drift is quite plentiful on the lower slopes of the mountains, but it has been altogether removed from the valley floor. In Sundance valley, however, the drift still lies very much as it was deposited, as no large rivers have occupied the valley since Glacial time. Along the valley of Fortymile creek there is little evidence of glacial drift except that of erratic boulders.

In Cascade valley glacial drift accumulated to a depth of at least 200 feet. Bow river has succeeded in removing these deposits from a large part of the valley, but, in many places, the drift still forms high cliffs along the river bank. The material is coarse and has become quite strongly cemented, which accounts for its cliff-forming habit. Differential erosion has produced an abundance of characteristic "hoodoo" forms which stand out as prominent features along the cliffs.

The effect of the Cordilleran ice-sheet may be observed also in the various changes of the drainage system in this area. These changes have been brought about by the blocking of the old river courses with glacial debris. The various changes have already been noted in an earlier part of the chapter and need not be repeated here.

There are no glaciers at the present time on any of the mountains in this area.

CHAPTER III

GENERAL GEOLOGY

GENERAL STATEMENT

The area in the vicinity of Banff is underlain by an immense thickness of strata ranging in age from Cambrian to Cretaceous. The whole area lies within the Rocky mountains, and in this region faulting rather than folding is responsible for the structure. The successive, tilted fault blocks afford excellent sections of the successive formations. The Palæozoic formations are chiefly limestones and dolomites, whereas the Mesozoic strata are represented to a greater extent by clastic rocks comprising sandstones, shales, and argillaceous limestones. On account of the superior hardness of the Palæozoic strata and their resistance to erosion they form the greater part of the existing mountain ranges, whereas the softer Mesozoic rocks, having suffered more severely from the mountain-building movements and from subsequent erosion, have been removed from the summits of the ranges and are found only on the back slopes or in the longitudinal valleys.

The Palæozoic and Mesozoic record, on the whole, is fairly continuous in the southern Rocky mountains of Canada. Nevertheless, in the area under review, or in its immediate vicinity, there are at least two rather important disconformities indicating time-breaks of considerable magnitude. The earlier of these occurs at the top of the Cambrian which is overlaid disconformably by limestones and dolomites of Devonian age. The second break is at the top of the Pennsylvanian (Rocky Mountain quartzite) which is overlaid disconformably by lower Triassic limestones, dolomites, and shales, constituting the Spray river, originally the Upper Banff shale formation. Neither of these disconformities is readily observed, but may be proved by detailed examination.

In order to understand properly the succession of strata within the area it was necessary to extend the investigation somewhat farther afield. In consequence, the following brief account of the general sequence contains reference to points outside the field assigned to the writer for examination.

Cambrian rocks appear only on the western border of the area where they are faulted against the Spray River shale of the Sulphur-Norquay range. The Cambrian Sawback formation is overlaid by the Minnewanka limestone of Devonian age. The absence of Ordovician and Silurian strata is probably due to non-deposition as stated by Walcott,[1] but deposition may have taken place during part of the interval, the resulting rocks having been subsequently eroded before the incoming of the Devonian sea.

The upper Palæozoic strata are represented chiefly by limestones and dolomites. The Ghost River formation and Minnewanka limestone of

[1] Smith. Miss. Coll., vol. 67, No. 8, p. 464.

Devonian age attain a total thickness of over 3,000 feet. Mississippian strata, with a thickness of over 3,000 feet, are represented by the Banff shale and part at least of the Rundle limestone. The age of the upper part of the Rundle limestone is in doubt and may be Pennsylvanian. The Rocky Mountain quartzite of Pennsylvanian age marks the top of the sequence and attains a thickness of nearly 700 feet. This succession of strata represents a period of continuous deposition under marine conditions.

Diastrophic movements at the end of Devonian time were reflected in this area by the deposition of the black shales forming the lower member of the Banff shale. There is no indication that the sea actually withdrew from the area at this time. The Rocky Mountain quartzite of Pennsylvanian time indicates a shallowing of the sea with the deposition of shore-line deposits. The absence of Permian strata indicates a complete withdrawal of the sea from this area at the close of the Palæozoic.

The Mesozoic succession in this part of the mountains cannot be fully studied in the area under consideration. The Jurassic represented by the Fernie shale, which forms part of the sequence to the east of Cascade valley, is absent, for the structure prevents its appearance. The Fernie shale marks the last marine invasion of this area. Clastic material is largely in evidence throughout the strata which are represented largely by argillaceous limestones and dolomites, shales, and sandstones, indicating that there was no recurrence of the clearwater conditions under which the Palæozoic sediments were deposited. The Kootenay sandstones and shales of Lower Cretaceous age are well developed in Cascade valley and are exposed along the eastern edge of the map-area where the Palæozoics of the Rundle-Cascade range are faulted against them. They were deposited in large lakes or lagoons which occupied the Cordilleran geosyncline subsequent to the withdrawal of the Jurassic sea and prior to the commencement of the great diastrophic movement, terminating in the Laramide revolution, which raised the mountains to their present position.

The various formations represented in this area are shown in the following table:

Table of Formations

System	Formation	Lithology	Approximate thickness
			Feet
Recent and Pleistocene	.....	Glacial drift River gravels	
Cretaceous	Kootenay	Sandstone and shale with coal	2,800
Triassic	Spray River	Dark grey to black argillaceous limestone and dolomite, and calcareous shale conspicuously banded	3,400?
Pennsylvanian	Rocky Mountain quartzite	Grey, siliceous dolomite with beds of quartzite	700

Table of Formations—Continued

System	Formation	Lithology	Approximate thickness
Pennsylvanian? and Mississippian	Rundle	Massive, light to dark grey limestone, much of it cherty	2,400
Mississippian	Banff	Brown, calcareous shale and argillaceous limestone	1,400
Devonian	Minnewanka	Upper part: massive, dark grey to black limestone and dolomite	1,000
		Lower part: thin-bedded, black limestone and grey dolomite, and massive dark grey to black dolomite	1,900
(?)	Ghost River	Buff-coloured dolomite and quartzite	300
Cambrian	Sawback	Thin-bedded limestone and shale, and massive dolomite and limestone	3,700

DESCRIPTION OF FORMATIONS

CAMBRIAN

Sawback Formation

General Character and Distribution. The Sawback formation, comprising a thick succession of limestones, dolomites, and shales, represents the oldest strata in the vicinity of Banff. It occurs in the Bourgeau-Sawback range which lies just to the west of the Sulphur-Vermilion range. The formation borders the area studied by the writer, being faulted against the Spray River formation, the youngest in the Sulphur-Norquay succession. The rocks were originally included in the Castle Mountain group by McConnell;[1] the formational name was given later by Allan,[2] who considered the rocks to be Devonian in age. Burling[3] and Kindle[4] working on this area since that time have found Upper Cambrian fossils in the Sawback formation, thus substantiating McConnell's conclusions. As most of the formation lies outside the area under consideration, it was not studied in detail.

Lithology. The Sawback formation is a series of limestones, dolomites, and shales over 3,000 feet thick. The upper part consists of grey, calcareous shales with intercalated beds of grey, fine-grained limestone.

[1] Geol. Surv., Canada, Ann. Rept., pt. B (1886).
[2] Geol. Surv., Canada, Sum. Rept. 1912, p. 172.
[3] Burling L.D.: Geol. Surv., Canada, Sum. Rept. 1915, p. 99.
[4] Kindle, E. M.: Pan-Am. Geol., vol. 24, p. 115 (1925).

Below this lies a series of thick-bedded, magnesian limestones, some beds being oolitic and fossiliferous. The base of the formation consists of hard, grey limestones, many of them crystalline in character, with a considerable development of arenaceous shale towards the bottom. These shales weather reddish and show as a conspicuous band on the Sawback range. Faults occur in the lower part of the formation, resulting in a repetition of some of the strata.

Palæontology and Correlation. Fossils are scarce throughout the formation, being most abundant in the oolitic limestones. A small collection was made in which *Eoorthis wichitaensis* (Walcott) and *Dikelocephalus* sp. were identified, indicating the Upper Cambrian age of the formation.

Walcott has proposed some new formational names for the Upper Cambrian rocks in the Glacier Lake section, 48 miles northwest of Lake Louise station.[1] These formations are, in ascending order, Sullivan, Lyell, and Mons. He ascribes the Mons formation to the Ozarkian of Ulrich, the remaining two being left in the Upper Cambrian. Walcott also recognizes these formations at Ranger canyon in the heart of the Sawback range where this series of strata has hitherto been known as the Sawback formation. The same three subdivisions were recognized by the writer in the Sawback formation at the south end of the Sawback range near Banff, but the boundaries between the subdivisions were not clearly defined.

DEVONIAN

Ghost River Formation

General Character and Distribution. The name Ghost River formation is applied to a succession of buff-coloured quartzites and dolomites exposed at the base of the Minnewanka limestone on Sulphur mountain. The name was proposed by Walcott for a formation of 285 feet of thin-bedded, shaly, buff-coloured magnesian limestones lying conformably between the Middle Cambrian limestone and the Minnewanka limestone in the front ranges and extending from the south fork of Ghost river to Red Deer river.[2] In no place was a complete section observed, the lower beds immediately above the Sulphur Mountain fault being covered with talus and some of the higher beds not exposed. The lowest beds exposed have been so folded that a detailed section could not be obtained. The estimated thickness of the formation is about 300 feet.

Lithology. The lowest beds exposed in any of the sections are massive, buff-coloured quartzites, in many cases containing an appreciable amount of dolomite. They weather easily, breaking down into fine, angular fragments. The upper beds of the formation, observed only in the gully just south of the Upper Hot spring, are soft, buff-coloured dolomites and magnesian limestones with an occasional bed of quartzite, the

1 Smith. Miss. Coll., vol. 67, No. 8, pp. 459-61.
2 Smith. Miss. Coll., vol. 67, No. 8, p. 463.

whole weathering very easily. The contact with the Intermediate limestone above is apparently conformable, though the change from the soft, buff-coloured dolomites of the Ghost River formation to the hard, grey dolomites of the Minnewanka formation is quite abrupt.

Palæontology and Correlation. As no fossils were collected from this formation its exact age could not be ascertained. On account of its conformable position below the Minnewanka limestone (lower part) which appears to be Middle Devonian and possibly in part Lower Devonian, it seems safe to infer that the Ghost River formation is Devonian in age, and either Middle or Lower Devonian, representing the basal member laid down by the transgressing Devonian sea.

In the area examined by the writer this formation was observed only on Sulphur mountain. A somewhat similar formation has been observed at a corresponding horizon in other areas. McConnell mentions a light-yellowish siliceous band, varying in thickness from 100 to 400 feet, occurring near the base of the Minnewanka (Intermediate) limestone on the south fork of Ghost river, along the eastern part of Devils Lake (Minnewanka) valley, and at the entrance of White Man pass.[1] Farther to the northwest, at the head of Clearwater River canyon and on mount Wilson, Walcott found a quartzite occupying the same horizon as the Ghost River formation. He named this quartzite the Mount Wilson formation.[2] It seems evident, from the information available, that McConnell's siliceous band at the base of the Intermediate limestone, Walcott's Ghost River formation and Mount Wilson quartzite, and the beds occurring on Sulphur mountain, occupy about the same geological horizon and represent the opening phase of Devonian sedimentation in the front ranges of the Rocky mountains.

Minnewanka Limestone (Lower Part)

General Character and Distribution. McConnell gave the formational name, Intermediate limestone, to a series of brownish and greyish crystalline dolomites with some sandstones and quartzites, about 1,500 feet thick, lying between his Castle Mountain group of the Upper Cambrian and the Banff Limestone group, all then considered to be of Carboniferous age. He found the formation represented in all the front ranges of the Rocky Mountain system in this region and considerably varied in character in different localities. Under the new nomenclature this formation is known as the Minnewanka limestone (lower part).

In Banff area the lower part of the Minnewanka limestone generally forms the lower slope of the eastern face of the mountains. On Cascade mountain it is not exposed, for there the upper part of the formation (Lower Banff limestone) has been faulted against the Cretaceous sandstones of Cascade valley. On mount Norquay only a few hundred feet of the top of the lower part of the Minnewanka are present, the lower part

[1] Geol. Surv., Canada, Ann. Rept., pt. D, p. 20 (1886).
[2] Smith. Miss. Coll., vol. 67, No. 8, p. 464.

being cut out by the Sulphur Mountain fault. A good exposure of the strata may be observed on Rundle mountain, but the beds are folded and faulted, making a study of the formation difficult. The best section for detailed study is on Sulphur mountain where practically the whole of the lower part of the Minnewanka formation is exposed.

Lithology. The Minnewanka formation (lower part) as developed in Banff area consists essentially of thin-bedded to massive, fine-grained, light grey to black dolomites with some thin beds of black, fine-grained limestone in the lower part. On Sulphur mountain the total thickness is 1,968 feet. The lithological character of the rock and the nature of the bedding vary to a certain extent throughout. As a rule, the dolomite is fine grained and light grey to medium grey. Coral reefs containing fine, branching, structureless corals occur in many places and in such localities the dolomite is dark grey to black with saccharoidal texture. Beds of light grey, coarse-grained dolomite also occur, especially in the upper part. Some of the beds contain a considerable amount of pyrite and when struck with a hammer emit an odour of sulphuretted hydrogen.

The assemblage is divisible into three members, differing mainly in the character of the bedding. Small lithological differences also occur.

The lowest member is characteristically thin bedded, with a considerable development of limestone. The dolomite is typically light grey and very fine grained. The limestone is black, fine grained, and lustreless. Some beds of soft, buff-coloured limestones occur in the upper part of the member, alternating with beds of limestone breccia. The brecciation of these beds appears to be secondary and due to crushing. Coral reefs do not occur in any of these beds. The member was observed only on Sulphur mountain where it attains a thickness of 338 feet.

The middle member, as typically developed, is the cliff-forming member, and is composed of massive beds of grey to black dolomite with saccharoidal texture, containing reefs of structureless corals and stromatoporoids. At some horizons the bedding is thinner and the rock weathers easily. In the measured section the rocks not exposed are probably underlain by thin-bedded dolomites. One 12-foot bed of black, fine-grained limestone is developed in this member. The total thickness is 1,390 feet.

The uppermost member comprises 240 feet of medium to thin-bedded, light grey dolomite which varies from a fine-grained to a rough, coarse-grained texture. The coarse-grained dolomites weather more easily than the finer-grained type. Some beds show a distinct banding of a very fine-grained dolomite with one of a little coarser texture and lighter colour. On weathered surfaces the finer-grained bands stand out more prominently than those of the coarser texture, forming a delicate tracery over the surface. These beds clearly define the top of the lower part of the Minnewanka.

The best measured section of the lower part of the Minnewanka limestone is on Sulphur mountain in a gully about 200 yards south of the Upper Hot spring. Here, the base of the formation is exposed, an occurrence not usual in this area. A detailed description of the section is given below:

Section of Minnewanka Limestone (Lower Part) on Sulphur Mountain

Character of the Beds	Thickness Feet
Overlying formation—Minnewanka limestone (upper part)	
Upper Member	
Not exposed	15
Thin-bedded, light grey dolomite varying from very fine grained to coarse grained. Some beds show banding of texture and colour producing tracery on the weathered surface..	225
Middle Member	
Massive, grey dolomite with saccharoidal texture	234
Thick-bedded, grey dolomite with saccharoidal texture	77
Massive, grey dolomite with saccharoidal texture, containing poorly preserved, branching corals	324
Massive, dark grey to black dolomite with saccharoidal texture, containing many specimens of *Diphyphyllum* and *Favosites limitaris?*	45
Medium-bedded, dark grey to black dolomite with saccharoidal texture, containing many reefs of poorly preserved corals..	104
Thin-bedded, black, very fine-grained limestone with *Atrypa missouriensis*	12
Massive, dark grey to black dolomite with saccharoidal texture, containing many poorly preserved corals and stromatoporoids	148
Thin- to medium-bedded, grey dolomite with fine-grained or saccharoidal texture	44
Lower Member	
Thin-bedded, light grey, fine-grained limestone	45
Soft, buff-coloured, fine-grained limestone	3
Thin-bedded, dark grey, fine-grained dolomite	7
Limestone breccia, with angular fragments of dark grey limestone with a calcite matrix of a lighter colour	4
Soft, buff-coloured, fine-grained limestone	2
Limestone breccia, as before	2½
Soft, buff-coloured, fine-grained limestone	1½
Medium grey, fine-grained limestone	3
Soft, buff-coloured, fine-grained limestone	5
Limestone breccia, as before	3
Thin-bedded, soft, buff-coloured, fine-grained limestone	30
Thin-bedded, dark grey, fine-grained dolomite, in many cases porous and blotched with iron stains	2
Reddish to orange-coloured, fine-grained dolomite	1
Thin-bedded, dark grey, fine-grained dolomite, in many cases porous and blotched with iron stains	14
Thin-bedded, grey, fine-grained dolomite	7
Not exposed	2½
Thin-bedded, dark brown to black, fine-grained limestone with shaly partings	21
Thin-bedded, brown, argillaceous limestone with *Atrypa missouriensis*	3½
Thin- to medium-bedded, dark grey to black, fine-grained limestone with *Atrypa missouriensis* and *Stromatopora?* alternating with thin-bedded, argillaceous limestone. One band of oolitic limestone	57
Not exposed	57
Thin-bedded, light grey, very fine-grained dolomite	67
Total	1,968
Underlying beds—Ghost River formation	

Palæontology and Correlation. The Minnewanka limestone (lower part), as developed in Banff area, contains few fossils with the exception of the reefs of structureless, branching corals and poorly preserved stromatoporoids that occur in the middle member. In a *Diphyphyllum* reef in this member the corals are somewhat better preserved. *Diphyphyllum* sp. indet., *?Favosites limitaris*, and *Acervularia* sp. indet. were obtained here. *Atrypa missouriensis* and *Chonetes deflecta* were collected from a limestone bed at a little lower horizon and *Atrypa missouriensis* and *Stromatopora?* occur in the limestones in the lower member. The complete list of fossils collected from the Intermediate limestone is as follows:

Diphyphyllum sp. indet.
Acervularia sp. indet.
?Favosites limitaris Rominger
Favosites? sp. indet.
Chonetes deflecta Hall
Atrypa missouriensis Miller
Grammysia? sp. indet.

Of this list, *Chonetes deflecta* and *Atrypa missouriensis* are the only fossils which are of much value in determining the age of the formation; they clearly indicate Devonian time. The horizon of the Devonian to which the formation may be ascribed is not so clearly demonstrated. *Chonetes deflecta* was originally described from the Hamilton formation of New York state. It occurs, however, according to Walcott, in both Lower and Upper Devonian in Eureka district, Nevada.[1] *Atrypa missouriensis* was described by Miller from an horizon of Hamilton age in Missouri. Girty identifies the same species in the Three Forks limestones of Upper Devonian age in the Yellowstone National park, Wyoming,[2] and also refers *Atrypa desquamata*, found by Walcott in the Lower Devonian of Eureka district, to the same species. Kindle reports *Atrypa missouriensis* from the Jefferson limestone of Montana, which he considers to represent both Lower and Middle Devonian.[3] It would appear, therefore, that in the Devonian succession of the Cordillera, neither of these species is of diagnostic value in determining a definite horizon.

The stratigraphic position of the lower part of the Minnewanka limestone gives a more definite idea of its age. It is overlain conformably by the upper part of the Minnewanka which contains an Upper Devonian fauna. It follows, therefore, that part at least of the Minnewanka limestone (lower part) probably represents Middle Devonian, and, considering the great thickness of the formation, may even include strata of Lower Devonian age.

The correlation of this lower part of the Minnewanka limestone will be discussed in conjunction with that of the higher part.

Minnewanka Limestone (Upper Part)

General Character and Distribution. Lying conformably on the Minnewanka strata just described is a series of massive limestones and dolomites that have been known as the Lower Banff limestone, but are now considered

[1] U. S. Geol. Surv., Mon., vol. 8, p. 124.
[2] U. S. Geol. Surv., Mon., vol. 32, pt. 2, p. 502.
[3] Bull. Am. Pal., vol. 4, No. 20, p. 29.

as forming the upper part of the Minnewanka. The formation is very resistant to erosion and forms a prominent cliff on the eastern face of all the mountains in the vicinity of Banff. The prominence of the cliff is accentuated by the fact that the Banff shale, which lies directly above it, erodes easily and forms a gentle slope on the face of the mountains. The lower boundary of the formation is fairly well defined, the lower beds being massive, whereas the upper beds of the underlying lower part of the Minnewanka are thin bedded. The upper boundary is very definite, the change from the limestone to the black shale above being quite abrupt. The formation weathers to a grey colour very similar to that of the underlying limestone with which it may be quite easily confused. A measured section on Sulphur mountain gave a total thickness of 1,050 feet.

Lithology. The Minnewanka formation (upper part), as developed on Rundle and Cascade mountains, consists of massive beds of black, very fine-grained limestone becoming thinner bedded toward the top. As developed in a measured section on Sulphur mountain, in a gully about 200 yards south of the Upper Hot spring, the rock is essentially a fine, dark grey to black dolomite with saccharoidal texture, except for the upper 50 feet which is limestone. In a section about a mile farther to the east on Sulphur mountain the formation is essentially a dolomite except for the upper beds and beds about 200 feet in thickness near the middle of the formation, which are limestone. On the north end of Sulphur mountain a limestone bed about 50 feet in thickness occurs about 300 feet below the top of the formation. On mount Norquay the same erratic relationship of limestone and dolomite occurs, no two sections showing the same distribution. The uppermost beds in all the sections are limestone.

The assemblage admits of division into two well-defined members. The upper member, about 50 feet thick, consists of thin-bedded limestones which are usually quite fossiliferous. The lower member consists of the massive beds of dolomite and limestone, usually unfossiliferous, which comprise most of the formation. Much of the dolomite of this formation is cavernous, the cavities as a rule being very small and many filled with fine, white dolomite. Near the top, much larger cavities occur, some as much as 2 feet in diameter. These larger cavities are filled with fine, white, crystalline calcite.

