SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 75, NUMBER 4

CAMBRIAN GEOLOGY AND PALEONTOLOGY

V

No. 4.—PRE-DEVONIAN SEDIMENTATION IN SOUTHERN CANADIAN ROCKY MOUNTAINS

(With Plate 25)

BY
CHARLES D. WALCOTT

(Publication 2870)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
APRIL 2, 1927

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

CAMBRIAN GEOLOGY AND PALEONTOLOGY

V

No. 4.—PRE-DEVONIAN SEDIMENTATION IN SOUTHERN CANADIAN ROCKY MOUNTAINS[1]

By CHARLES D. WALCOTT

(With Plate 25)

CONTENTS

ILLUSTRATIONS

PLATE

Plate

Text Figures

[1] Published posthumously. Dr. Walcott completed the manuscript only ten days before his death on February 9, 1927. The proofs have been corrected by Dr. Charles E. Resser.

EXPLANATION

Area of the Bow Trough. Includes deposits of Lower, Middle and Upper Cambrian, Devonian and Carboniferous time. In direct communication at the north with Glacier Lake Trough.

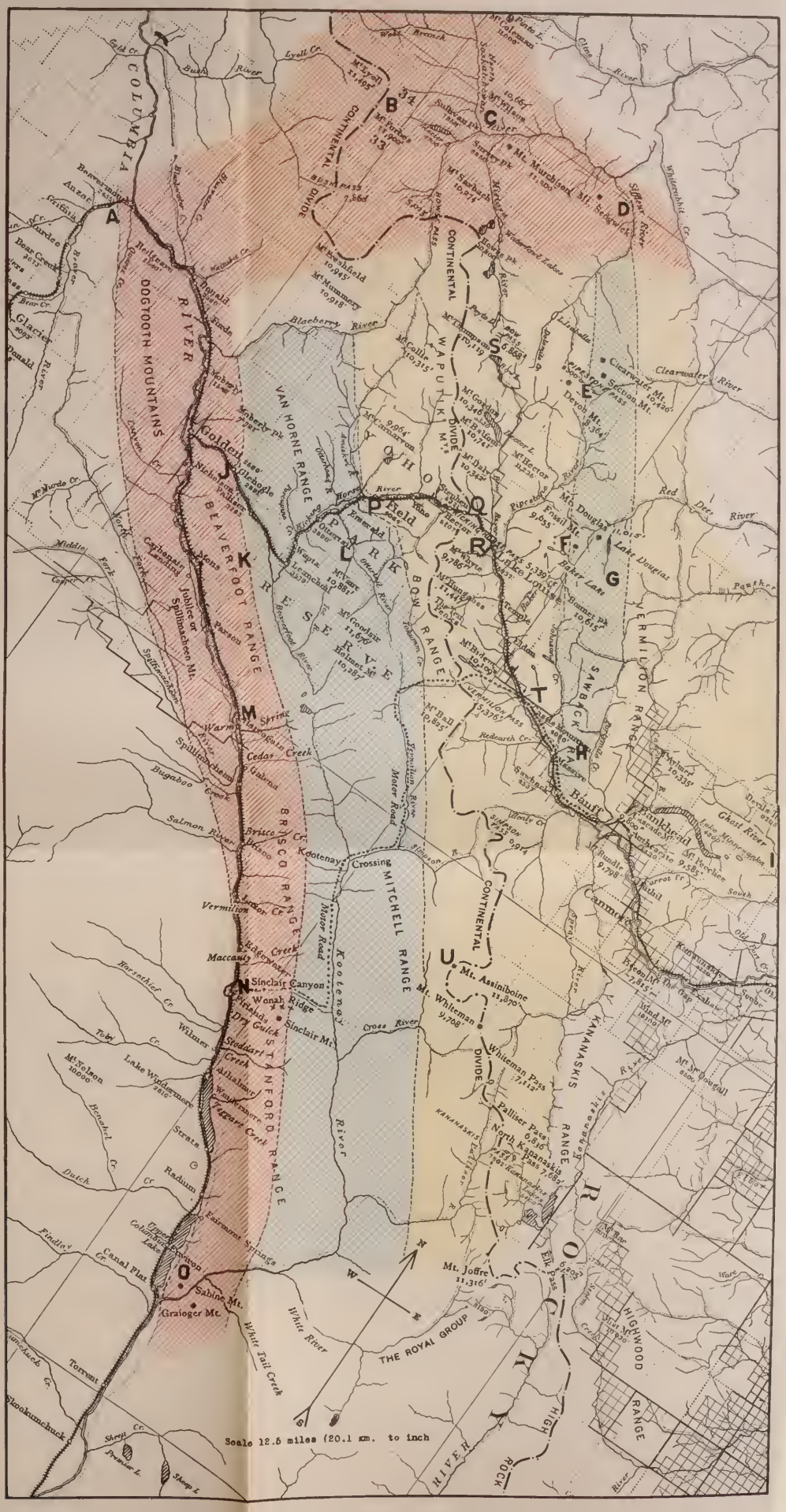
Southern portion of area of Glacier Lake Trough. Includes deposits of Lower, Middle, and Upper Cambrian, Ozarkian, Devonian, and Carboniferous time.

Area of Sawback Trough, which is superjacent to deposits of Bow Trough. Includes deposits of Upper Cambrian, Ozarkian, Ordovician, and Devonian time. In direct communication at the north with Glacier Lake Trough.

Area of Goodsir Trough. Includes deposits of Upper Cambrian and possibly of later time. A barrier separates it from Glacier Lake Trough at the north.

Area of Beaverfoot Trough. Includes deposits of Lower and Upper Cambrian, Ozarkian, Ordovician, Silurian, and Devonian time. In direct communication at the north with Glacier Lake Trough.

West of the Beaverfoot Trough the terraine is formed of pre-Cambrian rocks of the Purcell and Selkirk Mountains, and an occasional remnant of Devonian and Carboniferous limestone. In the eastern section of the Bow Trough area the Cretaceous rocks are folded and faulted in with the Paleozoic limestones, but east of the eastern margin of the trough the Cretaceous is subjacent by the eastward overthrust of the Paleozoic. This overthrust extends for hundreds of miles along the "Rocky Mountain Front," occasionally bringing up the pre-Cambrian with the Paleozoic above it.



DIAGRAMMATIC MAP OF AREAS OF SUBSIDIARY TROUGHS OF CORDILLERAN GEOSYNCLINE IN PALEOZOIC PRE-DEVONIAN TIME. BASED ON MAP, PLATE 1, SMITHSONIAN MISCELLANEOUS COLLECTIONS, VOL. 75, NO. 1, 1924. BY CHARLES D. WALCOTT, 1927

INTRODUCTION

In the progress of my reconnaissance in western Alberta and eastern British Columbia of the pre-Devonian formations of the Rocky Mountains from the Saskatchewan River drainage south to the line of Crows Nest Pass, many interesting problems appeared, for the detailed study of which there was but little time in the field. One of the most insistent of these was the problem of the location and extent of the original areas of deposition of the sediments now forming the series of stratigraphic formations between the pre-Cambrian and the Devonian. Much time and effort were devoted to collecting fossils from the Cambrian and Ozarkian rocks in order to obtain data that could be relied on regarding an area where irregularities of sedimentation, and subsequent displacement of strata by faulting and folding, had greatly complicated the normal stratigraphic succession of the formations. At first, with the great section of McConnell on the line of the Canadian Pacific Railway[1] as a guide (fig. 18), I considered that the entire series of sediments had been deposited in a broad seaway that filled the Cordilleran Geosyncline in upper Lower Cambrian time and that this seaway gradually narrowed as it received sediments from the great hinterland to the west and east until Devonian time. This impression was strengthened in studying the Glacier Lake-Saskatchewan River section, and in 1924 I published a transverse theoretical section of the Cordilleran Trough, based on conclusions reached at that date.[2] The section may possibly be a fairly correct one for the Glacier Lake-Saskatchewan area, but it does not now afford a satisfactory explanation for the Bow-Kicking Horse River section, 60 to 70 miles (96.5 to 112.6 km.) to the south-southeast.

The object of this paper is to call attention to conclusions based on further field studies and the working over since 1924 of a considerable amount of unpublished geological and paleontological data on the formation of the Cordilleran Geosyncline, located in the drainage areas of the Bow, Kicking Horse, and Saskatchewan Rivers.

The boundary between the Bow and Goodsir Troughs should be drawn about one-fourth of an inch to the west (left) where it crosses the Kicking Horse River, near Field (*P* on map) and con-

[1] Geol. and Nat. Hist. Surv. of Canada, Ann. Rep. for 1886, 1887, Pt. D, pp. 15D-31D, and accompanying colored section.

