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CANADA
DEPARTMENT OF MINES
HON. W. A. GORDON, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

GEOLOGICAL SURVEY

W. H. COLLINS, DIRECTOR

MEMOIR 163

**Geology of Southern Alberta and
Southwestern Saskatchewan**

BY
M. Y. Williams and W. S. Dyer



OTTAWA
F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1930

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Geology of Southern Alberta and Southwestern Saskatchewan

CHAPTER I INTRODUCTION

The general geological features of the southern plains were recognized by Dawson (1873-4) and McConnell (1883-5). More recently, Dowling, Stewart, Slipper, Rose, McLearn, and Allan have given more detailed accounts of the stratigraphy and general structural geology of much of the region. The general settlement of the country, however, with the accompanying increase of interest in its mineral development, especially as regards coal, gas, and oil, made necessary a revision of the stratigraphy and structure.

The region covered by this report extends from the disturbed belt on the west to the 109th meridian on the east, and from the 49th parallel to the 52nd parallel of latitude, that is from the International Boundary to a line 206 miles to the north. In the south it includes Dawson's type localities along the 49th parallel and McConnell's localities in Cypress hills, and joins with the work of United States geologists in Montana. The relationship of the undisturbed formations of the plains to those of the disturbed belt is to be seen in the west, and the problem of the Mesozoic-Tertiary boundary is raised in the west as well as in Cypress hills. The stratigraphic problems are those of the Mesozoic and Tertiary as no Palæozoic formations outcrop in the area.

The field work upon which the report is based has made it possible to prepare a geological map of the greater part of the area, and to give structural and stratigraphic interpretations. The map has been incorporated in the Calgary sheet, Map 204 A, which, with an accompanying sheet of structural sections, has already been published. The maps employed in the field and upon which the geology was originally plotted, varied greatly; some had accurate contours, others had only few determined elevations. For this reason the accuracy of the structure sections varies from place to place. Nevertheless, more information regarding altitude was available than ever before, and this was supplemented by levelling and plane-tabling.

Field work was begun in June, 1923, by E. J. Whittaker and M. Y. Williams. Due to Whittaker's illness during the summer of 1924, A. J. Childerhose carried on instrumental surveys for him under the supervision of Williams. After the untimely death of Mr. Whittaker, in September, 1924, W. S. Dyer took over his work and carried it to completion during the summers of 1925 and 1926. P. S. Warren did work in the northeastern part of the area during the summers of 1925 and 1926.

Williams, during the summers of 1923-24-25-26, surveyed the first row of eight townships extending north from the 49th parallel, and east and west across the area; Whittaker and Dyer surveyed the second row, townships 9 to 16 inclusive; and Warren surveyed the northeastern part of the area from the 109th meridian to range 8, west of the 110th meridian, and from the northern boundary of township 16 to the 52nd parallel of latitude. The northwestern part of the area was not surveyed in detail, but Dyer spent a few weeks on Bow and Red Deer rivers investigating the salient parts of the stratigraphy from the 109th meridian to range 8, west of the 110th meridian and from the northern boundary of township 16 to the 52nd parallel of latitude.¹

Of the student assistants employed during the four years of field work, four require special mention. C. H. Crickmay assisted Whittaker very efficiently in 1923 and by assisting Dyer in 1925 connected the work of Whittaker and Dyer. J. A. Abbott assisted Williams during 1923-24-25 and by his growing experience and appreciation of the problems to be solved, rendered very valuable service. A. J. Childerhose was in charge of leveling in a part of the area in 1924, doing semi-independent work. J. B. Webb was an efficient assistant to Dyer in 1925 and 1926. The following assistants also rendered faithful service on the various parties: Ralph Bird, Leonard Telfer, I. W. Jones, W. Yarwood, A. Pentland, J. O. G. Sanderson, F. M. Baker, H. A. Thompson, G. W. Crickmay, D. P. Goodall, and L. V. Bell.

To the managers of coal mines, oil syndicates, and ranches, the writers are indebted for many courtesies which aided materially in geological work. Mr. G. A. Nicholson, Land Agent at Lethbridge, deserves special mention. He not only supplied maps and information, but stored equipment and assisted the parties in many other ways. Mrs. E. M. Hamilton of Medicine Hat, likewise provided camping ground and storage space on different occasions and assisted the progress of the work in many ways. A. P. Philp of Medicine Hat, stored equipment and furnished logs of wells and other geological information. H. A. Parker, Supervisor of the Cypress Hills forest reserves, and his staff, supplied ponies and saddles, and by information and advice, greatly assisted work in this difficult region. Dr. J. H. Duncan, of Manyberries, pointed out the sandstone dykes described later in this report and assisted as a volunteer guide over a considerable area of country. To others, who most kindly allowed parties to camp upon their land, and assisted in various ways, the writers are sincerely grateful.

PREVIOUS WORK

The pioneer in the study of the geology of the western plains of Canada was Dr. G. M. Dawson. As geologist to the British North America Boundary Commission, he laid the foundations of geological knowledge for the region adjoining the 49th parallel from lake of the Woods to the Rocky mountains. During 1873 and 1874 he surveyed a linear distance of upwards of 1,400 miles, and it is clear from his reports that he covered large areas on both sides of the line. In those days field camps were liable to be stampeded by herds of buffalo driven onward by Indian hunters who were

¹In the preparation of this report, Dyer has been responsible for the identification of the freshwater and many of the brackish water fossils; Williams has taken the lead in the determinations of the marine, and near marine, forms.

not averse, the hunt being over, to steal horses or even to attack members of the party. Supplies had to be transported from Winnipeg and Fort Benton, the commissariat department being the largest and most important division of the organization. The general account of the operations is told by Capt. Anderson, astronomer to the Commissioner for the British Government, and makes most interesting reading. Although the organization and responsibility for the survey fell upon the executive officers of the commission, we must not overlook the risks taken and the difficulties overcome by Dawson, in accomplishing one of the most remarkable geological reconnaissance surveys on record. Much of southern Saskatchewan has not been geologically surveyed since Dawson's day, and the Sweet Grass hills of northern Montana have still no description in the literature to equal that of Dawson, although, as he explains, he had difficulty in examining the buttes for fear thieves would steal his horses in his absence. Of Dawson's more extensive work on the plains, Dowling says, "The classic description of the southern plains of Alberta is to be found in the report of Dr. G. M. Dawson on the region in the vicinity of the Bow and Belly rivers."

Next to Dawson, his one-time assistant, R. G. McConnell, deserves special mention. He discovered the Oligocene gravels of Cypress hills and the mammal bones from which their age was determined. His account of the deposition and origin of these gravels is still the foundation of all subsequent reports and his sections of the Fox Hills sandstone and "Fort Union" formation are accepted today as essentially correct. McConnell's map of Cypress hills, made in 1883, before any land surveys had been carried through this region, is remarkably accurate. To one who works in these regions today, with all the advantages of accurate maps, roads, and automobiles, the early work of Dawson and McConnell must remain a matter of wonderment.

Next to Dawson and McConnell, we owe most of our knowledge of the southern plains to D. B. Dowling and a group of younger men who worked for a number of years largely under his direction. These men are J. S. Stewart, S. E. Slipper, B. Rose, and F. H. McLearn. Dowling and his associates revised the work of Dawson, delimiting the Upper and Lower Pierre formations, subdividing the Belly River series, and giving the formations the names by which they are now known. Stewart worked out the structure of the southern part of the disturbed belt and Slipper did the same for Turner Valley region. Rose reported on Wood Mountain district and McLearn became the authority on the Mesozoic invertebrate faunas of the region. Dowling embodied the general information into his report on "The Southern Plains of Alberta" and turned his structural knowledge to commercial value in opening up the artesian water wells in the vicinity of Foremost. Three test wells were put down by the Dominion Government under Dowling's direction, and when all struck copious supplies of potable water, further development was carried on by the inhabitants of the region. The drilling in this field was much facilitated by the sub-surface contour maps and convergence maps which Dowling published from time to time. In fact the discovery of the Foremost gas field was in a sense an aftermath of the artesian water development.

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CHAPTER II

GENERAL CHARACTER OF REGION

The area described lies in southern Alberta and southwestern Saskatchewan between 49° and 52° north latitude and between 109° west longitude and a western boundary that crosses the 49th parallel at 113° 10' west longitude and runs northwest to latitude 52°. The dimensions are 206 miles from north to south and 220 miles, on an average, from east to west, the area being about 45,000 square miles. Of this about 8,600 square miles are in Saskatchewan and the rest is in Alberta.

The more important cities and towns located within the area are: Calgary, Lethbridge, Medicine Hat, Drumheller, Bassano, MacLeod, Cardston, Maple Creek, Pincher Creek, Raymond, Claresholm, High River, Okotoks, Robsart, Ravenscrag, and Coutts. Many other towns are situated within the area. Rail transportation is furnished by lines of the Canadian National and Canadian Pacific railways. Good, through roads connect the larger cities and towns and are supplemented by many secondary roads and trails. Most of the country is accessible by automobile during the summer months.

The area falls within the third or highest prairie steppe, the average elevation being about 3,500 feet above sea-level in the west, 2,200 feet in the northeast, and 3,000 feet in the southeast. On the height of land between the Missouri and South Saskatchewan drainage systems, greater elevations occur, as for example about 4,800 feet in Cypress hills and 4,450 feet on Milk River ridge. Porcupine hills in the west rise to 5,000 feet.

Although much of the area appears level, it is for the most part gently rolling with here and there prominent elevations, such as Porcupine hills, Cypress hills, and, to the south in Montana, the three mountains known as Sweet Grass hills. All these elevations affect the local weather conditions, precipitation and water supply being more abundant in their vicinity than elsewhere. In the north, most of the relief is due to glacial moraines which rise 300 feet or more above the general level of the country. The intervening areas appear to represent glacial lake bottoms.

Crossing the plains in various directions are entrenched river valleys, and a series of post-Glacial coulées, now dry for the most part. The valleys vary in depth, that of Oldman river at Lethbridge and that of the South Saskatchewan at Medicine Hat being about 250 feet deep, the gorge of the Saskatchewan 35 miles below Medicine Hat being 450 to 500 feet deep, and the gorge of Milk river near the 49th parallel being about 450 feet deep.

Two great river systems, the Missouri and the South Saskatchewan, drain the region. Milk river, Frenchman river, and a number of smaller streams flow into Montana to join Missouri river by which their water is conducted to Mississippi river and, eventually, to the gulf of Mexico. St. Mary, Belly, Waterton, Oldman, Bow, and Red Deer rivers are main branches of the South Saskatchewan system, which unites with the North Saskatchewan, below Prince Albert. The waters of this great river mingling with those of the great lakes of Manitoba, find an outlet in Hudson bay by way of Nelson river.

In certain parts of the area the drainage is interior. This is particularly the case along the north side of Cypress hills where, of the creeks that drain the hills, none, with the exception of Ross creek, reaches main drainage channels. The waters of these creeks are intercepted at no great distance north of their sources, by large, shallow saline lakes. The northeastern part of the area lies on the watershed between North and South Saskatchewan rivers. The streams are small and all the drainage is interior. Sounding creek, the principal stream in this part, traverses many miles of the area, but fails to reach a main drainage channel.

The divide between the Gulf of Mexico and Hudson Bay drainage extends in an arc of gentle curvature (bowing outward toward the northwest) from the foothills of northern Montana through the crests of Cypress hills. St. Mary river and the south branch of Milk river head in northwestern Montana only a short distance apart, an irrigation ditch diverting water from the former into the latter. Nowhere is the divide between these rivers wide, and from the foothills to Cypress hills the light annual precipitation provides no additional water supply to either of the great drainage systems, in fact irrigation systems and artesian wells abstract water derived from the foothills. Shallow alkaline lakes and dry coulees mark the drainage systems of the pluvial time at the close of the Ice age. Pakowki lake, still marked on maps, is totally dry, except perhaps in early spring, the drainage which formerly reached it by way of Etzikom coulee being now retained by a dam at Crow Indian lake. Semi-arid conditions prevalent in part of the region result partly from the small rainfall, partly from the drying winds of early July, and in no small measure from the presence of sandy subsoil due to the extensive outcrops of Belly River sandstones from which a large amount of the glacial deposits have been derived. Glacial erratics may be far-travelled, but the mass of glacial deposits owes its character to the subjacent formations which predominate a few miles backward along the course of the glacier.

The area east of the 112th meridian is largely within the dry belt, and ranching is the principal industry. On Cypress hills, however, and on the benches and uplands to the south, mixed farming, and even wheat raising, are successfully carried on, the conditions improving toward the eastern side of the region. Milk River ridge, lying north and west of Milk River town, Porcupine hills, and in general the region along the edge of the disturbed belt, are utilized mainly for ranching. The Raymond-Cardston-Lethbridge-MacLeod region is extensively irrigated from St. Mary, Waterton, and Oldman rivers, but large areas are also producing good crops of wheat by dry farming methods. The dry belt is nearly coincident with the outcrop of the Belly River formations, but extends farther south where glaciation has distributed the Belly River sands over the Pierre shale.

The only forests are those of Cypress hills, where the Dominion Department of Forestry administers three blocks as forest reserves. The timber consists of lodgepole pine (*Pinus contorta*), white spruce (*Picea canadensis*), and black poplar (*Populus balsamifera*). Forest growth is confined to the deep ravines, to the north-facing slopes down to 4,000 feet above sea-level, and to the tops of the hills above 4,500 feet. The growth of trees is clearly determined by moisture. Greater precipitation, along

with a longer period of snow-cover, assures moisture on the hilltops. In the ravines seepages and protection from sun and wind assure moisture down to 3,800 feet. On the north-facing slopes the lack of effective insolation protects the moisture from evaporation down to 4,000 feet. Isolated stands of poplar and willow occur lower down in stream bottoms.

Along Milk, St. Mary, and other rivers, stands of black poplar, cottonwood (*Populus canadensis*), and willow are to be found here and there on bottom lands, but for the most part even the river valleys are devoid of trees. Porcupine hills in the west have a scanty growth of white spruce on their upper slopes and willows and poplars grow quite commonly in the stream valleys of the disturbed belt. In the irrigated region, plantations of trees have made rapid growth, as may be seen in Lethbridge, Raymond, Cardston, and other towns; and the windbrakes planted on farms in the dry belt under the direction of the Dominion Department of Forestry are, in general, developing well. The windbrakes are commonly a mixture of Manitoba maple (*Acer Negundo*), cottonwood, ash, and willow.

The various streams of the region supply much of the country with an unfailing water supply, and this is supplemented in the dry belt between Bow Island and Manyberries, by artesian wells. The water-bearing sand is the Milk River sandstone, and the water is absorbed from Milk river where it crosses the sandstone outcrop. The water contains soda, and although everywhere suitable for stock is not good for irrigation and in some cases is not pleasant for domestic purposes.

The whole region is well supplied with coal. The extensive mines at Drumheller and Lethbridge supply most of the demand, but there are few places that are far from local mines of lignite.

The gas fields of Bow Island, Medicine Hat, and Foremost supply the finest and cheapest of fuels for lighting and heating. The new Foremost field has very large untapped reserves of gas, and to the south the 50,000,000 cubic foot Rogers-Imperial well is plugged because there is no demand for the gas. The production of gas in the Turner Valley field, as a by-product of oil production, has for the time being stopped further development in the other gas fields of southern Alberta.

The fine quality of the semi-refractory clays along Frenchman river has made possible the substantial brick, tile, and sewer-pipe industry of Medicine Hat, where natural gas is used for fuel. Enormous quantities of these clays are available.

The principal industries of the region are related to farming and ranching, the main products being wheat and other cereals, sugar beets, horses, cattle, sheep, wool, poultry, and butter. Corn is grown successfully for ensilage even in the driest regions, and it always finds ready sale for winter feed. Cattle pasture on the ranges the year round, but much hay and other feed are generally put up by the ranchers to tide over occasional periods of heavy snow and cold weather. In many parts of the country, mixed farming is making substantial progress. Much of the country is, however, best suited for ranching.

CHAPTER III

STRATIGRAPHY

GENERAL STATEMENT

Rocks ranging in age from the Milk River sandstone of lower Montana age, to the Cypress Hills conglomerate of Oligocene age outcrop on the plains of southern Alberta and southwestern Saskatchewan, and older strata have been penetrated by many bore-holes sunk for oil or gas. Nearly the whole area is covered by a mantle of glacial drift, and most of the exposures occur in the river channels or in coulees. The rocks have suffered little disturbance; faults are seldom met, and the folds present are of a gentle character with dips measurable in feet per mile rather than in degrees; over the greater part of the area the dips do not exceed 15 feet a mile. With one exception, the outcropping formations follow each other with apparent conformity and indicate nearly continuous deposition. Continental and marine formations alternate to near the top of the Mesozoic, above which the strata are entirely freshwater. As might be expected in an area of such vast proportions varying conditions of deposition existed contemporaneously in different districts and different names have been given to formations that are equivalent or approximately equivalent in age. Thus, the post-Fox Hills succession along Bow and Red Deer rivers is quite different from the succession on Oldman, St. Mary, and Belly rivers to the south, and the succession in both these areas differs entirely from that in Cypress hills and southern Saskatchewan (*See Table of formations*).

DESCRIPTION OF FORMATIONS

Palæozoic

The deeper bore-holes in the northern part of the area, after passing through the Cretaceous strata, encounter heavy limestone beds whose character almost undoubtedly indicates that the strata are Palæozoic, but an exact designation of the age of the beds is not possible at the present time.

In the south, Palæozoic limestone has been penetrated in at least seven wells, namely, Northwest Company's Red Coulee well; the Urban No. 1 well; the Coutts-Sweetgrass well; the Erickson Coulee well; the "Rogers-Imperial Well"; the Imperial Dead Horse Coulee well; and the Imperial Boundary well. Of these, the Erickson Coulee well appears to have penetrated about 1,100 feet of Palæozoic strata of which the upper 800 feet, or thereabouts, is probably Mississippian limestone and the lower 300 feet Devonian. The Mississippian formation is mostly light grey limestone with limited argillaceous horizons. The beds ascribed to the Devonian are mostly dark brown or grey limestone with shaly beds at the top. The age determination of these formations depends mainly upon work by the United States Geological Survey in Montana where, by studies

of the rocks outcropping around Sweet Grass hills and examinations of the fragments of fossiliferous rock brought up from bore-holes, the upper part of the Palæozoic has been determined to be the Madison limestone of lower Mississippian age. An erosion surface has been recognized at the top of this formation, but it is fairly safe to assume that the limestones below the Mesozoic strata in southern Alberta are also Mississippian and that still lower limestones are Devonian.

Table of Formations

—	NW. Districts Bow and Red Deer rivers	SW. Districts St. Mary, Belly, and Oldman rivers	SE. Districts Cypress Hills and south	NE. Districts
Oligocene	Oligocene (?) of the Hand hills		Cypress Hills formation	
Eocene	Paskapoo formation	Porcupine Hills formation		
		Willow Creek formation		
	Edmonton formation	St. Mary River formation	Ravenscrag formation	
			White Mud formation	
			Estevan formation	
	Fox Hills formation	Fox Hills formation	Fox Hills formation	
	Bearpaw formation	Bearpaw formation	Bearpaw formation	Bearpaw formation
	Pale beds		Pale beds	Pale and Variegated beds
Cretaceous	Belly River			Birch Lake sandstone
			Foremost beds	Grizzly Bear shale
				Ribstone Creek sandstone
			Pakowki formation	Lea Park formation
			Milk River formation	
			Colorado shale	Colorado shale
			Kootenay- Blairmore	(?)
Jurassic			Jurassic	
Palæozoic			Palæozoic	

The Mississippian limestone is commonly porous near its top and chert bearing. These features suggest erosion and weathering of an old land surface. The best oil "sand" of northern Montana and the most favourable sand in Alberta is the porous dolomitic limestone at the top of the Mississippian.

Jurassic

Upper Jurassic strata have been penetrated by wells at Medicine Hat and near Many Island lake and farther south by the seven wells mentioned above. The Urban well at Coutts penetrated 195 feet of strata referable to the Jurassic. These, in descending order consist of: 60 feet of red, purple, and green shale with bentonite near the base; 100 feet of dark to light green, calcareous shale; 10 feet of black limestone, green calcareous shale, and some black shale; 15 feet of black limestone, with white, cherty limestone near the base; 5 feet of white, porous limestone with 40 per cent of sand; 5 feet of black and white, cherty limestone. This assemblage is similar to the Ellis formation of northern Montana, as recognized by the United States Geological Survey in wells only a short distance to the south. The Ellis also outcrops about the Sweet Grass Hills intrusives and is known from fossil content to be Upper Jurassic.

Kootenay-Blairmore

In the northern part of the area, below the Colorado shale, soft sandstones and dark shales with a little coal are encountered in deep boreholes. There is no palæontological evidence as to the exact age of these strata, but their position in relation to the Colorado shale and the fact that they contain coal suggest that they correspond to some part of the Kootenay and Blairmore of the foothills and mountains. Beds generally referred to the Kootenay have been drilled through in the south by the seven wells already listed, and have been penetrated by at least two other wells. The characters of the Kootenay of the foothills are mostly lacking, but red or green shale generally marks the top of the formation and a sandy horizon (Sunburst oil sand) the lower 30 to 50 feet. The so-called Kootenay is 450 feet thick in the Urban well and 212 feet in the Woodpile Coulée well (Imperial Boundary well).

Colorado

Colorado shale underlies the whole region, but nowhere are the beds exposed. Knowledge of the formation is obtainable only from the records of deep wells. Information from this source is often difficult of interpretation. As shown by the records of wells, the Colorado is a very uniform series of dark grey to black shales. Thin beds of bentonite and some limy beds occur and near the bottom of the formation the beds are sandy. Thin beds or nodules of hard limestone or ironstone are numerous. Iron pyrite crystals are reported from some horizons.

In the southern part of the field, nine well logs show the thickness of the formation. In the northern area, the thickness is difficult to estimate because of the nearly similar lithologic characters of the overlying strata and, also, because of the gradational change from the shale to the underlying Lower Cretaceous sandstones. In the Misty Hills well, situated in sec. 29, tp. 32, range 4, W. 4th mer., the formation appears to be about 1,250 feet thick; in the Urban well the thickness is 1,780 feet, and in Woodpile Coulée well, 2,110 feet.

Milk River

The Milk River sandstone as represented by drill cuttings is a grey sand mixed with argillaceous material. In its typical outcrops, in the banks of Verdigris coulée and Milk river, it contains ledges of cream-coloured sandstone and may be separated into two natural divisions.

The lower division (known as Virgelle sandstone by oil geologists) is massive, notably crossbedded, and weathers near the top into peculiar castellated and wind-carved effects noted by Dawson in his original description. A hard bed is commonly present at the very top and is used in Milk River valley and the vicinity of the Kevin-Sunburst oil field as an horizon marker. This lower division along Milk river has a thickness of about 150 feet.

The upper division of the Milk River (Upper Eagle of oil geologists) has a few firm, ledge-forming beds, but in the main is friable and includes brown and purple, concretionary shales. The brown concretions owe their colour to encrustations of limonite, the purple patches being due to small quantities of manganese dioxide in the limonite. Fossil leaves, silicified wood, and dinosaur bones occur in these beds which were deposited by rivers over a huge flood-plain. The thickness of this upper division along Milk river is about 120 feet.

The Milk River sandstones outcrop along Red creek (west and north of Coutts), in Verdigris coulée from one-half mile below Verdigris lake to the junction with Milk River valley, and in the valley of Milk river and its tributaries from Red creek east to a point 2 miles below the mouth of Deadhorse coulée.

It is rarely possible from the record of bore-holes to separate the Milk River formation into subdivisions, although the lower part is generally the harder. Thicknesses vary much from place to place. At the Red Coulée well the thickness is 270 feet; in the Lethbridge well it is 88 feet; in the Foremost gas field about 150 feet; in the Sanctuary well in Pakowki lake it is 200 feet; and in the Woodpile Coulée well 100 feet. Farther north the Milk River is not divisible into lower and upper parts. The thickness and character of the formation are known only from logs of wells. In Roth No. 1 well, at Medicine Hat, the Milk River is 40 feet thick and consists of thin beds of fine-grained, grey sandstones alternating with shales. In the Drazan well, in the Many Island Lake area, its recorded presence is hypothetical. It is unknown north and east of this point. The northernmost point at which it is definitely known is at Brooks where recent, careful investigations of the well samples give a thickness of 100 feet for the Milk River.

Small collections of fossil plants made by Williams, from the upper division of the Milk River formation, were submitted to W. A. Bell who furnished the following report.

“Locality: Butte in Verdigris coulée, SE. corner sec. 12, tp. 3, range 15, W. 4th mer.

Tapeinidium ? undulatum (Hall) Knowlton

Glychenia sp.

Locality: Butte in Verdigris coulée, NE. $\frac{1}{4}$ sec. 36, tp. 2, range 15, W. 4th mer.

Pagiophyllum sp. cf. *Geinitzia formosa* (Heer)

Pterospermiles wardi Knowlton

Platanus sp.

Ficus sp.

Tapeinidium ? undulatum is a constituent of the Frontier flora of southwestern Wyoming. The Frontier formation on the basis of its invertebrate remains has been assigned a Colorado age, although its flora has distinct affinities with that of the Montana group. *Pterospermiles wardi* occurs in the Mesaverde and Mermejo formations of the Montana group. Conifer twigs with falcate spirally-disposed leaves are abundant in the collection. They agree closely with figured specimens of what is called *Geinitzia formosa* (Heer) a common Montana species. As the Alberta specimens are all sterile, it is considered advisable to place them in the non-committal genus *Pagiophyllum*. The remaining species are too fragmentary for satisfactory specific differentiation."

Pakowki

Marine shales have been recognized by Dowling as wedging, from the eastward, between the Milk River sandstone and the Foremost beds of the Belly River formation. The shales are well exposed near the mouth of Pakowki coulée from which Dowling took the formation name. In Verdigris coulée below Verdigris lake, and near the southeastern corner of tp. 3, range 15, W. 4th mer., sandy shale, containing cephalopod remains, underlies lignite-bearing sandstones and shales. The cephalopods are of lower Pierre age and identify the Pakowki shales, the overlying freshwater beds being Foremost. The contact here is marked by thin lenses of 2 to 3 inches thick consisting of "cones" of calcite starting at the top and bottom and interlocking near the centre. Such concretions occur quite commonly at this horizon, and selenite is also common in the shales. In general the Pakowki shales are green or dark brown, and contain some oyster shells (as below Milk River town on Milk river) as well as a sparse marine fauna. The upper and lower contacts of the formation are generally marked by 2 or 3 inches of fine conglomerate consisting of shiny black argillite pebbles.¹ As such pebbles are unknown at other horizons, their presence even in talus suggests the proximity of either the top or bottom of the Pakowki formation.

The Pakowki shales outcrop in Verdigris coulée below Verdigris lake; in Milk River valley below Milk River town and due north of Coutts; and in the tributaries of Milk River valley below Deadhorse coulée. They also occur in Woodpile coulée in the faulted section north of the Imperial well. The finest sections of all occur in the gorge of Milk river below Pakowki coulée.

For 2 or 3 miles below Deadhorse coulée, practically no outcrops occur, and Dawson assumed that the shales extended westward below the sandstone (now known as Milk River), whereas we now know the sandstone

¹This was first pointed out by Dr. J. S. Stewart.

dips eastward below the shales. Because of this mistake, Dawson included the Milk River sandstone in the Belly River series, and Dowling, having corrected the stratigraphic sequence, included the Pakowki shales in the Belly River. It is clear from Dawson's writings that he had no intention of including a marine member in the Belly River, and included the Milk River formation only because he believed it to be subjacent to the Foremost beds with which it compares closely in character and origin.

The Pakowki shale merges eastward into the lower Pierre shales and is the approximate equivalent of the Claggett shales of Montana. It varies in thickness from place to place, being 215 feet thick in the Lethbridge well; 255 to 330 feet in the Foremost gas field; 500 feet in the Sanctuary well; and 370 feet in the Woodpile Coulée well. In the north the thickness of the formation, as determined from the logs of wells, decreases rapidly between Medicine Hat and Bow Island. At Medicine Hat it is about 700 feet thick and at Bow Island, 50 miles to the west, only 320 feet thick. It should be noted that in the logs of Medicine Hat district the Belly River is with difficulty separated from the Pakowki, both consisting of soft, dark shales. The resemblance of the lower part of Belly River formation to the Pakowki increases toward the east.

The Pakowki formation is 215 feet thick at Lethbridge and probably does not go much past the edge of the disturbed belt. In the southern foothills (*vide* Stewart) it is replaced by Belly River sandstones. Hume¹ has shown that in Turner Valley area the upper part of the so-called "Benton" contains fossils of Montana age. This part may be equivalent to the Pakowki.

North of the region here dealt with, the shale occupying the same stratigraphic position as the Pakowki was named the Lea Park formation by Allan.² This formation probably underlies the whole northern part of the area dealt with in this report, but is nowhere exposed. As indicated by drill records, it consists of dark blue to dark grey, marine shales with occasional thin beds or nodules of limestone or ironstone. A little sand is generally present in the shale and the strata are often interpreted as sandy shale by well drillers. On the whole, the lithologic characteristics are very similar to those of the Colorado shale and in the northern part of the area, where the Milk River sandstone is absent and the Lea Park lies directly on the Colorado shale, the distinguishing of the two formations in drilling records is very difficult, but the more sandy nature of the Lea Park shale is of service in making a division between the two shale horizons.

In the Alderson well, in sec. 30, tp. 15, range 10, W. 4th mer., the Pakowki shale is interpreted as being about 500 feet thick. In the Misty Hills well, in sec. 29, tp. 32, range 4, W. 4th mer., the thickness of the Lea Park appears to be about 350 feet. This latter figure is uncertain on account of the difficulty of distinguishing this formation from the underlying Colorado shale and, therefore, the thinning of the formation northward, as shown by these figures, must be considered very doubtful.

¹ Hume, G. S.: Geol. Surv., Canada, Sum. Rept. 1926, pt. B, p. 6.

² Geol. Surv., Canada, Sum. Rept. 1917, pt. C, p. 13.

The main fossil-bearing localities are in Verdigris coulée at the south end of Verdigris lake; at the mouth of Pakowki coulée and along Milk River valley from Halfbreed creek to the middle of township 2, range 7; and Woodpile coulée.

Fossils of Pakowki Formation

	Verdigris coulée	Mouth of Pakowki coulée and vicinity	Woodpile coulée
PELECYPODA			
<i>Inoceramus tenuilineatus</i> Hall and Meek.....	X		
<i>Pteria nebrascana</i> E. and S.....	X	X	
<i>Ostrea glabra</i> M. and H.....		?	?
<i>Ostrea subtrigonalis</i> E. and S.....		X	
<i>Ostrea patina</i> M. and H.....		X	
<i>Gryphaea vesicularis</i> Lamarck.....	?		
<i>Cyprina subtrapeziformis</i> Whiteaves.....		X	
<i>Corbicula occidentalis</i> M. and H.....	X		
<i>Tellina equilateralis</i> M. and H.....	?		
<i>Tellina modesta</i> Meek.....	?		
<i>Macra alta</i> M. and H.....	X		
<i>Corbula subtrigonalis</i> M. and H.....		X	
GASTROPODA			
<i>Lunati subcrassa</i> M. and H.....		X	
CEPHALOPODA			
<i>Baculites compressus</i> Say.....	?	?	

Belly River Formation

In 1882, Dawson¹ described the Belly River formation as a series of fresh and brackish water deposits overlain conformably by the Pierre shales and lying conformably on the "Lower Dark shales." Dawson believed the dark shale exposed in Milk River valley above and below Pakowki coulée to be equivalent to the dark Colorado shales exposed on the sides of Sweet Grass hills. He also believed that the dark shale in Milk River valley underlay what has since been named the Milk River sandstone. He consequently believed that the castellated sandstones of Milk river formed part of the continuous continental series which he designated the Belly River formation. In 1905 Stanton and Hatcher² traced the Judith River formation and related beds of Montana across the International Boundary into Alberta. They showed that the dark shales of Pakowki coulée were not of Colorado age as supposed by Dawson, but were equivalent to the Claggett shales of Montana and that the continental Belly River series above the dark shales of Pakowki coulée and the Judith River formation of Montana were equivalent. Dowling later showed that the castellated sandstones of Milk river were a distinct continental series lying below, not above, as Dawson supposed, the dark shales of Pakowki coulée and were equivalent to the Eagle sandstone of Montana. In 1915 Dowling³ gave the name "Pakowki" to the dark shales exposed in

¹ Dawson, G. M.: "Report on the Country in the Vicinity of Bow and Belly Rivers"; Geol. Surv., Canada, Rept. of Prog. 1882-1884.

² Stanton, T. W., and Hatcher, J. B.: "Geology and Palaeontology of the Judith River Beds"; U.S. Geol. Surv., Bull. 257.

³ Dowling, D. B.: Geol. Surv., Canada, Sum. Rept. 1915, Map opp. p. 104.

Pakowki coulée, "Milk River" to the castellated sandstone of Milk river, and divided the beds lying between the Pakowki and the Bearpaw into two divisions, namely, Foremost formation and Pale and Yellow beds. He defined the Pale and Yellow beds, the Foremost formation, the Pakowki, and the Milk River as constituting the Belly River series. This practice is not desirable because it includes continental and marine deposits in one series. It is quite evident, also, that Dawson did not mean to place marine shales within his Belly River series. It is proposed, therefore, to follow Dawson's original intention and to define the Belly River as being composed of the continental beds lying between the Pakowki and the Bearpaw.

The period of time represented by the Belly River formation increases markedly from east to west as a natural outcome of the history of the plains in Montana time. The Pierre sea of Montana time twice invaded southern Alberta and Saskatchewan. The first invasion is represented by the Pakowki shales and the second by the Bearpaw shales. The continental Belly River formation lies like a wedge between the Pakowki and the Bearpaw with its thin edge toward the east; it is absent in Manitoba and thin in Saskatchewan, but thickens markedly in Alberta at the expense of the underlying Pakowki shales. In the foothills¹ it is 3,000 feet thick and its lower part occupies the place of the Pakowki shales and most of the Milk River sandstone; still farther west, in the Blairmore coal basin,² the Belly River formation or an equivalent, the Allison, replaces the Pakowki, the Milk River, and probably also the Bearpaw.³

In 1882 Dawson divided the Belly River formation into two parts, an upper, pale-coloured portion and a lower, sombre-coloured portion, which he called respectively the "Pale" and the "Yellowish" beds. It was left, however, for Dowling in 1915⁴ to map them separately. As already stated, he called the upper member, the Pale and Yellow beds, and to the lower member gave the name Foremost. The name of the upper member has since been contracted to Pale beds. Although the two members are more or less alike and the boundary between them is by no means definite, they are sufficiently different to form desirable mapping units. The outstanding difference, as already noted, is a difference in colour, the Pale beds being much lighter in colour than the Foremost. Other differences are as follows. The Pale beds include massive strata of hard, yellow and grey sandstone which are rare in the Foremost. Coal seams are common in the Foremost, but occur only near the top of the Pale beds, in the transition zone between the Pale beds and Bearpaw shales. Fossils are rare in the Pale beds and those that do occur are of freshwater type with the exception of occasional beds of oysters in the uppermost part, whereas, in the Foremost, fresh and brackish water fossils are comparatively abundant, and marine gasteropods and pelecypods are common. Finally, the Pale beds are characterized in places by foreset delta beds, some of large dimensions, which are not seen in the Foremost.