The dolomitization which affected these beds appears to bear no relationship to faults or cracks in the rock, which should be the case if the dolomitization had taken place since the rocks were raised to their present position. It is also difficult to conceive of such a series of beds being formed in their present condition by direct precipitation on the sea-floor. The erratic distribution of the two types of rock and the sudden lateral changes from dolomite to limestone would not admit of such an hypothesis. It seems more reasonable to assume that the dolomitization took place after the beds were deposited on the sea-floor and before they were raised to their present position.

Apart from the erratic dolomitization the formation is very homogeneous. A section, measured in a gully about 200 yards south of the Upper Hot spring, is as follows:

Section of Minnewanka Limestone (Upper Part) on Sulphur Mountain

Character of the Beds	Thickness Feet
Overlying formation—Banff shale	
Upper Member	
Medium- to thin-bedded, black, fine-grained limestone with many fossils	45
Lower Member	
Massive, dark grey to black dolomite with saccharoidal texture.	1,005
Total	1,050
Underlying formation—Minnewanka limestone (lower part)	

The dolomites of both divisions of the Minnewanka are somewhat alike, but in the lower part of the formation are usually lighter in colour and in many cases coarser in texture except where the coral and stromatoporoid reefs occur. Such reefs do not appear in the upper part. The dolomite of the upper part is usually much more cavernous than that of the lower part, and weathers in sharp, angular cliffs, whereas the dolomite of the lower part weathers in low, rounded cliffs.

Palæontology and Correlation. The upper part of the Minnewanka is not uniformly fossiliferous. Throughout most of the division recognizable fossils are extremely scarce and it is only in the upper, thin-bedded part that they occur in any abundance. Peculiar, branching, bryozoa-like forms are rather common, especially where the limestone has not been dolomitized. *Spirifer whitneyi* is the predominant form, being especially abundant in the upper beds. It was collected as low down as 600 feet from the top of the formation. The lower 400 feet proved to be entirely unfossiliferous in this area. The lack of recognizable fossils throughout most of the formation cannot be attributed to the dolomitization of the limestone, as fossils are also absent in sections where dolomitization has not taken place. Fossils, as a rule, are poorly preserved, generally being exfoliated, and seldom exhibiting the finer external ornamentation or the internal structure. The total known fauna of the formation is listed below:

Productella coloradoensis Kindle
Productella coloradoensis var. *plicata* Kindle
Productella lata sp. nov.
Schizophoria striatula (Schlotheim)
Schuchertella girtyi Shimer
Camarotoechia banffensis sp. nov.
Camarotoechia shimeri sp. nov.
Camarotoechia horsfordi (Hall)
Pugnax minutus sp. nov.
Leiorhynchus cascadensis sp. nov.
Spirifer whitneyi Hall
Spirifer whitneyi var. *monticola* Haynes
Spirifer whitneyi var. *gallatiensis* Haynes
Spirifer whitneyi var. *animascensis* (Girty)
Athyris angelica (Hall)
Athyris? sp. indet.
?Euomphalus eurekensis Walcott

Bellerophon sp. indet.
Diaphorostoma? sp. indet.
Loxonema sp. indet.
Orthoceras? sp. indet.
Cyrtoceras? sp. indet.
Poterioceras sp. indet.
?Platyclymenia americana Raymond

This fauna shows a distinct Upper Devonian aspect. Such forms as *Spirifer whitneyi* and its varieties, *Athyris angelica, Productella coloradoensis* and its variety *Productella coloradoensis plicata,* are very abundant and are characteristically Upper Devonian in age. A lower horizon is suggested by the form identified as *Camarotoechia horsfordi* which species is typical of Hamilton time. There seems little doubt, however, that this species, as it occurs in Banff area, falls within the limits of the species as described by Hall. The species is also listed by Walcott from the Devonian of Eureka district, Nevada.[1] Several of the species listed are new, and with many others which cannot be identified have little diagnostic value.

Few of the specimens identified as *Spirifer whitneyi* show the fine radiating striæ by which the species is distinguished from *Spirifer disjunctus.* In many cases this is probably due to the exfoliation of the shell, though one of our specimens, which is badly exfoliated, shows the surface markings quite distinctly; whereas others, but little exfoliated, show none. Kindle[2] has already pointed out the fact that the finer markings are of an evanescent character; it seems preferable, therefore, not to attempt to distinguish two species by the presence or absence of the finer striæ alone.

Schuchertella girtyi is a species described by Shimer from this formation in the Lake Minnewanka section. It bears a close relationship to *S. chemungensis* which occurs commonly in the Upper Devonian. *Platyclymenia americana* is a form characteristic of the Three Forks shale of Montana. Our specimen, which is doubtfully referred to this species, is fragmentary, preserving only the living chamber, and, therefore, cannot be identified definitely. It is a little more robust than the Montana forms, but the surface ornamentation seems to be identical.

This fauna is to be correlated with that of the Three Forks shale of Montana and with that of the Devonian part of the Ouray limestone of Colorado. In Montana the stratigraphic sequence corresponds very closely with the Palæozoic succession at Banff. In both localities the Cambrian is overlain by the Devonian which is succeeded conformably by strata of Mississippian age. The Devonian succession in Montana comprises the Jefferson limestone and the Three Forks shale, which correspond in stratigraphic position with the Ghost River formation and the whole of the Minnewanka limestone of the Banff section. The similarity of the fauna of the upper part of the Minnewanka and the Three Forks shale has already been mentioned. The fauna of the lower part of the Minnewanka is too meagre to make a definite comparison with that of the

[1] U. S. Geol. Surv., Mon., vol. 8, p. 152.
[2] U. S. Geol. Surv., Bull. 391, p. 25.

Jefferson limestone, but such evidence as can be obtained favours the correlation. The lithological character of the two formations, also, seems sufficiently similar to warrant the assumption that they both belong to the same stratigraphic unit.

Kindle concludes from his study of the fauna of the Jefferson limestone that both Lower and Middle Devonian are represented in the formation. In the Banff section there is no palæontological evidence to warrant the assumption that the Lower Devonian is represented, but the immense thickness of the Devonian section leads to the conclusion that the lower strata may have been deposited in that time.

The boundary between the Middle and Upper Devonian is not apparent on account of the absence of fossils through a large part of the section. *Spirifer whitneyi* was obtained as low as 600 feet from the top of the upper part of the Minnewanka limestone; consequently, that part of the formation above this horizon may safely be ascribed to the Upper Devonian. The boundary may lie much lower, but its exact position will have to be determined in sections where palæontological evidence is more abundant.

MISSISSIPPIAN

Banff Shale

General Character and Distribution. The Banff shale is the only development of argillaceous strata in the Palæozoic succession in this area. The formation comprises a series of beds ranging from shale to limestone. The beds weather easily, producing a conspicuous depression in the contour of the mountains. On Cascade and Rundle mountains, where the dip of the beds is low, the depression is not so well marked because the overlying Rundle limestone affords the shale considerable protection from erosion. On Sulphur and Norquay mountains the dip of the beds is steeper, consequently the shale is more easily eroded. On Norquay the depression produced by the erosion of the Banff shale has divided the top of the mountain into two peaks, one being formed by the overlying Rundle limestone and the other by the underlying Minnewanka limestone.

The total thickness of the formation, as measured on Rundle mountain, is 1,408 feet. The upper boundary is usually not well defined. The argillaceous limestones, which characterize the upper beds of the Banff shale, grade almost imperceptibly into the heavy limestones of the overlying formation. For this reason it is difficult to make accurate comparisons as to the thickness of the formation as developed in different localities. The boundary is fairly well marked in the Rundle-Cascade range, but very indefinite in the Sulphur-Vermilion range. The lower boundary is well defined, the change from the shale to the underlying limestone being very abrupt.

Lithology. The Banff formation includes a varied suite of rocks ranging from a black, fissile shale to a pure, grey limestone, the major part of the strata varying from argillaceous limestone to calcareous shale. The formation commences with a shale at the bottom and, in a broad sense, becomes more and more calcareous toward the top. The development of chert nodules and nodules of siliceous limestone in some of the beds is characteristic. The whole formation weathers brownish and assumes a shale habit irrespective of the composition of the beds.

The vertical distribution of the various types of strata admits of a subdivision of the formation into three rather distinct units—lower, middle, and upper members. The boundaries between the various members are not distinctly marked in all exposures and it is possible that the subdivisions, as developed in the vicinity of Banff, may not be recognized over a large area.

The lower member comprises a thickness of from 200 to 300 feet of fine, black, fissile shale which weathers brownish and is in many places blotched with yellow and stained with copper oxide. The thickness of this member varies in different localities, but the lithological characteristics remain constant. The shale in places becomes calcareous toward the top, but the change to the argillaceous limestone of the middle member is as a rule quite abrupt. Good exposures are hard to find on account of the mantle of talus which is generally present due to the easy weathering of the shale. No recognizable fossils were collected from these beds.

The middle member is differentiated from the rest of the formation by the occurrence of harder and more calcareous beds. In a typical section on Sulphur mountain this member is composed of pure, fine-grained, grey limestone containing chert nodules. The limestone, however, is generally slightly argillaceous and weathers brownish. These beds show a marked contrast with those of the lower member, but are not so strongly differentiated from the overlying beds. The superior hardness of the strata produces a well-marked prominence in the contour of the mountains where the shale is exposed. The thickness of the member is about 150 feet and the strata are generally very fossiliferous.

The strata comprising the upper member consist of alternating beds of calcareous shale and argillaceous limestone of varying thickness. As the top of the formation is approached the argillaceous beds become less pronounced and the series gradually passes over into pure limestone. Nodules of siliceous limestone and chert are of common occurrence in some of the beds. The lithological character of this member varies in different localities. Some sections show very little shale, whereas in others the shale beds are very prominent and in places possess a slaty cleavage. The total thickness of the member is about 950 feet and it is unfossiliferous except in the uppermost beds.

Several sections of the Banff formation were measured in different localities, but, on account of the ease of weathering of the formation, the

exposures were in many places much obscured by talus. The best section measured was on the north end of Rundle mountain where most of the beds are exposed. The details of the section are given below.

Section of Banff Formation on Rundle Mountain

Character of the Beds	Thickness Feet
Overlying formation—Rundle limestone	
Upper Member	
Hard, black, fine-grained, slightly argillaceous limestone in beds about 6 inches in thickness and containing a few chert nodules	130
Hard, rubbly, argillaceous limestone with chert nodules in lenses or irregularly dispersed	57
Hard, rubbly, argillaceous limestone with chert nodules in layers	100
Dark grey, calcareous shales and argillaceous limestones irregularly bedded	275
Soft, dark grey, argillaceous limestone with occasional beds of harder limestone containing nodules of chert and siliceous limestone	110
Hard, dark grey, fine-grained limestone with many beds of soft, argillaceous limestone and calcareous shale	196
Hard, dark grey, fine-grained, argillaceous limestone	26
Soft, dark grey to black, calcareous shale, in some places showing a slaty cleavage making an angle of 20 degrees with the bedding-plane	60
Middle Member	
Hard, dark grey, fine-grained limestone weathered light grey and containing nodules of siliceous limestone	12
Hard, dark grey, fine-grained limestone without nodules and weathering to a brownish colour	14
Hard, dark grey, fine-grained limestone weathering light grey and containing nodules of siliceous limestone, with occasional bands of softer argillaceous limestone weathering to a brownish colour	120
Lower Member	
Black, fissile shale, slightly calcareous in the upper part, and in many cases blotched with yellow and stained with copper oxide	308
Total	1,408
Underlying formation—Minnewanka limestone	

Palæontology and Correlation. The Banff formation is not uniformly fossiliferous, specimens being found only at two horizons. The lower member is devoid of any recognizable fossils and its exact age is in doubt. Stratigraphic evidence tends to place it in the Mississippian rather than in the Devonian as the change in sedimentation is more abrupt at the base of the member than at the top.

The middle member is the lowest horizon in which fossils are found; in many localities it contains an abundant fauna. The specimens leave much to be desired in their manner of preservation, having suffered con-

siderably from crushing and weathering and usually with obliteration of the finer surface markings. The fauna consists chiefly of brachiopods with *Spirifer centronatus* as the leading type. With the exception of one species the fauna is already known, most of it having been described from the Kinderhook of the Mississippi valley, from the Madison limestone of Wyoming, or from formations of a similar horizon in Nevada and Colorado. The following table gives a list of the fossils with the occurrence of the species in the Kinderhook group, or in the Madison limestone or related horizon:

Fauna of the Middle Member of the Banff Formation

Species	Kinderhook	Madison
Rhombopora cf. *subannulata* Ulrich		
Rhipidomella pulchella Herrick		X
Leptaena analoga Phillips	X	?
Schellwienella planumbona Weller	X	
Chonetes illinoisensis Worthen	X	X
Productella pyxidata Hall	X	
Productus arcuatus Hall	X	
Productus blairi Miller	X	
Productus burlingtonensis Hall		
Productus fernglensis Weller	X	
Productus ovatus Hall	X	X
Camarotoechia metallica White		X
Leiorhynchus haguei Girty		X
Rhynchopora pustulosa (White)	X	
?*Shumardella missouriensis* (Shumard)	X	
Dielasma chouteauensis Weller	X	
Dielasma utah (Hall and Whitfield)		X
Spirifer centronatus H. and W		X
Spirifer centronatus var. *albapinensis* H. and W		X
Spirifer cascadensis sp. nov		
Spirifer cf. *striatiformis* Meek	X	
Reticularia cooperensis (Swallow)	X	X
Reticularia tenuispinata (Herrick)		X
?*Spiriferina cristata* (Schlotheim)		X
Eumetria verneuiliana (Hall)		X
Cleiothyridina glenparkensis Weller	X	
Cleiothyridina hirsuta (Hall)	X	
Cleiothyridina lata Shimer		
Composita humilis Girty		X
Conocardium cf. *indianense* Miller		
Bembexia nodomarginata (McChesney)		X
Proetus missouriensis (Shumard)	X	
Cladodus cf. *succinctus* (St. John and Worthen)	X	

The table shows clearly the Kinderhook aspect of the fauna. Some of the forms, however, seem to indicate a higher horizon. *Eumetria verneuiliana* is characteristic of a much higher horizon in the Mississippi valley, but the species is also listed from the lowest beds of the Madison limestone where it occurs in association with a typical Kinderhook fauna. This species is found, also, in the Banff section in the uppermost beds of the Rundle limestone about 3,500 feet above the present occurrence. The form in these lower beds has fewer complications than the one at the higher horizon and agrees well with the Madison form. *Cleiothyridina hirsuta*

has been limited by Weller[1] to the Upper Mississippian, but a closely allied form, *C. tenuilineata*, occurs in the Kinderhook and Burlington. Weller states that there is, perhaps, no justification in considering them distinct.[2] The species from Banff show affinities with both species, but they are herein ascribed to the better known form *C. hirsuta*. *Conocardium indianense* is a typical Keokuk form, but on account of the fragmentary character of the specimens and of Miller's rather unsatisfactory description and illustration of his species, the identification is very doubtful. It is probable that a new species is represented. *Productus burlingtonensis* is distinctly a Burlington form and is the only species in the collection that definitely suggests a higher horizon. *Cleiothyridina lata* is a form described by Shimer from the Lake Minnewanka section and suggests *C. obmaxima* from the Upper Kinderhook, Burlington, and Keokuk of Mississippi valley.

The relationship of this fauna to that of the Madison limestone is also well shown in the table. Some of the specimens are common to both the Kinderhook and the Madison; others are known only from the Madison and related horizons in the Cordillera. Such forms as *Spirifer centronatus* and *Rhipidomella pulchella* are found in both the Madison limestone and the Waverly group of Ohio, but have not been reported from the Mississippi valley, though closely related forms occur there. *Reticularia tenuispinata* is a Waverly form which appears to be co-specific with *Reticularia cooperensis* var. from the Madison and in the list was considered to be so. Both forms bear a very close relationship to *Reticularia setigera* and it is doubtful if the fine distinction between these species is definitely shown in the Banff specimens. The form identified as *Spiriferina cristata* (Schlotheim) is undoubtedly the same as that found by Walcott in the Eureka district and ascribed to this species.[3] There is, however, some doubt in the mind of the writer whether this form is really identical with Schlotheim's species. The absence of most of the Productidae in the Madison limestone is rather remarkable. According to Weller[4] *Productus laevicostus* of the Madison limestone is a synonym of *Productus ovatus* of the Mississippi valley and in the list it is so considered.

An interesting feature of this fauna is the practical absence of any typical Devonian elements. *Rhombopora subannulata* is a Devonian form, but the identification of our specimens with this species is rather uncertain. *Bembexia nodomarginata* was described from the Devonian, but it occurs also in the Mississippian of Arkansas and in the Lower Carboniferous of Eureka district. *Productella pyxidata*, also, is common to both Devonian and Mississippian.

The second fossiliferous horizon of the Banff formation is in the uppermost beds, about 850 feet above the lower horizon. The fauna is not extensive, but some of the species are very abundant. The preservation on the whole is poor, the specimens having suffered considerably from squeezing. The most abundant forms are *Productus burlingtonensis*, *Spirifer*

[1] Illinois State Geol. Surv., Mon. 1, p. 480.
[2] Loc. cit., p. 478.
[3] U. S. Geol. Surv., Mon., vol. 8, p. 218, pl. 18, figs. 12, 13.
[4] Illinois State Geol. Surv., Mon. 1, p. 132.

centronatus, and *Spirifer grimesi*. The remainder of the fauna is meagre, being confined, in our collection, to one or two specimens of each form. The total fauna from this horizon is shown in the following table, together with the occurrence of the species in the Kinderhook and Madison limestone:

Fauna of the Upper Beds of the Banff Formation

Species	Kinderhook	Madison
Menophyllum ulrichanum Girty	.....	X
Worm tracks	.....	.....
Fenestella cf. *rudis* Ulrich	X	.....
Taeniodictya cingulata Ulrich	.....	.....
Schizophoria poststriatula Weller	X	.....
Schellwienella inequalis (Hall)	X	X
Productus burlingtonensis Hall	.....	.....
Productus gallatiensis Girty	.....	.....
Spirifer centronatus Winchell	.....	X
Spirifer grimesi Hall	?	.....
Spirifer cf. *marionensis* Shumard	X	?
Spirifer cf. *striatiformis* Meek	X	.....
Spiriferella cf. *minnewankensis* Shimer	.....	.....
Pseudosyrinx sp. indet	.....	.....

This fauna, also, shows a Kinderhook aspect, though not so well marked as the fauna of the lower horizon. *Schizophoria poststriatula* and *Schellwienella inequalis* are the only forms which may be regarded as definitely Kinderhook. *Spirifer marionensis* and *S. striatiformis* are both Kinderhook forms, but the identification of our specimens with these species is doubtful on account of their poor preservation. *Spirifer grimesi* has generally been considered as a Kinderhook (Fern Glen) form, but lately Weller has limited this species to the Burlington and has given a new specific name to the Fern Glen form.[1] Our specimens compare more closely with the Burlington form. *Fenestella rudis* occurs in the Kinderhook (Fern Glen) according to Ulrich[2], but apparently it is more typical of the Keokuk and Warsaw.

Other forms also suggest a higher horizon than the Kinderhook. *Taeniodictya cingulata* is a typical Keokuk form and *Productus burlingtonensis* signifies Burlington time. The forms *Spiriferella* cf. *minnewankensis* and *Pseudosyrinx* sp. indet. also suggest a higher horizon than the Kinderhook. The genus *Spiriferella* is definitely confined to the Burlington and Keokuk in Mississippi valley. Of the genus *Pseudosyrinx*, only one of the four species listed by Weller from the Mississippi valley occurs as low as the Fern Glen.

The Madison aspect of the fauna is well shown by such typical forms as *Menophyllum ulrichanum*, *Productus gallatiensis*, and *Spirifer centronatus*. Girty also lists doubtful specimens of *Spirifer marionensis* from the Madison limestone.[3]

[1] Illinois State Geol. Surv., Mon. 1, pp. 360 and 361.

[2] Hume, G. S.: "A Kinderhook Fauna from the Liard River, N.W.T., Canada"; Am. Jour. Sc., vol. 6, p. 48 (1923).

[3] U. S. Geol. Surv., Mon., vol. 32, pt. 2, p. 551.

A comparison of this fauna with that of the middle member would tend to indicate a little higher horizon according to the faunal succession of the Mississippi valley. The Kinderhook aspect of the fauna is still pronounced, but many of the typical species occurring in the lower horizon are absent and other species, indicating a higher horizon, have taken their place. The occurrence of species characteristic of Kinderhook, Burlington, and Keokuk time at the same horizon clearly indicates that the definite faunal horizons of the Mississippi valley are not indicated in the Banff formation.

In considering the Kinderhook aspect of the fauna from the Banff, it is evident that the best correlation is with the Chouteau-Fern Glen faunas of Missouri rather than with the more northerly Kinderhook faunas. This is shown by the occurrence of such species as *Schizophoria poststriatula, Productus fernglensis, Productus blairi, ?Shumardella missouriensis, Dielasma chouteauensis, Spirifer* cf. *striatiformis,* and *Cleiothyridina glenparkensis* which are practically confined to the Missouri formations.

The correlation of this fauna with that of the Madison limestone will be dealt with in the discussion of the fauna of the complete Mississippian section.

MISSISSIPPIAN AND (?) PENNSYLVANIAN

Rundle Formation

General Character and Distribution. The Rundle formation comprises a thickness of over 2,400 feet of massive, grey limestones with a considerable development of chert nodules in some beds. It is the most prominent formation of the Palæozoic succession as it forms the peaks and the back slopes of most of the mountains. This is well displayed on Rundle and Cascade mountains where the more gentle dip of the beds has prevented rapid weathering. Where the dip is greater, as on Sulphur and Norquay mountains, the formation has suffered more rapid erosion and is not displayed so conspicuously on the mountain tops. On the highest peak of Sulphur mountain there is left only about 200 feet of the Rundle limestone; on mount Norquay a little greater thickness remains.