[2] Soc. Géol. de Belgique. Livre Jubilaire 1924. La Discordance de Stratification et la Lacune Stratigraphique Pré-Dévonienne dans les provinces Cordillères d'Alberta et de Colombie Britannique, Canada.

tinues northwest to the Blaeberry River. Southeast of Field it passes eastward to the boundary line represented on the map.

CORDILLERAN GEOSYNCLINE

The Cordilleran Geosyncline has been characterized by Schuchert as the oldest, longest, and widest continuous seaway known. During the Palaeozoic it extended from the Arctic Ocean southward through what is now the mountainous region of western North America into northwestern Mexico, a distance of 3,000 miles (4,827 km.). In Canada the width of this seaway was in most places a few hundred miles, while in the United States it was many hundreds of miles wide. The eastern shore of this vast geosyncline (seaway) and its marine extensions was the Canadian shield and its southern prolongation, Siouia. On the west it was bounded by Cascadia.[1]

In this paper we are chiefly concerned with the portion of the geosyncline that is now embraced in the area between the 49th and 54th parallels, a distance of about 350 miles (563.2 km.). The width of the geosyncline in pre-Cambrian time is unknown, but judging from the presence of Proterozoic deposits of Beltian time far to the west of the Cambrian outcrops, it was probably 300 or 400 miles (482.7 or 643.6 km.). In early Paleozoic time it may have been in places 200 miles (321.8 km.) or more, but as yet we do not know conclusively what pre-Devonian formations are present in the area west of the "Rocky Mountain Trench"; of the later Paleozoic, limestones of Devonian and Carboniferous age have been recognized which were presumably deposited in bays and along the shores of the old Selkirkian land area. On a line (from *I* through *M* on map, pl. 25) extending from the Rocky Mountain front at Devils Gap, northeast of Banff, Alberta, west-southwest through Banff and over the Continental Divide to the pre-Cambrian Proterozoic terraine on the west side of the Columbia River valley, the geosyncline may have been 200 to 250 miles (321.8 to 402.3 km.) broad; at present, after narrowing of the area by compression, folding, and thrusting of the pre-Devonian Paleozoic formations, the width occupied by them is about 160 miles (257.4 km.). On a parallel line that crosses the strike of the Continental Divide and the Cordilleran Trough 100 miles (160.9 km.) north, the area over which the pre-Devonian formations now occur is about 180 miles (289.6 km.) in width.

To what extent during pre-Devonian time the bottom of the Cordilleran Geosyncline was wrinkled and thus made into a complex geosyncline with minor troughs has not been fully determined, but

[1] Bull. Geol. Soc. America, Vol. 34, 1923, p. 184.

we find evidence of the former existence of several troughs in which distinct series of sediments were deposited with the marine life of their time embedded in them.

There is also evidence of longitudinal undulations of the bottom of the troughs that influenced the depth and character of the sediments to such an extent as to now cause a most disconcerting disappearance and reappearance of formations with their characteristic faunas.

It is clear that at the beginning of Proterozoic time the Cordilleran Geosyncline was broad, and relatively shallow, with extended land areas on both its eastern and western sides. This is indicated by the immense amount of fine sand and silts that were brought into the trough and distributed by gentle currents and wave action. There are neither great conglomerates indicating lands of high relief, nor coarse, cross-bedded sandstones suggesting a sea with strong tidal currents and waves attacking the coast line. The Beltian limestones, of which great thicknesses occur in Montana [1] and possibly in Alberta, are relatively shallow water deposits similar to those of the great inland lakes of Tertiary time, east of the Rocky Mountains.

Many thousand feet of arenaceous, calcareous and siliceous deposits accumulated as the geosyncline gradually deepened because of the downward pressure of the load of sediments it was receiving. There may have been longitudinal troughs within the geosyncline as in Paleozoic time, but at present the study of the areal geology is not sufficiently advanced to outline more than one of them.

PROTEROZOIC DEPOSITS IN THE CORDILLERAN GEOSYNCLINE

At the close of Proterozoic time the greatest thickness of deposits was in the area that is now the Purcell and Selkirk Mountains of British Columbia. Daly gives the following sections of the formations: [2]

	Feet	Meters
Ross quartzite (in part)	2,500	762
Nakimu limestone	350 +	107 +
Cougar formation	10,800 +	3,292 +
Laurie formation	15,000 +	4,572 +
Illecillewaet quartzite	1,500 +	457 +
Moose metargillite	2,150	655
Limestone (marble)	170	52
Basal quartzite	280 +	85 +
	32,750	9,982

[1] Bull. Geol. Soc. America, Vol. 17, 1906, p. 7. Bull. U. S. Geol. Surv., No. 384, 1909, p. 41.

[2] Geol. Surv. Canada, Transcontinental Excursion No. C 1, Guide Book No. 8, pt. II, 1913, p. 183.

This enormous mass of sediments accumulated in a trough (Selkirk), the western margin of which was formed by a pre-Beltian land area west of the present Alberta Canyon on the Canadian Pacific Railway, or it may have been as far west as Revelstoke in the Columbia River valley. This distance is now only 40 to 60 miles (64 to 97 km.), as it has been shortened by compression, folding, and more or less faulting of the strata.

To the eastward of the Purcell Range, the pre-Cambrian (Beltian) is concealed by Cambrian and later formations all the way to the Bow Valley[1] where a series of fine, impure sandstones and shales of pre-Cambrian age are exposed that indicate the approach to an eastern shore line of relatively low relief. On this eastern side of the geosyncline there are only about 3,470 feet (1,057.6 m.) of Beltian sediments exposed. These accumulated in a broad, shallow sea that preceded the Bow Trough.

To the south in Montana, Beltian sediments similar to those of the Bow Valley area accumulated to a depth of 36,000 feet (10,972.8 m.)[2] or more prior to the advent of the Cambrian sea.

The close of the period of deposition of Beltian sediments was followed by a slight diastrophic movement that in the Canadian area resulted in low undulations and minor faulting of the strata and the formation of the Bow Trough, so that when the Lower Cambrian sea advanced from the south it had an unobstructed seaway. This trough deepened as sediments were deposited until over 2,000 feet (609.6 m.) in depth of sands and siliceous muds accumulated in it. On the western side of the geosyncline the Purcell Trough deepened and a great thickness of sands referred by Daly to the Lower Cambrian were deposited. These include:

	Feet	Meters
Sir Donald Quartzite	5,000+	1,524.0+
Ross Quartzite	2,750	838.2
	7,750+	2,362.2+

The upper part of the Ross Quartzite is referred by Daly to the Lower Cambrian and the lower 2,500 feet (762 m.) to the Beltian. He states that "The lower part of this formation is of pre-Cambrian age; the upper part is probably to be assigned to the Lower Cam-

[1] Smithsonian Misc. Coll., Vol. 53, No. 7, 1910, pp. 423-431.

[2] Bull. Geol. Soc. America, Vol. 17, 1906, pp. 7, 15. Bull. U. S. Geol. Surv., No. 384, 1909, p. 41.

brian."[1] A detailed study of the Ross Quartzite and the Sir Donald Quartzite may result in the discovery of a fauna or of an unconformity that will serve as a boundary between the Beltian and the Cambrian, if the latter is actually present in the Selkirk Mountains.

It is my present opinion that the troughs and embayments of the Cordilleran Geosyncline in Proterozoic Beltian time were filled with fresh or brackish waters that had for long periods very slight connection, if any, with either the Pacific or Arctic Oceans. The land surface of the continent then extended out to the margins of the continental platform, and the epicontinental bodies of water discharged their overflow into shallow streams that finally reached the oceans through deep and narrow channels. As far as known there is little if any evidence of the existence of open seaways connecting the inland seas and the oceans during Proterozoic time. Any sediments brought by streams were carried out to the margin of the continental shelf and deposited on the steep slopes descending to the abyssal depths of the oceans. This almost complete separation of the epicontinental waters from the oceans serves to explain the nearly entire absence of marine faunas in the sandstones, shales, and limestones of the Beltian series of formations, and the presence of great algal deposits and of a few species of invertebrates of marine derivation that became adapted to a fresh water habitat after working their way up a favorable stream to the inland bodies of water. In no other way can I explain the presence of a few fossil forms in narrow bands of shale and sandstone in the Beltian formations of the Cordilleran Geosyncline in Montana[2] and the absence of the marine faunas of Lipalian time[3] that preceded the marine faunas accompanying the flooding of the Cordilleran and Appalachian Geosynclines at the beginning of Lower Cambrian time.

TROUGHS OF PALEOZOIC TIME

Plate 25 and fig. 14

In the latitude of the Bow-Kicking Horse Rivers the earliest of these troughs was the Bow Trough on the eastern side of the geosyn-

[1] Geol. Surv. Canada, Transcontinental Excursion No. C 1. Guide Book No. 8, pt. II, 1913, p. 137.

[2] Bull. Geol. Soc. America, Vol. 17, 1906, pp. 1-28.