¹ Stewart, J. S.: "Geology of the Disturbed Belt of Southwestern Alberta"; Geol. Surv., Canada, Mem. 112.

² Leach, W. W.: "Geology of the Blairmore Map-area"; Geol. Surv., Canada, Sum. Rept. 1911, p. 198.

³ It has, however, not yet been made clear whether the Bearpaw is replaced by continental beds, or has been eroded from above the Allison.

⁴ Geol. Surv., Canada, Sum. Rept. 1915.

The dark shales and sands of the Foremost, with enclosed coal seams, pass very gradually into the light-coloured sands and shales of the Pale beds, and, hence, the boundary line between them is very difficult to draw. Dowling says:

"The top of the formation (Foremost) is placed generally at a certain coal seam that in various places is important enough to be mined. As the seam is not confined to any exact position in the upper part of the formation this horizon marker is not strictly the top of the formation and the apparent thickness of the division may for this reason appear variable."

DISTRIBUTION

The Belly River formation outcrops over the central part of the map-area adjacent to the International Boundary with the exception of a part of Milk River valley, and extends north and then northeast in the form of a very broad band. The upper division, the Pale beds, occupies all the northeastern part of this band-like area. The lower division, the Foremost, is exposed in the valley of South Saskatchewan river and over a large area farther south. The Belly River underlies younger strata in central Saskatchewan for it was penetrated in a deep well at Moose Jaw. It has not been reported east of this point and probably does not occur in Manitoba.

Although Dawson took the formation name from Belly river, he first saw this formation along the gorge of Milk river while on the survey of the 49th parallel. In his "Report on the Region in the Vicinity of the Bow and Belly Rivers" he describes (pages 43-44) these rocks and recognizes both subdivisions of the formation. His measured section, however, includes 132 feet of Pakowki shale at the base. Complete and excellent exposures of the Foremost beds occur along the gorge of Milk river from the 49th parallel northwesterly for 15 miles. The north side of the gorge is steeper and less broken than the south side and the sections there are more nearly complete and show both top and bottom contacts. The Foremost beds outcrop over a large area extending northwesterly from Milk River gorge including the larger part of Verdigris, Etzikom, Chin, Fortymile, and Sevenpersons coulees. It was from the exposures in Chin coulee near the town of Foremost that Dowling described this subdivision of the Belly River formation, but neither top nor bottom of the division occurs at the type locality. About 21 miles to the westward, however, the Pale beds overlie the Foremost beds. Good exposures of Foremost beds also occur in Milk River valley west of Milk River town and in the hills southwest of Milk river.

Excellent exposures of Pale beds occur between the gorge of Milk river and the "badlands" bordering Cypress hills on the south and west. Lost river, Sage creek, Manyberries creek, and the flaring valleys tributary to them have large areas of exposures of grey sandstone belonging to the Pale beds; and the coal of the upper horizon is worked by stripping in the banks of Manyberries and Sage creeks.

Sections showing the contact between the Pale beds and the Bearpaw shales occur on Petrified coulee in secs. 25 and 26, tp. 9, range 6, W. 4th mer.; on Ross creek south of Irvine; at many points on the sides of the mesas north of Irvine and in the vicinity of Walsh; on the western slopes

of Bullshead and in the valley of Manyberries creek south and east of Manyberries. Exposures also occur in the various coulees south of Medicine Hat; on the lower part of Little Bow river; on Bow river between Eyremore and the junction with Oldman river; on the north branch of Milk river; and on St. Mary river at the Magrath mine and near its mouth: but the best exposures are in the deep valleys of Oldman and South Saskatchewan rivers along which the Belly River formation can be followed for over 300 miles. On descending Oldman river the upper part of the Pale beds with its coal seams first appears from under the Bearpaw shales near the mouth of St. Mary river. The horizon can be followed northward to the railway bridge west of Lethbridge, but at this point is carried below river level by the northward dip of the rocks on the south flank of a well-marked syncline. At Diamond City, the southward dip on the north flank of the same syncline causes the horizon to reappear and from Diamond City to within a few miles of the mouth of Little Bow river, the Pale beds are continuously exposed. The regional westward dip, which prevails between Diamond City and the Little Bow, causes the dark-coloured, underlying Foremost beds to appear at water-level about 2 miles west of the mouth of the Little Bow and for many miles eastward the Foremost beds appear at the base of every section. Between Taber and Bow Island, the South Saskatchewan follows the strike of the rocks and the river gradually cuts deeper into lower parts of the Foremost. Between Bow Island and Rapid narrows, the rocks dip eastward at a rate nearly equalling the fall of the river, and, hence, very nearly the same series of beds is exposed throughout. In the pre-Glacial parts of the valley, where the scarped banks are low and the glacial drift thick, only the Foremost beds are exposed, but in the deep, gorge-like, freshly cut, post-Glacial parts, the Pale beds can be seen resting on the Foremost. The Pale beds occur at the top of the sections in the post-Glacial part of the valley which extends for 10 miles below the mouth of Bow river. They, also, occur in the upper part of the sections near the mines north of Winnifred and cap every exposure between this point and Redcliff. Unusually high sections showing 200 feet of the Foremost surmounted by about the same thickness of Pale beds line the valley sides on the northwest-southeast reach of South Saskatchewan river centring about the southwest corner of tp. 13, range 8, W. 4th mer. The deposits of the Pleistocene lake basin at Medicine Hat hide bedrock in the immediate vicinity of the city, but good sections showing both the Foremost and the Pale members occur on the river south of Redcliff. The outcrops between Medicine Hat and the northern outline of township 16, with a few exceptions, are small and show only Foremost beds, but to the north the Pale beds appear again, and in the deep gorge at Rapid narrows a complete section of the Pale beds 350 feet thick is found above 90 feet of the Foremost and below 50 feet of Bearpaw shales.

North of Rapid narrows the beds dip to the north and east and the Foremost member in tp. 19, range 3, W. 4th mer., disappears from view along the river. It does not reappear to the west along Red Deer river. The Pale beds outcrop at intervals on South Saskatchewan river as far north as Red Deer forks. They form the surface member over a large area in the northeast, but are seldom exposed because of the heavy covering of glacial drift. Exposures occur in Misty hills south of Monitor, along

Sounding creek in tp. 30, range 4, W. 4th mer., and in the valley of Red Deer river. The chief exposures in Red Deer River valley are west of range 8 in an area that includes the famous badlands of the Red Deer. Exposures also occur on the same river in range 4 and on a small tributary opposite Empress. The Pale beds are also exposed along an old water course in sec. 2, tp. 17, range 8, W. 4th mer., where they are overlain by the Bearpaw shale.

LITHOLOGY

Southern Districts

The Belly River formation as developed south of latitude $50^{\circ} 30'$ is of an alternating series of fine-grained sandstones, shales, and sandy shales. The sandstones consist of angular to subangular grains of quartz ranging in size from 0.05 mm. to 0.25 mm. The cement is in nearly every case calcite, but in some cases a mixture of calcite and clay, and makes up from 10 to 20 per cent of the rock mass. Accessory minerals are biotite, muscovite, chlorite, feldspar, apatite, and occasional grains of zircon. Many of the sandstone beds have been firmly recemented and stand out prominently in the cut banks; this is more characteristic of the Pale beds than of the Foremost. Many of these hard beds are crossbedded and show current or wave ripple-marking. In both members are numerous beds of soft, uncemented sands in which the stratification is marked only by slight differences in colour. Perhaps the most abundant rock type is a mixture of sand and clay in variable proportions; these beds are usually soft and show little stratification. In the Pale beds a characteristic rock type is a light grey, massive sandstone which becomes nearly white on drying. It contains a large amount of colloidal clay which renders the exposures very slippery after a rain. In a section on the south side of South Saskatchewan river in the SW. $\frac{1}{4}$ sec. 11, tp. 13, range 9, W. 4th mer., a 10-inch bed of conglomerate occurs 50 feet above water-level in the Foremost member. This bed consists of iron stone pebbles exclusively, no foreign matter being present; it also contains an abundance of shark's teeth, fragments of other bones, and fish vertebræ. Beds of brownish, very fine-grained, unstratified, calcareous material are found which probably originated as chemical precipitates in the lakes of the time; these are noted as "concretionary" beds in the sections given on later pages. Some selenite occurs in the bedding planes of coal seams, but is not nearly so abundant as in the Bearpaw formation. Bentonite also is far less abundant than in the marine Bearpaw, but thin seams of impure bentonite do occur.

Oyster shells are abundant, especially in the Foremost member, and in some cases beds 5 feet thick consist entirely of them. Some of these beds are silicified and very hard.

Numerous coal seams occur throughout the Foremost member and some are as much as 5 feet thick. Coal is not abundant in the Pale beds, but the transition phase between the freshwater Pale beds and the overlying marine Bearpaw is marked by a series of seams, some of which assume considerable thicknesses; the well-known Lethbridge coal seams in which several large mines in the vicinity of Lethbridge are located, occur at this horizon.

A wide variety of colours is exhibited by the rocks of the Belly River formation. In the Pale beds grey, varying from dark grey to nearly white, is the predominant colour, but green shales are abundant. Brownish and yellowish sands and shales are common in the Foremost beds. Where red shales occur, the red colour is generally caused by the burning of adjacent coal seams. The town of Redcliff derives its name from the large amount of red shales due to this cause, in the banks of South Saskatchewan river south of the town. These shales are commonly burned hard and exhibit a curious parallel jointing with resulting four to six-sided prisms 2 to 3 inches across and 6 to 8 inches long which are strewn in large numbers on the banks.

A prominent feature of the Belly River formation is the lenticular character of the beds, very few of which can be followed for any considerable distance. Dependable horizon markers are rare with the possible exception of some coal seams. Even the coal seams and the oyster shell beds in short distances may split into two or more beds, join with other beds, or fade out altogether. In Etzikom, Chin, Fortymile, and Sevenpersons coulees, beds carrying *Corbular* were found to be reliable horizon markers over considerable areas, and were used to advantage in determining structure. Channelling is almost altogether absent. Large-scale crossbedding such as is commonly associated with the foreset beds of a delta deposit is of common occurrence, especially in the Pale beds. These foreset beds, in many cases, measure 15 feet across. Good examples may be seen in the valley of Ross creek one mile south of Irvine, and on Little Bow river east of the bridge in section 30, tp. 12, range 19, W. 4th mer. The bottomset beds are represented by dark, flat-lying shales and the topset bed by flat-lying, light grey and yellow sandstones.

Concretions of various shapes and sizes and of differing composition are very abundant. The most abundant type occurs in sandstone and consists of sand grains locally cemented by calcite. They range in size from 1 inch up to 15 feet in length and in most cases occur in soft, porous sands. They are commonly stratified and the stratification planes appear to be continuous with those of the country rock. This type of concretion is very abundant in the Foremost member on Oldman river near Taber where one row was followed along the river for 6 miles. On the north side of the road bridge north of Taber, ten rows of large concretions occur in a 90-foot section. Some concretions were found with a core of hard, fine, unstratified sandstone surrounded by concentric, considerably contorted, layers of more porous sand; these were probably formed by outward growth after consolidation of the surrounding sediments. Cone-in-cone structure coats sandstone or iron carbonate concretions, layers 5 inches in thickness being common. One peculiar branching type of sandstone concretion was found which must have been formed around branching vegetation; fragments measured 1 to 2 feet in length and $\frac{1}{2}$ to 1 inch in diameter; the surfaces of the concretion were covered with closely clustered, small, rounded knobs, raised 2 to 4 mm. above the surface. The peculiar knobs may represent the leaf scars of the plant. This type of concretion was found in a single bed of sandstone which was followed along the banks of South Saskatchewan river for about 3 miles south of Bow Island. Many concretions consist of iron carbonate or a mixture of iron carbonate with clay.

These are much smaller than the arenaceous concretions and of more irregular shape; nodular forms and irregular discoidal forms are the most abundant. They have a very hard, fine-grained, homogeneous interior and are coated with black or brown iron oxide and commonly assume a peculiar honeycombed structure on the surface. Some of the carbonate concretions have been fractured irregularly and the fractures filled with calcite. They are thought to be of recent origin because nearly everywhere they occur in porous sands through which ground water can easily percolate.

The Foremost beds are a mixture of brackish water and freshwater deposits, and consist of shaly silts, sandstones, and beds of coal. Hard sandstone and ironstone concretions and silicified oyster shell beds stand out from the coulée and river banks as local horizon markers. Alternating colour bands, in some cases narrow, and in others wide and diffuse, extend for considerable distances: these include grey, black, brown, yellow, and red. The general distribution of coal seams, oyster shells, and brackish water fossils such as *Corbular*, combined with the prominent changing colour scheme, may be used to recognize the Foremost beds.

The Pale beds are essentially grey, argillaceous sandstones, interbedded with pea green, freshwater, sandy shales. Near the top, dark grey shales are common; these contain coal seams at many localities, and form transition beds from the continental Belly River to the marine Bearpaw formation. Huge ovoid sandstone concretions are common in the weathered outcrops of the Pale beds.

A few representative sections of the formation on South Saskatchewan river follow.

SE. cor. sec. 17, tp. 11, range 12, W. 4th mer., north side South Saskatchewan river, 5 miles below the mouth of Bow river.

	Feet Inches	
<i>Pale Beds</i>		
Heavy-bedded sandstone.....	11	
Black, carbonaceous shales and some true coal.....	7	
Brown shales.....	16	
Concretionary bed.....	0	3
Greenish to brown shales.....	5	
Concretionary band.....	0	3
Pale sandstone.....	1	
Brown shales.....	3	6
Pale sandstone.....	5	
Concretionary band.....	0	6
Pale sandstone.....	3	
Concretionary band.....	0	6
Pale sandstone.....	4	
Concretionary band.....	0	4
Pale, crossbedded sandstone.....	6	
Hard sandstone.....	0	6
Pale sandstone.....	0	6
<i>Foremost Beds</i>		
Coal.....	0	6
Pale sandstone with ironstone partings.....	11	
Red concretionary band.....	0	6
Shaly sandstone.....	2	6
Coal.....	1	

	Feet Inches	
<i>Foremost—Con.</i>		
Pale sandstone.....	6	
Coal.....	1	
Shale and sandstone.....	8	
Coal.....	2	
Shale.....	8	
Brown carbonaceous shale.....	2	
Shale and sandstone.....	6	6
Oyster bed.....	0	6
Brown shales.....	15	
Pale sandstone.....	3	
Concealed.....	16	
Coal.....	2	6
Brown shale.....	7	
Coal.....	2	
Concealed to river-level.....	60	

SW. $\frac{1}{4}$ sec. 28, tp. 12, range 10, W. 4th mer., north side South Saskatchewan river. The line between the Pale beds and the Foremost beds is very difficult to draw in this section.

	Feet Inches	
<i>Pale Beds</i>		
Yellowish-weathering sandstone.....	30	
<i>Foremost Beds</i>		
Shale.....	2	
Sandstone.....	3	
Black shale.....	0	6
Brown shale.....	2	
Sandstone.....	3	
Shale.....	5	
Coal.....	0	5
Shale.....	5	
Coal.....	0	14
Green shale.....	9	
Pale sandstone.....	2	
Brown shale.....	2	
Soft sandstone with concretions in middle.....	8	
Hard sandstone.....	1	
Soft sandstone.....	1	
Brown shale.....	1	
Hard sandstone.....	1	
Soft, pale yellow sandstone.....	10	
Row of big concretions.....		
Soft, pale sandstone.....	15	
Oyster bed.....		
Soft, pale sandstone.....	20	
Brown shale.....	10	
Soft, pale sandstone.....	15	
Concretionary band with oysters.....	3	
Pale sandstone.....	17	
Oyster bed.....		
Brown shale.....	1	
Sandstone.....	5	
Brown shale.....	3	
Grey shale.....	5	
Carbonaceous shale.....	1	
Grey shale.....	11	
Brown shale.....	3	
Grey shale.....	10	
Brown shale.....	1	
Grey shale to water-level.....	11	

NE. $\frac{1}{4}$ sec. 1, tp. 13, range 9, W. 4th mer., north side South Saskatchewan river. In this, as in most sections, it is difficult to fix a boundary between the Pale Beds and the Foremost.

<i>Pale Beds</i>	Feet
Rusty weathering, hard sandstone.....	10
Shale.....	5
Sandstone.....	10
Concretionary bed.....	2
Pale greenish shale.....	10
Hard sandstone.....	10
Brown shale.....	5
Pale grey shale.....	5
Concretionary bed.....	5
Grey shale.....	5
Grey sandstone.....	5
Grey, sandy shale.....	20
Grey sandstone.....	5
Pale greenish shale.....	4
Sandstone.....	6
Pale greenish shale.....	10
Hard, pale sandstone.....	5
Soft, pale sandstone.....	60
Brown shale.....	5
Sandy shale.....	6
Hard, grey sandstone.....	10
<i>Foremost Beds</i>	
Carbonaceous shale, thin band.....	
Brown shale.....	10
Hard sandstone.....	3
Pale sandstone.....	5
Carbonaceous shale with a little coal.....	13
Brown shale.....	5
Coal.....	2
Brown shale.....	5
Pale sandstone.....	5
Dark shale.....	2
Coal.....	1
Dark shale with numerous concretions.....	20
Coal.....	2
Dark shale.....	3
Coal.....	4
Dark shale.....	2
Sandy shale.....	3
Grey shale.....	10
Concretionary band.....	
Dark shale.....	2
Grey sandstone.....	8
Concretionary bed.....	
Shale.....	2
Grey shale with two thin seams of coal.....	5
Grey shale.....	5
Yellow concretionary bed.....	
Dull greenish shales.....	17
Concretionary bed with cone-in-cone.....	
Dull greenish shales.....	30
Concealed to water-level.....	20

NE. $\frac{1}{4}$ sec. 5, tp. 13, range 6, W. 4th mer., South Saskatchewan river south of Redcliff

<i>Pale Beds</i>	Feet
Hard, pale sandstone.....	15
Pale, sandy shale.....	20
Grey shale.....	5
Pale sandstone.....	30
Brown shale.....	2
Pale sandstone.....	50
Shale.....	2
Pale sandstone.....	5
Grey shale, carbonaceous in the middle.....	20

<i>Foremost Beds</i>	Feet	Inches
Grey sandstone, red concretions.....	2	
Coal.....		8
Grey shale.....	2	
Grey sandstone.....	3	
Brown shale.....	1	
Grey sandstone.....	3	
Grey shale.....	1	
Coal.....	5	
Brown shale.....	2	
Pale sandstone.....	1	
Grey shale.....	5	
Oyster bed.....		
Sandy shale.....	4	
Oyster bed.....		
Grey sandstone.....	10	
Oyster bed.....		
Coal.....		4
Brown shale.....	8	
Coal.....	3	
Sandstone.....	1	
Coal.....	2	
Shale.....	2	
Coal.....	2	
Concealed.....	23	
Brown shale.....	3	
Sandy shale.....	8	
Hard sandstone.....	2	
Concealed.....	28	

Rapid narrows, sec. 7, tp. 17, range 3, W. 4th mer.

<i>Bearpaw Shale</i>	Feet	Inches
Black shale.....	119	
Sandy shale.....	37	
Shaly sandstone.....	3	
Brown shale.....	35	
Greenish shale.....	11	
Brown, carbonaceous shale.....	2	
Dark shales.....	6	
Ironstone band.....		6
Pale sandstone.....	8	
Sandy shales.....	14	6
Shale, dark.....	20	
Sandstone.....	10	
Shaly sandstone.....	8	
<i>Pale Beds</i>		
Sandstone.....	7	
Carbonaceous sand.....	5	
Soft sandstone.....	77	
Sandstone with concretions.....	73	
Carbonaceous shale.....	4	
Brown and grey shale.....	6	
Grey sandstone.....	3	
Sandy shale.....	17	
Shale with coal.....	4	
Light sandstone.....	19	
Shaly sandstone.....	14	
Hard sandstone.....	7	
Sand.....	10	
<i>Foremost Beds</i>		
Coal seam.....		3
Sandstone.....	4	
Concretionary sandstone.....	4	
Soft sandstone.....	8	6
Covered.....	22	

Northern Districts

In the northern districts, north of Rapid narrows on the South Saskatchewan, only the higher beds of the Belly River formation are exposed. These higher beds have been represented on the Calgary map-sheet as belonging to the Pale beds, although there is some doubt as to whether they are exactly equivalent to the Pale beds of the southern districts. Lithologically the strata of both regions are much alike and are traceable, by intermittent exposures, from one region into the other. It seems probable that the Pale beds constitute a definite horizon extending over the two regions.

The Belly River strata underlying the Pale beds of the northern districts are known only from well records and from these it appears that they more nearly correspond with divisions outcropping farther north along the North Saskatchewan and its tributaries than with the Foremost beds of the south. The general succession in North Saskatchewan River district consists of, in ascending order: Benton (Colorado); Lea Park (Montana); Ribstone Creek; Grizzly Bear; Birch Lake; Variegated beds; Pale Beds; and Bearpaw.

The Pale beds of northern Alberta have the same stratigraphical position and relations as the Pale beds of southern Alberta, are lithologically like them, and are traceable by intermittent exposures into the area occupied by the southern Pale beds. The Pale beds of the north and the Pale beds of the south appear to be correlatives and, in their respective regions, to form the uppermost member of the Belly River series. The Variegated beds are very closely related lithologically to the overlying Pale beds and should, probably, wholly or in part, be considered as part of that formation.

Another correlation that seems reasonably certain is that of the Pakowki shales of the south and the Lea Park shales of the north. The identical lithological character, the similar stratigraphic position in respect to the underlying Colorado shale and the fossil content all tend to demonstrate the equivalent age of the two formations.

In the south, the Pakowki and Colorado shales are separated by a sandstone bed—the Milk River sandstone—which does not appear in the north according to information from well records. This sandstone should be considered merely a local sedimentary phase showing nearer shore conditions of deposition in the south than in the north.

In the south, the Foremost beds lie between the Pakowki shale and the Pale beds. In the north, several members, viz., the Ribstone Creek sandstone, the Grizzly Bear shales, and the Birch Lake sandstone, occur in a similar stratigraphic position and are here correlated with the Foremost.

The correlation is based largely on the stratigraphic evidence. Both sets of beds represent a shallowing of the sea with near shore conditions and both are followed by beds of freshwater origin. There is also no great disparity between the thicknesses of the two sets of beds. The lithology of the beds is, probably, not sufficiently similar to warrant a correlation, yet not sufficiently dissimilar to prohibit one. The palæontological evidence is of little value. In the north, faunas collected from the members under consideration are marine and brackish water; in the south, brackish

and fresh water. This is evidence of stronger marine conditions in the north than in the south, and such evidence is corroborated in a lower horizon by the presence of the Milk River sandstone intercalated between the Colorado and Pakowki shales in the south and the absence of any such bed in the north. It is quite possible that part, or even all, of the Variegated beds should be included in this correlation. This formation is, as yet, little known and further study of its field relationships will be necessary before more definite conclusions can be drawn.

S. E. Slipper¹ gave the name Ribstone Creek formation to a set of beds that occurs typically in an area in the vicinity of the town of Wainwright, Alberta, to the north of the present area. Beds of a similar nature and at about the same stratigraphic horizon underlie the northern part of the area under discussion as shown by the log of the Misty Hills well. Slipper described the Ribstone Creek as comprising "greenish yellow, massive, soft sandstone at top, green and carbonaceous shales and coal, light grey sandstone at base." He considered the deposits to be of brackish water origin. In the Misty Hills well, clay, sandstone, sandy shales, and coal were reported immediately overlying what is considered the Lea Park shale. From their stratigraphical position and lithological character it seems evident that these beds may be correlated with the Ribstone Creek member. According to Slipper, the total thickness of the member is 225 feet. In the Misty Hills well, the beds ascribed to this member are 290 feet thick. Information obtainable from well logs is not sufficiently satisfactory to give a very definite idea of the thickness of such a formation, so the latter figure should not be considered as the exact thickness of these beds in this area.

The Grizzly Bear formation was so named by Slipper who found the beds exposed in the vicinity of Wainwright.¹ Though but a comparatively thin member, it has a fairly wide distribution and beds of similar lithological character are reported in the log of the Misty Hills well. Nowhere in the area are these beds exposed, but they must be quite close to the surface in the northeastern corner as they outcrop on Tramping lake about 6 miles from the eastern border. The low elevation of the outcrop, however, and the general westerly dip of the strata exclude the possibility of their appearance in any part of the area. Little is known regarding the southward extension of these shales. They have not been found in a similar horizon in the southern area and so are believed to thin out or change in character in that direction.

In his original description of this member, Slipper says that it comprises "Dark blue, grey, marine shale, contains ironstone and sandstone nodules. Some beds of yellow, incoherent sandstone." In the Misty Hills well the beds considered to represent this member are dark grey clays and sandy clays. The lithology seems sufficiently similar to warrant the correlation. Slipper attributes a thickness of from 40 to 100 feet to this member where exposed in the north, and Hume corroborates this figure.² The beds ascribed to this member in the Misty Hills well are 90 feet thick, thus agreeing pretty well with the thickness of the member in the vicinity of Wainwright.

¹ Geol. Surv., Canada, Sum. Rept. 1917, pt. C, p. 8.

² Geol. Surv., Canada, Sum. Rept. 1924, pt. B, p. 3.

The Birch Lake sandstone is exposed in its typical development along Battle river to the north and west of Wainwright and at Birch lake where the member was named and described by Slipper.¹ Its extension in a southerly direction is known only through the information supplied by well logs. It is possible that it underlies a small portion of the northeast corner of the area, but no rock outcrops there. It seems more probable, however, that this member does not appear at the surface in any part of the area. Beds ascribed to this member were encountered in the Misty Hills well, but there is no available data regarding their extension south of this point.

Regarding the lithology of this member, Slipper described it as "Massive, crossbedded sandstone, buff-coloured, containing lenses of harder sandstone. Brackish water deposits." The formation lends itself excellently as an horizon marker either in outcrops or in bore-holes on account of its lithological character and its stratigraphic position above the soft shales of the Grizzly Bear member. In the Misty Hills well, dark grey or buff-coloured sands with some carbonaceous material are reported from the horizon at which this member would be expected to occur. These beds are considered to represent the Birch Lake sandstone. The Birch Lake sandstone is a thin formation with a total thickness of from 60 to 100 feet where exposed on Birch lake and Battle river. The beds encountered in the Misty Hills well, which are ascribed to this member, are 60 feet thick.

A set of beds about 200 feet thick occur between the Birch Lake sandstone and the typical Pale beds in Wainwright district. Slipper, in naming this member, described it as "Interlayered sandstone and shale showing various tints of greens and browns and yellows, also coal seams; brackish water deposits." These beds closely resemble the overlying Pale beds and the separation of the two formations is not possible from the drilling records of wells. Undoubtedly, the Variegated beds immediately underlie a considerable part of the northeastern portion of our area, but no exposures were found. On account of the strong similarity of the Pale and Variegated beds, no attempt was made to separate the two members on the map or in the sections.

The Pale beds comprise a monotonous succession of alternating beds of light grey, bentonitic shales and soft, grey to buff-coloured sandstone. As exposed in the south of the area, sandstone is more prevalent in the lower part of the member and shale in the upper part. The sandstones are in many cases consolidated, though in a very irregular manner, and produce castellated erosional forms along the river banks. Laterally, the beds change very rapidly and no bed may be used as an horizon marker over any large area. For this reason, sections measured in quite close proximity are very difficult to correlate.

The shale beds in the upper part of the member are decidedly bentonitic. In the vicinity of Misty hills, beds of almost pure bentonite were found. In close proximity in the section occur siliceous beds which have some of the characteristics of volcanic ash.

¹ Geol. Surv., Canada, Sum. Rept. 1917, pt. C, p. 8.

In the upper part of the formation the beds are more uniform than in the lower part and are traceable for considerable distances. One shale bed in this part of the section contains many crystals of selenite which seems to point to marine deposition. As the top of the formation is approached, beds of dark grey or chocolate-coloured shales, often containing a considerable quantity of carbonaceous material, become interspersed with the lighter beds. These beds increase in importance toward the top where the member grades almost imperceptibly into the overlying, dark grey or chocolate-coloured Bearpaw shales. Nowhere throughout the area could a definite boundary between the two divisions be established.

Toward the base of the member, thin, local coal seams occur. They are lens-like in habit and may occur throughout a considerable thickness of the section. A coal seam of greater thickness than usual is exposed at the top of the Pale beds along Red Deer river in tps. 22, 23, and 24, ranges 14 and 15, W. 4th mer. This seam increases in thickness locally to $4\frac{1}{2}$ feet and has been exploited in several places.

A complete section of the Pale beds, measured at Rapid narrows, where both the underlying and overlying formations are exposed, gave a thickness of about 350 feet. No complete section could be obtained on Red Deer river as the base is not exposed. In the log of the Misty Hills well in the northern part of the area a thickness of 840 feet of Pale and Variegated beds is shown. The well did not commence at the top of the member and probably 100 feet more should be added to give the complete thickness of the beds. In his work in the Wainwright area, Slipper gives a thickness of about 500 feet for the Pale beds and 200 feet for the Variegated beds.¹

THICKNESS

The Belly River formation varies greatly in thickness from east to west. At Medicine Hat the Foremost beds are about 350 feet thick and at Rapid narrows 30 miles to the north the Pale beds are 350 feet thick, the total thickness of the Belly River formation in this district thus being 700 feet. Over a large part of the area the upper part of the Pale beds has been eroded and no estimate of the total thickness of the member could be made, but the Foremost beds appear to be fairly uniform in thickness; at Alderson (from a well log) 340 feet, and at Taber 325 feet. At Lethbridge the formation is considerably thicker, the Foremost being 550 feet thick and the Pale beds 500 feet, giving a total for the Belly River formation of 1,050 feet. The log of the Monarch well is difficult to interpret, but it seems clear that the Belly River formation is considerably thicker than at Lethbridge. One interpretation of the log makes the Foremost 625+ feet thick and the Pale beds 735 feet, a total of 1,360+ feet. In the northern part of the area, the Belly River formation is estimated to be 1,440 feet thick, the thickness being made up as follows: Pale and Variegated beds 1,000 feet; Birch Lake sandstone 60 feet; Grizzly Bear shales 90 feet; and Ribstone Creek member 290 feet. Stewart estimates the thickness of the Belly River formation as exposed on the upper reaches of Oldman river in the disturbed belt to be 3,000 feet; farther west in the Blairmore coal basin Leach reports a thickness of 1,900 feet of Allison sandstone, an equivalent of the Belly River formation.

¹ Geol. Surv., Canada, Sum. Rept. 1917, pt. C, p. 8.

In Milk River gorge the Foremost beds measure from 220 to 240 feet in thickness and in the Woodpile Coulee well the Foremost beds are 290 feet and the Pale beds 500 feet thick. The locality has been referred to several times as it gives the best section, in southwestern Saskatchewan, of the formations below the Bearpaw shale.

PALÆONTOLOGY

The Foremost member contains abundant remains of freshwater and brackish water gasteropods and pelecypods as well as a smaller number of marine shells. Plants are found in both members, and the remains of vertebrates are very abundant at some localities, especially in the Pale beds of Red Deer river where fragments of reptile bones and teeth may be found almost anywhere where the formation is exposed. Vertebrate fossils have been collected for years from the badlands of Red Deer river and many of the larger museums of the world contain representative collections.

Invertebrate Fossils from the Belly River Formation

Fresh Water

Unio danae M. and H.
Unio consuetus Whiteaves
Unio supragibbosus Whiteaves
Unio priscus M. and H.
Unio priscus abbreviatus Stanton
Unio senectus White
Unio primaevus White
Unio subprimaevus Dyer
Unio mclearni Dyer
Unio subspatulus M. and H.
Unio propheticus White
Unio humei Dyer
Unio cryptorhynchus White
Anodonta propatoris White
Sphaerium planum M. and H.
Sphaerium formosum M. and H.
Sphaerium recticardinale M. and H.
Viviparus conradi M. and H.
Viviparus nidaga Dyer
Campeloma vetula M. and H.
Campeloma vetula tenuis Dyer
Campeloma praecursa Dyer
Goniobasis subtortuosa M. and H.
Goniobasis williamsi Dyer
Goniobasis judithensis minimus Dyer
Goniobasis gracilentia Meek
Goniobasis sublaevis (M. and H.)
Physa copei White
Physa copei canadensis Whiteaves
Hydrobia subcylindraca Whiteaves
Planorbis amplexus M. and H.
Hyalina occidentalis M. and H. ?
Helix vetusta M. and H.

Brackish Water

Ostrea subtrigonalis E. and S.
Ostrea glabra M. and H.
Ostrea patina M. and H. ?
Ostrea subsinuata M. and H.
Corbicula occidentalis M. and H.
Corbicula cytheriformis M. and H.
Corbula perundata M. and H.
Corbula subtrigonalis M. and H.

Corbula of. mactriformis M. and H.
Anomia micronema Meek
Anomia gryphorhynchus Meek
Tancredia americana M. and H.
Velatella rectistriata Dyer
Melania whiteavesi Stanton
Lunatia concinna Hall and Meek
Rhytophorus? glaber Whiteaves

*Brackish Water Fossils of Foremost Beds in Milk River Valley below Pakowki
 Coulée*

Ostrea glabra M. and H.
Ostrea patina M. and H. ?
Ostrea subtrigonalis E. and S.
Ostrea subsinuata M. and H. ?
Anomia sp.
Corbula perundata M. and H.
Corbula subtrigonalis M. and H.
Melania whiteavesi Stanton
Rhytophorus ? glaber Whiteaves

Plants

W. A. Bell has identified the following plants from the lower beds of the Foremost formation from NE. $\frac{1}{4}$ sec. 2, tp. 3, range 16, W. 4th mer.

Pagiophyllum sp. cf. *geinitzia formosa* (Heer)
Juglans sp.
Sapindus sp.