Tunnel and Stoney Squaw mountains are erosion remnants composed almost entirely of this limestone; they afford excellent opportunities for the study of the formation. The south end of Tunnel mountain shows the best section, and here the characteristic weathering of the formation into lighter and darker bands is well shown.

The lower boundary of the formation is not well defined. In the measured sections it was placed at the bottom of the lowest bed of coarse-grained limestone. Below this the beds begin to assume an argillaceous character and are very fine-grained. The upper boundary is more definite. The lowest beds of the overlying Rocky Mountain quartzite are dolomite, and the break between the limestone and the dolomite in Banff area is usually quite abrupt.

Lithology. The formation consists of thick-bedded to massive, light grey to dark grey, coarse-grained limestone alternating with beds of dark

grey to black, fine-grained limestone with or without chert nodules. The chert nodules are more characteristically developed in the fine-grained beds and are more common in the lower part of the formation. The coarser grained beds do not, as a rule, contain chert nodules. Some of the lighter-coloured beds are very coarse grained, containing many fragments of crinoid columns and brachiopods; they probably represent shallow water conditions of deposition.

The limestone weathers grey, the finer-grained beds assuming a much darker grey than the coarser-grained beds. The alternation of these two types of beds produces a very distinct banding of light and dark grey where a section of the formation is well exposed.

The character of the beds is not constant when traced laterally and no two sections of the formation are exactly alike. Sections measured on different mountains show the same types of limestone, but there are no beds with characteristics sufficiently definite to be traceable over the whole area. On the whole, the formation is homogeneous in respect to the vertical distribution of the various types of beds and will not admit of division into members.

The most complete section measured was on the south end of Tunnel mountain, the details of which are given below:

Section of Rundle Limestone on Tunnel Mountain

Character of the Beds	Thickness Feet
Overlying formation—Rocky Mountain quartzite	
Alternating beds of light grey, coarse-grained, and dark grey, fine-grained limestone, the beds varying from 2 to 6 feet in thickness	123
Black, very fine-grained, thin-bedded limestone	6
Grey, medium- to fine-grained, massive limestone	44
Black, very fine-grained, thick-bedded limestone	16
Dark grey, fine-grained, massive limestone with chert nodules	77
Grey, coarse-grained, massive limestone	11
Dark grey, fine-grained, massive limestone	53
Brown, very coarse-grained limestone with many fragmentary fossils	3
Alternating beds of dark grey, fine-grained, and light grey, coarse-grained, massive limestone	225
Grey, coarse-grained, thick-bedded limestone with Diphyphyllum reef in upper 10 feet	47
Dark grey, fine-grained, massive limestone	132
Alternating beds of dark grey, fine-grained, and light grey, coarse-grained, massive limestone	328
Dark grey, fine-grained, massive limestone with chert nodules	14
Alternating beds of dark grey to black, fine-grained, and light grey, coarse-grained, massive limestone	71
Dark grey, fine-grained, massive limestone with chert nodules	30
Alternating beds of dark grey, fine-grained, and light grey, coarse-grained, massive limestone	170
Grey, medium-grained, massive limestone with chert nodules	35
Alternating beds of light grey, coarse-grained, and dark grey, fine-grained, massive limestone with some chert nodules in the fine-grained beds	212
Dark grey, fine-grained, massive limestone weathering to a very dark grey colour	46
Light grey, very coarse-grained, massive limestone	19

Section of Rundle Limestone on Tunnel Mountain—Continued

Character of the Beds	Thickness Feet
Alternating beds of dark grey, fine-grained, and light grey, coarse-grained, massive limestone, with chert nodules in the fine-grained beds	182
Light grey, very fine-grained limestone with a shaly habit, weathering to a buff colour	15
Light grey, very coarse-grained, massive limestone with an occasional bed of dark grey, fine-grained limestone	132
Alternating beds of light grey, coarse-grained limestone and dark grey, fine-grained limestone with chert nodules	220
Dark grey, fine-grained, thick-bedded limestone with chert nodules with an occasional bed of light grey, coarse-grained limestone	88
Light grey, coarse-grained, thick-bedded limestone with occasional beds of dark grey, very fine-grained limestone with chert nodules	132
Total	2,431

Underlying formation—Banff shale

Palæontology and Correlation. The Rundle limestone is sparsely fossiliferous, except at certain localities. Where fossils do occur they are usually abundant but poorly preserved and many do not admit of identification. Some of the coarser-textured beds are largely composed of fossil fragments, especially joints of crinoid columns, showing that life was abundant in the sea at that time but that conditions were unsuitable for the preservation of the specimens. The heavy beds of fine-grained limestone in many places show fossil remains, in some cases in considerable abundance, but the massive character of the beds usually prohibits the collecting of recognizable specimens.

The upper part of the formation carries the most abundant fauna. It is especially rich in corals which in places occur in massive reefs such as are well displayed on the west slope of Tunnel mountain. Unfortunately, the corals do not weather out of the rock, thus making it almost impossible to collect them in a satisfactory state of preservation. Some fair collections of brachiopods can be obtained in the more shaly limestone beds where they are so exposed that the weathering has broken them down.

It is not proposed to discuss the entire fauna of the formation collectively on account of the immense thickness of the strata from which the collections were derived. A subdivision of the formation into different horizons is herein attempted, partly on faunal evidence but to a greater extent arbitrarily, in order to show the faunal changes which occurred during the deposition of the formation.

The lower 200 feet yielded no recognizable fossils. Between 200 and 500 feet from the bottom the following fauna was collected:

Actinocrinus sp. indet.
Productus burlingtonensis (Hall)
Spirifer centronatus Winchell
Spirifer logani (Hall)
Spirifer rundlensis sp. nov.
Reticularia pseudolineata (Hall)

This fauna is dominated by a large Spirifer of the *S. striatus* type which has been identified as the typical Keokuk form *Spirifer logani.* The separation of *Spirifer logani* and *Spirifer grimesi* in this section may be attended with some doubt, but the criteria used in distinguishing these forms in the Mississippi Valley section seem to apply here almost equally well. The specimens of *Spirifer centronatus* in this horizon are a little larger and with rather coarser ribs than those which characterize the lower horizons and closely resemble the form *Spirifer boonensis* Swallow, from the Pennsylvanian. This resemblance has already been noted by Girty in discussing some specimens from the Ouray limestone of Colorado.[1] The genus *Actinocrinus,* although occurring throughout the Lower Mississippian, is more typical of Burlington and Keokuk time. *Productus burlingtonensis* is typical of the Burlington limestone and *Reticularia pseudolineata* of the Keokuk limestone.

A notable feature of this small fauna is the absence of any typical Kinderhook forms. A Burlington-Keokuk horizon is indicated, and the occurrence of *Spirifer logani* instead of the Burlington form, *S. grimesi,* which is typical of a little lower horizon in this section, is more suggestive of Keokuk time.

About 800 feet from the bottom the following specimens were collected:

Spirifer banffensis sp. nov.
Deltodus sp. indet.
Psammodus sp. indet.

This small faunule is of little diagnostic value. The genus *Deltodus* ranges from Burlington to Pennsylvanian time. *Psammodus* is confined to the Mississippian and has not been reported lower than the Burlington. Both these genera, however, are more characteristic of the Upper than of the Lower Mississippian. The *Spirifer* is typically Mississippian in aspect.

In the beds from about 1,000 to 1,500 feet from the bottom the following fauna occurs:

Syringopora surcularia Girty
Fenestella sp. indet.
Evactinopora? tenuiradiata sp. nov.
Evactinopora? stellata sp. nov.
Pustula punctata (Martin)?

Of this fauna *Syringopora surcularia* is a typical Madison form which occurs rather abundantly in the upper beds of the Rundle limestone. The two bryozoans referred doubtfully to the genus *Evactinopora* are of little diagnostic value. The genus itself has not, to the knowledge of the writer, been reported from an horizon higher than the Keokuk. The remaining species, *Pustula punctata,* is commonly considered to be a Pennsylvanian form, being represented in the Mississippian by the closely allied form, *P. alternata.* The criteria for the distinction of these species, as defined by Weller,[2] is rather unsatisfactory when applied to the specimens in our collection which seem to be intermediate between the two

[1] U. S. Geol. Surv., Prof. Paper No. 16, p. 285.
[2] Illinois State Geol. Surv., Mon. 1, p. 139.

forms. At this point it is well worth noting Weller's statement that some specimens of *P. alternatus* from the St. Louis limestone approach more closely the Pennsylvanian form.[1] It is apparent, however, that little exact evidence is available for the determination of the age of these beds.

At about 1,850 feet from the bottom a small reef of *Diphyphyllum astraeiforme* sp. nov. occurs on Tunnel mountain. This form bears a very close resemblance to *Acervularia adjunctiva* described by White from the Carboniferous in the Blackfoot range south of Yellowstone National park.[2]

About 400 feet from the top of the formation a *Lithostrotion* reef occurs. This reef was found only on Stoney Squaw mountain. The following species were identified:

Lithostrotion whitneyi Meek
Lithostrotion pennsylvanicum Shimer
Lithostrotion banffense sp. nov.

Lithostrotion whitneyi was described by Meek as occurring in the Carboniferous limestone, Boxelder peak, Wasatch range, Utah,[3] and White identified it from the Upper Carboniferous?, Fossil hill and Ice creek, Steptoe valley, White Pine county, Nevada.[4] It also occurs in the Madison limestone of Montana.[5] On account of the long time-range thus indicated the species is of little use for correlation purposes. *L. pennsylvanicum* is described by Shimer[6] from the Rundle limestone at lake Minnewanka; and *L. banffense*, the most abundant species, is new.

It is noteworthy that *L. canadense*, the characteristic form from the St. Louis limestone, has not been found in this region. The occurrence, however, of these closely allied species which, in the Banff section, appear at only one horizon, rather suggests the correlation of this horizon with the St. Louis limestone.

Above the Lithostrotion reef, fossils are more plentiful and a considerable collection was made, as is shown in the following list:

Hapsiphyllum calcareforme (Hall)?
Triplophyllum minnewankense Shimer
Lophophyllum? cascadense sp. nov.
Clisiophyllum? banffense sp. nov.
Lithostrotion flexuosum sp. nov.
Syringopora surcularia Girty
Pentremites perelongatus sp. nov.
Pentremites grandis sp. nov.
Fenestella serratula Ulrich
Fenestella cf. *tenax* Ulrich
cf. *Evactinopora sexradiata* Meek and Worthen
Rhipidomella cascadensis sp. nov.
Productus inflatus McChesney
Productus inflatus var. *coloradoensis* Girty
Productus cf. *pileiformis* McChesney
Productus cf. *arkansanus* Girty
Pustula punctata (Martin)
Rhynchopora banffensis sp. nov.
Rhynchopora cascadensis sp. nov.

[1] Loc. cit., p. 140.
[2] Proc. U. S. Nat. Mus., vol. 2, p. 255, Pl. I, figs. 1-3.
[3] U. S. Geol. Expl. 40th Par., vol. 4, p. 58.
[4] U. S. Geol. Surv., W. 100th mer., vol. 4, p. 103.
[5] Jour. of Geol., vol. 22, No. 6, p. 557.
[6] Shimer, H. W.: Geol. Surv., Canada, Bull. 42, p. 27 (1926).

Moorefieldella parva sp. nov.
Spirifer cf. *arkansanus* Girty
Spirifer cf. *increbescens* Hall
Eumetria marcyi (Shumard)
Eumetria vera (Hall)
Composita trinuclea (Hall)
Composita transversa (Mather)
Orthonychia costata sp. nov.
Igoceras compressus sp. nov.
Igoceras banffensis sp. nov.
Phillipsia? sp. indet.
Deltodus sp. indet.
Ctenacanthus cf. *canaliratus* St. John and Worthen

It will be noted that a considerable number of the species listed above are new and of little value in the determination of the age of the fauna. The poor preservation of many of the specimens prohibited definite identification; they are, therefore, of little diagnostic value. This is especially true of the forms listed as *Productus* cf. *pileiformis, Productus* cf. *arkansanus,* and *Pustula punctata.* Forms very closely allied to these three species of Productidae occur both in the Mississippian and in the Pennsylvanian, and the material at our disposal is not sufficiently well preserved to distinguish the various allied forms. The specific name is used in a biological rather than in a stratigraphical sense. The form listed as *Spirifer* cf. *increbescens* occurs very abundantly, but all the specimens are exfoliated and the finer surface markings could not be observed. In this condition the shell very closely resembles *Spirifer rockymontanus* and it is quite possible it is the form actually dealt with. Its occurrence, however, in beds replete with *Eumetria marcyi* and *Eumetria vera,* rather leads to the conclusion that the form is probably *Spirifer increbescens* which has a similar association in the Mississippi valley. These specimens, however, may be the Pennsylvanian forms and it is to be noted that Shimer has recorded typical Pennsylvanian species at a considerably lower horizon in his section on lake Minnewanka.

A large proportion of the specimens, which have been definitely identified, suggest a late Mississippian age for the fauna. *Productus inflatus* and *Eumetria vera,* which occur quite abundantly at this horizon, are both confined to the Chester group of Mississippi valley. *Composita trinuclea* and *Eumetria marcyi,* although both occur in the Chester, have a longer range in the Upper Mississippian. *Fenestella serratula* is also a long-range form which occurs in the Chester. The occurrence of two species of Pentremites is rather indicative of the Kaskaskia, though the genus occurs at a much lower horizon. Such an association of forms, however, occurs only in the Chester group and it is with that horizon that it is proposed to correlate these beds.

Other forms occur in this fauna which are suggestive of late Mississippian age. *Composita transversa* is a form described by Mather from the Morrow group of Arkansas in which occurs a mixture of late Mississippian and Pennsylvanian species.[1] *Productus inflatus* var. *coloradoensis* was originally described as a Pennsylvanian form, but it also occurs in the Batesville sandstone and Moorefield shale of Arkansas, both formations of which are late Mississippian in age. *Spirifer arkansanus* is also

[1] Bull. Sci. Lab. Denison Univ., vol. 18, Art. No. 3.

a common form in the Moorefield shale. The form which we have compared with *S. arkansanus* is extremely abundant in the upper beds, but it is doubtful if it is absolutely identical with that species. It is probable that this is the same form that Shimer has identified as *Spirifer cameratus* in his Minnewanka section. In the writer's opinion, however, the form is much more closely related to Girty's species from the Moorefield shale. *Moorefieldella* is also a Mississippian form and the two new species of *Rhynchopora* are closely allied to Mississippian species. *Ctenacanthus canaliratus* is a Chester species; the form which has been compared with this species is very closely related to, if not absolutely identical with, it.

Of the corals, *Hapsiphyllum calcareforme* is Mississippian, and *Triplophyllum minnewankense* and *Lithostrotion flexuosum* have Mississippian affinities. *Syringopora surcularia* is a Madison form, the only survival of that fauna at this horizon.

The total fauna of these beds has been shown to be predominantly Mississippian with certain Chester affinities. Certain elements occur, however, which may be typically Pennsylvanian. Shimer claims that definite Pennsylvanian forms occur at a much lower horizon in his Minnewanka section and considers all the upper beds of the Rundle limestone to be of Pennsylvanian age. Shimer's conclusions are not substantiated in the Banff section so far as the writer has been able to discover; nevertheless it is necessary to consider his conclusions very carefully before attempting to fix a definite age for the beds in question.

It is to be noted that most of Shimer's Pennsylvanian fauna from the Rundle limestone consists of species which have a very close counterpart in Mississippian faunas. It seems quite probable that the fine distinction between the various allied species as they occur in the Mississippian valley may disappear in an area so far removed and in strata deposited under different conditions. This fact was impressed upon the writer when studying other specimens in this area. Such an explanation would account for much of the divergence in opinion regarding the age of the upper beds of the Rundle limestone.

In consideration of the Mississippian age of these beds it has been shown that there is a certain parallelism between the Mississippian faunas of the Banff shale and Rundle limestone of the Banff area, and the successive faunas in the Mississippian valley. If the Pennsylvanian age for most of the Rundle limestone is insisted upon, it is very difficult to account for the disappearance of the Upper Mississippian strata in this area, as the Mississippian beds would carry only a Lower Mississippian fauna.

A similar problem is encountered with reference to the age of the Madison limestone which carries only a Lower Mississippian fauna that has been shown to be closely related to the Lower Mississippian faunas at Banff occurring in the Banff shale and the lower beds of the Rundle limestone. The absence of the Upper Mississippian fauna in the Montana and Wyoming sections seems to bear out the suggestions of Calkins that an unconformity exists at the top of the Madison limestone.[1] It is also

[1] U. S. Geol. Surv., Prof. Paper No. 71, p. 381.

possible that the lower beds of the overlying Quadrant formation may represent the higher Mississippian beds, as Girty has pointed out that they contain Mississippian elements.[1]

In northern Utah, however, the Brazer limestone of Upper Mississippian age overlies the Madison limestone,[2] and in Idaho limestones of Upper Mississippian age separate the Madison limestone from the overlying Pennsylvania beds.[3] The known fauna of the Upper Mississippian limestones cannot be correlated with much success with that of the upper part of the Rundle limestone, but taking into consideration their stratigraphic position and lithologic character and the occurrence in the Idaho beds of large cup corals, *Syringopora*, and one or more species of *Lithostrotion*, the correlation seems more evident.

The writer is forced to the conclusion, therefore, from his studies of the Banff section alone, that all the Rundle limestone could be considered Mississippian in age, which conclusion is difficult to correlate with Shimer's findings in the Minnewanka section. Although it has been pointed out that some of Shimer's Pennsylvanian species from the Banff limestone may not prove to be sufficiently diagnostic of that age, the total fauna listed by him from these upper beds shows such decided Pennsylvanian affinities that the writer is forced to the decision that these beds may be Pennsylvanian in age. Such decision, however, only introduces greater difficulties, such as, for instance, the disappearance of the Upper Mississippian strata. The consideration of these points leads us to the hypothesis that Pennsylvanian elements may have been introduced in this area considerably earlier than in the type area in the Mississippian valley. Any such hypothesis would account for the difficulties presented in this area. It is thought best, therefore, in the limits of this thesis, to speak of the age of upper beds of the Rundle limestone as "Pennsylvanian?"

PENNSYLVANIAN

Rocky Mountain Quartzite

General Character and Distribution. The Rocky Mountain quartzite was originally included in the Rundle limestone by McConnell, but was later made a distinct formation by Dowling.[4] It represents a thickness of about 700 feet of dolomite, quartzite, and chert lying conformably on the Rundle limestone. In most sections examined, the contact between these formations is well marked. The formation is overlain disconformably by the Spray River shale, though in most sections the contact might easily be regarded as appearing to be conformable.

In spite of the superior hardness of the strata, the formation weathers easily and does not form a conspicuous member in the stratigraphic sequence. It underlies the lower part of the western slope of the mountains and is as a rule so obscured by glacial drift and talus that good exposures of the formation are rare.

[1] U. S. Geol. Surv., Prof. Paper No. 71, p. 287.
[2] Richardson, C. B.: Am. Jour. Sci., 4th ser., vol. 36, p. 406.
[3] Richards, R. W., and Mansfield, G. R.: Jour. Geol., vol. 20, p. 681.
[4] Geol. Surv., Canada, Pub. No. 949, 1907.

Measured sections on different mountains show a considerable variation in thickness. This variation is probably due to a great extent to the shallow water conditions under which the formation was laid down. Post-formational erosion may account also for some of the variations in thickness.

Lithology. The Rocky Mountain quartzite presents rather a varied suite of rocks, the principal type of which is a hard, compact, light grey dolomite which breaks with a rough, conchoidal fracture. At many horizons the dolomite is arenaceous. The silica content is variable in different beds and gradations occur from pure dolomite to pure quartzite. In other beds the silica occurs as chert nodules which were probably formed by the leaching of the silica content of the beds and its accumulation around definite centres. Beds of pure quartzite are rather rare, but they occur especially towards the top of the formation. The quartzite varies from grey to pink in colour. Pure chert in beds of varying thickness also occurs, particularly toward the top of the formation. The best development of such beds is seen on mount Norquay where the upper 90 feet of the formation is composed of beds of almost pure chert. The chert is usually grey, but black, pink, and white nodules also occur.

An interesting feature of the upper part of the formation is the occurrence of a bed of rock phosphate. In the area under discussion the bed varies from 2 inches to 24 inches in thickness and is widespread, forming a very definite horizon near the top of the formation. Its position below the upper boundary is variable, apparently as the result of the erosion of the upper beds. The phosphate is dark grey to black, and fine grained, with a considerable admixture of quartz grains. Bones and fish-scales occur commonly throughout the bed and fluorite is generally present as crystals in small cavities or as a thin film in the cracks of the rock. Beds immediately above and below this horizon also contain a slight amount of phosphate.