[3] Smithsonian Misc. Coll., Vol. 57, No. 1, 1910, p. 14, Footnote: "Lipalian (λειπω) is proposed for the era of unknown marine sedimentation between the adjustment of pelagic life to littoral conditions and the appearance of the Lower Cambrian fauna. It represents the period between the formation of the Algonkian continents and the earliest encroachment of the Lower Cambrian sea." See also Vol. 64, No. 2, 1914, p. 82.

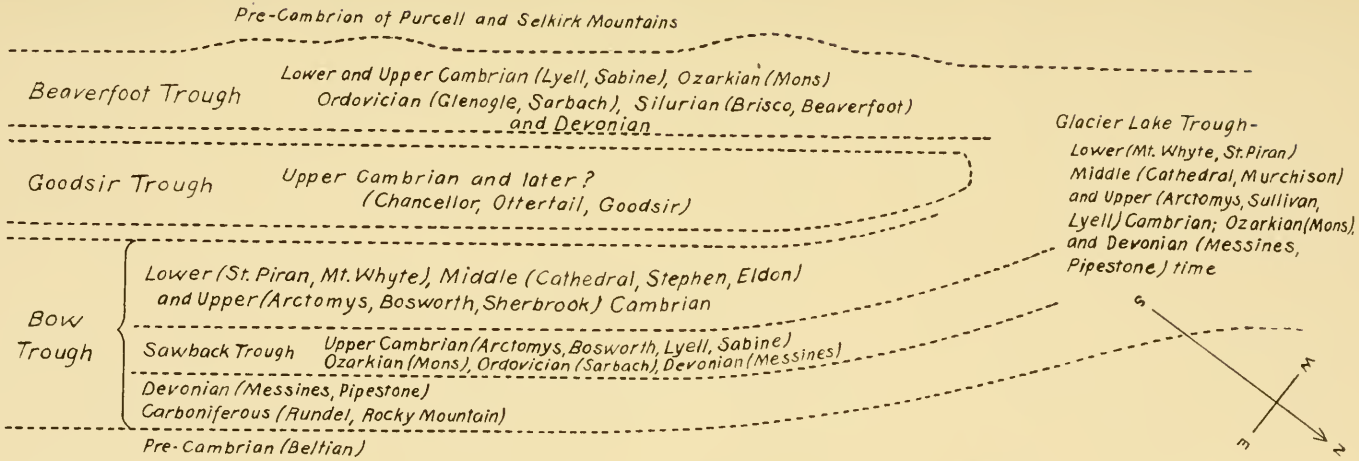


FIG. 14.—Diagrammatic outlines of subsidiary troughs of Cordilleran Geosyncline in pre-Middle Devonian time, based on map, pl. 25. The theoretical barrier boundaries between the Bow, Goodsir, and Beaverfoot Troughs are indicated by dotted lines, as are the margins of the Sawback Trough. All of the troughs except the Goodsir were connected by an open seaway at the north with the broad Glacier Lake Trough.

The troughs as here outlined represent only that portion of their original areas that remain after narrowing by compression, folding, faulting, and thrusting of the formations deposited in the troughs: this narrowing was probably from 10 to 30 per cent and in some instances much more.

cline. This was followed to the west by the Goodsir and finally the Beaverfoot Trough. The Bow Trough had open connection with the Glacier Lake Trough on the north (*B, C, D* on map and fig. 14) and with troughs or broad seaways to the south more or less intermittently all through Paleozoic time. The Goodsir Trough, as we now recognize it, did not have a direct connection with either the Bow or Beaverfoot Troughs, and except during a relatively short period in late Lower Cambrian time there was no connection between the areas of the Bow and Beaverfoot Troughs by which the fauna in one could have access to the other. The Goodsir Trough had no known connection with the Glacier Lake Trough and only very slight and short connections in Upper Cambrian time with the seaways to the south. The Beaverfoot Trough was in open connection with the Glacier Lake Trough on the north and at intervals with the seaways to the south. Deposition in the Sawback Trough appears to have been active at about the same time as in the Beaverfoot Trough, and there was an open seaway connection on the north into the broad Glacier Lake Trough that permitted the Sabine and Mons faunas to pass freely between the south end of the Beaverfoot Trough at Sabine Mountain (*O* on map) to Ranger Canyon (*H* on map) in the Sawback Trough, a distance of approximately 225 miles (362.0 km.). The probability is that the faunas mentioned passed from the Glacier Lake Trough south into the Sawback Trough, but they may have come in from the south through a seaway of which as yet we have no information. There was nowhere a regular uninterrupted sequence of deposits in any of these troughs from the beginning to the end of Paleozoic time. This was prevented by diastrophic movements of greater or less extent that occurred in the Cordilleran Geosyncline, from its inception until the "high Ancestral Rocky Mountain geanticline" blotted out its eastern side and later its median portion.[1]

Usually the boundaries of the troughs were low and afforded little mechanical sediment for deposition and, as determined by the faunas that lived in the seaways, we learn that they were not all of the same age and that the diastrophic movements affecting the geosyncline were subject to long periods of quiescence, in which accumulation of sediments may have caused deepening, and local tilting caused both deepening and shallowing of the troughs.

At present it is very difficult to form a clear conception of the original condition of the troughs in pre-Devonian time. On the eastern

[1] Schuchert, *loc. cit.*, pp. 186, 187.

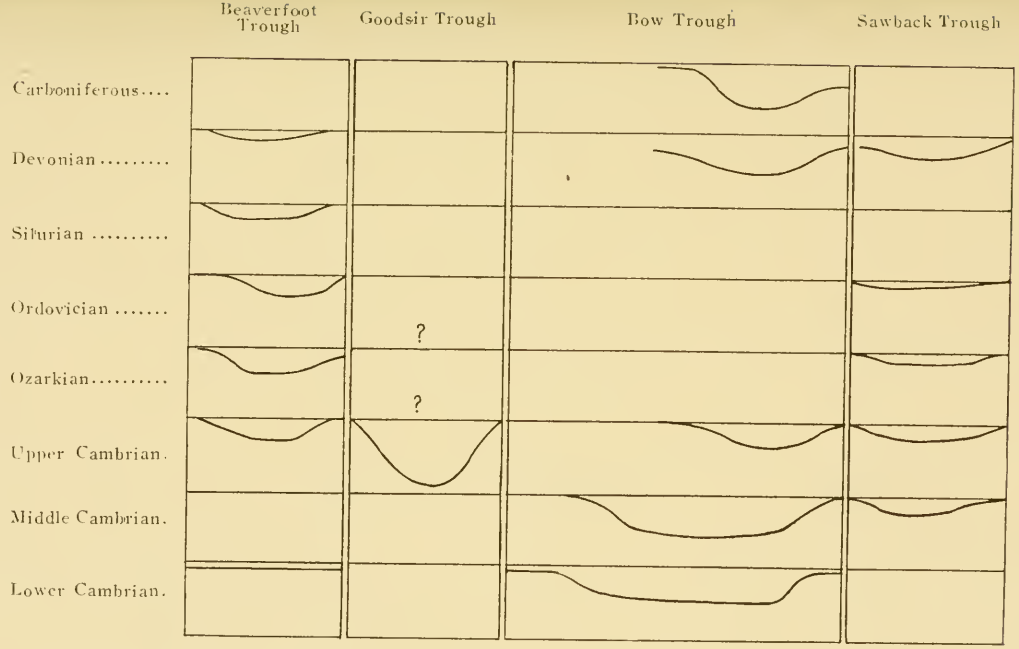


FIG. 15.—Diagrammatic sketch to show extent of maximum deposition of sediments as now known in the Bow, Goodsir, Beaverfoot and Sawback Troughs in each geologic period of Paleozoic time. This is intended to illustrate: (1) the relative amount of sedimentation in each trough; (2) the relationship in time of the Beaverfoot and Sawback Troughs; (3) the independent character of the Goodsir Trough; and (4) the great development of the Lower and Middle Cambrian in the Bow Trough.

How much, *if any*, of the later sediments of the Goodsir Trough are of Ozarkian or Ordovician age is undetermined.