Brackish Water Fossils of Pale Beds

	Sec. 27, tp. 2, range 4, W. 4th mer.	Woodpile coulée
<i>Ostrea glabra</i> M. and H.	x	x
<i>Anomia micronema</i> Meek.		x
<i>Corbicula cytheriformis</i> M. and H.		?
<i>Cardium speciosum</i> M. and H.		x
<i>Corbula perundata</i> M. and H.	x	
<i>Corbula subtrigonalis</i> M. and H.		x
<i>Corbula perangulata</i> Whiteaves.	x	
<i>Panopaea simulatrix</i> Whiteaves.		x
<i>Martesia tumidifrons</i> Whiteaves.	?	x

Marine (In Foremost beds)

Volsella meeki (E. and S.) Meek
Modiola tenuisculpta Whiteaves
Modiola dichotoma Whiteaves
Tancredia americana M. and H.
Crenella (?) parvula Whiteaves
Mastra alta M. and H.
Cardium speciosum M. and H.
Lunatia obliquata (Hall and Meek)
Panopaea berthoudi White
Panopaea simulatrix Whiteaves
Bryozoa

The freshwater species characterize much the greater part of the formation although by no means uniformly distributed through it. They are restricted to narrow lenses with many feet of barren rock between. *Unio danae* is the most abundant species and in places beds over 2 feet thick consist almost entirely of its remains. *Campeloma vetula*, *Campeloma*

vetula tenuis, *Campeloma praecursa*, *Goniobasis williamsi*, *Sphaerium planum*, *Physa copei*, and *Physa copei canadensis* are present at most of the freshwater fossil localities and commonly are quite abundant. *Anodonta propatoris* was noted several times in the Pale beds, but is quite rare in the Foremost member. The other freshwater species enumerated are quite rare; some of them, such as *Unio subprimaevus*, *Unio propheticus*, *Unio cryptorhynchus*, and *Planorbis amplexus* are very rare, being represented by only one or two specimens. No zoning of the species in the formation could be made out, and there is very little difference in the fauna of the two members except perhaps that that of the upper member is less prolific.

Certain Belly River freshwater species recur in one or more post-Bearpaw formations. Among these are *Physa copei*, *Physa copei canadensis*, *Unio danae*, *Unio consuetus*, *Unio senectus*, *Unio subspatulus*, *Unio propheticus*, and *Sphaerium planum*. In addition *Hydrobia subcylindraca* usually regarded as characteristic of the Belly River has been reported by Warren from the Saunders formation in a fauna of apparently Paskapoo age, and Russell notes that *Sphaerium formosum* regarded as characteristic of the post-Bearpaw formations occurs in the Belly River. There remains, however, a much larger list of species characteristic of the Belly River formation or its Montana equivalent the Judith River; and, moreover, there is an absence of many forms distinctive of the post-Bearpaw formations among which may be mentioned *Valvata filosa*, *Valvata bicincta*, *Hydrobia recta*, *Limnaea tenuicostata*, *Thaumastus limnaeiformis*, *Campeloma producta*, *Campeloma multilineata*, *Goniobasis tenuicarinata*, etc., etc. With fairly extensive collections there should be little difficulty in distinguishing the fauna of the Belly River from that of higher formations. Especially is there a marked difference between the fauna of the Belly River and the next succeeding continental formations; the only species in common between the Belly River and the Edmonton being *Unio danae*, *Unio consuetus*, *Sphaerium planum*, *Physa copei*, and *Physa copei canadensis*, and between the Belly River and the St. Mary River, *Unio danae*, *Sphaerium planum*, *Physa copei*, and *Physa copei canadensis*.

Among the thirty-two definitely determined forms: nine are confined to the Belly River; thirteen also occur in the Judith River but do not range into higher formations; and seven occur in the Judith River as well as in one or more higher formations.

Although the brackish water beds form only a small part of the thickness of the Belly River formation, nevertheless many of the species are so abundant that in any large collection from the formation they are in the majority. Although the individual beds are seldom over 1 or 2 feet thick they consist almost wholly of shells, and *Ostrea subtrigonalis*, *Corbula subtrigonalis*, and *Corbula perundata* are much more abundant than any other forms in the formation. The first mentioned form is especially abundant and forms beds well over 10 feet thick on South Saskatchewan river north of Bow island where the steep banks are literally strewn with it. Oyster shell beds are present in almost all outcrops of the Foremost member and occur also in the transition zone between the Pale beds and the Bearpaw formation. Several of the forms such as *Corbula subtrigonalis*, *Corbula perundata*, *Rhytrophorus? glaber*, *Velatella rectistriata*, and *Melania whiteavesi* must have become adapted to fresh as well as brackish conditions, since

they are frequently found in the same bed as *Unio*, *Viviparus*, *Campeloma*, and *Goniobasis* which are regarded as strictly freshwater genera, whereas the oyster beds represent more nearly marine conditions.

The gasteropods in the foregoing list, as well as the pelecypod *Corbula perundata*, appear to be distinctive of the Belly River or the equivalent Judith River formations. *Velatella rectistriata* was found only in the Foremost member and is very easily distinguished from the Fort Union species *V. baptista* by the possession of straight colour bands. The peculiar little form *Rhytrophorus? glaber* was also found only in the Foremost member, but *Melania whiteavesi* and *Corbula perundata* are found in the Judith River formation. In Alberta *Melania wyomingensis* and *Corbula perungulata* appear to be distinctive of higher formations and do not range below the Fox Hills. The remaining pelecypods range throughout the Upper Cretaceous and occur in sandy facies at whatever horizon they may be developed. Some of the species recur in the Fox Hills and Edmonton, others reappear in the Cannonball marine member of the Lance, and still others range downward into the Colorado, Pakowki, and Claggett. Even among these pelecypods, however, certain differences distinguish the fauna of the Belly River or Judith River. As stated by Stanton:

"Comparing the oysters, in the Laramie the large *Ostrea glabra* is the common form, while in the Judith River *O. subtrigonalis* is by far the most abundant and most widely distributed. *Corbicula* also has a different development in the Laramie, the types *C. occidentalis* and *C. cytheriformis* being comparatively rare, while there are many other species that are more abundant."

The marine fossils were found principally¹ in the Foremost beds at two localities: one on Oldman river in sec. 13, tp. 11, range 15, west 4th mer., and the other on the South Saskatchewan in sec. 6, tp. 13, range 10, W. 4th mer. These localities are so far apart and the exposures so disconnected that it cannot be proved whether there is one or more marine horizons, but from the fact that at both localities the fossils occupy about the same position in the member it is judged that one horizon only is represented. It may represent a marine invasion from the north of short duration at the time of the deposition of the marine Grizzly Bear shales.

The marine species have not been previously reported from the Belly River or Judith River formations, but their occurrence can have no bearing on the problem of correlation as they are all typical Pierre forms and are not distinctive of any particular horizon within this broad group.

Vertebrate Fossils From the Belly River Formation²

PISCES

Myledaphus bipartitus Cope
Ceratodus eruciferus Cope
Acipenser albertensis Lambe
Lepidosteus occidentalis (Leidy)
Diphyodus longirostris Lambe

AMPHIBIA

Scapherpeton tectum Cope

¹ The marine forms *Panopaea berthoudi*, *Panopaea simulatrix*, and *Cardium speciosum* were found in the Pale beds at scattered localities; they had probably drifted into fresh water from the nearby Bearpaw sea. *Macra alta* and *Crenella (?) parvula* have also been recorded by Whiteaves from the Pale beds.

² The list has been compiled by C. M. Sternberg.

REPTILIA

Trionyx vagans Cope?
Aspideretes foveatus Leidy
Aspideretes coalescens? (Cope)
Aspideretes maturus Lambe
Aspideretes subquadratus Lambe
Aspideretes latus Gilmore
Aspideretes allani Gilmore
Adocus? *lineolatus* Cope
Basilemys variolosa (Cope)
Neurankylus eximius Lambe
Boremys albertensis Gilmore
Baena antiqua Lambe
Baena pulchra Lambe
Cimoliasaurus magnus Leidy
¹*Paleosaniwa canadensis* Gilmore
Champsosaurus annectens Cope
Champsosaurus profundus Cope
Champsosaurus brevicollis Cope?
Crocodylus humilis Leidy
Leidyosuchus canadensis Lambe
Deinodon horridus Leidy
Deinodon? *explanatus* (Cope)
Deinodon? *hazenianus*? Cope
Gorgosaurus libratus Lambe
Gorgosaurus sternbergi Matthew and Brown
Dromaeosaurus albertensis Matthew and Brown
Chirostenotes pergracilis Gilmore
Struthiomimus altus (Lambe)
Trachodon? *selwyni* Lambe
Trachodon? *altidens* Lambe
Kritosaurus? *marginatus* (Lambe)
²*Kritosaurus?* *notabilis* (Lambe)
Kritosaurus? *incurvimanus* Parks
Prosaurolophus maximus Brown
Lambeosaurus lambei Parks
Corythosaurus casuarius Brown
Corythosaurus excavatus Gilmore
Corythosaurus intermedius Parks
Parasaurolophus walkeri Parks
Troödon formosus Leidy?
Troödon validus (Lambe)
Troödon brevis (Lambe)
Eoceratops canadensis Lambe
Brachyceratops dawsoni Lambe
Centrosaurus apertus Lambe
(Monoclonius flexus Brown)
Monoclonius? *nasicornus* Brown
Monoclonius? *cutleri* Brown
Styracosaurus albertensis Lambe
Chasmosaurus belli Lambe
Palaeoscincus costatus Leidy
Palaeoscincus asper Lambe
Euoplocephalus tutus Lambe
Panoplosaurus mirus Lambe
Dyoplosaurus acutosquameus Parks

MAMMALIA

Cimolomys primaevus (Lambe)
Boreodon matutinus Lambe
Eodelphis browni Matthew
Cimolestes? *cutleri* Woodward

"An examination of the faunal lists of the Belly River and Judith River formations shows many genera and species in common and there seems to be no doubt that the two formations are equivalent in age. Many of the Judith River species are based on fragmentary material and it is not possible to identify with them the better specimens subsequently discovered in the Belly River, but if extensive collecting were done in the Judith River it is probable that many more Belly River forms would be found".³

¹ MS. name by C. W. Gilmore.

² Brown, Parks, and Gilmore have referred Lambe's genus *Gryposaurus* to Brown's genus *Kritosaurus* from the Kirtland shale of New Mexico.

³ Sternberg, C. M.: "Notes on the Vertebrate Fauna".

Bearpaw

The Bearpaw formation is very similar to the Pakowki, both lithologically and faunally, but is greyer and less sandy than the brown-weathering Pakowki shale of southern Alberta. The Bearpaw and the Pakowki represent two invasions of the same sea and are separated by the continental deposit of the Belly River formation.

DISTRIBUTION

The Bearpaw shales are exposed on both flanks of the broad Sweet Grass arch having been eroded from the higher parts of the arch, thus leaving the Belly River and lower formations there exposed on the surface. Good exposures of the Bearpaw formation occur along most of the creeks draining the north side of Cypress hills. The lower part of the formation, including the contact with the Pale beds, is exposed in Boxelder and Ross creeks and the upper part, including the contact with the overlying Fox Hills, is to be found on Gap creek southwest of the town of Maple Creek. The contact with the Pale beds is exposed in Petrified coulée and on the sides of several of the mesas in the vicinity of Irvine and Walsh and elsewhere as stated in the description of the Belly River formation. Outcrops showing the Pale beds-Bearpaw contact occur on South Saskatchewan river at Rapid narrows, but the contact does not appear again to the north and east within the area. It was found far east of the area, in range 17, west of the 3rd meridian, demonstrating that the Pale beds-Bearpaw contact dips to the northeast from Rapid narrows at the rate of about $6\frac{1}{2}$ feet a mile. The best known contact with the overlying Foxhills sandstone occurs along Willow creek, 3 to 4 miles south of Thelma¹, Alberta. Excellent exposures of the Bearpaw also occur in the badlands east of Manyberries; along Battle creek above Woodpile coulée; and in the vicinity of Oldman-on-his-back plateau.

West of the Sweet Grass arch the best exposures are on Oldman river between the mouths of Belly and St. Mary rivers, and also between Lethbridge and Diamond City. A few good sections also occur on Little Bow river in tp. 14, range 21, W. 4th mer. Here can be seen to good advantage the very gradual transition from the Bearpaw shale to the Fox Hills sandstone. Numerous sections of the Bearpaw occur on Bow river between Bassano and Eyremore and also along Red Deer river for 50 miles below the town of Rosedale. The most easterly exposure on Red Deer river is in range 9, west of the 4th meridian, where the very lowermost beds occur. The section becomes thicker as it is traced westward and the Pale beds-Bearpaw contact comes to the level of the river in the eastern side of range 15. Exposures also occur in Misty hills, on Sounding creek, and in the inner Rainy hills.

The exposure of the Pale beds and lower formations through the central part of the area is the result of the broad flexure of the Sweet Grass arch. The dip of the Bearpaw on the western side of the arch is to the west and on the eastern side to the north and northeast. Patches of Bearpaw still

¹"Sandstone Dykes in Southeastern Alberta"; M. Y. Williams, Trans. Roy. Soc., Canada, 1927, pp. 153-174.

cover parts of the intervening area. The formation is exposed capping hills in sec. 2, tp. 17, range 8, W. 4th mer., and sec. 34, tp. 16, range 8, W. 4th mer., and it probably underlies a higher area in tps. 20 and 21, range 6, W. 4th mer., and also the outer Rainy hills. No exposure of any rock was found in these two last-mentioned areas and the boundaries shown on the map are conjectural. Other small patches of the Bearpaw may occur, which are not mapped.

LITHOLOGY

The Bearpaw formation consists very largely of dark grey, greenish grey, and chocolate brown, soft, fissile shales. The strata are very much alike in texture and colour. The layers are separated by thin lines of darker muds. The rocks are very friable and weather to banks of earthy appearance.

Beds of soft sands are present in places. On Ross creek, 3 miles south of Irvine, and on Gros Ventre creek, about 2 miles to the west, light grey sand beds 8 feet thick occur about 75 feet above the base of the formation. On Little Bow river, in sec. 19, tp. 14, range 20, W. 4th mer., in the upper part of the formation, there are two beds of light grey sand and sandy clay separated by 10 feet of brownish shale. All these beds contain marine fossils. On Bow river, in sec. 24, tp. 19, range 18, W. 4th mer., in the upper part of the formation, there is a bed of soft, massive, dark grey sand about 50 feet thick, containing characteristic marine fossils.

In the exposures in the northern part of the area the colour of the formation changes considerably laterally as well as vertically. The lower beds are generally dark brown or chocolate-coloured with some intermingling of lighter beds near the contact. Higher in the formation the beds are generally dark grey. On Sounding creek, however, the lower beds are grey and strongly resemble some of the upper members of the Pale beds, but their marine character was proved by fossil evidence. Higher in the formation, probably near the middle, a considerable intermixture of sand occurs in the shales and gives them a very white appearance on the weathered surface and at a distance the beds resemble a sandstone. These beds are well exposed on Red Deer river just west of the east exposure of Pale beds. They probably represent the southward extension of the Bulwark sandstone which is a definite sandstone horizon in the Bearpaw farther north.¹

Elliptical calcareous concretions are abundant in the Bearpaw shales. They consist of very fine-grained, homogeneous material and usually show irregular fracturing with the fractures filled with calcite. They should more properly be termed septaria. They range in size from 6 inches up to 5 feet. In most of them the relations with the country rock could not be determined on account of the hard surfaces of the concretions and the friable natures of the shales in which they are embedded, but in a few cases it was definitely seen that the shale laminæ are bent upward over them and downward under them. They commonly have fossil nuclei,

¹ Slipper, S. E.: Geol. Surv., Canada, Sum. Rept. 1917, pt. C, p. 8.

and some contain numerous well-preserved fossils, though the surrounding shales may be quite barren. Fossils have been found in the shale similar to those in the concretions, but evidently conditions for preservation were not nearly so favourable as in the concretions. The Taber well penetrated similar concretions in the Colorado formation. Core samples from the well show that the irregular fractures filled with calcite, which are always found in the concretions exposed at the surface, also exist at depth. This shows that the fracturing is not a surface phenomena; it is probably due to the shrinkage of the clay content in the iron carbonate concretions.

Continuous bands of carbonate are also plentiful, these are usually not more than a few inches thick, but in one place a band a foot thick was found carrying very numerous fossils such as *Pteria*, *Placenticeras*, and *Baculites*. Cone-in-cone structure is also often found in the carbonate bands.

Seams of bentonite are common in the Bearpaw. The seams are usually 1 or 2 inches thick, but 4 to 6-inch seams are present, and on Little Bow river one heavy seam of impure bentonite is 20 feet thick.

Gypsum is very abundant in the Bearpaw formation and wherever found is in the form of fibrous selenite or thin, flat plates of selenite occupying the partings in the shales. The mineral also occurs in well-defined monoclinic crystals and in swallowtail twins of selenite as much as 3 inches long, lying on the weathered slopes of exposures. These crystals are entirely a surface development. The gypsum originally was disseminated through the Bearpaw formation and was afterward dissolved by percolating waters and concentrated in the partings. The large crystals evidently recrystallized at the surface. Gypsum seems to be somewhat more abundant in the upper 100 feet and lower 100 feet than elsewhere.

THICKNESS

It is difficult to estimate the thickness of the Bearpaw formation in the eastern part of the area, as no wells have been drilled and no continuous exposures exist. However, by determining distances between fossil zones on the creeks north of Cypress hills, the approximate figure of 525 feet for the thickness of the formation was arrived at. In the west a well drilled at Scabby butte gave a thickness of 622 feet, and another at Kipp station gave 625 feet, but in the latter well there is some uncertainty as to the exact stratigraphic position of the top.

PALÆONTOLOGY

A careful study of the distribution of fossil species resulted in the discovery of certain fairly well-defined fossil zones. Stratigraphic distances between the zones, the distance of the lowest zone above the base of the formation, and the distance of the highest zone below the Fox Hills sandstones were measured by plane-table; their results are tabulated below.

*Composite Section of the Bearpaw Formation in the Northwestern End of
Cypress Hills*

	Height in feet, above base
Fox Hills formation: brown, soft sandstone and sandy shale.....	
Bearpaw formation: dark grey and brownish grey shales, no fossils, selenite abundant..	450-525
Row of large, calcareous concretions filled with <i>Baculites compressus</i> , also contains <i>Schaphites</i> , <i>Anchura</i> sp., and <i>pelecypods</i> (<i>Baculites compressus</i> zone).....	450
Dark grey shale with few fossils.....	400-450
Medium-sized concretions overlain by a well-defined cone-in-cone bed.....	400
Shale with several rows of small concretions containing <i>Inoceramus barabini</i> , <i>Baculites compressus</i> , and a few specimens of <i>Baculites grandis</i>	325-400
Dark shale with <i>Inoceramus barabini</i> , <i>Baculites grandis</i> , <i>B. compressus</i> , <i>Placenticerus meeki</i> , and <i>P. intercalare</i>	250-325
Dark shale containing: <i>Baculites grandis</i> , <i>Placenticerus meeki</i> (abundant), <i>P. intercalare</i> , <i>Baculites compressus</i> (rare), <i>Lucina</i> , <i>Inoceramus vanuxemi</i> , <i>I. barabini</i> , <i>Liopistha undata</i> , <i>Protocardia borealis</i> , <i>P. subquadrata</i> , <i>Pteria linguiformis</i> , <i>Modiola dichotoma</i> , <i>Gervillia recta borealis</i> , <i>Bryozoa</i> , etc.....	100-250
Row of large calcareous concretions filled with <i>Arctica ovata</i> (<i>Arctica ovata</i> zone).....	100
Barren, dark grey shale with some concretions.....	50-100
Sandstone bed about 10 feet thick overlain by thin oyster beds with <i>Ostrea</i> cf. <i>patina</i> ...	50
Barren, dark grey shale.....	0-50
Base of Bearpaw formation.....	0

The lower 400 feet of the formation is best seen on Ross creek, from which the lower part of the composite section is compiled. The outcrops in Boxelder creek show much the same succession, but continue somewhat higher and include the *Baculites compressus* zone. The outcrops on Gap creek in secs. 13 and 24, tp. 9, range 27, W. 3rd mer., show the upper part of the succession from 375 feet above the base to the Fox Hills sandstone. The most notable horizons are the *Arctica ovata* zone 100 feet above the base, the *Baculites compressus* zone 450 feet below the base, and the cone-in-cone layer 400 feet above the base. The *Arctica ovata* zone was found on Ross creek, Boxelder creek, and Little Boxelder creek. *Arctica ovata* is most abundant in this formation on Oldman river near the mouth of St. Mary river about 170 feet above the base, but there is distributed through about 25 feet of shale, instead of being confined to a row of concretions. On Bow river it was found at only one horizon about 50 feet above the base of the formation. The *Baculites compressus* zone was found on Boxelder creek, Gap creek, and on the upper end of Boxelder creek in sec. 30, tp. 9, range 29, W. 3rd mer. The cone-in-cone layer was found on Boxelder creek, Gap creek, and on Bullshead creek near the fault in sec. 2, tp. 9, range 5, W. 4th mer.

Fossils from Bearpaw shale have been collected at many localities, *Arctica ovata*, *Baculites compressus*, and *Placenticerus meeki* being common where they occur. Rich faunal assemblages were found at a few places such as Bullshead butte and in Gros Ventre, Ross, and Boxelder creeks which flow northward from Cypress hills; and in the banks of St. Mary and Oldman rivers near Lethbridge. At the latter localities *Arctica ovata* occupies a fairly definite zone from 100 to 170 feet above the base of the formation.

Bearpaw Fossils

Fossils	Lethbridge vicinity		North slope of Cypress hills		Else-where
	Arctica zone	Higher beds	Arctica zone	Higher beds	
PELECYPODA					
<i>Yoldia microdonta</i> Meek.....				?	
<i>Gervillia recta</i> M. and H.....				x	
<i>Gervillia borealis</i> Whiteaves.....	x	x	x	x	x
<i>Inoceramus barabini</i> Morton.....		x	x	x	x
<i>Inoceramus balchii</i> M. and H.....			x	?	
<i>Inoceramus convexus</i> H. and M.....				?	
<i>Inoceramus vancouverensis</i> Shumard.....				x	
<i>Inoceramus simpsoni</i> Meek.....				x	
<i>Inoceramus tenuilineatus</i> H. and M.....				x	x
<i>Inoceramus vanuxemi</i> M. and H.....				x	W.C.
<i>Pteria linguiformis</i> E. and S.....		x	x	x B.H.	x
<i>Pteria (Oxytoma) nebrascana</i> E. and S.....				x B.H.	
<i>Ostrea nasuta</i> Morton.....			B.H. ?		
<i>Ostrea patina</i> M. and H.....			?	x	
<i>Ostrea subtrigonalis</i> E. and S.....		x			
<i>Gryphaea vesicularis</i> Lamarck.....			?	?	
<i>Chlamys nebrascensis</i> M. and H.....				x	
<i>Synsclonema rigida</i> H. and M.....				x	
<i>Modiola attenuata</i> M. and H.....	x		B.H.	x B.H.	
<i>Voltsella meeki</i> (E. and S.) Meek.....				x	
<i>Liopistha (Cymella) undata</i> M. and H.....	x		B.H.x	x B.H.	x
<i>Arctica ovata</i> M. and H.....	x		x		
<i>Arctica ovata alta</i> Whiteaves.....	x		x B.H.		
<i>Arctica ovata compressa</i> M. and H.....			x		
<i>Corbicula cytheriformis</i> M. and H.....	x				
<i>Lucina occidentalis</i> Morton.....		x	B.H. (var)	x	
<i>Lucina subundata</i> H. and M.....				x B.H.	x
<i>Protocardia borealis</i> Whiteaves.....	x		x B.H.	x B.H.	
<i>Protocardia subquadrata</i> E. and S.....	x		x	x B.H.	?
<i>Veniella subtrapeziformis</i> var. <i>dyeri</i> Williams.....				x	
<i>Callista occidentalis</i> Morton.....					x
<i>Callista pelucida</i> M. and H.....				B.H.	
<i>Callista (Dositopsis) deweyi</i> M. and H.....	x	x	x	x B.H.	x
<i>Mactra (Cymbophora) alta</i> M. and H.....	?		x	x	
SCAPHOPODA					
<i>Dentalium gracile</i> M. and H.....		x		?	x
GASTROPODA					
<i>Trachytroton vinculum</i> H. and M.....				x	
<i>Neritina cf. wyomingensis</i> Walcott.....			B.H.		
<i>Vanikoro ambigua</i> M. and H.....				B.H.?	x
<i>Vanikoropsis tuomeyana</i> M. and H.....				x	
<i>Anchura americana</i> E. and S.....				x	?
<i>Anchura nebrascensis</i> E. and S.....			x	x	
<i>Pseudobuccinum nebrascense</i> M. and H.....					?
<i>Actaeon attenuata</i> M. and H.....					x
<i>Actaeon subellipticus</i> M. and H.....				x	
<i>Cinulia (Oligoptycha) concinna</i> M. and H.....					x
CEPHALOPODA					
<i>Scaphites ventricosus</i> M. and H.....				?	
<i>Acanthoscaphites nodosus</i> Owen var. <i>brevis</i> Meek.....		x	var.?		x W.C.
<i>Baculites compressus</i> (Say).....	x	x	x	x	x W.C.
<i>Baculites grandis</i> H. and M.....				x	x
<i>Baculites crickmayi</i> Williams.....				x	
<i>Platoniceras meeki</i> Boehm.....	x	x	x	x	
<i>Platoniceras intercalare</i> M. and H.....	x	x	x	x	W.C.
<i>Rhaeboceras halli</i> M. and H.....				x	
CRUSTACEA					
<i>Macrura crustacea</i>			B.H.		

B.H. = Bullshead butte

W.C. = Woodpile coulée

Fox Hills

Wherever in southern Alberta and southwestern Saskatchewan the top of the Bearpaw formation is exposed, the dark marine shales grade upward into brown sands and shales representing a near-shore phase of the shallowing Pierre sea and constituting the Fox Hills formation. Since this formation as exposed west of the Sweet Grass arch is of somewhat different character and may differ in age from its development east of the arch, the two developments will be described separately.

WEST OF THE SWEET GRASS ARCH

The Fox Hills formation is well exposed on St. Mary river, the north branch of Milk river, and on Oldman river for 3 miles downstream from the road bridge at Monarch, and in these places lies between the Bearpaw and the St. Mary River formations. It outcrops on Little Bow river in the vicinity of Wolf coulee, on Bow river near Bassano, and on Red Deer river below Rosedale, and at these localities lies between the Bearpaw and Edmonton formations.

It is, essentially, a variable series of brown, grey, and green sandstones and sandy shales. Fine banding due to slight changes of colour of the laminae are common. In places black, carbonaceous bands occur and these on Little Bow river constitute lignite seams thick enough to mine. Seams of lignite 1 to 2 feet thick also occur on Bow river. Much of the sandy shale is fine-grained, colloidal, and may even be bentonitic, as it swells when wet, to a pulpy, greasy, very slippery mass. These colloidal shales flow and commonly assume peculiar contorted shapes. Pieces of silicified wood commonly occur, the originals having probably drifted from a nearby shore. Thick beds of oyster shells occur and consist almost entirely of the remains of *Ostrea glabra* and *Ostrea subtrigonalis*. The Fox Hills beds as exposed on St. Mary river differ somewhat from those of the more northern exposures, in being more massive and having less shale, and it was this difference that caused Dawson to consider the beds on St. Mary river as Fox Hills, but to include the beds of equivalent age on the Oldman with the St. Mary River formation.

A well drilled at Scabby butte started at the top of the Fox Hills formation and reached the coal horizon at the base of the Bearpaw at 1,000 feet. Assuming 600 feet as the thickness of the Bearpaw in this region, the Fox Hills would be 400 feet thick. Farther south on Oldman river the thickness is very difficult to determine as the strata lie in a complicated series of fault blocks; it must be somewhat less than at Scabby butte as the formation thins from north to south. On St. Mary river the thickness from the top of the Bearpaw shale to the lignite horizon is 180 feet, on Little Bow river it is about 300 feet, and it is about the same on the Bow. It is difficult to give definite figures for the thickness of the formation since the contacts with both overlying and underlying formations are transitional, and uncorrelatable parts are found in different exposures.

The fauna is largely brackish and marine, as shown by the following list.

Fossils of Fox Hills Formation West of the Sweet Grass Arch

Ostrea subtrigonalis E. and S.
O. glabra M. and H.
Corbicula cytheriformis M. and H.
C. occidentalis M. and H.
Corbula perangulata Whiteaves
Melania wyomingensis White
Lunatia subcrassa M. and H.
L. obliquata M. and H.
Anchura sp.
Arctica ovata (M. and H.)
Unio danae M. and H.
Tancredia americana M. and H.
Baculites compressus Say
 Sharks teeth

These fossils serve to show the brackish water and marine nature of the formation, only one freshwater species, *Unio danae*, being present and this probably drifted in from the nearby shore. They indicate the Montana age of the formation, but all are long-ranging species, and not distinctive of any particular part of the Montana. Much the same assortment characterizes sandy facies wherever they occur in the Pierre. The Fox Hills formation west of the Sweet Grass arch is probably somewhat older than east of the Sweet Grass arch, since the beds immediately overlying the former development are pre-Lance in age whereas the beds overlying the Fox Hills in the east contain typical Lance dinosaurs. This is to be expected as it must have taken an appreciable length of time for the Pierre sea to withdraw to the east across the province.

EAST OF THE SWEET GRASS ARCH

The only complete section of the Fox Hills formation so far discovered in Cypress hills is that measured by McConnell¹ along Willow creek, from the contact with the Bearpaw shale in sec. 25, tp. 6, range 3, W. 4th mer., toward Thelma post office in sec. 18, tp. 7, range 2, W. 4th mer. This section was carefully re-measured by plane-table survey, and the section from the Bearpaw to the Whitemud beds is as follows.

Whitemud beds: white clay, about 3 feet visible	Feet	Inches
<i>Estevan</i>		
Covered interval about.....	20	
Grey and buff sand and silt.....	20	
Lignite (being mined).....	10	
Yellowish, silty sandstone.....	45	
Thin coal seams, fire-clay, and lignite shale.....	25	
Soft, buff-coloured sandstone.....	50	
Lignite and lignitic shale.....	25	
Sandstone.....	5	
Shale.....	5	
Cream-coloured friable sandstone.....	80	
<i>Fox Hills</i>		
Grey, silty shale.....	80	
Lignite.....		8
White, silty sandstone.....	50	
Dark grey shale with bentonite, gypsum, and hard beds.....	110	
Loose, friable, grey to light brown sandstone.....	130	
<i>Bearpaw Shale</i>		
Grey shale.....	6	
Yellowish sandstone.....	2	
Grey, sandy shale.....	5	
Dark grey shale cut by sandstone dykes.....	38	

¹ 1885, pt. C, p. 25.

This section is almost identical with that given by McConnell, but the thickness assigned the Fox Hills is 370 feet instead of 150 feet as given by McConnell. The dark shales now included in the formation are clearly marine and near the Head of the Mountain, along Frenchman river, and elsewhere contain a marine Pierre fauna.

Sandstone ledges referred to the Fox Hills formation flank the hills on both sides of Medicine Lodge coulée for several miles, but owing to the large amount of outwash from the hills, they are exposed in only a few places. Perhaps the best exposure is on the east side of the coulée in sec. 6, tp. 8, range 5, W. 4th mer. Sandstones also outcrop in a gully in the SE. $\frac{1}{4}$ sec. 30, tp. 9, range 1, W. 4th mer. The sandstones are grey, medium grained, massive bedded, quartzose, with a large biotite content. Crossbedding is prevalent, and the sand is sufficiently coherent to form ledges. Gentle slopes occurring between the steep outcrops of sandstone suggest the presence of shale such as outcrops in stream valleys in sec. 8, tp. 8, and sec. 32, tp. 7, W. 4th mer. Toward the base the sandstone is soft and shaly. Thinner-bedded, calcareous sandstone in the middle of the formation yielded the following marine fossils: *Linearia formosa*, *Inoceramus* sp., *Protocardia borealis*, *Mastra warrenana*, *Yoldia evansi*, *Protocardia subquadrata*, *Pteria nebrascana*, *Scaphites* sp., *Nucula* cf. *subplana*. Stanton¹ reports finding the following additional species at the same locality: *Tancredia americana*, *Callista nebrascensis*, *Schaphites nodosus* var. *quadrangularis*. He says, "Part of these species are in the Fox Hills beds in other regions and most of them occur in the Pierre and Bearpaw shales. It has long been known that the faunas of the Fox Hills and the Pierre are too closely related to be considered really distinct."

Excellent exposures of Fox Hills sandstone also occur in Fish creek in sec. 32, tp. 9, range 28, W. 3rd mer., and in the banks of Battle creek below old Fort Walsh.

Fox Hills shales outcrop in the banks of Cypress lake; and in Frenchman valley, especially below Ravenscrag. In these eastern occurrences, they resemble the Bearpaw shale so closely in character and fossils that McConnell and Davis have mistaken them for the lower shales. Where the Fox Hills sandstone is exposed below, the shales are readily determined. Elsewhere they are best identified by the absence of Fox Hills sandstone above them, for this would be present were the shales Bearpaw in age.

The lower sandstone, in general, contains few fossils, only some vertical Scholithus, a shark's tooth, and some fragments of wood having been found. The lower shale member of the section, page 47, is probably in the strata exposed on the shores of Cypress lake, they contain marine Pierre fossils. At this locality the middle sandstone contains many marine pelecypods, and this member contains oysters in Medicine Lodge coulée. The upper shale as exposed in the same coulée contains numerous marine pelecypods and a few gasteropods.

¹ Stanton, T. W., and Hatcher, J. B.: "Geology and Paleontology of the Judith River Beds"; U.S. Geol. Surv., Bull. 257, p. 55.