The most complete section of Rocky Mountain quartzite measured was on the south end of Tunnel mountain. The details of the section are given below:

Section of Rocky Mountain Quartzite on Tunnel Mountain

Character of the Beds	Thickness Feet
Overlying formation—Spray River formation	
Dark grey, fine-grained, massive, phosphatic dolomite with many chert nodules	11
Dark grey, to black, fine-grained, siliceous phosphate rock	1
Grey, fine-grained, massive, phosphate dolomite with a few lenses and nodules of chert	6
Grey, fine-grained, thin-bedded, phosphatic dolomite	3
Dark grey to black, fine-grained, siliceous dolomite, slightly phosphatic	2
Grey, fine-grained, thin-bedded dolomite with lenses and layers of black chert, slightly phosphatic	12
Grey, fine-grained, medium-bedded dolomite with black chert nodules	67
Dark grey, fine-grained, thin-bedded dolomite	5

Section of Rocky Mountain Quartzite on Tunnel Mountain—Continued

Character of the Beds	Thickness Feet
Grey, fine-grained, thin-bedded dolomite with light grey chert nodules	2
Grey, fine-grained, massive dolomite with bands of light grey chert nodules	5
Grey, buff, or pink, massive quartzite	9
Light grey, fine-grained, thick-bedded dolomite with occasional lenses of chert nodules	55
Grey, fine-grained, massive dolomite with grey chert nodules comprising about one-half the bed	12
Grey, massive chert	4
Light grey, fine-grained, thin-bedded dolomite	7
Grey, fine-grained, massive dolomite with grey chert nodules.	5
Light grey, fine-grained, thin-bedded dolomite	8
Light grey, fine-grained, thick-bedded dolomite, with scattered chert nodules	18
Grey, pink, or brown, massive chert	7
Grey, fine-grained dolomite with a few lenses and layers of chert	11
Pink and grey, thick-bedded quartzite	6
Grey, fine-grained, massive dolomite containing lenses and layers of white and pink quartzite and a few nodules of grey chert	22
Grey, fine-grained, thick-bedded, arenaceous dolomite, and dolomite quartzite, the proportion of dolomite and quartz varying greatly in different beds	84
Grey, fine-grained, thick-bedded dolomite with a few nodules of chert	15
Light grey, fine-grained, massive, arenaceous dolomite with occasional bands and nodules of chert in less siliceous beds.	260
Light grey, fine-grained, medium-bedded dolomite with a few scattered chert nodules and fossils preserved in chert	61
Total	698

Underlying formation—Rundle formation

Palæontology and Correlation. The Rocky Mountain quartzite is not a fossiliferous formation except at rather restricted localities. Complete sections of the formation were measured without observing a single fossil and a great majority of the specimens collected were too poorly preserved for accurate determination. The distribution of the fauna is peculiar in that certain species are restricted to certain localities, the same horizons from which they were collected being unfossiliferous elsewhere. This erratic distribution of the fauna may be ascribed to the near-shore and shallow-water conditions under which the formation was apparently deposited. Most of the forms which have been definitely identified as Pennsylvanian or Permian species were obtained near the top of the formation.

The complete fauna from this formation, as collected by the writer, is given below:

?Campophyllum torquium (Owen)
Syringopora sp. indet.
Aulopora sp. indet.
Orbiculoidea arenaria Shimer
Schuchertella? sp. indet.
Pustula nebrascensis (Owen)
cf. *Stricklandinia? subquadrata* Herrick

Spirifer rockymontanus Marcou
Spirifer sp. indet.
Deltopecten occidentalis var. *latiformis* Shimer
Deltopecten? sp. indet.
Schizodus sp. indet.
Solenomya? sp. indet.
Bakewellia? sp. indet.
cf. *Pleurophorus mexicanus* Girty
Euphemus carbonarius var. *arenaria* Shimer
Pleurotomaria sp. indet.
Plagioglypta canna (White)

This fauna is undoubtedly representative of Pennsylvanian and, perhaps, of Permian time. Most of the species that can be identified have a wide geographical distribution and also a long vertical range throughout the Pennsylvanian and Permian. Shimer ascribes a Permian age to these beds on account of "such Permian species as *Euphemus carbonarius* var. *Plagioglypta canna*, and *Bakewellia parva*"[1] and on account of the same association of forms "in the Permian? of the region between Pipe Spring and Toroweap valley in northwestern Arizona."[2] The writer cannot altogether concur in Shimer's conclusions. All the species listed above occur, also, in strata still considered to be of Pennsylvanian age and, therefore, cannot be definitely diagnostic of Permian time. The association of *Euphemus carbonarius* and *Plagioglypta canna* in the Rocky Mountain quartzite may be more indicative of Permian time as Shimer has demonstrated, but this association occurs in a bed only 10 feet from the top of the formation and it does not seem advisable to consider the whole formation as Permian on that account. Taking into consideration that the stratigraphic evidence shows no unconformity between the Rocky Mountain quartzite and the Rundle limestone, which latter formation carries Mississippian elements to the very uppermost beds, it seems preferable at the present time to consider the age of the Rocky Mountain quartzite as Pennsylvanian, though Permian time may be represented by the very uppermost beds.

On account of the meagreness of the fauna it is difficult to make any exact correlation of the formation with any well-known Pennsylvanian unit, but, on the basis of stratigraphic and lithologic evidence, it is probably equivalent to the upper part of the Quadrant formation of Montana. The occurrence of a phosphate horizon in the upper beds of both of these units strengthens the assumption that they represent the same stratigraphic unit. On similar evidence it is possible to correlate the upper part of the Rocky Mountain quartzite with the Park City formation of Idaho, Wyoming, and Utah, though the fauna which is characteristic of that formation does not occur in the Banff beds with the exception of *Plagioglypta canna*. The tentative identification by Lambe[3] of a peculiar Selachian form, found by de Schmid in the phosphate bed in Sundance canyon, as *Lissoprion ferrieri*, a species originally described from the Park City formation,[4] lends additional evidence in favour of the correlation. Our collections from this formation are as yet so meagre and the fauna of the Quadrant formation

[1] Geol. Surv., Canada, Bull. No. 42, p. 7.
[2] Loc. cit., p. 4.
[3] Geol. Surv., Canada, Sum. Rept. 1916, p. 294.
[4] Hay, O. P.: Science, vol. 26, p. 22, and Proc. U.S.N.M., vol. 37, p. 52.

and the Weber quartzite, which underlie the Park City formation, are so little known that it seems preferable to defer any attempt to make an exact correlation of the Rocky Mountain quartzite until such time as the faunas of these formations may be more thoroughly studied.

CONFORMITY BETWEEN MISSISSIPPIAN AND PENNSYLVANIAN STRATA

In most areas where both Mississippian and Pennsylvanian rocks occur an unconformity exists between them. It is to be noted that, in the Banff section, sedimentation was continuous throughout Mississippian and that part of Pennsylvanian time represented by the Rocky Mountain quartzite. A change in sedimentation, however, occurs between the Rundle limestone and the Rocky Mountain quartzite and, although the change is usually distinctly marked, a gradation from limestone to dolomite is apparent in some sections and the boundary between the formations is less distinctly marked. The conformable strata, the evidence of continued marine conditions, and the progressive nature of the faunas unite to indicate the lack of any break between the Mississippian and the Pennsylvanian in this region.

DISCONFORMITY AT THE TOP OF THE ROCKY MOUNTAIN QUARTZITE

Most of the contacts which have been observed between the Rocky Mountain quartzite and the overlying Spray River shale seem to indicate that the two formations are apparently conformable. At the contact the dip of the beds of both formations is identical and evidence of an erosion interval between them is lacking in most sections. The fact that the contact between the formations in no instance can be traced laterally for any great distance prohibits its study in detail. The variation in thickness of the formation cannot be used as a criterion of erosional conformity on account of the near-shore conditions under which the beds were deposited.

The only horizon in the formation which may be correlated with any certainty in the different sections is the phosphate bed. This bed occurs near the top of the formation and lends itself excellently to the purpose of determining the character of the upper contact. On mount Norquay the phosphate bed is 90 feet below the top of the formation; on Tunnel mountain it is only 12 feet from the top, and at the west end of lake Minnewanka, which lies to the east of Cascade valley, the Spray River shale lies directly on the phosphate bed. At the latter exposure the beds at the contact are rubbly and strongly stained with iron oxide, thus suggesting an erosion surface. The variation in thickness of the quartzite which lies above the phosphate bed, together with the evidence of a weathered surface in the exposure at lake Minnewanka, is indicative of a period of elevation and erosion prior to the deposition of the Spray River formation.

TRIASSIC

Spray River Formation

General Character and Distribution. The Spray River formation comprises a rather diversified group of strata, including argillaceous limestones and dolomites, banded calcareous and dolomitic shales, and arenace-

ous shales. It forms the top of the sequence of rocks exposed in the Sulphur-Vermilion range and the Rundle-Cascade range. The formation rests disconformably on the Rocky Mountain quartzite and its upper boundary is marked by great thrust faults separating it from older strata which have been overthrust upon it. The formation has suffered so severely from the mountain-building movements that faulting and folding are common throughout. The beds weather easily and are now generally found underlying the valley floors between the mountain ranges where they are usually obscured by glacial drift and talus.

It is difficult to obtain the exact thickness of the formation on account of the lack of exposures and the faulting and folding of the strata. The best section for studying the formation in detail is along the Spray gorge at the south end of Sulphur mountain. Here a thickness of 3,400 feet was measured, but this figure is probably high as faulting or folding may have occasioned some duplication.

Although many of the beds are quite massive they disintegrate easily and generally assume a shaly habit. The formation weathers to a dark red or brown colour by which it may be distinguished easily even at a great distance.

Lithology. The Spray River shale consists essentially of calcareous or dolomitic shales and argillaceous limestones and dolomites. The rocks are generally dark grey to black and many are finely banded. The banding is due to alternating layers of dark, argillaceous material and light grey dolomite or limestone. Such beds disintegrate easily where exposed to the weather and assume a shaly habit. Other beds of argillaceous limestone and dolomite are quite homogeneous and show no banding. They are extremely tough and very fine-grained and do not weather easily. Such beds are common in the lower part of the formation where they yield an excellent building stone.

Beds of nodular limestone occur in places in the banded calcareous shales near the bottom of the formation. The nodular character of these beds appears to be due to the irregular leaching of the calcareous material from the surrounding shale. Such leaching has apparently taken place also in some of the finely laminated shales, as the banding is in many cases irregular and nodular.

Beds of pure, grey limestones, dolomites, and magnesian limestones of a coarser texture occur at irregular intervals throughout the formation. Near the top, a bed of dolomite 142 feet in thickness forms a prominent member. It is light grey with a fine-grained texture and contains lenses and layers of chert nodules. Another characteristic bed which occurs near the middle of the formation is a limestone. It is soft, light grey to yellowish, and in many cases porous and brecciated. Arenaceous shales are developed in some localities, but they are limited in their distribution and are not of general occurrence. Small amounts of arenaceous material, however, may be observed in some of the calcareous and dolomitic shales when studied in thin section.

Mud-cracks and rain-prints and other evidences of shallow-water conditions of deposition are characteristic of the lower beds of the formation and are also found higher up in the section. True ripple-marks seldom occur. Many of the so-called ripple-marks, which are so prevalent in many of the beds, are merely nodular layers of limestone due to irregular leaching.

The only complete section measured of the Spray River shale was along Spray river at the south end of Sulphur mountain. The details of the section are given below:

Section of Spray River Formation at the South End of Sulphur Mountain

Character of the Beds	Thickness Feet
Fault-contact with overlying Devonian rocks not observed	
Grey, very fine-grained, thick-bedded, magnesian limestone....	34
Dark grey, fine-grained, laminated, dolomitic shales.....	39
Grey, fine-grained, thick-bedded, laminated, argillaceous dolomite	47
Dark grey, fine-grained, laminated, dolomitic shale.....	129
Not exposed	110
Dark grey, fine-grained, laminated, dolomitic, and calcareous shales	430
Light grey, fine-grained, thick-bedded dolomite with lenses and layers of grey chert nodules.....	142
Black, very fine-grained, thin-bedded dolomitic and calcareous shales, many of them laminated.....	535
Dark grey, fine-grained, argillaceous, magnesian limestone interspersed with beds of fine shale.....	73
Dark grey, very fine-grained, massive, argillaceous, magnesian limestone	8
Grey, fine-grained, magnesian limestone interspersed with beds of light grey, medium-grained limestone and light grey to buff-coloured, soft, porous limestone.....	139
Grey, fine-grained, thin-bedded, magnesian limestone.....	33
Black, very fine-grained, dolomitic shale.....	31
Light grey, medium-grained, thin-bedded limestone.....	8
Grey, very fine-grained, massive dolomite.....	69
Dark grey, very thin-bedded, dolomitic shale.....	50
Dark grey, very fine-grained, thin-bedded, argillaceous, magnesian limestone	25
Dark grey, fine-grained, thick-bedded, laminated, argillaceous, magnesian limestone	82
Dark grey, fine-grained, medium-bedded, magnesian limestone. These beds are badly folded in the section.....	40
Soft, light grey or buff-coloured, fine-grained limestone with an occasional bed of hard, fine-grained, rubbly limestone, in many cases badly brecciated, and very porous, tufa-like limestone	133
Dark grey, fine-grained, thick-bedded, argillaceous, magnesian limestone	17
Soft, dark grey, dolomitic shale.....	37
Light grey, medium-grained, thick-bedded, magnesian limestone	5
Dark grey, fine-grained, massive, argillaceous, magnesian limestone	61
Grey, fine-grained, thick-bedded, magnesian limestone.....	18
Grey, fine-grained, nodular, magnesian limestone interbedded with thin layers of fine, black shale.....	20
Dark grey, thin-bedded, laminated, argillaceous, magnesian limestone	54
Grey, fine-grained, thick-bedded, magnesian limestone	41
Dark grey, medium-bedded, laminated, argillaceous limestones or calcareous shales.....	238

Section of Spray River Formation at the South End of Sulphur Mountain—Continued

Character of the Beds	Thickness Feet
Grey, fine-grained, medium-bedded, magnesian limestone with thinner argillaceous beds variously interspersed	52
Dark grey, thin-bedded, laminated, calcareous or dolomitic shales	374
Black, calcareous shales with a few beds of fine-grained, nodular, magnesian limestone	109
Black, fine-grained, laminated, calcareous shale interspersed with beds of dark grey to black, fine-grained, argillaceous limestone	64
Black, very fine-grained, dolomitic shale interspersed with beds of black, fine-grained dolomite	153
Total	3,400

Underlying formation—Rocky Mountain quartzite

NOTE. Many of the beds designated as limestone in this section probably contain considerable magnesium. The distinction between argillaceous, magnesian limestone and limestones, and dolomitic and calcareous shales was made in the field largely on the basis of the colour of the rock and the character of the bedding. The terms are used, therefore, rather loosely.

Palæontology and Correlation. The fauna from the Spray River formation has not been studied in detail by the writer. Fossils are scarce and poorly preserved, as a rule, but they occur rather abundantly in restricted layers at certain localities. *Lingula* and poorly preserved ammonites were obtained from the lower beds, higher horizons yielded many pelecypods. Among these the genus *Aviculopecten* was the most abundant. The fauna appears to be largely new, but some of the pelecypods are close to, if not identical with, some forms from the Triassic (Meekoceras) bed of the Western States. Among these may be mentioned *Aviculopecten parvulus* Hall and Whitfield and *Aviculopecten idahoensis* Meek. The ammonites are too poorly preserved to admit of identification.

A collection of fossils, obtained in the neighbourhood of Banff from the Spray River formation, was submitted to Dr. Girty of the United States Geological Survey who referred them to the horizon of the Lower Triassic (Meekoceras beds) of Idaho, Utah, and Wyoming.[1] Kindle[2] and Shimer[3] have both accepted Girty's determinations. It seems evident, therefore, from the writer's own preliminary study of the fauna and from Dr. Girty's contribution regarding its affinities, that the Spray River must be considered as Lower Triassic in age.

CRETACEOUS

The Palæozoic strata of the Rundle-Cascade range are faulted against the Cretaceous sandstones of Cascade valley which lies, for the most part,

[1] Lambe, L. M.: Trans. Roy. Soc., Canada, vol. 10, sec. IV, pp. 37-8 (1916).
[2] Pan-Am. Geol., vol. 42.
[3] Geol. Surv., Canada, Bull. 42, p. 4 (1926).

outside the area studied by the writer. Accordingly, no detailed examination of the strata was attempted. The stratigraphy of the Cascade basin has been the subject of a memoir by D. B. Dowling, to which reference may be made for more detailed information than is contained in this report.[1]

PLEISTOCENE

Heavy deposits of glacial drift accumulated throughout this area in Pleistocene time as a result of the action of the Cordilleran glaciers. The drift was deposited on the valley floors and on the lower slopes of the mountain ranges. Post-Pleistocene erosion has removed a large part of this material, but in localities where the accumulation was exceptionally heavy or where erosion has been ineffective, large deposits of glacial debris still remain. The distribution of glacial material in the area has already been discussed in the section of this report dealing with glacial geology.

STRUCTURAL GEOLOGY

The mountain ranges are, as a rule, immense fault-blocks which have been thrust over the younger strata of the succeeding fault-block to the east. The beds in this type of mountain usually dip to the west at an angle varying from 45 to 80 degrees. The thrust which produced this effect, being from the west, the trend of the ranges is in a north-south direction, or more accurately about 30 degrees west of north. The Sulphur-Vermilion range is an example of this type of structure.

Another type of mountain is the broken, or eroded, fold. In this case the strata, instead of breaking sharply along the fault, were first squeezed into an anticlinal fold and then overthrust towards the east. The top of the fold was then eroded, leaving a structure very similar to the fault-block type. The Rundle-Cascade range is an example of this type of structure.

All the ranges are very similar in their stratigraphy as the same succession of strata is to be observed throughout. Certain diversities of character occur, but the main features persist throughout all the mountains east of the watershed. The Palæozoic strata now form the backbone of the mountain ranges. The Mesozoic strata, being softer, suffered more in the mountain-building movements and were badly folded and faulted. Exposed to the elements, they were easily eroded and now underlie the valleys behind each successive range. The folding of the Mesozoics can still be observed in the valleys where exposures can be obtained. This structure is usually of secondary importance and seldom produces any striking stratigraphical features. The large synclinal fold, into which the Cretaceous strata in the Cascade valley have been compressed, is an exception, the structure being of a major order though of little physiographic significance.

A structure of considerable dimensions occurs in the valley between Cascade and Norquay mountains. The valley is synclinal and is underlain by Palæozoic strata which are exposed on both limbs, the centre of the basin

[1] Geol. Surv., Canada, Pub. No. 949, 1907.

being occupied by the Spray River formation. A strong anticlinal fold, flattening out towards the north, occupies the western limb of the syncline. This limb is truncated by the Norquay overthrust, the Minnewanka limestone of the Mount Norquay succession being faulted against the Rundle limestone on the western limb of the syncline. This Palæozoic syncline does not occur in the valley between Rundle and Sulphur mountains and for this reason it is presumed that an east-west fault underlies Bow valley at this point.

The major fault-lines which separate the large fault-blocks are not observable, as a rule, as they are generally situated in the valleys and are covered by talus from the mountain-sides. The fault between the Sulphur-Vermilion range and the Rundle-Cascade range, which will be designated the Sulphur Mountain fault, is clearly seen on mount Norquay where it is located quite high up on the face of the mountain. It follows along the base of the eastern face of Sulphur mountain where it is never actually exposed but may be located within a very few feet. The dip of the fault corresponds to the dip of the beds in Norquay and Sulphur mountains.

The Rundle-Cascade fault was not observed along the front of Rundle mountain. It may be seen, however, along the face of Cascade mountain, and may be observed still better in a railway cut in the valley of Cascade river where it may be studied in detail. The dip of the fault is in accordance with the dip of the overlying beds.

Less pronounced faults with a strike parallel to the main faults also occur. A fault of this nature was observed on mount Norquay just below the Sulphur Mountain fault. The result of this faulting is the obscuring of some, or all, of the Rocky Mountain quartzite on the western limb of the syncline which occupies the valley between Cascade and Norquay mountains. Another fault of this nature occurs on the face of Rundle mountain above the main Rundle-Cascade fault. This fault lies at the base of the big anticline which characterizes the Rundle-Cascade range. The beds between this fault and the major fault below dip to the west at an angle of about 20 degrees.

Small faults with a strike at right angles to the main system of faulting also occur throughout the area. These are of such minor character—the displacement never being more than a few feet—that they were not mapped. The small gullies which occur along the sides of the mountain ranges generally follow these small faults which probably were the chief factor in determining the course of the stream.

CHAPTER IV

DESCRIPTION OF NEW SPECIES OF FOSSILS

Class ANTHOZOA

Genus LOPHOPHYLLUM Milne-Edwards and Haime

Lophophyllum? cascadense sp. nov.

Plate III, figure 1

Description. Corallum simple, elongate-conical, curved. Dimensions of average sized specimens: length, at least 5 cms.; diameter near calyx, 2·3 cms. Epitheca apparently thin. Calyx unknown. Columella prominent, laterally flattened. Septa numerous; primaries about fifty in number, in some cases extending to the columella, many of the inner ends becoming fasciculate and deflected around the central structure; secondaries short, extending less than a third of the distance to the columella. Fossula prominent, extending from the side of convex curvature to the columella and widening as the columella is approached. Septa in the immediate vicinity of the fossula joining the fossula wall, the inner ends of other septa in the adjacent quadrants being deflected around the inner end of the fossula to reach the columella. Dissepiments numerous in the peripheral region, arching upward and outward between the septa. Tabulæ present in the inner region in the form of large, curved, vesicular plates arching upward to the columella.

Remarks. This form is referred with considerable doubt to the genus *Lophophyllum.* The specimens at our disposal are fragmentary and do not lend themselves to accurate study. It is not at all clear that a septum traverses the whole length of the fossula and joins the columella as set forth in the original description of the genus. A primary septum is present in the fossula in the peripheral area, but cannot be traced to the centre. This may be due to faulty preservation, so it seems preferable to defer a definite generic reference until more satisfactory material can be obtained.

Age and Locality. Pennsylvanian?; upper beds of the Rundle limestone in the Rundle-Cascade range.

Genus DIPHYPHYLLUM Lonsdale

Diphyphyllum astraeiforme sp. nov.

Plate III, figures 2, 3; Plate VI, figure 1

Description. Corallum compound, astraeiform; size and shape unknown. Corallites crowded, polygonal, flexuous, varying considerably in size; diameter varying from 2 to 12 mm. Exterior wall with irregularly spaced transverse wrinkles and quite prominent longitudinal ridges or

costæ. Calyx unknown. Primary septa 16 in an average corallite, thick, not reaching to the centre. Secondary septa shorter, alternating with the primaries and not reaching beyond the outer dissepimental zone. Dissepiments in a single series in the peripheral area, large, strong, curved; arising at right angles from the thecal wall, curving inwards and downwards, the inner limb becoming parallel to the outer wall and continuing downwards to meet the subjacent dissepiment. Tabulæ regular, not numerous, 7 to 8 in 10 mm., generally depressed and not passing into the dissepimental zone. Tabulate area occupying about one-half the diameter of the corallite.