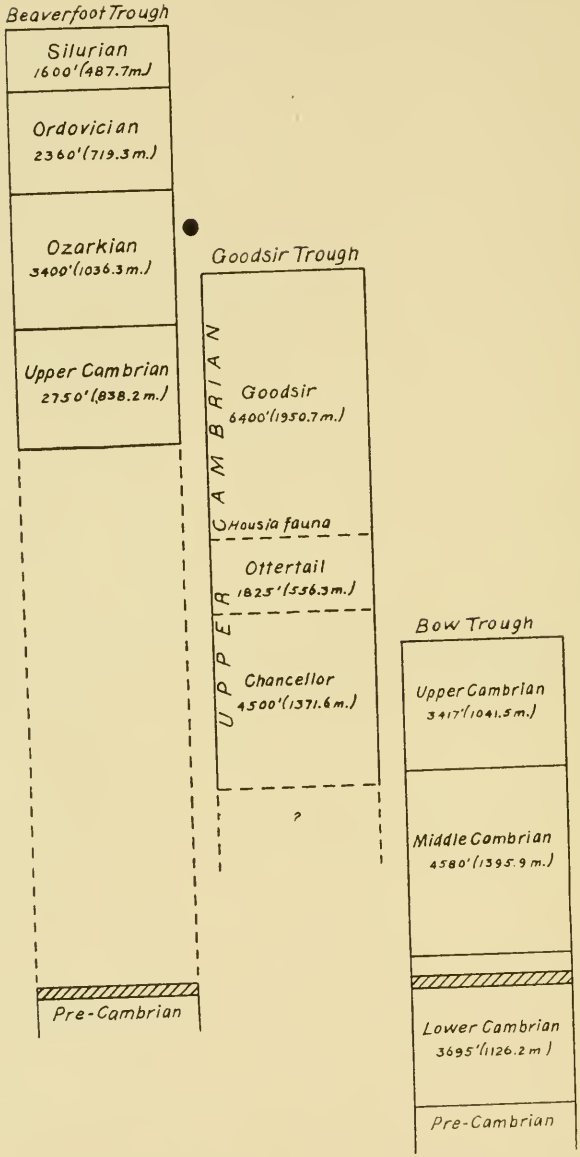


FIG. 16.—Stratigraphic sections of the Bow, Goodsir, and Beaverfoot Troughs. Each section is placed with reference to the time at which the various formations were deposited. Thus the sediments of the upper portion of the Lower Cambrian (Mesonacis zones) were deposited in the Bow and Beaverfoot Troughs about the same time, but there is no record of the deposition of sediments of this time in the Goodsir Trough. These sections serve to further explain the diagrammatic outlines of fig. 15.

side[1] the faulting and eastward thrusting of the sedimentary formations has forced the rocks, representing deposits in originally distinct troughs, eastward over each other until all evidences of land or shallow sea barriers between the troughs have been destroyed or deeply buried. On the western side the strata of the Beaverfoot Trough have been forced into overturned folds at the north end of the Beaverfoot Range west of the Kootenay fault, also faulted and possibly folded at the south in the Brisco and Stanford Range. The strata of the Goodsir Trough were also deeply affected, as shown by Allan's fine sections accompanying Map 142A of the Kootenay District.[2] These movements were usually, if not always, accompanied by displacements that are now recorded by profound faults and the juxtaposition of unlike formations containing faunas that are not in their normal stratigraphic order. The more or less irregular thrusting with concurrent and later erosion are accountable for the present position and exposures of the buried sections of the original troughs and the disappearance of their intervening barriers.

Examples of the overthrust of the sedimentary contents of a former trough are the thrust of the Cambrian and later limestones of the Bow Trough of the Rocky Mountain Front over on the Cretaceous formations, and the thrust of the Ozarkian, Ordovician, and Silurian rocks of the Beaverfoot Trough against, and probably on, the Upper Cambrian rocks of the Goodsir Trough. The great Lewis fault now marks the eastern limit of the Bow Trough, and the Kootenay fault the eastern limit of the Beaverfoot Trough.

A number of fine sections accompanying the report of Dr. D. B. Dowling of the Geological Survey of Canada[3] illustrate the effect of the eastward pressure that displaced and compressed the strata of the Bow Trough and the superjacent Cretaceous and Jurassic strata. A section a little south of Panther River is outlined by text figure 17.

The section on the line of the Bow-Kicking Horse Rivers illustrates the geological structure, as determined by McConnell and Allan, from the Rocky Mountain Front to the Columbia River, a distance of 72 miles (115.8 km.). The broad features of this section are shown by figure 18.

A typical section displaying the overthrust of the strata of the Bow Trough on the Devonian of the Sawback Trough is shown by figure

[1] See sections accompanying McConnell's Report D. Rept. Geol. Surv Canada, Vol. 11, for 1886 (1887). Also sections of Dowling on maps of Cascade Coal Basin, Sheets 1-10, Geol. Surv. Canada, No. 26b, 1907, No. 949.

[2] Geol. Surv. Canada, 1915. Accompanying memoir No. 55 by J. A. Allan

[3] Cascade Coal Basin of Alberta, 1907.

19, where the pre-Cambrian with the superjacent Lower and Middle Cambrian is thrust over the Devonian of Fossil Mountain. Tilted up at a steep angle beneath the Devonian (fig. 20) are the Ordovician (Sarbach), Ozarkian (Mons), Upper Cambrian (Sabine, Lyell, Bosworth and Arctomys), and Middle Cambrian (Eldon), and finally the Eldon is thrust over on the upturned strata of Devonian age.

Ulrich, in discussing the overthrust troughs within the Appalachian Geosyncline, says, "The evidence on which this belief in distinct troughs is based is threefold in character, faunal, lithologic, and structural. The first is shown by differences in fossil contents. * * * The second is expressed, first by peculiarities in the succession of the various types of sediments, and second, the degree of metamorphism to which the deposits have been subjected. The third component of the evidence is the physical proof of excessive folding and overthrusting shown by the structure of the various rock masses."[1]

The following descriptions of the Cordilleran troughs include the criteria on which they have been distinguished and named.

BOW TROUGH

Plate 25

The area considered to have been included in the Bow Trough now has a width, on a line from the Devils Gap at Ghost River to Mt. Stephen (*I* to *P* on map, pl. 25), of about 40 miles (64.4 km.). The trough was narrow and confined to the eastern portion of the Cordilleran Geosyncline when the waters of Lower Cambrian time first flooded it and began to deposit siliceous silts and fine sands derived from the pre-Cambrian Beltian rocks on the gently sloping eastern shores of the seaway and brought into it by tributary streams. As this early trough deepened, more than 2,000 feet (609.6 m.) of sands and silts accumulated before the waters overlapped the margins of the trough on the east and west and deposited sand and arenaceous and calcareous muds during the closing period of Lower Cambrian time. This widening of the trough extended westward as far as Mt. Stephen (*P* on map) and eastward to the line of the Ghost River (*I* on map) at Devils Gap. At this time the Cambrian sea penetrated into the Beaverfoot Trough (*J*, *K*, *M*, *N* on map) and brought with it a late Lower Cambrian (Mesonacidae) fauna similar to that in the Bow Trough (see figs. 15, 16).

The broad Bow Trough gradually deepened, the sands and siliceous silts being succeeded by calcareous sediment with interbedded sili-

[1] Bull. Geol. Soc. America, Vol. 22, 1911, pp. 442, 443.

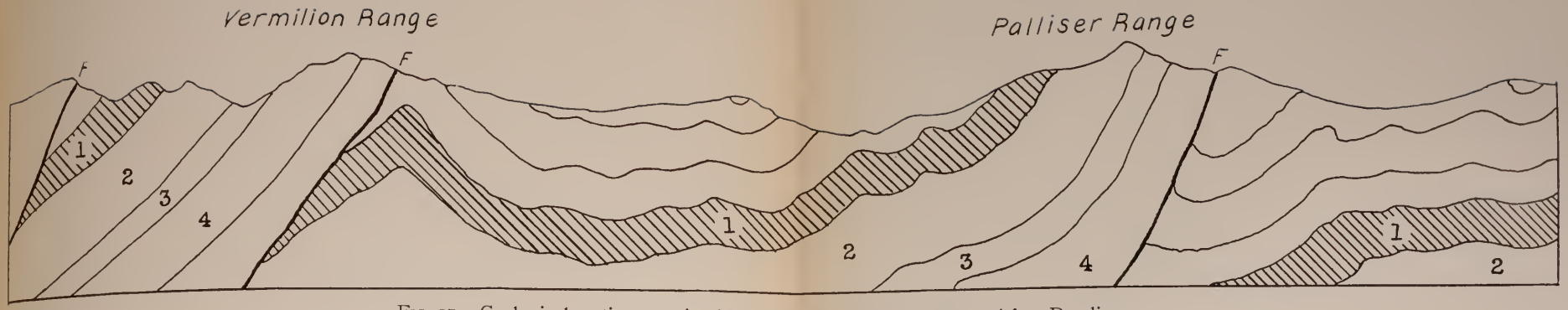


FIG. 17.—Geological section crossing Vermilion and Palliser Ranges. After Dowling.

