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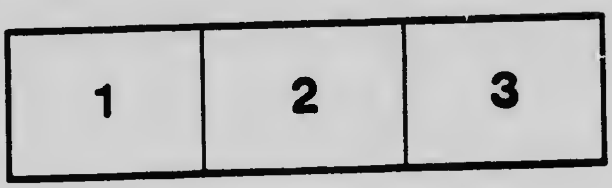

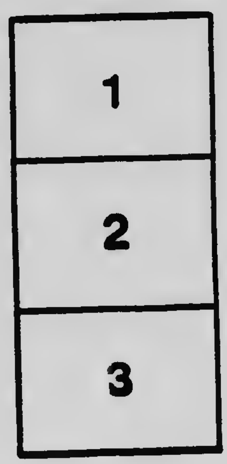

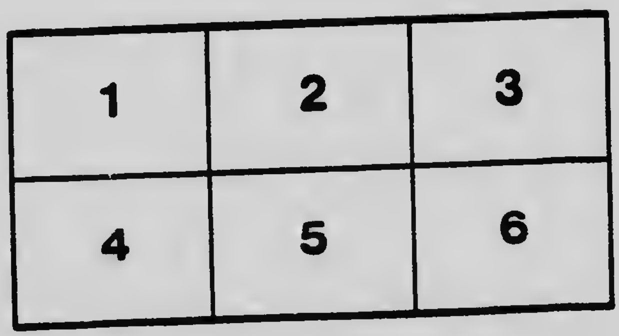

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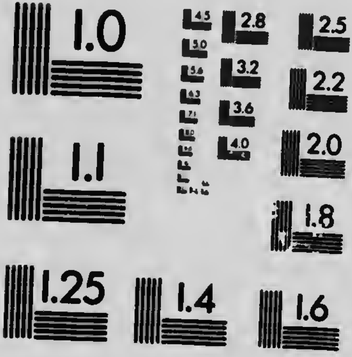

CANADA

DEPARTMENT OF MINES

HON. MARTIN BURRELL, MINISTER; R. G. McCONNELL, DEPUTY MINISTER.

GEOLOGICAL SURVEY

WILLIAM McINNES, DIRECTING GEOLOGIST.

MEMOIR 112

No. 93, GEOLOGICAL SERIES

Geology of the Disturbed Belt of Southwestern Alberta

BY

J. S. Stewart

OTTAWA
J. DE LABROQUERIE TACHÉ
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1919

No. 1740

Plate I.

Waterfall on Crowsnest river, near Lundbreck. The falls are due to the resistance to erosion of the Belly River sandstone, which is locally horizontal. (Page 12.)

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Geology of the Disturbed Belt of Southwestern Alberta.

CHAPTER I.

GENERAL SUMMARY.

The folded and faulted belt of southwestern Alberta is a strip from 12 to 25 miles wide situated at the eastern base of the Rocky mountains. The part of it with which this report deals extends for about 100 miles in a northwest direction from the International Boundary and includes an area of about 2,000 square miles. A description of the stratigraphy and structure of this region forms the principal part of this report. The rocks of the area are all of sedimentary origin, and are in the main a long and almost complete sequence of Cretaceous deposits. They have been separated into eight formations, one of Lower Cretaceous age, five of Upper Cretaceous, and two of questionable Tertiary age. The division is made primarily on the basis of the contained fossils, and secondarily on the lithological character. All of the strata were laid down prior to the time of the great Laramide Revolution, and they now exhibit an intensely folded and faulted structure. The surface boundaries of the formations are mapped. The map (No. 1712) is accompanied by structure sections across the area, to illustrate the nature and degree of folding and faulting.

GENERAL STATEMENT AND ACKNOWLEDGMENTS.

The disturbed belt is a narrow strip of foothill country lying between the Rocky mountains and the Great Plains.

The field work on which the present report is based was done during the summers of 1914 and 1915. Active assistance in the field was rendered during 1914 by A. E. Cameron and L. W. Gould, and in 1915 by S. A. Childerhose.

The writer wishes to express his thanks to Dr. T. W. Stanton of the United States Geological Survey for permission to use for study and comparison the palæontological collections under his charge in the United States National Museum, and keenly appreciates his criticism and assistance in the identification of fossils. For many suggestions and criticisms incorporated in the following pages the writer acknowledges his indebtedness to Professor Joseph Barrell and Professor Charles Schuchert of the Geological Department of Yale university.

PREVIOUS WORK.

The earliest explorations in this region which included geological investigations were made by Dr. Hector and Captain Blakiston of the Palisser expedition, in the years 1857 to 1860.

In 1874 G. M. Dawson examined the extreme southern part of the area as geologist to H. M. North American Boundary Commission.

In 1881–82–83 the general region was explored geologically by Dr. Dawson and R. G. McConnell. In 1894 Dr. Dawson and Mr. McConnell again visited the region and made a study of the glaciation.

In 1902 W. W. Leach included part of the area in his geological map of the Blairmore coal area.

Areas directly adjoining, with similar stratigraphy and structure, were examined and mapped in recent years by Mr. Leach, J. D. Mackenzie, and S. E. Slipper; and during the field seasons of 1914 and 1915, F. H. McLearn made collections of fossils and examined several sections. The mountains immediately to the west, in the vicinity of the International Boundary, have been investigated by R. A. Daly.

F. H. H. Calhoun, in the course of his examination of the Montana lobe of the Keewatin ice-sheet, during the field seasons of 1901–1903, extended his work into the adjoining region on the Canadian side of the 49th parallel.

In 1911 Mr. W. C. Alden of the United States Geological Survey made a study of the glaciation in the region of Glacier National park, and extended his work across the International Boundary at a few points. In 1912, Mr. Alden and Mr. Eugene Stebinger made a further study of the glacial geology of Montana in the vicinity of Glacier National park, and their investigations led them over a considerable part of southwestern Alberta.

D. B. Dowling, of the Geological Survey, Canada, has covered practically the entire foothill belt, and is the author of several papers dealing with its geology.

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CHAPTER II.

GENERAL CHARACTER OF THE DISTRICT.

LOCATION AND MEANS OF COMMUNICATION.

The belt dealt with in this report extends in a northwest direction from the International Boundary for about 100 miles along the foot of the Rocky mountains. At the southern end it lies east of west longitude 114 degrees and at the north extends on both sides of this meridian.

The region is crossed in an east-west direction by the Crows Nest branch of the Canadian Pacific railway. The Cardston branch of the same railway system provides access to the southeastern part, and the Calgary Macleod branch reaches the northeast part from the towns of Claresholm, Nanton, or High River.

The Crows Nest line was built in 1897-1898 and provided direct communication with eastern Canada, southern British Columbia, and the United States.

The branch railway from Lethbridge to Cardston was built as far as Spring Coulee in 1900-1901; some time later a narrow-gauge line (3-foot gauge) was built from Spring Coulee to Cardston and was reconstructed as a standard-gauge line in 1905.

The Calgary Macleod line was opened for traffic in 1902 and provides connexion with Edmonton and northern Alberta and with the main line of the Canadian Pacific railway at Calgary.

From the railway lines, wagon roads or trails ramify into practically every part of the area. With the settling of the country and the gradual increase in grain-growing, the ranches are being fenced and travel is now confined to the road allowances, which in places become deeply cut up during wet weather.

TOPOGRAPHY.

RELIEF.

The area at its lowest altitudes stands about 3,500 feet above sea-level. The higher ridges attain elevations of 6,000 feet and over in a few places, and some of the mountains which border the west rise abruptly to altitudes of 8,000 feet. The southern part of the area looks like a great embayment of the plains, and, with the exception of a small strip close to the mountains, has a relief of 150 to 400 feet. The northern part, which may be conveniently divided into an eastern or Porcupine Hills section and a western or Foothills belt, has a relief of 800 to 1,500 feet.

DRAINAGE.

The region is well drained by numerous swift-flowing streams which rise in the mountains and flow to Hudson bay by way of the South Saskatchewan. Most of them are tributary to Belly river, though a few in the north reach the Bow through Highwood river.

St. Mary River Basin.

St. Mary river, an important tributary of Belly river, heads in northern Montana on the eastern slope of the Rocky mountains. Starting from Blackfeet glacier, it receives numerous affluents from several smaller glaciers. These streams unite within a short distance of their source, and flow into Upper St. Mary lake and thence into Lower St. Mary lake. The river flows from this lake at an elevation of 4,460 feet above mean sea-level, and takes a northerly course through the foothills to the International Boundary. From the boundary it flows northeast through a rolling country, finally emptying into Belly river near Lethbridge. The upper part of the basin receives a fairly large precipitation, mostly in the form of snow, and is forested; but the lower and larger part has a small precipitation and is totally devoid of trees. The Alberta Railway and Irrigation Company has water rights on this river in Canada and has constructed over 230 miles of ditches to irrigate land surrounding Lethbridge. The head-gates of the canal are at Kimball, 5 miles north of the boundary. The discharge at Kimball varies from about 130 cubic feet per second in December to 4,000 cubic feet in May and June. The drainage area of St. Mary river at Kimball is 472 square miles. The total discharge at Kimball for 1913 was 29·759 inches on the drainage area, or 749,112 acre feet.[1]

Belly River Basin.

Belly river rises near Chief mountain in northern Montana. The main stream is augmented on the United States side of the boundary line by Middle Fork, and on the Canadian side by North Fork. The upper tributaries drain a forested region, but the main stream flows through a deep valley with many bluffs of cottonwood on its banks. There is an abundant snowfall in the upper portion of the basin, the precipitation diminishing considerably on the lower courses of the stream. Freshets caused by melting snow and heavy rains are frequent in summer. The flow is usually greatest in June or July, and afterwards gradually decreases until it reaches a minimum in January or February. The drainage area of Belly river at Stand Off is 461 square miles. The total discharge for the year 1913 was 11·48 inches on the drainage area, or 282,412 acre feet.[1]

Waterton River Basin.

Waterton river rises in northwestern Montana, on the east slope of the Rockies. It flows in a northerly direction, passing through a chain of lakes known as Waterton lakes. There is a large snowfall in the upper part of the basin and the melting of the snow, combined with heavy rains, often causes floods on the river in early summer. The volume of water steadily decreases through the summer and autumn and is smallest about midwinter. The drainage area of Waterton river at Waterton mills equals 214 square miles. The total discharge for the year 1913 was 45·52 inches on the drainage area, or 516,419 acre feet.[1]

[1]Rept. of progress of stream measurements, 1911-1913. Dept. of the Interior, Can.

Oldman River Basin.

Oldman river is formed on the west side of Livingstone range by the junction of four large creeks. From the gap cut in the mountain range it flows in a general southeastward direction to about Cowley, where it is joined by the Crowsnest and Castle (South Fork) rivers. The river has a steep grade with consequent swift water interspersed with falls and rapids (Plate I). The river bed is of rock and gravel, but changes to quicksand and mud in the prairie region, where the current is more sluggish.

The following is a tabulation of some of the discharge data:

Table of Discharge Data.

Stream	Drainage area, square miles	Location of station	Run-off for 1913 in inches on drainage area
Pincher creek	53	Pincher Creek village	10·82+water used by town
Mill creek	66	SW. ¼ sec. 18, tp. 6, range 1	15·05
Canyon creek	27	NE. ¼ sec. 14, tp. 6, range 2	5·50
Castle river	374	SW. ¼ sec. 2, tp. 7, range 1	24·04
Crowsnest river	263	Lundbreck	13·63
Oldman river	820	NE. ¼ sec. 34, tp. 7, range 1, near Cowley	9·23

CLIMATE.

The accompanying tables of mean temperatures, rainfall, and snowfall have been compiled from data supplied by the Director of the Meteorological Service, Toronto.

Temperature Records, Pincher Creek.

Approximate altitude, 3,750 feet.

—	Average temperature 1893-1898 1900-1913	1915			
		Mean	Highest	Lowest	Mean daily range
January	17·5	24·2	46	−18·0	16·6
February	13·7	26·8	46	1·0	16·2
March	26·2	33·5	66	− 3·0	19·4
April	40·5	47·1	74	28·0	23·0
May	48·2	47·8	70	33·0	16·4
June	54·8	51·7	73	33·0	18·4
July	60·7	58·0	80	37·0	20·0
August	59·3	64·0	83	46·0	24·0
September	51·3	47·0	74	16·0	22·0
October	43·8	46·0	69	20·0	20·0
November	28·0		Not available		
December	26·3		Not available		

Monthly Precipitation in Inches.

Pekisko.

1914	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total for year
Rain	0·00	0·00	0·00	0·92	2·96	4·43	2·07	2·92	1·29	0·49	0·09	0·00	15·17
Snow	9·1	8·0	11·7	7·6	3·1	.....	.....	trace	5·7	8·7	17·7	4·7	76·3
1915													
[1]Precipitation	1·33	1·35	1·28	1·47	8·92	10·02	4·07	1·88	3·40	1·73			

Nov. and Dec., 1915, not reported nor available.

[1]In a few cases the distinction between snow and rain is not made; 10 inches of snow being considered equal to 1 inch of rain.

Lyndon.

—	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total for year
1911—Rain	0·00	0·00	0·00	0·00	0·53	1·16	0·24	6·29	5·77	0·26	0·56	0·00	14·98
—Snow	10·70	14·10	5·50	16·50	0·00	0·00	0·00	0·00	0·00	3·50	8·50	5·60	64·20
1912—Rain	0·00	0·00	0·00	0·87	1·30	2·81	7·73	2·00	2·12	2·45	0·00	0·00	19·28
Snow	12·45	4·70	9·10	2·20	.....	.....	.....	.....	.....	2·10	10·20	5·10	45·90
1913—Rain	0·00	0·00	0·00	0·80	1·36	6·08	3·53	3·06	0·96	0·21	0·00	0·00	16·00
Snow	13·90	15·50	14·30	1·40	.....	.....	.....	.....	.....	13·00	7·60	5·20	70·90
1914—Rain	0·00	0·00	0·06	2·50	0·80	3·76	0·40	2·81	1·32	0·73	0·00	0·00	12·38
Snow	12·00	9·00	13·50	0·00	.....	.....	.....	.....	.....	22·50	24·40	6·00	87·40
1915—Rain	0·00	0·00	.....	.....	6·21	11·70	4·33	0·71	2·46	.....	.....	.....	.....
Snow	5·2	5·3	.....	.....	.....	.....	.....	.....	.....	6·0	.....	.....	.....

March, April, November, and December, 1915, not reported nor available.

Maycroft.

—	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total for year.
1911—Rain	0·00	0·00	0·25	0·15	2·68	1·42	1·61	4·08	2·41	0·15	0·02	0·00	12·72
Snow	25·5	13·5	2·0	11·0	8·2	.....	.....	.....	7·0	3·0	19·0	7·2	96·4
1912—Rain	0·00	0·00	0·00	1·21	1·10	2·95	4·44	0·99	1·08	0·61	0·51	0·00	12·89
Snow	7·3	6·0	4·8	0·0	.....	.....	.....	.....	2·7	12·7	15·7	4·6	53·8
1913—Rain	0·00	0·09	0·00	0·27	1·90	2·65	2·13	2·82	0·66	0·19	0·41	0·00	11·02
Snow	19·3	5·4	13·2	3·2	3·3	.....	.....	.....	0·0	5·7	9·1	1·7	60·9
1914—Rain	0·26	0·02	0·13	1·62	1·21	2·85	0·81	2·94	1·65	0·54	0·04	0·00	12·07
Snow	12·0	4·3	23·2	.....	.....	.....	.....	.....	0·0	17·2	22·7	6·8	86·2
1915—Rain	0·00	0·00	0·00	0·95	4·14	6·32	3·75	2·60	1·90	1·33	.....	.....	.....
Snow	0·91	10·9	0·74	0·5	.....	.....	.....	.....	.....	3·6	.....	.....	.....

November and December, 1915, not reported nor available.

Monthly Precipitation in Inches. (Concluded.)

Lundbreck.

1915	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total for year.
Total precipitation........	......	0·73	1·43	0·87	5·12	6·83	4·54	1·32	1·50	1·58	......	....	....

Pincher Creek.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total for year.
Aug., 1898–Dec., 1914.													
Average rainfall.	0·00	0·00	0·11	0·51	3·20	3·02	2·71	2·01	1·67	1·10	0·07	0·01	14·41
Average snowfall	7·1	8·8	8·1	9·8	4·2	.....	.....	.....	1·4	1·7	8·4	3·4	52·9
Average precipitation.........	0·71	0·88	0·92	1·49	3·62	3·02	2·71	2·01	1·81	1·27	0·91	0·35	19·70
1915													
Total precipitation..........	1·03	1·73	1·24	1·80	3·37	7·68	4·01	1·24	2·31	1·60	0·33	1·2	27·54

Caldwell.

—	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total for year.
1915—Rain......	0·00	0·00	0·7	1·70	3·70	7·36	.....	4·19	2·10	0·99	0·00	0·00	
Snow......	14·5	8·5	3·0	.....	.....	.....	.....	.....	1·0	8·0	0·00	14·5	

July not reported.

Mountain View.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total for year.
1915—Rain......	0·00	0·00	0·00	1·84	3·01	10·87	5·15	0·45	3·46	0·79	0·00	0·00	25·57
Snow......	0·91	12·0	5·0	1·0	.....	.....	.....	.....	2·0	11·0	4·0	14·0	49·91

Waterton Mills.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total for year.
1915—Rain	0·00	0·00	0·17	2·18	3·92	8·89	7·40	1·78	4·14	2·71	0·63	0·71	32·53
Snow	20·00	17·5	17·0	1·5	.....	.....	.....	.....	2·0	10·5	16·0	26·5	111·0

AGRICULTURE.

The region was first given up to large stock ranches, for which it was well suited, as cattle and horses could rustle a good living on the ranges during the entire winter. In recent years, however, a number of homesteaders have settled in the district and the fencing in of the homesteads has considerably diminished the open range, so that stock ranching is being displaced by mixed stock and grain farming. In the southern half of the area, which is plains-like and has a deep, boulder-clay soil, wheat, oats, and hay grow to perfection. In the northern section, which is higher and more rugged, stock ranching is the main occupation, but practically everywhere the ranchers are able to grow enough potatoes and vegetables for their own use.

FLORA.

Although no part of the area rises above timber-line, it contains only two sections of forest that are worthy of mention; these are: (1) the Porcupine hills, and (2) an area adjacent to Glacier National park, Montana, which has recently been made part of the Waterton Lakes park—a forest and game reserve. The principal trees in the area are: Engelmann spruce, white spruce, douglas fir, lodgepole pine, balsam poplar, and cottonwood.

The Engelmann spruce, one of the chief timber trees, is found on northern exposures and along river bottoms. It grows to a height of 130 feet and attains a maximum diameter of 42 inches.

Douglas fir grows mostly in small groves on southern exposures and only on the lower slopes. Some of the trees have diameters of 30 inches and rise to heights of 90 feet.

Lodgepole pine, found mostly on northern exposures, rarely exceeds 18 inches in diameter and 85 feet in height; in close stands it grows very tall and straight.

Balsam poplar and cottonwood are mostly small in size; they are found principally along the river bottoms.

The following excerpt relating to the height of the timber-line is from a report by T. W. Dwight, of the Forestry Branch, Department of the Interior.[1]

"The influence of altitude on the tree growth of the east slope of the Rocky mountains is due more to topography, in its effect on the depth and moisture of the soil, than to variations of atmospheric conditions, either of temperature or rainfall, which are usually extremely important factors in tree distribution in mountainous regions. The latter factors here limit the range only of minor species. The two main species, spruce and pine, may commonly be found occurring at any position between timber-line and the bottoms of the lowest valleys. The main valleys even within moderate distances of the continental divide lie between 4,000 and 5,000 feet and the timber-line is usually 7,000 feet high. It is the steepness coupled with exposure to storms that limits the tree growth and if sufficient protection and soil is afforded, practically all of the main species will grow to the highest elevations."

[1]Forest conditions in the Rocky Mountains Forest reserve. Forestry Branch, Dept. of the Interior, Bull. 33.

Besides the two forested sections mentioned, small groves or clumps of trees occur at frequent intervals along the river bottoms. Scattered trees also occur on some of the higher ridges. The rest of the country is open and grassed, even the highest ridges being well covered, many of them to the summit.

FAUNA.

Some of the animals included in the following list are really mountain species, but make frequent excursions into the neighbouring foothill country.

The mountain and forest mammals include: bears, wolves, deer, mountain sheep and goats, cougar, lynx, cotton-tail rabbits, beaver, porcupines, squirrels, and chipmunks. The species most commonly seen in the open country are: gophers, weasels, coyotes, badgers, and jack-rabbits.

The game birds include prairie chickens, grouse, and wild ducks.

Practically all the streams are well stocked with trout and grayling and large pike are taken from lakes close to the mountain front.

CHAPTER III.

PHYSIOGRAPHY.

REGIONAL PHYSIOGRAPHY.

GENERAL FEATURES.

Western Alberta may be broadly separated into four main physiographic divisions, three of which persist in a north-south direction throughout the southern half of the province. To the west lies the Rocky Mountain system, to the east, the plains, and between them lies the foothills, the third persistent physiographic unit. The fourth subdivision, the Porcupine hills, falls almost entirely within the area here described. It occupies a position between the foothills and the plains.

ROCKY MOUNTAINS.