Fox Hills Fossils

	Milk River valley, tp. 1, range 21, W. 4th mer.	Upper Medi- cine Lodge coulée	Fort Walsh	Cypress lake Lower beds	Cypress lake Upper beds	French- man river near Davis creek	South of Old- man-on- his- back plateau
PELECYPODA							
<i>Nucula cancellata</i> M. and H.		x	x				
<i>Yoldia evansi</i> M. and H.		?	?	x		?	
<i>Yoldia microdonta</i> M. and H.		x				x	
<i>Gervillia borealis</i> Whiteaves.				x			
<i>Gervillia recta</i> M. and H.				x			
<i>Inoceramus convexus</i> H. and M.						x	
<i>Inoceramus incurvus</i> M. and H.						?	
<i>Inoceramus tenuilineatus</i> H. and M.						x	
<i>Pteria linguiformis</i> E. and S.		x					
<i>Pteria nebrascana</i> E. and S.		x	x	x		x	x
<i>Ostrea glabra</i> M. and H.		x					
<i>Ostrea patina</i> M. and H.	var. C						
<i>Ostrea sub-sinuata</i> M. and H.	x						
<i>Modiola attenuata</i> M. and H.							?
<i>Volsella meeki</i> (E. and S.) Meek.							x
<i>Pholadomya subventricosus</i> M. and H.			?				
<i>Liopistha (Cymella) undata</i> M. and H.		x					
<i>Corbicula cytheriformis</i> M. and H.			x	x			
<i>Sphaeriola warrenana</i> Meek.				x			
<i>Tancredia americana</i> M. and H.			x	x			
<i>Protocardia borealis</i> Whiteaves.				x			
<i>Protocardia rara</i> E. and S.			?	x	?	x	
<i>Protocardia subquadrata</i> E. and S.							x
<i>Tellina equilateralis</i> M. and H.				x		x	
<i>Tellina modesta</i> Meek.		?					
<i>Linearia formosa</i> M. and H.				x			
<i>Mactra (Cymbophora) alta</i> M. and H.	?						
<i>Mactra (Cymbophora?) formosa</i> M. and H.			x			x	
<i>Mactra (Cymbophora?) gracilis</i> M. and H.		x					
<i>Mactra (Cymbophora) utahensis</i> Meek.				?			
¹ <i>Corbula perangulata</i> Whiteaves.		x					
SCAPHOPODA							
<i>Dentalium gracile</i> M. and H.				x		x	x
GASTEROPODA							
<i>Trachytroton vinculum</i> H. and M.				x			
<i>Lunatia subcrassa</i> M. and H.			x	x			x
<i>Anchura americana</i> E. and S.					?		x
<i>Odontobasis ventricosa</i> Meek.				x			
<i>Pyrifusus (Neptunella) newberryi</i> M. and H.							x
<i>Cinulia (Oligoptycha) concinna</i> M. and H.						x	
<i>Haminea occidentalis</i> M. and H.							x
CEPHALOPODA							
<i>Acanthoscaphites nodosus</i> Owen var. brevis Meek.			x	x		x	
<i>Baculites compressus</i> (Say).				?			?
<i>Placenticeras meeki</i> Boehm.				x			
PLANTAE							
SCHOLITHUS.		x					

¹ Also collected at Monarch.

Edmonton Formation

DISTRIBUTION

The Edmonton formation was first described by Tyrrell,¹ in 1886, as the coal-bearing series lying above the marine Fox Hills and Bearpaw formations and below the freshwater Paskapoo series.

The most southerly point at which undoubted Edmonton beds have been recognized is on Little Bow river northeast of Carmangay. South of the Little Bow the Edmonton formation is represented by the approximately equivalent St. Mary River formation which extends southward across the International Boundary into Montana. Very extensive exposures occur on Red Deer river and tributary streams. The strata are also well shown on Bow river where they are first seen near the western boundary of the Black Foot Indian reservation. Numerous outcrops extend eastward from this point to about 5 miles south of the irrigation dam at Bassano.

LITHOLOGY

The composition of the Edmonton beds varies greatly both laterally and vertically. The formation consists of thin alternating beds of white and pale grey, argillaceous sands, grey and brown clay, arenaceous shales, black carbonaceous shales, and coal. Most of the beds are soft and weather into typical badland forms. There are thin, pure beds of bentonite and many of the sands contain an admixture of fine, colloidal clay which may be bentonitic and which renders them very greasy and slippery when wet. There are few sandstone members with the exception of certain hard, flaggy, crossbedded strata that occur in well-defined horizons, and being resistant to erosion, form ledges and often cap mesas and buttes in the badlands. Elliptical, sandstone and calcareous concretions, and small, nodular, calcareous concretions coated with red and brown iron oxide are abundant, and on weathered outcrops strew the banks; they are much like those occurring in the Belly River formation described elsewhere. Some bands of hard, siliceous shales occur. There are also a few hard bands of calcium and iron carbonate, one of which afforded most of the freshwater fossils that were found. Coal seams are more or less regularly distributed throughout the formation. Eleven seams were counted in Drumheller region, where three of them are mined. Thick coal seams also occur in the Edmonton formation on Bow river near Bassano, where they have been mined sporadically. Coal seams are also mined in Wolf coulee 15 miles northeast of Carmangay and at a few points northeast of Champion.

The following section of the Edmonton formation appears in Allan's report on the "Geology of the Drumheller Coal Field."²

¹ Tyrrell, J. B.: "Report on a Part of Northern Alberta and Portions of the Adjacent Districts of Assiniboia and Saskatchewan"; Geol. Surv., Canada, Ann. Rept., vol. II.

² Allan, J. A.: 3rd Ann. Rept. Min. Res. Alberta, 1922, pp. 30, 31.

	Thickness Feet
Yellowish clays, unconsolidated.....	60
Dark grey shales.....	2
Light grey sandstone, shaly lenses, and hard, yellowish, sandstone nodules	12
Coal.....	1-6
White sandstone with hard, nodular lenses, fossil bones horizon.....	19-1
Yellowish grey shale.....	5-3
Whitish sandstones with ironstone bands about 2 feet apart, and bituminous, shaly lenses.....	20
Red, ironstone band.....	1-5
Coal, and carbonaceous black shale, No. 9 seam.....	1-5
Dark grey shales.....	9
Coal, No. 8 seam.....	4
Dark grey, arenaceous shales, with white, sandstone lenses and ironstone beds about 1 foot thick.....	31-5
Carbonaceous shale.....	1-5
White sandstone grading into light grey shales.....	8-5
Yellowish grey, sandy shales (dinosaurs).....	25-7
Ironstone.....	2
Whitish, bentonitic sandstone.....	7
Light grey, and yellowish, sandy shales.....	12
Brownish yellow shales.....	3
Ironstone and black, carbonaceous shales.....	1-2
Beds of dark grey shales becoming more arenaceous to base (dinosaurs) ..	11-5
Whitish, bentonitic sandstone.....	9-3
Grey shales grading down to bentonitic sandstone.....	15-5
Crossbedded sandstone.....	2
White, bentonitic sandstone.....	6
Coal.....	2
Ironstone and yellowish grey, clay shales and bentonitic sandstone.....	6
Bentonitic, grey shales and sandstones.....	20
Yellowish, bentonitic shale.....	9
Coal.....	2
White, bentonitic sandstone.....	3
Coaly shale.....	1
Yellow, clay shale.....	1
White, bentonitic sandstone.....	5
Yellow, grey, and white, bentonitic sandstone or shale with ironstone bands towards base.....	23-5
Carbonaceous shale.....	2
Brownish yellow, bentonitic shale.....	11-5
White, bentonitic shale and sandstone.....	6-5
Brown, fissile shale.....	0-5
Yellowish and grey, sandy shales.....	10
Brown shale.....	2
Coal.....	3-5
White and grey shales.....	6-5
Carbonaceous shale.....	0-5
Brown shale.....	1-5
White, bentonitic sandstone and shale.....	5-5
Reddish shale with wood fragments.....	1-5
Coal.....	1-5
Brownish shale.....	0-5
Grey, bentonitic sandstone.....	8-0
Yellowish shale and small, ironstone band, ochre toward base.....	3-0
Coal.....	2
Grey, bentonitic shale.....	4-5
Yellow ochre or ironstone.....	1
Coal and shale.....	1
White, bentonitic sandstone with clay lenses and ironstone band.....	38
Dark, arenaceous shale.....	3
Coal.....	6
Bentonitic sandstone and ferruginous shale.....	28
Grey, bentonitic, clay shale.....	9
Coal.....	2
Dark, clay shale.....	9
White, bentonitic sandstone.....	42
Chocolate brown shales with gypsum crystals (Fox Hills).....	—

EROSIONAL UNCONFORMITY BETWEEN THE EDMONTON AND PASKAPOO FORMATIONS

On Bow and Red Deer rivers the contact between the Edmonton and overlying Paskapoo formations is very clearly marked by a disconformity first discovered by Sanderson. Hume¹ notes the presence of conglomerate sandstone at the base of the Paskapoo formation. He says:

"In a section exposed east of the bridge over Fish creek at Priddis, a conglomerate sandstone with quartzite pebbles up to 3 inches in diameter overlies greenish clay shales presumed to be Edmonton in age. This conglomerate sandstone may be of more than local significance and may represent the base of the Paskapoo, since Allan² has reported that an erosional interval separates the Paskapoo and Edmonton in the Plains region. The conglomerate sandstone outcrops in various places on the ridge southeast from Priddis, but was not seen elsewhere."

This disconformity was also seen at the northern bend of Bow river about 3 miles west of Barstow siding, 7 miles west of Gleichen. At one point the following descending section was measured:

Bed No.		Feet
11	Ledge-making, buff sandstone to top of cliff.....	50
10	Grey, soft sandstone.....	1
9	Conglomeratic sandstone with clay pellets and some well-rounded pebbles with quartzite.....	1
8	Soft, grey sand.....	1½
7	Conglomeratic sandstone with well-rounded, water-worn pebbles of quartzite and porphyry up to 3 inches in length (Paskapoo).....	½
6	Black clay (bentonitic?) (Edmonton).....	2
5	Soft, fine-grained, white argillaceous sand.....	15
4	Brown shale.....	7
3	Soft, grey sand.....	5
2	Massive, grey to buff sandstone.....	25
1	Soft, grey, thinly laminated sandstone (to water-level).....	15

At another point one-half mile to the east, bed No. 6 is 10 feet thick and 13 feet of grey clay shale, 1 foot of carbonaceous shale, and 7 feet of grey shale intervene between beds Nos. 6 and 7. Thus, there is a distinct break between the two formations indicated by the conglomerate in the Paskapoo and by evidence of an erosional unconformity.

The contact between the Paskapoo and Edmonton was also observed in one of the small coulées tributary to Kneehills creek, in sec. 29, tp. 28, range 22, west of 4th mer., about 5 miles southeast of Carbon. The section here is not so clear as on Bow river as it was more or less hidden by talus, but the contact appears to be almost as sharp, and the Edmonton must have been eroded to about the same depth, as similar black clay and white arenaceous sand occur very near the top of the Edmonton in both places. The lower part of the Paskapoo is of ledge-making, buff sandstone at both places.

Since the Edmonton formation, or some part of it, as shown by its dinosaur content, is pre-Lance in age and since the Paskapoo by its mammal content is known to be younger than Fort Union, the unconformity must represent at least all Fort Union time and perhaps part of Lance time as well.

¹ Hume, G. S.: Geol. Surv., Canada, Sum. Rept. 1926, pt. B, p. 7.

² Allan, J. A.: Can. Inst. Min. and Met., April, 1925, p. 346.

THICKNESS

The Edmonton formation varies greatly in thickness from north to south. On Little Bow river it is probably about 400 feet thick, although an estimate is difficult to form owing to the scattered nature of the exposures. North of Little Bow it thickens abruptly, since on Bow river it is thought to be nearly as thick as on Red Deer river where a fairly accurate estimate indicates that the thickness is close to 1,000 feet.

ORIGIN

Conditions must have been exceedingly variable to produce such markedly varying series of beds as are found in the Edmonton formation. The light grey sands with their characteristic foreset beds must have been deposited in deltas at the mouths of large rivers. The crossbedded layers of sandstone were probably laid down in channels of rapidly flowing rivers. Some of the dark-coloured, more uniformly bedded, ripple-marked shales were undoubtedly formed on mud flats and flood-plains of rivers. Some of the beds, especially those containing carbonaceous materials and coal, must have originated in enclosed basins or swamps. The continental origin is also suggested by the freshwater shells found in many places. The large number of brackish water and marine shells found at one horizon a little more than half-way up in the formation indicate, however, that the sea must have invaded the lands during at least one period.

The Edmonton, in part at least, is equivalent to the St. Mary River formation to the south in which the sediments are more uniform in character and wholly of freshwater origin. The beds which in the foothills belt (Sheep River area) have been referred to the Edmonton are darker and do not contain as much coal as the strata to the east. They appear to be of lacustrine and fluviatile origin and in lithology are more like the Paskapoo and St. Mary River beds. Freshwater shells such as *Unio* and *Viviparus* are common.

PALÆONTOLOGY

Invertebrate fossils are not abundant in the Edmonton. Freshwater gasteropods occur sparsely at different horizons and are especially numerous in a calcareous layer about 600 feet above the base. An oyster shell bed consisting of large numbers of *Ostrea glabra* and *Ostrea subtrigonalis*, but with other marine and brackish water fossils, occurs about 50 feet above the freshwater fossil horizon. Dinosaurs and other vertebrate remains are abundant at several horizons. Fossilized tree trunks are abundant, but leaf impressions are rare. According to Allan, considerable numbers of fossil tree trunks up to 3 feet in diameter occur in the beds immediately above the No. 3 coal seam in Drumheller district. Many of them are in an upright position which would seem to indicate that they have not been transported far, if at all, from their original position. Similar tree trunks were found in one of the lower coal seams on Bow river near Bassano and also on the shores of lake McGregor.

Freshwater Invertebrates of the Edmonton Formation

	Belly River	St. Mary River	Willow Creek	Paskapoo	Lance	Fort Union
<i>Unio danae</i> M. and H.	x	x	x	x	x	x
<i>Unio consuetus</i> Whiteaves.	x					
<i>Unio sandersoni</i> ¹ Warren.						
<i>Unio minimus</i> ¹ Warren.						
<i>Sphaerium planum</i> M. and H.	x	x			x	
<i>Sphaerium formosum</i> M. and H.	?	x	x	x		x
<i>Sphaerium heskethense</i> ¹ Warren.						
<i>Viviparus leai</i> M. and H.		x	x	x		x
<i>Viviparus retusus</i> (M. and H.)				x		x
<i>Viviparus tasgina</i> Dyer.		?				
<i>Viviparus crickmayi</i> Dyer.			x			
<i>Campeoloma multilineata</i> (M. and H.)		x	x	x	x	x
<i>Goniobasis whittakeri</i> Dyer.		x				
<i>Goniobasis webbi</i> Dyer.		x	x			
<i>Goniobasis tenuicarinata</i> (M. and H.)			x	x		x
<i>Thaumatostus limnaeiformis</i> M. and H.		x	x	x	x	x
<i>Thaumatostus limnaeiformis tenuis</i> Warren.				x		
<i>Hydrobia recta</i> White.		x	x	x		x
<i>Valvata filosa</i> Whiteaves.		x	x	x		S
<i>Limnaea tenuicostata</i> M. and H.			x	x		x
<i>Physa copei</i> White.	x	x	x	x		x

¹ Reported by Warren.

S Similar form in Fort Union.

This fauna seems to be more closely related to later rather than to older faunas. With the exception of the long ranging forms, *Sphaerium planum* is the only species that occurs also in the Belly River and Judith River, but this form has been also recorded from the Lance. All other species, so far as known, are confined to the Edmonton or to the St. Mary River and the Edmonton, or range upward into higher formations.

A new species *Goniobasis whittakeri* occurs in the Edmonton and St. Mary River formations. *Goniobasis webbi* occurs in the Edmonton, St. Mary River, and Willow Creek formations. *Sphaerium planum* occurs in the Belly River, Judith River, Edmonton, St. Mary River, and Lance, but is not known to extend higher than the Lance. The dinosaur genus *Leptoceratops* is common to the St. Mary River and Edmonton and is not found elsewhere. The correlation of the St. Mary River and the Edmonton formations is thus strongly suggested. It is not known that these two formations are exactly equivalent. The break that occurs between the Paskapoo and the Edmonton on Red Deer and Bow rivers has not been found farther south. The St. Mary River formation is nearly twice as thick as the Edmonton. It is thus possible that the upper part of the St. Mary River is younger than any part of the Edmonton. The St. Mary River strata grade upwards into the Willow Creek beds. It thus seems to be possible that the upper part of the St. Mary River beds and the succeeding Willow Creek beds represent part or all of the interval which farther north is marked by the disconformity between the Edmonton and Paskapoo.

Brackish and Marine Invertebrate Fossils From the Edmonton Formation

Melania wyomingensis White
Bryozoa
Nucula subplana M. and H.
Ostrea glabra M. and H.
Anomia micronema Meek
Anomia cf. perstrigosa Whiteaves
Mytilus albertensis Warren
Modiolus dichotomus Whiteaves
Corbicula occidentalis M. and H.
Corbicula cytheriformis M. and H.
Corbicula subtrigonalis M. and H.
Panope simulatrix Whiteaves
Lunatia obliquata M. and H.
Lunatia occidentalis M. and H.

The above forms are all long-ranging Montana species and give no exact information as to the position of the Edmonton formation within the Montana group. On the basis of the brackish water fossils the Edmonton might be placed anywhere from the Pakowki (Claggett) to the Cannonball marine member of the Lance.

*Vertebrate Fossils From the Edmonton Formation*¹

PISCES

Myledaphus bipartitus Cope
Acipenser sp. indt.
Lamna sp.
Palaeospinax eyncidus Lambe
Diphodus? longirostris Lambe
Priscacaridae gen. et. sp. nov.

REPTILIA

Leurospondylus ultimus Brown
Aspideretes sp.
Trionychid (probably undescribed form)
Basilemys sp.
Champsosaurus sp.
Crocodylia gen. et. sp. indeterminable
Albertosaurus sarcophagus Osborn
 Small theropod not determined
Struthiomimus breviterius Parks
?Ornithomimus velox Marsh
Ornithomimus sp.
Ornithomimipus angustus Sternberg
Troodontidae gen. undetermined
Thescelosaurus warreni Parks
Thescelosaurus sp.
Saurolophus osborni Brown
Hypacrosaurus altispinus Brown
Cheneosaurus tolmanensis Lambe
Edmontosaurus regalis Lambe
Thespesius edmontoni Gilmore
Anchiceratops ornatus Brown
Anchiceratops sp.
Leptoceratops gracilis Brown
Arrhinoceratops brachyops Parks
Ankylosaurus magniventris Brown
Ankylosauridae gen. et. sp. nov.

MAMMALIA

?Edelphis sp.

¹This list and the remarks on vertebrate fossils were prepared by C. M. Sternberg.

The vertebrate fossils from the Edmonton formation indicate that in age these beds are intermediate between the Belly River and Lance formations, but closer to the latter. The dinosaurs are of special value for correlation purposes because they evolved very rapidly during Upper Cretaceous time and are the most common vertebrate fossils found in these beds.

All the families and sub-families of dinosaurs represented in the Belly River are also represented in the Edmonton, but some do not continue into the Lance. On the other hand, several genera are present in both the Edmonton and Lance formations, but, with one exception, probably no genus is present in both the Belly River and the Edmonton. The dinosaurian fauna of the Lance is less extensive than that of either the Belly River or Edmonton, yet one family (the *Hypsilophodontidae*) is present in the Edmonton, but not in the Belly River.

Two of the three sub-families of the *Hadrosauridae*, the *Lambeosaurinae* and *Saurolophinae*, which are so common in the Belly River and Edmonton formations, are not represented in the Lance. The third sub-family, the *Hadrosaurinae*, is represented in all three formations. This may be partly due to different facies, but it is more likely that the *Hadrosaurinae* was a more virile group and outlived the members of the other sub-families. On the other hand, no genus of Hadrosaur is present in both the Belly River and Edmonton, but the Lance genus *Thespesius* is also found in the Edmonton.

With the exception of *Leptoceratops*, which, according to Gregory and Mook, is more nearly related to *Protoceratops* of the Lower Cretaceous of Mongolia than to the Belly River form, the horned dinosaurs (*Ceratopsia*) of the Edmonton show a decided advance over those of the Belly River and *Arrhinoceratops brachyops* Parks is approaching *Diceratops* or *Triceratops* of the Lance in the closing of the fontanelles and the greater development of the brow horns at the expense of the nasal horn. No genus of horned dinosaurs is common to any two of the above-mentioned formations.

The armored dinosaurs of the Edmonton have not been thoroughly studied and the only genus of this group so far definitely reported from these beds is the Lance genus *Ankylosaurus*. Brown referred *Euoplocephalus tutus* Lambe, a Belly River form, with some doubt to *Ankylosaurus*, but Gilmore, after a study of the species, considers it more nearly related to *Palaeoscincus* a Belly River form.

The *Troodontidae* are represented in the Belly River, Edmonton, and Lance, but no well-preserved specimen has yet been collected from the Edmonton or Lance and it is not possible to state whether they are generically distinct from those of the Belly River.

Thescelosaurus has been reported from both the Edmonton and Lance formations, but no member of the *Hypsilophodontidae* family has been reported from the Belly River formation.

The carnivorous dinosaurs of the Edmonton have not been thoroughly studied, but none of the Belly River or Lance genera has been recognized in these beds.

The "Bird mimic" dinosaurs, *Ornithomimidae*, are quite numerous in the Edmonton formation. Brown has recognized two species of *Ornithomimus* and Parks has described a new species which he refers to the Belly River genus *Struthiomimus*. This species is quite distinct from *Struthiomimus altus* Lambe, but Parks refers it to that genus, rather than to the Lance genus *Ornithomimus*, largely on the strength of the presence of the vestigial fifth metatarsal which is preserved in *Struthiomimus altus* but was not found with the type of *Ornithomimus velox* Marsh, and for which Osborn says there is no facet. In the large carnivorous dinosaurs the vestigial fifth metatarsal is present in the genera from the Belly River, Edmonton, and Lance formations and there is very little change in this element, though in other details the forms are quite distinct.

The fish, champsosaurs, crocodiles, and turtles are of little help in correlation due to the scarcity and fragmentary nature of the material or the long range of the genera. Plesiosaurs have been reported from the Edmonton formation and a plesiosaur vertebral centrum has been collected from the transition beds between the Fox Hills and the Lance in southern Saskatchewan. Only one mammal specimen has been reported from the Edmonton formation, a single tooth, and it is too badly worn for precise determination, but Mr. G. G. Simpson of the Peabody Museum considers that it pertains to a form intermediate between *Eodelphis* of the Belly River and *Diaphorodon* of the Lance formation.

Triceratops, *Torosaurus*, and *Tyranosaurus*, typical Lance forms, were much farther advanced in their peculiar specializations than any of the Edmonton genera, yet the fact that no less than four genera of dinosaurs (*Thespesius*, *Ankylosaurus*, *Thescelosaurus*, and *Ornithomimus*) are common to the Edmonton and Lance formations would indicate that the time between the deposition of these formations was much less than that between the deposition of the Belly River and the Edmonton.

Plants from the Edmonton Formation

The following notes on the plants of the Edmonton formation are taken from an article by Barnum Brown.¹

"Near the home of Mr. Simpson, on the left bank [of Red Deer river], 20 feet above the river and almost opposite the mouth of Kneehills creek, there is a bed of leaves from which several well preserved specimens were secured. They are identified as follows: *Populus cuneata* Newb., *Populus acerifolia* Newb., *Populus nebrascensis* Newb., *Populus amblyrhyncha* Ward, *Ptersospermites* prob. *Whitei* Ward, *Ginkgo laramiensis* Ward, *Sequoia nordenskioldii* Heer, *Sequoia langsdorfi* (Brgh.) Heer, *Glyptostrobus* sp.

After an examination of the plants collected in 1911—that is *Sequoia nordenskioldii*, *S. langsdorfi*, *Glyptostrobus*? sp., *Ptersospermites* prov. *whitei*, and *Populus cuneata*—Dr. Knowlton reports that 'the species indicate beyond all manner of question or doubt that the age is Fort Union'. Additional better material was secured from the same spot in 1912, and the species enumerated in the complete list above were determined by Dr. Hollick, who says that 'the specimens from the Edmonton formation (near Simpson's house, opposite mouth of Kneehills creek, etc.) indicate unquestionably, the Fort Union age of this horizon'.

The position of this plant layer in the Edmonton beds is not less than 250 feet below the *Ostrea* layer."

¹ "Cretaceous Eocene Correlation in New Mexico, Wyoming, Montana, Alberta"; Bull. Geol. Soc. Am., vol. 25, p. 367 (1914).

Summary

The apparently conflicting evidence of the age of the Edmonton, the flora indicating a Fort Union age, and the vertebrates suggesting an age between Belly River and Lance, can best be explained by assuming that these two forms of life evolved at different rates. Under this assumption, the plants passed through the greatest evolutionary change in the time between Belly River and Edmonton, whereas from Edmonton on they were more or less stationary. The vertebrates, on the other hand, were steadily and rather rapidly changing until the end of Lance time when the primitive forms disappeared. It would seem, therefore, that greatest reliance should be placed on the vertebrates to differentiate between the ages of Upper Cretaceous formations, and accordingly the Edmonton should be considered pre-Lance, or as Sternberg states in this report (page 50) "intermediate in age between the Belly River and the Lance formations, but closer to the latter." Perhaps at least the upper part of the Edmonton is of Lance age.

St. Mary River Formation

This formation was named by Dawson in 1884 from St. Mary river (a tributary of the Oldman), on which the formation is well exposed. On St. Mary river, Dawson recognized the Fox Hills and separated it from the St. Mary River formation, but on the Oldman, owing to the pronounced change of lithology, he failed to recognize it and included the Fox Hills in the St. Mary River formation. Stewart¹, also, included the Fox Hills with the St. Mary River. The sandy phase at the top of the Bearpaw has been found on all the rivers between and including the St. Mary and the Red Deer, and in this report has been separated as the Fox Hills formation. The St. Mary River formation is, therefore, re-defined as consisting of the series of continental rocks lying between and making transitional contacts with the brackish water Fox Hills below and the reddish Willow Creek freshwater formation above.

DISTRIBUTION

The type locality for the St. Mary River formation is along St. Mary river west of Magrath, where excellent exposures occur for more than 20 miles. The formation is also exposed almost continuously for 12 miles along Oldman river westward from the road bridge south of Monarch. At Scabby butte pale grey sands overlying the Fox Hills may belong to the St. Mary River, but their light grey colour renders it more likely that they are part of the Edmonton formation. Stewart found the St. Mary River formation in the eastern part of the disturbed beds where it forms strike ridges closely following the meridian of 113 degrees west longitude. Farther west in the Rocky mountains near the headwaters of Oldman and Highwood rivers Dawson found rocks which probably belong to the St. Mary River formation. To the north (Sheep River area, etc.), beds occupying the stratigraphic position of the St. Mary River formation have generally been referred to the Edmonton.

¹ Stewart, J. S.: "Geology of the Disturbed Belt of Southwestern Alberta"; Geol. Surv., Canada, Mem. 112 (1919).

LITHOLOGY

The St. Mary River formation consists largely of alternating series of hard, dun-coloured, and grey sandstones with soft, grey, brown, and greenish sands, shales, and sandy shales. Thin beds of black, carbonaceous shales are locally present, and at the base a coal seam has been penetrated in the well at Monarch. The St. Mary River formation is very similar to the Belly River formation, more particularly the Pale beds member, and Stewart reports that in the foothills the St. Mary River can scarcely be distinguished from the Belly River. He made a petrographic examination of the harder beds of each and found them almost exactly alike. They consist of very fine, angular to subangular grains of quartz, the grains being almost small enough to be regarded as silt. Accessory minerals are biotite, muscovite, chlorite, apatite, zircon, and tourmaline. On the average 70 per cent of the grains are of quartz and 30 per cent of feldspar. From Stewart's examination the feldspar appears to have undergone more alteration than in the case of the Belly River sandstone. The cement is nearly always entirely of calcite and forms a proportion of the rock mass varying from 10 to 60 per cent, with an average of 20 per cent; those rocks with as high a content of calcite as 60 per cent might properly be regarded as arenaceous limestone, such rocks, however, are rare.

The St. Mary River formation is distinguished from the Belly River as developed on the plains by the greater proportions of hard beds. Its colour is intermediate between that of the Pale and that of the Foremost members. Channelling was seen in a few places and the beds are lenticular and cannot be followed for long distances laterally.

The following section illustrates the character of the beds of the St. Mary River formation.

Section of St. Mary River formation on Oldman river, north side, SW. $\frac{1}{4}$ sec. 29, tp. 29, range 24, W. 4th mer.

	Thickness Feet
Hard, buff sandstone.....	7
Grey shale.....	15
Hard, buff sandstone.....	10
Grey shale.....	1
Dark, carbonaceous shale.....	1
Grey shale.....	12
Alternating beds of buff sandstone and grey shale in beds about 1 foot thick	15
Hard, buff sandstone.....	2
Greenish shale.....	3
Dark, carbonaceous shale.....	1
Hard, grey sandstone.....	2½
Black, fissile, carbonaceous shale.....	1
Grey shale.....	1
Hard, buff sandstone.....	1
Grey shale.....	17
Grey sandstone rather hard with <i>Viviparus</i> , <i>Valvata</i> , <i>Goniobasis</i> , <i>Campeloma</i> , <i>Sphaerium</i> , plant fragments.....	½
Grey shale.....	2
Hard, buff sandstone.....	1½
Brown shale.....	5
Hard, buff sandstone.....	7
Dark grey shale.....	4
Hard, buff sandstone.....	1
Grey shale.....	3
Hard, buff sandstone.....	1½
Grey shale.....	5

The St. Mary River formation lies conformably below the Willow Creek formation on Oldman river, on Upper St. Mary river, and in Milk River valley, but elsewhere the relationships are imperfectly known. Since on Bow and Red Deer rivers the Edmonton and Paskapoo formations are separated by an unconformity representing a considerable length of time, the Willow Creek and St. Mary River may also be separated in a similar way over part of their extent. Such an unconformity is suggested by the change in colour of the sediments from the dun of St. Mary River to the red of the Willow Creek, but no break has been found and it is possible that the upper St. Mary River and the lower Willow Creek sediments bridge the gap so evident farther north.

The following section shows the character of the beds at the contact of the two formations. It was measured on the north side of Oldman river in the NW. $\frac{1}{4}$ sec. 23, tp. 10, range 25, W. 4th mer.

	Thickness Feet
Boulder clay.....	7
Willow Creek formation	
Alternating beds of green and red shales with some grey, sandy layers.	23
Alternating pale grey sands and brown clays with nodules of white- weathering calcareous concretions.....	10
Red clay.....	2
St. Mary River formation	
Grey sandstone.....	3
Soft, grey and brown, sandy clays.....	21
Hard, grey sandstone, crossbedded with many hard, clay pellets at base.....	3
Brownish, sandy clay.....	9
Grey, fairly hard sandstone.....	2
Grey and brownish, sandy clay.....	16
Hard, grey sandstone to water-level.....	4

THICKNESS

The rocks exposed on Oldman river dip westward at varying rates, the rate increasing from east to west. At the eastern end of the exposure, just west of the bridge south of Monarch, the dip is about 1 degree to the west; near the western end of the exposures the dip averages 5 degrees to the west. Taking into account the progressive change in the value of the dip, the length of the series of exposures from east to west, and the height of the rocks at either end of the series of exposures, the figure of 1,600 feet was arrived at for the thickness of the formation. In the disturbed belt Stewart reports a thickness of 2,500 feet on Indian Farm creek, but the top and bottom of the formation are not visible there. He estimates a thickness of 2,700 feet on Crowsnest river, but the section shows much intense folding. The section on Oldman river in the foothills is also complicated by folding and faulting; here Stewart estimated a thickness of 3,000 feet. The type section along St. Mary river is very complete but is complicated by gentle flexures in outcrops exposed along a sinuous river course. A careful estimate from a graphic reproduction of the section gives a total thickness of about 1,600 feet.

ORIGIN

The St. Mary River beds were undoubtedly deposited in freshwater lakes or in rivers as attested by the fossil content, fine-grained character of the clastics, and the lenticular character of the beds.

PALÆONTOLOGY

Freshwater gasteropods and pelecypods are rather sparsely distributed throughout the formation, but several species are represented among them, *Unio* is the most common genus and it is a peculiar fact that only one species *U. danae* is represented, although the Lance to which the St. Mary River may be in part equivalent is characterized by the varied species of *Unio*. Dinosaur bone fragments have been found in a few places as well as the remains of plants.

Invertebrate Fossils of the St. Mary River Formation

	Belly River	Edmonton	Willow Creek	Paskapoo	Lance	Fort Union
<i>Unio danae</i> M. and H.....	x	x	x	x	x	x
<i>Sphaerium formosum</i> M. and H.....		x	x	x		x
<i>Sphaerium planum</i> M. and H.....	x	x			x	
<i>Sphaerium formosum whiteavesi</i> ¹ Russell?.....	?			x		
<i>Viviparus leai</i> M. and H.....		x	x	x		x
<i>Viviparus prudentius</i> White.....			x	x		x
<i>Viviparus planolateris</i> Russell.....			x	x		
<i>Viviparus</i> sp.....		x				
<i>Campeloma multilinea</i> (M. and H.).....		x	x	x	x	x
<i>Goniobasis whittakeri</i> Dyer.....		x				
<i>Goniobasis webbi</i> Dyer.....		x	x			
<i>Physa copei</i> White.....	x	x	x	x		x
<i>Physa copei canadensis</i> Whiteaves.....	x	x	x	x		x
<i>Thaumastus limnaeiformis</i> M. and H.....		x	x	x	x	x
<i>Hydrobia recta</i> White.....		x	x	x		x
<i>Valvata filosa</i> Whiteaves.....		x		x		S
<i>Valvata bicincta</i> Whiteaves.....				x		S
<i>Patula obtusata</i> Whiteaves.....			x	x		
<i>Patula angulifera</i> ? Whiteaves.....			x			
<i>Acrolaxus minutus</i> Whiteaves.....						x
<i>Anchistoma parvulum</i> Whiteaves.....						
<i>Pupa</i> sp.....						
<i>Gasteropoda opercula</i>						

¹ Reported by Russell.

S Very similar form.

The most notable feature of the freshwater fauna of the St. Mary River formation is its much closer affinity to higher rather than lower formations. With the exception of three long-ranging forms which cannot be used for correlation, only one species, *Sphaerium planum*, occurs in a lower formation, but this species also occurs in the Lance. Eleven out of seventeen definitely determined species occur in higher formations. On the basis of the invertebrates alone, the St. Mary River formation would be placed nearly as high as the Fort Union.

Plants

W. A. Bell has identified the following aquatic plants: south side of Belly river, centre of sec. 3, tp. 8, range 24, W. 4th mer.

Trapa? *microphylla* Lesquereux*Trapa* n.sp.*Pistia* n.sp.*Vertebrate Fossils from the St. Mary River Formation*

Dinosaur bone fragments occur in the St. Mary River formation, but are rare. Those that have been found are not determinable as to species or genus. A very important occurrence of the genus *Leptoceratops*, however, has been reported by Brown¹ in the St. Mary River formation

¹ Personal communication.

in northwestern Montana. This species has been found previously only in the Edmonton formation of Alberta. This strongly suggests the correlation of these formations.

The general consensus of opinion places the age of the Edmonton, in which more evidence is found than in the St. Mary River, between the Belly River and the Lance, but much nearer the latter than the former. This would, therefore, apply to the age of at least the lower part of the St. Mary River formation.

Paskapoo Formation

DISTRIBUTION

The Paskapoo formation underlies a very large area in central Alberta. In the area treated in this report it outcrops on the creeks flowing into Red Deer river from the west and along Bow river from Calgary to its contact with the Edmonton 15 miles west of Gleichen, where it forms many exposures, some of large size.