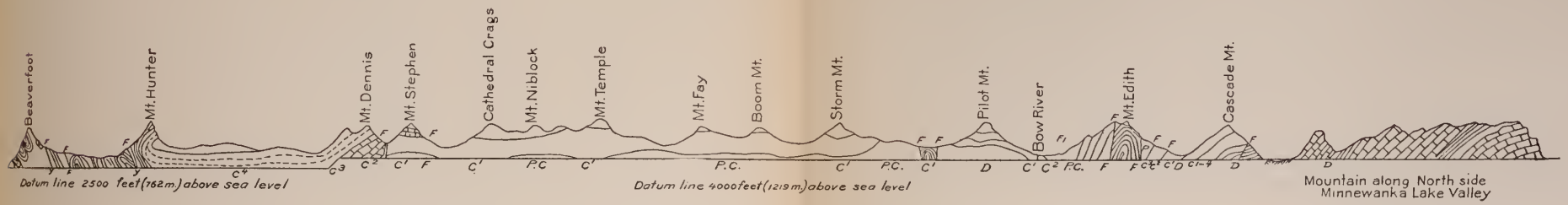


FIG. 18.—Diagrammatic section along the Bow-Kicking Horse Rivers illustrating the geologic structure as determined by McConnell and Allan. Vertical scale twice the horizontal Length of section 72 miles (115.8 km.). The section is on the strike of the formations from Storm Mountain to Cathedral Crags. See map (pl. 25) on line of letters, *J*, *P*, *Q*, *T*, *H*, *I*.

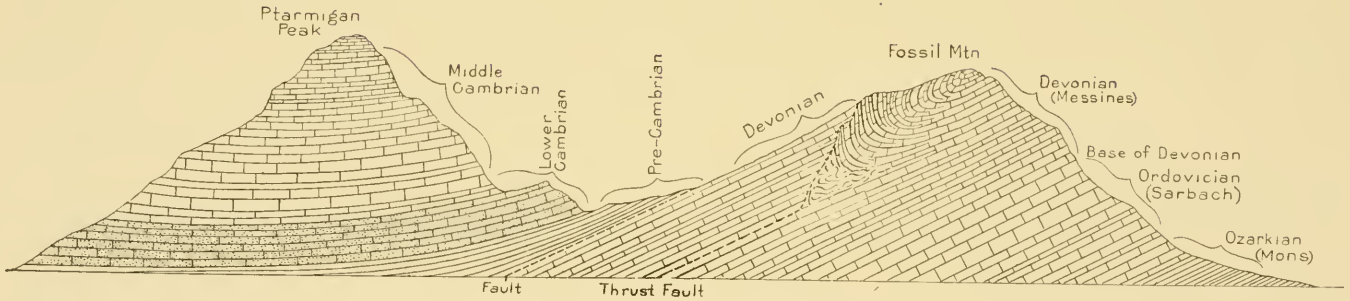


FIG. 19.—Diagrammatic section of the geological formations occurring in Ptarmigan Peak and Fossil Mountain (*F* on map, pl. 25) on the north side of Ptarmigan and Baker Lakes, showing the position of the strata and the overthrusting of the Ptarmigan Peak pre-Cambrian Hector sandy shales on the Devonian limestones.

Locality.—Baker Lake is 7.25 miles (11.7 km.) northeast of Lake Louise Station on the Canadian Pacific Railway, Alberta.

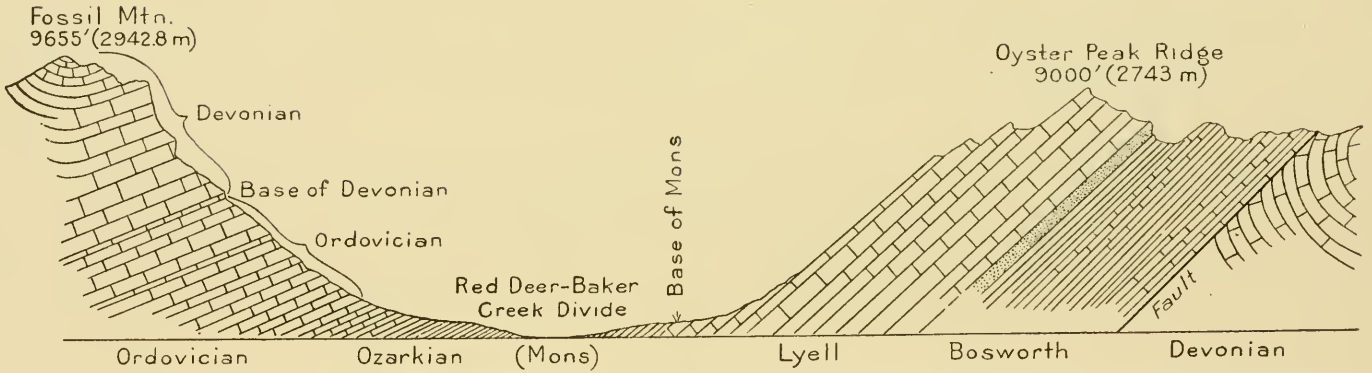


FIG. 20.—Diagrammatic outline of section northeast of Baker Lake from summit of Fossil Mountain eastward across the Red Deer-Baker Creek Divide to Oyster Peak Ridge at Cotton Grass Cirque in Sawback Range. This is a continuation eastward of the section illustrated by fig. 19.

Locality.—Same as fig. 19.

ceous muds which now form the Mt. Whyte limestones and shales as they occur at the base of Castle Mountain in the Bow Valley, at Mt. Assiniboine and Mt. Bosworth on the Continental Divide, and their western outcrop at Mt. Stephen. The trough, now 20 to 30 miles (32.2 to 48.3 km.) or more in width, continued to deepen during the time of the deposition of the limestone of the Middle Cambrian Cathedral formation, 1,212 feet (369.4 m.); the Stephen, 640 feet (195.1 m.); and the Eldon, 2,728 feet (831.5 m.); a total of 4,580 feet (1,395.9 m.) of limestones before a shallowing of the seaway resulted in the deposition of the Arctomys siliceous silts that marked the close of Middle Cambrian time and the beginning of the deposition of the Upper Cambrian formations. After the deposition of the Arctomys silts and fine sands, 268 feet (81.7 m.) thick,[1] the seaway again deepened and the deposits now forming the Upper Cambrian limestones of the Bosworth formation 1,587 feet (483.7 m.), the Paget and Sherbrook 1,735 feet (528.8 m.) were laid down, a total thickness,with the Lower and Middle Cambrian sandstones and limestones, of 10,170 feet (3,099.8 m.). As far as we now know, the Chancellor shales of the Goodsir Trough do not follow the Sherbrook limestones and they were not deposited within the Bow Trough.

About the time sedimentation in the Bow Trough ceased, or just before, calcareous sediments were being deposited in the then forming Goodsir Trough in an area now occupied in part by the Van Horn Range. These calcareous deposits were later buried beneath a great thickness of argillaceous and siliceous muds that now form the Chancellor shales. The latter may have been deposited and subsequently removed by erosion from part of the area east of their present surface outcrop, but my impression is that when the floor of the Bow Trough was elevated and the long period of limestone forming deposits abruptly ceased with the close of the Sherbrook, it was only within the limits of the Goodsir Trough that the fine argillaceous and siliceous material, now forming the Chancellor shales, was deposited in the Goodsir seaway. The limestones beneath the base of the Chancellor formation in the Van Horn Range are probably of Upper Cambrian age, but until diagnostic fossils are found, it will not be practicable to correlate them with any of the known formations of the Bow Trough.

Near the eastern side of the Bow Trough at Ghost River (*I* on map), about 500 feet (152.4 m.) of late Lower Cambrian sand-

[1] At Glacier Lake the Arctomys formation has a thickness of 1,386 feet (422.5 m.).

stones and shales and 1,122 feet (341.9 m.) of Middle Cambrian limestones represent the eastern extension of the Middle Cambrian limestones of the Mt. Bosworth and Mt. Stephen area, where they are 5,244 feet (1,598.4 m.) thick. No sediments of Upper Cambrian or Ozarkian age appear to have been deposited in this eastern area.

Extent of Bow Trough.—The seaway of the Trough was probably from 50 to 60 miles (80.5 to 96.5 km.) in width, at the time of its greatest development. Its extension to the south-southwest appears to have been limited by the pre-Cambrian Kintla Island uplift,[1] but it was undoubtedly connected on the south with an open seaway, as yet unrecognized, of the Cordilleran Geosyncline, for the Lower and Middle Cambrian faunas of Utah and Nevada are closely related to those of the Bow Trough Lower and Middle Cambrian formations. To the north-northwest of the Bow Valley, similar characteristic faunas of Lower and Middle Cambrian age have been found 42 miles (67.6 km.) distant in the Glacier Lake, Saskatchewan area, also in the Robson Peak District 167 miles (268.7 km.) from the Bow Valley. It is probable that the Bow Trough was an open seaway from the Bow Valley to the Saskatchewan area in Lower and early Middle Cambrian time, for the Lower Cambrian St. Piran and Mt. Whyte formations, the Middle Cambrian Cathedral limestones, and a representative of the Stephen formation (Murchison) occur in Mt. Sedgwick (*D* on map, see figs. 20, 21, p. p. ?), but the great Eldon limestone is absent. The Arctomys shales which followed the close of the Middle Cambrian have a large development at Glacier Lake, gradually thinning out to the southeast in the Sawback Range (*F* and *H* on map) and on Mt. Bosworth (*R* on map) in the Bow Trough. With the Arctomys, the formations common to the Bow Trough and the Saskatchewan area terminate, unless the fauna of the Upper Cambrian Sullivan formation be found later to be similar to that of the Bosworth of the Bow Trough sections, in which case the Bosworth will be the last of the Bow Trough formations deposited in the Saskatchewan area.