The Lewis range, the most easterly or front range of the Rockies in northern Montana, extends into Canada for about 3 miles. At that distance from the boundary the mountain front turns sharply to the west and runs in that direction for about 6 miles, presenting a steep face to the north. Beyond, the continuity of the mountains is broken by the deep depression occupied by Waterton lakes and Waterton river. To the west of the depression rises the Clarke range which forms the front range in Canada from near the International Boundary to the valley of Castle river. Across this depression the continuity of the mountains of the front range type is broken by a transverse band of Cretaceous rocks about 12 miles wide which forms low mountains of the foothills type. Northward from the valley of Castle river the Livingstone forms the front range to Highwood river in north latitude 50° 25′. The Livingstone range is separated from the mountains to the west by an infold of Mesozoic rocks about 10 miles wide showing foothills topography. The rocks which form the Livingstone range are of Devonian and Carboniferous ages. The rocks composing the Clarke range are Cambrian and Pre-Cambrian in age.

FOOTHILLS.

The foothills form a belt, averaging from 10 to 20 miles in width, bordering the east side of the Rockies for practically their entire length (Plate III B). They form a distinct topographic feature, though they gradually merge into the plains to the east. The mountains generally rise abruptly from the foothills, but in a few places the two are so nearly alike in height that they can be distinguished mainly by the lack of soil and vegetation on the limestones and quartzites forming the front range.

PLAINS.

The plains are a continuation of the Great Plains which extend westward with a gradual ascent from the valley of Red river and lake Winnipeg to the foothills of the Rockies. The western plains are rolling in character and owe their general topographical uniformity to base-levelling supplemented by glacial accumulations.

LOCAL PHYSIOGRAPHY.

All the physiographic units are represented within the area studied; the mountains forming the western boundary of the southern part of the area.

FOOTHILLS.

The strata composing the foothills are intensely folded and faulted, but have a general northwesterly trend. The rocks belong to several sedimentary formations and differ considerably in their resistance to erosion. The general forms resulting from their erosion are a series of long strike ridges with parallel valleys in which small streams flow. The ridges are parallel with the base of the mountains, even following their smaller sinuosities. In a few places they reach altitudes of 6,000 feet, but the general elevation of the higher ridges is 5,200 to 5,600 feet.

Most of the ridges have steep slopes, in places as high as 30 degrees. The steeper slope is usually toward the east, owing to the westerly dips of the rocks. The difference in height of the ridges is due mainly to the relative hardness or resistance of the capping strata and some of the high buttes are clearly synclinal in structure.

The drainage system ramifies into every part of the foothills and has dissected them completely. In a few places glacial debris has interfered with the drainage and caused small ponds to collect. Some of these ponds in the uplands entirely disappear in dry seasons.

The master streams rise in the mountains and flow in a general eastward direction, cutting the ridges and parallel valleys at right angles. These transverse valleys are well developed and generally wide, although they are narrower where they cross ridges of hard rock. The longitudinal valleys, on the other hand, are very regular in width, the divides being sharply defined by the parallel ridges. The streams that drain them are very small and in some cases intermittent in character. Some of these longitudinal valleys are of considerable length and remarkable for their continuity across several divides between main transverse streams (Plate II A and B). The largest streams, for example, Oldman, Crowsnest, and Castle rivers, over much of their courses are entrenched in rock gorges, cut in their old valleys. North of Oldman river, the foothills within this area are drained by small streams only. These creeks, throughout most of their courses, flow over till and reach bedrock only where the stream in its meanders impinges on the side of the old valley, forming a scarp and where, in a few places it has left the old channels and flows through a narrow rock gorge. The valley is so narrow where some of the gorges are located that there is no room for a buried channel and it is probable that at these places it has been over-deepened on the upstream side of the gorge by valley glaciers.

Along Oldman, Crowsnest, Castle, and other large streams, well marked terraces form a conspicuous feature of the valleys. The terraces occur at three different levels on Crowsnest river, and it is thought that there are as many as five on Oldman river. In places they are like a succession of steps rising from the bed of the river on either side, the rise being nearly always abrupt and the tread or flat surface varying in width. The highest terrace on Crowsnest river, at Lundbreck, is about 200 feet above the river-bed. The surface of the terraces is generally covered with glacial gravel or till. The deposit is generally thin, but in a few places the gravels were observed to form a deposit of considerable thickness. Where this occurs, the surficial deposits were noted at one point to project as spurs from the edge of the highest step and are apparently morainal accumulations of the mountain glaciers that overran this region in the Pleistocene time. Wherever the river has cut into the face of the terraces, exposing bedrock, the rock surface is also seen to be flat and as the dips are generally steep it is the edges of the beds that are exposed. The bevelling of these beds which are composed of comparatively resistant sandstones and non-resistant shales, to produce flat surfaces, can mean only that these are terraces of denudation carved in pre-glacial time by the river when its bed lay at relatively higher levels.

PORCUPINE HILLS.

The Porcupine hills proper extend in a continuous upland about 20 miles wide from Oldman river northward to Highwood river, a distance of about 60 miles. The western boundary is marked by a longitudinal valley which forms also the eastern boundary of the intensely folded strata of the foothills.

The hills near the southern end of the range rise about 2,000 feet above the plains and about 1,500 feet above the valley stretching along their western base and attain elevations of 6,000 feet at a few points.

The rocks underlying the Porcupine hills are the youngest in the region and consist of a series of sandstones and sandy shales in alternating hard and soft bands. The hills mark the axis of a wide synclinal, the beds at the western edge dipping east at angles of from 10 to 15 degrees and gradually flattening out until the strata lie horizontally or dip only a few feet per mile.

McConnell,[1] who examined the region in 1882, describes the hills in part as follows:

"The surface of the hills is very rough and is generally cut up by the deep and wide valleys of numerous small streams. The great valleys, which even the most insignificant of these streams have excavated, give evidence of an erosive activity at one time, far exceeding anything which is now going on. The grassy slopes which nearly all the valleys present at the present day show how small the denudation in progress is.

"The principal drainage of the hills is to the east and south in consequence of the difference of elevation of the country east and west of them, which amounts to over 450 feet. Viewed broadly their surface is composed of the broken remnants of a wide plateau with an eastward inclination.

"The lower slopes of the hills are open grassed land. At a somewhat greater elevation scattered trees begin to occur, but it is only on some of the higher western points that any areas of continuous woodland occur."

In the part of the Porcupine hills hurriedly examined by the writer, several flat-topped areas of small extent were noticed at different elevations. In every case looked into, the flat surface was formed by the outcrop of practically horizontal bands of sandstone. Neither here nor in the foothills does there appear to be any accordance of summit levels, and if a base-levelled surface ever existed at the higher elevations it would appear to have been entirely destroyed.

[1]Geol. Surv., Can., Rept. of Prog., 1882-83-84, p. 10 C.

ROLLING PLAINS.

The part of the area here designated rolling plains was included by Dawson with the foothills, and structurally the two are alike. Dawson,[1] however, mentions that "for twenty-four miles northwestward along the base of the mountains from the 49th parallel, the foothills are comparatively low." There are practically no foothills fronting the mountains in the southern part of the area, and the greatest obstacle to travelling in a direct course across country is deep valleys rather than high ridges. There is a stretch of upland, however, extending along the International Boundary from Waterton lakes eastward to the headwaters of Lee creek. The rest of the disturbed belt running north for about 25 miles from the boundary exhibits in a broad way an unbroken slope extending from the plains to the base of the mountains.

Two flat-topped, mesa-like remnants of the upland surface reach an altitude of 6,000 feet. One of these lies close to the east bank of Belly river and is parallel with it, extending about 6 miles north from the boundary. The other occurs between Belly river and lower Waterton lake, close to the mountain front. These remnants have been correlated by Willis with his Blackfoot peneplain and the gravels capping them he has correlated with the Kennedy gravels.[2]

The upland forested area forming the headwaters of Lee creek is covered by the terminal moraine of the Keewatin continental ice-sheet. Farther east along the International Boundary, to St. Mary river, the country is broken by low, scarp-like rock ridges. This whole southern part of the area is heavily covered with glacial drift which masks the preglacial topography. Many shallow ponds and small lakes, without outlets, dot the surface of the flatter parts of the interstream spaces. Instead of a regular series of rock ridges running parallel to the mountains as in the foothills there are spurs running off from the base of the mountains at right angles. These spurs evidently represent the lateral moraines of valley glaciers issuing from small valleys in the mountain front.

VALLEYS.

The rolling plains are drained by Waterton, Belly, and St. Mary rivers and their tributaries. These streams rise in the mountains and are consequent on the general northeastward slope of the plains. During the glacial epoch glaciers issuing from the mountains filled the valleys and deployed on the plain to the east. As a result of the deposition of drift by these mountain glaciers there were minor changes in drainage. The changes effected by the Keewatin ice-sheet were more marked; the rivers were dammed by ice and drift and extensive lakes were formed in the river basins west of the ice. After the retreat of the ice-sheet the valleys were almost completely filled with drift and the streams overflowing and cutting through the morainic dam, were superimposed upon the drift, perhaps at some distance from their old beds. In most cases the displacement of the stream channel was not great, the post-glacial streams generally occupying the old valley though not the old channel. On the other hand,

[1]Idem, p. 11 C.
[2]Willis, B., Bull. Geol. Soc. Am., vol. 13, p. 329.

small valleys that were tributary to the main courses were probably in many cases completely filled and after the retreat of the ice the change in topography forced the drainage to follow new courses.

Waterton River.

Waterton lake, the source of Waterton river, has an altitude of about 4,200 feet at the International Boundary. The river from its source to its confluence with Belly river has an average fall of about 25 feet per mile. For the first 18 miles of its course, Waterton river flows in a valley deeply filled with glacial deposits, and bedrock is exposed at only a few places where the current is directed against the side of the old valley. Farther down stream the river is confined to a rock gorge and continues in this kind of channel beyond the boundary of the area.

Belly River.

Belly river crosses the International Boundary at an elevation of about 4,650 feet and for the next 50 miles of its course has a fall of about 30 feet a mile. Near the boundary the stream flows in a wide, flat-bottomed valley of typical U-shaped, glacial form. In this part of its course the river is held up in ponds for considerable stretches and the bottom lands are wet and boggy. About 8 miles north of the boundary the river enters a rock gorge, and beyond swings from side to side across the old valley. Stretches of post-glacial rock gorge alternate with drift-filled sections which expose no bedrock and probably represent the old preglacial channel.

St. Mary River.

St. Mary river crosses the International Boundary at an elevation of about 4,150 feet and falls at the rate of about 25 feet a mile along the part of its course within the area studied. The channel is cut deeply below the general surface of the valley. The west bank, though it has many flat, terrace-like stretches, is generally hilly. The east bank shows a plateau-like surface extending to the edge of a gorge with almost vertical walls and in places about 200 feet deep.

Tributary Valleys.

The valley of Lee creek, an important tributary of St. Mary river, is for the most part a deep notch cut in a plateau-like surface, the approaches to the stream being generally very steep. The stream for much of its course is confined to a rock gorge and the difference in width between the top and bottom of the valley is small. In places the stream has been superimposed on low, sandstone ridges in which it has cut water gaps. One of the best examples of these is to be seen about 6 miles above Cardston (Plate III A).

Pine creek, a tributary of Waterton river, heads in the mountain front and follows an almost straight course to the river. On the way it crosses a wide, flat-bottomed valley running parallel to the mountain front and filled with gravel and boulders. In the valley the stream sinks beneath the surface of the gravel for a short distance and is lost. It emerges by several outlets and flows through a valley which gradually narrows until about 1½ miles from its junction with the river, the creek enters a gorge in sandstone, 200 feet deep, and joins the river at grade. This is one of the best examples of post-glacial gorge-cutting in the area. The natural course for the headwaters of this creek to follow would appear to have been either south to Cottonwood creek or north to Yarrow creek, but these avenues of escape were blocked by morainic material projecting from the mountain front.

Drywood river is the largest tributary of the Waterton. The valley appears to have been partly filled with glacial material and the bottom is consequently wide. For much of its course the stream appears to follow its old channel and has not yet cut through the deep filling of gravel and boulders.

SUMMARY.

The rolling plains province differs from both Porcupine hills and the foothills in the stage to which erosion processes have reduced it and differs from the Porcupine hills in structure also, the rocks and structure being similar to those of the foothills.

The rock gorges show that the strata are bevelled independent of structure and hardness. This bevelled surface extends back from the rivers as a wide terrace. The interfluves are in general low and rounded. There may be more than one bevelled surface or erosion terrace, but the highest and most widely developed is about 1,000 to 1,200 feet below the remnants representing the Blackfoot peneplain.

The statement that the rivers follow their old pre-glacial valleys is strictly true of their upper courses only. It is true in a general way for the lower courses if we include as part of the valley the wide, terrace-like plains which in places extend back with very gentle slope almost to the stream divide. The greater denudation of the western part of the Great Plains was due to greater initial uplift.

SUPERFICIAL DEPOSITS AND GLACIATION.

GENERAL STATEMENT.

Glaciation was general over this entire region and was of two main types, mountain and continental. A comprehensive study of the glaciation should include all of southwestern Alberta and the adjacent part of Montana. The glacial deposits were not studied by the writer so that what follows is mainly a summary of the literature on this phase of the geology.

MOUNTAIN GLACIATION.

The drift left by the mountain glaciers belongs to two different stages, and may be divided into Wisconsin and pre-Wisconsin respectively.

Pre-Wisconsin Stage.

The earliest drift deposited by the mountain glaciers was described by Dawson and McConnell,[1] and given the name Albertan; but as admitted

[1] Dawson, G. M., Bull. Geol. Soc. Am., vol. 7, pp. 31-66.

in the original paper, all the deposits correlated and included under this name may not be contemporaneous. In Montana, however, the earliest drift has been definitely isolated from similar material deposited at a later date, and this pre-Wisconsin drift has been traced into Canada. It may, therefore, be opportune to describe this first.

Distribution. In the region of Glacier National park, Montana, the earliest record of mountain glaciation occurs on several high, flat-topped ridges of Cretaceous rocks. These are capped by deposits of glacial drift, which, because of its topographic relations and surficial modification, is regarded as much older than the drift in the intervening valleys. It was described by Willis[1] under the name Kennedy gravels (Pleistocene?), and later shown by Alden[2] to be glacial. The drift in the valleys is regarded as being practically coincident with the Wisconsin stage of continental glaciation, hence the name pre-Wisconsin for the older drift. The original extent of this older drift is not known, but outliers of it are found 30 to 40 miles from the mountain front. It has been recognized only on the remnants of the Blackfoot peneplain. In these places the areal and topographic relations are such as to render the differentiation unquestionable. In Canada these remnants are confined to the vicinity of the International Boundary.

"Farther north........the high-level tracts were probably largely cut away, even at the time of the early glaciation, and they have now wholly disappeared. This being the case, it is to be expected that with increasing distance northward from the boundary line the ratio of lowland to highland on which this early mountain drift was deposited must have gradually increased."[3]

Character of the Deposits. "Between Belly river on the west and the heads of Lee creek on the east, a high ridge, which may be designated as Belly river ridge, extends northward to a point 5 or 6 miles across the boundary. At the abrupt north end this stands about 1,300 feet above Belly river, or about 5,750 feet above sea-level. This ridge is capped with about 100 feet of glacial drift, which is exposed in several places in scarps left by landslides on the underlying Cretaceous or Tertiary clays and shales. The drift is composed of angular to subangular (and some well rounded) pebbles and boulders up to 5 feet in length, representing the several kinds of rock from the mountains, embedded in a matrix of clay. Glacially scored stones are not abundant, but search resulted in finding numerous well striated pebbles of greenish argillite. In the upper part there are almost no pieces of limestone, though these are plentiful lower down. Evidently such have been removed by solution, and ledges of tillite outcropping 10 to 15 feet below the top of the section show the results of cementation by the calcium carbonate carried down by percolating waters.

"The drift here is of the same character as that found in 1911, 8 to 10 miles farther south on this same ridge, west of Chief mountain, at elevations of 6,000 to 6,300 feet above the sea, and also on Kennedy, Swift Current, Boulder, Saint Mary, and other ridges near the mountain front, with simiiar topographic relations, so that it is evident that there is here another remnant of the pre-Wisconsin glacial drift."[4]

[1]Willis, B., Bull. Geol. Soc. Am., vol. 13, p. 329.
[2]Alden, W. C., Bull. Geol. Soc. Am., vol. 23, pp. 687-708.
[3]Alden, W. C., and E. Stebinger, Idem, vol. 24, p. 577.
[4]Alden and Stebinger, Idem, p. 531.

Correlation. The Saskatchewan gravels described by Dawson and McConnell[1] are thought to represent an early period of glaciation. These are quartzite gravels of mountain derivation found underlying all other glacial deposits in several sections as far east as Medicine Hat and Cypress hills in Canada, and are thought to be derived from a western drift. The interpretation and age of these Saskatchewan gravels is questioned by Alden and Stebinger,[2] who extended their study of the glaciation into southern Alberta. Their remarks are as follows:

"The 'quartzite gravels' in southern Alberta are largely concentrated along what appear to be pre-Wisconsin drainage lines. So far as we have seen them, these gravels are not exposed continuously for any considerable distance in the bluffs along the present courses of the streams unless it be at Lethbridge, nor even in numerous consecutive, interrupted sections. It seems rather as though they are exposed only at places where the present streams have cut across older stream channels. Where the gravels appear in one section, neighbouring sections above and below may show no such gravels, even where the stream has cut entirely through the drift deposits and into the underlying Cretaceous and Tertiary shales and sandstones."

"It is quite possible that there is pre-Wisconsin mountain drift in the valley of Oldman river or farther north and that this grades eastward into 'quartzite gravels' such as those underlying the lower boulder clay of the Keewatin ice-sheet at Lethbridge. We did not, however, observe such a relation.

"We are inclined to think that a part at least, if not all, of the so-called 'Saskatchewan' gravel exposed at intervals along the valleys in southwestern Alberta is an interglacial deposit derived by erosion from the pre-Wisconsin drift, which near the boundary line and to the south was originally confined very largely to the high-level plains, but which farther north mantled the slopes and lower surfaces that had been reduced by degradation prior to the early advance of the mountain glaciers."[3]

Wisconsin Stage.

Distribution. The ice spread as valley glaciers into the foothills and extended to the western edge of the plains from the collecting ground on the continental divide. How far east in Alberta this mountain ice travelled is not exactly known, as the mountain drift is overlapped by drift of the continental ice-sheet. Mountain drift is found, however, as far east as the Porcupine hills and to the south of these hills the mountain glaciers probably extended almost to the eastern edge of the disturbed belt. Farther south in Montana, where there has been no overlapping of the continental on the mountain drift, the eastern limit of mountain glaciation varies considerably in the different valleys. The area covered by the mountain glaciers in northern Montana has been mapped by Calhoun.[4] This map shows the maximum eastward extension of these glaciers to have been in the valley of Two Medicine river where the ice reached points 35 to 40 miles from the mountain front.

Character of the Deposits. The deposits directly due to the action of these glaciers consist of morainic material, boulder clay, erratics, and

[1]Dawson, G. M., Idem, vol. 7, pp. 31-66.
[2]Alden and Stebinger, op. cit., p. 562.
[3]Alden and Stebinger, Idem, p. 570.
[4]Calhoun, F. H. H., U. S. Geol. Surv., Prof. Paper No. 50, map, Pl. 1.

outwash gravels. Large erratics were observed near the Livingstone range in the valley of Oldman river. It is probable that besides the above deposits there are stratified sands and silts laid down in lakes due to damming of the streams by moraines, but in Canada these have not been differentiated from similar deposits due to damming of the streams by the continental ice-sheet.

Land Forms. Under this head are included spurs, U-shaped valleys, hanging valleys, and lakes.

Spurs. These are lateral moraines of the valley glaciers and run off from the base of the mountains at right angles. They occur all along the eastern base of the Clarke range.

U-shaped Valleys. Waterton river and Belly river near the mountains are typical U-shaped valleys with wide, flat bottoms that have apparently been overdeepened and then filled with debris. Belly river near the International Boundary shows some ponded stretches, but the bedrock is not seen. Waterton River valley near the mountains is also debris-filled and has a lake outside the mountains which is probably due in part to overdeepening.

Hanging Valleys. The best example of a hanging valley observed by the writer was Cameron falls where Cameron brook empties into Waterton lake. On the upper courses of Belly and Waterton rivers some of the small tributaries join the main stream by a series of small cascades cut in bedrock.

Lakes. Waterton lake, which falls for the most part outside of our area, is the only example of a rock basin seen by the writer. It is typical of the lakes of this class, being elongate and narrow and also walled in by high mountains. Several, small, shallow ponds occur in the foothills and are apparently due to blocking of drainage channels by glacial debris.

Age and Correlation. This last mountain glaciation is referred to the Wisconsin stage because there is no evidence that any considerable interval elapsed between the exposure of the mountain drift on the recession of the fronts of the mountain glaciers, and the deposits of the overlying drift of the continental ice-sheet. The amount of erosion to which the two drift sheets have been subjected is about the same, so far as field study has shown. The northeastern drift which overlaps that from the mountains is generally regarded as belonging to the Wisconsin stage on account of the youthfulness of the morainal topography, and the unmodified character of the drift, hence the reason for referring the underlying mountain drift to the same Wisconsin stage.

CONTINENTAL GLACIATION.

Distribution.