LITHOLOGY AND THICKNESS

The general character of the lower part of the formation is much like that of the St. Mary River formation and descriptions of the latter can be applied to the former. Higher up in the formation the hard, ledgy sandstones are not so abundant, the rocks being on the whole softer, more variable in character, and more like the Willow Creek formation except that a red colour is not present. These higher beds undoubtedly represent the northern extension of the Willow Creek and it was because of the absence of the red colour from the strata along Bow river that Dawson there discarded the division into the St. Mary River, Willow Creek, and Porcupine Hills formations and placed the beds together as the Paskapoo. The Paskapoo beds along Bow river are not, however, exactly equivalent in age, to the three formations found to the south, as the lower part of the St. Mary River formation is equivalent to the Edmonton and hence older than the Paskapoo.

It is very difficult to determine the thickness of the Paskapoo as no wells have been drilled through it, and since it is the youngest formation in the area it has undergone considerable erosion.

The nature of the unconformable contact with the Edmonton formation is discussed on pages 53, 54, and 55.

The following section illustrates the character of the beds in the Paskapoo formation on Bow river.

Section of Paskapoo on Bow river, north side, NW. $\frac{1}{4}$ sec. 27, ¹⁰⁻¹¹tp. 21, range 26, W. 4th mer.

	Thickness Feet
Brown shales.....	14
Brown sandstone, heavy ledge, mostly coarse grained.....	6
Light brown, sandy shale.....	8
Hard, brown to grey sandstone, coarse textured.....	3
Soft sands and sandy shales, light brown or drab coloured, few thin, hardened lenses.....	10
Ledge of light brown sandstone.....	2
Light brown shale.....	9
Fairly hard ledge of light brown sandstone.....	2
Light brown to greenish, sandy shale.....	3
Light brown, soft sand.....	1
Grey to dark green shale.....	4
Ledge of soft, grey sandstone.....	1

	Thickness Feet
Grey, sandy shale grading upward from coarse to fine grained.....	6
Greenish to grey, shaly sandstone (Unios).....	4
Soft, greenish shale.....	8
Heavy sandstone ledge, rusty in lower 2 feet grading from brown to grey at top. <i>Unio</i> layer at base.....	13
Green to grey, sandy shale.....	8
Soft, grey sandstone.....	3
Brown, sandy shale.....	3
Greenish shale.....	4
Black shale.....	1
Yellowish brown, sandy shale.....	4
Greenish shale.....	6
Soft, greyish sands.....	2
Shale, brownish to greenish grey, mostly sandy.....	4½
Soft, greenish grey sand.....	1
Fairly hard ledge grey sandstone weathering brown.....	4½
Soft, grey, sandy shale.....	3
Covered by slide to water-level—probably shale.....	8

PALÆONTOLOGY

Freshwater gasteropods and pelecypods, plant remains, and vertebrate bones (chiefly mammalian) are found in the Paskapoo.

Invertebrate Fossils From the Paskapoo Formation

	Belly River	St. Mary River	Edmon- ton	Willow Creek	Lance	Fort Union
<i>Unio danae</i> M. and H.....	x	x	x	x	x	x
<i>Unio senectus</i> White ¹	x			x		
<i>Unio priscus</i> ?.....	x					?
<i>Unio subspatulus</i> M. and H.....	x			x		
<i>Sphaerium formosum</i> M. and H.....	?		x	x		x
<i>Sphaerium formosum whiteavesi</i> ¹ Russell.....		x				
<i>Sphaerium aequale</i> ¹ Russell.....			x			
<i>Viviparus leai</i> M. and H.....		x	x	x		x
<i>Viviparus planolateris</i> Russell.....		x		x		
<i>Viviparus prudentius</i> White.....		x		x		x
<i>Viviparus trochiformis</i> ¹ (M. and H.).....						x
<i>Viviparus retusus</i> ¹ (M. and H.).....			x			x
<i>Campeloma producta</i> White.....				x		x
<i>Campeloma multilineata</i> M. and H.....		x	x	x	x	x
<i>Campeloma multistriata</i> ¹ (M. and H.).....						x
<i>Goniobasis tenuicarinata</i> M. and H.....			x	x		x
<i>Goniobasis gracilentia</i> M. and H.....	x					x
<i>Thaumasius limnaeiformis</i> M. and H.....		x	x	x	x	x
<i>Thaumasius limnaeiformis tenuis</i> Warren.....			x			
<i>Thaumasius limnaeiformis procerior</i> ¹ Russell.....						
<i>Hydrobia recta</i> White.....		x	x	x		x
<i>Hydrobia warrenana</i> ¹ (M. and H.).....						x
<i>Hydrobia anthonyi</i> ¹ (M. and H.).....						x
<i>Valvata filosa</i> Whiteaves.....		x	x	x		S
<i>Valvata bicincta</i> Whiteaves.....		x		x		S
<i>Planorbis</i> sp. ¹						
<i>Limnaea tenuicostata</i> M. and H.....			x	x		x
<i>Acrolazus radiatulus</i> ² Whiteaves.....						
<i>Columna teres</i> ¹ M. and H.....				x		x
<i>Columna vermicula</i> ¹ M. and H.?.....						x
<i>Columna vermicula contraria</i> ¹ Meek.....						x
<i>Micropyrgus minutulus</i> ¹ Meek.....						x
<i>Physa copei</i> White.....	x	x	x	x		x
<i>Physa copei canadensis</i> Whiteaves.....	x	x	x	x		
<i>Physa longiuscula</i> ¹ (M. and H.).....						x
<i>Physa galei</i> ¹ Russell.....						
<i>Patula obtusata</i> Whiteaves.....		x		x		
<i>Patula angulifera</i> Whiteaves.....		x		x		

¹ Reported by Russell.² Reported by Whiteaves.

S Similar form.

The invertebrate fauna of the Paskapoo formation is closely allied to the Fort Union, nearly all the forms in the above list having been recorded from that formation.

Vertebrate Fossils From the Paskapoo Formation

The mammalian fauna of the Paskapoo formation has been described and the age relationships discussed by Simpson.¹ The fauna is as follows:

- Catopsalis calgariensis* Russell
- Propalaeosinopa albertensis*, new genus and species
- ??*Pantolestid*, genus and species undetermined
- Nothodectes* cf. *gidleyi* Matthew
- Elpidophorus elegans*, new genus and species
- ?*Phenacodus*, species undetermined
- ?*Taligrada*, species undetermined

Simpson has summarized his discussion on the age relationships of the Paskapoo fauna as follows:

"There is nothing in it (Paskapoo mammalian fauna) suggestive of Lance or early Paleocene age. The known genera are few but significant. *Catopsalis* is known elsewhere definitely only from the Torrejon. The Paskapoo species is very distinct from the Torrejon one, larger and rather more progressive, and while this does not in itself necessarily mean later age, it agrees with the evidence of the other mammals that the fauna is slightly later than the Torrejon. This form is from a slightly higher horizon than the others, but it does not in any way suggest a later fauna. *Propalaeosinopa* and *Elpidophorus* are so isolated as to be of little value in correlation. The nothodectid, however, is extremely suggestive. It belongs to a group not known before from the Fort Union, and is slightly more advanced than *Pronothodectes* from the latter and either belongs to or is in an exactly comparable stage of evolution with *Nothodectes* of the Tiffany and Clark Fork. The same is even more strikingly true of the phenacodont. It belongs to a phylum the evolutionary development of which is fairly clear. It is certainly more advanced than the Torrejon-Fort Union *Tetraclaenodon* (*Euprotogonia*) and rather less advanced than the Wasatch *Phenacodus* and *Ectocion*, thus appearing to belong to the intermediate horizon, the Clark Fork again. It may well belong with the form mentioned by Gidley from a Clark Fork equivalent in the Powder River basin, Wyoming, as a 'Phenacodont intermediate between Phenacodus and Euprotogonia.'" ¹

Further evidence will be very welcome, and the fauna when better known will certainly be one of considerable interest and significance; but it seems possible even on the basis of the few teeth of the present collection to establish the age of at least part of the Paskapoo as probably post-Torrejon-Fort Union and pre-lower Wasatch, that is, as equivalent to the Tiffany-Clark Fork-Cernaysian.

Willow Creek Formation

DISTRIBUTION

Dawson separated the Willow Creek formation from the remaining freshwater beds overlying the Fox Hills because he considered it well defined by colour and to some extent by physical character.

¹ Simpson, G. G.: Am. Mus. Novitates, No. 268, April 30, 1927.

² U.S. Geol. Surv., Prof. Paper 108, p. 59 (1918).

These beds are well exposed on Oldman river where they can be followed for over 50 miles. The best exposures, however, are east of McLeod in tp. 10, range 25, W. 4th mer., and in the northern part of tp. 9, range 25, W. 4th mer. They also outcrop at intervals for many miles along Willow creek from which they derive their name. They can be seen underlying the Porcupine Hills sandstone on some of the small creeks that are tributary to Willow creek and drain the eastern side of Porcupine hills. Some patches of red shales and sands characteristic of the formation were seen on Mosquito creek and on small creeks at the base of Porcupine hills as far north as Nanton, but in this region it is doubtful whether the formations can be separated. North of Nanton the red colour fades out altogether. In the disturbed belt to the west the formation is present as a single strip running northwestward from the International Boundary. In the northern part of the foothills it loses its identity and beds occupying the stratigraphic position of the Willow Creek formation are included in the Paskapoo.

As noted by Dawson, excellent exposures of Willow Creek shales occur in the valleys of St. Mary and Waterton rivers. On the St. Mary, slumping red and variegated shales outcrop from the edge of the disturbed belt above Kimball for 22 miles downstream; and along Waterton river the upper measures of the Willow Creek, comprising red and grey sandstones and shales, form the steep banks of the river from the edge of the disturbed belt to its junction with Belly river. The picturesque badlands of the Blood Indian reserve, east of the junction of Waterton and Belly rivers, are a topographic expression of Willow Creek shales. Most conspicuous here is Mokowan butte, the site of the ancient sun-dance of the Blood tribe, and still the scene of the less picturesque annual festival of these Indians. The southwestern slopes of the hill, particularly in the afternoon sun, are aglow with soft colour bands of purple, reds of various shades, browns, greys, and greens, forming a picture appealing alike to the savage and the civilized taste.

Willow Creek beds are exposed over a considerable area near the 49th parallel on Upper St. Mary river in the vicinity of Fareham, the transitional contact with the St. Mary River formation being visible at several places. Excellent exposures also occur below Porcupine Hills sandstone between Waterton and Oldman rivers.

LITHOLOGY

The Willow Creek formation consists of thin, alternating beds of sands, clays, and sandy clays; the colours are purplish, reddish brown, grey, and green. In the lower part of the formation the beds are nearly all soft and incoherent, but toward the top harder beds of grey and buff sandstones make their appearance; they become more numerous toward the top of the formation and the red beds gradually fade out. The line between the Willow Creek and the Porcupine Hills is vague owing to the transitional relations, but is drawn at the point where hard beds of grey sandstone begin to comprise the major part of the rock. The contact of the St. Mary River formation is also transitional, but is drawn at the point where the red beds first make their appearance. Many of the clay beds are characterized by white weathering, small, irregular-shaped nodules of calcite.

The following section occurring on the south side of Oldman river in sec. 34, tp. 9, range 25, W. 4th mer., illustrates the character of the beds.

	Thickness Feet
Alternating thin beds of red, green, and brown shales.....	30
Red clay shale.....	2
Brown, sandy shale.....	3
Green shale.....	4
Red shale.....	4
Green shale.....	2
Red shale.....	5
Alternating beds of soft, red and green shales.....	5
Grey, soft sandstone.....	6
Green shale.....	3
Red shale.....	1
Green shale.....	2
Red shale.....	5
Green shale.....	1
Concealed to water-level.....	8

THICKNESS

It is difficult to form even an approximate idea of the thickness of the Willow Creek formation as the beds are so lenticular that they cannot be followed far enough to get an idea of the dip, and the outcrops for the most part are small and spaced at wide intervals. The elevation of the contact with the underlying St. Mary River formation on Oldman river is 2,400 feet above sea-level and the contact with the overlying Porcupine Hills formation along the eastern side of Porcupine hills is usually 3,400 feet. Thus, assuming that the beds are flat, the thickness would be 1,000 feet. Stewart gives an estimate of 500 feet for the formation on Oldman river west of Porcupine hills in the disturbed belt, and at Mokowan butte on the Blood Indian reserve a 700-foot section of Willow Creek shales has neither top nor bottom exposed.

ORIGIN

Dawson¹ believed that the reddish tint of the beds was connected with a period of greater waste of red beds of the Rocky mountains which he correlated with the Triassic. He pointed out that the extension of the characteristic tint to the north was conterminous with that of the development of the red beds in the mountains. As shown by Barrell,² red beds may be formed by the exposure of sediments on flood-plains under conditions of semi-arid climate. The iron-bearing minerals break down in whole or in part during wet seasons and become oxidized to the ferric condition during dry seasons, when due to the lowering of the water table, the sediments become exposed to the atmosphere. Alternating beds of oxidized and partly oxidized sediments would be formed as a result of cycles of dry and wet years. On consolidation into rock, such beds would show variations of colour from red, through yellow or brown, to grey or green.

There is also the possibility, as noted by Dawson, that the red colour is derived from erosion of highly oxidized sediments. In this case the alternating beds of red and grey colours need explanation. There are at least two possibilities: seasonal or cyclic variation in precipitation may

¹ "Report on the Bow and Belly Rivers Region"; Geol. Surv., Canada, 1882-84, pt. C, p. 113.

² Geol. Soc. Am., Bull., vol. 18, pp. 449-476.

result in variations in the sediments deposited, both as to texture and to origin, and such changes may be expressed in colour; on the other hand, the varying precipitation may result in marked changes in plant growth, and it is a well-known fact that humic acid secreted by plant roots acts as a reducing agent, changing ferric salts to ferrous and thus changing the colour from red to green. Furthermore, varying percentages of lime in clay control the colour of burnt brick, much lime tending to form a lime-iron-silicate and preventing the oxidation of the iron to ferric oxide. That the percentage of lime in sediments will vary with changing climatic conditions is evident and this factor may account for the banding of the Willow Creek shales.

PALÆONTOLOGY

Several species of freshwater gasteropods and pelecypods were found in the Willow Creek formation chiefly at localities on Willow creek near Granum. Chara seeds and fish scales were also found.

Invertebrate Fossils of the Willow Creek Formation

	Belly River	St. Mary River	Edmon- ton	Paskapoo	Lance	Fort Union
<i>Unio danae</i> M. and H.....	x	x	x	x	x	x
<i>Unio senectus</i> White	x			x		
<i>Unio subspatulus</i> M. and H.....	x			x		
<i>Unio albertensis</i> Whiteaves.....						
<i>Corbula subtrigonalis</i> M. and H....	x		x			
<i>Sphaerium formosum</i> M. and H....	?	x	x	x		x
<i>Viviparus leai</i> M. and H.		x	x	x		x
<i>Viviparus prudentius</i> White				x		x
<i>Viviparus trochiformis</i> M. and H....				x		x
<i>Viviparus crickmayi</i> Dyer.....			x			
<i>Viviparus cf. planolateris</i> Russell..		x		x		
<i>Campeloma producta</i> White.....				x		x
<i>Campeloma multilineata</i> (M. and H.).....		x	x	x	x	x
<i>Goniobasis subtrigonalis tenuis</i> Dyer..						
<i>Goniobasis tenuicarinata</i> M. and H....			x	x		x
<i>Goniobasis webbi</i> Dyer.....		x	x			
<i>Thaumastus limnæiformis</i> M. and H.....		x	x	x		x
<i>Hydrobia recta</i> White.....		x	x	x		x
<i>Valvata filosa</i> Whiteaves.....		x	x	x		S
<i>Limnæa tenuicostata</i> M. and H.....			x	x		x
<i>Patula obtusata</i> Whiteaves.....		x		x		
<i>Patula angulifera</i> Whiteaves.....		x		x		
<i>Columna cf. teres</i> M. and H.....				x		x
<i>Physa copei</i> White.....	x	x	x	x		?
<i>Physa copei canadensis</i> Whiteaves..	x	x	x	x		
<i>Acrolaxus</i> sp.....						

S Similar form.

The invertebrate fauna is closely allied to that of the Paskapoo and is very similar, also, to that of the Fort Union. The Willow Creek formation is probably equivalent in part at least to the Paskapoo, and is, therefore, equivalent to the Sentinel Butte shale and Clark Fork of Big Horn basin, Wyoming, which is lower Wasatch (cf. Thom and Dobbin, page 498). The lower part of the Willow Creek is probably Fort Union.

Porcupine Hills Formation

DISTRIBUTION

The Porcupine Hills sandstone is the third and uppermost division of the post-Fox Hills continental series of western Alberta (Laramie of Dawson), and was so named by Dawson because it forms the greater part of Porcupine hills. It is exposed in all of the creeks that traverse the hills and outcrops on them as ridges in many places. It is the youngest series of beds in the area under consideration and consequently has suffered much erosion.

Besides capping Porcupine hills, the Porcupine Hills sandstone outcrops widely along the slopes and on top of the plateau on the Peigan reserve, south and east of Brocket. Beds transitional to the underlying Willow Creek formation are exposed along the southeastern side of Porcupine hills.

LITHOLOGY

The Porcupine Hills formation consists mainly of fine-grained, cross-bedded, light grey, ledge-making sandstone with interbedded shaly clays. The ledge-making sandstones are the most markedly crossbedded sediments found in southern Alberta, the true bedding being determined with difficulty. The clays usually form depressions between the ridges of sandstone and are not commonly exposed. No true conglomerates were seen, but some beds of conglomeratic sandstone with clay and sandstone pellets were found and mud-cracks and ripple-marks occur. The sandstone commonly weathers with brown colours. The formation occurs in a low, broad syncline, the greatest observed thickness, as recorded by Stewart, being 2,500 feet.

PALÆONTOLOGY

Very few fossils have been found. The only forms seen being a few freshwater gasteropods and pelecypods including *Viviparus*, *Physa canadensis*, *Unio danae*. A very few deciduous leaves were also found at some points.

The fossil remains, the transitional contact with the Willow Creek, and the fact that the formation along with the underlying formations were all affected by the Laramide revolution, point to its closeness in age with the Willow Creek.

The beds were undoubtedly formed in freshwater lakes or rivers.

POST-FOX HILLS SUCCESSION OF CYPRESS HILLS

General Statement

The rocks exposed in Cypress hills well represent the gradual transition from marine deposits to freshwater deposits, which occurs in the uppermost part of the Mesozoic in many parts of the northwestern United States and the Prairie Provinces of Canada. The lowest beds exposed are marine shales of Bearpaw or upper Pierre age, and above them follow

in apparent conformity the Fox Hills sandstones and shales. These in turn pass gradually into freshwater beds of sand or sandy clay with fragmentary plant remains and lignite which continue nearly to the top of the section. These freshwater beds throughout the area are clearly divisible into three units which are thought to agree with the three formations defined by Davis¹ in Saskatchewan, i.e., in ascending order, the Estevan, Whitemud, and Ravenscrag. The Estevan beds are undoubtedly of Lance age, as Lance dinosaurs have been found in them on Rock creek in Saskatchewan. The Lance dinosaur *Triceratops* has also been reported by Sternberg from beds which he considered the Whitemud² beds. So far no dinosaurs have been found in the Ravenscrag beds, but plant remains and invertebrates of Lance or Fort Union age have been found in them.³

Fossil plants were collected from the Estevan and Ravenscrag formations at a number of localities. These have been studied by E. W. Berry who reports on them as follows:

"The collections are too limited to afford any Palaeobotanical basis for differentiating the Ravenscrag, Whitemud, and Estevan in the Cypress Hills section. . . . All (the species) are either undeterminable, or new, or are common Lance and Fort Union forms. All are post Laramie: thus (Lot 1) is Estevan and not Fox Hills, and (Lot 4) contains what is probably a Lance species."

Following are the identifications:

Estevan Formation

(1) *Estevan beds.* SW. $\frac{1}{4}$ sec. 16, tp. 7, range 29, W. 3rd mer.

Fiscus viburnifolia Ward. Fort Union.

Sequoia nordenskioldi Heer. Paskapoo, Lance, and Fort Union.

Trochodendroides sp.

(2) *Estevan.* Sec. 21, tp. 7, range 3, W. 4th mer.

Ginkgo adiantoides Unger. Lance, Fort Union, and Kenai.

Ginkgo (?) fruits, same as 3, 5.

(3) *Estevan.* SW. $\frac{1}{4}$ sec. 28, tp. 7, range 3, W. 4th mer., along road up hill

Ginkgo (?) fruits.

Marchantites sp. (small thallose liverwort).

Trapa microphylla Lesq. Lance and Fort Union and earlier and later, very common in Fort Union.

¹ Davis, N. B.: "Report on the Clay Resources of Southern Saskatchewan"; Mines Branch, No. 468, p. 9.

² Sternberg, C. M.: "Notes on the Lance Formation of Southern Saskatchewan"; Can. Field Nat., vol. 38, No. 4, p. 69.

³ Since the above was written, F. H. McLearn has published "Stratigraphy, Structure, and Clay Deposits of Eastend Area, Cypress Hills, Saskatchewan"; Geol. Surv. Canada, Sum. Rept. 1927, pt. B, pp. 21-43. For his area which adjoins in the east the one being described, McLearn includes in the Whitemud beds not only the "white band" of McConnell, but overlying shales which extend upward to an "unconformity" he has discovered, or "where the disconformity is obscure, about midway between the top of the typical Whitemud sediments and the first coal seam in the overlying Ravenscrag formation." The total included thickness for the Whitemud is about 75 feet. McLearn also finds Lance dinosaur bones in the Ravenscrag beds below the lower coal seam, thus limiting the rocks of Fort Union age to the coal seam and higher beds. In Ravenscrag butte, only 25 feet of strata intervene between the white band and the lowest coal seam there present, and it is not clear that these represent either the upper division of the Whitemud as redefined by McLearn, or the lower dinosaur beds of the Ravenscrag. As further field work is required to clear up these important points, it seems best to leave the present report as it is, although recognizing the possibility of further revision.

(4) *Estevan*. Sec. 35, tp. 7, range 4, W. 4th mer.

Rhizome of *Equisetum*, probably same as *E. arcticum* Heer from Lance of Saskatchewan.

(5) *Estevan* above coal. SW. $\frac{1}{4}$ sec. 6, tp. 8, range 3, W. 4th mer.

Ginkgo (?) fruits. Same as 2, 3.

Pakurus (?) sp.

Ravenscrag Formation

(6) *Ravenscrag*. SE. $\frac{1}{4}$ sec. 22, tp. 7, range 22, W. 3rd mer.

Celastrus wardii Knowlton and Ckl. Lance and Fort Union.

Cercocarpus n. sp.

Leguminosites n. sp.

Rhamnites knowltoni Berry. Denver, Raton, and Wilcox.

Viburnum limpidum Ward. Fort Union.

Viburnum or *Celastrus* sp.

Petrified wood.

(7) $3\frac{1}{2}$ miles east of *Ravenscrag* near centre of sec. 27, tp. 6, range 23, W. 3rd mer.
(*Ravenscrag* beds)

Apeibopsis discolor Lesq. Post Laramie of Black Buttes, Wyoming and Hanna formation.

Aristolochia crassifolia (Newb.) Ckl. Paskapoo and Fort Union.

Celastrus taurinensis Ward. Lance, Fort Union, and Wilcox.

Euonymus splendens Berry. Raton and Wilcox.

Juglans nigella Heer. Paskapoo, Fort Union, Raton, and Kenai.

Sequoia nordenskioldi Heer. Paskapoo, Lance, and Fort Union.

Taxodium dubium (Sternb.) Heer. Paskapoo, Lance, and later.

Trochodendroides cuneata (Newb.) common. Lance and Fort Union.

Viburnum finale Ward. Fort Union.

A new aquatic plant.

(8) *Ravenscrag*. Sec. 28, tp. 7, range 24, W. 3rd mer. Below road bridge on central branch of Fairwell creek

Equisetum sp.

Trochodendroides speciosa (Ward). Paskapoo, Lance, and Fort Union.

Of the five more definite determinations of *Estevan* plants, three are known elsewhere in Fort Union and Lance beds; one in Lance beds only, and one in Fort Union beds only. The Lance age of the *Estevan* formation as determined by the vertebrate remains found in it is, therefore, in harmony with the less determinative evidence of the plants.

Of the thirteen definite determinations of plants from the *Ravenscrag* formation, two are known elsewhere only in the Fort Union; two in the Lance and Fort Union; three in the Lance, Fort Union, and younger formations (Wilcox, Paskapoo, Raton); two occur in the Fort Union and younger formations (Paskapoo, Raton, Kenai, Wilcox), one is "Post Laramie"; and one occurs only in formations younger than Fort Union (Raton, Wilcox). Such an assemblage favours a Fort Union age for the

Ravenscrag formation, even though the evidence is inconclusive; this is in harmony with the position of the Ravenscrag above the Whitemud formation with its Lance dinosaurs.

This freshwater series was called Laramie by McConnell, and outcrops (as already shown by him) in the flanks of Cypress hills. Excellent exposures occur on Eagle butte and the adjoining hills (Bud buttes of McConnell); in the west end of Cypress hills; south of Elkwater lake; on Willow creek south of Thelma; on Battle creek; and especially along Frenchman river.

These sediments are overlain unconformably by the Cypress Hills formation described below. So marked is this unconformity along Frenchman river, that in an old river channel the Cypress Hills conglomerate lies directly on Fox Hills shale, although nearly at the edge of the channel it rests on the Whitemud and farther east upon different horizons of the Ravenscrag division.

The Estevan, Whitemud, and the lower beds of the Ravenscrag divisions outcrop in Boundary plateau; and the Estevan on the top of Old-man-on-his-back plateau.

Estevan Formation

Davis named the "Estevan group" from the occurrences in the Souris valley and states "They do not occur in the Frenchman River plateau, Swift Current Creek plateau, or in the Cypress hills." It is now known, however, that freshwater deposits bearing seams and lenses of lignite lie between the Fox Hills and Whitemud beds throughout the Cypress Hills-Eagle Butte areas, and outcrop also on Old-man-on-his-back plateau and in the Boundary plateau. In general characters and stratigraphic position these beds correspond with the Estevan subdivision of Davis and are so classified in this report. They differ somewhat from the Estevan of the more typical Saskatchewan localities in being more sandy, lighter in colour, and without the fine banding of clay and sandy clay, so characteristic of the beds farther east.

Excellent outcrops occur along the road south of Elkwater lake, on Bullshead creek, on the slopes of Eagle butte, on Willow creek below Thelma, along the upper part of Battle creek, and especially along the escarpments of Frenchman river between Cypress lake and East End. Other good exposures occur at many places in the various units of Cypress hills, on Old-man-on-his-back plateau, and on Boundary plateau.

The formation consists of sandstone, sandy shale, fire-clay, and lignite and is well illustrated by the measured sections below Thelma, already described, and the Ravenscrag section given below. The exposures of lignite in the western part of Cypress hills have been consumed at a number of places by spontaneous combustion which has baked the underclays to a brick red colour. These "red shales" are very conspicuous in the slopes of the hills along the upper waters of Medicine Lodge coulee and elsewhere.

Ravenscrag Butte Section in Descending Order¹

	Feet	Inches
<i>Ravenscrag Beds</i>		
Buff sandstone.....	3	
Light clay and silt.....	10	
Hard sandstone.....	3	
Buff silts.....	32	
Hard sandstone.....		6
Bluish and creamy shale.....	9	
Hard, buff silt.....	6	
Dark shale and silt.....	11	
Buff silt.....	8	
Buff silt and blue shale.....	17	
Lignite and shale.....	10	
(5-foot seam of lignite near middle)		
Carbonaceous shale with streaks of lignite.....	5	
Buff silt.....	11	
Carbonaceous shale and lignite.....	5	
Green and yellow clays.....	16	
Clay concretions.....	1	
Grey silt and green clay.....	10	
Buff, sandy clay.....	4	
Dark shale and silts.....	13	
Lignite.....	1	
Dark shale and silts.....	6	
Buff silt and blue shale.....	8	
Hard sandstone.....	1	
Buff silt and blue shale.....	12	
Blue shale and streaks of lignite.....	6	
Lignite and shale.....	5	
Brown, sandy silt.....	25	
Ironstone concretions.....	1	
<i>Whitemud Beds</i>		
Whitemud beds.....	26	
<i>Estevan Beds</i>		
Lignite.....	1	
White silt.....	65	
Green-grey shale.....	6	
Buff sandstone, concretions near middle.....	105	
<i>Fox Hills Beds</i>		
Transition grey clay-shale mostly covered.....	25	
Grey shale containing selenite.....	50	

The Estevan here has a thickness of 177 feet, the thickness on Willow creek being 285 feet.

Lignite deposits of the Estevan beds are being mined on Elkwater lake, at Thelma, near old Fort Walsh, near Ravenscrag, and elsewhere. Many small mines have caved in where former operations were carried on. The "coal" is useful for domestic purposes, but decrepitates badly on drying.

Whitemud Formation

A white weathering formation of semi-refractory clay containing sand lenses overlies the Estevan lignite-bearing formation. This formation has been called the "Whitemud beds" by Davis, who has reported on it in some detail because of its economic importance. Outcrops are recognized by their pure white colour and occur in the flanks of Cypress hills from Eagle butte to East End.

¹ This is the "Eagle Butte" section near Ravenscrag measured by McConnell and quoted by Davis. The section given here is from a new survey by plane-table, detail being added by hand level. The section below the Whitemud beds is supplemented by the section exposed on the south side of the river.

Numerous outcrops were found in Medicine Lodge coulée; and in the long, narrow coulée that extends from the western end of Elkwater lake to the small lake in section 7, tp. 8, range 3, W. 4th mer., and thence southward to Medicine Lodge coulée. They are also found on Bullshead creek on the downthrow side of the fault, and at various points on Eagle butte. Owing to the pure white colour of the beds on exposure, they show up very plainly and serve as an ideal horizon marker for structural work. Beds referable to the same formation have been found at many widely scattered points in south Saskatchewan and at many localities the clay portion of the beds is refractory in character. At Claybank they are made use of for the manufacture of fire-brick. No analyses have been made as yet of the clays in the western part of the hills, and it is not known whether they are refractory or not.

The following section of the formation was measured in Medicine Lodge coulée in sec. 31, tp. 7, range 3, W. 4th mer.

Section Through the Whitemud Beds

	Feet
Soft, light grey clay, weathering pure white.....	10
Black or dark brown (bentonitic?) clay.....	1
Yellowish green bentonite.....	$\frac{1}{2}$
Light grey, soft, very fine-grained sand, weathering pure white.....	10
Light grey clay apparently grading downward into the buff-coloured sands of the Estevan.....	4

Ravenscrag Formation

Silts and sands of the Ravenscrag formation rest upon the Whitemud beds of Cypress hills except where removed by erosion (as stated elsewhere Cypress Hills conglomerate rests upon Whitemud beds in the north bank of Frenchman river). The sediments include lignite and mud beds, especially in the east, and vary in colour from drab, to yellow, brown, green, and dark red. Beds of intraformational conglomerate, consisting of clay pellets and pebbles of sandstone, are present locally. In Saskatchewan lignite beds occur which have been worked at a number of places.

Ravenscrag beds are exposed to advantage on the sides of Eagle butte, in the stream valleys flowing southwestward from the Head of the Mountain, on the road ascending Cypress hills south of Elkwater lake, along Battle creek, and in the banks of Frenchman river. Numerous other exposures occur on the flanks of Cypress hills below the Oligocene conglomerate and on the top of Boundary plateau.

Because of the semi-consolidated characters of many of the beds, and the unconformity at their top complete sections of the Ravenscrag formation are unknown.

The following descending section was measured along the road south of Elkwater lake, the details in brackets being supplied from a similar section measured on the western slope of the Head of the Mountain.

	Feet
Quartzite pebbles, probable base of Cypress conglomerate.....	
White silt.....	10
Friable, grey sandstone.....	15
Covered interval.....	70
(Pink clay).....	20
Red-brown, and green clay.....	10
Covered interval.....	30
(Grey silt).....	10
Covered interval.....	65
(Soft cream sandstone with lenses and balls of silt).....	10
Covered interval.....	30
(Grey silt).....	5
Covered interval.....	10
(Cream sandstone).....	10
Covered interval.....	60
(Grey sandstone).....	10
Covered interval.....	10
Soft, friable, grey sandstone with nodular lenses and beds of silt balls.....	100
Covered interval.....	50
Covered interval probably including Whitemud beds.....	

The lower part of the Ravenscrag formation is described on page 137. Here many plant remains occur as described under palæontology.

In Ravenscrag butte and along Frenchman river, yellowish silts form the basal beds of the Ravenscrag formation overlying the Whitemud beds; but on the north side of Eagle butte in the SE. $\frac{1}{4}$ sec. 20, tp. 8, range 4, W. 4th mer., beds of hard, grey shale and dark brown, soft clay shale separate the Whitemud beds from the yellow sands of the Ravenscrag. In the bottom layers of these beds occur the following freshwater fossils: *Campeloma producta*, *C. cypressensis* (n. sp.), *Thaumastus limnaeiformis tenuis*, *Hydrobia recta*, *Unio* sp., and *Sphaerium* sp. These at least indicate a post-Bearpaw and probably a Fort Union age for the beds.

The thickness of the Ravenscrag beds as measured in the western slope of the Head of the Mountain from the Whitemuds to the Cypress Hills conglomerate is about 460 feet. In the section south of Elkwater lake the Whitemud is not well exposed, but the Ravenscrag beds have a probable thickness of 500 feet. At Ravenscrag the section given above includes 235 feet of Ravenscrag beds without sign of the overlying Cypress conglomerate. In the valley of Frenchman river, however, as already stated, the Cypress Hills conglomerate rests on an unconformable surface and in places the Ravenscrag and Whitemud, and even the Estevan, beds have been eroded away. It is probable that the Ravenscrag beds farther north have a preserved thickness of 300 to 400 feet.

The Ravenscrag formation is to be correlated with a part of the Fort Union of Montana, and more particularly with the Tongue River member. Whether or not any of the upper dark shales may be correlated with the Sentinel Butte member is a question of great importance, but this cannot be settled on the evidence at hand. If the Tongue River member only is present, the formation belongs to the Upper Cretaceous as defined by Thom and Dobbin¹ who summarize their conclusions thus:

"The assignment of the Lance and Fort Union transition beds to Cretaceous or Eocene will depend on the type section against which a comparison is made. On the basis of diastrophic and other natural relationships found in eastern Montana and northern Wyoming, a worker in the region would select the Tongue River-Sentinel Butte contact, or base of the Kingsbury conglomerate as the local Cretaceous-Eocene boundary."