A band of limestone 165 feet (50.3 m.) thick beneath the Lyell formation in the Sawback Range (*H* on map) may represent the Bosworth, but a thickening of this band, 18 miles (28.9 km.) farther to the north-northwest in the Range, to 500 feet (152.4 m.) leads to the inference, in the absence of fossils, that it is a thinning out of an extension of the Sullivan from the northwest rather than the extension of the Bosworth to the northwest.

[1] Smithsonian Misc. Coll., Vol. 53, No. 5, p. 191.

The development of a narrow trough at the close of Middle Cambrian time within the area of the northern extension of the Bow Trough is mentioned in the description of the Sawback Trough.

A comparison of the three sections is given in figure 16, p. 156.

Longitudinal undulation.—The extent of a longitudinal undulation, or a tipping of the bottom, of the Bow Trough during the deposition of the Lower and Middle Cambrian formations is shown by the thinning out of the Middle Cambrian Eldon formation from a thickness of 2,728 feet (831.5 m.) at Mt. Stephen (*P* on map) to zero in the section on the Saskatchewan River about 50 miles (80.5 km.) to the north (*D* on map). The subjacent Stephen formation persists; also the superjacent Arctomys formation which is conformable with the Stephen (see fig. 22, p. 168). The Arctomys is nearly five times as thick in the Glacier Lake section (*B* on map, pl. 25) as at Mt. Bosworth (*R* on map).

GOODSIR TROUGH

Plate 25 and fig. 14

West of the Bow Trough and east of the Beaverfoot Trough (*K*, pl. 25) and subparallel to it a deep narrow trough was developed and gradually silted up in Upper Cambrian time by fine, argillaceous and siliceous muds that ultimately formed the laminated Chancellor shales 4,500 feet (1,371.6 m.) thick; calcareous-siliceous sediments that formed the Ottertail limestones 1,825 feet (556.3 m.) thick and the Goodsir shales and limestones 6,400 feet (1,950.7 m.) thick, a total of over 12,700 feet (3,870.9 m.) of Upper Cambrian and possibly some later sediments, and there may have been earlier Cambrian deposits of which there is no known record.

In the absence of fossils from the upper 5,500 feet (1,676.4 m.) of strata of the Goodsir formation we are unable to determine the age of that part of the section. I have searched in vain on the flanks of Mt. Goodsir for traces of fossils in the abundant talus from the Goodsir formation above the lower fossiliferous 500 feet (152.4 m.) and Dr. Allan met with no better success. These limestones and shales are even more barren of indications of life than the 4,500 feet (1,371.6 m.) of Chancellor shales which have an occasional faint outline of a fragment of an *Agnostus* or the cranidium of a small trilobite. None of the above mentioned formations has been recognized either east or west of the area assigned to formations of the Goodsir Trough, and they do not appear to have been deposited in the trough for a greater distance than 120 miles (193.1 km.) and a

width of about 20 miles (32.2 km.) but they may be found in the future west of the Continental Divide in the drainage areas of the Blaeberry, Bush and other rivers to the north-northwest, but my present impression is that they were limited to about where we now know them. The greatest thickness of sedimentation was on the line of the broad syncline of the Ottertail Range, where the strata referred to the Goodsir formation form a high mountain ridge that rests in a synclinal trough of the Ottertail limestone, which is superjacent to the Chancellor shales. The area of the formations of the Goodsir Trough is outlined by faults, both on the east and west, that serve to delimit roughly the compressed lateral boundaries of the trough. The northern extension of this trough has not been traced beyond the Van Horn Range, and nothing was seen of its included formations or their contained faunules about the headwaters of the Saskatchewan River (*B*, pl. 25), 50 miles (80.5 km.) north of the Kicking Horse Canyon at Ottertail. To the south-southeast of the Ottertail Range, in the Vermilion and Mitchell Ranges, a great thickness of thin-bedded limestones with shaly partings appears to represent the Goodsir and Ottertail formations; the Chancellor shales extend along the southwestern side of the Ottertail, Vermilion, and Mitchell Ranges; and the broad canyon valleys of the Beaverfoot and Kootenay Rivers were largely eroded in the shales of the Chancellor and the readily broken down Ottertail formation.

In places these Goodsir Trough shales and limestones rise nearly to the summit of the northeastern side of the Beaverfoot-Brisco-Stanford Range, and are in contact with the Silurian, Brisco and Beaverfoot limestones of the Beaverfoot Trough along the line of the great Kootenay fault which now outlines the contact between the formations deposited in the two Troughs.

No fossils have been reported from the Goodsir, Ottertail, or Chancellor formations of the Beaverfoot-Kootenay River area that are upturned against the east-northeast side of the Beaverfoot-Brisco-Stanford Range, but as soon as the great Kootenay fault is crossed to the strata on the southwest side of the fault, fossils are abundant in the Silurian, Brisco and Beaverfoot; Ordovician (Canadian), Glenogle and Sarbach; Ozarkian, Mons; and Upper Cambrian, Sabine formations. Almost in a step one passes from a singularly barren series of shales and limestones to a record of abundant and varied marine life. This indicates that the seaway of the Goodsir Trough had little direct connection with the great Cordilleran seaways and their faunas, while the Beaverfoot Trough, in its time, was

in open connection with the seaways to the north and the connecting seaways on the south.

BEAVERFOOT TROUGH

Plate 25 and fig. 21

On the western side of the Cordilleran Geosyncline there was a narrow trough that connected on the north with the Glacier Lake Trough (*B* on map), and terminated on the south, as far as we now know, at about what is now the southern end of the Stanford Range. That this trough connected with seaways extending north to the Arctic Ocean and far to the south, is indicated by the presence of similar genera in the faunules of Cambrian, Ozarkian and Silurian formations in Alaska, British Columbia, Idaho, Utah, and Nevada. In this trough, south of the Kicking Horse Canyon, there were deposited in Upper Cambrian time the following formations: Lyell limestones, 860 feet (262.1 m.),[1] and the Sabine shales, 750 feet (228.6 m.); in Ozarkian time, the Mons limestones and shales, 3,400 feet (1,036.3 m.); in Ordovician (Canadian) time, the Sarbach limestone, 200+ feet (60.9+ m.), and the Glenogle shales, 2,160 feet (658.4 m.); and in Silurian time, the Beaverfoot and Brisco formations, 1,600 feet (487.7 m.); making a total thickness of over 8,700 feet (2,651.7 m.) of sediments deposited prior to the incursion of the Devonian sea. There was also a considerable thickness of arenaceous and siliceous material deposited in Lower Cambrian time that now forms the Lower Cambrian sandstones and shales on the eastern slopes of the pre-Cambrian on the western side of the Columbia River Valley. These Lower Cambrian sands and muds were deposited in the Bow, Glacier Lake, and Beaverfoot Troughs, and in the depressed areas of the Purcell and Selkirk Mountains. This is evidenced by the presence of the same character of sandstone, containing a similar late Lower Cambrian fauna, wherever the outcrops now occur from Ghost River on the eastern side across the area of the Bow Trough and on the western side of the Columbia River Valley.

The extension of the Beaverfoot Trough has not been traced north of the Kicking Horse River, but at Glacier Lake, about 50 miles (80.5 km.) north of the Kicking Horse River, the thick-bedded Upper Cambrian Lyell limestones are overlain by calcareous shales and thin layers of interbedded limestone of the Sabine formation, and

[1] Walker reports a maximum thickness of about 2,000 feet (609.6 m.) south of Fairmount Springs, where he confuses it with the Ottertail formation. Geol. Surv. Canada, Memoir 148, 1926, p. 21.