Remarks. The inclusion of this form in the genus *Diphyphyllum* perhaps requires an explanation, as it is customary to regard forms of this genus as fasciculate. Lonsdale's original definition of the genus distinctly specifies fasciculate forms, but Thomson, considering internal structure to be more important than the mode of growth, has amended the genus to include astraeiform types.[1] The inclusion of both astraeiform and fasciculate forms in one genus is paralleled in the genus *Lithostrotion* which includes such forms as *L. whitneyi* and *L. canadense.* The genus *Lithodendron* was originally erected to include the fasciculate types of *Lithostrotion,* but it has long since passed into the synonomy of that genus. It seems preferable to the writer, therefore, to place this form under the genus *Diphyphyllum* rather than erect a new genus which would differ only in the manner of growth of the corallites.

The specimens on hand are few and imperfect. The calyx was not observed, though the breaking of the corallite along the plane of the strongly developed tabulæ and arching dissepiments produces a surface which may be mistaken for the calyx.

In a transverse section the septa appear to be absent from the dissepimental zone, though the primaries may be observed protruding into the tabulate area. For this reason it was considered at first that the form had affiliation with the genus *Thysannophyllum,* Nich., and Thom., but more careful study showed that the septa were once present in the outer zone and that they had broken down later, probably by the crystallization of the calcite which fills the corallites, as the remains of the septa may be seen as low ridges passing over the curved dissepiments when the corallite is broken transversely. This point is illustrated in the figures.

This form approaches very closely to *Acervularia adjunctiva,* White.[2] In his description of that species White does not mention any secondary septa, but an examination of his figures would lead one to suspect that they were present. His form appears to have smaller corallites than the one described above, the tabulæ more numerous and not depressed, and the costæ not so well developed.

Age and Locality. Pennsylvanian?; near the top of the Rundle limestone on Tunnel mountain.

[1] Ann. and Mag. of Nat. Hist., Oct., 1888.

[2] U. S. Geol. Surv. of Territories, 12th Ann. Rept., pt. 1, p. 120, Pl. 35, figs. 1a, b, c, d.

Genus Clisiophyllum Dana

Clisiophyllum? banffense sp. nov.

Plate III, figure 4

Description. Corallum simple, elongate-conical, curved. Length of average specimen at least 6 cms., diameter near calyx 3·5 cms. Epitheca thin, but generally eroded, exposing the outer ends of the septa. Surface marked by fine growth rings and also by restrictions of much greater age. Calyx unknown. Septa numerous, thin; primaries about 60 in number, reaching nearly or quite to the central boss of pseudo-columella, the inner ends being in some cases slightly deflected; secondaries alternating with the primaries and extending from one-third to one-half the distance to the centre. Fossula well developed, extending from the pseudo-columella to the side of the corallum with the convex curvature. Pseudo-columella about 6 mm. in diameter and apparently cellulose in structure. Dissepiments well developed in the peripheral area, arching upward and outward between the septa. Tabulæ well developed between the pseudo-columella and the dissepimental area, appearing as large vesicular plates arching upward to the central structure.

Remarks. The generic relationship of this form is not clear. The primary septa do not show the bilamellar structure characteristic of the genus as developed in the Carboniferous limestone of Scotland and described by Thomson.[1] This structure, however, was not mentioned by Dana in his original description of the genus.[2] The exact nature of the columellar structure in our specimens is doubtful on account of the poor preservation, but, apparently, it is cellular in character, and undoubtedly it forms a boss in the centre of the calyx. The specimens, as preserved, with almost equal facility may be ascribed to any one of several closely related genera and, therefore, it does not seem expedient to make a definite generic reference at the present time.

Age and Locality. Mississippian; upper beds of limestone in the Rundle-Cascade range.

Genus Lithostrotion Lhwyd

Lithostrotion banffense sp. nov.

Plate III, figures 5, 6; Plate V

Description. Corallum compound, massive; size and shape unknown; surface irregular. Corallites crowded, polygonal, slightly flexuous, varying greatly in diameter in the same colony; width from 3 to 11 mm., averaging about 6 mm. Exterior surface with transverse wrinkles irregularly spaced, about 6 in 10 mm., also with longitudinal ridges (costæ). Calyx shallow, outer area sloping gently inwards; central area vertically depressed into a cup-shaped cavity about 2 mm. deep and about one-third the diameter

[1] Proc. Phil. Soc. of Glasgow, Sept., 1882.
[2] Rept. U. S. Explor. Exped., vol. 3, p. 360.

of the corallite in width; bottom of cavity slightly convex. Columella small, slightly compressed, piercing the floor of the central cavity and rising nearly to its top. Primary septa 20, reaching nearly or quite to the columella; secondary septa alternating with the primaries, short, not reaching beyond the dissepimental zone. Tabulæ numerous, about 4 in 2 mm., upwardly arched, convex externally and concave internally; vertical section of one-half a tabula is a sigmoid sloping upward; angle over the summit about 90 degrees. Dissepiments occurring in a single series, confined to the outer zone, arising at right angles from the outer wall, curving inward and downward, the inner extremities being almost parallel to the wall; each dissepiment, as seen in vertical section, being practically a quarter of a circle.

Remarks. In general structure this species approaches very closely to *Lithostrotion pennsylvanicum* Shimer, but differs chiefly in the much smaller size of the corallites. It grows to considerable dimensions, upwards of a foot in diameter, but no complete specimens were collected. The corallites appear to arise from central position, spread horizontally, and then quite abruptly turn to a vertical position. They grow to a considerable length, the longest measured (incomplete) being 9 cms.

Age and Locality. Pennsylvanian?; near top of Rundle limestone on Stoney Squaw mountain.

Lithostrotion flexuosum sp. nov.

Plate III, figure 7; Plate VI, figure 2

Description. Corallum, size and shape unknown; composed of slender, round, flexuous, cylindrical corallites increasing by lateral gemmation. Corallites 3 to 4 mm. in width and, on account of their flexuous character, irregularly spaced, occasionally being in contact and in some cases as much as 6 mm. apart. Epidermis transversely wrinkled; restrictions at irregular intervals. Calyx unknown. Primary septa 16 in number, thin, and not quite reaching the columella. Secondary septa short and alternating with the primaries. Dissepiments poorly preserved, but occasionally seen as arched structures inclined upward and outward against the thecal wall. Tabulæ thin and arched upward to the columella; from 4 to 5 in 2 mm. Columella laterally compressed and quite prominent; corallite normally round, in some cases slightly elliptical in accord with flattening of the columella.

Remarks. The type specimens are fragmentary and do not lend themselves to accurate description. The exact determination of the character of the dissepiments and tabulæ is impossible on account of the coarsely crystalline character of the calcite which fills the corallites. The dissepiments are more to be inferred than observed as the peripheral layer is practically structureless in longitudinal section and only occasionally a dissepiment-like structure is observed arched against the outer wall. The tabulæ, usually much distorted, can be distinctly seen only in well-preserved specimens.

This form approaches rather closely to *L. irregulare* from the Mountain limestone of England. It differs from that species in the number of septa and in the smaller size and wider spacing of the corallites. It also resembles *L. junceum* from the same formation, but differs in its stouter form and more compressed columella.

Age and Locality. Pennsylvanian?; upper beds of Rundle limestone on Tunnel mountain.

Class BLASTOIDEA

Genus PENTREMITES Say

Pentremites grandis sp. nov.

Plate III, figure 8

Description. Specimens incomplete and weathered. Body large, ovate, widest below the middle and above the bases of the ambulacra. Length to bottom of radials about 50 mm., maximum width at least 32 mm. Base unknown; basal plates not observed. Radials rather short for the size of the body; length 26 mm.; length of fork about 18 mm. Deltoids prominent, over half the length of the ambulacra; length at least 27 mm., maximum width 8 mm. Ambulacra gradually widening towards the summit; length about 38 mm., maximum width about 7 mm.; side plates about 14 in the space of 5 mm.

Remarks. The species is founded on one poorly preserved specimen, but another from the same locality compares very favourably with it, differing only in the rather narrower width of the ambulacra. Such variation is probably due to the weathered condition of the specimens.

This form differs considerably from any species of the genus known to the writer. The large size, ovate outline, and the length of the deltoidal plates are outstanding features of this species, which are not met with together in any other form. Owing to the condition of preservation some of the structural details are not revealed, but those that are preserved seem to justify a specific description.

Age and Locality. Pennsylvanian?; upper beds of Rundle limestone on Cascade mountain.

Pentremites perelongatus sp. nov.

Plate III, figure 9

Description. Specimen fragmentary. Body large, elongate-ovate, widest below the middle and above the bases of the ambulacra. Length at least 54 mm.; maximum width at least 25 mm. Base unknown; basal plates not observed. Radials elongate; length at least 40 mm.; length of fork about 29 mm. Deltoids relatively small; length at least 12 mm., maximum width about 4·5 mm. Ambulacra very elongate, gradually widening towards the top; length at least 41 mm., maximum width about 7 to 8 mm.; side plates numbering about 12 in 5 mm.

Remarks. The above description was founded on one fragmentary specimen. In this specimen the base was obscured, the summit imperfect, and the sides mostly eroded or broken. After a careful study of the specimen, however, it was considered that the form showed sufficient features for specific distinction.

This species resembles most closely *P. grandis,* but may be distinguished from that form by its more elongate form, and the much smaller deltoids.

Age and Locality. Pennsylvanian?; upper beds of Rundle limestone on Stoney Squaw mountain.

Class BRYOZOA

Genus EVACTINOPORA Meek and Worthen

This peculiar genus of bryozoa is characterized by the vertical, radially arranged folia composing the zoarium. Four species have been described which differ mainly in the number and size of the radiating folia. The base from which the folia arise is the part which is usually preserved. Weller reports it as the only part preserved in the Fern Glen formation.[1] So far the genus has been reported only from the Lower Mississippian.

In the Rundle limestone on Tunnel mountain several specimens were collected which appear to be the weathered remains of bases of forms belonging to this genus. They occur in a bryozoan reef, which association is suggestive of their relationship to that group. No part of the zoarium showing the zooecia was found, but only the characteristic bases.

Evactinopora? stellata sp. nov.

Plate III, figure 10

Description. Zoarium known from the base only. Base, as exposed, slightly convex, about 8 mm. in diameter and composed of 16 short, slender, oblong-lanceolate rays springing from a central disk. Rays nearly 3 mm. in length and about 0·4 mm. in width near the base. Central disk slightly more than 2 mm. in diameter. Surface markings unknown.

Remarks. There are three specimens of this form in our collection. They are characterized by the large number of short, slender rays which, in our weathered specimens, cannot be traced nearer to the centre than the outside of the central disk. This form is much smaller than *Evactinopora? tenuiradiata,* but has twice the number of rays. The rays are much more slender and greater in number than those of *E. multiradiata.*

Age and Locality. Pennsylvanian?; about 1,000 feet from the bottom of the Rundle limestone on Tunnel mountain.

[1] Geol. Surv., Am., Bull., vol. 20, p. 291.

Evactinopora? tenuiradiata sp. nov.

Plate III, figure 11

Description. Zoarium known from the base only. Base, as exposed, flat, composed of 8 comparatively long, slender, slightly flexuous rays, the longest measuring, as preserved, 10 mm. in length and 0·4 mm. in width. Rays not tapering. Central disk scarcely developed. Surface markings unknown.

Remarks. The very slender rays are the characteristic feature of this species. The sides are parallel, though some show a slight expansion at the base. The rays appear as of different lengths on account of their broken condition and it is not at all certain that the longest measured is complete. Folia growing on these slender rays would be very delicate structures and not likely to be preserved. The character of the rays is sufficient to distinguish this form from any hitherto described.

Age and Locality. Pennsylvanian?; about 1,000 feet from the bottom of the Rundle limestone on Tunnel mountain.

Class BRACHIOPODA

Genus RHIPIDOMELLA Oehlert

Rhipidomella cascadensis sp. nov.

Plate VI, figures 3, 4

Description. Shell about medium size, subovate in outline, a little longer than wide, the greatest width being a little anterior to the mid-length of the shell. Cardinal shoulders sloping and rounding regularly to the antero-lateral margins. Anterior margin truncate and slightly sinuous. Dimensions of an average-sized specimen: length 28 mm., width 26 mm., thickness 13 mm.

Pedicle valve with the greatest convexity in the umbonal region, the surface sloping abruptly to the cardinal margins and very gently to the lateral and anterior margins. Anterior part of valve marked by a very broad, ill-defined sinus. Beak prominent and protruded beyond that of the brachial valve.

Brachial valve a little more convex than the pedicle valve, the greatest convexity being a little posterior to the mid-length of the shell, the surface sloping with about equal convexity in all directions. Mesial portion of valve marked by a narrow, ill-defined sinus. Beak small and but slightly incurved over the cardinal area.

Surface of both valves marked by fine, rounded or slightly depressed, radiating striæ, from 2 to 3 occupying the space of 1 mm. Shell substance ramified by a series of radiating canals, a canal lying directly beneath each costa; canals separated from each other by a vertical wall corresponding in position to the furrows on the outer surface. Surface of shells pierced by pores of two sizes, both being connected with the radiating canals, the larger

pores opening along the summits of the striæ and the smaller ones along the sides of the costæ and in the furrows. Rather conspicuous lines of growth mark the surface of both valves.

Remarks. This species is closely affiliated with *R. burlingtonensis* (Hall), but differs from that species in being a little longer than wide, in its less prominent cardinal shoulders, and in the more strongly developed sinus in the brachial valve. The internal structure of the valves is only slightly known, but, so far as revealed, it seems to agree with that of Hall's species. The radiating canal system is well developed in this species and, on the weathered surface, is very conspicuous. The species is very abundant, but most of the specimens are fragmentary.

Age and Locality. Pennsylvanian?; uppermost beds of Rundle limestone on Cascade and Stoney Squaw mountains.

Genus PRODUCTELLA Hall

Productella lata sp. nov.

Plate IV, figure 1

Description. Shell large, wider than long, moderately convex. Dimensions of an imperfect specimen: length at least 37 mm., width at least 55 mm., convexity of pedicle valve at least 15 mm.

Pedicle valve with greatest convexity a little posterior to the middle, the surface rounding a little more abruptly toward the beak than toward the anterior margin. Postero-lateral areas flattened. Beak small, pointed, and only very slightly produced beyond the hinge-line.

Surface marked by numerous, irregular, concentric wrinkles and fine lines of growth. Spine-bases few, limited to the lateral and postero-lateral slopes, a row of very prominent ones being situated near the hinge-line on either side of the beak.

Brachial valve unknown.

Remarks. The species is known from two rather imperfect pedicle valves, both of which are badly exfoliated. In some of its characters the shell resembles *P. depressa* Kindle, from the Ouray limestone, but differs in the absence of a sinus and in the distribution of the spines.

Age and Locality. Upper Devonian; upper beds of Minnewanka limestone on the north end of Sulphur mountain.

Genus CAMAROTOECHIA Hall and Clark

Camarotoechia banffensis sp. nov.

Plate IV, figures 7-9

Description. Shell subtriangular in outline, wider than long, the greatest width in front of the mid-length of the shell; postero-lateral margins but slightly convex, meeting at the beak in an angle of about 110

degrees; anterior margin truncate, the antero-lateral margins rounding rather sharply to it. Dimensions of the only specimen: length 20 mm., width 23 mm., thickness about 13 mm.

Pedicle valve less convex than the brachial, rather flattened in the middle and sloping very abruptly to the postero-lateral margins. Mesial sinus obsolete in the posterior half of the valve, broad and shallow anteriorly and produced upward in a regularly rounded lingual extension to meet the fold of the brachial valve. Beak apparently pointed, but slightly incurved and produced beyond that of the brachial valve. Plications simple, angular, becoming nearly obsolete at the beak, about 36 in number, of which 12 occupy the mesial sinus.

Brachial valve quite strongly convex, the greatest convexity apparently in front of the mid-length of the shell; surface sloping abruptly to the postero-lateral margins. Mesial fold obsolete in the posterior part of the valve and rather broad and flat anteriorly. Plications similar to those of the pedicle valve, 6 occupying the flat top of the fold and 3 considerably smaller ones occupying the slope on either side.

Remarks. The species is described from a single specimen in which the mesial fold is a little crushed and the beak of the ventral valve rather imperfect. The form bears a close resemblance to *Camarotoechia alleghania* (Williams), but the plications are finer and more numerous than those of that species and the fold and sinus of our species are distinctly broader than that of the eastern form.

Age and Locality. Upper Devonian; upper beds of Minnewanka limestone on Sulphur mountain.

Camarotoechia shimeri sp. nov.

Plate IV, figures 5, 6

Description. Shell of medium size, subovate in outline; full grown specimens gibbous, the brachial valve being much more convex than the pedicle; greatest width about the mid-length of the shell. Dimensions of an average specimen: length 17 mm., width 20 mm., thickness 10 mm.

Pedicle valve moderately convex, the greatest convexity being near the umbo. Lateral area flattened. Beak small, pointed, acute, and but little incurved over that of the brachial valve. Sinus shallow, rounded in the bottom in young specimens but becoming flattened in more gibbous forms, commencing about the mid-length of the shell, rapidly broadening anteriorly and being produced upward in a lingual extension to meet the fold of the brachial valve.

Brachial valve more convex than the pedicle valve, the point of greatest convexity usually anterior to the mid-length of the shell; a tendency toward flattening evident along the lateral margin. Fold commencing about the middle of the shell and becoming quite pronounced at the anterior margin, flat on top on strongly convex forms, rounded and rather poorly defined on less convex forms.

Surface marked by from 40 to 50 rounded to subangular striæ, from 12 to 16 occupying the top and sides of the fold and the bottom and sides of the sinus, 6 being the usual number on the flattened top of the fold on the more convex forms.

Remarks. This is apparently the same form described, but not named, by Shimer, from the Lake Minnewanka section.[1] In some respects it resembles small forms of *C. endlichi,* but the striæ are much too fine and numerous and the lateral margins are not geniculate as in that species. It more closely resembles *C. horsfordi,* but may be distinguished from that species by the finer and more numerous striæ.

Age and Locality. Upper Devonian; uppermost beds of Minnewanka limestone on Sulphur mountain.

Genus Leiorhynchus Hall

Leiorhynchus cascadense sp. nov.

Plate IV, figures 10-12

Description. Shell large, ventricose, transversely subovate in outline. Brachial valve much more strongly convex than the pedicle valve. Proportions of length to width varying in different specimens. Dimensions of an average specimen: length 28 mm., width 32 mm., thickness 25 mm.

Pedicle valve moderately convex, the point of greatest convexity being about the mid-length of the valve. Beak comparatively small, pointed, strongly incurved, and not extending beyond the beak of the brachial valve. Sinus deep, rounded at the bottom, commencing at the beak and rapidly widening anteriorly to about half the width of the shell and being produced upward in a broad lingual extension to meet the fold on the brachial valve. Lateral slopes rather abrupt in the umbonal region and more gently convex anteriorly. Plications in the sinus restricted to the centre, 3 in number, narrow and rounded; plications on the lateral slopes restricted to the area bordering the sinus, in some cases nearly obsolete, from 2 to 3 in number and much wider than the plications occupying the sinus.

Brachial valve strongly convex, the point of greatest convexity being a little posterior to the mid-length of the shell. Beak rather pointed and incurved. Fold strong and well defined, commencing near the beak and becoming high and prominent anteriorly; top rounded and bearing from 2 to 3 narrow, rounded plications in the centre. Lateral slopes rounding abruptly to the cardinal margins and more gently to the lateral and anterior margins. Plications on the lateral slopes large, about 2 in number, and in some cases nearly obsolete.

Remarks. This form varies considerably in dimensions, but the most characteristic features are constant. A considerable number of large Leiorhynchid shells have been described from the Upper Devonian of the

[1] Geol. Surv., Canada, Bull. 42, p. 45.

Cordillera and other localities, but it is impossible to ascribe this form to any of the known species. It most closely resembles *L. jeffersonense* Haynes, but differs from that species in its greater convexity, the rounded top of the fold and concave bottom of the sinus, and the fewer number of plications on the fold and sinus. Some specimens suggest small forms of *Camarotoechia endlichi* (Meek), but the sinus of our specimens never attains so great a width relative to the width of the shell, and the plications are never developed so abundantly as in Meek's shell.

Age and Locality. Upper Devonian; uppermost beds of Minnewanka limestone on Cascade mountain.

Genus MOOREFIELDELLA Girty

Moorefieldella parva sp. nov.

Plate VI, figures 9, 10

Description. Shell small, subpentagonal in outline, moderately convex. Greatest width a little anterior to the mid-length of the shell. Dimensions of one of the co-types: length 7 mm., width 7 mm., thickness 3·5 mm. Postero-lateral margins straight, approaching the beak at an angle of about 75 degrees; anterior margin straight in the region occupied by the fold and sinus and rounding regularly from there to the postero-lateral margin, the whole anterior margin being vertically truncate. Surface of both valves marked by about 30 simple, round, or subangular plications, 6 or 7 of which occupy the fold and sinus. Plications becoming less distinct laterally and posteriorly.

Pedicle valve less convex than the brachial. Beak prominent, produced, and but slightly incurved. Valve convex posteriorly; marked anteriorly by a broad, shallow, ill-defined sinus occupying about one-third the width of the shell along the anterior margin.

Brachial valve quite strongly convex, the greatest convexity being posterior to the middle. Surface rounding quite abruptly to the beak and the postero-lateral margins and much less so to the antero-lateral margins. Fold broad, low, and ill-defined, commencing anterior to the mid-length of the shell, the width at the anterior margin being about one-third the total width of the shell. Interior marked by a well-defined cardinal septum.

Remarks. This form differs from *M. eurekensis* in its smaller size, fewer plications, and the vertical truncation of the anterior margin of the shell. It seems improbable that this is a small form of that species as Girty states that the fold and sinus are not developed on the smaller forms of *M. eurekensis.*[1]

Age and Locality. Pennsylvanian; upper beds of Rundle limestone on Stoney Squaw mountain.