¹ Thom, W. T., and Dobbin, C. E.: Bull. Geol. Soc. of Am., vol. 35, p. 497 (1924).

The Bureau of Mines of Montana, the South Dakota Geological and Natural History Survey, and Professor Schuchert are cited as supporting this view, which is "partly concurred in by Matthew". "Objections to these views have been summarized by Cross and Knowlton."

Under this classification, no Eocene sediments occur in Cypress hills, unless some of the upper dark shales of the Ravenscrag formation are to be correlated with the Sentinel Butte member of Montana.

Cypress Hills Formation

GENERAL CHARACTERS

The conglomerate formation forming the top of the Cypress Hills was originally described and mapped by McConnell.¹ On the basis of the fossil mammals and other vertebrates found in it, the age was determined as Miocene (used in the sense of including Oligocene). More recent determinations have fixed the age as Lower Oligocene.

The formation consists of conglomerate, sandstone, silts, and marl. The induration of the beds varies much from place to place, loose gravel and sand as well as hard, resistant conglomerate being present. The cementing material is generally calcareous, although sand is present in varying quantities. The pebbles of the conglomerate are generally of flattened, spheroidal form and lie in imbricated structure, their tops tilted toward the east or southeast. Sandstone and conglomerate replace one another within short distances horizontally and vertically, and the lower contact is unconformable with underlying formations which range from the Fox Hills to the Ravenscrag, as may be seen in an excellent section in the north bank of Frenchman river east of the mouth of Davis creek. There sandstone containing conglomerate lenses lies on an erosion surface of Ravenscrag and Whitemud beds with a slope to the southwest of 55 degrees. The pebbles of the conglomerate are imbricated toward the south. Across, in the south bank of Frenchman river, the Cypress Hills formation rests on dark Fox Hills shale, the Estevan and Whitemud beds having been entirely eroded away.

In Hand hills, Red Deer valley, Tyrrell² reports 270 feet of

"stratified argillaceous marls and sands. . . . the beds being as far as can be seen, perfectly horizontal. On some of the highest points of the hills, a bed of 27 feet of quartzite gravel overlies the stratified marls, the matrix being a mixture of sand and lime, sometimes loose and sometimes cementing the mass into an exceedingly hard conglomerate. These conglomerates, with the underlying marls and sands, are so similar to the Miocene (now known to be Oligocene) beds of the Cypress hills, that I have very little hesitation, even in the absence of fossil remains, in classing them in that formation, although, as this material was doubtless brought down from the mountains to the west by different streams, the deposition of the two may not have been exactly contemporaneous."

DISTRIBUTION

The Cypress Hills formation is co-extensive with the upland surface of Cypress hills and caps several small plateau remnants south of Frenchman river. As McConnell has shown, the conglomerate has been the

¹ Geol. Surv., Canada, Ann. Rept., vol. 1, pt. C, pp. 31 and 32 (1886).

² Tyrrell, J. B.: Geol. Surv., Canada, vol. 2, 1886, pt. E, p. 77.

cause of the preservation of the plateau. Rocks of the same age as the Cypress Hills formation have been recognized in Wood Mountain plateau, although no conglomerate is present, and Tyrrell's marls and conglomerates of Hand hills are provisionally accepted as being approximately equivalent in origin and age to the Cypress Hills formation.

LITHOLOGY

The lowest division of the Cypress Hills formation consists of about 50 feet of coarse quartzite-conglomerate held together by more or less calcareous cement. This is the resistant member underlying the plateau surface, but it is exposed only by landslides and stream erosion near the plateau level. Where the lower contact is with the upper Ravenscrag beds, loose sand and quartzite pebbles are mixed for a number of feet below the conglomerate proper. Where the contact is with Whitemud, or Fox Hills shale beds, conglomerate and sand lenses lie on the eroded mud or shale surface.

McConnell has reported a thickness of 500 feet of "pebble and clay conglomerates, with occasional beds of loose pebbles, hard and soft sandstones, the latter usually very coarse-grained and affected with false bedding, clays of various colours, but usually dark grey, and small beds of impure limestone and whitish marls" in the coulées north of Frenchman river.

The following descending section was made in Calf creek, a branch of the north branch of Frenchman river. It is here that most of the mammal and other vertebrate remains have been found:

	Feet
Loose sand and soil.....	10
White, silty clay, containing small vertebrate bones.....	50
Mottled conglomerate; quartzite pebbles, limy clay pebbles, large mammal bones, silicified wood and sand.....	60
Quartzite conglomerate, 3-inch pebbles.....	10
Finer conglomerate, 1½-inch pebbles (top only exposed).....	4

Sands and loose stone on the neighbouring hills probably represent higher beds of the Cypress Hills formation.

The pebbles of the lower conglomerate formation are mostly light-coloured, fine-grained quartzite, weathering pink or buff. Lithologically they appear to be identical with samples of Rocky Mountain quartzite of Carboniferous age. They vary in maximum size from 10 inches to 12 inches in larger diameter near the Head of the Mountain to about 3 or 4 inches at Calf creek. The larger pebbles are chatter-marked, as described by previous writers. These percussion markings are generally semicircular with a radius of $\frac{1}{4}$ -inch to $\frac{1}{2}$ -inch and extend about $\frac{1}{4}$ -inch into the pebbles. Pebbles under 2 inches in diameter rarely show percussion marks.

Other pebbles occur of dark grey or rusty colour with coarser grain, and without chatter-marks. The larger pebbles are beautifully rounded and are ovoid in shape. Smaller pebbles are more irregular and the small ones are quite angular, although smooth. The cement is generally highly

calcareous and in the absence of lime the formation may be quite loose. Lateral and vertical gradations from sand to conglomerate are common, and the pebbles are generally imbricated or shingled with the slope of their broader surfaces toward the west or northwest, thus indicating a movement of the current of deposition toward the east and southeast.

The marly conglomerate where seen on Calf creek rests upon an irregular surface of the lower conglomerate. Its quartzite pebbles are less numerous, and smaller in size, and are mixed with marl pebbles, mammal bones, silicified wood, and impure sand. Lenses of white marl recorded by McConnell in the valley of Lone Pine creek may represent a phase of this conglomerate.

Upward the conglomerate grades into marly clay and silt containing vertebrate remains and silicified wood.

ORIGIN

As clearly described by McConnell, the Cypress Hills formation is a fluvial deposit laid down on a broad flood-plain by streams heading in the Rocky mountains. The course of the principal river is probably indicated by the heavy conglomerate capping of the western hills of the Cypress Hills group. North of Frenchman river a wide flood-plain received thick deposits of conglomerate, sand, marl, and silt, but the approximate location of the main channel is indicated by an old channel recorded in the sediments of Frenchman valley near the mouth of Davis creek. The slope of the old channel in regard to the underlying formations and the imbrication of the pebbles indicates a southern direction of flow. The formation slopes today toward the southeast, and taking all available evidence into account, it appears that the Oligocene river system which deposited the Cypress Hills conglomerate was tributary to the ancestral Missouri system, emptying into the Gulf of Mexico waters.

As more particularly described under "Saskatchewan gravels", stones from the Cypress Hills formation are scattered broadly over the region adjoining Cypress hills, and between the hills and the mountains. The extent of the distribution is less toward the north than toward the south as might be expected from the direction of the flow of the glaciers. In the west, pebbles of the Cypress Hills formation, or pebbles identical in characters, underlie the Keewatin glacial deposits, and rest, in some places at least, on bedrock.

It is natural to conclude from the distribution of the debris, that the Cypress Hills conglomerate was at one time a widespread formation, extending from the Rocky mountains to Wood mountain and beyond.

PALÆONTOLOGY

The vertebrate fossils from which the age determination of the Cypress Hills formation has been made, are listed below.¹

¹ Lambe, L. M.: Contributions to Canadian Palæontology, vol. III, pt. IV. "The Vertebrata of the Oligocene of the Cypress Hills, Saskatchewan". The species in brackets have been added from collection by Williams identified by Chas. M. Sternberg.

Pisces

ACTINOPTERYGII

Amia whiteavesiana Cope
Amia macrospondyla Cope
Amia exilis Lambe
Lepidosteus longus Lambe
Rhineastes rhaeas Cope
Amiurus mcconnelli Cope

Reptilia

CHELONIA

Anosteira ornata ? Leidy
Stylomys nebrascensis Leidy
Testudo exornata Lambe
Triconyx leucopotamicus Cope

SQUAMATA

Lacertilia

Peltosaurus granulosus Cope

Ophidia

Ogmophis compactus Lambe

CROCODYLIA

Crocodylus prenasalis ? Loomis

Mammalia

MARSUPALIA

Didelphys valens Lambe

UNGULATA

Arctiodactyla

Ancodus (Hyopotamus) brachyrhynchus Osborn and Wortman
Anthracotherium ? pygmaeum sp. nov.
Elotherium coarctatum Cope
Agriochoerus antiquus Leidy
Merychoidodon culbertsoni Leidy
Merychoidodon gracilis Leidy
Poebrotherium wilsoni Leidy
Leptomeryx esulcatus Cope
Leptomeryx mammifer Cope
Leptomeryx speciosus Lambe
Leptomeryx semicinctus Cope
Hypertragulus transversus Cope

*Perissodactyls**Equidae*

- Meshippus westoni* (Cope)
- Meshippus praeacidens* Lambe
- Meshippus propinquus* Lambe
- Meshippus brachystylus* Osborn
- Meshippus stenolophus* Osborn
- Meshippus planidens* Lambe
- Meshippus assiniboensis* Lambe

Hyracodontidae

- Hyracodon nebrascensis* Leidy
- Hyracodon priscidens* Lambe

Rhinocerotidae

- Aceratherium mite* Cope
- Aceratherium occidentale* (Leidy)
- Aceratherium exiguum* Lambe
- Leptaceratherium trigonodon* Osb. and Wort.

Titanotheridae

- Megacerops angustigenis* (Cope)
- Megacerops selwynianus* (Cope)
- Megacerops syceras* (Cope)
- Megacerops primitivus* Lambe
- Megacerops assiniboensis* Nom. prov. Norwood and Evans
- (*Titanotherium prouti* Owen)

Ancylopoda

- Chalicotherium bilobatum* Cope

Rodentia

- Sciurus ? saskatchewanensis* Cope
- Ischyromys typus* Leidy
- Cylindrodon fontis* Douglass
- Eutypromys parvus* Lambe
- Palaeolagus turgidus* Cope
- Palaeolagus haydeni* Leidy

Carnivora

CREODONTA

- Hyaenodon cruentus* Leidy
- Hyaenodon crucians* Leidy
- Hemipalodon grandis* Cope

CARNIVORA VERA

Canidae

- Cynodictis lippincottianus* (Cope)
- Daphaenus felinus* Scott
- Protemnodon partshornianus* (Cope)

Felidae

- Dinictis felina* Leidy

Lambe concludes¹ that

"Although the beds of the Cypress Hills deposits in question probably belong, in a general sense, to the horizon of the Titanotherium beds of Montana, some of their upper members may be synchronous with the Oreodon beds. Whether the time equivalent of the uppermost division of the Oligocene (Protoceras beds) is present at all is problematical."

Saskatchewan Gravels

GENERAL STATEMENT

Gravels of Rocky Mountain origin have been found by various geologists, in southern Alberta and southwestern Saskatchewan overlying bed-rock and covered by glacial deposits. The pebbles compare in size and character with those of the Cypress Hills conglomerate, and the gravel differs in no essential character from the known erosion products of the Cypress Hills formation. These secondary Cypress Hills gravels are found mainly on the plateau adjoining Cypress hills, where they have been protected in large measure from the direct action of the continental ice-sheet. In part they are mixed with "Laurentian" granites, gneisses, etc., this being more especially the case north of Cypress hills. The wide distribution of this quartzite gravel with its chatter-marked, ovoid pebbles, has been used as evidence of the great extent of the original Cypress Hills conglomerate formation. Alden found the gravel capping his Flaxville plain and containing the remains of Pliocene and younger mammals. Erosion of the Cypress Hills conglomerate was, therefore, well advanced in Pliocene time, and the resulting products have been reworked, at least in part, during every subsequent erosion cycle. When these facts are considered, it will be clear that, as McConnell says, the gravels are "not all contemporaneous"; in fact he included river and upland gravels in the Saskatchewan gravels. Both McConnell and Dawson recognized that the gravels in their upper and western extension, contain "Laurentian" stone and are in part of glacial origin. McConnell stated that there was "little doubt as to the derivation of these gravels, in part, at least, from the Miocene" and believing them to be pre-Glacial, dated them as Pliocene, Dawson², impressed by the glacial phase seen in the west, considered them as the work of a pre-Kansan glaciation which he named Albertan. Alden and Stebinger³ concluded that with the exception of

"the gravel underlying the lower boulder clay of the Keewatin ice-sheet at Lethbridge (which) may be pre-glacial" . . . "Part at least, if not all, of the so-called 'Saskatchewan' gravels, exposed at intervals along the valley in southwestern Alberta, are interglacial deposits derived by erosion from the pre-Wisconsin mountain drift."

They then proceed to give reasons for discarding the term "Albertan" as the name of a period or stage of glaciation.

From the above discussion, it is clear that the exact age and extent of McConnell's "Saskatchewan gravels" is much in doubt. Alden's Pliocene gravels of the Flaxville plain, and their counterparts on the first terrace below Cypress plateau, in the vicinity of Cypress hills, are of the age ascribed by McConnell to the Saskatchewan gravels, but their position

¹ Ibid., p. 8.

² Geol. Soc. Am., Bull. VII, pp. 31-66.

³ Geol. Soc. Am., Bull. XXIV, pp. 562-3.

high on plateaux sets them apart from the low-lying river gravels and gives them an age considerably greater. The Flaxville gravels are probably early Pliocene, but the river gravels are either early Glacial as thought by Dawson or interglacial as stated by Alden and Stebinger. Whether the gravels near Lethbridge and other occurrences on South Saskatchewan river, described by McConnell, are older than the rest and pre-Glacial is still an open question.

OCCURRENCE

Water-laid gravels resting upon Mesozoic formations, and overlain by glacial till, have been recognized by Dawson, McConnell, and later workers, in the valley of St. Mary and Oldman rivers. The gravel near Lethbridge has been referred to by Alden and Stebinger as the oldest gravel seen and possibly pre-Glacial. One of the best exposed gravel deposits is in the southeast bank of the north branch of Milk river in the road grade at the bridge 3 miles east of Fareham and 2 miles north of the 49th parallel. About 40 or 50 feet of coarse, roughly bedded gravel rests upon St. Mary River sandstone. The pebbles are generally under 9 inches in diameter, and consist of white, pink, and green quartzite, similar lithologically to the Beltian rocks exposed at Waterton lake. Similar gravel occurs plentifully on the hills to the west of Milk river, although it is mixed in places with "Laurentian" stone brought by the continental ice-sheet.

McConnell records gravels in the valley of Saskatchewan river "underlying the boulder clay for several miles below Medicine Hat." He also includes the Flaxville and other reworked gravels in the vicinity of Cypress hills, at Rush Lake creek, and on Boundary plateau in his Saskatchewan gravels. Outcrops of conglomerate identical in appearance with the Cypress Hills conglomerate occur on a hill south of Adams lake in the northeastern corner of sec. 15, tp. 8, range 29, W. 3rd mer., and on hills west of Battle creek in the NW. $\frac{1}{4}$ sec. 16, tp. 6, range 29, W. 3rd mer. The first-mentioned occurrence has an elevation of about 4,040 feet or 240 feet lower than the base of the 80-foot bed of Cypress Hills conglomerate capping Cypress Hills plateau one-half mile to the south. The Battle Creek occurrence has an elevation of about 3,220 feet. Although at both exposures the beds appear to be horizontal it is now concluded from their limited extent that they are detached blocks, remnants of the once extensive Cypress Hills formation lowered by erosion of the underlying beds. This appears quite clearly to be the case with the northern occurrence, where the isolated exposure and the conglomerate in place are within sight of each other.

CONCLUSIONS

The deposits included under Saskatchewan gravels by McConnell clearly vary in age of deposition from early Pliocene to early Pleistocene or even interglacial.

As the Cypress Hills conglomerate and the till of the piedmont glaciers were both derived from the front ranges of the Rocky mountains, the resistant pebbles in each case are likely to be the same. The till, however, should have limestone and argillite pebbles mixed with quartzite, and the

pebbles should have those shapes and surfaces characteristic of glacial transportation. In some of the deposits along the edge of the disturbed belt, the stone is mixed in character and clearly was derived from the Lewis and Clarke ranges by glacial action; but in the river gravels described by Dawson, McConnell, and others, the stone is practically identical with that of the Cypress Hills formation. These observations lead to the conclusion that whatever the final means or age of deposition, most of the quartzite gravels of the southern plains belonged originally to the Cypress Hills conglomerate formation of vast extent, the clastics of which were derived by stream and river action from the Rocky mountains.¹ While the larger stream courses were depositing 9- and 12-inch boulders 200 miles from the mountains and building up the capping of the Cypress hills of today, smaller streams were mantling the piedmont slopes with fans of similar gravel. Such vast deposits were thus spread over the plains bordering the mountains that all subsequent erosion agencies have been taxed to the limit of their energy in removing the load. Thus even the Pleistocene ice, whether in the form of a continental sheet or as piedmont glaciers, has been so overburdened in places with Cypress Hills debris, as to be unable to bring large amounts of new material into the areas affected.

Pleistocene and Recent

GENERAL STATEMENT

A mantle of unconsolidated materials, consisting generally of glacial till, outwash gravels, sand, and silt, covers the whole of the southern plains of Saskatchewan and Alberta with the exception of the tops of some of the higher plateaux, such as Cypress hills. Moraines are particularly marked in the vicinity of the major elevations of the region, including the north and south sides of Cypress hills, the north slopes of Sweet Grass hills, the Milk River ridge, the hills of the disturbed belt, and Porcupine hills.

The deposits of Glacial age fall into two main subdivisions, those made by the mountain or piedmont glaciers and those made by the continental glaciers. These merge and overlap in a belt about 25 miles wide bordering the front ranges of the Rocky mountains. The deposits of the mountain glaciers generally underlie those of the continental ice, but the two are partly mixed at many localities. Fragments of limestone, dolomite, argillite, and quartzite make up most of the larger stone from the mountains, but subangular, striated pebbles are rare. Most of the pebbles are well-rounded quartzite of river origin and similar to the Oligocene gravel deposits. A few huge, extremely angular quartzite boulders are of mountain origin. Blocks of quartzite 40 by 30 by 22 feet, or even larger, have been seen by Dawson and the present writer 25 miles from the mountains and a large block of limestone, probably Devonian or Carboniferous in age, was noted by the writer in the valley of the southeast branch of Pothole creek, about 40 miles from the nearest mountains. The transportation of huge fragments of rock for such distances is unusual, but not nearly so remarkable as would be the carrying of large Precambrian boulders from

¹ Compare conclusions by Dawson, Geol. Surv., Canada, Rept. of Prog. 1882-83-84, pt. C, p. 142.

northern Saskatchewan to southwestern Alberta, over a distance of at least 550 miles. The till of mountain origin has been much obscured by admixture with masses of gravel resulting from the erosion of the Cypress Hills conglomerate, has been modified by stream action, and mixed with the glacial deposits of the continental ice-sheet.

Typical deposits of the Keewatin ice occur over the whole area, excepting the highlands mentioned, and extend to the front ranges of the mountains, where they were identified by Dawson "near the trail leading to the Crowsnest pass, at a height of about 4,200 feet." Such deposits include tills and outwash gravels and sands, the contained boulders being Precambrian granite and gneiss, and Palæozoic limestone, all clearly derived from northern Saskatchewan or Manitoba. Moraine and kettle topography accompanying the glacial deposits is common. The maximum depth of the unconsolidated deposits of the prairies is over 200 feet and the thickness of the tills varies much from place to place.

A thin blanket of silt overlies much of the glacial deposits and deep deposits of silt fill parts of several of the river valleys, as Milk River valley below Milk River town, where the river has cut through 50 feet of silt which stands as steep banks bordering the valley. In Frenchman river below Ravenscrag, silts occur on the flanks of the valley sides 400 feet above the present level of the river, and extensive deposits of semi-consolidated silts occur in the valleys of the streams flowing northward from Cypress hills. Thinner silt deposits occur in nearly all the streams of the region, although the present tendency is toward removal of the silt. Sand and silt deposits cover large areas of nearly flat prairie as, for example, the Lethbridge-Raymond plain, the sand-plains of Bow island, and elsewhere.

The prairie soil is generally a weathered product of the underlying unconsolidated deposits, but in some cases consists of decayed bedrock. There is, in general, a marked relationship between the bedrock and the soil, as may be seen in the dry belt. Here the unproductive areas are mainly underlain by Belly River sandstone; the Pleistocene deposits contain much local sand, and the transported material is derived in large measure from the "Laramie" sandy beds. Thus in a region of inadequate precipitation, an absorbent sub-soil accentuates the aridity, which farther east in Saskatchewan where the subsoil is clay is not prohibitive of successful agriculture.

Igneous Intrusives and Sandstone Dykes

GENERAL STATEMENT

The general sedimentary character of the rocks of southern Alberta is varied in a minor way by intrusives associated with the igneous plugs of Sweet Grass hills, and by locally developed sandstone dykes. Small in size and occurring within a limited area, these intrusives are of scientific rather than of economic interest. Their underground character and extent are, however, factors to be considered in relation to oil, gas, and water accumulation.

IGNEOUS INTRUSIVES

Sweet Grass hills, Montana, were originally studied by Dawson¹ while engaged on the survey of the 49th parallel in 1874 and were again reported on in 1884². All subsequent reports on the igneous rocks have been based upon Dawson's field work, although much detailed petrographic investigation has been carried on by a number of men. Dawson describes "mica-trap" dykes occurring in radial arrangement, several miles from the hills, and quotes F. D. Adams' determination of the intrusions of East and West buttes as "hornblende-trachyte, rich in plagioclase." He finds the intruded rocks, which are much altered close to the igneous masses, are Cretaceous, the highest beds recognized being "the castellated series" (Milk River sandstone). These sedimentaries, dipping at high angles, flank the intrusives to within 2,000 feet of the top of the buttes. Of the intrusives Dawson says "If of the nature of volcanoes, they must be very ancient ones, of which the cones or stumps now only remain. . . ."

S. E. Slipper³ made a section of the sedimentaries on the northeastern side of East butte in 1915, finding rocks ranging in age from Carboniferous to the top of the Benton (Colorado).

The most important petrographic study of Sweet Grass Hills intrusives is that by W. H. Weed and L. V. Pirsson.⁴ For field relations they quote Dawson, but compare the intrusives with the laccoliths of Moccasin mountains, the northeastern part of the Little Belt range, the Bearpaw, Little Rocky, and Judith ranges. This comparison is based largely upon similarity of rock types found in these various mountain groups. Two rock specimens from West butte are described as quartz diorite porphyrite and two from East butte as quartz syenite porphyry. A dyke north of East butte is described as a minette allied with the syenite of East butte, both rocks containing aegirite.

Although many small dykes and intrusives probably lie beneath the drift in southern Alberta, between Milk river and Sweet Grass hills, but few are known. A dyke has been reported in the upper part of Deadhorse coulée, but was not found by the writer. No intrusives are known farther west. A small dyke occurs east of Bear gulch in secs. 5, 8, and 9, tp. 1, range 9, W. 4th mer. The most northerly intrusive known is an irregular plug on the north bank of Milk river at the mouth of Pendant d'Oreille coulée (SE. cor. sec. 30, tp. 2, range 8, W. 4th mer.). The largest intrusive known on the Canadian side is that of Black butte, a dome-shaped hill 2 miles north of Pinhorn customs station, and crossing the northwest corner of sec. 10, tp. 1, range 8, W. 4th mer. The most easterly intrusive observed is a large, wall-like dyke crossing the 49th parallel near the southwest corner of sec. 5, tp. 1, range 5, W. 4th mer. The known area including intrusives in Alberta, therefore, extends about 37 miles along the 49th parallel and 10 miles to the north. All the dykes are directed toward the nearest of the Sweet Grass hills and all the intrusives are minettes.

¹ Dawson, G. M.: British North American Boundary Commission, Montreal, 1875.

² Dawson, G. M.: Geol. Surv., Canada, Rept. of Prog. 1882-83-84, pt. 5, pp. 16-17 and 45-47.

³ Dowling, D. B.: Mem. 93, p. 65.

⁴ Am. Jour. Sc., ser. 3, vol. L, pp. 309-313 (1895).

The dyke east of Bear gulch cuts sandstone and shale of the Foremost beds and is exposed for about 100 yards. It is nearly vertical, strikes about 5 degrees east of north, and varies in width from 4 to 5 feet. The rock is a minette containing black mica crystals up to 1 inch in length; and the intruded sandstone and shale are baked at the contacts for 1 to 2 inches from the dyke, and contain secondary mica.

The most easterly dyke crosses the 49th parallel about 200 yards east of the western boundary of sec. 5, tp. 1, range 5, W. 3rd mer., and strikes 58 degrees east of north. It occurs as a vertical wall 4 or 5 feet thick and extending about 300 feet from the south bank of Milk River gorge directly across the International Boundary. The intruded grey and brown silts of the Foremost beds are hardened at the contacts and cling to the sides of the intrusive, which is a typical minette. Near its outer extent, the dyke rock rises about 20 feet above the flanking sediments, and forms such a striking landscape feature as to be illustrated opposite page 26 in the United States report on "The Survey of the Northern Boundary of the United States from the Lake of the Woods to the Summit of the Rocky Mountains (Washington 1878)." This may be the dyke referred to by Dawson as occurring 10 miles north of the summit of East butte, and may also be the one from which the specimen came which was studied by Weed and Pirsson.

The igneous intrusion at the mouth of Pendant d'Oreille (Pakowki) coulée was discovered by Dawson¹ who also records "A similar little trap-pean projection . . . about 2 miles off to the southeast on the opposite side of the river." The main intrusion forms a knoll on the north bank of Milk river and near the western side of Pendant d'Oreille coulée. The mass outcrops for about 80 feet along the river bank, extends about 50 feet back from the river, and rises about 50 feet above the water-level. The rock is dark green and basaltic in appearance, but contains black mica in masses up to $\frac{1}{4}$ inch across. Inclusions of hardened shale, Milk River sandstone, and light grey, crystalline limestone occur in the intrusive which is cut, especially toward the top, by calcite veins. The limestone when struck has a strong smell of sulphuretted hydrogen, and has probably been brought up from the Madison limestone which here lies about 3,200 feet below the surface.

"Black butte," the largest of the Sweet Grass intrusives in Alberta, has a distinctive appearance and topographic expression, hence its name. It is situated about 2 miles from the Canadian customs house and quarantine station at Pinhorn and close to the main trail leading to it. The butte is an oval hill rising about 100 feet above the plain and extending from an ovoid development in the southwest to a narrow prolongation in the northeast. Its length is about 460 yards and its average width about 125 yards. The intrusive is a fine-grained minette, but in places the black mica crystals are large in size. There are many inclusions up to 1 foot in diameter, some appearing dioritic in character. Parts of the intrusive tend to weather to a pink colour. Along the east side of the butte, a "stack" or "flower pot" of crossbedded, grey sandstone rises about 10 feet above the hill side. It is evidently a part of the intruded formation, hardened by metamorphism. The sandstone appears to belong to the Pale beds.

¹ Ibid., pt. C, pp. 43-44.

Recent writers have referred to Sweet Grass hills as laccoliths, but the evidence does not appear conclusive. If laccoliths, their bases must be below the horizon of the Madison limestone, some 3,000 feet from the surface, for this limestone is thrown up around their flanks. Wells drilled near the intrusives penetrate the lower formations without encountering igneous rock. Thus a well drilled in Montana about 3 miles south of sec. 3, tp. 1, range 10, W. 4th mer., and about 3 miles west of East butte penetrated the Madison limestone at 2,730 feet without meeting with igneous rock. A well was drilled by the Grand Trunk Development Company on sec. 1, tp. 1, range 12, W. 4th mer., which reached the Madison limestone at a reported depth of 2,800 feet without penetrating igneous rock. This location is on the foothills slope of West butte and proves that no laccolith extension occurs in this direction unless at great depth. Other wells have been drilled in Montana on the slopes of the buttes and have penetrated the Madison limestone without encountering igneous rock. A water well at Whitlash, Montana, close to Centre butte, struck igneous rock at shallow depth, but this was to be expected from the proximity to the intrusives. Moreover, as brought out by Dawson and others, the igneous rocks stand as plugs extending about 1,000 feet above the sharply upturned sediments that cling to their sides. If laccoliths occur, they are deep seated and surmounted by plugs.

As already stated by Weed and Pirsson, the radial dykes and small, outlying igneous bodies are closely related to the intrusives in petrological characters, and may be safely interpreted as having subterranean connexions with the same igneous source.

The age of the intrusives is known to be post-Belly River, as Foremost beds and Pale beds are cut by them: the metamorphosed coal, mined in the southwest flank of West butte, is probably Foremost in age. On the other hand, the intrusion antedated the planation of the top of the West butte which is believed to be a part of the Cypress plain and of Miocene age. Alden and others consider the age of the intrusives as early Tertiary.

SANDSTONE DYKES¹

Sandstone intrusives cut the Bearpaw formation from top to bottom, in an area of southeastern Alberta south of Cypress hills. The localities noted are on sec. 6, tp. 5, range 4; sec. 14, tp. 5, range 5; and sec. 23, tp. 6, range 3, all W. 4th mer.

At the first locality a small, irregular dyke cuts the lignite seam at the top of the Pale beds and also the overlying Bearpaw shale. The sand of the dyke is so similar to the sand of the Pale beds, which outcrop nearby, that it seems certain that the sand from this lower formation has been forced into the overlying shale in the form of dykes.

At the second locality, numerous, light grey sandstone dykes occur over an area of "badland" topography, cutting dark grey Bearpaw shale. They are generally under 1 foot thick, stand nearly vertical, and run in various directions, cutting one another in a complicated manner. The horizon of the Bearpaw shale here represented is probably 100 to 200 feet above the base of the formation.

¹ Williams, M. Y., and Phemister, T. C.: "Sandstone Dykes in Southeastern Alberta"; Trans. Roy. Soc., Canada, sec. IV, pp. 153-174 (1927).

The third locality is at the base of the Fox Hills section on Willow creek below Thelma. In a 140-foot cut bank east of the creek, about 100 feet of Bearpaw shale is exposed below about 30 feet of Fox Hills sandstone. Several vertical sandstone dykes about 6 inches thick cut the Bearpaw shale section, but terminate sharply at the base of the Fox Hills sandstone. Nearby, nearly vertical dykes of small size converge upward and widen out abruptly into a mass of sandstone about 40 feet in diameter and about 40 feet high. This is bevelled off at the top of the slope of the hill; but the intrusive probably extended originally to the base of the Fox Hills sandstone. The convergence of the feeding dykelets from below, their irregular penetration of the Bearpaw shale, and the lack of connexion of the nearby dykes with the overlying Fox Hills sandstone (the sand is unlike and the dykes are bevelled by an erosion surface) leads to the conclusion that the intrusion was from below. For about 1 mile down Willow creek, small sandstone dykes cut Bearpaw shale, to an horizon about 200 feet below the top of the formation.

As the Bearpaw shale has an estimated thickness of about 525 feet, it may be seen from the above descriptions that sandstone dykes are known to cut almost every part of it, and it is logical to suppose that they have cut it from the bottom to the top. Studies of sandstone dyke material, made by T. C. Phemister, support intrusion of the sand into the Bearpaw shale from the underlying Pale beds of the Belly River formation. The time of intrusion is limited to the comparatively short interval elapsing between the deposition of the normal marine Bearpaw shale and the near-shore marine Fox Hills sandstone. Evidently some shale was eroded away with the contained dyke material during the indicated retreat of the sea. As from this time on the sea continued to retreat, and the lands to rise, the interval may be considered as the beginning of the Laramide revolution.

As shown in the paper noted above, sandstone dykes are known in many parts of the world. Those of similar character are recognized as being intrusive from below, and are shown to resemble dykes formed by gushing springs following the earthquakes at Calabria in 1783; at New Madrid, Mo., in 1811-1813; at Valparaiso in 1822; and in Sonora in 1887. Dykes almost identical with those in Alberta occur in northern California. Diller¹ considers them intrusions of Tertiary age.

¹ Out of many papers on sandstone dykes the two most inclusive are: Diller, J. S.: "Sandstone Dykes"; *Geol. Soc. Am., B. 1*, pp. 411-442 (1890); and Newsom, J.: "Clastic Dykes"; *Geol. Soc. Am., B. 14*, pp. 227-268 (1903).

CHAPTER IV

STRUCTURAL GEOLOGY

REGIONAL

The part of the plains described in this report has three structural axes, each well marked in the south. These are: the edge of the disturbed belt forming the western boundary of the area; the Sweet Grass arch; and the Cypress Hills arch. These three axes strike nearly northwest approximately parallel to each other and to the front range of the Rocky mountains. The structural arrangement is very regular and is that which might be predicted for the landward side of a great mountain system. The overthrust fault blocks of the front ranges of the Rocky mountains are succeeded eastward by tightly folded and crushed structures comprising upwards of 20 miles of disturbed belt, the eastern edge of which is generally well defined. There crushed and faulted formations lie against little disturbed beds of the same formations which dip quite uniformly at 200 to 600 feet a mile into the great Alberta geosyncline. The syncline is succeeded eastward by its complement, the Sweet Grass arch, whose main axis is about 50 miles, from the edge of the disturbed belt. This arch extends northwesterly from the western edge of the Sweet Grass Hills uplift of Montana, as a broad, diffuse anticline with an axial dip to the northwest, decided dips into the syncline on the west, and very gentle dips to the northeast. In fact the "Sweet Grass" arch, as popularly known, includes several subsidiary arches which radiate from Sweet Grass hills. These are discussed below.

General northeasterly dips of 10 to 25 feet a mile continue to the foothills of Cypress hills, from which the structure rises into a broad fold located about 80 miles from the axis of the Sweet Grass arch. The main uplift is apparently broad and rather diffuse, but Dyer found comparatively steep dips occurring along the northern flank, particularly north and west of Eagle butte. The axis of the main uplift is difficult to define but is thought to lie southwest of Cypress Hills plateau in the "badlands" region, and from it, terraces and subsidiary folds extend to the northeast beneath Cypress hills. To the southeast the arch appears to merge into a low terrace at Govenlock, but nearer the International Boundary it is again defined as a low arch forming the eastern flank of the faulted depression of Woodpile coulée. These structures appear, as described below, to merge into the disturbed region of Bearpaw mountains, Montana. Northward, the Cypress Hills arch extends to the main line of the Canadian Pacific railway at Irvine as determined by plane-table work on the fossil zone characterized by *Arctica ovata*, which occurs about 100 feet above the base of the Bearpaw formation. Thus, on Ross creek, dips to the north of 10 to 15 feet to the mile occur, the rate increasing to the south. North of Irvine the rocks are almost flat.