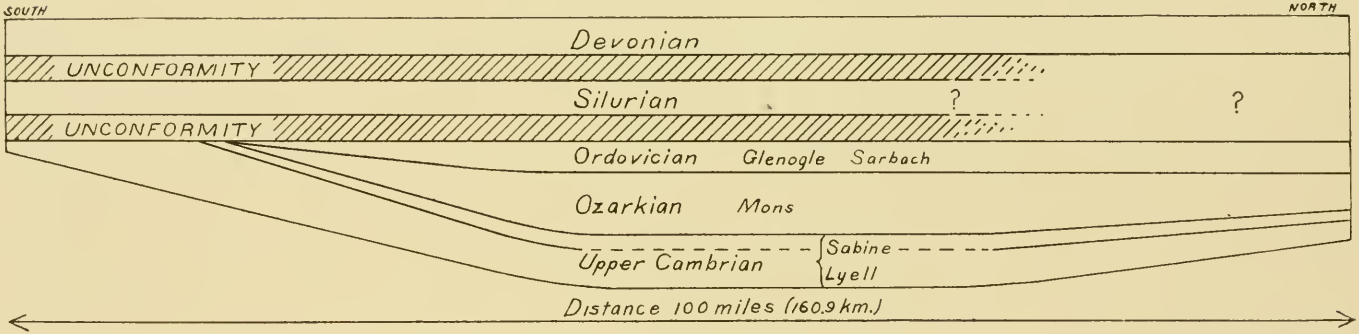


FIG. 21.—Diagrammatic northwest-southeast section of formations deposited in Beaverfoot Trough between the pre-Cambrian of Grainger Mountain (southeast of *O* on map, pl. 25), and Glacier Lake (*B* on map). The Silurian not having been reported from the Glacier Lake area is not extended north of the position of the lower Kicking Horse River drainage area.

the latter are subjacent to the limestones of the Ozarkian, Mons formation, and they, in turn to the limestones of the Ordovician (Canadian) Sarbach formation, indicating strongly that they were deposited under similar conditions. The presence of diagnostic faunules in the Sarbach, Mons, and Sabine formations proves that there was an open seaway from Sabine Mountain to Glacier Lake, a distance of 130 miles (209.2 km.). None of these faunules or a similar succession of formations has been recorded east or northeast of the Beaverfoot Trough for a distance of 38 miles (61.1 km.) or until the southwestern side of the Sawback Trough east of the great Castle Mountain fault is reached.

The Silurian, Brisco and Beaverfoot formations and Ordovician (Canadian) Glenogle graptolite shales extend from the southern end of the Stanford Range (*O* on map) north-northwest to the Kicking Horse Canyon (*J* on map), but they have not been reported from beyond the Kicking Horse drainage area. They should be looked for in the Blaeberry River and Bush River drainage areas, along the western slopes of the Continental Divide.

The character of the folding and faulting to which the strata of the Beaverfoot Trough have been subjected is shown by the sections of McConnell[1] and Allan[2] of the northern portion of the Beaverfoot Range and the Walcott section of the Brisco-Stanford Range at Sinclair Canyon, 55 miles (88.5 km.) southeast.[3]

SAWBACK TROUGH

Plate 25

The Bow Trough appears to have shallowed towards the close of Middle Cambrian time, so that the shallow water Arctomys formation and the calcareous sediments of the Sullivan were almost excluded from it except in the depression we are now designating as the Sawback Trough. This trough extended from the Glacier Lake Trough (*D* on map), with which it was connected by an open seaway, southeast as far at least as the Bow Valley (*H* on map).

The Sawback Trough was at first a narrow depression or downwarp in the bottom of the Bow Trough that accompanied the slight

[1] Rept. Geol. Surv. Canada, Rept. D., Vol. II for 1886 (1887). Section p. 42 D.

[2] Geol. Surv. Canada, Guide Book No. 8, Pt. II. Transcontinental Excursion C, 1, 1913. Structure section.

[3] Smithsonian Misc. Coll., Vol. 75, No. 1, p. 10, fig. 2.

The anticline of the eastern end of this section is probably broken by faults or possibly by a synclinal fold, or both faults and fold. Such a structure is suggested at the head of Dry Gulch a little south of Sinclair Canyon.

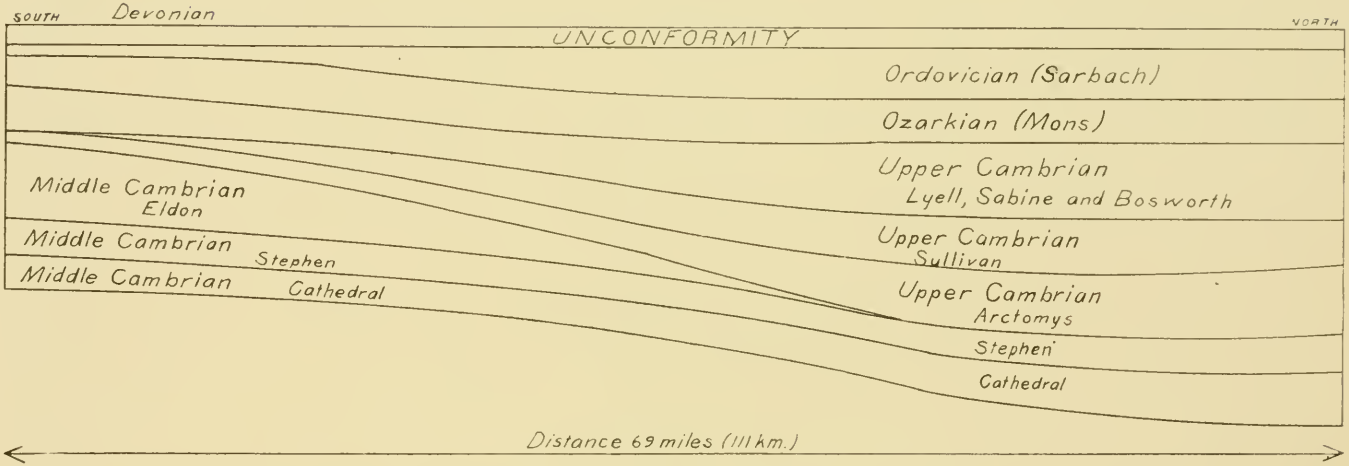


FIG. 22.—Diagrammatic northwest-southeast section of formations deposited in the Sawback Trough between Bow Valley (*H* on map) and Glacier Lake Trough, *B*, *C*, *D*, on map, pl. 25, and fig. 19.

diastrophic movement marking the close of Middle Cambrian time. We might consider it a continuation of the Bow Trough, but as a series of sediments were deposited in it that are not found elsewhere in the Bow Trough, and which are limited, as now known, to the Sawback, Glacier Lake, and Beaverfoot Troughs, it is more convenient to give it a distinct name and thereby more closely record the history of sedimentation in this area of the Cordilleran Geosyncline. Judging from the thickness of sediments deposited (see fig. 22), this depression gradually deepened from the Bow Valley on the south to the north-northwest as far as Glacier Lake and beyond, except in late Middle Cambrian time.

As now known, the area of outcrops of Upper Cambrian, Ozarkian, and Ordovician sediments in this Trough is between the great Castle Mountain fault at Johnston Creek and the faults of the Sawback Range southwest of Forty Mile Creek, and thence north-northwest to the head of the Saskatchewan River drainage. (On the map from *H* to *F* and *G*, to *E* to *C*).

On the line of the headwaters of Red Deer River (*F* and *G* on map) the pre-Devonian formations include the Skoki; Ordovician, Sarbach; Ordovician (Canadian), Mons; Ozarkian, Lyell, Bosworth and Arctomys; Upper Cambrian, and Eldon; Middle Cambrian in the Sawback Range. The Upper Cambrian Sherbrook, Paget, and most, if not all, of the Bosworth formation were not deposited, and the Eldon limestone is thin and confined to the eastern side of the Trough.

At the head of Clearwater River (*E* on map) about 42 miles (67.6 km.) north-northwest of Bow Valley, there is a fine development of the Sarbach, Mons, and Lyell formations, and these are all present in the Glacier Lake Trough as well as in the Beaverfoot Trough.

With the close of the period of deposition of the Ordovician, Sarback and Skoki formations, the Sawback Trough ceased to function so that the succeeding Devonian sea occupied nearly all of the original Bow Trough area, the Glacier Lake Trough, and much of the area of the Beaverfoot Trough.