Drift of the Keewatin ice-sheet extends almost to the base of the Clarke range in southwestern Alberta. Farther north the Porcupine hills formed an effectual barrier to the direct westward movement of this ice-sheet, but it apparently reached to the west of the Porcupine hills by a circuitous route, for a few small boulders of crystalline rocks have been observed in the valley of Oldman river. The western limit of eastern erratics was marked on the map accompanying Dawson's report of 1882–1884[1]. Later work by Dawson and McConnell[2] seems to show that

[1]Dawson, G. M., Geol. Surv., Can., Rept. of Prog., 1882-1884, map.
[2]Dawson, G. M., Bull. Geol. Soc. Am., vol. 7, p. 64.

this line nearly corresponds to observed drift of this origin in the boulder clays proper, slightly exceeding this to the south of the Porcupines and falling a little short of it to the north, but that scattered erratics occur in places considerably to the west.

Character of the Drift.

The drift consists of crystalline erratics, pebbles of mountain origin, sedimentary rocks derived from the plains, and a matrix of sand and clay. The crystalline erratics represent a great variety of rocks, but granites and syenites predominate. The mass of the finer material appears to have been derived from the underlying rocks of the immediate vicinity and as a consequence the colour changes from place to place. In general the drift is unstratified and on account of its massive character it frequently weathers in river-cliffs into prismatic and columnar forms.

Land Forms.

With reference to the forms which the Keewatin drift has produced, Dawson[1] says:

"Except in the case of the moraines evidently referable to glaciers of the Rocky mountains . . . . the more obvious evidences of the work of glaciers are particularly absent in this entire region of the foothills and Porcupine hills. The highest and farthest limits of the drift are not marked by moraines, and moraines, kames, and eskers are, with the above exceptions, entirely wanting."

The terminal moraine of the Keewatin ice-sheet was traced into southern Alberta by Calhoun[2], who describes it as follows:

"The terminal moraine of the continental ice-sheet crosses Belly river about 10 miles north of the line. It consists of a sharp ridge, in front of which there is no outwash or valley train. Within the terminal ridge there is a well-defined ground moraine, which, at this point, is 4,163 feet above sea-level. Between the Belly and St. Mary rivers the edge of the drift is in places attentuated. The ice-sheet pushed in from the northeast and surrounded but did not cover an irregular series of foothills which trend in an irregular line between the two rivers. These hills are about 800 feet above St. Mary river. Their tops and slopes for about 400 feet from the summit are covered with quartzite gravels, below which appear the crystalline boulders characteristic of the drift of the Keewatin ice-sheet. Small lakes dot the surface and the topography is hummocky and irregular.

"From the top of one of these hills at the edge of the drift the country covered by the northeastern drift can easily be distinguished from that covered by the mountain drift by the number of its lakes and ponds. To the north many small bodies of water may be seen, while to the south, nearer the mountains, there are but few. The local mountain glaciers were eroding and not depositing, and as a result but few morainal depressions were formed, so that the line of abundant lakes marks approximately the edge of the northeastern drift. The moraine between Belly river and Lee creek shows well developed kettles."

[1]Dawson, G. M., Idem, p. 65.
[2]Calhoun, F. H. H., op. cit., p. 23.

Following closely the base of the mountains and northward to Pincher Creek village, the terminal moraine is marked by sags and swells in the topography with numerous ponds and marshy tracts.

Age and Correlation.

Two distinct drift sheets from the Keewatin centre have been recognized near Lethbridge, Alberta, and also near the Sweet Grass hills in northern Montana.[1] At other points farther west in Alberta two glacial deposits of northeastern origin are suspected to have occurred. The most westerly section which suggests this is described by Alden and Stebinger[2] as occurring on Oldman river near Brocket; another section described by Calhoun[3] occurs on St. Mary river about 2 miles north of the boundary. It is generally believed, however, that it is the uppermost boulder clay of the plains that extends farthest west. It has already been intimated that this upper boulder clay is of Wisconsin age. This correlation is based on the unmodified character of the till and the youthfulness of the morainal topography, which is comparable only to the morainal belt of the Wisconsin drift in the Missouri and Mississippi valleys.

INTERRELATIONS AND SUMMARY.

Dawson's diagrammatic section[4] of the glacial deposits from Lethbridge to the base of the Rocky mountains along the valley of Oldman river is as follows, beginning with the lowermost deposits:

A—(Albertan stage). Western boulder clay passing to the eastward into Saskatchewan gravels.
B—"Lower" boulder clay. (Keewatin glacier.)
C—Interglacial deposits.
D—"Upper" boulder clay. (Keewatin glacier.)
E—Terraces and drift on the Porcupine hills.

The assumption that the same gravels which underlie the lowermost Keewatin drift–B– pass westward into boulder clay, is regarded by Alden and Stebinger[5] as not proved. Their opinion is that the so-called Saskatchewan gravels may be in part preglacial, in part pre-Wisconsin and of the same age as the gravels capping the remnants of the Blackfoot peneplain, and in part interglacial derived from erosion of the latter gravels. The summary of the above writers has already been quoted.

Dawson suggested the correlation of the lower boulder clay–B–with the "Kansan formation." According to Alden and Stebinger:[6]

"The name Kansan was at that time applied to the till-sheet underlying the Aftonian interglacial beds, and this sub-Aftonian till was regarded as the oldest known deposit of the Keewatin glacier. Believing that the drift of the Cordilleran glaciers, which he had correlated with the gravels underlying the lower boulder clay of the continental glacier, was older than this early till of the Keewatin ice-sheet, and should have a distinct name, he proposed the name 'Albertan.'

[1]Alden and Stebinger, op. cit., pp. 571–572.
[2]Alden and Stebinger, Idem, p. 553.
[3]Calhoun, F. H. H., op. cit., p. 49.
[4]Dawson, G. M., op. cit., p. 45.
[5]Alden and Stebinger, op. cit., p. 570.
[6]Alden and Stebinger, Idem, pp. 564–565.

"The name 'Albertan,' thus passed into use tentatively as correlated with the sub-Aftonian of Chamberlin. Such usage was continued until Calhoun concluded as a result of his observations that the drift of the mountain glaciers which is overlapped near the 49th parallel in the valleys of St. Mary and Belly rivers by drift of the Keewatin glacier was of Wisconsin age and that the 'quartzite gravels' on the high-level tracts in the region under discussion were pre-Glacial in age."

According to our present knowledge, the superficial deposits in southwestern Alberta may be differentiated as follows, taking them in the apparent order in which they were laid down:

I. Pre-Wisconsin drift of Rocky Mountain glaciers, mainly quartzite gravels.
II. Interglacial gravels, derived from I.
III. Pre-Wisconsin boulder clay of the Keewatin glacier.
IV. Interglacial stratified beds, sand, clay, and lignite.
V. Drift of the mountain glaciers, Wisconsin stage, coarse gravels, and boulder clay.
VI. Boulder clay of the Keewatin glacier, Wisconsin stage, also stratified sands and silts with included boulders, deposited in lakes due to damming of the mountain streams by the Keewatin glacier.
VII. Recent fluvial deposits.

The thickness of these deposits varies greatly. A section on Belly river near Lethbridge, where the general surface of the country is flat, shows a thickness of over 200 feet composed entirely of glacial deposits.[1] In general the work of the glaciers in the area tended to fill up the depressions in the preglacial topography, so that, if the morainal belts are excepted, the thickest deposits are likely to occur where the preglacial valleys were deepest.

[1]Dawson, G. M., op. cit., p. 40.

CHAPTER IV.

STRATIGRAPHY.

GENERAL STATEMENT.

The rocks within the area described belong to the Mesozoic and Cenozoic eras. They are all sedimentary in origin and are mostly of Lower and Upper Cretaceous age. The different formations follow one another with apparent conformity and indicate continuous deposition. Although as originally laid down these deposits were practically horizontal, the beds are now tilted and folded and in places are almost vertical. This intense folding and faulting, with the lack of persistent and easily recognized lithologic horizons make measurements of the thicknesses of formations extremely difficult.

In the Lewis and Clarke ranges which form the southwestern boundary of the area the rocks are of Pre-Cambrian age and have been brought into their present position by a great thrust fault. The geology of this mountain region in the vicinity of the 49th parallel has been described by Willis[1] and Daly.[2]

[1] Willis, B., Bull. Geol. Soc. Am., pp. 305-352.
[2] Daly, R. A., Geol. Surv., Can., Mem. 38, pt. 1.

Table of Formations.

Geological time		Formations
Quaternary	Recent	Alluvium
	Pleistocene	Glacial drift
Tertiary?	Eocene?	Porcupine Hills Willow Creek St. Mary River Bearpaw Belly River
Upper Cretaceous	Montana group	
	Colorado group	Benton
	Dakota group	Blairmore
Lower Cretaceous[2]		Kootenay

Correlation Table.

System	Series	Teton county, Montana[1]		Equivalent in southwestern Alberta
		Group and formation		
Quaternary	Recent	Alluvium		Alluvium
	Pleistocene	Glacial drift		Glacial drift
Tertiary?	Eocene?	Wanting Willow Creek St. Mary River		Porcupine Hills Willow Creek St. Mary River
Cretaceous	Upper Cretaceous	Montana group	Horsethief sandstone	
			Bearpaw shale	Bearpaw shale
			Two Medicine Virgelle sandstone	Belly River
		Colorado shale		Benton shale
				Blairmore
	Lower Cretaceous	Kootenai		Kootenay

[1]Stebinger, E., U. S. Geol. Surv., Bull. 621-K.

Tabulated Description of Formations Occurring in this Area.

Period	Formation	Thickness in feet. At northwest	Thickness in feet. At southeast	Character of the rocks.	Fossils
Quaternary		0–100	0–200	Glacial gravel, boulder clay.	
Tertiary?	Porcupine Hills	2,500±	Entirely eroded	Sandstones, shaly clays. Continental.	Freshwater molluscs. A few land plants.
	Willow Creek	500±	500±	Clay and soft sandstone, commonly red in colour. Continental.	Freshwater molluscs. A single chelonian.
	St. Mary River	3,000±	1,600±	Irregular-bedded shale, crossbedded and ripple-marked sandstones. Coal at base. Mainly continental.	Freshwater molluscs, land plants, oysters, and other brackish water fossils at base.
Upper Cretaceous	Bearpaw	750±	500±	Dark grey clay-shale with limestone concretions. Marine.	An abundant marine Pierre fauna. Baculites, Placenticeras, Cyprina.
	Belly River	3,000±	1,600±	Light grey sandstone and thick-bedded arenaceous shale, commonly greenish in colour. Coal at top. Mainly continental.	Freshwater molluscs, dinosaur bones, and land plants.
	Benton	2,000±	1,500±	Dark blue-grey shales with limestone concretions. Marine.	Marine molluscs. Inoceramus, Scaphites, and Baculites common.
	Blairmore	2,000±	Not definitely recognized	Conglomerate, sandstone, thick-bedded arenaceous shale. Prevailing colour dark green. Continental.	Unios and land plants. Angiosperms abundant in upper part.
				Erosion interval.	
Lower Cretaceous	Kootenay	600±	Covered by younger formations	Grey sandstone, thin-bedded carbonaceous shale, and coal beds. Continental.	Numerous land plants. Ferns, cycads, and conifers.

KOOTENAY FORMATION.[1]

DISTRIBUTION.

The Kootenay formation occurs along the western border of the area only. There, the upper beds of the formation are found abutting against the younger Benton and Belly River formations, the sequence being broken by a fault with upthrow on the west side. Along this fault-line between Crowsnest river and Pincher creek, the Kootenay, capped by basal beds of the overlying Blairmore formation, rises above the adjacent country to the east, forming a prominent ridge. In this part of its outcrop the formation falls within the areas studied by Leach and Mackenzie (see Bibliography).

[1]Also spelt Kootenai and Kootanie. In the following pages the spelling is varied to conform with that of the author cited, except in the case of quotations from the reports of the Geological Survey, Canada, where the ruling of the Geographic Board is followed.

The Kootenay outcrops on Oldman river also, where about 100 feet of the upper part is exposed. Outside of this area it is distributed over the Rocky Mountain region from Flathead river in southern British Columbia and Castle river, Alberta, northward to beyond the line of the Grand Trunk Pacific railway. Being an important coal-bearing horizon, it has been much searched for and its distribution is fairly well known. The Kootenay occurs chiefly in narrow belts and in small downfolded and downfaulted basins within the mountains. In the foothill region west of the area under consideration the Kootenay is brought to the surface in many places by faults and folds. The best sections are found in the Blairmore area and the lithological description of the rocks is largely based on these sections. In the southern part of the area, east of the Clarke range, the Kootenay nowhere appears at the surface, being buried under younger formations.

LITHOLOGIC CHARACTER AND THICKNESS.

In the Blairmore and Southfork coal areas described, respectively, by Leach and Mackenzie, the Kootenay formation rests conformably on the Fernie shales of later Jurassic age. The passage of the one formation to the other is thought to be transitional in character, and the position of the dividing line between them is somewhat indefinite. The base of the Kootenay is usually placed at the horizon where the arenaceous beds and sandstones become predominant, and these strata consist of a series of thin-bedded sandstones and shales of a dark greenish colour, that are rather friable on weathering. They are followed by alternating bands of shale and sandstone with coal beds and carbonaceous shales. The sandstones become more massive, coarser, and more strongly cemented towards the top of the formation, and many of the shales weather rusty. The coal seams vary in number from place to place. One section at Blairmore shows six seams; the thinnest 3 feet thick and the thickest 17 feet. The total thickness of the formation in the foothills is 600 to 750 feet, with the coal beds confined to the upper 300 feet.

The Kootenay shows extreme variations in thickness within comparatively short distances, throughout its geographic distribution in Canada. In all cases, however, the greatest thicknesses are at the west, the thinnest at the east. The most pronounced eastward thinning is noted in the more southerly basins.

AGE AND CORRELATION.

In the adjacent Blairmore area many fossil plants have been collected from this formation within recent years, but are not yet determined. These consist mainly of ferns, cycads, and conifers, without admixtures of leaves of flowering or angiosperm plants. The identity of the formation is, however, usually easy to establish on account of its characteristic lithology and stratigraphic position.

In 1884 G. M. Dawson made collections in the vicinity of Coal creek and Elk river, southern British Columbia, and also at Canmore and on the North Branch of Oldman river, Alberta. These collections were studied by Sir J. W. Dawson[1] whose conclusions may be summed up as follows: The plants consist of ferns, cycads, and conifers, some of them

[1]Dawson, Sir J. W., Trans. Roy. Soc., Can., 1885, vol. III, sec. 4, pp. 1-22.

identical with or closely allied to those of the Jurassic of the Amur country in northern Siberia and others similarly related to those of the Lower Cretaceous of Greenland described by Heer. Dawson concludes that the plants appear to correspond to the oldest Lower Cretaceous floras known in Europe, Asia, and the Kome formation of central-western Greenland.

Newberry[1] in discussing the flora of the Kootenay in the Great Falls coal field, Montana, correlates this formation with the Potomac of Maryland and places it in the Lower Cretaceous.

Similar plants were collected from the Kootenay by Cairnes[2] in the Moose Mountain district, Alberta, and were examined by Dr. Penhallow.

Fossils were collected from this formation by Malloch[3] in the Bighorn coal basin, Alberta. These consisted of both plants and animals and were examined by Knowlton and Stanton. The faunal remains occur near the middle of the formation and, according to Stanton, "The most surprising thing about them is that they appear to be marine, whereas the Kootenay has always been considered a freshwater formation." From his conclusions it is, therefore, learned that the Kootenay is at least in part of brackish-water origin and laid down along the margin of an overlapping ocean. From the palæontological evidence there is some doubt as to whether part of the formation should be assigned to the bottom of the Lower Cretaceous or the top of the Jurassic.

The most comprehensive discussion of the flora of the Kootenay formation is that given by Berry in his article on the Lower Cretaceous floras of the world. He gives a combined list of the flora and concludes as follows[4]:

"The Kootanie flora of Montana and British Columbia is an extensive one, consisting of 86 nominal species of which at least 20 are present in the Potomac, and several others are closely related to species which occur in the Potomac. Six of these are forms which do not range above the Patuxent-Arundel in the east. No characteristic Patapsco species is known from the Kootanie nor have any dicotyledons been discovered. . . . There are also present a large number of Kome species (Greenland) and several from the Barremian of Europe, so that the Kootanie cannot be considered younger than the Patuxent-Arundel of Maryland and it may be in part slightly older, although the two were at least partly contemporaneous."

BLAIRMORE FORMATION.

The Blairmore formation in the Crowsnest region, has been provisionally described as Dakota. The name Blairmore was given by the late W. W. Leach[5] and was used on his preliminary map of the Blairmore area, although its application was not exactly defined.

The formation consists of a series of sedimentary rocks lying immediately above the Kootenay formation, the basal member being a thick, cherty conglomerate. The top of the series in the area from which the name was derived is formed by the base of the Crowsnest volcanics. Outside

[1]Newberry, J. S., Am. Jour. Sc., vol. XLI, March, 1891, pp. 191-201.
[2]Cairnes, D. D., Geol. Surv., Can., Mem. 61, p. 32.
[3]Malloch, G. S., Geol. Surv., Can., Mem. 9-E, pp. 43-44.
[4]Berry, E. W., Maryland Geol. Surv., volume on the Lower Cretaceous, 1911, pp. 118-121, 162-164.
[5]Leach, W. W., Geol. Surv., Can. Sum. Rept., 1912, p. 234.

this area, which is very small, the top of the Blairmore formation passes into the base of the Colorado marine shale or Benton formation.

The Blairmore includes Dawson's Mill Creek series,[1] but the Mill Creek section is incomplete, the sequence in descending order being broken by a fault at the old Mountain mill.

DISTRIBUTION.

As above defined the Blairmore formation would include all the strata in the Canadian Rockies that has been described as Dakota, and it is found overlying the Kootenay in practically all places where the latter occurs. It seems probable also that the formation is equivalent to part of the Kootenay of northwestern Montana.

The Blairmore formation is found only in the western half of the area here described, where it extends along the eastern edge of the fault blocks. It occurs as ridges between Crowsnest river and Pincher creek, also in the northern part of the area between Willow creek and Pekisko creek. The formation was not recognized in the southern part of the area, but it is quite possible that it may outcrop in the strip that has been represented on the maps as geologically undifferentiated.

LITHOLOGY AND THICKNESS.

The thick, cherty conglomerate forming the basal member of the formation is the best horizon marker in the foothills. It is very persistent and has been used as a guide from Castle river northward to the Bow, a distance of about 120 miles. The conglomerate is made up of well rounded pebbles of black, white, and greenish chert, set in a hard siliceous matrix. The pebbles have been well sorted and are of even size, averaging from 1 to 1½ inches in diameter. The bed averages from 6 to 10 feet in thickness and reaches 30 feet in places. The contact with the underlying Kootenay formation is conformable and in most places the conglomerate grades into sandstone upward and downward and in the eastern part of the Blairmore area, horizontally also. The conglomerate in places is 50 feet above the uppermost coal seam of the underlying Kootenay formation, and in other places it practically forms the roof of the seam.

Complete sections of the Blairmore formation are found in the adjacent Blairmore map-area, where it is composed of greenish grey and brown sandstones interstratified with thick-bedded, sandy shales. Irregular, lenticular beds of conglomerate, some of which are very coarse, are also present, and near the bottom of the formation there is a persistent bed of limestone which carries a small, freshwater snail fauna.

Leach[2] who measured four complete sections in the Blairmore area, found the greatest thickness of the formation to be 2,865 feet and the least, 2,200 feet.

In the area mapped the best sections are exposed on the Crows Nest railway east of Burmis, on Castle river, and on Mill creek. The Mill Creek section shows about 1,000 feet of the upper beds overlain by Benton shale, and may be roughly summarized as follows:

[1]Dawson, G. M., Geol. Surv., Can., Rept. of Prog., 1882-1884, p. 99 C.
[2]Leach, W. W., Geol. Surv., Can., Sum. Rept., 1911, pp. 195-196.

		Feet.
1.	Benton dark marine shales.	
2.	Interstratified, grey sandstone and green, blue-grey, and reddish shales	300
3.	Grey sandstone containing coaly matter and plant fragments, mostly large stems	10
4.	Grey sandstones interstratified with vari-coloured shales, thick-bedded and arenaceous	400
5.	Hard, fine-grained sandstone, weathers brown	100
6.	Light grey sandstone and thick, irregularly-bedded clay shales, some very light grey in colour	200
	Fault contact.	

The section on Castle river, which is about 2 miles north of that on Mill creek, shows about 200 feet more at the base of the formation, very largely thin-bedded sandstones and shales. They are the most evenly-bedded deposits seen in the formation and contain scattered plant remains and what appear to be worm tubes.

The section on Crowsnest river shows an aggregate thickness of 3,000 feet of westerly dipping sandstones and shales that have been referred to the Blairmore formation. A considerable part of this thickness is without doubt due to the duplication of beds by faulting and overturned folding, although the top of the formation with the overlying Benton shales is exposed only once in the section. The exposure is in a railway cutting and shows fully the passage from irregularly-bedded Blairmore shales into regularly-bedded, fissile Benton shales which carry marine fossils. The difficulty experienced in measuring the true thickness lies in the lack of horizon markers, sandstones and shales of similar lithological appearance recurring throughout.

The shales of the Blairmore formation occur in beds about a foot thick which weather to a crumbly mass. They show a variety of colours including red and brown, which in some cases are only surface stains, but greenish shades predominate. The shales are usually arenaceous, but in places are quite calcareous. Many of the calcareous beds are concretionary in structure.

The sandstone beds vary in thickness from 1 foot to 10 feet and in many cases show minute crossbedding. In colour they are greenish grey, weathering in places to a pale brown. On the whole they are fine-grained and argillaceous.