[1] U. S. Geol. Surv., Bull. 439, p. 63.

Genus PUGNAX Hall and Clarke

Pugnax minutus sp. nov.

Plate IV, figures 2-4

Description. Shell very small, subovate to subtrigonal in outline, moderately convex in mature specimens, wider than long, the greatest width a little anterior to the mid-length of the shell. Dimensions of an average specimen: length 6 mm., width 7 mm., thickness 3·5 mm.

Pedicle valve less convex than the brachial, the point of greatest convexity being posterior to the mid-length of the shell. Surface distinctly flattening toward the lateral margins. Beak sharp, prominent, not curved, and produced beyond that of the brachial valve. Sinus commencing about the mid-length of the shell, broad, flat, and rounding sharply upwards in a lingual extension to meet the fold of the brachial valve.

Brachial valve moderately convex, the point of greatest convexity being about the mid-length of the shell. Fold distinguished only on the anterior half of the shell, flat on top, and bounded laterally by a well-marked depression.

Plications rounded to subangular, becoming faint or nearly obsolete on some specimens and always restricted to the anterior half of the shell. Sinus occupied by from 1 to 3 plications and the fold by from 2 to 4; lateral slopes usually marked by 2 plications, the outer one faint or obsolete.

Remarks. This little form would pass as a miniature of *P. utah* from the Pennsylvanian, the only definite distinguishing features between the species being the size. Large forms of this species may also be compared with small specimens of *P. pugnus,* but the latter species does not show the subtrigonal form that is characteristic of our specimens. The species occurs in only one locality, but it is abundantly represented there. The specimens vary in size from 7 mm. to 4 mm. in length. The smaller specimens are comparatively narrower and less convex than the larger, with the fold, sinus, and plications faint or obsolete.

Age and Locality. Upper Devonian; uppermost beds of Minnewanka limestone on the north end of Sulphur mountain.

Genus RHYNCHOPORA King

Rhynchopora banffensis sp. nov.

Plate VI, figures 5, 6

Description. Shell small, subtriangular to subovate in outline; a little wider than long, the greatest width being anterior to the mid-length of the shell. Postero-lateral margins slightly concave and meeting at the beak in an obtuse angle; antero-lateral margins rounded; anterior margin straight. Valves unequally convex, the brachial valve being more convex than the pedicle. Dimensions of specimen: length 7·5 mm., width 8 mm., thickness 5 mm.

Pedicle valve moderately convex in the umbonal region, curving rather abruptly to the postero-lateral margin and quite gently to the antero-lateral margin. Sinus broad, rather deep, and well defined, originating a little posterior to the middle of the shell and being produced anteriorly in a lingual extension, meeting the fold on the brachial valve at an angle of about 90 degrees. Beak (imperfect on our specimens) apparently rather prominent and not strongly incurved.

Brachial valve more strongly convex than the pedicle, the point of greatest convexity being near the anterior margin. Surface sloping to the antero-lateral margins in a strong convex curve, and toward the beak at first with a gentle curve, but becoming more abrupt as the beak is approached. Fold originating near the middle of the valve, becoming broader, higher, and more sharply defined on approaching the anterior margin.

Plications on both valves strong, subangular, 12 to 13 in number, 4 much finer than the others, occupying the fold and sinus, the plications on the lateral slopes becoming fainter toward the margins. Shell substance rather sparingly punctate.

Remarks. This species is known from one specimen which is rather badly exfoliated, but otherwise nearly perfect. It resembles *R. hamburgensis* from the Kinderhook of Illinois, but differs from that species in its smaller size and in the pronounced difference in the size of the plications on the fold and sinus from those on the lateral slopes.

Age and Locality. Pennsylvanian?; upper beds of Rundle limestone on Stoney Squaw mountain.

Rhynchopora cascadensis sp. nov.

Plate VI, figures 7, 8

Description. Shell small, subtriangular to subovate in outline, a little longer than wide, the greatest width being anterior to the mid-length of the shell. Postero-lateral margins apparently straight; antero-lateral margins strongly curved; anterior margin straight. Valves very unequally convex, the brachial valve being much more convex than the ventral. Dimensions of the only specimen: length about 10 mm., width 9·5 mm., thickness 6 mm.

Pedicle valve moderately convex in the umbonal region, flattened toward the middle of the shell, and depressed into a broad, shallow sinus toward the anterior. Sinus curving upward in a broad lingual extension, meeting the fold of the brachial valve at an angle of about 80 degrees.

Brachial valve more convex than the pedicle, the point of greatest convexity being near the middle of the shell. Surface sloping gently at first but with increasing abruptness toward the antero-lateral and lateral margins. Mesial fold not differentiated in the posterior half and only slightly in the anterior half of the shell.

Surface marked by about 15 simple, angular to subangular plications, 4 of which occupy the sinus and 5 the fold, the lateral plications becoming fainter on the extremities of the slopes. Shell substance faintly and sparsely punctate.

Remarks. This species is described from one specimen which is imperfect but sufficiently well preserved to show most of the characteristic features. The form bears a considerable resemblance to *R. banffensis* found in the same locality, but differs in its comparatively narrower form and the more nearly equal size of all the plications. It also resembles *R. hamburgensis*, but the plications are more angular and the sinus more sharply defined than is shown in that species. In general form our species approaches very closely to *Camarotoechia chouteauensis* and except for the punctations of the shell it would be difficult to distinguish between the two species.

Age and Locality. Pennsylvanian?; upper beds of Rundle limestone on Stoney Squaw mountain.

Genus SPIRIFER Sowerby

Spirifer banffensis sp. nov.

Plate VI, figures 11, 12

Description. Specimens imperfect. Shell above medium size, apparently about twice as wide as long, with the greatest width at the hinge-line. Dimensions of an average specimen: length at least 24 mm., width at least 54 mm., thickness about 10 mm.

Pedicle valve with greatest convexity posterior to the mid-length of the shell, the surface rounding abruptly to the cardinal margin and becoming depressed and flattened toward the cardinal extremities. Beak small, pointed, and very little incurved over the cardinal margin. Cardinal area low and slightly concave, becoming more so toward the beak; the upper margin sloping very gently from the beak to the cardinal extremities; surface marked by horizontal striæ. Sinus shallow, well-defined, of moderate width, with a low, poorly defined plication extending down either flank in the depressed area. Surface of the valve on either side of the sinus marked by from 20 to 30 simple, rounded plications, the one bordering the sinus on either side being conspicuously broader than the others.

Brachial valve a little more convex than the pedicle, the greatest convexity being posterior to the mid-length of the shell. In general shape and character of plications closely resembling the pedicle valve. Fold low, rising but little above the general curvature of the valve, divided medially by a shallow furrow, extending nearly or quite to the beak. Beak very similar to that of the brachial valve, but a little more curved on account of the greater convexity of the valve.

Minute surface markings not observed except for an occasional line of growth on some of the valves.

Remarks. Several specimens of this form were collected, but they are all more or less imperfect, the cardinal extremities and the anterior margins never being preserved. The brachial valve bears a considerable resemblance to that of *S. desiderata* from Eureka district, Nevada, but the fold on our specimens is more distinctly bilobed and there are a greater number of plications on the lateral slopes. It may also be compared with *S. winchelli* from the Waverly of Ohio, but differs in being larger and in having a greater number of plications and a less pronounced fold.

Age and Locality. Pennsylvanian?; about 800 feet from the bottom of the Rundle limestone on Tunnel mountain.

Spirifer cascadensis sp. nov.

Plate VII, figures 1, 2

Description. Shell of medium size, about twice as wide as long, the greatest width being at the hinge-line. Cardinal extremities acutely angular or slightly mucronate. Anterior margin curving gradually and regularly from the cardinal angles to the point of greatest length. Dimensions of an average specimen: length 32 mm., width 60 mm., thickness 21 mm.

Pedicle valve moderately convex, the greatest convexity being a little posterior to the mid-length of the shell. Surface rounding rather abruptly to the cardinal margin and more gently to the anterior margin. Cardinal extremities depressed. Beak of medium size, pointed, rather strongly incurved over that of the brachial valve. Cardinal area concave, the curvature becoming greater toward the beak; upper margin sharply defined, sloping gently from the beak to the cardinal extremities. Delthyrium broadly triangular, a little wider than long. Sinus narrow but distinct posteriorly, shallow and rather indefinite anteriorly; bottom rounded or subangular. Surface marked by from 30 to 35 rounded plications on each lateral slope; plications bifurcating once in passing from the beak to the anterior margin, the point of bifurcation varying greatly on different specimens. Sinus occupied by from 7 to 9 plications at the anterior margin, the plication in the centre being persistent from the beak to the front and usually bifurcating once; plications on the sides of the sinus originating by the repeated bifurcation of the lateral bounding plications.

Brachial valve about equally convex with the pedicle. Beak small, inconspicuous, scarcely raised above the hinge-line. Fold very little raised above the general curvature of the shell, but distinctly marked by a conspicuous furrow on either side. Plications similar to those of the pedicle valve, from 6 to 8 occupying the fold and originating by the repeated bifurcation of the one strong plication in the umbonal region.

Surface of both valves, especially on the anterior part, marked by concentric, lamellose lines, some being more conspicuous than others; about 12 lines on one valve.

Remarks. In many respects this species resembles *S. incertus* from the Burlington limestone of Iowa. It differs from that form in its less conspicuous sinus and fold and in the fact that the medial plication of the sinus generally bifurcates. The concentric, lamellose lines, also, are far more numerous on *S. incertus* than in the Banff specimen. The character of the plications of *S. cascadensis* is similar to that of *S. striatiformis*, but the general shape of the shell and the finer surface markings are sufficient to distinguish the two forms. With imperfect specimens, however, the two species may easily be confused.

Age and Locality. Mississippian; middle member of Banff shale on north end of Rundle mountain.

Spirifer rundlensis sp. nov.

Plate VII, figures 9, 10

Description. Specimens fragmentary. Shell of medium size, at least twice as wide as long, the greatest width apparently at the hinge-line. Exact measurements not determined on account of the imperfection of the specimens.

Pedicle valve much flattened and squeezed in all specimens in the collection. Beak small, pointed, a little incurved, and but slightly raised above the hinge-line. Sinus scarcely defined anteriorly, stronger posteriorly, and flanked on either side by a strong plication which bifurcates anteriorly; bottom of sinus occupied by from 4 to 6 intercalated or bifurcating plications. Surface on either side of the sinus marked by from 30 to 35 fine, simple, rounded, or slightly flattened plications, the interspaces being much narrower than the plications.

Brachial valve similar to the pedicle in general form, size, shape of beak, and character of the plications. Fold very little elevated above the general curvature of the shell and flanked on either side by a well-defined furrow. Bounding plications on the fold strong posteriorly, bifurcating anteriorly; the interspace occupied by 1 or 2 bifurcating plications, apparently introduced anterior to the beak.

Finer surface markings unknown excepting from 2 to 3 widely separated lines of growth apparent on some valves.

Remarks. The specimens in our collection are all poorly preserved and do not lend themselves for the purpose of accurate description. Sufficient distinctive characteristics are expressed, however, to warrant a specific definition. The form may be compared with *S. tenuicostatus* Hall, from which it differs in the character of the fold and sinus and in the apparent absence of the numerous, lamellose lines of growth which characterize Hall's species.

Age and Locality. Mississippian; lower beds of Rundle limestone on north end of Rundle mountain.

Class GASTROPODA

Genus ORTHONYCHIA Hall

Orthonychia costata sp. nov.

Plate VII, figures 5, 6

Description. Shell elevated, acuminate, slightly twisted to the right; anterior border arcuate, posterior border concave. Surface ornamented by from 15 to 20 strong, somewhat irregular, longitudinal ridges, or costæ, terminating abruptly 3 to 4 mm. behind the beak. Left antero-lateral side angular, right antero-lateral side rounded, and left postero-lateral side flattened due to the twist of the shell. Aperture apparently subtrigonal.

Remarks. The costated surface of this shell is sufficient to distinguish the form from any other Carboniferous species of this genus known to the writer. In some respects it resembles *O. acutirostre* Hall, but differs in its abruptly pointed spire and the more irregular outline of the aperture.

The species is described from three imperfect specimens.

Age and Locality. Pennsylvanian?; upper beds of Rundle limestone on Stoney Squaw mountain.

Genus IGOCERAS Hall

Igoceras compressus sp. nov.

Plate VII, figures 7, 8

Description. Shell short, conical, antero-posteriorly compressed, wider than high, the posterior side being slightly concave and the anterior side distinctly convex. Lateral sides approaching the apex roughly at an angle of 90 degrees. Height of largest cotype 15 mm., length at aperture 23 mm. Shell not plicated, the surface marked by fine, concentric lines of growth and ornamented by low, irregular pustules.

Remarks. The distinguishing characteristics of this species are its antero-posteriorly compressed form, lack of plications, and the peculiar pustolose ornamentation. The aperture of the shell is not well known as all the specimens are rather imperfect, but there are no traces of plications visible around it. This species resembles *I. banffensis* in its surface ornamentation, but differs in its compressed form and lack of plications.

Age and Locality. Pennsylvania?; upper beds of Rundle limestone on Stoney Squaw mountain.

Igoceras banffensis sp. nov.

Plate VII, figures 3, 4

Description. Shell roughly conical, curving posteriorly and a little laterally toward the apex. Apex slightly attenuated and curved, situated posterior to the centre and a little to the left side. Posterior and left lateral

slopes shortest and concave in outline, right lateral slope longest and convex in outline. Aperture apparently oval and a little more rounded at the posterior end than at the anterior. A few plications present in the proximity of the aperture. Surface ornamented by fine, concentric lines of growth and by low, irregular pustules.

Remarks. This species is described from two imperfect specimens, the peristomes of both of which are poorly preserved. In many respects it resembles *I. pabulocrinus* from the Burlington and Keokuk limestones, but differs in its more pronounced curvature toward the apex and in the surface ornamentation. It differs from *I. compressus*, with which it is associated, in its general shape and in the presence of longitudinal plications around the aperture.

Age and Locality. Pennsylvanian?; upper beds of Rundle limestone on Stoney Squaw mountain.

82065—5½

CHAPTER V

ECONOMIC GEOLOGY

THERMAL SPRINGS

INTRODUCTORY STATEMENT

The thermal springs at Banff have already acquired a world-wide reputation. Their popularity is greatly enhanced by the remarkable beauty of the surroundings. Since the springs have been put under the control of the Government, splendid accommodation has been arranged, so that visitors may take full advantage of the bathing facilities. Bath-houses have been built, with swimming pools at the two most important springs; the others have been left essentially in their natural state.

The springs that are best known on account of the high temperature of the water are the Upper Hot spring, the Kidney spring, the Middle springs, and the Cave and Basin springs. These springs are all situated on the lower slope of the northeast flank of Sulphur mountain.

The cooler springs are not named and attract only passing interest. The best known is at the foot of mount Norquay on the Lake Louise road. Another is situated on Fortymile creek between mount Norquay and the Vermilion range. A very small one appears at the foot of Stoney Squaw at the bend in the Lake Louise road.

DETAILED DESCRIPTIONS

Upper Hot Spring

This spring derives its name from its altitude, being the highest of the group on Sulphur mountain. Its elevation is 5,196 feet A.T., being over 600 feet above the level of the town of Banff with which it is connected by a road. The spring rises in a shallow well which has been sunk for the purpose of controlling the water supply. Surrounding the spring are great banks of calcareous tufa which have been deposited by the water when running freely in the spring. This tufa is a feature common to all the springs at Banff. The water is piped from the well to the bath-house which is situated on the side of the road just below the spring. Some of the water is also piped down to the Brett Hospital in the town, a distance of about 2 miles.

The water from this spring is much used by invalids for therapeutic treatment on account of its high temperature which normally stands at 115° F.

Kidney Spring

The Kidney spring is little known by visitors to Banff. It is situated near the Upper Hot spring at a little lower elevation. The spring rises in a small depression, or scar, in the side of the hill above the road.

The water is piped down to the Banff Springs Hotel, nearly a mile distant, where it is used in the swimming pool of that establishment. The spring has a small flow, but the temperature of the water is nearly as high as that from the Upper Hot spring.

Middle Springs

This group of springs is, probably, the least known of any of the springs on Sulphur mountain. Its name follows from the situation which is midway between the Upper Hot spring and the Cave and Basin springs. It is about a quarter of a mile distant from the main road and is seldom visited. The springs are at present the site of a summer camp of the Alpine club which takes full advantage of the beautiful view of the surrounding scenery obtainable from the springs.

The principal springs of this group rise in a shallow cave on the side of the mountain and the water flows away down the natural slope of the ground. Another important spring rises about 100 yards away on nearly level ground which is well banked up with tufa over a large area. The algæ which grow in the streams leading from the springs assist in the building up of this material.

The springs are still in their natural state and no attempt has been made to utilize the water.

Cave and Basin Springs

These springs are the best known of any in the Banff area, partly on account of their proximity to the town and partly on account of the splendid facilities for bathing. There are two main springs at this locality, known respectively as the Cave spring and the Basin spring; two smaller ones rise a little higher on the hillside. They are the lowest of the Sulphur Mountain springs, being nearly on the level of the bottom of Bow valley.

The Cave spring is the most interesting on account of its unique situation. It rises at the bottom of a pool in a large cave about 40 feet in diameter and 20 feet high. The original entrance to the cave was through a hole in the top, but now a passage has been cut from the bath-house into the level of the pool. The water is piped out through this channel to the big swimming pool in the bath-house, where it is enjoyed by the many thousands of visitors who visit Banff every summer. The walls and roof of the cave were originally ornamented with stalactites, but these have long since disappeared. The cave is lighted by the hole in the roof and also by electric lights which are rather ingeniously placed in niches and hollows in the walls, the subdued light lending rather an eerie aspect to the scene.

A cold spring empties its water into the pool at the bottom of the cave, cooling the water considerably, thus making bathing in the swimming pool more enjoyable in the summer.

The Basin spring is situated close to the Cave spring and is also connected with the bath-house. The spring rises at the bottom of a

pool of water from 4 to 6 feet deep and about 30 feet in diameter, situated in a basin of rock. Its natural situation lends itself excellently to bathing and it is much patronized, especially in the cooler weather when the temperature of the water proves an attraction.

Other Springs

The warm spring on the Lake Louise road, at the foot of mount Norquay, is the best known of the cooler springs. It rises in the Upper Banff limestone at about the level of the Vermilion lakes and flows directly into them. The spring on Fortymile creek, between mount Norquay and the Vermilion range, is of somewhat similar type and comes to the surface through the Upper Banff shale, as does also the small spring at the foot of Stoney Squaw mountain. These springs are still preserved in their natural state.

POSITION OF THE THERMAL SPRINGS IN RELATION TO THE GEOLOGICAL STRUCTURE

A study of the position of the thermal springs shows that many of them may be closely related to the principal geological structure of the region. In tracing the Sulphur Mountain fault along the northeast flank of Sulphur mountain, it will be observed that all the springs in this neighbourhood are in its immediate vicinity. Although the fault, along this part of its strike, cannot actually be seen, its position can often be ascertained within a very few feet. It appears, therefore, that this group of springs bears a close relationship to the Sulphur Mountain fault.

The other thermal springs in the neighbourhood of Banff appear to have a different relationship. They are not connected with any special geological structure, nor do they seem to bear any special relationship to a definite stratum, but come to the surface through strata of different ages. These springs differ from those connected with the fault in their much lower temperature.

ANALYSES OF THE WATER

Introductory Statement

In order that a proper judgment may be formed regarding the source of supply of these springs complete analyses of the waters are necessary. Such analyses have been made previously by Messrs. J. Satterly and R. T. Elworthy[1] and the results of their determinations have been partly embodied in this report. The following tables give their analyses of the waters of some of the principal springs. In explanation of the units used in measuring the radium and radium content, it may be stated that the radium unit used is 1×10^{-12} grammes. The radium emanation unit used is 1×10^{-12} curie, a curie being the amount of emanation in equilibrium with one gramme of radium.

[1] Mines Branch, Dept. of Mines, Canada, Bulls. Nos. 16 and 20.