GLACIER LAKE TROUGH

The formations deposited in this Trough were studied in the Glacier Lake area (*B*, *C*, and *D* on map) about the headwaters of the Saskatchewan River, 54 miles (86.9 km.) north-northwest of the Bow Trough section and 120 miles (193.1 km.) south-southeast of the Robson Peak District section. The typical section of the formations

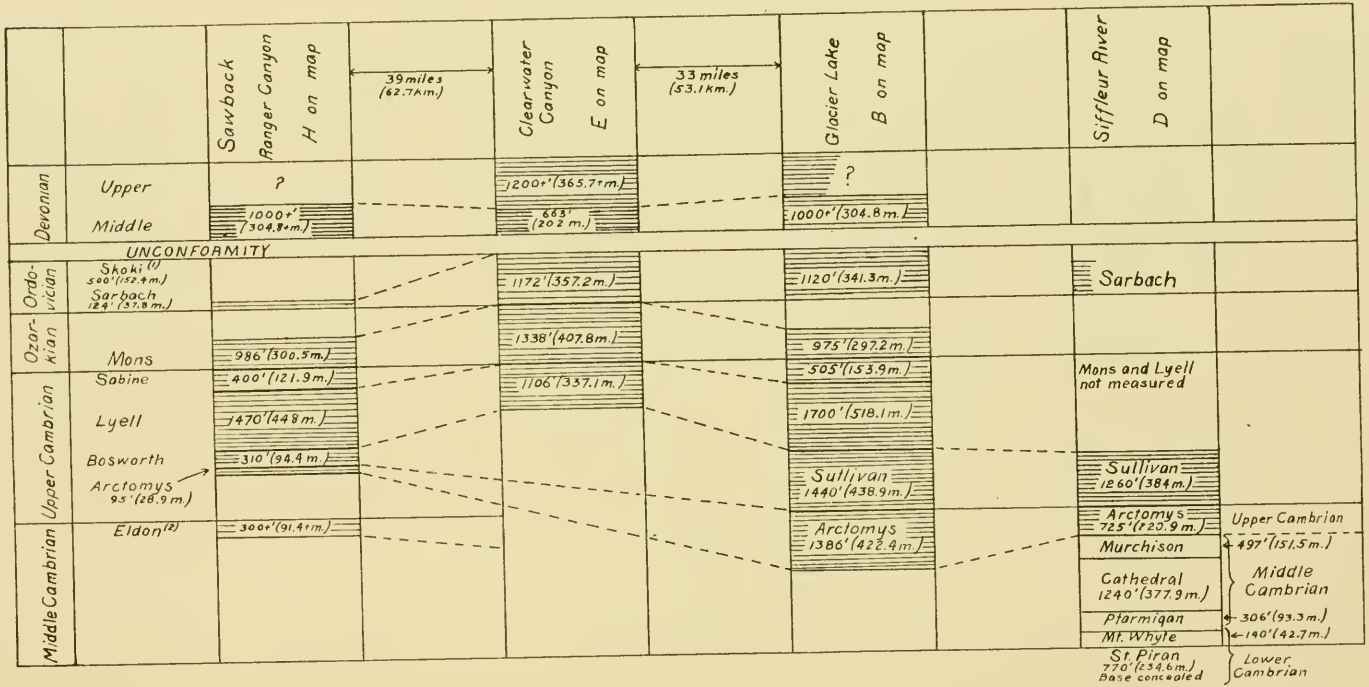


FIG. 23.—A diagrammatic sketch of four sections crossing the formations deposited in the Sawback Trough, and, as far as known, of the subjacent Middle Cambrian formations of the Glacier Lake and Bow Troughs, as exposed in the Siffleur Saskatchewan River section.

[1] The Skoki formation occurs at Fossil Mountain (*F* on map), 23 miles (37 km.) north-northwest of Ranger Canyon section (*H* on map), where it has a thickness of 500 feet (152.4 m.). It has not been identified at Ranger Canyon as elsewhere in the Sawback Trough.

[2] Six miles (9.7 km.) west of Ranger Canyon section, at Castle Mountain, the Eldon has a thickness of 1,905 feet (580.6 m.) and at Mt. Bosworth, 28 miles (45.1 km.) northwest, 2,728 feet (831.5 m.).

deposited in the Trough as they now occur, after being faulted, upturned, and undulated by compression, extends from the western side of Whiterabbit Creek at 52° north latitude, west-southwest, over the ridge east of Siffleur River (*D* on map) and along the north side of Mt. Sedgwick, Mt. Murchison, Mt. Sarbach, and Mt. Forbes to Mons Peak on the Continental Divide west of Glacier Lake (*B* on map), a distance of about 35 miles (56.3 km.). It is quite probable that it should be continued still farther to the west to the pre-Cambrian in the area at the head of Bush River on the western side of the Continental Divide. Unfortunately we have no knowledge of the formations there; they may be displaced by faults with possibly one or more troughs indicated, as in the Bow-Kicking Horse section, where the formations of the Goodsir and Beaverfoot Troughs occur between the Continental Divide and the Proterozoic Beltian formations.

Glacier Lake Trough was of long duration. It was in existence in middle Lower Cambrian time, and continued to receive deposits until the close of the Sarbach Ordovician (Canadian) formation, and possibly in Silurian and Devonian time.

The continuity of deposition seems to have been largely uninterrupted except in Middle Cambrian time, when the calcareous sediments that formed the Eldon limestone, 2,728 feet (831.5 m.) thick in the Bow Trough, 40 miles (64.4 km.) to the south-southeast, were not deposited; at least they have not been observed at any of the outcrops where the Arctomys and Stephen are in contact. There were also some minor interruptions, and certainly one great one (Mons), occasioned presumably by a diminution of the supply of sediment or a temporary raising of the level of the bottom of the trough.

The sediments deposited may be summarized as follows:

Calcareous shales and limestones .....6,668 feet (2,032.4 m.)
Arenaceous and siliceous sandstones and shales.....2,911 feet (887.3 m.)

On the eastern side the northwesterly extensions of the Bow and Sawback Troughs were in open communication with the sea of the Glacier Lake Trough except during Middle Cambrian Eldon time, with possibly a few minor interruptions.

On the western side, the Beaverfoot Trough presumably had an open seaway to the Glacier Lake Trough, for the faunas of the Upper Cambrian Sabine formation and the large faunas of the Ozarkian Mons formation are essentially of the same type in the Stanford Range (*N* on map) and the Glacier Lake section (*B* on map). The fauna of the Ordovician (Canadian) Sarbach formation is of the

same type in the Beaverfoot, Glacier Lake, and Sawback Troughs, but the Glenogle graptolite fauna of the Beaverfoot Trough has not been found in the Glacier Lake Trough, although there is a strong probability that it may be present in the region west of Mons Peak in the area of the upper Bush River drainage basin.

We know little of the Glacier Lake Trough northwest of Glacier Lake, except that it extended 24 miles (38.6 km.) as far as Wilcox Pass at the head of the North Saskatchewan River, and had open communication to Robson Peak District more than 96 miles (154.5 km.) northwest of Wilcox Pass.

ROBSON TROUGH

The typical section of this trough in the Robson District is 174 miles (279.9 km.) north-northwest of the Bow Valley, where the great formations of the Bow Trough are so finely exposed to view, and 120 miles (193.1 km.) north-northwest of the section of the Glacier Lake Trough. It is now bounded on the southwest by Proterozoic Beltian sandstones and shales of the ridges of Little Grizzly and Whitehorn Peaks of the Selwyn Range, and on the northeast by the great Moose Pass fault between the Lower and Upper Cambrian formations that extends from Moose Pass south-southeast down the canyon of Moose River and north-northwest towards and into the high broken ridge northeast of the Smoky River Canyon. At Moose Pass the Lower Cambrian is thrust over the Upper Cambrian limestones, and from their character I am inclined to think that these Upper Cambrian and presumably later formations were deposited in a trough that began to form in early Upper Cambrian time east of the Robson Trough after deposition of sediments in the Robson Trough seaway had ceased.

The Robson Trough as now interpreted, after being narrowed by compression and faulting, has a width of 14 miles (22.5 km.) on a line extending from Moose Pass southwest to Little Grizzly Peak above Lake Kinney. If the Upper Cambrian and other pre-Devonian formations north-northeast of Moose River were included in the Robson Trough and not in a trough adjoining it on the northeast, the width of the Robson Trough as now outlined would be correspondingly increased to 22 miles (35.4 km.) or perhaps 24 miles (38.6 km.).

The known Paleozoic deposits of the Robson Trough have a thickness of 13,300 feet (4,053.8 m.) exclusive of any that may have been deposited east of the Moose Pass fault. These include Ordovician ?,

Ozarkian, Upper and Middle Cambrian limestones and Lower Cambrian sandstones, arenaceous and siliceous shales.

Limestones	9,400 feet (2,865.1 m.)
Sandstones and shales	3,900 feet (1,188.7 m.)

The formations of the Robson Trough are of the general character of those of the Glacier Lake and Bow Troughs. They differ in details and contained faunas, but there is sufficient similarity to lead to the conclusion that they were deposited in connecting troughs of the Cordilleran Geosyncline and possibly in a more or less continuous trough that extended from north of the Robson District to south of the Bow Valley.

It is to be regretted that we do not have a section of the pre-Devonian formations east of the Moose Pass fault, as it is possible that not only a great thickness of Upper Cambrian strata is present, but also Ozarkian, Ordovician, and possibly Silurian. The Silurian occurs to the north in Alaska and to the south in the Beaverfoot-Brisco-Stanford Range of British Columbia, and the Devonian in the ridges east of the Upper Cambrian and northeast of Henry House.

It is to be noted that in the Robson and Glacier Lake Districts the known Upper Cambrian rocks are east of the Continental Divide and in the Bow-Kicking Horse area they are west of the divide.