In the northern part of the area where exposures are few, a conglomerate bed occurs near the top of the formation. This is only a local phase, however, as the bed ranges from a true conglomerate 3 feet thick to a conglomerate sandstone with a few pebbles, within a distance of a few hundred feet. The pebbles are mostly small in size and range up to three-quarters of an inch in diameter. They are largely quartz of various colours, white, [illegible], and black being common.

AGE AND CORRELATION.

The age of the formation and its correlation with the Blairmore formation to the west are based on its stratigraphical position immediately beneath the Benton shales, supplemented by the evidence of fossil plants collected by G. M. Dawson on Mill creek, from strata which he referred to as the Mill Creek series. These fossils were identified by Sir J. W. Dawson[1] who found them to resemble very closely those of the Dakota group as described by Lesquereux and those of the Atané and Patoot formations of Greenland as described by Heer. The list of species given shows the flora to be composed largely of dicotyledons. From Dawson's description of the location and the writer's personal knowledge of the section, it is believed that the plant remains were collected from beds about 300 to 350 feet from the top of the formation, i.e., beneath the base of the Benton shales. A flora representing the same horizon and described in the same work by Sir J. W. Dawson was obtained on the northwest branch of Oldman river from a zone about 400 feet below the Crowsnest volcanics.[2]

Cairnes[3] also gives a list of a flora of Dakota age which he gathered in the Moose Mountain district.

During the summer of 1915 McLearn[4] made collections from this formation in the Blairmore area. He found that angiosperms were abundant in the upper 200 feet, and extremely rare below. From the foregoing it will be seen that the fossil evidence is rather meagre, but seems to indicate that the upper 400 feet of the formation at least is of Dakota age. Whether or not all the strata referred to the Blairmore formation are of Dakota age is yet an open question.

The wide geographical distribution of the basal conglomerate indicates some change in the topography or climate, or both, at the time it was laid down, which greatly increased the transporting power of the streams; and the relation of the conglomerate to the uppermost coal seam of the Kootenay seems to imply previous erosion of the Kootenay formation. It is not known with certainty whether the uppermost coal bed in the Kootenay represents a single continuous seam or different seams at different points; but from field observation and the known continuity of the coal beds, it is here assumed that it is a single continuous seam within the Blairmore area, and that the basal conglomerate has a variable position above it. This variation in the position of the conglomerate with respect to the coal bed, implies erosion of the underlying Kootenay and indicates that there is a hiatus below the conglomerate, although it appears to be conformable on the series below.

The conglomerate at the base of the Blairmore formation, with a distinctly Lower Cretaceous flora below it and a distinctly Upper Cretaceous flora above it, though at some distance above, makes a very strong argument in favour of placing the large break at this point. The conglomerate is so distinctive that it can be easily separated in hand specimens from other conglomerates which occur in the region. Its persistence for 120 miles along the strike, and its sudden appearance after a period characterized by deposition of shale and coal, all suggest that it marks a time when a considerable change in physical conditions took place. Furthermore, the only marked change in the lithology between the horizons carrying distinct Lower Cretaceous floras on the one hand and Upper Cretaceous floras on the other is found at the horizon of the conglomerate. The apparent conformability of the conglomerate with the sandstone below,

[1]Dawson, Sir J. W., Trans. Roy. Soc. Can., vol. III, sec. 4, pp. 1-22.
[2]Dawson, G. M., Geol. Surv., Can., Ann. Rept. 1885, vol. I, p.88 B.
[3]Cairnes, D. D., op. cit., p. 54.
[4]McLearn, F. H., Geol. Surv., Can., Sum. Rept. 1915, p. 112.

which is seemingly of Kootenay age, and its gradation into it in places may be due to the local absence of conglomerate. In all events, the pebbles were not derived from the Kootenay formation.

It is true that the conglomerate at the base of the Blairmore formation appears to be conformable with the underlying Kootenay in many places, but, as has been pointed out, it occupies a variable position with respect to the uppermost coal bed. Gentle warping may have caused local erosion and deposition immediately prior to Blairmore time. Later, with uplift on the west, coarse deposits of true Blairmore type were brought in. That this uplift did not affect the basin of deposition except in a minor degree is evident from the fact that the pebbles of the basal conglomerate do not include material of the underlying Kootenay formation, but were derived from rocks that were exposed some distance to the west. The combination of pebbles and siliceous cement of this conglomerate, which is as resistant as the pebbles themselves, gives the rock a distinctive character and makes it separable from similar rocks even in hand specimens. To sum up the reasons, then, for making this conglomerate bed the base of the Upper Cretaceous:

(1.) The persistence and distinctive character of the bed, which makes it a marked horizon for 120 miles along the strike.

(2.) Its sudden appearance after a period characterized by deposition of shale and coal beds, suggesting a decided change in the physical conditions.

(3.) It is the only horizon where there is a marked change in the lithology between series of beds carrying a distinct Lower Cretaceous flora below and a distinct Upper Cretaceous flora above.

BENTON FORMATION[1].

DISTRIBUTION.

Outcrops of the Benton, like those of the Blairmore, are confined to the western half of the area, where partial sections may be seen at many points from the 49th parallel to the northern edge of the map sheet and beyond. In the Rocky Mountain region, the Benton is known to extend westerly almost to the base of the mountain range which forms the continental divide. It has been definitely recognized by characteristic fossils as far north as the Moose Mountain district, Alberta, and shales of Colorado age are described by Malloch[2] as occurring in the Bighorn Coal basin. Shales supposed to be of the same age are reported to occur farther north on Peace and Pine rivers[3] in Alberta and British Columbia, and on the Liard river[4] in the Mackenzie River basin. Northward from Bow river the Upper Cretaceous section changes considerably, but the published reports seem to indicate that the marine invasion of the Coloradoan sea extended through to the Arctic ocean.

LITHOLOGY AND THICKNESS.

The Benton is dominantly composed of dark grey to black clay shales with thin arenaceous bands in smaller amount. In places a little sandstone occurs and occasional calcareous bands, but on the whole these are

[1]The U. S. Geol. Surv. uses the name Colorado shale for an equivalent development of the Colorado group.
[2]Malloch, G. S., Geol. Surv., Can., Mem. 9-E, pp. 36-37.
[3]McConnell, R. G., Geol. Surv., Can., Ann. Rept., 1890-1891, vol. V, pt. 1, pp. 55-58 D.
[4]McConnell, R. G., Geol. Surv., Can., Ann. Rept., 1888-1889, vol. IV, p. 20 D.

insignificant. These shales are recognized in the field by their thin-bedded, fissile character and by the marine invertebrate fauna which they carry.

The Benton shales overlie the Blairmore formation with apparent conformity and there is a gradual transition from dark green, thick-bedded, arenaceous shales to the dark, thin-bedded, finer-grained Benton shales. At the top the shales alternate with thin-bedded sandstones for about 100 feet, the sandstone beds gradually becoming dominant and thicker and the shale bands less frequent, until finally the shale gives way entirely to sandstones of the Belly River formation.

Owing to its easy disintegration, the Benton is exposed only along the river channels, but it may also be found beneath the superficial deposits in many of the depressions. The following is a short list of locations where partial sections are well exposed.

Location.	*Part of formation exposed.*
Belly river, 13 miles north of the 49th parallel.	Upper 1,000 feet, as well as overlying sandstones.
Pine creek, 1½ miles from Waterton river.	Upper 200 feet, with overlying sandstones.
Upper courses of Drywood river and Yarrow creek.	Upper part, several hundred feet.
Mill creek, lower 4 miles of its course.	Two different partial sections, one almost complete.
Crowsnest river.	Three different partial sections, upper contact shown in an anticline; lower contact shown in a syncline.
Oldman river.	About 1,500 feet of upper part with large section of overlying Belly River sandstones.
Willow creek near Dick's ranch, sec. 30, tp. 14, range 2, W. 5th mer.	1,100 feet underlain and overlain by sandstones.

Complete undisturbed sections of this formation are not yet known. The crumpling of the shales under pressure, coupled with their susceptibility to erosion, makes the measurement of sections extremely difficult. The estimated thickness of the Benton in the vicinity of Crowsnest river is 2,000 feet.

AGE AND CORRELATION.

Marine invertebrate fossils collected from this formation at several localities, fix the age as Coloradoan and correlate it with the Colorado shales of Montana. The fossils include the following species.[1]

Baculites asper
B. gracilis
Scaphites ventricosus
Prinotrophis cf. *woolgari*
Inoceramus labiatus
Inoceramus deformis
Ostrea congesta
Pteria nebrascana
Anomia sp. undet.
Tessarolax hitzii
Cardium pauperculum

[1]The fossils were identified tentatively by comparing them with collections in the Victoria Museum, Ottawa. The writer then took a representative collection to Washington, where under the supervision of Dr. Stanton the collections in the United States National Museum were studied and compared. The identifications were then verified by Dr. Stanton.

This extends the range of *Pteria nebrascana* down into the Colorado group; previously it has only been described from the Montana group.

In some cases the horizon from which fossils were collected is definitely known, with reference to the top or bottom of the formation:

Horizon—lowermost 75 feet.
Baculites asper
Tessarolax hitzii
Inoceramus sp. undet.

Horizon—about 350 feet from base of the formation.
Inoceramus labiatus (?)
Prinotropis cf. *woolgari*

Horizon—about 500 feet below basal thick-bedded sandstone of the Belly River formation.
Baculites asper
Scaphites ventricosus
Inoceramus labiatus
Cardium pauperculum
Pteria nebrascana

Small fish scales are also found at several horizons throughout the formation.

The Benton formation is the sole representative of the Colorado group in the foothill region. Conditions of deposition remained practically the same throughout, and no faunal zone or lithological unit, such as the chalk of the Niobrara, has been seen.

BELLY RIVER FORMATION.

DISTRIBUTION.

The Belly River is the most widely distributed formation in the area and extends throughout its entire length. The sandstones of this formation cap many of the ridges and uplands and form the channel walls of the more important streams. In the foothills and plains adjacent to the Rocky mountains various local names have been applied to similar series of strata occupying the same stratigraphic position and these are now believed to be equivalents of the Belly River formation. In the Blairmore region the Allison[1] formation, which is without doubt the equivalent of the Belly River, extends westward to the foot of the mountain range which forms the continental divide. Going northward the formation occurs in the Moose Mountain district, and was described by Cairnes first under the name of Judith River and later as Belly River beds.[2]

Tyrrell[3] describes the Belly River series as occurring on Red Deer and Battle rivers.

The Brazeau formation in the Bighorn coal basin described by Malloch[4] is also thought to be an equivalent of the Belly River formation.

[1]Leach and Mackenzie, Geol. Surv., Can., Sum. Rept. 1912, pp. 234-247.
[2]Cairnes, D. D., Geol. Surv., Can., Pub. No. 968, also Mem. 61.
[3]Tyrrell, J. B., Geol. Surv., Can., Ann. Rept., 1886, vol. II, pp. 128-129 E.
[4]Malloch, G. S., op. cit., pp. 37-38.

LITHOLOGY AND THICKNESS.

The Belly River formation is dominantly composed of fine-grained, light grey sandstones, interstratified with a considerable amount of irregularly-bedded shale. Fine-grained conglomerates are found at a few places. Coal seams occur at several horizons, but in most cases only locally. The most persistent coal seams occur near the top of the formation and have been worked at Lundbreck on Crowsnest river, on Waterton river, 22 miles north of the International Boundary, and at Lethbridge.

Conglomerates were observed at several points between Oldman and Crowsnest rivers. They are small in amount, grade into sandstones both vertically and horizontally in single exposures, and are mostly a thin sprinkling of small black chert pebbles on a sandstone.

The shales are in general arenaceous, and darker in colour than the sandstones. In a few places they occur in a series 50 feet or more in thickness, but generally alternate with the sandstones in beds from a few inches to 2 feet thick. Stratification is seldom observed in these beds, which appear at the surface as a loosely coherent mass and fall apart into small fragments on weathering or on being struck by a hammer. Diamond drill cores from some depth showed the same character, the shales being solid and firm when first taken out, but in a few days falling apart without being disturbed. Fossils are rare and those preserved are mainly small gastropods. Many of the shales are light grey and green in colour, although in the vicinity of the coal seams they are quite dark and carbonaceous in places.

Many of the sandstones are minutely cross-bedded, others show well developed ripple-marks. In many places they contain unios and fresh-water gastropods associated in the same bed. Plant fragments, pieces of coal and shale are common. Some of the beds contain numerous rounded fragments of shale and resemble conglomerates on weathered surfaces. The similarity of the sandstones of this formation to those of the St. Mary River series makes it practically impossible to tell them apart in isolated outcrops, and a microscopic study of several thin sections from the two formations failed to reveal anything of a diagnostic character.

Ten thin sections of samples taken at intervals from the lower 1,000 feet of the formation, where there could be no question of the exact horizon, show a remarkable similarity to one another. The microscopic descriptions may be summarized as follows: component grains—quartz, orthoclase and plagioclase feldspar, biotite, muscovite, zircon (an occasional grain), apatite (included in quartz), chlorite, and kaolin; cement—calcite; average percentages of the clastic material—quartz 65, feldspar 30, other minerals 5; average size of the rounded grains—in coarsest specimens 0·25 mm., in finest specimens 0·09 mm.

The material is well sorted; many of the fragments are angular to subangular, and many of the plagioclase feldspars are remarkably fresh.[1]

The formation as a whole seems to be composed of a great series of interlocking lenses and differs considerably in character and thickness within comparatively short distances. No complete undisturbed section was observed. The thickness on Oldman river is estimated at about

[1]For tabular description of slides from specimens of rocks, of Belly River and St. Mary rocks see under the heading of St. Mary River formation.

3,000 feet and thins toward the north and south. On Crowsnest river, where a complete though badly disturbed section is present, the thickness is estimated at 2,500 feet. On St. Mary river near the 49th parallel the thickness cannot be much over 1,600 feet.

AGE AND CORRELATION.

The Belly River formation as here described includes all the strata which overlie the marine shales of the Benton and underlie the marine shales of the Bearpaw formation. The separation in the field is not difficult, as the Belly River differs both lithologically and in the fossils from the enclosing Benton and Bearpaw formations. The stratigraphic position of the Belly River formation fixes its age within comparatively narrow limits. Fossils on the whole are scarce and poorly preserved in this formation; those collected by the writer were mostly unios and small freshwater gastropods. A few limb bones of a dinosaur and some leaf impressions which resemble those of a modern deciduous tree were also obtained. These fossils have not been studied and it is doubtful if there is anything of a distinctive character in them. The evidence of the fossils and the character of the strata show the formation to be wholly or mainly of continental origin. Near Crowsnest lake McLearn[1] has detected in the lower 300 feet beds containing a fauna which he regards as brackish-water forms.

The Belly River formation as here defined is equivalent to the Virgelle sandstone and Two Medicine formation of northwestern Montana described by Stebinger[2]. This opinion was confirmed by a personal interview which the writer had with Mr. Stebinger. Farther east along the International Boundary, the Belly River series is equivalent to the Judith River, Claggett, and Eagle of the north-central Montana section.[3]

Within the area dealt with in this report the Belly River group is a lithological unit of essentially continental deposits, in which so far as our present knowledge of the region goes, no subdivisions can be made owing to the rarity of diagnostic fossils. Cairnes[4] has attempted to correlate the rocks in the disturbed belt with Stanton and Hatcher's section of the Montana group as developed along the Missouri river. This correlation by Cairnes has been frequently quoted, but recently its accuracy has been questioned by Stebinger[5] and later by Sinclair.[6] How far west in southern Alberta, the Eagle and Claggett, marine, subdivisions of the Pierre are distinguishable is not exactly known, but they have not been recognized in the southern part of the disturbed belt and presumably are represented in that region by continental deposits. No mention is made of Eagle or Claggett by Leach[7] or by Mackenzie[8] in describing the Allison formation of the Crowsnest region, the equivalent of the Belly River formation. The Belly River and its relation to overlying and underlying formations

[1]McLearn, F. H., Geol. Surv., Can., Sum. Rept. 1914, pp. 62–63.
[2]Stebinger, E., U. S. Geol. Surv., Bull. 621-K; and Prof. Paper 90 C, pp. 61–67.
[3]Dowling, D. B., "Structural geology of the Alberta oil fields," Bull. Can. Min. Inst., March 1915, p. 164, and Trans. Can. Min. Inst., 1915, p. 182.
Dowling, D. B., "Cretaceous sea in Alberta," Trans. Roy. Soc. Can.
[4]Cairnes, D. D., op. cit., 1915, vol. IX, sec. 4, pp. 34–39.
[5]Stebinger, E., U. S. Geol. Surv., Prof. Paper 90 G, p. 66.
[6]Sinclair, J. H., Geol. Soc. Am., Prelim. list of papers with abstracts, Dec., 1915, p. 27.
[7]Leach, W. W., Geol. Surv., Can., Sum. Rept., 1911, pp. 192–200; also Twelfth Inter. Geol. Cong., Guide Book No. 9, p. 23.
[8]Mackenzie, J. D., Geol. Surv., Can., Sum. Rept., 1914, pp. 46–47.

have been discussed recently by Dowling[1] and by McLearn.[2] For a description of the stratigraphy of the Montana group in north-central Montana the reader is referred to a paper by C. F. Bowen.[3]

BEARPAW FORMATION.

DISTRIBUTION.

The Bearpaw formation is exposed in the eastern part of the disturbed belt on all the rivers between the St. Mary and Oldman. Outcrops have not been observed on the interfluves between the stream channel nor are they likely to be exposed in such places, as the strata are very susceptible to erosion and form a subdued and rounded topography. The formation has not been found north of Oldman river, its probable northward extension is marked by a persistent depression. Near Oldman river this depression is a well-defined longitudinal valley which merges with others into a common lowland at the northern edge of the area. At this point Pekisko creek cuts across the strike of the rocks and exposes the Bearpaw formation, but the marine shales can not be recognized nor were any of the characteristic fossils found, though a careful search was made for them.

In the adjacent Sheep River area to the north the Bearpaw formation cannot be separated, as the marine shales appear to be replaced by sandy shales, many of them light coloured and interbedded with thin coal seams. Farther northwest, in the Moose Mountain district Cairnes[4] reported Bearpaw shales carrying a few marine fossils. The evidence for assigning these shales to the Bearpaw seems to rest very largely on the occurrence in them of *Baculites compressus*, a typical and long enduring Montanian species. If the sea extended so far west as the Moose Mountain district, the shore-line must have been very irregular, as the Bearpaw formation has not been recognized in the adjacent areas north and south.

The Bearpaw has not been found west of the area, but it is quite possible that it may occur, especially near the mountains which form the continental divide. From Dawson's description of the rocks on Oyster creek[5] and northwest branch of North Fork of Oldman river[6] it seems probable that the Bearpaw may be found in these localities if its marine character is preserved so that it can be recognized. The following quotation from Dowling's discussion of Upper Pierre summarizes our knowledge regarding the distribution of the Bearpaw formation in Canada.[7]

"The deposits of this division [Upper Pierre] are in the main of marine origin. The western margin of the Pierre sea early in the history of this marine invasion, received great masses of detritus from the newly elevated portions of the land area. Following the partial retirement of the early Pierre sea there was another advance which appears to have been of long duration judging by the thickness of the fine-grained material deposited. This over a considerable portion of Alberta amounts to nearly 900 feet of grey and dark grey clay shales. The fossils found are of similar types to

[1]Dowling, D. B., Geol. Surv., Can., Sum. Rept., 1914, pp. 46–47.
[2]McLearn, F. H., op. cit., pp. 62–63.
[3]Bowen, C. F., U. S. Geol. Surv., Prof. Paper 90 I.
[4]Cairnes, D. D., op. cit., pp. 24, 52.
[5]Dawson, G. M., Geol. Surv., Can., Ann. Rept. 1885, vol. I, p. 92 B.
[6]Dawson, G. M., Idem, p. 85 B.
[7]Dowling, D. B., Trans. Roy. Soc. Can., 1915, vol. IX, sec. 4, pp. 39–40.

those of the lower member, the Claggett. In Montana it is called the Bearpaw shale. The name is generally retained in Alberta instead of the Pierre-Foxhill; but for Saskatchewan there is a possibility (in well-sections especially) that the two divisions of the Pierre may not be recognized owing to the lack of shallow-water deposits which elsewhere separate them. The use of the term Bearpaw which is distinctive may find favour for distinguishing these shales throughout Alberta. They are well exposed on either side of the broad anticline which shows exposures of Belly River rocks in southern Alberta. The margin of this sea was well within the foothills of the country near the 49th parallel; but within the present mountains it is not thought that any of the deposits of this period remain from which to infer the original extent. Marine fossils occur in the Bearpaw in the section on Oldman river, but on Highwood river the formation is mostly of dark sandy shales with considerable carbonaceous filaments between the beds and having a coal seam at the base. This possibly indicates an approach here to shallow water and an eastward bend in the shore-line. Whether the area so affected formed a large delta of which this is the southern part is problematical; but it may be remarked that in the North Saskatchewan section these shales are not definitely recognized below the Edmonton outcrops, while the same can be said of the exposures on the upper Athabaska. The reference to these beds in the discussion of the Smoky River shales was in connexion with the finding of *Inoceramus altus* at the summit of Table mountain and was merely an intimation that salt water deposition occurred in that locality after the deposition of the Wapiti sandstones. The northern extension of the Pierre sea is not known. Exposures in the MacKenzie valley and elsewhere in the north show marine beds similar in fossil content and appearance to the Benton shales, but above these, sandstone beds of Tertiary age. There is, therefore, a probability that the Pierre sea advanced from the south and did not cover the northern portion of the continent. The beds at the summit of Table mountain on Pine river may indicate possibly the extreme northwestern limit of this advance.