ANALYSES

Upper Hot Springs

Samples collected ..... December, 1916, and January, 1917
Temperature ..... 46° C. (115° F.)
Flow ..... 120 gallons per minute
Taste ..... Flat with slight evidence of hydrogen sulphide
Specific gravity at 15° C..... 1·002
Radioactivity ..... Emanation .....221 units
Dissolved radium ..... 8·5 units
Emanation in gas evolved

Properties of reaction in per cent

Primary salinity ..... 2·16
Secondary salinity ..... 83·92
Primary alkalinity .....
Secondary alkalinity ..... 13·92

Constituents	Parts per million	Total inorganic matter in solution	Reacting value
		Per cent	Per cent
Sulphuric acid (SO_4)	634	57·60	42·14
Bicarbonic acid (HCO_3)	133	12·08	6·96
Chlorine (Cl)	10	0·91	1·90
Silica (SiO_2)	31	2·82	
Iron (Fe) / Aluminium (Al)	1·7	0·15	0·19
Manganese (Mn)	0·01	.....	
Calcium (Ca)	239	21·71	38·07
Strontium (Sr)	3·2	0·29	0·23
Magnesium (Mg)	39·7	3·61	10·43
Lithium (Li)	0·1	.....	0·04
Potassium (K)	3·7	0·34	0·30
Sodium (Na)	5·3	0·48	0·73
Ammonium (NH_4)	0·1	0·01	0·01
Total	1,100·81	100·00	100·00
Total solids in solution, residue dried at 110° C....	1,098		Concentration value 31·34

	c.c. per litre	Parts per million
Gases: Carbon dioxide (CO_2)	25·3	49·8
Hydrogen sulphide (H_2S)	1·2	1·83

Hypothetical Combinations

Constituents	Parts per million	Total inorganic matter in solution
		Per cent
Ammonium chloride (NH_4Cl)	0·27	0·02
Lithium chloride ($LiCl$)	0·59	0·05
Potassium chloride (KCl)	7·08	0·64
Sodium chloride ($NaCl$)	9·82	0·89
Sodium sulphate (Na_2SO_4)	4·40	0·40
Magnesium sulphate ($MgSO_4$)	196·50	17·85
Calcium sulphate ($CaSO_4$)	672·20	61·07
Calcium bicarbonate ($Ca(HCO_3)_2$)	165·80	15·07
Strontium bicarbonate ($Sr(HCO_3)_2$)	7·65	0·69
Ferrous bicarbonate ($Fe(HCO_3)_2$)	5·43	0·49
Silica (SiO_2)	31·0	2·82
	1,100·74	100·00

Middle Spring

Sample collected ..... December, 1916
Temperature ..... 33·5° C. (92° F.)
Flow ..... 50 gallons per minute
Taste ..... Slight taste of hydrogen sulphide
Reaction ..... Neutral
Specific gravity at 15° C..... 1·0017
Radioactivity ..... Emanation ..... 294 units
Dissolved radium ..... 8·6 units
Emanation in gas evolved.....1910

Properties of reaction in per cent

Primary salinity ..... 2·10
Secondary salinity ..... 83·94
Primary alkalinity .....
Secondary alkalinity ..... 13·96

Constituents	Parts per million	Total inorganic matter in solution	Reacting value
		Per cent	Per cent
Sulphuric acid (SO_4)	610	57·93	42·27
Bicarbonic acid (HCO_3)	128	12·16	6·98
Chlorine (Cl)	8	0·76	0·75
Silica (SiO_2)	27·6	2·62	
Iron (Fe) / Aluminium (Al)	3·3	0·31	0·39
Calcium (Ca)	228	21·65	37·84
Strontium (Sr)	1·0	0·10	0·07
Magnesium (Mg)	38·9	3·69	10·65
Lithium (Li)	0·2	0·02	0·09
Potassium (K)	3·3	0·31	0·28
Sodium (Na)	4·6	0·43	0·66
Ammonium (NH_4)	0·1	0·01	0·02
Total	1,053·0	100·00	100·00
Total solids in solution, residue dried at 110°C.	1,059		

	c.c. per litre	Parts per million
Gases: Carbon dioxide (CO_2)	19·2	37·7
Hydrogen sulphide (H_2S)	2·2	3·3

Hypothetical Combinations

Constituents	Parts per million	Total inorganic matter in solution
		Per cent
Ammonium chloride (NH_4Cl)	0·27	0·03
Lithium chloride ($LiCl$)	1·19	0·11
Potassium chloride (KCl)	6·26	0·59
Sodium chloride ($NaCl$)	6·37	0·60
Sodium sulphate (Na_2SO_4)	6·46	0·61
Magnesium sulphate ($MgSO_4$)	192·51	18·29
Calcium sulphate ($CaSO_4$)	640·78	60·86
Calcium bicarbonate ($Ca(HCO_3)_2$)	158·66	15·07
Strontium bicarbonate ($Sr(HCO_3)_2$)	2·41	0·23
Ferrous bicarbonate ($Fe(HCO_3)_2$)	10·50	1·00
Silica (SiO_2)	27·6	2·61
	1,053·01	100·00

Basin Spring

Sample collected ..... January, 1916
Temperature ..... 34·5° C. (94° F.)
Flow ..... 150 gallons per minute
Taste ..... Flat, with evidence of hydrogen sulphide
Specific gravity at 15° C..... 1·0026
Radioactivity ..... Emanation ..... 232 units
Dissolved radium ..... 8·5 units
Emanation in gas evolved.....2370 units

Properties of reaction in per cent

Primary salinity ..... 1·50
Secondary salinity ..... 87·64
Primary alkalinity .....
Secondary alkalinity ..... 10·86

Constituents	Parts per million	Total inorganic matter in solution	Reacting value
		Per cent	Per cent
Sulphuric acid (SO_4)	1,120·00	61·28	44·09
Bicarbonic acid (HCO_3)	175	9·58	5·43
Chlorine (Cl)	9·0	0·49	0·48
Silica (SiO_2)	31	1·70	
Iron (Fe) / Aluminium (Al)	4·0	0·22	0·17
Calcium (Ca)	400	21·88	37·70
Strontium (Sr)	8·0	0·44	0·35
Magnesium (Mg)	71·0	3·88	11·03
Lithium (Li)	0·1	.....	0·03
Potassium (K)	3·3	0·18	0·16
Sodium (Na)	6·3	0·33	0·52
Ammonium (NH_4)	0·4	0·02	0·04
Total	1,828·1	100·00	100·00
Total solids in solution, residue dried at 110°C....	1,905		

	c.c. per litre	Parts per million
Gases: Carbon dioxide (CO_2)	20	39·4
Hydrogen sulphide (H_2S)	3·2	4·89

Hypothetical Combinations

Constituents	Parts per million	Total inorganic matter in solution
		Per cent
Ammonium chloride (NH_4Cl)	1·18	0·06
Lithium chloride ($LiCl$)	0·59	0·03
Potassium chloride (KCl)	6·26	0·34
Sodium chloride ($NaCl$)	7·83	0·43
Sodium sulphate (Na_2SO_4)	9·94	0·54
Magnesium sulphate ($MgSO_4$)	351·63	19·24
Calcium sulphate ($CaSO_4$)	1,180·10	64·57
Calcium bicarbonate ($Ca(HCO_3)_2$)	212·22	11·61
Strontium bicarbonate ($Sr(HCO_3)_2$)	19·18	1·05
Ferrous bicarbonate ($Fe(HCO_3)_2$)	8·10	0·43
Silica (SiO_2)	31·0	1·70
	1,828·01	100·00

Warm Spring on Lake Louise Road

Sample collected ..... December, 1916
Temperature ..... 19·4° C. (67° F.)
Flow ..... 50 gallons per minute
Taste ..... Flat, with slight indication of hydrogen sulphide
Reaction ..... Alkaline
Specific gravity at 15° C..... 1·0015
Radioactivity ..... Emanation .....640 units
Dissolved radium ..... 23·5 units
Emanation in gas evolved

Properties of reaction in per cent

Primary salinity ..... 1·94
Secondary salinity ..... 60·70
Primary alkalinity .....
Secondary alkalinity ..... 37·36

Constituents	Parts per million	Total inorganic matter in solution	Reacting value
		Per cent	Per cent
Sulphuric acid (SO_4)	147·5	30·79	22·62
Bicarbonic acid (HCO_3)	155	32·37	18·68
Chlorine (Cl)	42·0	8·77	8·70
Silica (SiO_2)	12·4	2·59	
Iron (Fe) / Aluminium (Al)	0·7	0·14	0·18
Calcium (Ca)	95·0	19·83	34·92
Magnesium (Mg)	23·0	4·80	13·93
Lithium (Li)	0·05	.....	
Potassium (K)	1·1	0·23	0·21
Sodium (Na)	2·0	0·42	0·64
Ammonium (NH_4)	0·3	0·06	0·12
Total	479·05	100·00	100·00
			Concentration value
Total solids in solution, residue dried at 110°C	434		13·60

	c.c. per litre	Parts per million
Gases: Carbon dioxide (CO_2)	5·0	9·8
Hydrogen sulphide (H_2S)	0·4	0·63

Hypothetical Combinations

Constituents	Parts per million	Total inorganic matter in solution
		Per cent
Ammonium chloride (NH_4Cl)	0·86	0·18
Lithium chloride (LiCl)	0·30	0·06
Potassium chloride (KCl)	2·09	0·44
Sodium chloride (NaCl)	5·09	1·06
Magnesium chloride ($MgCl_2$)	49·76	10·39
Magnesium sulphate ($MgSO_4$)	50·98	10·64
Calcium sulphate ($CaSO_4$)	151·73	31·66
Calcium bicarbonate ($Ca(HCO_3)_2$)	203·79	42·52
Ferrous bicarbonate ($Fe(HCO_3)_2$)	2·23	0·46
Silica (SiO_2)	12·4	2·59
	479·23	100·00

ORIGIN OF THE SPRINGS

Type of Water

Two theories may be advanced for the origin of the water of the Banff springs. The first theory, which ascribes the water to magmatic origin, may be dismissed without much comment. The flow of water is too great and has lasted too long at the present rate to give support to the theory that it is juvenile and derived from an igneous mass. The very small amount of potassium and sodium in the water also indicates that it could not have been long in contact with igneous rocks. Further, no intrusion of igneous rocks is known of in the neighbourhood.

The more probable explanation of the source of these waters is that they are of meteoric origin; that surface water has found its way down through joints and faults in the rocks to reappear as springs at points determined by the topography and by the structure of the formations. During its course the water has dissolved from the rocks the various constituents shown in the analyses.

An examination of the various analyses of the water shows that the principal constituents are calcium sulphate, magnesium sulphate, and calcium bicarbonate. Such a suite of chemical salts could easily be obtained by hot water passing through the various sedimentaries underlying the vicinity of the springs. The chemical nature of the salts suggests the following explanation of their origin.

The surface water containing carbonic acid and oxygen derived from the atmosphere has acted as a solvent on the limestone, giving rise to calcium bicarbonate which is soluble in water containing carbonic acid. Pyrite undergoes decomposition in the presence of water and oxygen, giving rise to sulphuric acid; this acid attacks the carbonate of calcium and magnesium with the production of sulphates of these elements and free carbonic acid which further assists in the solution of the limestone and in the addition

of the resulting bicarbonates to the water. Carbonic acid would also account for the presence of a small amount of ferrous carbonate. The rocks through which the waters pass are known to contain sufficient pyrite to account for the amount of sulphates in the water.

Temperature of the Water

Accepting, as above, the stratified rocks as the source of the mineral salts in the water, it is necessary to explain whence these rocks could have derived the heat necessary to raise the water to the high temperature observed. A very general explanation for the occurrence of thermal springs in regions such as that at Banff is that the temperature indicates depth from which water has returned to the surface. The highly inclined strata and faults would tend to induce deep circulation of water with a resultant increase in temperature. Another factor which pertains to the explanation is the increase of the temperature gradient in mountain-built regions, due to heat resulting from friction along planes of movements. On account of the very poor conductivity of rock the cooling of these strata would be very slow. It is worthy of note that the hottest springs occur on the fault-lines where it is assumed the highest temperature would be developed.

It is considered that chemical action is not an important factor in the production of heat in these waters. This conclusion is reached from the consideration of the fact that the water from the cooler springs has much the same chemical composition as the water from the hotter springs.

The difference in temperature of the various springs situated along the strike of the Sulphur Mountain fault may be due to an increase in volume by admixture with local cold water prior to their appearance at the surface. Cold water springs are of rather common occurrence at the base of the mountain, especially along the fault, the cold spring behind the buildings of the Alpine Club being a good example. That such cold water does enter the channel of the hot springs is well shown in the Cave spring where the cold water is seen flowing directly into the pool in the cave, reducing its temperature considerably before it flows out into the swimming pool. The fact that the thermal springs decrease in temperature with decreasing altitude is probably due to the greater prevalence of cold springs at lower levels.

Source of the Water

Having accepted the theory of meteoric origin for the water of the springs, it is necessary to discuss briefly a probable source of supply. The large amount of water emitted and the steady rate of flow leads one to presuppose a large and constant supply of water at the source. Such supply would most likely be obtained from a lake or large swamp at an altitude equal to, or greater than, that of the springs. An examination of the region to the west of Banff shows the existence of such lakes and swamps at a sufficient altitude to supply the necessary head.

Intermittent Character

The constant rate of flow of the water is a feature common to all the springs except the Upper Hot spring. This spring is peculiar in that the flow always diminishes in the latter part of the winter, notably during the months of March and April. A decrease of temperature, as a rule not exceeding 15° F., accompanies this decrease in volume of water. Prior to the winter of 1922-23, the spring never actually ceased flowing, although occasionally baths could not be given on account of the very small supply of water. Full records of the actual flow of water in the previous years have not been kept, but information regarding the behaviour of the spring was obtained from the officers of Rocky Mountains park, who have known the spring for many years.

In the winter of 1922-23 the decrease commenced earlier than usual. On January 23 the flow was at the rate of only 11·5 gallons per minute with a temperature of 105° F., the regular flow being 120 gallons per minute at 115° F. The spring continued to flow with various fluctuations until March 11, at which date the flow was at the rate of two gallons per minute at a temperature of 90° F. On March 12 the spring was dry and remained so until May 11, at which date it commenced to flow at the rate of 11 gallons per minute at a temperature of 95° F. The flow and temperature gradually increased and became normal on July 14.

Cause of Intermittency

Taking for granted the meteoric origin of the spring, the intermittency of this spring may be easily explained. The water at the source will accumulate only during the summer months, as the supply is derived from rain and the melting snow and ice. During the winter months the supply is not replenished and the level of the water in the reservoir will be lowered in response to the continual drainage of water to the springs. If the difference of level between the source and the spring is small, the diminishing head of water will have its effect on the flow at the spring by a reduction in its volume. If the level of water at the source were to fall below the level of the spring, the flow would cease. The Upper Hot spring, having the highest altitude, would be most easily affected by the lowering of the water supply. Such an explanation seems to accord with the various facts connected with the intermittency.

The complete stoppage of the flow of the spring for the two months during the winter of 1922-23 signifies a smaller amount of water than usual at the source. This occurrence is in strict accord with the meteorological records of the region, which show an abnormally small precipitation for the year 1922.

Remedial Measures

According to our explanation, it was the exceptionally light precipitation during the year 1922 which was responsible for the failure of the

spring during the following winter—the only time on record that this spring has been completely dry. It seems reasonable to assume that the conditions responsible for this cessation of flow are not likely to occur frequently. If there should be such a recurrence of conditions, it would be a feasible project to sink a shaft down the feeding channel of the spring to the receding water level and have recourse to pumping to obtain the necessary supply of water. Such an operation would have to be so carefully undertaken that the rock in the neighbourhood of the feeding channel might not be shattered. Unnatural disturbances of the strata might give rise to a new outlet for the water at a level lower than the bath-house. An alternative suggestion would be to pump the necessary supply of water from the Kidney spring which is also close to the bath-house but at a lower level. This plan would avoid any danger of damaging the Upper Hot spring by the necessary excavation.

PHOSPHATE

INTRODUCTORY STATEMENT

The occurrence of rock phosphate in the neighbourhood of Banff has been known since 1915 when its discovery was reported by officers of the Commission of Conservation of Canada.[1] The importance of this discovery induced the Department of Mines, Canada, to investigate the occurrence, with a view to determining the economic importance of the deposit. Accordingly, a complete survey of the area in the vicinity of Banff was carried out by Hugh S. Spence (de Schmid) to whose findings very little can be added.[2]

GENERAL CHARACTER

The phosphate occurs at an horizon near the top of the Rocky Mountain quartzite and appears as a regularly bedded member of the formation. It is dark grey to black in colour, very fine-grained, and bears a strong resemblance to basalt. Oolitic structure, which is characteristic of the phosphate in Montana, is only occasionally observed in this deposit. The weathered surface of the rock generally assumes a light brownish colour and never shows the characteristic bluish-white " bloom " so noticeable on the Montana phosphate. When struck with the hammer, the phosphate emits a characteristic fœtid odour, but the same odour may be obtained from the types of rock in the section, which have a very low phosphate content.

The phosphate rock is usually a mixture of amorphous phosphate and quartz grains, the amount of quartz varying greatly in samples from different localities. As a rule the quartz grains are angular and are closely intermixed with the phosphate. In some localities fragments of bone and

[1] Adams, D., and Dick, W. J.: "Discovery of Phosphate of Lime in the Rocky Mountains"; Bull. Com. of Cons. of Canada, 1915, and Trans. Can. Min. Inst., 1916.

[2] Mines Branch, Dept. of Mines, Canada, Bull. No. 12.

fish-scales are quite abundant and, where such occur, the phosphate is in many cases cavernous, probably on account of the leaching of the bony material from the rock. In such places there is a considerable development of fluorite which occurs either as crystals in the cavities or as thin, purple film in the cracks and joint-planes of the rock. The fluorite is apparently derived from the bones which are known to contain a certain percentage of fluorine. In regard to the fluorine content of bone Carnot has shown that fossil bones contain a greater proportion of fluorine than modern bones and that the fluorine content increases with the age of the bone.[1] In bones from Silurian and Devonian formations he found that the relation of fluorite to phosphate was nearly the same as that in apatite.

The specific gravity of the phosphate rock is about 3 and its hardness about 5. It breaks with an uneven fracture, but where the phosphate content is high a tendency to conchoidal fracture is evident.

DISTRIBUTION

The Rocky Mountain quartzite occurs at the top of the Palæozoic succession and underlies the lower part of the western slope of the ranges or the valley floors between them. On account of its position it is generally covered with talus or glacial drift; consequently good exposures of the formation are rare. The phosphate bed, occurring near the top of the formation, is rarely exposed. Its occurrence was always noted where the upper part of the formation was sufficiently exposed for detailed study, and it is supposed that the bed extends over the whole area.

The phosphate bed varies in thickness and in phosphate content in different localities. The best exposure occurs in Sundance canyon on the west slope of Sulphur mountain where the bed attains a thickness of 18 inches. Badly decomposed bones, and scales and teeth of fish are quite common in the bed at this locality and fluorite is very noticeable throughout the deposit.

The northerly continuation of this bed outcrops on the west slope of mount Norquay where it is exposed in several gullies which cut the mountain side. The bed here reaches a thickness of 2 feet, but it is generally very low in content of phosphate.

In the Rundle-Cascade range the best exposure of the bed is on Tunnel mountain where it occurs about 12 feet from the top of the formation. It is best exposed along the Tunnel Mountain road just above Bow falls. The bed varies in thickness from 2 inches to 1 foot, and in some places contains a considerable amount of bone and some fine fluorite crystals.

Farther to the south along the west slope of Rundle mountain the bed is not exposed. To the north of Bow river it is exposed on the north side of Stoney Squaw mountain. The bed outcrops on the bank of Fortymile creek and occurs within 3 feet of the top of the quartzite. The bed here is about 11 inches in thickness.

[1] Annales des Mines, 9th ser., vol. 3, 1893, p. 155.

ANALYSES

It has already been mentioned that the phosphate content of the bed varies considerably in different localities. It ranges, according to the analyses, from 3·68 to 27·63 per cent phosphoric acid (P_2O_5). The following table shows the results of the analyses of samples from the different outcrops in this area, as ascertained by Spence.

Analyses of Representative Samples of Main Phosphate Bed from Various Outcrops in Banff District

Sample No.	Phosphoric acid P_2O_5	Equivalent to bone phosphate $Ca_3(PO_4)_2$	Lime CaO	Insoluble	Ferric oxide Fe_2O_3	Alumina Al_2O_3	Thickness of bed	Locality
							Ft. Ins.	
6.....	18·16	39·68	25·56	49·98	1·14	0·76	1 6	Sundance canyon
14.....	20·68	45·19	31·58	39·02	0·71	0·46	0 11	" "
100.....	24·93	54·47	32·67	31·43	1·28	0·37	0 9	Mount Norquay
102.....	8·39	18·33	15·20	66·34	1·28	0·36	2 0	" "
200.....	9·43	20·60	13·15	68·13	1·57	0·32	1 9	" "
300.....	27·38	59·83	36·72	26·58	1·00	0·53	0 11	Fortymile creek
400.....	24·00	52·44	32·16	34·79	2·14	0·51	1 0	Bow river
401.....	19·36	42·30	27·40	43·60	2·71	0·42	0 4	"
402A.....	27·63	60·37	36·18	29·75	1·57	0·43	1 0	"

The author collected a sample of phosphate from the same horizon at the west end of lake Minnewanka. The analysis, as determined by M. F. Connor, of the Geological Survey, Ottawa, is given below:

Insoluble	84·39
Al_2O_3	0·80
Fe_2O_3	0·70
CaO	6·14
MgO	0·51
CO_2	2·00
P_2O_5	3·68
F	0·16
MnO	traces
H_2O	1.25
	99·63

ORIGIN

It is generally considered that the large phosphate deposits of Montana, Idaho, and adjacent states were original marine deposits and it seems evident that the Banff deposits must be considered in the same category. As originally laid down, the bed was probably a dolomite with an admixture of quartz grains and considerable amounts of phosphatic animal matter. The occurrence of the phosphate in its present condition is probably the result of the action of ammonium phosphate (derived from the decomposition of the organic matter) upon the original dolomite, producing calcium phosphate. The subsequent removal by leaching of the more soluble material left only the quartz grains in the phosphate matrix.

The action of ammonium phosphate on various carbonates and other mineral substances has been proved experimentally by Gautier[1] and is accepted by Clarke[2] as a basis for the general theory for phosphatization. The occurrence of bones and scales and teeth of fish in the phosphate bed suggests the origin of the ammonium phosphate, though it is evident that most of the organic matter, from which this substance was derived, has been entirely decomposed.

ECONOMIC VALUE

The average phosphate content of the main bed, obtained by Spence, from the result of nine analyses, is 43·7 per cent tricalcic phosphate, and the average thickness of the bed is about one foot. The present method employed for the conversion of the raw material into acid phosphate is the sulphuric acid process. This method would be impracticable in dealing with the Banff phosphate on account of the high silica content, only a part of which would be removed and the finished product would, in consequence, be of an inferior grade. In considering this deposit as a commercial possibility it must be taken into consideration that phosphate deposits in Montana, Idaho, Wyoming, and Utah run as high as 80 per cent tricalcic phosphate and occur in beds up to 8 feet in thickness; also, that little or no silica is mixed with the ore. In view of the competition that would probably arise from this source if an attempt were made to utilize the Banff deposits, it seems reasonable to assume that, under existing conditions, the phosphate deposits at Banff cannot be considered as of any commercial value.

BUILDING STONE

INTRODUCTORY STATEMENT

Stone from different horizons in the Palæozoic and Mesozoic succession has been used to some extent for building purposes in the town of Banff. Most of the stone, however, does not reach the quality of a first-class building stone. On the whole the beds are too massive for satisfactory quarrying operations. This is particularly true of the heavy, Palæozoic dolomites and limestones which form the major part of the succession. The dolomites, as a rule, are too hard and tough, and break too irregularly to be of much value for building purposes. The formations that contain stone that has been used, or that may have some value as a building stone, are the Minnewanka limestone (upper part), Rundle limestone, Rocky Mountain quartzite, and the Spray River formation.