SWEET GRASS ARCH

The most prominent structural feature of the southern plains is the Sweet Grass arch, a low, broad dome which centres about the series of igneous plugs situated south of the International Boundary, east of Coutts, and known as Sweet Grass hills. On the Canadian side the arch extends as far north as Red Deer river and on the United States side it extends for many miles into the state of Montana.

As might be expected in the case of so large a structure, this arch may be subdivided into subsidiary structures, of considerable extent. Thus, the Kevin-Sunburst oil dome is situated west of West Butte uplift proper, and holds its identity as a separate structure in a northerly direction past Coutts to Conrad on the Lethbridge-Manyberries line of the Canadian Pacific railway. North of the valley of Milk river a western branch of the Kevin-Sunburst arch runs through Milk River town to Verdigris lake, thence westerly south of Warner and so northerly past New Dayton to Chin on the Crow's Nest branch of the Canadian Pacific railway. This branch has subsidiary structures, extending northwesterly into the Alberta syncline.

Another prominent subdivision of the Sweet Grass arch extends from West butte north-by-east through the location of the Rogers-Imperial well on Deadhorse coulée, through Lucky Strike to the Foremost gas field. This may be called the Deadhorse Coulée-Foremost anticline.

Other structures of less importance extend northeasterly and north-east-by-east toward lake Pakowki and Comrey.

The beds on the western flank of the Sweet Grass arch dip more steeply than those elsewhere within the structure and form the eastern side of Alberta syncline whose western side is formed by the upturned beds at the edge of the disturbed belt of the foothills. The westerly dipping attitude of the strata along the west side of the Sweet Grass arch is well shown on Oldman river; where this river cuts through the St. Mary River formation dips varying from 1 to 8 degrees to the west have been measured within a distance of 10 miles. On Little Bow river, westward dips of 50 feet to the mile were determined on outcropping coal seams and the coal seams in the Wolf Coulée coal mine dip north 40 degrees west at the rate of 50 feet per mile.

The dips on the east side of the arch are very low, and in the south are interrupted by the reversed dips bordering Cypress hills. The elevation of the Bearpaw-Belly River contact was determined at many points in the vicinity of Many Island lake and at Irvine, Walsh, and Maple Creek. This showed that between Irvine and Maple Creek the beds dip easterly at a rate not exceeding 8 feet per mile. By following the same contact it has been determined that the beds along South Saskatchewan river north of Rapid narrows dip northeasterly at a rate of about $6\frac{1}{2}$ feet a mile. The low eastward dip of the beds on the east side of the arch is also seen in South Saskatchewan river between Bow Island and Redcliff, where the beds dip eastward at a rate nearly equalling the fall of the river (not more than 5 feet a mile). It should be noted here that between Bow Island and Redcliff, a distance of 50 miles, the Pakowki formation thickens from 320 feet to 700 feet, so that the formations underlying the Pakowki have a much greater eastward dip than the overlying outcropping formations.

The position of the northern edge of the arch is not exactly known. On Red Deer river the beds dip northward at a rate not exceeding 5 feet to the mile, but farther to the north in Misty hills and on Sounding creek they dip southward at an average rate of 6 feet a mile. The evidence available, therefore, suggests that the arch terminates north of Red Deer river and that just north of the river there is a low, structural area which is probably more complicated than the existing evidence would indicate.

The crest of the arch is very broad and comparatively flat and the axis is very difficult to define.

The dips vary somewhat, but increase gradually toward Sweet Grass hills. The northerly dip of the Milk River sandstone along the crest of the arch between the vicinity of Coutts and Chin coulée 18 miles east of Lethbridge is about 1,400 feet or 26 feet a mile. Gentle, broad fluctuations are noticeable which do not coincide in the different formations: this is due to the varying thicknesses of the formations. Small subsidiary domes are in places superimposed on the main structures; most of these contain gas.

REGIONAL STRUCTURE NORTH OF THE SWEET GRASS ARCH

The rate of dip has been calculated at certain points north of the Sweet Grass arch. In the Drumheller coal basin¹ on Red Deer river, the Edmonton beds are nearly flat. Allan reports as follows:

"Except for slight local undulations and warpings the dips are so small that they cannot be readily detected. The major structure was determined from numerous accurately measured sections and by establishing the attitude of the various coal seams at many points along the outcrops and in the underground workings throughout the district. From all available data it has been found that in general the strata have a west-south-westerly dip at the rate of about 20 feet to the mile. . . . The general westerly dip in the beds represents the slopes of the eastern side of a broad synclinal trough which has a northwest trend through central and western Alberta (Alberta syncline)."

On Bow river exposures are not nearly so continuous as on Red Deer river. Hence it is much more difficult to determine the dip. It is thought, however, that the Edmonton formation on the Bow is of about the same thickness as on the Red Deer. Assuming this to be true the dips along the Bow would be in the neighbourhood of 30 feet a mile to the west.

As previously noted, in the northern part of the area on Sounding creek and in Misty hills, the beds dip southward at an average rate of 6 feet a mile and on South Saskatchewan river north of Rapid narrows they dip northeastward at about 6½ feet a mile.

CYPRESS HILLS ARCH

The structure of Cypress Hills region has been worked out from information relating to a number of horizons, chief of which are the top of the Bearpaw shale, the main coal seams of the Estevan formation, the White-mud formation, and coal seams and red clays in the Ravenscrag formation. Sandstone beds in the Fox Hills and Estevan formations have been used locally.

¹ Allan, J. A.: "Geology of the Drumheller Coal Field, Alberta"; Sci. and Ind. Res. Coun., Alberta, No. 4, 1922.

The main axis of the Cypress arch extends from the 4th meridian (the Alberta-Saskatchewan boundary) near the northern side of township 5 northwest by west to the N.E. corner tp. 6, range 3, W. 4th mer. Extensive terraces and subsidiary structures extend north and northeasterly beneath Cypress hills, and a diffuse terrace extends southeasterly to the faulted area at Woodpile coulée. The closure on the north side of the main uplift varies from 350 feet on the east to 800 feet on the west and the northerly dip appears to reach as great a rate as 270 feet in one mile (north of Eagle butte). On the north a gentle slope continues to the main line of the Canadian Pacific railway. The structure is terminated to the northwest by a fault or a sharp monocline. The depression south of the arch extends from the vicinity of Altawan, tp. 3, range 30, W. 3rd mer., northwesterly to the northwest corner of tp. 5, range 3, W. 4th mer. This structural depression is caused by the reversal of the regional northeasterly dip of the formations, due to the Sweet Grass uplift. Eastward of the arch, the dip is mainly to the east and is modified by gentle terraces and sags.

WOODPILE COULÉE-SENTINEL BUTTE STRUCTURE

Woodpile coulée is occupied by a westerly branch of Battle creek and joins the main stream in Montana. It lies in the western part of tp. 1, range 27, W. 3rd mer., and crosses the International Boundary at the west side of section 3. In this area the bedrock outcrops are of flat-lying Bearpaw shale. Just north of section 3, however, and continuing upstream for 2,000 feet, there is a remarkable section of sandstones, lignites, and soft shales tilted to the south at an average dip of 45 degrees. Here is exposed the Belly River formation from top to bottom, although some of the intermediate beds are drift covered. Lower in the section the beds are much obscured by drift, but the full thickness of the Pakowki shales also appears to be brought to the surface. No Milk River sandstone is known. Farther up stream all is obscured by drift for about 200 yards, beyond which flat-lying Bearpaw shale occurs in occasional outcrop for several miles to the north. In the stream bottom at the top of the tilted section, a well was drilled in 1923 by the Imperial Oil Company. In the log of this well the strata have the same thicknesses as obtained by surface measurements and hence it appears that the drill penetrated flat-lying sediments. The disturbed section evidently represents the upturned edge of a thrust block, the gliding plane being in the lower part of the Pakowki shale.

The reported occurrence of disturbed coal beds in the creek, 2 miles to the east, indicates a continuation of the thrust block at least that far eastward.

Signal butte is a dome-shaped hill in Montana about $3\frac{1}{2}$ miles south of the centre of tp. 1, range 29, W. 3rd mer. It is a fine example of a quaquaversal structure, or dome, from which the arch has been eroded, exposing some 200 feet of Belly River sandstones and lignites below the bordering rim of Bearpaw shale. A well was bored on this dome for oil, but the record has not been seen.

The structures at Woodpile coulée and Signal butte appear to be of the same origin, and it is thought that pressure from the south caused

doming in the one case and overthrusting farther northeast. The faulting has consequently been interpreted as passing into a monoclinical fold forming an extension of the Signal Butte dome.

Bearpaw mountains are situated about 30 miles to the south and appear to bear a similar relation to the structures described above, as that of Sweet Grass hills to the Sweet Grass arch.

ORIGIN OF FOLDING

The regional folding, exemplified in the Sweet Grass and Cypress Hills arches with their subsidiary structures, parallels the Rocky Mountains folding and was probably formed at the same time. These gentler folds may be considered as representing the dying out of the thrust from the west which piled up the mountains.

F. R. Clark¹ believes that:

"The folding involved was probably induced by lateral pressure exerted during the Rocky Mountains uplift which resulted in the overthrust faults of the Front range. Offsetting this pressure from the west was the influence of the Highwood and Bearpaw mountains and the Sweet Grass hills on the east causing the rocks to buckle and fold into the Sweet Grass arch."

For this hypothesis, however, it is necessary that the Sweet Grass plugs and the Bearpaw mountains were in existence previous to the "Rocky Mountains uplift." Their age is not known except that they are post-Belly River in one case and post-Bearpaw in the other. Alden considers them of early Tertiary age.

It is to be borne in mind that the building of the Rocky mountains was brought about by progressive uplift and thrust from the west which probably culminated at the close of Fort Union time. Eocene uplift is generally assumed to have affected the whole of the great plains and Cordilleran region, and to this stage has been ascribed the volcanic activity which has left as records the stocks, laccoliths, lavas, dykes, etc., of Sweet Grass hills and Bearpaw mountains. Accepting this chronology, the initial folding of the Sweet Grass and Cypress arches may be accepted as Laramide and the thrusting and uplift from the south as early Tertiary.

FAULTS

A fault of large dimensions for the plains occurs on the upper end of Bullshead creek in sec. 11, tp. 9, range 5, W. 4th mer. Figure 1 illustrates its position and character. At locality A, Figure 1, on the west side of the creek, the Whitemud beds occur near the top of the bank at an elevation of 3,349.6 feet, and below them are visible about 70 feet of slumped beds of the Estevan. About one-half mile farther down the creek, still on the west side, at locality B, there is a coal mine where the Estevan lignite seam is worked spasmodically. There are two or more openings on the seam; at a western opening the coal is 3,330.1 feet in elevation, whereas 100 yards to the east the same seam is at an elevation of 3,283.8 feet, or 46 feet lower. A little less than a half mile to the north on the east side of the creek there is a second coal mine where the elevation of the coal is 3,343.1 feet, and just east of the mine about 25 feet higher up the bank at locality C the Whitemud beds are again exposed. In the northern mine a dip of 28

¹ "Kevin-Sunburst Oil Fields, Montana"; Bull. Am. Ass. Pet. Geol., vol. 7, p. 271 (1923).

degrees was measured on the coal seam in a direction north 120 degrees east. About 500 yards to the west on the north bank of the creek there is a 100-foot outcrop of Bearpaw shale. The elevation of the top of the Bearpaw here is 3,350.2 feet, but judging from the assemblage of fossils found it would appear to be 100 feet or more short of the upper limit of the formation. Since the Whitemud beds are normally 400 feet above the Bearpaw the total vertical displacement must be at least 400 feet and possibly as much as 550 feet. At a point E, Figure 1, on a second small creek which flows into the Bullshead a small outcrop of Bearpaw shale was found and at localities F and G the Whitemud beds were found. The strike of the fault-plane must, therefore, lie within the directions north 30

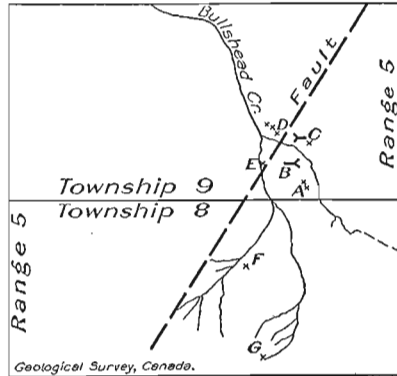


Figure 1. Position of fault, rock outcrops, and coal "mines" in the vicinity of Bullshead creek.

degrees east and north 60 degrees east, but it is probably nearer the latter figure which agrees with the strike of the coal seam in the northern mine. The eastward dip of the seam is very likely caused by the drag away from the fault on its downthrow side and the strike of the seam would compare closely with the strike of the fault-plane. This strong easterly dip is present only very near the fault, since a short distance to the east the beds first flatten out and then rise again into the flank of the main structure.

Two small faults occur in a gully in sec. 30, tp. 9, range 1, W. 4th mer., where grey shales and soft sands which normally occur above the ledge-making sandstones of the Fox Hills have been down-faulted to a level with them. The vertical displacement is not known but is thought to be small. Owing to the small size of the exposure it was impossible to determine the direction of the fault-plane.

At certain points greater dips than the average have been caused by slumping. Thus in the NE. $\frac{1}{4}$ sec. 14, tp. 8, range 4, W. 4th mer., extensive ledges of Fox Hills sandstone and overlying Estevan beds dip to the east at angles approaching 45 degrees. This is clearly due to slumping, no fault being in evidence. In the SE. $\frac{1}{4}$ sec. 20, tp. 8, range 4, W. 4th mer., in a small gully near the base of Eagle butte, a section showing Whitemud beds and Ravenscrag beds dips quite strongly to the north or northwest. At a point near the northern end of the outcrop a dip of 10 degrees was measured in a direction north 5 degrees east. However, the elevations of certain horizons were determined at different points which gave an average

dip of 175 feet a mile in a northwest direction. The lower dip is probably the true one for this locality, the large one being caused by slumping. In the SW. $\frac{1}{4}$ sec. 16, tp. 8, range 4, W. 4th mer., a little more than half-way up Eagle butte, a dip of between 2 degrees and 5 degrees in a direction north 40 degrees east was measured; this was probably caused by slumping.

A slump of very recent date occurs near the top of Eagle butte in sec. 3, tp. 8, range 4, W. 4th mer. Here a mass, 100 feet across, of chocolate-coloured shale of the Ravenscrag formation, has slumped down the hillside, carrying trees and surficial deposits with it. The surface now lies in furrows, the trees standing at various angles, or being entirely overthrown.

Several normal faults of varying displacements and directions have been found in the Lethbridge coal fields. In most of these the displacement is only a few feet, but two of them are larger. North of the road bridge over Oldman river on the east side of the river in sec. 1, tp. 9, range 22, W. 4th mer., the main coal seam is 60 feet below river-level, whereas immediately south of this point on the south side of the bridge the seam is about 10 feet above river-level. The fault has been found in the mines on the east side of the river and its direction determined to be about northeast.

Levels driven along the coal seams in a northeast direction from the main shaft of the Chinook Coal Company in the northwest corner of the SE. $\frac{1}{4}$ sec. 12, tp. 10, range 22, W. 4th mer., ran out of the coal. Four bore-holes were then driven in different directions, one for 52 feet upward, a second at an inclination of 45 degrees for 45 feet, a third horizontally for 40 feet, and a fourth downward for 22 feet, in each case without striking the seam. There is no doubt that a fault of considerable dimensions exists. Its vertical displacement is thought to be in the neighbourhood of 100 feet and the downthrow side is the southwest. This fault passes the workings of the Diamond mine on the south side. It is also found in an outcrop on the northwest bank of Oldman river in the SW. $\frac{1}{4}$ sec. 6, tp. 10, range 21, W. 4th mer., but the throw could not be measured as the downthrown side of the seam is below water-level. At the outcrop the fault plane makes an angle of 80 degrees with a horizontal and it was noticed that there was considerable downward drag along the fault-plane on the up-throw side. What is thought to be the same fault has been reported from the old Royal Colliery workings on the east side of the river in the SE. $\frac{1}{4}$ sec. 31, tp. 9, range 21, W. 4th mer.

DISTURBED BELT AT MONARCH

On Oldman river east of the road bridge south of Monarch in sec. 31, tp. 9, range 23, W. 4th mer., a very interesting exposure occurs which shows a series of greatly disturbed Fox Hills beds. The section can be followed for about three-quarters of a mile along the south bend of the river and extends from water-level up to an average of 100 feet above it, where it is covered by glacial drift. In the western part of the section where the character of the disturbance can be most clearly made out, a series of fault blocks are seen with the fault-planes making angles of

between 20 and 50 degrees with the horizontal and with strikes of south 20 degrees east to south 25 degrees west. The western blocks have been thrust up over the eastern blocks. At the eastern end of the exposure the rocks are more highly contorted. To the west of the disturbed belt the faulting dies away into the low western dips (1 to 2 degrees) of the western flank of the Sweet Grass arch. Not more than one-quarter of a mile downstream from the eastern end of the exposure on the north side of the river another exposure occurs which does not show faulting, but rather highly contorted isoclinally folded beds. Still farther downstream the beds flatten out again into normal attitudes. The beds consist of brownish banded shales and sandy shales and massive, soft grey sandstone with some thin carbonaceous shales. Some beds as much as 5 feet thick consist mainly of oysters. They belong to the Fox Hills formation and are overlain to the west by the St. Mary River formation. They overlie the Bearpaw shales which are found outcropping to the east. Dawson¹ describes the section, but did not notice that faulting had occurred.

It is difficult to account for such highly disturbed beds so far from the foothills (over 50 miles) and among rocks which are ordinarily not disturbed in any way. It is clear that the force was exerted from the west and the strike of the fault-planes approximately parallels the axes of disturbance in the mountains. The most plausible explanation appears to be that a thrust fault of considerable magnitude and low angle exists and that the disturbed beds represent the eastern limit of the fault and were disrupted by the friction set up along the fault-plane. In such a case the faults and folds would not be deep.

STRUCTURE IN MISTY HILLS

In Misty hills and the area immediately adjacent, the uppermost beds—the Pale beds and the Bearpaw shale—are severely folded and faulted. O. B. Hopkins² attributes the cause of this structure to pressure resulting from the advance of the Pleistocene ice-sheet. Hopkins contends that this structure is superficial as the base of the Colorado shale has not been affected by the folding and that the folding and faulting are largely at right angles to the direction from which the ice-sheet is presumed to have approached. G. S. Hume,³ from a study of similar structure farther north, prefers to consider the deformation as the result of land-slip and draws attention to the bentonitic character of the beds concerned in the structure which, when wet, would produce an excellent surface for slip.

Both the Pale beds and the Bearpaw shale have been affected. The hills are entirely underlain by the Bearpaw shale which, wherever exposed, shows signs of disturbance. Folded Bearpaw shale is exposed in the highest summit of Misty hills where the structure could not have been the result of slumping. The folding of the Bearpaw in Misty hills is on a much broader scale than that displayed in certain places in the Pale beds and is also more irregular with a considerable variance in strike.

The best exposure of disturbed strata is in the Mud buttes, secs. 19 and 20, tp. 33, range 4, W. 4th mer. There, the only strata entailed in

¹ Geol. Surv., Canada, Rept. of Prog. 1882-84, pt. C, p. 68.

² "Some Structural Features of the Plains Area of Alberta Caused by Pleistocene Glaciation"; Geol. Soc. Am. Bull., vol. 34, pp. 419-430 (1923).

³ Geol. Surv., Canada, Sum. Rept. 1925, pt. B, pp. 12-14.

the structure are the Pale beds. The general strike of the beds is about 100 degrees east of north, though a considerable variation occurs. The dip is to the north and varies between 20 and 50 degrees. The strata are far more severely dislocated than elsewhere observed. Faulting, folding, and crumpling occur and subsequent slumping has increased the confusion. It is quite evident, however, that only the very uppermost members of the Pale beds are included in the structure, and that these have been repeated at least four times by faulting. The faults are of the thrust type and the folds are overturned, one good example of a drag-fold being displayed. The greatest deformation is on the northern side.

A careful consideration of all available evidence regarding the structure in these hills leads to the conclusion that the advancing Pleistocene ice-sheet was responsible for the pressure necessary to produce the observed deformation. Taking for granted, as seems reasonable, that the structure is superficial, no other theory seems to conform so fully with the facts as observed throughout Misty hills. Slumping can be considered only as a very secondary factor, and not as the underlying cause of the deformation.

SLUMPING

Structures caused by slumping have been found in many places along the rivers and coulées and in the hills in many parts of southern Alberta. These usually take the form of gentle fluctuations of small size, but faults are present in some places. In most cases the superficial character of the structure is quite evident. The porous sandstones of the various outcropping formations absorb surface water very readily and the interbedded shales when saturated become ideal gliding planes. Landslides are consequently more common than might be supposed, and, therefore, in many places, it is difficult to obtain the true dip and strike of formations. The slumping that has taken place along the rivers and coulées has obscured many fine sections. On Bow river several of the sections that Dawson described fully have been obscured in this way. Among them is one that occurred 2 miles south of the church at the north camp of the Blackfoot Indian reservation where a large block of Edmonton beds 100 feet in height and $\frac{1}{2}$ mile in length has quite recently slid into the river. Another series of outcrops in which Dawson reported coal seams and which occurred at the sharp bend of the river about 4 miles upstream from the south camp of the Blackfoot reservation has been obscured by extensive slumping.

RELATION OF TOPOGRAPHY TO STRUCTURE

Hume¹ has found that within the Wainwright-Vermilion area the drainage bears a definite relation to the structure. Analogous relations seem also to hold in the south as in the case of the southward bend of the pre-Glacial channel of Oldman river at Taber which, undoubtedly, was caused by the monocline existent at that place. There is little doubt that the formation of certain buttes and hills was controlled by structures. Cypress hills were likely caused in part at least by the domes that exist there and Scabby butte, also, was formed partly at least by the low arching of the rocks.

¹ Geol. Surv., Canada, Sum. Rept. 1924, p. 12, et. seq.

CHAPTER V

PHYSIOGRAPHY

INTRODUCTION

The area dealt with in this report is part of the third prairie step, including the deeply eroded belt adjoining the foothills of the Rocky mountains. In the south, as stated by Dawson, the foothills are absent from the region of the Lewis overthrust, but even there the foothills belt is characterized by elevated rolling country with deep river valleys. The northwestern four-fifths of the area lies within the drainage system of South Saskatchewan river and the stream channels, for the most part, are of youthful character, with steep banks. The southeastern part of the area is drained by Milk river, a part of the Missouri system. Here, two stages of development are clearly demonstrated, a youthful stage with deep valleys dating back to the pluvial climate at the close of the Ice age; and an older stage exhibited by the upper part of the river, where a small stream occupies a flaring valley of early maturity.

The dry coulées between the Saskatchewan and Milk River systems, belong to the youthful stage of Milk river and are the channels by which the run-off of the melting ice-sheet was carried first to the Missouri system and later, by detours, to the Saskatchewan system.

Above the general level of the third prairie step, rise plateau-like hills of late Cretaceous and Tertiary sediments; these hills are the Porcupine hills west of Macleod, Cypress hills of the southeastern part of the area, Hand hills of Red Deer valley, and Misty hills of tp. 32, range 4, W. 4th mer., Sweet Grass hills of northern Montana lie just south of the 49th parallel, but their foothills extend northward well into Alberta. Milk River ridge separating the upper waters of the Milk and Saskatchewan drainage systems, is only 200 feet lower than Cypress hills.

Generally speaking, the area is a rolling, treeless plain sloping north-eastward from the foothills of the Rocky mountains, and dissected by rather intricate stream-systems, whose steep-walled valleys are clearly imposed upon a mature land surface. The small plateaux rising above the old surface represent still older land surfaces, which have elsewhere been removed by erosion. Ancient river channels, glacial moraines, and out-wash deposits have given the surface its final character. In the north, most of the hills are morainic, their sporadic distribution bearing testimony to the irregularity of the retreat of the ice-sheet.

LOCAL

Sweet Grass Hills

Sweet Grass hills consist of three more or less conical mountains, each surrounded by foothills. They are situated close to the 49th parallel and lie between 111° and $111^{\circ} 40'$ west longitude. East and West buttes are approximately 20 miles apart, and Centre (or Gold) butte lies nearly mid-

way between and somewhat south of a line joining them. These three peaks are prominent features in the midst of a wide area of treeless, rolling prairie. Their height is sufficient to cause clouds to form about their summits during otherwise clear days, and to cause an appreciable increase in local precipitation.

The upper third of each mountain is a jointed, steep-sided porphyry plug from which the wall-rock has been eroded. Lower down, are concentric rings of Palæozoic and Mesozoic formations, which commonly take the form of inward facing foothills. Among them are lakes and streams, the rugged topography representing a youthful stage of erosional development which is marked more particularly on the north side of the hills. Dykes and small outlying plugs of igneous rock occur miles away from Sweet Grass hills. Of them only one, "Black butte", near Pin Horn, affects the topography on the Canadian side, and here has only resulted in the formation of a low, rounded hill a few hundred yards in diameter.

West butte lies close to the 49th parallel, and its foothills, having elevations of 4,200 feet at the boundary, extend as a definite swell reflecting the rock structure, as far north as the Milk River valley, or 6 to 8 miles into Canada. The top of West butte, according to Alden, is about 6,300 feet above sea-level, or about 3,300 feet above the average elevation of the surrounding plains. Glacial and post-Glacial erosion have so modified the sides of the buttes that no old land surfaces have been recognized.

Dawson described West butte as "a large, blunt-topped mountain." Its summit appears level to an observer standing upon its surface, but is gently domed and in strong contrast with the steep side slopes. A regolith of coarse rock fragments grading upward into soil completely covers the porphyry bedrock, and with grassy sod forming a cover over all, the half acre of mountaintop seems like an elevated bit of the surrounding prairie. Eastward from the main peak, a hogback forested with pine, extends for 100 or 200 yards to a sharp, rocky peak with jointed, precipitous sides on the south and east.

The flat top of West butte may be a remnant of an old land surface, preserved because of the resistance of the porphyry rock to erosion. The character of the underlying rock debris and of the soil supports this conclusion. The gentle doming of the surface, at first thought, appears to be opposed to such a theory, but when it is considered that the intrusive porphyry is comparatively small in diameter and steep-sided, it is clear that on a peneplained surface it would stand above the softer sedimentaries as a gentle dome. A second explanation is that West butte formerly had a jagged top and that this has been reduced to its present domed shape by frost and gravity action, known elsewhere on mountains and described by D. D. Cairnes¹ as "equiplanation". The available evidence bearing upon the origin of the flat character of the top of West butte seems to favour the theory that the flat top is a remnant of an old land surface perhaps to be correlated with Alden's Oligocene and Miocene (?) Cypress plain of Bighorn mountains and elsewhere. The elevation of this plain in Bighorn mountains is 9,000 feet above tide and on Cypress hills is 4,800 feet and less, so that the tops of Sweet Grass hills may have formed only a gentle swell in the eastward sloping plain.

¹ Bull. Geol. Soc. Am., vol. 22, No. 3, pp. 333-348.

Cypress Hills

Cypress hills rank next to the Sweet Grass hills among the elevations that interrupt the general low, rolling character of the part of the plains under discussion; and in wealth of interest both for the stratigrapher and the physiographer, Cypress hills hold a unique place. This has been generally recognized since McConnell's descriptions and conclusions were published in the Annual Report of 1885. All succeeding reports have been based upon his account and in no important particular have his conclusions been disputed.

Cypress hills appear as a gentle swell in the prairie level, rather than a sharp feature. They, in fact, are the central part of a large, elevated tract of land forming the divide between the Saskatchewan and Missouri drainage in southwestern Saskatchewan and the adjoining portion of Alberta. The elevation of the "Head of the Mountain", which is the western summit of the hills, is 4,800 feet. Eastward and southward the plateau surface slopes downward to about 3,500 feet north of East End. In the west, the hills rise about 1,600 feet above the general level of the plains and in the east only about 600 to 700 feet.

The most striking feature of Cypress hills is the nearly level, plateau-like tops whose characters are those of a plain and upon which a heavy growth of grass formerly flourished between areas of park land or forest growth. The steep slopes and gorges meet the upland surfaces at marked angles and strongly contrast with them. The plateaux include two much dissected remnants crossing the Alberta-Saskatchewan boundary, and a larger area partly subdivided by shallow depressions north of Cypress lake and Frenchman river. South of Frenchman river, there are seven or more small plateau remnants which though now separated by valleys are parts of one plane having an eastward slope of from 16 to 17 feet a mile. As shown by McConnell, this old land surface is established upon a conglomerate of early "Oligocene or late Eocene age", now called the Cypress Hills conglomerate. Quoting McConnell:

"The area now covered by the Cypress Hills has been changed from a depression in.....(Oligocene) times into the highest plateau of the plains, which is its present position, entirely by the arrest of denudation over its surface by the hard conglomerate beds which cover it, whilst the surrounding country destitute of such protection has been gradually lowered."

The "bone beds" with early Oligocene vertebrates overlie the Cypress Hills conglomerate, and along the north branch of Frenchman river consist of more than 125 feet of conglomerate, sand, and silt. McConnell found sections 500 feet thick. No fossils younger than early Oligocene have been recognized in these beds, but their incomplete sections suggest the possibility of a considerable lapse of time before sedimentation ceased. These Oligocene and, perhaps, younger deposits were conceived by Alden to have.....

"spread over a broad, gently sloping, nearly flat plain composed of coalescing fans heading at those points where the streams debouched from the mountain gorges. For this plain, as represented by correlated terrace remnants, the name Cypress Plain is proposed."

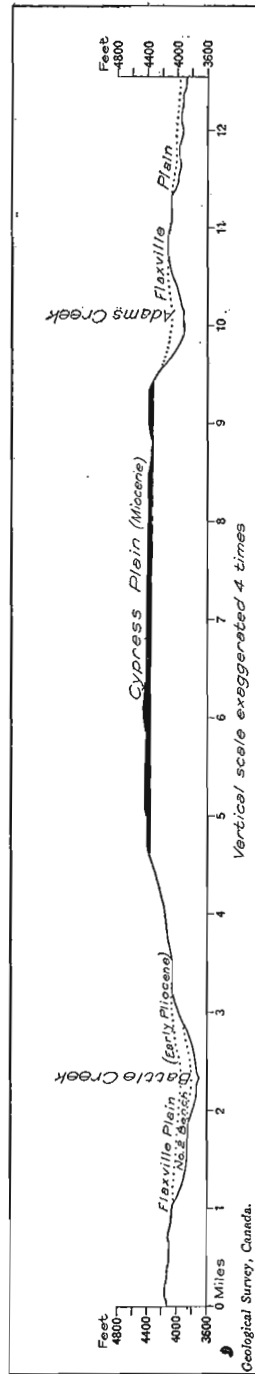


FIGURE 2. Cross-section of northern plateau of Cypress hills.

From this and other statements by Alden, it appears that the term "Cypress Plain" is to be thought of as the name of a region which during Oligocene, and probably a part of Miocene, time was a plain receiving fluvial materials from the mountains in the west. The present surface of erosion which forms the summit of Cypress hills, corresponds, in a general way, with the Cypress Plain, but, was actually, developed at a later time, presumably during the Miocene period. The plateau remnant on West butte may well be a portion of one of the higher prominences of the erosion surface that developed over the Cypress Plain. That is, it may have been a prominence on a Miocene peneplain. The hardness of the intrusive porphyry was the cause of preservation of Sweet Grass area, and the Cypress conglomerate determined the elevation and gradient of the surface in the vicinity of Cypress hills. In both areas the higher land forms are unglaciated and thus preserve, approximately, their pre-Glacial condition.

The top of Cypress hills does not mark the only old land surface found in this region, although the significance of the other features seems to have been overlooked by previous writers.

The upper valley of Battle creek has been protected from the glaciers by Cypress hills to the north, and in it near the headquarters of the Forest reserve, there are clearly represented three topographic developments below the plateau level (*See* Figure 2). The highest of these is preserved on the numerous long spurs which extend from the plateau edges into the valley of Battle creek. Its profile (*See* Figure 2), extended from the north and south, meets smoothly about 200 feet above the present creek bed in the form of a flaring valley bottom. The stream in this old valley was probably 500 feet below Cypress Hills plateau to the north, and doubtless headed a considerable distance northwest of Cypress hills. The valley may be followed today northwesterly through the hills past a marshy divide containing lakelets, to the north slope of Cypress hills which has been sculptured by later agents of erosion. Numerous other upland remnants are to be correlated with this land form as found in the upper valley of Battle creek. The "gap" between the eastern and western main divisions of Cypress hills is such a form, although its original character has been greatly modified by glaciation. Plateaux on the tops of Eagle butte and adjoining hills west and south of the Head of the Mountain (Bud buttes of McConnell), and the benches sloping gently south from the Head of the Mountain, are clearly the remnants of an old land surface entrenched, during a long period of erosion, below Cypress Plain. The benches rise to the edge of the Cypress Plain and the isolated plateaux have elevations between 4,360 and 4,400 feet with a southerly slope of 2 degrees. The plateaux are commonly covered with loose gravel from the Cypress Hills conglomerate, although wide valleys may now separate the areas occupied by these products of erosion from the areas still underlain by the conglomerate.

The relationships of the surface described, to the Cypress Plain, and their gravelled character, lead to their correlation with the Flaxville Plain so named by Alden who recognized it widely over Montana and northern Wyoming and classed it as No. 1 of the three main sets of benches and terraces found by him below the horizon of the Cypress Plain. The

term Flaxville was originally given by Collier and Thom¹ who found vertebrate fossils in the Flaxville gravel and regarding which Gidley wrote: "With the exception of the specimen reported as Pleistocene, all the material appears to belong to the upper Miocene. It can be stated positively, I think, that, with the exception noted, the beds from which these fragments were collected cannot be older than Miocene or younger than lower Pliocene." Regarding this statement by Doctor Gidley, Alden wrote: "The fossil reported as Pleistocene is a *Camelops* tooth. Apparently taking everything into consideration, there is some ground for regarding fluvial deposition as having continued on this plain into Pliocene, if not also early Pleistocene, time." The set of terraces and benches correlated by Alden with the Flaxville Plain was, according to Alden, "probably completed in Pliocene time".

At favourable localities along Battle creek two valleys are recognizable as having developed on the Flaxville Plain. The first of these may be correlated with Alden's No. 2 set of benches, and has a projected surface (See Figure 2) about 150 feet below that of the reconstructed Flaxville valley. The second is about 100 feet deeper and is filled in part by outwash silt, sand, and gravel, into which the present stream is now cutting. Alden considered that the No. 2 set of benches, etc., were a result of regional uplift occurring at the close of the Tertiary and that they are of early Pleistocene age. The lower valley recognizable along Battle Creek valley clearly belongs to the time of ice retreat, showing in its bedrock profile the effect of rapid erosion and in its filling of silt and sand the sedimentation of the later stages of run-off as the water from the melting ice decreased in volume. The present downcutting was initiated by post-Glacial uplift.