"In the foothills north of the Bow river it is not definitely known that marine deposits of the upper Pierre are to be found. This may indicate land areas there during this last westward swing of the sea coast. The deposits in these localities being of continental formation may show by unconformities the land surfaces of this period, or land areas in proximity to sea-level may be marked by a carbonaceous zone indicating the former rich vegetation. The division between the continental formations of the Belly River group and those of the succeeding Edmonton may be difficult to define in the foothills beyond the western limit of the Upper Pierre sea."

LITHOLOGY AND THICKNESS.

The Bearpaw formation is composed essentially of dark clay shales holding calcareous concretions. Some of the concretions are quite large and in many of them fossils are found forming the nucleus. Disk-shaped forms which have collected around large ammonites are common. On Lee creek a limestone band about 1 foot thick was observed about 200 feet above the base of the formation, and the section on Oldman river shows three lenses of massive buff coloured sandstone, one of these sandstone beds being minutely cross-bedded.

The extension of the Bearpaw formation northward from Oldman river is not observed until Pekisko creek is reached. In this section the typical dark clay shales and marine fossils are absent and the Bearpaw horizon is represented by an alternation of sandstones, arenaceous shales, and thin coal seams, a combination characteristic of the upper part of the Belly River and the lower part of the St. Mary River formations. No fossils of a diagnostic character have been found in this zone, and so far as our present knowledge of it goes, this series of strata lying between sandstones of the Belly River formation below and the St. Mary River formation above might be included in either of those formations. These formation boundaries are extremely arbitrary at the north end of this area. A brief description of the section on Pekisko creek has been given in the Summary Report for 1914[1].

From Oldman river south the lithological distinction between the Bearpaw and the formations which enclose it is marked. The change from the sandstone of the Belly River formation to the shales of the Bearpaw is completed in a zone 50 feet thick or less. The transition is best seen on Lee creek and on Oldman river, where the sandstones of the Belly River formation give place to thick-bedded arenaceous shales, and these in turn to thin-bedded clay shales holding marine Bearpaw fossils.

No complete undisturbed section of the formation was observed, but the entire thickness, though only partly exposed, is present on Oldman and Crowsnest rivers and on Lee creek. The maximum thickness, making due allowance for repetition by crumpling and folding, is estimated to be about 700 feet.

AGE AND CORRELATION.

The formation carries a marine molluscan fauna which correlates it with the Bearpaw of central and northwestern Montana and places it, therefore, well up in the Montana group.

Fossils collected by the writer from this formation include the following which have been identified[2]:

Cyprina ovata
Avicula Linguiformis
Inoceramus sagensis
Modiola, sp. undet.
Baculites compressus
Placenticeras whitefieldi
Placenticeras intercalare

Cyprina ovata and *Placenticeras whitefieldi* were found practically wherever the formation is exposed from Oldman river in the north to Lee creek in the south.

ST. MARY RIVER FORMATION.

DISTRIBUTION.

The St. Mary River formation occurs only in the eastern part of the disturbed belt where its outcrop forms prominent strike ridges. In the north, this ridge-making quality of the formation is less pronounced and the country where it outcrops is almost flat. In the southern part of the disturbed area the formation is repeated by faulting and folding, but generally it occurs in a single continuous strip of comparatively uniform width.

[1]Dowling, D. B., Geol. Surv., Can., Sum. Rept. 1914, pp. 48-49.
[2]The identifications were verified by Dr. Stanton.

The series to which the name St. Mary River beds was applied by Dawson is limited in its distribution to southern Alberta, where it occurs on both limbs of a syncline, the western and more compressed limb falling within the area described in this report. The syncline is comparatively narrow at the south, but becomes more open toward the north where the east limb assumes a more gentle dip, causing the outcrop on that side to widen accordingly. This outcrop runs north from the International Boundary, closely following the meridian of 113 degrees west longitude. Beyond this region, rocks which probably belong to the St. Mary River formation were found by Dawson in the Rocky mountains, near the headwaters of Oldman and Highwood rivers[1]. To the north, beds occupying the stratigraphical position of the St. Mary River formation generally go by the name of Edmonton beds.

At the northern edge of the area described the stratigraphical limits of the St. Mary River formation are hard to define, as lithological differences in the strata are not great and no fossils of diagnostic value have been found. From Oldman river the formation was traced by practically continuous exposures northward to Highwood river, where beds of the series generally known as the Edmonton are identical with the lower part of the St. Mary River formation. The Edmonton occurs also in the Moose Mountain district[2] and on the Red Deer, Battle, and North Saskatchewan rivers where the formation was originally described by Tyrrell[3]. The Edmonton is also mapped by Dowling[4] running northwestward in Alberta in two broad belts which coalesce in the vicinity of Athabaska river.

LITHOLOGY AND THICKNESS.

The St. Mary River formation is mainly composed of highly calcareous, light grey sandstones, with smaller amounts of sandy shales. The section varies considerably from place to place, but in general the lower part is more shaly and calcareous than the upper and everywhere contains coal seams and oyster beds. The sandstones are all fine-grained; in a few of the beds small pieces of coal and of shale are found, but no conglomerates have been observed. Fine cross-bedding and ripple-marks are common in these sandstones, in fact, all that has been said of the Belly River sandstones might be said of these. The shales also are irregularly-bedded like those of the Belly River formation, but are in less amount and some of the beds are calcareous and concretionary. The coal, which occurs only in the lower part of the formation, is good domestic fuel, but is badly crushed everywhere and in many places is dirty. The seams vary very much both in number and thickness. One of the best horizon markers in the southern part of the area is a bed composed almost entirely of the shells of oysters and other molluscs, which overlies the coal near the base of the formation. This bed forms a nearly continuous ridge between St. Mary and Belly rivers.

The best sections of the formation are seen along some of the stream gorges.

On St. Mary river one complete although intensely folded section and two partial sections are exposed. At the base are a few feet of sandy

[1]Dawson, G. M., op. cit., pp. 89 and 92 B.
[2]Cairnes, D. D., op. cit., p. 23.
[3]Tyrrell, J. B., Geol. Surv., Can., Ann. Rept., 1886, vol. II, pp. 131-135 E.
[4]Dowling, D. B., Geol. Surv., Can., Mem. 53, map 55 A.

sha'es which grade into sandstones; the two together are 60 feet in thickness and are followed by thin coal seams overlain and in places also underlain by oyster beds. The uppermost shell bed, which is about 80 feet above the uppermost Bearpaw shales, is followed by irregular beds of clay and shale for about 50 feet. These are followed in ascending series by an alternation of light grey sandstone and light coloured arenaceous shales, a few of the latter beds being reddish in colour. At the top there is a fault of small throw and on the downstream side of this fault the typical red clays and shales of the Willow Creek formation make their first appearance near Kimball. The complete thickness of the formation is here estimated to be about 1,600 feet.

On Lee creek, exposures of this formation are scattered and show considerable folding and faulting. Near the Leavitt coal mine on this stream, about 100 feet of the lowermost beds show the following succession:

	Feet
Belly River sandstone.	
Fault contact.	..
Alternating dark and light greenish shales................about	..
Sandstone with many plant remains..........................	40
Sandy shale, carbonaceous..................................	2
Coal..	1
Sandy shale full of shells of *Ostrea*........................	9
Sandstone, light grey, cross-bedded........................	2
Bearpaw shales not exposed.	50
	..

The series is descending from the fault contact to the Bearpaw. The thick sandstone at the base is in many places full of impressions that appear to be worm borings. The thickness of the coal seam is in part due to crumpling; minute folds showing streaks of white clay through the coal may be seen inside the mine.

On Belly river the formation is poorly exposed. At one point, however, the passage from sandstones of St. Mary River age to the Bearpaw shales is almost entirely exposed, and the position of the persistent oyster bed and associated coal seams with reference to the Bearpaw may be observed. The bed of shells may here be seen to change in thickness from about 8 feet to 2 feet in a distance of approximately 150 yards along the strike.

Waterton river has exposed a complete but badly folded section of this formation. The oyster bed near the base is again one of the most prominent members and is in places nearly 12 feet thick.

Continuing northwestward the next good exposure of this formation is on Indian Farm creek, where a thickness of about 2,500 feet is shown and the top and bottom are not seen.

Pincher creek and Castle river exhibit almost complete sections, only the basal part being badly disturbed and in places covered.

Crowsnest river has an almost complete section exposed and a sandy bed full of oyster shells may be seen about 20 feet above the Bearpaw shales. Following downstream from Lundbreck thin coal seams occur at two horizons in the lower part of the formation. The section shows numerous small folds, very intense in the more shaly parts. The estimated thickness on Crowsnest river is 2,700 feet.

Oldman river shows a section which is almost complete, but complicated by folding and faulting. An oyster bed is practically at the base and is overlain by a coal seam of extreme variation in thickness. The thickness of the formation here is estimated at 3,000 feet.

PETROGRAPHIC DESCRIPTION.

From the section on Oldman river a suite of rock specimens was collected from the St. Mary River and Belly River formations. The specimens represent the harder and more resistant beds only, and were collected at points where there could be no question as to their stratigraphical position or the formation to which they belonged. Those from the St. Mary River formation represent beds at more or less equally spaced intervals throughout the formation. Those from the Belly River formation, which are described here for comparison, represent the lower 1,000 feet. Thin sections of these specimens were examined and a condensed description is given in the following table.

Rocks of the St. Mary River Formation.

Clastic material						Cement		
Slide	Mineral composition			Character of grains				
No.	Essential		Accessory	Dominant		Alteration of feldspars. Amount	Kind	Rock mass %
	Quartz %	Feld-spars %	Less than 2%	Size: diam. in mm.	Shape			
13	65	30	Biotite chlorite muscovite	0·05	Subangular	Much	Calcite	40
12	75	25	Biotite zircon muscovite	0·07	Subangular to round	Much	Calcite	50
11	55	40	Apatite zircon tourmaline biotite chlorite muscovite	0·14	Angular	Much	Calcite and clay	Calcite 45
10	60	35	Zircon apatite tourmaline biotite chlorite	0·10	Angular to subangular	Much	Calcite and clay	Calcite 30
9	58	40	Biotite zircon muscovite chlorite	0·15	Subangular	Much	Calcite	10
8	70	28	Biotite	0·07	Angular	Slight	Calcite	60
7	60	35	Biotite chlorite muscovite	0·13	Subangular	Much	Calcite	10
6	65	30	Biotite muscovite chlorite apatite	0·12	Subangular	Much	Calcite	10
5	80	20	Biotite	0·10	Rounded to subangular	Much	Calcite	40
4	80	20	Chlorite zircon biotite apatite tourmaline	0·10	Subangular	Much	Clay and calcite	Calcite 20
3	70	25	Biotite apatite	0·10	Angular to subangular	About half the grains	Calcite	25
2	80	20	Biotite	0·05	Subangular	About half the grains	Calcite	60
1	80	20	Negligible	0·05	Subangular	Half	Calcite	60

NOTE. The specimens are arranged in the tables to conform with the relative position of the beds in the formation, that is, No. 1 represents a bed near the base of the formation, No. 13 a bed near the top. The percentages given are per cents by volume, obtained by the Rosiwal traverse method.

Rocks of the Belly River Formation.

Slide No.	Clastic material: Mineral composition: Essential: Quartz %	Feldspars %	Accessory: Less than 2%	Character of grains: Dominant: Size: diam. in mm.	Shape	Cement: Alteration of feldspars. Amount	Kind	Rock mass %
23	70	25	Biotite chlorite muscovite	0·10	Angular.	Slight	Calcite	20
22	70	25	Biotite chlorite apatite	0·11	Subangular	Slight	Calcite	60
21	65	30	Biotite	0·25	Angular to subangular	Slight	Clay and calcite	Calcite 10
20	....	....	Biotite chlorite muscovite	0·12	Subangular			
19	60	35	Biotite chlorite muscovite zircon	0·10	Subangular	Much	Calcite	60
18	70	28	Biotite chlorite zircon	0·05	Subangular	About half the grains	Calcite	75
17	55	40	Biotite chlorite muscovite zircon	0·12	Angular to subangular	Much	Clay and calcite	Calcite 15
16	60	35	Biotite chlorite muscovite zircon	0·09	Angular	Slight	Calcite	45
15	60	35	Quartzite apatite	0·20	Subangular	Considerable	Calcite	10
14	70	25	Biotite chlorite muscovite	0·0[illegible]	Rounded to subangular	About half the grains	Calcite	20

Calcite fills the most minute spaces. The rocks of the St. Mary River and Belly River formations are apparently not very porous and water does not percolate freely through them.

The angularity of the clastic material in some cases is due to post-depositional fracturing, but the grains show no strain effects such as undulatory extinction.

The large percentage of calcite in some of the sections is probably in part due to a recrystallization of original calcareous grains such as fragments of shells. In some of the beds small and broken fragments of shells were actually observed in the field.

The coarseness of the clastic material, the cross-bedding and general continental character of many of these rocks are antagonistic to the idea that the calcite as it now occurs is original and deposited as a limestone. The deposits of the bordering seas at this time were also muddy and generally lacking in limestones.

In some places the parts of fractured clastic grains are separated by a very thin film of calcite, in other places the separation is not complete.

This suggests that the final breaking up of many of these grains may have been due to the force of crystallization of calcite deposited from solutions which penetrated incipient fractures.

Fresh feldspar of both soda and potash varieties is indiscriminately mixed with badly weathered grains of the same minerals in many of the sections. This would suggest that most of the weathering has been predepositional. Nothing in the character or composition of the specimens from the St. Mary River formation seems to distinguish them from those of the Belly River formation.

AGE AND CORRELATION.

The St. Mary River formation overlies the Bearpaw without any evidence of a break, the shales passing gradually upward into sandstones, some of which are so highly calcareous as to be practically limestones. Within the lowermost 100 feet there is always at least one bed composed largely of oyster shells with other brackish-water fossils in lesser amounts. The following species have been identified from this zone: *Ostrea glabra, O. subtrigonalis, Corbicula occidentalis, Anomia perstrigosa,* and *Melania wyomingensis.* Of these the first three species are found in the Belly River, Judith River, Fox Hills, and Lance formations; and the last two species are usually listed as Laramie. Throughout the rest of the formation unios and freshwater gastropods are common and at one locality a concretionary bed rich in plant remains contains some fairly well preserved fossil leaves. As no fossils of a diagnostic character have been identified the age of the formation is inferred from its stratigraphical position above the marine Bearpaw shales. In Canada the St. Mary River formation is generally placed in the Upper Cretaceous, but the separation of it from the overlying Willow Creek formation, which is considered to be Tertiary, is made on lithological grounds chiefly because of the characteristic, red colour of the latter formation.

The St. Mary River formation as here described is equivalent to the St. Mary River and Horsethief sandstone of northwestern Montana. It includes also the sandstone band which Dawson[1] correlated with the "Fox Hills." The Fox Hills sandstone of Dawson, which has been named Horsethief sandstone by Stebinger[2] in the adjacent part of Montana has not been separated from the overlying sandy series in the disturbed belt. The Fox Hills and St. Mary River formations are a lithological unit, and if separated, the stratigraphical boundary would be extremely vague, as the thickness of the sandstones at the base, which hold brackish-water fossils, is variable, and would require considerable detail work to determine, on the various river sections.

In the northern part of the area examined the top of the St. Mary River formation is also hard to define and here Dawson found himself unable to carry out the subdivisions of the Laramie which he had made in the south. His remarks are as follows:[3]

"But for the existence in the southern part of the district of the well marked Willow Creek horizon, the separation of the Porcupine Hills series from the lower part of the Laramie (St. Mary River beds) would be

[1]Dawson, G. M., Geol. Surv., Can., Rept. of Prog., 1882-1884, pp. 114-115 C.
[2]Stebinger, E., U. S. Geol. Surv., Bull. 621-K, p. 124, and Prof. Paper 90-G.
[3]Dawson, G. M., op. cit., p. 113 C.

impossible and it has not been attempted to carry out on the map the subdivision of the Laramie in the northern part of the district."

The observation of the writer corroborates the above statement and can add little or nothing to it. In the northern part of Map 1712, therefore, the boundary between the St. Mary and younger beds is an arbitrary line. This line has been made to correspond as nearly as possible to the horizon of the lowermost red beds of the Willow Creek series, the most northerly exposure of which is seen in township 14.

The Edmonton formation, which is often correlated with the St. Mary River, is, according to Tyrrell's definition,[1] equivalent to the lower 700 feet of the St. Mary River formation. The substitution of the name Edmonton for the St. Mary River formation in the south is, therefore, not strictly correct.

WILLOW CREEK FORMATION.

The series of rocks to which this name is applied was first recognized at the mouth of Willow creek near what is now the town of Macleod. The best sections of the formation, however, are to be seen on St. Mary, Waterton, and Oldman rivers.

The beds which compose this series are not very resistant and the resulting topography is smooth and rounded. In some places where the formation is covered its presence may be detected by the red colour of the soil.

DISTRIBUTION.

The Willow Creek formation is found only in southern Alberta and the adjacent part of Montana. Within the area examined it occurs at the east as a single strip running northwestward from the International Boundary. In the northern part the formation loses its identity and in the region to the north beds occupying the stratigraphic position of the Willow Creek series are included in the Paskapoo formation.

LITHOLOGY AND THICKNESS.

The Willow Creek formation is composed of clays, shales, soft sandstone, and a little thin-bedded limestone. The formation as a whole has a pronounced reddish colour which is perhaps its most characteristic feature. This colour assumes various shades of purple, maroon, and brown. The sandstones are fine-grained, calcareous, and thin-bedded; they are most prominent near the top. The limestones are arenaceous and usually assume a purple colour on weathering. The clays and shales are also quite arenaceous, weather reddish, and in places appear quite unconsolidated. The only place where a well exposed section of the formation was traversed was on Oldman river, and Olin creek, a small tributary which flows westward from the Porcupine hills. The base of the formation is seen on the river in a steep cutbank. One hundred feet of unconsolidated

[1]Tyrrell, J. B., op. cit., p. 127 E.

clays and sands that have only an occasional thin, hard bed overlie with apparent conformity the sandstones of the St. Mary River formation. The upper part of the Willow Creek formation is seen on Olin creek, where it consists of an alternation of reddish and brownish arenaceous clays and sandstones. The bands of sandstone become more numerous and thicker as the top of the formation is approached, until finally the clays become insignificant in amount and lose their typical red colour. Where this occurs the line is drawn between the Willow Creek and the overlying Porcupine Hills formation. The upper part of the Willow Creek formation is seldom exposed and the dividing line at the top is vague. The thickness of the Willow Creek formation on Oldman river west of the Porcupine hills is about 500 feet. From this outcrop on Oldman river northward, the formation is the locus of a wide longitudinal valley and good sections are not seen until Pekisko creek is reached; here the Willow Creek formation cannot be recognized as a stratigraphic unit and as no evidence of an erosion unconformity has been observed, the writer considers that the Willow Creek beds have simply changed in character.

South of Oldman river the formation was not closely examined as only the region of intense folding and faulting was studied and the Willow Creek formation occurs only along the eastern edge of the disturbed belt.

The thickness of the Willow Creek series in the section on Oldman river is given as 2,000 feet in the Summary Report of the Geological Survey for 1914[1]. The section includes 1,500 feet of the overlying Porcupine Hills formation, which the writer, at that time, had not separated from the Willow Creek formation.

AGE AND CORRELATION.

The Willow Creek formation is generally considered as early Tertiary and probably Eocene in age. In Canada this determination appears to be based entirely on stratigraphic relations of the formation. No fossils were observed by the writer in the beds, but Dawson reports finding a few freshwater molluscs and a single chelonian[2]. So far as the writer knows there are no palæontological grounds for separating this series of beds from the St. Mary River below or the Porcupine Hills series above.

The Willow Creek formation is recognized as a stratigraphic unit in the adjacent part of northwestern Montana where fragments of fossil bones are reported to be commonly found in the beds of the formation. The nature of the fossil material is not mentioned and the age of the formation is given as Eocene but is questioned[3].

North of this area, rocks which occupy the stratigraphic position of the Willow Creek formation are included in the Paskapoo series which is also considered Eocene in age.

[1] Dowling, D. B., Geol. Surv., Can., Sum. Rept. 1914, p. 46.
[2] Dawson, G. M., op. cit., p. 113 C.
[3] Stebinger, E., U. S. Geol. Surv., Bull. 621-K, p. 124.

PORCUPINE HILLS FORMATION.

DISTRIBUTION.

The Porcupine Hills formation is found only in the Porcupine hills from which it derives its name. It is the youngest series of beds occurring within the area under consideration. In the south the beds have been completely eroded away. To the north of the area the Paskapoo formation probably includes all of the Porcupine Hills formation. The Paskapoo occupies the centre of a broad syncline and its outcrop is continuous northward from the Porcupine hills to Athabaska river[1].

LITHOLOGY AND THICKNESS.

The Porcupine Hills formation is composed mainly of sandstones with lesser amounts of interbedded, greyish, shaly clays. The sandstones are generally fine-grained and light grey in colour. No conglomerates were observed, but a conglomeratic sandstone bed with a few small pebbles was noted at one point. The beds as a whole appear to be highly calcareous and frequently weather a brown colour. The lower beds in many places show thin, paper-like layers on the weathered edge. The greatest observed thickness of this formation where it has been least eroded is about 2,500 feet.