MINNEWANKA LIMESTONE (UPPER PART)

The Minnewanka limestone, where not dolomitic, possesses certain qualities which are rather favourable for building purposes. The beds are generally too massive to permit of easy quarrying, but the upper 50 feet of

[1] Annales des Mines, 9th ser., vol. 5, 1894, p. 1.
[2] U. S. Geol. Surv., Bull. 695, p. 519.

the formation is thinner-bedded and more suitable for this purpose. An analysis of this rock and its physical properties in relation to its qualities as a building stone, as given by Parks[1] from a sample collected near Exshaw, Alberta, is given below:

The physical properties are as follows:

Specific gravity	2·723
Weight per cubic foot, lbs.	169·428
Pore space, per cent	0·328
Ratio of absorption, per cent, one hour	0·024
Ratio of absorption, per cent, two hours	0·029
Ratio of absorption, per cent, slow immersion	0·083
Ratio of absorption, per cent, in vacuo	0·10
Ratio of absorption, per cent, under pressure	0·12
Coefficient of saturation, one hour	0·2
Coefficient of saturation, two hours	0·24
Coefficient of saturation, slow immersion	0·69
Coefficient of saturation, in vacuo	0·83
Crushing strength, lbs. per sq. in., dry	27,174
Crushing strength, lbs. per sq. in., wet	21,429
Crushing strength, lbs. per sq. in., wet after freezing	20,072
Transverse strength, lbs. per sq. in.	1,779
Shearing strength, lbs. per sq. in.	2,975
Loss on corrosion, grammes per sq. in.	0·158
Drilling factor, mm	.....
Chiselling factor, grammes	9·2

The analysis is as follows:

	Per cent
Calcium carbonate	95·80
Magnesium carbonate	3·38
Ferric oxide	trace
Ferrous oxide	0·13
Alumina	0·06
Soluble silica	0·04
Insoluble mineral matter	0·64

Regarding this stone, Parks says, in part.....

"The rock is a hard, dark, splintery, greyish blue limestone of exceedingly fine grain. The rubbed surface shows a faint brownish mottling and fine lines of secondary calcite. The polished surface is very dark, almost black, with fine white lines and dots. The material takes an excellent polish and, if it can be obtained in large blocks, it has a positive value as a black marble."

RUNDLE LIMESTONE

The Rundle limestone has been used to a limited extent for building purposes at Banff. Throughout most of the succession the beds are too massive to permit of quarrying with any degree of facility. The presence of chert nodules throughout most of the formation also detracts greatly from its value as a building stone and the small cavities that occur in many of the coarser-grained beds are deleterious, especially to its use as a marble. Some fine-grained beds of medium thickness and free from chert, that occur

[1] Mines Branch, Dept. of Mines, Canada, "Building and Ornamental Stones of Canada," vol. 4, p. 116.

in the upper part of the formation, would possess a certain value for building purposes. The analyses and physical properties of the Rundle limestone, according to Parks,[1] are given below:

The physical properties are:

Specific gravity	2·706
Weight per cubic foot, lbs.	167·44
Pore space, per cent	0·88
Ratio of absorption, per cent, one hour	0·15
Ratio of absorption, per cent, two hours	0·15
Ratio of absorption, per cent, slow immersion	0·189
Ratio of absorption, per cent, in vacuo	0·301
Ratio of absorption, per cent, under pressure	0·329
Coefficient of saturation, one hour	0·45
Coefficient of saturation, two hours	0·45
Coefficient of saturation, slow immersion	0·57
Coefficient of saturation, in vacuo	0·91
Crushing strength, lbs. per sq. in., dry	17,772
Crushing strength, lbs. per sq. in., wet	18,369
Crushing strength, lbs. per sq. in., wet after freezing	14,660
Transverse strength, lbs. per sq. in.	1,969
Shearing strength, lbs. per sq. in.	1,600
Loss on corrosion, grammes per sq. in.	0·154
Drilling factor, mm	14
Chiselling factor, grammes	4·75

The analysis is as follows:

	Per cent
Calcium carbonate	97·94
Magnesium carbonate	1·17
Ferric oxide	trace
Ferrous oxide	0·09
Alumina	0·12
Soluble silica	0·08
Insoluble mineral matter	0·94

ROCKY MOUNTAIN QUARTZITE

In the public camping ground, at the base of the north end of Rundle mountain, an attempt has been made to quarry some of the dolomite beds of medium thickness in the Rocky Mountain quartzite. This material, however, proved much too hard and tough, and the fracture too irregular, to give it any value as a building stone.

SPRAY RIVER FORMATION

The best building stone in the neighbourhood of Banff is obtained from the lower beds of the Spray River formation. The stone varies from an argillaceous limestone to an argillaceous dolomite and occurs in regular beds less than a foot in thickness separated by thin layers of shale. It is very tough, dark grey to black, and very fine-grained. It is quarried along the east side of Spray river, just south of the bridge below the Banff Springs Hotel. The beds are exposed in a cliff about 75 feet in height and dip toward the river at an angle of about 60 degrees. The rock is quarried

[1] Mines Branch, Dept. of Mines, Canada, "Building and Ornamental Stones of Canada," vol. 4, p. 144.

easily as the successive beds may be removed quite readily by means of a crowbar. Parks gives the following analyses and physical properties of this stone:[1]

The physical properties are as follows:

Specific gravity	2·764
Weight per cubic foot, lbs.	172·04
Pore space, per cent	0·292
Ratio of absorption, per cent, one hour	0·018
Ratio of absorption, per cent, two hours	0·022
Ratio of absorption, per cent, slow immersion	0·091
Ratio of absorption, per cent, in vacuo	0·091
Ratio of absorption, per cent, under pressure	0·106
Coefficient of saturation, one hour	0·17
Coefficient of saturation, two hours	0·20
Coefficient of saturation, slow immersion	0·86
Coefficient of saturation, in vacuo	0·86
Crushing strength, lbs. per sq. in., dry	50,000
Crushing strength, lbs. per sq. in., wet	50,669
Crushing strength, lbs. per sq. in., wet after freezing	40,937
Transverse strength, lbs. per sq. in.	6,657
Shearing strength, lbs. per sq. in.	5,222
Loss on corrosion, grammes per sq. in.	0·0363
Drilling factor, mm	1·0
Chiselling factor, grammes	0·01

The analysis is as follows:

	Per cent
Calcium carbonate	49·01
Magnesium carbonate	8·52
Ferric oxide	0·29
Ferrous oxide	1·54
Alumina	1·06
Soluble silica	0·25
Insoluble mineral matter	38·56

Considerable carbonaceous matter is also present

This stone has been used in the building of the Banff Springs Hotel, the Cave and Basin bath-house, and for trimming on the Bow River bridge at Banff.

ROAD METAL

INTRODUCTORY STATEMENT

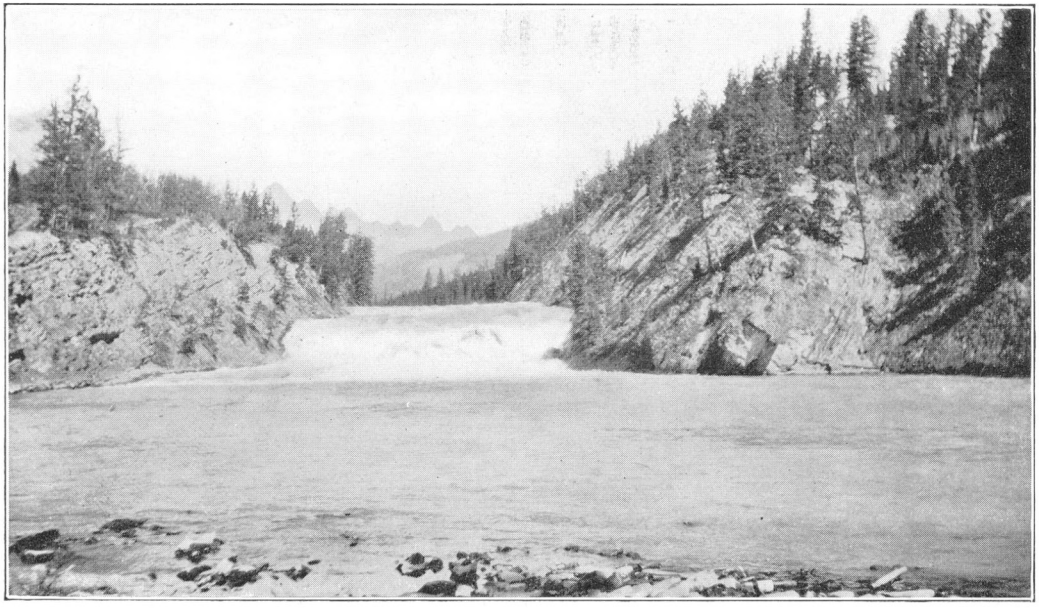
There has been, until very recently, only a small demand for road metal in this section of the mountains, on account of the scarcity of roads. Public highways, however, are gradually being built with the resulting greater demand for road metal. The construction of the Lake Louise and Windermere highways through Rocky Mountains park has initiated investigations with the object of obtaining a sufficient supply of material suitable for building and maintenance purposes.

[1] Mines Branch, Dept. of Mines, Canada, "Building and Ornamental Stones of Canada," vol. 4, p. 146.

SOURCE OF SUPPLY

The rather limited demand for road metal throughout Rocky Mountains park is chiefly supplied from the deposits of glacial drift which are widely distributed throughout the mountains. The material in these deposits is as a rule of such quality that it may be applied directly with little re-sorting except for the removal of the larger boulders. The wide distribution and abundance of this type of material make it a valuable asset for road building in this area.

In restricted localities the talus from the mountain sides may be used for road metal, the talus slope on the north end of Rundle mountain being used at the present time for this purpose. The material is screened and the various sizes are used according to demand. As a rule, however, the talus slopes are of material too coarse to have any wide application as a road metal.



Bow falls at the confluence of the Bow and the Spray. (Page 6.)

PLATE III

(All figures are natural size unless otherwise stated)

FIGURE 1. *Lophophyllum? cascadense* n.sp. Cross-section of a cotype. (Page 44.)

FIGURES 2, 3. *Diphyphyllum astraeiforme* n.sp. Figure 2, cross-section showing primary septa broken down in the dissepimental zone, but extending into the tabulate area. Figure 3, longitudinal section. Cotypes. (Page 44.)

FIGURE 4. *Clisiophyllum? banffense* n.sp. Cross-section of a cotype. (Page 46.)

FIGURES 5, 6. *Lithostrotion banffense* n.sp. X 4. Figure 5, cross-section of a corallite. Figure 6, section of a corallite. (Page 46.)

FIGURE 7. *Lithostrotion flexuosum* n.sp. X 4. Cross-section of a corallite. (Page 47.)

FIGURE 8. *Pentremites grandis* n.sp. Sketch of an imperfect specimen. Type. (Page 48.)

FIGURE 9. *Pentremites perelongatus* n.sp. Sketch of an imperfect specimen. Type. (Page 48.)

FIGURE 10. *Evactinopora? stellata* n.sp. Sketch of an imperfect base of a cotype. (Page 49.)

FIGURE 11. *Evactinopora? tenuiradiata* n.sp. Sketch of an imperfect base of a cotype. (Page 50.)

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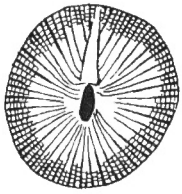

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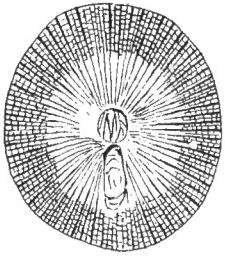

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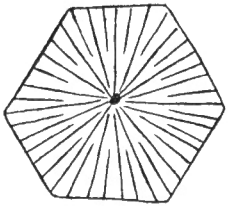

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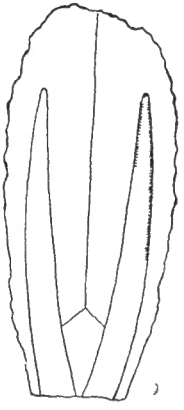

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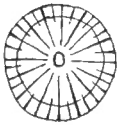

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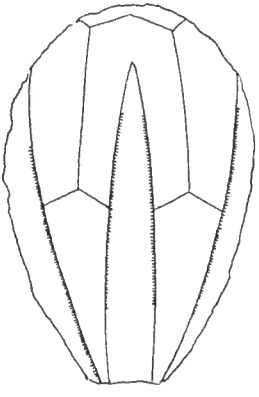

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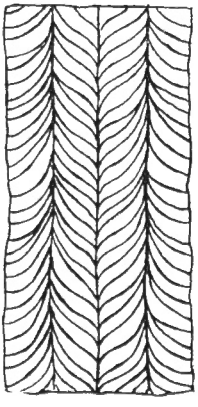

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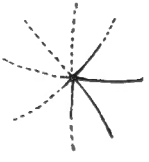


PLATE IV

(All figures are natural size unless otherwise stated)

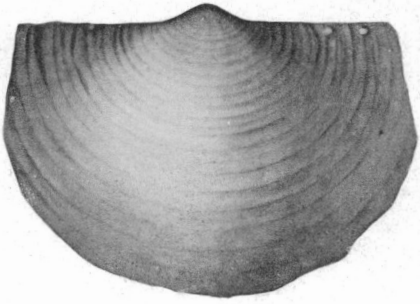
FIGURE 1. *Productella lata* sp.nov. View of the incomplete pedicle valve of the type. (Page 51.)

FIGURES 2–4. *Pugnax minutus* sp.nov. X 2. Brachial, pedicle, and anterior views of a cotype. (Page 55.)

FIGURES 5, 6. *Camarotoechia shimeri* sp.nov. Pedicle and brachial views of a cotype. (Page 52.)

FIGURES 7–9. *Camarotoechia banffensis* sp.nov. Pedicle, brachial, and lateral views of the type. Fold partly restored. (Page 51.)

FIGURES 10–12. *Leiorhynchus cascadensis* sp.nov. Figures 10, 11, anterior and brachial views of an average specimen. Figure 12, pedicle view of a much wider specimen. Cotypes. (Page 53.)



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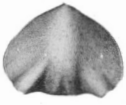

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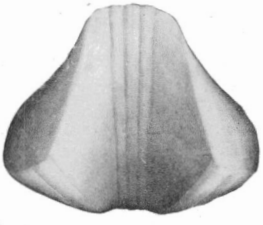

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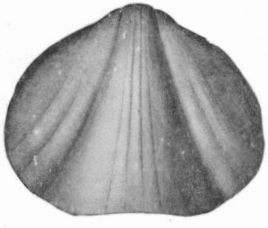

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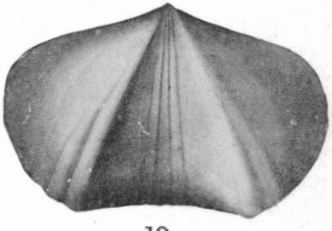

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PLATE V

FIGURE 1. *Lithostrotion banffense* sp.nov. View of a cotype. About three-quarters natural size. (Page 46.)

PLATE V

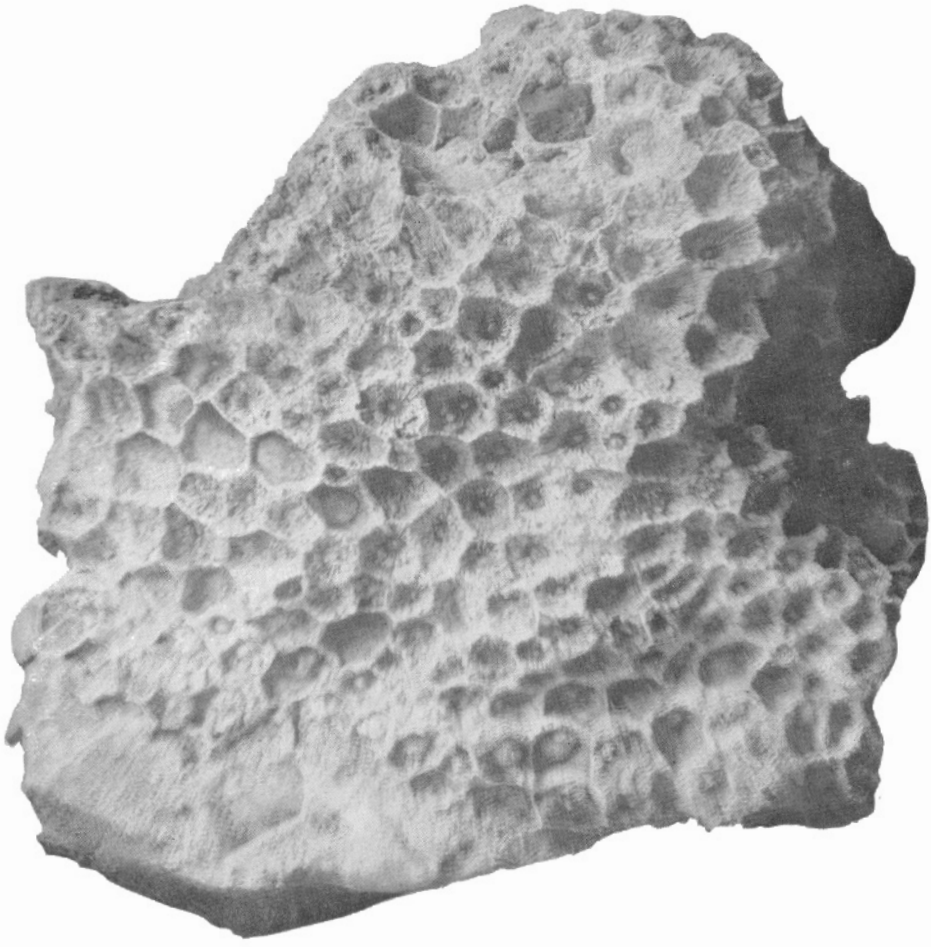

PLATE VI

(All figures are natural size unless otherwise stated)

FIGURE 1. *Diphyphyllum astraeiforme* sp.nov. View of a cotype. (Page 44.)

FIGURE 2. *Lithostrotion flexuosum* sp.nov. View of a cotype. (Page 47.)

FIGURES 3, 4. *Rhipidomella cascadensis* sp.nov. Brachial and lateral views of a cotype. (Page 50.)

FIGURES 5, 6. *Rhynchopora banffensis* sp.nov. X 2. Pedicle and brachial views of the type. Beak slightly restored. (Page 55.)

FIGURES 7, 8. *Rhynchopora cascadensis* sp.nov. X 2. Pedicle and brachial views of the type. (Page 56.)

FIGURES 9, 19. *Moorefieldella parva* sp. nov. X 2. Brachial and pedicle views of a cotype. (Page 54.)

FIGURES 11, 12. *Spirifer banffensis* sp.nov. Pedicle and brachial views of imperfect specimens. Cotypes. (Page 57.)

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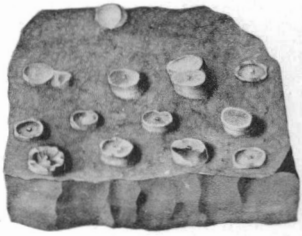

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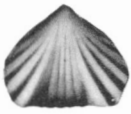

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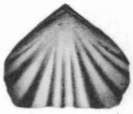

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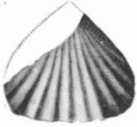

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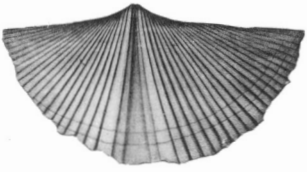

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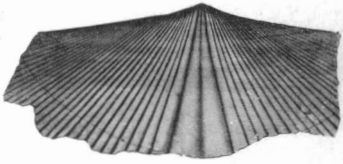

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PLATE VII

(All figures are natural size unless otherwise stated)

FIGURES 1, 2. *Spirifer cascadensis* sp. nov. Pedicle and brachial views. Figures constructed from several cotypes. (Page 58.)

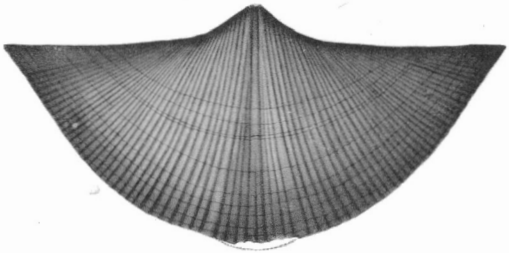
FIGURES 3, 4. *Igoceras banffensis* sp. nov. Anterior and lateral views of a cotype. (Page 60.)

FIGURES 5, 6. *Orthonychia costata* sp. nov. Anterior and lateral views of a cotype. (Page 60.)

FIGURES 7, 8. *Igoceras compressus* sp. nov. Anterior and lateral views of a cotype. (Page 60.)

FIGURES 9, 10. *Spirifer rundlensis* sp. nov. Pedicle and brachial views of imperfect specimens. Cotypes. (Page 59.)

PLATE VII



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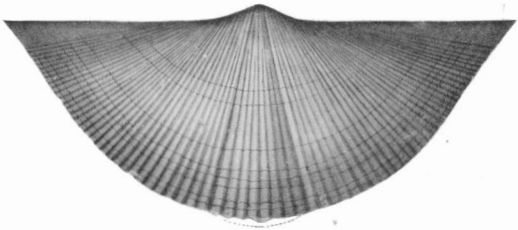

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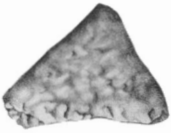

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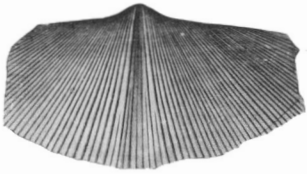

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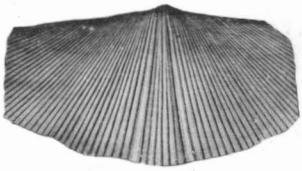

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