AGE AND CORRELATION.

So far as observed this formation rather lacks fossils. The only remains seen by the writer were unios and gastropods, and the only fossils from this series of rocks noted by Dawson are a few plants[2]. The little evidence obtained indicates freshwater deposition. In age the formation is usually considered early Tertiary and probably Eocene, based entirely on the stratigraphic relations. The "Laramie group" of Dawson (St. Mary River, Willow Creek, and Porcupine Hills formations) appears as a conformable series, suggesting more or less continuous deposition and, therefore, a close relation in age.

The entire group was involved in the "Laramide" or post-Laramie revolution which is generally thought to have ended early in Eocene time.

[1]Dowling, D. B., Geol. Surv., Can., Mem. 53, Map 55 A.
[2]Dawson, G. M., op. cit., p. 113 C.

CHAPTER V.

STRUCTURAL GEOLOGY.

INTRODUCTION.

The rocks occurring at the surface in this area, except the superficial boulder-clays and gravels, were deposited below or near sea-level in practically horizontal layers. Some of these strata are to-day, however, over 6,000 feet above the sea, and the original horizontal attitude of the beds is seen only at the east. Elsewhere the beds are tilted and stand at various angles up to vertical, exposing the edges. This disturbed condition of the strata was produced by a horizontal thrust which was the result of internal stresses within the earth's crust. Epeirogenic movements, those great continental warpings, subsequent to this deformation are largely responsible, however, for the present elevation of the beds so high above the sea.

The generalized structure shown in the geologic sections, accompanying Map 1712, is for the most part based on actual observation of surface exposures. This is best seen where the rivers have cut gorges across the strike of the rocks, exhibiting an almost continuous stretch of rock outcrop.

The entire area might be thought of as the much disturbed and broken eastern limb of an anticlinorium with the crest represented by Livingstone range. Livingstone range lies just to the west of the Porcupine hills, but its southern end is 40 miles north of the boundary, where the hard Palæozoic limestones and quartzites, here bowed into an anticline, plunge southward and are covered by Cretaceous and Jurassic beds. The general trend of the outcrops is northwest, the strike being nearly parallel with the base of the mountains.

STRUCTURAL PROVINCES.

The area may be divided into two structural units based on the amount of deformation to which the rocks have been subjected. These are: (1) the Porcupine hills; (2) the disturbed belt proper.

PORCUPINE HILLS.

The Porcupine hills occupy the centre of a broad syncline which extends along the eastern edge of the disturbed belt. This syncline appears to be continuous from the International Boundary to Athabaska river, a distance of about 400 miles. The fold is asymmetric, the western limb having a steeper dip than the eastern one. The beds have a maximum dip of 15 degrees to 20 degrees at the west, flatten rapidly toward the east, and are practically horizontal in the eastern part of the area.

DISTURBED BELT.

General Features.

The disturbed belt proper is characterized by a predominance of westward dips. Dips of 45 degrees to 80 degrees are common. Dips of 20 degrees to 30 degrees may be considered comparatively gentle. Horizontal and vertical dips occur locally, but are rare. This dislocation has been produced by faulting and in a much lesser degree by overturned folding (Plates IV and V).

Trend of the Rocks.

The regularity of the northwest trend of the rocks is broken by two major bends in the strike. On St. Mary river near the International Boundary the beds have a strike of about 30 degrees west of north. The first bend occurs about 12 miles north of the boundary, where the ridges may be seen to swing in a more decidedly westward direction and the strike is 50 degrees to 60 degrees west of north. This general trend is maintained to the vicinity of Crowsnest river, where the second bend is located. North of Crowsnest river the strike is about 15 degrees west of north and gradually swings to about 5 degrees west of north. In this northern part of the area several small variations in the strike occur, which appear to be induced by faults, but they are all gradual. The major bends appear to be a response to the thrust from the west, as they are parallel to the mountain front.

Classification and Description of Folds.

The folds are of various sizes, forms, and attitudes, and for the most part unsymmetrical. Classed as to form and attitude and listed according to size, beginning with the smallest, they may be separated into: small open folds, overturned folds, sharp crested inclined folds, unsymmetrical open folds, and broad undulatory types.

Small Open Folds. These are minor corrugations that do not extend to any great depth, affect only one formation at the surface, and cannot be traced any distance from the river gorges. Several of these small undulations affecting St. Mary River sandstones may be seen on St. Mary river and Waterton river at the eastern edge of the disturbed belt.

Overturned Folds. Overturned folds that can be observed are small and cannot be traced any distance at the surface back from the river valleys.

Sharp, Crested, Inclined Folds. These are narrow, unsymmetrical types resembling somewhat the letter N. A typical fold would have the west limb of the anticline dipping about 60 degrees and the east limb about vertical. Several of these N-shaped folds may be seen in the face of the hills between Crowsnest and Oldman rivers.

Unsymmetrical Open Folds. The unsymmetrical, open folds are perhaps the most common and have the limbs dipping steeply in most cases. Examples are found in the district as follows: an anticlinal fold of this type extends from the northern part of township 13 through almost the entire length of township 14 in range 2. The top of this arch is formed by sandstones of the Belly River formation on the uplands and by Benton shales in the valleys. The west limb is concealed a short distance from the crest and is apparently broken by a fault.

On Crowsnest river near Lundbreck the Benton shales are exposed in the top of a sharp anticlinal fold. This anticline can be traced about 5 miles south where it appears to be cut by a fault. It can also be followed about 4 miles north, but beyond this its extension cannot be traced with any degree of accuracy.

A synclinal fold of a somewhat broader type, with Benton shales exposed in the centre, may be seen along the railway about 2 miles east of Burmis station. This syncline pitches north and can be definitely traced in that direction for about 4 miles. Within less than a mile south of the railway this fold dies out and is replaced by a westward-dipping monocline developed in sandstones of the Blairmore formation.

An anticlinal fold developed in Belly River sandstones extends along the eastern part of the area between Castle river and Pincher creek. On St. Mary river about a mile north of the International Boundary the Belly River sandstones exhibit an anticlinal fold, but the east limb is broken close to the crest by a fault. This same structure extends through and is again well exposed on Lee creek, but here the fold is so narrow that the east limb extends for only a few feet, steepens rapidly, and is broken by a fault. The eastern dip is in reality due to the drag of the fault.

Broad Undulatory Folds. Bordering the Clarke range at the south is a strip 6 to 8 miles wide in which the dips are remarkably gentle and the folds wide as compared with the structure immediately to the east. The exposures in the stream channels are not so continuous in this part as they are in other places. They are, however, sufficiently numerous to show the general structure, and if any breaks occur they are of comparatively small displacement.

Faults.

Strike. The faults in general follow closely the strike of the rocks and nowhere have faults been recognized which cut the strike at an angle greater than a few degrees.

Dip. The dip of many of the faults has not been accurately determined, but where observed it is westward. Doubtful or unknown dips are shown in the structure sections as nearly vertical. The probability, however, is that most of the faults dip westward.

Displacement. The displacement of some of the faults can be measured in thousands of feet, the greatest being at the west side which has been uplifted with regard to the east side in all the faults of any great displacement.

Faults with the east side uplifted have not been recognized, and if present the displacement is small.

Evidence of Faulting.

Sudden and pronounced breaks in the sequence of the rocks were the most reliable evidence of faulting and distinguish the surface expression of the faults from the erosion features of the folds. Where the displacement has been greatest, the rocks near the fault-contact generally show very little disturbance. The smaller breaks, on the other hand, are often accompanied by intense folding. It is quite probable that there are many small breaks that cannot be detected at the surface, but may be encountered in mining or boring operations.

Thrust Faults.

There are three faults of large displacement which appear to be overthrusts. These may be called for convenience the Pekisko fault, the Rowe fault, and the Lewis-Clarke overthrust. The Pekisko fault occurs in the vicinity of Pekisko creek, where it follows the western side of range 2, townships 16 and 17. It is difficult to prove the existence of this fault as much of the bedrock is concealed, but it is inferred because of the peculiar relation of sandstones of the Blairmore formation which appear both to overlie and underlie Benton shales. The fault is also indicated by marked irregularity in the strike and dip of the sandstones.

The Rowe fault occurs at the western margin of the disturbed belt in the vicinity of Oldman river, where the Kootenay and basal beds of the Blairmore formation have been thrust eastward and superposed upon sandstones of the Belly River formation. The actual surface of the contact was not seen, but its position was determined within 30 feet where cut by the river. On the hills north and south of the river the older Kootenay and Blairmore rocks are found one-half to one mile east of where they occur at the level of the river. The outcrop of the older rocks on the hills is less than 500 feet above the river, showing that the slope of the fault-plane is less than 500 feet in 3,000 or 4,000 feet. The relations, therefore, indicate a very flat dip for the fault-plane. The overthrust can be traced for about 2 miles north and about the same distance south of the river. Following the strike southward the overthrust part of the fault seems to end rather abruptly against hills composed of Belly River sandstones which project west. This irregular distribution suggests that the surface previous to the overthrusting was a rough one. The points of higher relief on the pre-existing surface may have formed a barrier to the overthrust. On the other hand, the older rocks may well have been overthrust and superposed upon the pre-existing hills, and in consequence of their greater elevation have been removed by erosion.

LEWIS-CLARKE OVERTHRUST.

In the southern part of the area the Lewis series,[1] comprising rocks of Cambrian and Pre-Cambrian age, abuts against Cretaceous rocks of the adjacent plains. The actual fault-contact was not observed, the rocks being concealed by glacial debris. The overthrust relation is, however, strongly suggested by the sinuous outcrop of the Lewis series. Willis[2] has demonstrated that the Lewis range in northern Montana has been driven eastward or northeastward over the Cretaceous formations of the plains. There are several outliers of older rocks superposed upon Cretaceous strata in the Crowsnest region to the northwest. The best known of these is perhaps Crowsnest mountain.[3] The evidence of a great overthrusting at these several points is sufficient to show that this phenomenon was a general one throughout the eastern mountain ranges.

[1] Daly, R. A., Geol. Surv., Can., Mem. 38, pt. I, p. 49.
[2] Willis, B., Bull. Geol. Soc. Am., vol. 13, pp. 331-343.
[3] Dawson, G. M., Geol. Surv., Can., Ann. Rept. 1885, vol. I, pp. 66-67 B.

PROBABLE CAUSE OF GENTLE DIPS IN CRETACEOUS STRATA NEAR THE MOUNTAINS.

A notable structural feature is the gentle dip of the Cretaceous strata in the vicinity of the Clarke range. A strip 6 to 8 miles wide stretches along the foot of the mountains, and is characterized by broad undulations and gentle dips, whereas the same rocks immediately to the east are intensely folded and faulted.

The rocks of the Lewis series superposed upon the Cretaceous probably originally extended some distance east of their present outcrop and have been since removed by erosion. It seems possible that the break along the overthrust fault-plane took place before any great amount of folding in the Cretaceous strata had been accomplished. Once the break was formed, the pressure would be relieved by movement along the fault-plane. In this way the Cretaceous strata may have been overridden by older rocks for 6 to 8 miles east of the Clarke range. This superposing of a great load of older rocks on the Cretaceous made the latter competent to withstand subsequent stresses. When the friction along the thrust-plane became too great, the compressive stresses were transmitted to the Cretaceous strata farther east, where relief was obtained by intense folding and faulting of those rocks without a supporting capping or load. At the same time the stresses were probably in part relieved by folding and faulting in the overthrust itself.

CHAPTER VI.

SUMMARY OF GEOLOGICAL HISTORY.

The main features in the geological history of the disturbed belt may be summarized as follows: (1) a long period of sedimentation with intervals of erosion that lasted from Jurassic to early Tertiary time; (2) the Laramide Revolution—a great orogenic movement which folded and faulted all of the rocks that occur in the region. This disturbance probably ended in early Eocene time, according to present standards of correlation; (3) erosion accompanying and following the deformation; (4) continental uplift and local warping in Middle Cenozoic time, followed by: (5) erosion and local base-levelling; (6) renewed continental uplift in Pliocene time; (7) invasion of the region by the Pleistocene continental ice-sheets from the east and by glaciers from the mountains.

JURASSIC PERIOD.

The geological record of the disturbed belt (or foothill region) begins in the upper Jurassic. The oldest rocks are the Fernie shales. These shales were deposited in a sea which had a boreal fauna and hence was probably connected with the northern Pacific and Arctic oceans.

The fauna is a small, monotonous one, and is almost altogether made up of molluscs, including a few ammonoids and squids. These indicate that the waters were not those of the open sea but rather of a large bay.

LOWER CRETACEOUS.

The earth-movements which resulted in the draining of the Jurassic sea were reflected as gentle warping in this area, for the next formation, the Kootenay, lies conformably on the Jurassic beds. Schofield[1] correlates this movement with the disturbance which built the Purcell range in eastern British Columbia. The uplift developed a barrier in the eastern British Columbia region effectually barring the seas which later in Cretaceous time covered the Great Plains and foothills from connexion with the Pacific region.

The large amount of fine-grained sediment and the occurrence of numerous coal seams indicate low marshy lands in this vicinity. The deposits are known to extend several hundred miles in a northwest-southeast direction. They thicken rapidly toward the west where conglomerate and sandstone beds are more numerous, suggesting that the higher land lay in that direction.

In southern Alberta the fossils which occur in these deposits are entirely plants: ferns, cycads, and conifers.

[1]Schofield, S. J., Geol. Surv., Can., Mem. 76, p. 97.

UPPER CRETACEOUS.

BLAIRMORE STAGE.

Some high land apparently existed to the west at the beginning of the Upper Cretaceous period. The elevation of this land mass, taking place in late Lower Cretaceous time, was probably during one of those times of marked continental warpings which so often occur towards the close of a period. The evidence of the elevation is seen in the persistent conglomerate which is at the base of the Upper Cretaceous sediments in the disturbed belt. This conglomerate is apparently derived from the Purcell range 50 to 75 miles west of the area examined. The conglomerate in places is 50 feet above the uppermost coal seam, whereas in other places it practically forms the roof of the seam. Its persistence and uniformity make it useful as a reference bed for a distance of 120 miles in a north-south direction.

BENTON OR COLORADOAN STAGE.

During early Upper Cretaceous time the sea again began to invade North America, spreading from the gulf of Mexico until it merged with an invasion from the Arctic. This was the Coloradoan sea, which split the North American continent into two unsubmerged parts, a small western one and a larger eastern one. In the Rocky Mountain region the sea was apparently shallow, as the sediments are mainly clay-shales and the fauna consists entirely of mud-loving molluscs.

BELLY RIVER STAGE.

The downwarping of the Cretaceous geosyncline did not keep pace with the sedimentation at the west, and the Benton sea withdrew from this region. During the Belly River stage which followed, there were many fluctuations in this downwarping and filling up of the sea. At times the continental deposits were built up so as to force the shore-line a considerable distance eastward. Then downwarping would set in and the sea again spread westward. This fluctuation in the comparative level of sea and land in this vicinity resulted in a series of interleaving of marine and continental deposits to the east of the foothills. There is no evidence to show that the open sea again covered continuously what is now the disturbed belt, before the Bearpaw stage. That the sea was close by is evident, however, from the occurrence of brackish-water molluscs in some beds of the Belly River formation at the west.

The sediments deposited during Belly River time have frequently been described as lake deposits, but the probability is that they were laid down upon the broad flood-plains of rivers near sea-level. It is inevitable that great ponded stretches existed under such conditions, but that lakes of any considerable depth occupied the region is highly improbable. Evidence which favours a fluvial or flood-plain deposition is found in the following: (1) The presence of dinosaurs, land-inhabiting reptiles. (2) Numerous plant remains, impressions of leaves, stems, and vertical rootlets. (3) Coal beds of varying thickness and in many cases of local extent. (4)

Numerous occurrences of unios, bivalves which live only in fresh waters where there are currents. (5) The common occurrence of crossbedding and ripple-marks in the sandstones. (6) The shales occur in irregular, thick beds, suggesting rapid deposition. If deposited in deep, still water of lakes, the muds would be found in thin and regular layers. (7) The clastic material of the sandstone is mostly angular and in size is near the lower limit of rounding for quartz grains in water as determined by Goldman.[1] The predominance of angular fragments suggests deposition by rivers.[2]

BEARPAW STAGE.

Toward the close of the Belly River stage the land at the west had apparently become well worn down, the supply of sediment became smaller in amount, and a great coal swamp extended along the seaward margin. With the settling of the deposits and further downwarping the sea again spread over much of the Rocky Mountain region. It was shallow, as might be expected, and was inhabited by mud-loving molluscs, large ammonoids and baculites being abundant.

The record of the original extension of this invasion has been removed by erosion from the western foothills, but as the marine deposits are over 700 feet thick, and show no evidence of thinning or increasing coarseness of sediment in the most westerly exposures observed, the shore probably lay some considerable distance west of their present known occurrence.

The Bearpaw stage was brought to a close by crustal warping and by filling up of the sea. These combined to drain the marine waters from this part of the continent for the last time. The sea, however, remained some time longer in the plains region to the east.

ST. MARY RIVER STAGE.

During the early part of the St. Mary River stage the land to the west of this region was very low. Extensive coal swamps spread along the eastern margin of the land and oysters flourished in great abundance in the brackish water at the mouths of the river valleys. There were some minor oscillations of sea-level during this early time, but they were unimportant and the general tendency was for the land to rise. The deposits, and the record of life which they contain, are very similar in every respect to those of the Belly River formation. Conditions of deposition, climate, and topography are thought, therefore, to have been a repetition of what has just been described as existing during the Belly River stage.

TERTIARY (?)

WILLOW CREEK STAGE.

Deposition of a continental character was practically continuous in this region, from St. Mary River time until all of the Porcupine Hills formation was laid down. It is probable that many minor unconformities or disconformities occur within this thick series which Dawson grouped under the general name of "Laramie," but deposition is thought to have

[1]Goldman, M. I., Am. Jour. Sc. (4), vol. XXXIX, p. 272, and Figure 4, p. 269.
[2]Idem, p. 273.

been continuous. During this time broad rivers with low gradients meandered over the wide flood-plains and near the sea were probably split up into many distributaries. The channels were shifted by lateral erosion, and alternate erosion and deposition in the same place followed one another at comparatively short intervals. As more material was carried in from the higher lands the basin gradually settled and the rate of settling was apparently about equal to the rate of deposition.

The sedimentation which took place during the Willow Creek stage is distinguished by the red colour of the deposits.

PORCUPINE HILLS STAGE.

The change which occurred at the end of the Willow Creek stage not only eliminated the development of a red colour in the sediments but it also enabled the streams to transport somewhat coarser material.

The numerous intercalations of crossbedded sandstones and irregular, thick-bedded shales and shaly clays, together with the presence, though rare, of freshwater molluscs and a few plant remains, are perhaps sufficient to show the general continental character of the deposition at this time.

LARAMIDE REVOLUTION.

The whole region was folded and faulted after the laying down of the Porcupine Hills formation. This is the deformation generally known as the "Laramide Revolution," and the structures produced at this time have exercised a controlling influence in the carving of the Rocky mountains.

Since all of the rocks in the region were affected by this deformation, the disturbance postdates the youngest deposits of the Porcupine Hills formation. The Porcupine Hills formation is correlated with the Paskapoo because it occupies the same stratigraphic position and occurs to the south of the latter in the same synclinal basin. On the basis of contained fossils the Paskapoo is considered to be the equivalent of the Fort Union of Montana. This then dates the Laramide disturbance as post-Fort Union.

EOCENE.

Deposits of later date than the Laramide Revolution, in the disturbed belt, consist entirely of glacial drift. During Eocene time the region was probably being eroded.

OLIGOCENE.

The Oligocene is recorded in the Cypress Hills region of southern Canada, about 200 miles east of the Rockies[1] where it is found that conglomerate beds of this age cap all the more elevated parts of the uplands over an area 15 miles wide by about 140 miles long. The linear extension of these deposits is in a northeast direction. The pebbles of the conglomerates are nearly always composed of hard quartzite and vary in size from coarse sand to 8 and 9 inches in diameter, though the usual size is from 2 to 4 inches. These conglomerates are unconformable on the Laramie and overlap on the Fox Hills and Pierre, implying a considerable erosion during Eocene time.

[1]McConnell, R. G., Geol. Surv., Can., Ann. Rept. 1885, vol. 1, pp. 30–31, 68–70 C.

The history of the western plains and foothills region seems to have been about as follows. Early in Oligocene time the land at the west was uplifted, which rejuvenated the streams and enabled them to transport coarse gravels. In the west they were confined to narrow channels, but farther east they spread out over wide valleys, lost their momentum, and deposited their loads of sediment.

MIOCENE AND PLIOCENE.

A quantitative estimate of the amount of denudation during Tertiary time, or, more accurately, since the Oligocene, is obtainable in the Cypress Hills region, where erosion remnants, capped by flat-lying Oligocene gravels, rise 2,000 feet above the surrounding plains.

PLEISTOCENE.

ICE AGE.

The foothills and mountains had attained much of their present altitude and were incised by deep valleys by the end of Pliocene time. The climate became very cold following the elevation of the continent and great accumulations of snow collected, formed ice, and began to radiate from three main centres, commonly known as the Cordilleran, the Keewatin, and the Labradorean.

The first ice to invade this foothills region came from the mountains in the form of valley or piedmont glaciers and these early mountain glaciers left gravels which are preserved on some of the highest foothill ridges. This invasion was followed by a great ice-sheet that had been spreading from the Keewatin centre west of Hudson bay. Owing to changes in climate this ice-sheet disappeared leaving traces of its retreat in some of the valleys in the form of boulder clay. For some time the climate was sufficiently warm for the growth and accumulation in places of a considerable amount of vegetation which formed peat bogs. The boulder-clay was considerably weathered and part of it was reworked by the streams and laid down as stratified silts.

The interglacial period came to an end when ice which had accumulated in the mountains again spread into the foothills. The ice deployed into the valleys, completely filled them, and in many cases spread across the stream divides, merging with the ice in adjoining valleys to produce glaciers of the piedmont type. Only the largest of these glaciers reached the plains; the smaller ones owing to wastage were unable to push beyond the foothills. These mountain glaciers overdeepened the valleys near their head and produced rock basins in the mountains. Toward the eastern margin their erosive activity was small.

The mountain glaciers of this latest Wisconsin stage were immediately followed by a continental ice-sheet which had spread from the east, showing that the plains region had by no means a warm climate. North of the International Boundary this eastern ice spread to the foot of the Clarke range. Farther north, the ice appears to have had sufficient grade at its western edge to enable it to reach well up on the Porcupine hills.

The effect of this great mass of ice, which spread from the east, was to dam the streams flowing from the mountains and this developed numerous long lakes in the valleys at the west. As the ice receded, the water in these lakes was lowered. When the ice had retreated, the mountain streams found their old valleys almost completely filled with morainal material and were forced to cut new channels in the drift. In most cases the present channels are in the old valleys, but have been shifted laterally from the centre of the old valley. Where this occurs the streams, on cutting through the drift, have been in places superimposed upon hard rock ridges in which they have cut narrow gorges with steep, often vertical walls. On the uplands the irregular distribution of the glacial drift of the terminal moraine has produced numerous small kettle lakes and marshy tracts. The poor development of the drainage in this region where the relief is quite marked, together with the fresh character of the glacial debris, is sufficient evidence of the recency of the last great continental glaciation.

CHAPTER VII.

ECONOMIC GEOLOGY.

COAL.

Coal occurs in three formations in this region, namely, in the Kootenay, the Belly River, and the St. Mary River. There are no shipping mines within the area, but coal seams have been opened up at several points by small prospect tunnels, to supply the local demand for domestic fuel.

Coal of the Kootenay Formation.

The Kootenay formation is persistently coal-bearing throughout its whole extent in the Rocky Mountain region. The rocks outcrop at the surface only at the western edge of the area mapped, the formation lying mainly within areas studied by Mackenzie[1] and Leach[2] and, more recently, by Rose.[3]

Coal of the Belly River Formation.

The Belly River formation is coal-bearing at two horizons, at one of which the coal is persistent over a large area. The lower of these two coal-bearing horizons occurs about 400 feet above the base of the formation, that is, above the upper, dark, marine, Benton shales. The upper horizon is within the upper 100 feet of the formation, immediately beneath the marine Bearpaw shales.

The beds at the lower horizon are coal-bearing from Oldman river to Crowsnest river. They contain only one workable seam, associated with carbonaceous shales and sandstone showing thin coaly streaks. The coal bed is very irregular in thickness and feathers out in places. In a short tunnel on Oldman river the seam shows a change in thickness from 2 feet to 6 feet within a distance of 50 feet. The coal bed at this prospect shows pinches and swells which have been caused apparently by the unequal distribution of the compressive forces to which the beds have been subjected. The following is a list of localities where the seams at this horizon have been opened by prospect pits or trenches.

Location.	Thickness. Feet.
SE. ¼ sec. 31, tp. 10, range 2, west 5th mer.	3 to 5
NE. ¼ sec. 19, tp. 10, range 2, west 5th mer.	Average 3 to 4, very irregular
SW. ¼ sec. 31, tp. 8, range 2, west 5th mer.	3 to 6
NE. ¼ sec. 6, tp. 8, range 2, west 5th mer.	4

The upper beds are more persistently coal-bearing than the lower. Exposures of this part of the formation, showing at least one coal seam of workable thickness, were observed in the valley of Oldman river in the

[1]Mackenzie, J. D., Geol. Surv., Can., Sum. Rept., 1912, pp. 235-246.
[2]Leach, W. W., Geol. Surv., Can., Sum. Rept., 1911, pp. 192-200; Sum. Rept., 1912, map p. 234.
[3]Rose, B., "Blairmore map-area," Geol. Surv., Can, (in preparation).

northern part of the area and in the banks of Waterton river in the southern part. Southeast of the exposure on Waterton river, in township 4, the coal apparently pinches out as it was not observed on Lee creek nor on St. Mary river where the Belly River formation is well exposed and shows no coal beds.

As the coal beds are at the same horizon as those at Lethbridge and vicinity it seems very likely that the seams are continuous eastward from the disturbed belt. In the Porcupine hills, along the middle of the syncline they are deeply buried beneath younger rocks. The following is a list of localities at which work has been done at this horizon:

Location.	Thickness. Feet.
Oldman River—	
SE. ¼ sec. 22, tp. 10, range 2, west 5th mer.	1
Crowsnest river to Lundbreck—	
NE. ¼ sec. 26, tp. 7, range 2, west 5th mer.	6 to 7
Waterton river—	
SW. ¼ sec. 26, tp. 4, range 28, west 4th mer.	3
SE. ¼ sec. 35, tp. 4, range 28, west 4th mer.	Caved.

Between the years 1903 and 1911 an attempt was made to work the coal in this upper part of the Belly River formation on a somewhat larger scale and machinery was installed at Lundbreck for the purpose. The mines worked spasmodically until 1912 and much of the coal was shipped to Spokane. The last mining on a large scale was done on the occasion of a general strike of the miners at all the larger mines throughout the west, when the Lundbreck mines, being non-union, were able to operate continuously. Since 1912 all the workings have been closed with the exception of a small tunnel in the north bank of the river from which coal is taken to supply a small local demand. The main causes of the decline in production seem to have been the lack of a home market and the competition with more favourably situated mines, together with mismanagement in mining operations. The seams are intensely folded and broken by small faults. The mines require careful timbering and timber is only to be procured at a distance. West of Lundbreck are the highly bituminous to anthracitic Kootenay coals, to the east is the great Lethbridge field. Under such conditions it is not surprising that the coal at Lundbreck has not been continuously worked.

Coal of the St. Mary River Formation.

The beds of the St. Mary River formation are coal-bearing at several horizons in the lower 1,000 feet. They are persistently coal-bearing, however, only within the first 100 feet of sandy beds which follow in upward sequence the marine Bearpaw shales. Exposures of this horizon showing coal seams may be seen on all of the main streams from Oldman river southward to the International Boundary.

The following prospects on this coal were examined:

Location.	Thickness. Feet.
Oldman river—	
SE. ¼ sec. 11, tp. 10, range 2, west 5th mer.	3
Crowsnest river—	
NW. ¼ sec. 25, tp. 7, range 2, west 5th mer.	3
Castle river—	
NE. ¼ sec. 29, tp. 7, range 1, west 5th mer.	1
Pincher creek—	
NE. ¼ sec. 17, tp. 6, range 30, west 4th mer.	Prospect flooded.
Indian Farm creek—	
SE. ¼ sec. 34, tp. 5, range 29, west 4th mer.	2
Waterton river—	
NW. ¼ sec. 35, tp. 4, range 28, west 4th mer.	1
Belly river—	
SE. ¼ sec. 4, tp. 4, range 27, west 4th mer.	2
Lee creek—	
NE. ¼ sec. 26, tp. 2, range 26, west 4th mer.	9
St. Mary river—	
NE. ¼ sec. 9, tp. 1, range 25, west 4th mer.	4

No samples of the coal were taken by the writer, but its bituminous character is generally known. The available information regarding the character of the coals in the various formations throughout the entire foothills region has been brought together and tabulated by Dowling.[1] The coal is bituminous and unquestionably of good quality. Its future exploitation will depend on the thickness of the seams, the attitude of the beds, and the amount of folding and faulting which they have suffered. Where the seams in the Belly River and St. Mary River formations are thick the value of the coal is lowered in many places by partings of crumbly shale which cannot be separated in mining, giving a high percentage of ash and, consequently, a low heating value.

OIL AND GAS.

In 1915 prospect holes for oil were being drilled at widely separated points within this area by different companies. Up to the present (1916), however, the results have been negative.

Small seepages of inflammable gas with a decidedly gasoline-like odour are known to occur at two points, namely NW. ¼, sec. 20, tp. 15, range 2, west 5th mer., and NW. ¼ sec. 6, tp. 6, range 1, west 5th mer.

Some of the Benton shales give off an odour of paraffin on being struck by the hammer, and may be of value in the future as oil shales.

Small seepages of oil and gas in the part of the disturbed belt cut by Sheep river southwest of Calgary led to the drilling of a test hole in 1913. At a depth of 1,550 feet, a small amount of light oil was found in sandy beds, now thought to be of Dakota age. This find encouraged the prospectors in the hope that further boring might lead to the discovery of oil in commercial quantities. As a result, the entire foothill belt has since been the scene of active boring operations. Other discoveries of oil in small quantities have been reported from this region and are generally believed to have been made in the Dakota.

In regard to the probability of productive oil reservoirs being found in this region it may be stated that the experience gained in other parts of the world indicates that areas in which the rocks are intensely folded

[1]Dowling, D. B., Geol. Surv., Can., 1914, Mem. 53.

and faulted as they are in the greater part of the disturbed belt are unfavourable for the accumulation of large quantities of oil. The results of boring operations so far in this region tend to confirm the above statement. There are so many unknown factors to be taken into consideration, however, that it would be hazardous to state dogmatically that oil may not be found in commercial quantities in these rocks. For example, although a light oil requires a covering of impervious shale to prevent its escape a heavy oil containing much bitumen may collect where there is a monoclinal structure in the rocks, as the bitumen left behind by the evaporation of the lighter constituents seals up the exposed end of the oil-bearing stratum.

The most favourable structures observed are found in the belt of rocks affected by gentle and open folding, which lies along the east base of the Clarke range in the southwestern part of the disturbed area.

SHALE.

Shales suitable for the manufacture of common brick are of widespread occurrence in practically all of the formations within the area. Several of these shale beds have been reported on by Ries and Keele.[1] Their tests showed that though generally suitable for the manufacture of common brick no sample was of a sufficiently high grade for the manufacture of fire-brick or vitrified wares.

Four additional samples of shales occurring in the St. Mary River formation were submitted to the Mines Branch and the following report upon them was made by Joseph Keele, chief of the ceramic division.

Locality: Indian Farm creek, sec. 4, tp. 5, range 29, west 4th mer., southern Alberta.

Lab. No. 377, Field No. 1. Light grey, hard shale.

This material contains enough lime to cause it to effervesce on application of acid. When ground and mixed with water, it has only medium plasticity, being rather short in texture. Its drying qualities are probably good, and the shrinkages are low in drying and burning.

This shale burns to a light red colour and porous body at lower temperatures, but tends to turn to a buff or brown colour at the higher temperatures. It is easily fusible and will show effects of overfiring at 2,000 degrees F.

Uses: Common building brick.

Lab. No. 378, Field No. 2. Grey shale rather soft and crumbling.

When ground and mixed with the right amount of water this shale forms a very plastic mass which is rather stiff in working. Moulded shapes made from this shale dry very slowly and have a tendency to crack. The shrinkage on drying is large, but within working limits.

It burns to a fine red colour and steel hard, dense body at about 1,900 degrees F.

Uses: On account of its poor drying qualities this shale is not recommended for the manufacture of wet moulded clay products, but might be used for making building brick by the dry press process.

Lab. No. 379, Field No. 3. Light grey, hard, non-calcareous shale.

This material has good plasticity and working qualities in the wet state, and the drying shrinkage is not unduly high. It requires to be dried

[1] Ries, H., and Keele, J., Geol. Surv., Can., 1912, Mem. 24 E.

slowly, otherwise it will crack. On burning to about 1,900 degrees F. it becomes deep red in colour and steel hard. It is easily fusible.

This material is very similar in its properties to No. 378, and like it would make dry pressed bricks of fine deep red colour.

Field No. 4. This sample was a soft, grey shale containing some hard lumps or nodules. This material is highly plastic and sticky in the wet state. It cracked and warped so badly in drying that it was discarded as useless for the manufacture of clay products.

Summary of Tests.

The three samples on which the tests were carried to a conclusion, fuse at fairly low temperatures and do not approach the requirements of even semi-refractory clays. They are not suitable for the manufacture of vitrified wares, as their range of vitrification is so small that they easily become overfired.

A mixture of the three shales might be used for the manufacture of wire cut bricks or hollow blocks, but the drying qualities of the mixture would have to be carefully tested beforehand.

The commercial limits of burning structural wares made from these shales would probably range from 1,750 to 1,900 degrees F.

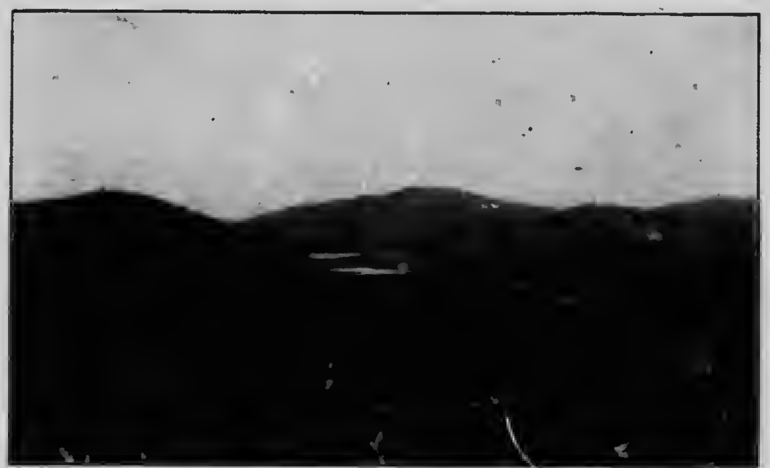
PLATE II.

A. View across valley of Willow creek along strike of rocks. (Page 18.)

B. Longitudinal valley at west base of Porcupine hills. (Page 18.)

57186

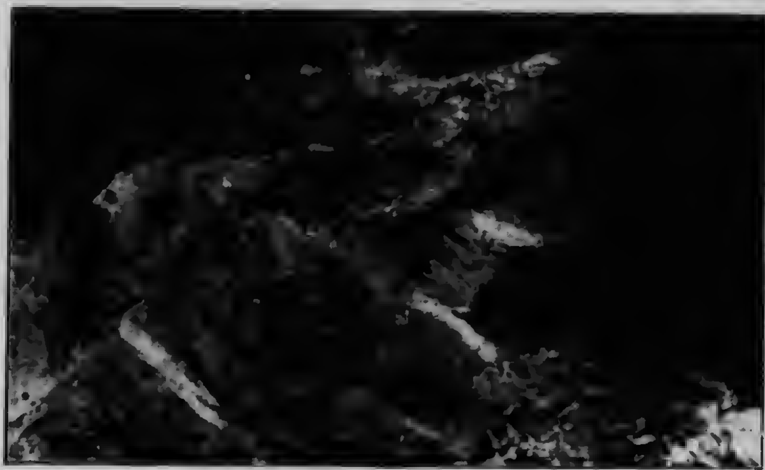
A. Water-gap on Lee creek about 6 miles above Cardston. (Page 21.)



B. Foothills in township 8, north of Crowsnest river. (Page 17.)

PLATE IV.

Small fold in sandstones of the Belly River formation on Lee creek. (Page 54.)



A. Overturned fold in arenaceous shales of Kootenay formation on Oldman river. (Page 54.)

B. Faulted sandstones of St. Mary River formation on Lee creek. (Page 54.)

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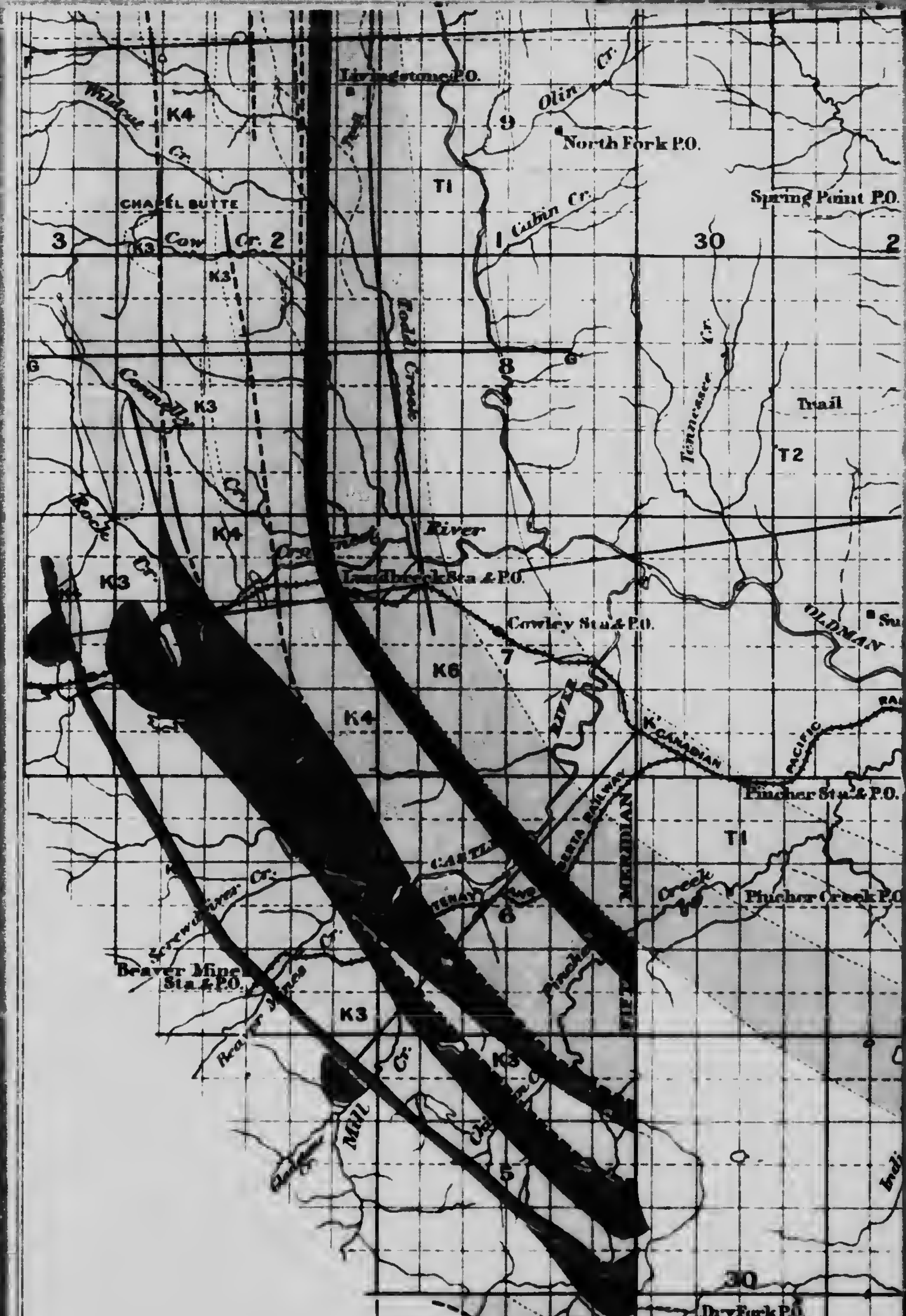
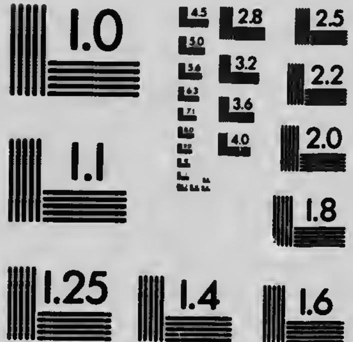
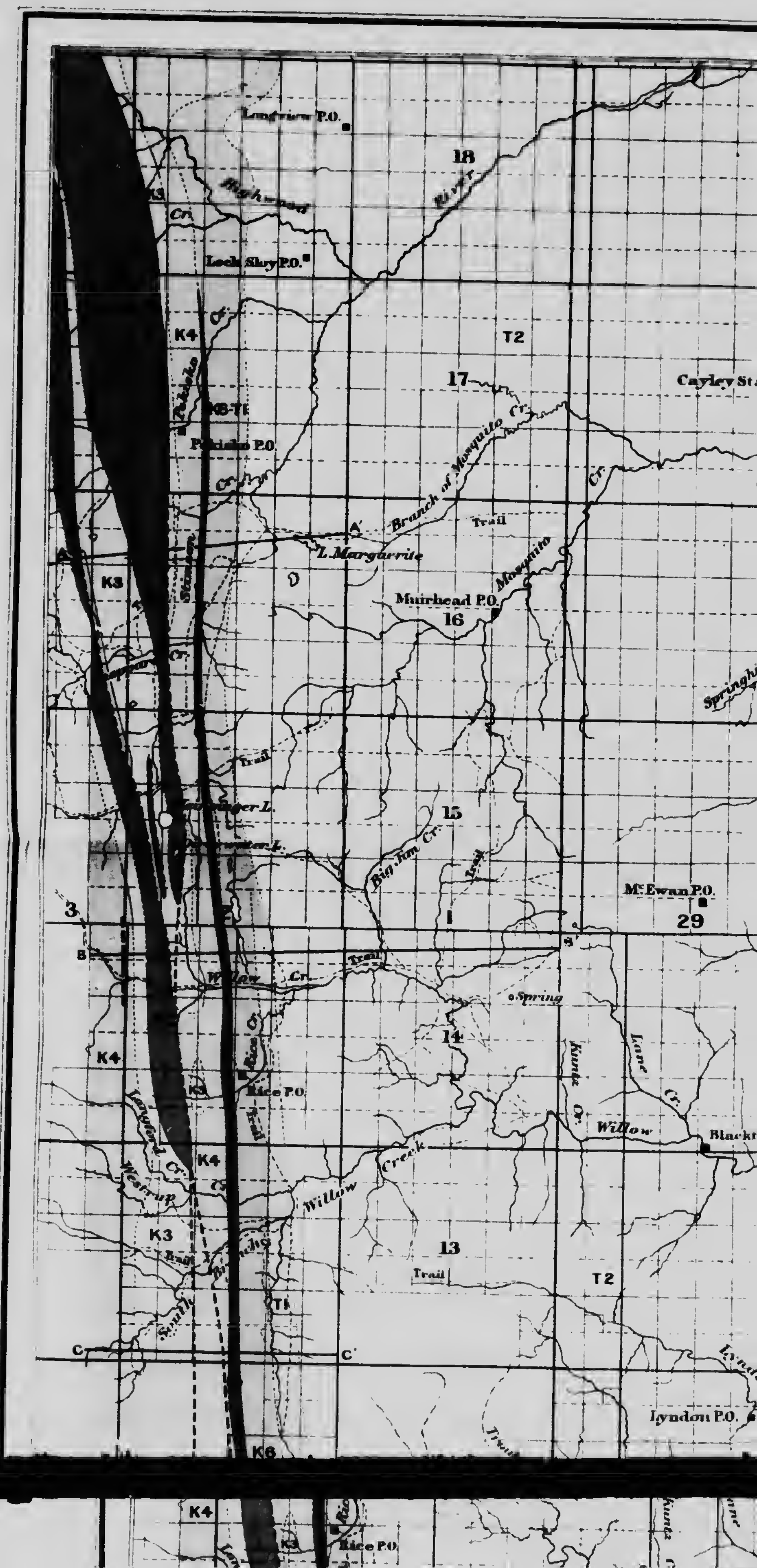


Livingstone P.O.
Olin Cr.
North Fork P.O.
Spring Point P.O.
Cabin Cr.
Wildcat Cr.
CHAPEL BUTTE
Cow Cr.
Todd Creek
Connelly Cr.
Tennessee Cr.
Trail
Rock Cr.
River
Lundbreck Sta. & P.O.
Cowley Sta. & P.O.
OLDMAN
CANADIAN PACIFIC
Pincher Sta. & P.O.
MERIDIAN
CASTLE
Creek
Pincher Creek P.O.
Beaver Mines Sta. & P.O.
Beaver Mines
Mill Cr.
PRAIRIE BLUFF
Dry Fork P.O.
Pincher
Cr.

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)





LEGEND

T2

Porcupine Hills sandstone

TERTIARY

Canada
Department of Mines

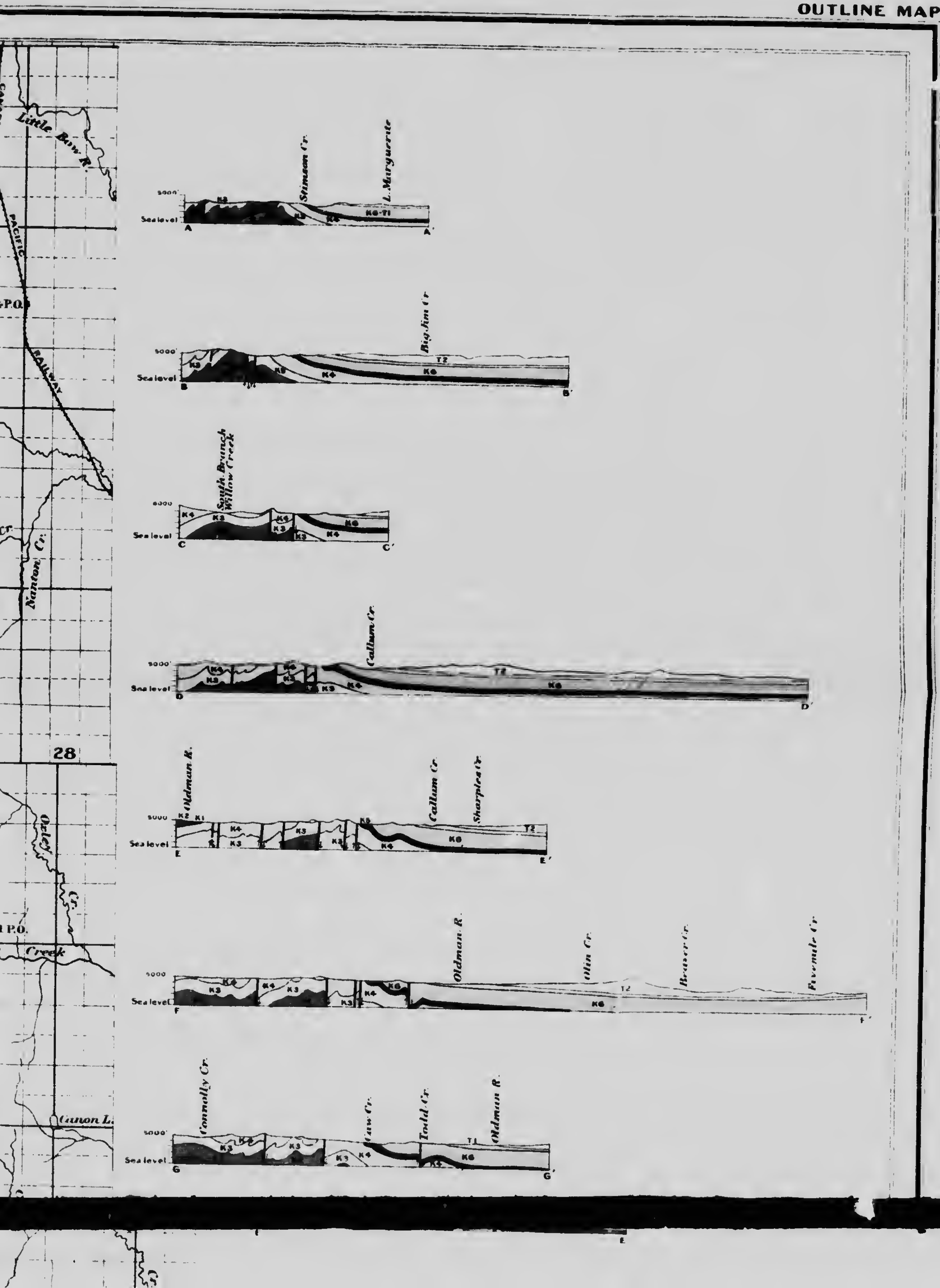
N. BURRELL, MINISTER; R. G. McCONNELL, DEPUTY MINISTER

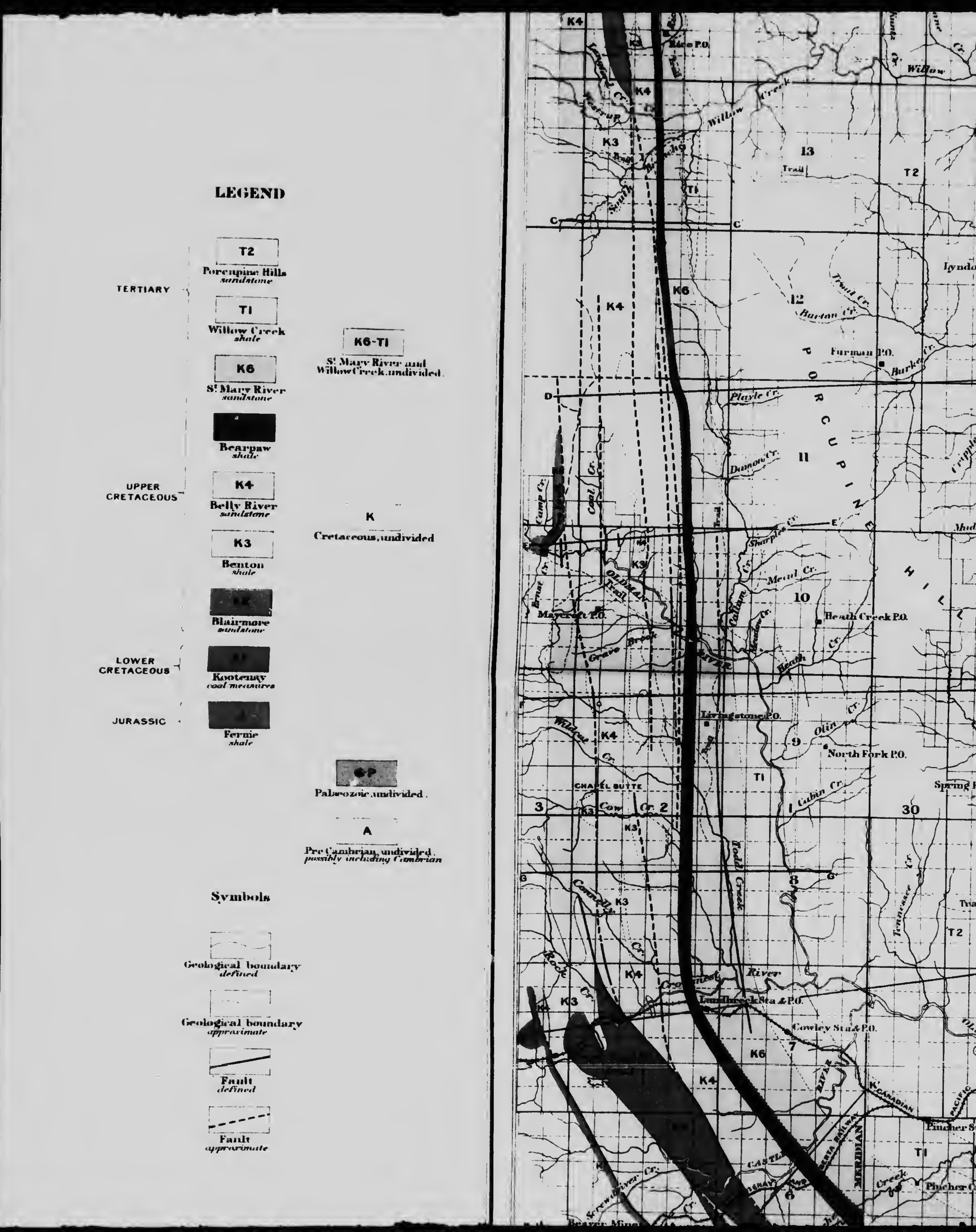
GEOLOGICAL SURVEY

WILLIAM McINNES, DIRECTING GEOLOGIST

Issued 1918

OUTLINE MAP




LEGEND
TERTIARY
T2
Porcupine Hills sandstone
T1
Willow Creek shale
K6
St. Mary River sandstone
Bearpaw shale
UPPER CRETACEOUS
K4
Belly River sandstone
K3
Benton shale
Blairmore sandstone
LOWER CRETACEOUS
Kootenay coal measures
JURASSIC
Fernie shale
K6-T1
St. Mary River and Willow Creek, undivided.
K
Cretaceous, undivided
Palaeozoic, undivided.
A
Pre Cambrian, undivided, possibly including Cambrian
Symbols
Geological boundary defined
Geological boundary approximate
Fault defined
Fault approximate
Willow Creek
PORCUPINE HILLS
Furman P.O.
Heath Creek P.O.
Livingstone P.O.
North Fork P.O.
Mayeroft P.O.
Lundbreck Sta. & P.O.
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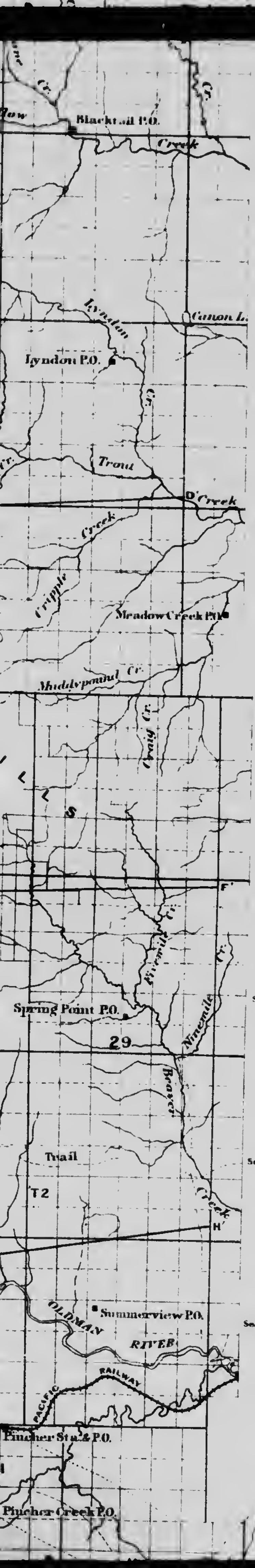
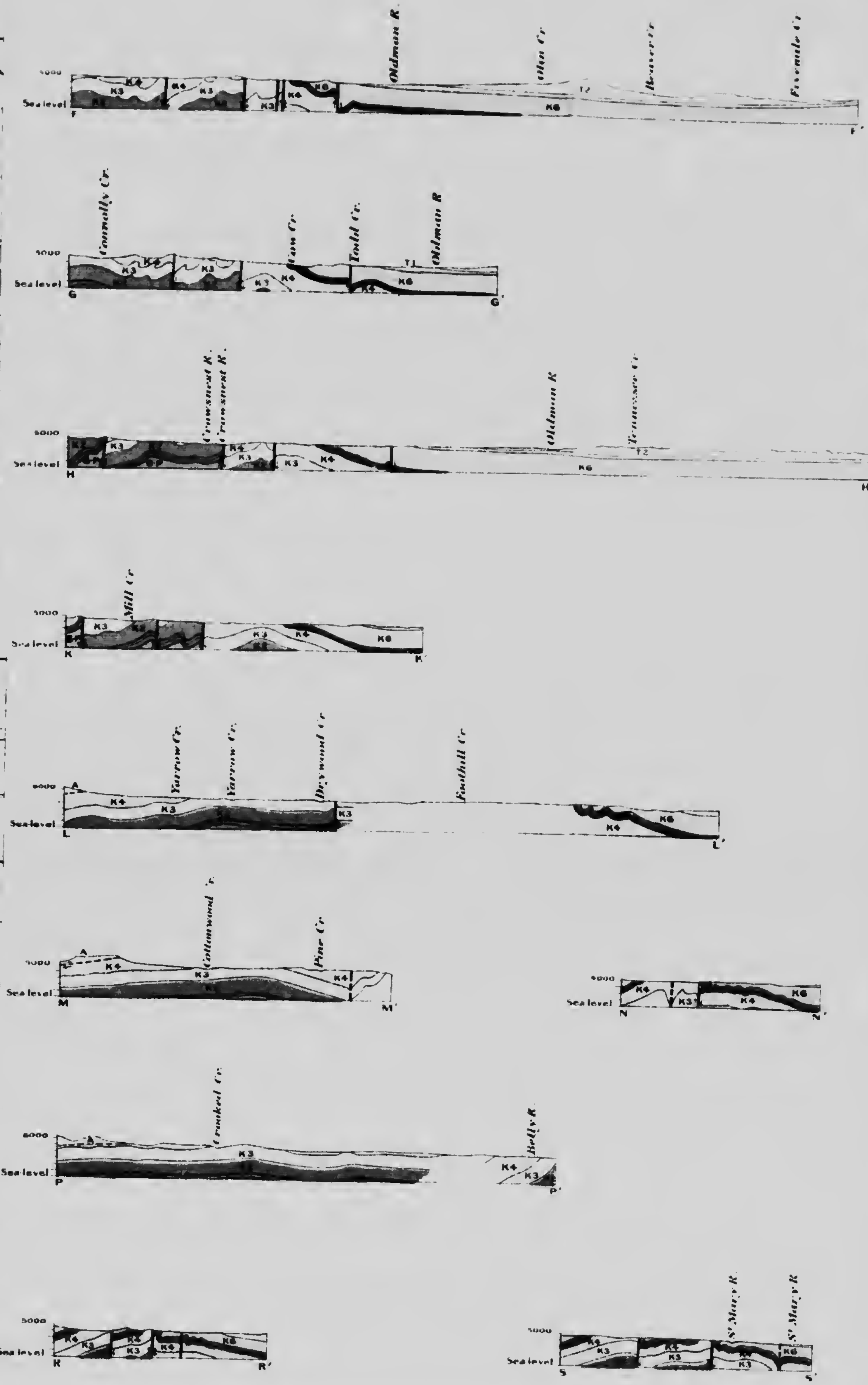
Cow Cr.
Tennessee Cr.
MERIDIAN
CANADIAN PACIFIC
Pincher Creek
Rice P.O.
Beaver Mines





Structure sections along lines AA'–SS'

Horizontal Scale of Miles

2 1 0 2 4

Note; The faults, shown in the sections by vertical lines, probably dip west.

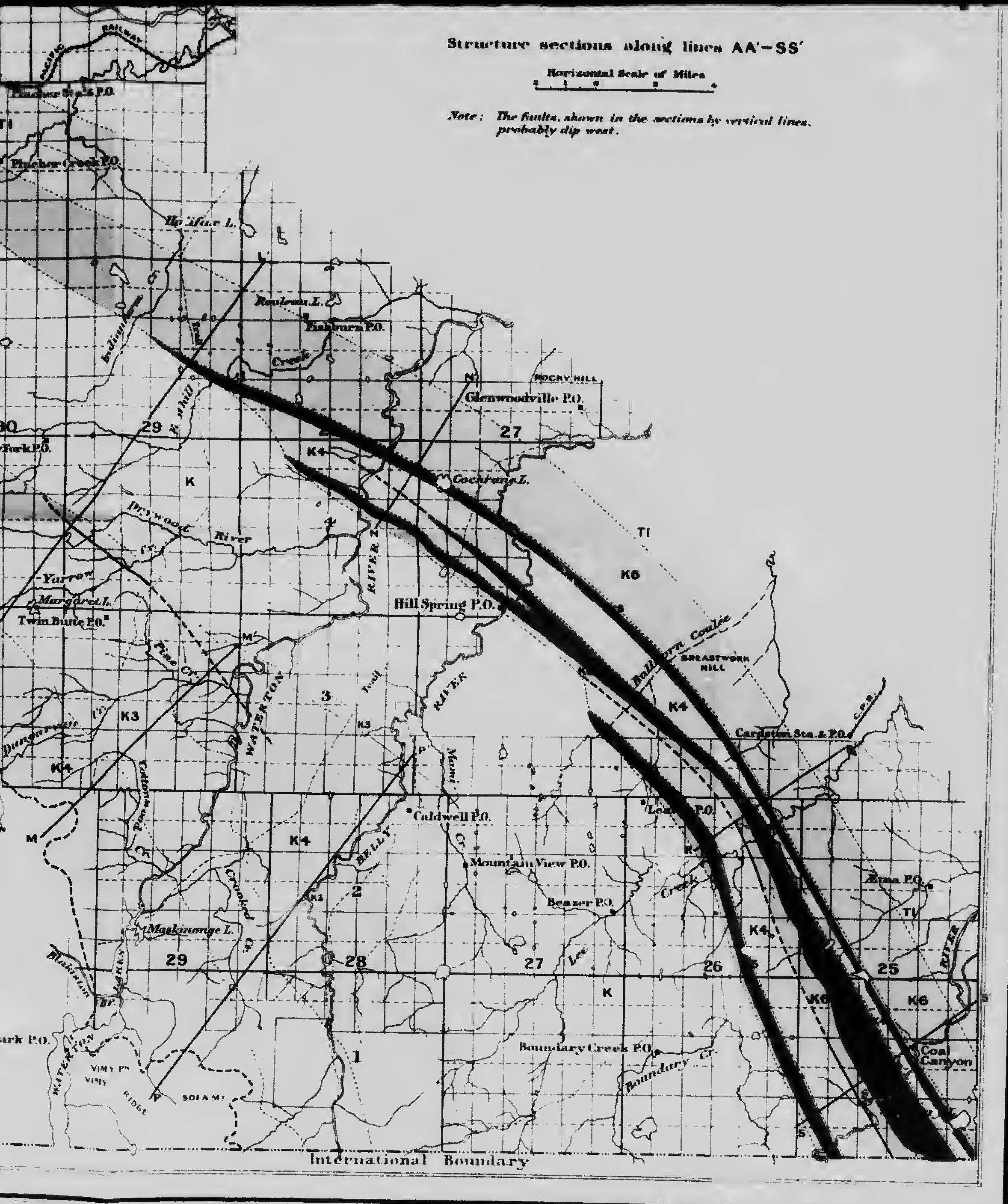
Fault
defined

Fault
approximate

C.O. Senécal, *Geographer and Chief Draughtsman*
A. Braidwood *Draughtsman*

THE FOOTHILLS OF SOU

To accompany Memoir by J.S Stewart



Publication Nº 1712

F SOUTHERN ALBERTA, S^T MARY RIVER TO HIGHWOOD RIVER

Scale of Miles

Geology by J.S. Stewart, 1914, 1915 and S.E. Slipper, 1914.