Milk River Ridge

An elevated, dome-shaped area, known as the Milk River ridge, forms the height of land between the Saskatchewan and Missouri drainage systems in southwestern Alberta. West of it is a region of moraines and kettle lakes occupying a belt about 6 miles wide, beyond which is the valley of St. Mary river. Cutting off Milk River ridge from the highlands to the southeast, with which it was formerly connected, lies the main or north branch of Milk river, and the South Branch subdivides the southern highlands into eastern and western divisions. The Canadian portion of this elevated tract is about 18 miles wide along its western side, and 24 miles long in an east-west direction, being terminated in the east by the lowlands bordering the late glacial valley marked by Verdigris coulée and Tyrrell lake. The crest of the upland rises above 4,000 feet and in the vicinity of Fareham a series of plateau remnants have an elevation of 4,600 feet. To the south, in Montana, the old upland surface is less dissected and appears to be of wide extent. Gravel on the plateau surfaces is mainly of quartzite from the mountains, although granite and gneiss boulders from the Canadian shield occur in the stream valleys near by. That the whole area has been glaciated is evident, but it appears that the plateau surfaces have been but little modified by glacial action, and that their

¹ Collier, A. J., and Thom, W. T.: U.S. Geol. Surv., Prof. Paper 108, 1918.

origin dates back to a pre-Glacial erosion period probably of Flaxville time. In fact the gravel lying upon the surfaces is similar in character to the Flaxville gravels described by Alden, and may be for the most part pre-Glacial. Alden mapped the Montana highlands as a part of the Flaxville Plain, but referred the western end of Milk River ridge to his second terrace. The greater part of Milk River ridge has been eroded several hundred feet below the level of the Flaxville Plain and may belong to Alden's second terrace, but much of the erosion has been accomplished by the continental ice-sheet.

Porcupine Hills and the Foothills

The highest hills within the area are Porcupine hills which rise from 4,000 to 5,000 feet above sea-level. They are formed of strata lying in a broad, low syncline with scarcely perceptible westerly dips on the east side, but with more noticeable easterly dips on the west side. Due to the advanced stage of dissection, few benches or plateau remnants have been preserved. Dawson noted terraces on their eastern side, but "this aspect was found to be due to the outcrop of the nearly horizontal sandstone beds." Elsewhere than in Porcupine hills, however, Dawson found terraces as "prominent features in some parts of the river valleys." Such are the

"terraces in the entrance to the south Kootenay pass at a height of about 4,400 feet, in the valleys of Mill and Pincher creeks, and those of the Forks of the Oldman, east of the actual base of the mountains, wide terraces and terrace-flats are found, stretching out from the ridges of the foothills and running up the valleys of the various streams. Actual gravelly beaches occasionally mark the junction of the terraces with the bounding slopes, and they have no connexion with the present streams which cut through them. The level varies in different localities, but the highest observed as well characterized attains an elevation of about 4,200 feet."

Similar terraces are mentioned as occurring "In the Bow valley near Morley, and thence to the foot of the mountains"—in the wide valley of Kananaskis pass and "in the Bow and Crowsnest passes, within the first range of the mountains—".

In range of elevation and general characters these terraces referred to by Dawson appear to belong to the inner or mountain border of the Flaxville Plain, which would naturally have a greater elevation than farther down the course of the rivers that shaped its surface.

Hand Hills

Hand hills are situated east of Red Deer valley in tps. 29 and 30, range 17, W. 4th mer. Of them Tyrrell¹ says:

".....the Hand Hills rise to a height of 3,550 feet, being 1,350 feet above the river to the southwest and 1,150 feet above the surface of the plains to the east.

These hills consist of an elevated tableland, the top of which, however, is not flat, but composed of five ridges which radiate from a centre lying to the southeast, showing a rough resemblance to the outstretched fingers of a hand, whence their name. To the northwest, west, and southwest, this plateau rises abruptly from the sloping plain at its base in bold escarpments 500 feet high, and thickly wooded in some of the sheltered recesses; but to the east and southeast it slopes gradually to Egg and Little Fish lakes, which are picturesque sheets of clear water lying in the bottom of sloping valleys, the former at an elevation of 2,970 and the latter of 2,890 feet above sea-level.

¹ Tyrrell, J. B.: Geol. Surv., Canada, Ann. Rept., vol. II, pt. E, pp. 29 and 78 (1887).

On some of the highest points of the hills, a bed of 27 feet of quartzite gravel overlies the stratified marls, the matrix being a mixture of sand and lime, sometimes loose and sometimes cementing the mass into an exceedingly hard conglomerate. These conglomerates, with the underlying marls and sands, are so similar to the Miocene [Oligocene] beds of the Cypress hills, that I have little hesitation, even in the absence of fossil remains, in classing them in that formation, although, as their material was doubtless brought down from the mountains to the west by different streams, the deposition of the two may not have been exactly contemporaneous. The conglomerates in the upper part of this series being very much harder than the underlying sandstones and shales of the Laramie [Paskapoo], offered a much greater resistance to the denuding agencies which wore down the surface of the surrounding country, thus preserving these hills as an elevated plateau rising 1,000 feet above the level of the adjoining prairie. They have, however, been themselves largely denuded, and the quartzite pebbles of the upper beds have been redistributed over the greater portion of the hills lying on the eroded surface of the underlying marls."

The loose gravel Tyrrell refers to McConnell's Saskatchewan gravels.

From the characters exhibited in the surface of Hand hills, it seems probable that they represent an erosion remnant of the Cypress Plain, thus extending the known range of that ancient land surface into the region of Red Deer valley. The lower, gravelled slopes may well be a northern extension of the Flaxville Plain.

Misty Hills

Misty hills, situated in and adjacent to tp. 32, range 4, W. 4th mer., rise to a height of over 2,800 feet, the highest points occurring in the northeast corner of tp. 32, range 5. These hills differ from most other elevations in the area in that many of them are not formed of glacial moraine, but represent, to a certain extent, erosion remnants of the underlying formation. This is particularly true of the highest peaks where glacial moraine is conspicuously lacking. The underlying formations exposed in these hills are rather severely folded and in some cases, as well displayed in the Mud buttes, situated in tp. 33, range 3, severely faulted. Glacial moraine, however, does play an important part in the formation of some of these elevations. This is particularly noticeable toward the eastern side of the area comprised in the hills. The relationships between the two types of hills is often difficult to interpret. The surface of the highest peaks may represent an eroded remnant of the Flaxville Plain, but no definite proof of age is known.

Other Prominent Hills

The hilly regions so far described have special significance in that they present well-preserved evidence of periods of uplift and erosion. There are a number of other hills that are of considerable local interest, but which, due to their position, structure, or rock formation, have been so modified by the later stages of erosion that they shed little light on pre-Glacial history. Such are Bullshead, 20 miles west of Cypress hills; the "badlands" east of Manyberries; Old-man-on-his-back plateau 18 miles southwest of Ravenscrag; and Boundary plateau on the 49th parallel just east of the 109th meridian. All these rise more than 3,500 feet above sea-level and doubtless are reduced remnants of the Flaxville Plain and may indeed represent Alden's No. 2 bench. Correlation of these highlands is difficult and their preservation may be explained on the ground of structure, rock composition, and relation to the streams of the region.

Bullshead is a dome-shaped hill, scarcely rising above 3,500 feet in elevation. It is carved from soft Bearpaw shale and clearly owes its preservation to its interstream location.

The "badlands" extending east from Manyberries to the Saskatchewan border, are bounded on the north by the lower terraces of Cypress hills and on the south by the Manyberries-Shaunavon branch of the Canadian Pacific railway. The term "badlands" may well be applied to large areas south of the railway also, but the height and much dissected character of the region under discussion place it in a class by itself. Sage and Lodge creeks with their many branches drain this area, which is utilized for ranching. High interstream areas stand up as modified and dissected plateau remnants, and the valleys are characterized by steep, slumping sides, exposing the soft Bearpaw shales. Glistening crystals of selenite litter many of the erosion surfaces, and soft, sticky mud with an efflorescence of alkali on its surface commonly borders the streams. The higher hills reach elevations of 3,500 to 3,700 feet, but the elevations are lower to the south and east.

These "badlands" may be compared with those of Red Deer valley, where the steep gradient to the river has resulted in this phase of youthful topography. The chief area of "badlands" occurs in ranges 11 and 12, W. 4th mer., and in some places they are developed as far as 3 miles back from the river. The "badlands" are an area partly eroded through the action of small streams and atmospheric agents into a vast assortment of buttes and erosion remnants of various shapes and sizes entirely devoid of vegetation. Differential erosion has produced a variety of strange shapes and contours which lend an air of grotesqueness to the landscape. The light grey colour of the sandstone and shale forming the buttes adds materially to their beauty. The formation of "badlands" at this place appears to be due to the lack of a protective covering of glacial drift. In the neighbourhood of the "badlands" and especially to the south of the river, the drift is very thin or entirely lacking, for reasons that are not clear as most of the area is covered with a very heavy mantle of moraine. The glacial drift, though not consolidated to any marked degree, stands up well to erosion and provides a considerable protection to the underlying strata.

Old-man-on-his-back plateau is a dome-shaped hill near the eastern edge of the area and 12 miles north of the International Boundary. It rises to but little over 3,500 feet in elevation, and is capped by the Estevan sandstones. The large Boundary plateau occurring, for the most part, to the east of the southeastern corner of the area, is capped by Estevan, Whitemud, and Ravenscrag beds, and like Old-man-on-his-back plateau, is an erosion remnant of the plateau region once surrounding Cypress hills.

The crest elevations of the hills between Cypress hills and the main line of the Canadian Pacific railway decline northward from 4,000 to 3,000 feet. The hills are very irregular in shape, are commonly covered with glacial deposits, and are dotted with moraines and kettle lakes. The Flaxville and No. 2 terraces, if represented, are much obscured by glacial erosion and moraine accumulations, but the elevations here as elsewhere are descendants of older land forms.

Rainy Hills

Rainy hills comprise two sets of elevations known respectively as Inner and Outer Rainy hills. Inner Rainy hills lie in the eastern part of tps. 19, 20, 21, range 10, W. 4th mer. Outer Rainy hills lie directly south in tps. 17 and 18. They are a low group of hills rising from 100 to 200 feet above the surrounding country and are due both to preservation of the underlying strata and to a superimposed load of glacial drift. The moraine is the most prominent feature, the underlying Cretaceous formations being rarely exposed.

General Prairie Surface

Apart from the elevated areas described above and the special features described under "Glacial and Post-Glacial Topographic Forms", there are the general plains areas which occupy perhaps 90 per cent of the region. They are nearly everywhere treeless and vary from almost flat to decidedly rolling. Glacial features are prominent in many places, and ancient and modern stream channels cut their surfaces. In the south the average elevation of the plains is about 3,000 feet, but north of South Saskatchewan river it is about 2,400 feet. The development of the general plains area of southern Alberta and Saskatchewan is pre-Glacial, since glacial action appears to have modified rather than to have determined the land forms. Quoting Dawson,¹

"The preglacial aspect of the country has been much rougher and more diversified than that which it at present presents. The glaciating agents have doubtless planed off many of these irregularities, and the surface has besides been deeply buried in its deposits. These have been laid down in greatest thickness in the pre-existing hollows and low tracts, and the general effect has been the filling up of the asperities and the production of wide areas of almost perfectly level prairie. That this has been the case has been evidenced by the fact that while some of the plateaux and ridges are but scantily covered with drift, the thickness shown in many of the river sections is over 200 feet."

The region during the Glacial period was in general one of deposition rather than one of erosion. The formation of the great plains in a broad sense may thus be fixed as terminating with the Ice age.

Glacial and Post-Glacial Forms

Glacial deposits are of almost universal distribution over the area excepting on Cypress Hills plateaux, and consist of till, erratics, outwash gravel, sand, and silt. They occur as various types of moraines or more generally as a sheet which may be 200 feet or more in depth, obliterating many of the irregularities in the pre-Glacial surface. The deposits from the great Keewatin ice-sheet "may be said to reach the base of the Rocky mountains, in the vicinity of the 49th parallel",² but for some miles east of the disturbed belt, morainal materials from the mountain glaciers give evidence of the meeting and overlapping of the ice from the two sources.

¹ Dawson, G. M.: Rept. of Prog. 1882-83-84, pt. C, p. 140.

² Dawson, G. M.: Rept. of Prog. 1882-83-84, pt. C, p. 147.

Glacial erratics do not occur on Cypress hills above 4,400 feet (McConnell), nor on West butte above 4,660 feet (Dawson). Dawson reports the highest observed "Laurentian stones" as occurring in the front of the Rocky mountains at a point "about 20 miles north of the 49th parallel, at an elevation of 5,280 feet."

Some of the most marked moraines occur at the western end of Milk River ridge east of St. Mary river; and among them, as might be expected, are a large number of kettle lakelets. Similar forms extend west of the edge of the disturbed belt to the foot of the mountains outside of the area being described.

A typical example of a moraine may be seen in Lumpy butte 8 miles east and 2 miles north of Cardston. This elongated hill extends in direction 36 degrees west of north and rises to a height of 4,050 feet above sea-level, or 200 feet above the surrounding plain. Nothing but gravel resulting from the action of the continental ice-sheet is to be seen on the butte, unless it be some pink porcellaneous limestone. Some of the boulders of granite and gneiss are 2 feet in diameter. A small pond lies among the upper hillocks and shallow lakes are common about the butte.

An excellent example of a morainic area occurs just north of the Lacombe-KerRobert branch of the Canadian Pacific railway between Monitor and Fusilier. The general elevation is considerably higher than that of the surrounding country and the surface is studded with irregularly rounded or conical hills among which occur a great profusion of "alkali" sloughs or lakes. Kettle-holes are also developed, many of which contain water throughout the year. Farther south, a conspicuous moraine occurs just south of the Calgary-Saskatoon branch of the Canadian National railway, in the neighbourhood of Benton and Oyen. Still farther south a prominent moraine extends for a few miles south of Red Deer river in ranges 7, 8, and 9. Others extend intermittently along both banks of Saskatchewan river in its course through the area.

Less conspicuous moraines are scattered over the northeast part of the area, producing an uneven, or rolling surface, and only occasionally do flat, open spaces occur. The most conspicuous of these is west of Rainy hills and south of Red Deer river. This area is sufficiently flat to admit of irrigation on a large scale. Areas of low relief occur also to the south of Saskatchewan river and to the north of Red Deer river. In the latter locality, Acadia valley, in ranges 2 and 3, W. 4th mer., is worthy of special mention. This broad valley extends from the big moraine south of Oyen and Benton to Red Deer valley. It is now occupied by a small creek and was probably formed by stream erosion during Glacial time.

Smaller flats occur interspersed among the moraines and many represent the bottoms of glacial lakes which have since been drained either completely or partly. Good examples are in Grassy Island lake near Monitor, and White Heron lake near KerRobert.

As already clearly shown by Dawson, the granite and gneiss boulders derived by the glaciers from the Canadian shield some 700 miles to the northeast, prevail to within 3 miles of the base of the mountains. Along Shanks creek; in Milk River valley near Fareham; in the vicinity of Kimball; along the edge of the disturbed belt near Glenwoodville; and along

Oldman river near Macleod; Monarch; and for many miles below Lethbridge; gravel beds composed of well-rounded pieces of quartzite, conglomerate, and tuffs up to 9 inches in diameter, occur, apparently below the eastern drift which is found on the hilltops nearby. These gravel deposits and accompanying silts rest directly upon bedrock and evidently were derived from formations in the Rocky mountains to the west. Such deposits have been called Saskatchewan gravels by Dawson. As shown by Dawson the greatest accumulations of glacial erratics are to be found where erosion has removed the finer glacial debris. He says¹

"In a few places the surface is pretty thickly strewn with boulders, but these areas are quite inconsiderable, and the prominence of the boulders is generally to be traced to the removal by denudation—owing to some local circumstance—of a considerable depth of the finer materials of the drift. The general absence of boulder-strewn tracts thus shows how small must have been the effect of denudation since the deposition of the boulder-clay and other glacial materials."

A notable boulder ridge extends for about 3 miles along the bottom of Verdigris coulée across the boundary between ranges 9 and 10. Parts of the undisturbed moraine are found on the north bank of the coulée and eastward beyond where the coulée bends to the south. The accumulation of boulders is clearly due to the causes described by Dawson.

A few huge erratics of quartzite in the valley of Waterton river and on Peigan Indian Reserve south of Brocket have been described by Dawson² as follows:

"Very large boulders were noted in a few places in the district. A remarkable group of these, composed of Huronian quartzites, occurs near the lower part of the Waterton river, and it is notable generally that some of the heaviest boulders are found not far from the western limit of the Laurentian and Huronian drift. One of these erratics is 42 by 40 by 20 feet, a second 40 by 30 by 22, and both are partly buried in the soil. . . . In common with all the larger boulders of the district these are surrounded by a shallow, saucer-like depression, caused by the pawing of the buffalo, and their angles are worn quite smooth and glossy by the rubbing of these animals upon them."

The erratics referred to have, probably, been seen by the writer in the SW. cor. sec. 29, tp. 5, range 26, W. 4th mer., at an elevation of about 3,550 feet. Dawson estimated the elevation as between 3,200 and 3,300 feet. Another huge boulder occurs near the Springridge-Brocket trail about 4 miles southeast of Brocket. The quartzite is very angular and in shape quite unlike boulders from the east. The rock seems identical with the Cambrian quartzites of Waterton Lakes and Windermere regions, and moreover a boulder of conglomerate about 8 feet in diameter, apparently belonging to the Blairmore formation, was found 4 miles east and 1 mile south of Brocket at about 3,800 feet in elevation. It seems, therefore, that these huge blocks have come from the Rocky mountains, carried on the ice of the mountain glaciers, which locally overlapped the morainal deposits of the continental ice.

Along the banks of Willow creek west of Stavely and Claresholm are a number of angular boulders 2 to 3 feet in diameter, which were quite unlike erratics from the east and were probably derived from the Rocky mountains. A very large boulder of the same character was found in Porcupine hills at an elevation of 3,450 feet in sec. 8, tp. 14, range 28, W. 4th mer. It was roughly tetrahedral in shape with sides 20 feet long.

¹ Geol. Surv., Canada, Rept. of Prog. 1882-83-84, pt. C, p. 9.

² Ibid., pp. 148, 149, and Plate.

Other notable morainal deposits occur on the hills flanking Cypress plateau on the north and southeast. Examples are numerous about Elkwater lake. Here the ice-sheets were evidently deflected westward as glacial erratics are not found on Cypress plateau: and with the check of movement due to deflexion the load of the ice was deposited as moraines.

The following is from McConnell¹:

"At the base of the steep escarpment which ends Cypress hills on the north, is a broken plain, which falls rapidly towards the north for the first few miles, after which it becomes more level, and stretches away to the Saskatchewan. This great plain, which embraces an area of nearly 8,000 square miles, presents an unusually diversified surface. Ridges of high, rolling hills, covered with erratics, and extensive areas of bare sand-hills, alternate with broad plains of remarkable fertility, considering the aridity of the climate, and with wide, sage-covered, clay flats, and every part of it is more or less thickly dotted with lakes, some of which, as Many Island lake, Crane lake, and Big Stick lake, are of large size. The lakes vary through every degree of salinity, from those covered with a thick crust of crystallized salts down to others in which the water is perfectly fresh, and the two extremes are not infrequently met with side by side.....

Another noteworthy feature of this plain is the utter absence of any general drainage system. A multitude of small streams, some of which carry considerable volumes of water during the spring floods, descend into it from the northern slopes of the Cypress hills, but they are all intercepted at no great distance from their source by lakes where their waters are evaporated, and with the exception of Ross creek and its tributaries, none succeeds in reaching the Saskatchewan. In the central and northern parts the evaporation is everywhere equal to the precipitation, and no streams of any kind are produced."

In the northern part of the area, apart from the main drainage channels, South Saskatchewan river with its tributary stream, Red Deer river, the drainage is poor. The level nature of the country, in conjunction with the great dumps of glacial drift, is undoubtedly responsible for this condition. The great moraines lying on both sides of Saskatchewan river and in some places along Red Deer river form an effectual barrier to the natural drainage of the country toward these water courses. Only to the north of Red Deer river and to the south of that stream west of range 10 are the tributaries developed to any extensive degree and even here the large number of "alkali" lakes testify to a poorly developed drainage system.

Farther to the north, Sounding creek is the largest stream and drains a considerable portion of the country. After traversing the central part of the area in an easterly direction, it swings north and would appear to enter the North Saskatchewan drainage basin. The stream, however, is part of an interior drainage system. The water, after travelling about 145 miles, empties into lake Manitou, a lake without an outlet, near North Saskatchewan river.

This paucity of tributary streams may be attributed partly to the prevailing dry climate, but the major factor is undoubtedly the great dumps of morainic material liberally distributed on either side of the river. These moraines form an efficient barrier to the natural drainage of the surrounding area, with the result that interior drainage systems may occur quite close to the river as exemplified in Cabri lake in tps. 24 and 25, range 27, W. 3rd mer., and in the lake in tp. 20, range 4, W. 4th mer.

A large area of typical moraine and kettle topography occurs on the uplands south of Ravenscrag and eastward.

¹ Geol. Surv., Canada, Ann. Rept., vol. I, pt. C, p. 15 (1886).

River Channels

Of the courses of late Pliocene rivers, we have only the evidence of the benches cited above, and some deeply buried channels partly exposed by the present streams. Dawson says¹

"Whatever the courses of the pre-Glacial rivers (and there is no evidence that they departed widely from the present west-to-east system of drainage) the new streams which began to form channels for themselves when the glacial conditions had passed away, certainly did not follow the old beds. This is shown by the fact that while in some cases almost the entire height of the scarped banks along the streams is formed of Cretaceous and Laramie rocks, in others these banks are altogether composed of drift deposits, the base of which lies even lower than the present river-bed."

An example such as cited by Dawson is found under the city of Lethbridge where a bore-hole near the Canadian Pacific Railway station penetrated drift to a depth of 299 feet or 35 feet below the top of the rock formation as exposed in the valley of Oldman river about one mile away. It is an interesting fact that the pre-Glacial channel bottom, where penetrated by the well, lies at almost exactly the same elevation as that of low water today and 9 feet higher than the bottom of Oldman channel beneath the Lethbridge railway bridge. McConnell has described another pre-Glacial valley at Medicine Hat as follows:

"At Medicine Hat, the valley of the Saskatchewan enters, and traverses for some distance one of those drift-filled depressions which so constantly interrupt the sections on all the principal streams. The entrance of a stream into one of these old basins is indicated at once by the increased width of its valley, as well as by the absence of all exposures of the older rocks. The Saskatchewan west of Medicine Hat is somewhat closely confined by steep, rocky banks which force it to follow a comparatively direct course, but east of that point it becomes much more tortuous and continues so until it crosses the pre-Glacial hollow. This hollow, which may represent either a portion of the buried channel of some ancient river, or more probably, a lake basin, is of small extent, as going in a northeasterly direction from Medicine Hat, the underlying rocks appear near the bottom of the valley in about 8 miles, though they do not rise to any height in the banks for 8 or 10 miles farther. In a southerly direction up Big Plume creek the edge of the basin is reached in 7 miles, and in an easterly direction up Ross creek in about 15. Its extent in other directions could not be ascertained.

The deposits in this basin are partly glacial and partly pre-Glacial. The pre-Glacial deposits consist of pebble conglomerate, coarse ferruginous sands filled with small pebbles, silts, and sands, and are very similar in lithological composition and in appearance to the Miocene rocks of the Cypress hills, from which they were without doubt derived. They are probably of Pliocene age.

The Rocks of the Belly River series which disappear below the Pliocene at Medicine Hat, reappear about 7 miles farther down.

A few miles east of Sandy point, the western edge of a second preglacial basin is reached."

The underlying strata are exposed only in the lower part of the banks which are made up largely of glacial drift. The drift is more prominent and the rock exposures fewer down stream, the last exposure occurring about 7 miles above Red Deer forks. The banks are composed entirely of glacial drift across the rest of the area described. Red Deer river enters a pre-Glacial valley with high banks of glacial drift, in range 8, and continues in it to its confluence with South Saskatchewan river with the exception of one short tract. In that part of its course where it swings to the north in range 4, W. 4th mer., high banks of the underlying strata are exposed. This part of its course is not considered to be of post-glacial origin.

¹ Rept. of Prog. 1882-83-84, pt. C, p. 140.

It is obvious that the pre-Glacial valley now occupied by the lower stretches of Red Deer river is a continuation of one occupied by South Saskatchewan river east of Sandy point. No evidence could be obtained regarding the westward continuation of this valley past range 8, but it is believed to extend to the northwest on account of the lack of outcrops in creeks in that direction. It also extends a considerable distance past the eastern boundary of the area, outcrops of Cretaceous rocks not appearing until 35 miles farther down stream.

In one locality some idea of the width of this pre-Glacial valley may be obtained. A small creek north of Red Deer river in range 1, W. 4th mer., affords low exposures of Cretaceous sandstone. These exposures become a little higher in a northerly direction and probably mark the northern slope of the valley. Directly to the south of these exposures, on South Saskatchewan river, the most northerly exposures of the same sandstone occur in secs. 23 and 24, tp. 22, range 1, W. 4th mer. These exposures become higher toward the south and are presumed to represent the southern slope of the valley. If this interpretation of the facts is correct, the bottom of the valley in this place was about 7 miles wide and would thus represent a watercourse in a far later stage of development than the rivers in this area at the present time.

Oldman River valley from the mouth of the Little Bow to the mouth of the Bow is pre-Glacial in age; the stream meanders considerably, the banks are low and fully matured, the drift is thick and descends to within a few feet of the water-level, and in most cases the exposures of Cretaceous sediments are small. Bow river is also very largely of pre-Glacial origin. Its valley shows occasional small outcrops of Upper Cretaceous sediments, but the scarped banks are for the most part of boulder clay or of quartzite gravel. Especially large banks of boulder clay occur south of Cluny and from here eastward to the Bassano irrigation dam.

Although Dawson's conclusions and later observations point to a close correspondence between modern and pre-Glacial drainage, there is a wealth of evidence to show that the present drainage was developed by stages as the ice-sheet retreated to the north and east; in fact, it seems possible to reconstruct in order of age a number of the old systems. Before attempting such a reconstruction, however, the old channels will be described.

The north (and main) branch of Milk river flows for the first 20 miles of its course in Canada in a wide, flaring valley of pre-Glacial age. The stream is, however, down-cutting and new adjustments are being made where the current impinges upon the rock rim. An inner valley is evident within the older one, and steep banks 150 feet in height occur where the new drainage has accentuated the steeper portions of the old valley, as for example east and west of the bridge, on the main road running south from Magrath.

In tp. 2, range 20, W. 4th mer., Lonely valley joins Milk River valley from the northwest. This valley averages more than a mile in width and extends across Milk River ridge, being occupied in its northwest extension by a branch of Pothole creek. Lonely Valley creek is a small, inter-

mittent stream and is certainly not the agent that produced the valley. Below Lonely valley, Milk river flows for 18 miles through a narrow channel, which is gorge-like in places with banks 250 feet high, the upper 150 feet being cut through drift. For 6 miles above Milk River town the river meanders across a nearly level plain of silt where bedrock is rarely exposed. Below Milk River town, the channel is cut deeply into silt deposits, the banks being nearly vertical at many places. These conditions extend to the outcrop of the Milk River sandstone formation, beyond which the valley is commonly of the nature of a box canyon 50 feet or more deep and bordered by castellated, and curiously sculptured sandstone. South of Milk River town, old channels extending in a north-south direction occur both east and west of Coutts. Playa lakes occupy portions of their bottoms, and they clearly connect with valleys running south into Montana.

Near the eastern side of range 14, Verdigris coulée enters the box canyon from northwest by west. The coulée valley is wider and more impressive than that of Milk river, but it is entirely dry and forms a hanging valley 50 feet above the low water-level of the river. This old valley extends northwestward with gently increasing elevations past the shallow playa lakes known as Verdigris and Weston, beyond which the valley is mostly a flaring depression with local steep sides along the perennial Tyrrell lake. Suds lake, southeast of New Dayton, is usually dry by midsummer and northwestward the Coutts branch of the Canadian Pacific railway follows the descending grade of the shallow depression to Stirling Station. Stirling lake, a part of an extensive irrigation system, extends nearly 5 miles westerly, marking the direction of the old valley, which continues past playa lakes to a branch of Pothole creek, a tributary of St. Mary river.

Within 30 miles to the eastward, five canyon-like valleys enter Milk River valley from the south, carrying flowing streams from Sweet Grass hills. Of these, Deadhorse coulée opens into Milk River valley at both ends and represents an abandoned channel of the river 6 miles long, and 50 feet higher than the present river bottom. The reason for the diversion is to be found in the local northerly dip of the Milk River sandstone, coupled with the location of the new channel in the soft, upper beds of the Milk River sandstone just below the Pakowki shale. The abandoned channel, on the other hand, lies across the nose of an anticline in the Milk River sandstone, and the river had already reached the resistant lower beds before its northerly diversion occurred.

Several small valleys enter Milk river from the north on ranges 11, 10, and 9, but the next major valley is Pendant d'Oreille coulée in the northwestern corner of tp. 2, range 8. This valley has a nearly level floor 1 to 1½ miles wide which is used for ranching and farming. At its mouth it is about 10 feet above the average level of Milk river, but it slopes gently northward until at the location of former lake Pakowki it is about 36 feet below Milk River level (not 89 feet as stated by Dawson). The sides of the coulée are steep but well grassed as far north as "lake Pakowki", beyond which the valley flares out into a wide depression. Lake Pakowki is now an alkaline flat containing muddy water during rainy seasons, such water as would lie in its basin being held by a dam at the foot of Crow Indian lake in Etzikom coulée. This coulée extends in a generally westerly direction from the northwest arm of Pakowki Lake basin. It has the

general characters associated with these Pleistocene channels, and below Crow Indian lake is principally dry in midsummer, although pools of water occur at places in the old creek bed. Crossing range 9, the sides are gentle and the coulée has a central ridge of boulders which appears to be a residual part of the glacial moraine occurring on the prairie level to the north, as already described. Higher up, Etzikom coulée varies from one-half mile to one mile in width with an average depth of about 200 feet.

Westward from Crow Indian lake the elevation of the bottom rises until the coulée finally merges into the low area occupied by Stirling lake, already described.

Below Pendant d'Oreille coulée, Milk river flows through a canyon-like gorge which extends beyond the Canadian boundary. This gorge averages about 1 mile in width and 400 feet in depth, and exposes the finest and most picturesque rock sections to be found in southeastern Alberta. The insignificant Milk river of the present meanders over flats of silt and quicksand which fill the bottom of the gorge, and its muddy waters are making but slow headway in the erosion of these soft sediments. It is clear that the canyon was formed by an ancestral river of much greater magnitude, doubtless carrying the floods issuing from the Rocky Mountain glaciers, as well as from the continental ice-sheet during the retreat of the ice. Silt deposition followed as the floodwaters diminished in quantity or were diverted to the Saskatchewan drainage system.

Many steep-sided coulées enter Milk River canyon from the north and south, but the next major valley is that of Lost river which joins Milk river in Montana south of sec. 2, tp. 1, range 4. This valley, which is occupied by a small stream, is about $\frac{1}{2}$ mile wide and varies from 150 to 200 feet in depth. It extends in a northwest direction past a low divide in sec. 29, tp. 2, range 5, into the southeastern extension of the basin surrounding the previous site of Pakowki lake. Its northwest slope is occupied by Canal creek.

The ancient river channels so far described join Milk River valley: the coulées next to be considered belong in the main to the South Saskatchewan drainage system.

Chin coulée crosses the Crow's Nest branch of the Canadian Pacific railway west of Chin station, from which point it is occupied to the northeast by an irrigation spillway which empties into Oldman river. To the south, the coulée bends around to the southeast and for 20 miles contains a series of reservoir lakes connected with an irrigation system. For this distance the slope is gently toward the northwest, the valley bottom is about one-half mile wide, and the banks are generally steep, varying from 100 to 200 feet in height. To the east of the lakes, the coulée extends east by south as a dry valley with gentle, easterly slope. North of Foremost, an intermittent creek extends along the valley bottom, changing to a permanent stream north of Nemiskam, where the valley trends northeasterly to its junction with Fortymile coulée in the west half of tp. 7, range 9.

Fortymile coulée leaves the valley of South Saskatchewan river north of Burdett as a depression between 3 and 4 miles wide. Three miles south of Burdett it contracts to 1 mile in width and $1\frac{1}{2}$ miles farther

south it is joined by a narrow valley from the west with marshy bottom. Southward the coulée is less than one-half mile in width and contains playa lakes for 4 miles of its course; beyond which it is dry to within 6 miles of its junction with Chin coulée where it is marshy. For its lower 12 miles, Fortymile coulée is about $\frac{3}{4}$ mile wide and from 150 to 250 feet in depth.

Chin and Fortymile coulées curve eastward below their junction and finally bend northward forming Sevenpersons coulée. This is a valley of more than one-half mile in width becoming shallower to where it widens out 12 miles southwest of Sevenpersons town, continuing as a wide, shallow valley to South Saskatchewan river at Medicine Hat. Starting about 8 miles below the junction of Fortymile and Chin coulées, an intermittent stream flows in Sevenpersons coulée to Saskatchewan river at Medicine Hat. From Burdett, to Chin Coulée mouth and along Sevenpersons to its expansion into the broad valley, the bottom elevations are nearly the same, varying mainly between 2,570 and 2,575 feet. At the entrance to the broad valley the elevation of the stream is about 2,550 feet.

An old channel connecting Pakowki basin with Sevenpersons coulée via Peigan creek is suggested by low elevations shown on the railway profile. Until a more accurate survey is available, this course cannot be determined definitely.

At Medicine Hat, the shallow valley of Sevenpersons creek joins the similar valley of Ross creek and enters the deep, drift-filled, pre-Glacial valley, which for several miles in this district is occupied by the present channel of South Saskatchewan river.

Of Ross Creek valley McConnell says:¹

"One of the most remarkable of these (old water-courses) commences at Medicine Hat and runs east for over 30 miles, then bends to the north, and continues into Many Island lake. At the bend, it is several miles wide, and encloses four small plateaux, which were probably islands at one time. In its lower part, this valley is now followed by Ross creek, and in its upper part, by Stony creek, Mackay creek, and other streams flowing into Many Island lake. From Many Island lake, an old channel, which may be an extension of the same system, leads into Bitter lake and then on to Big Stick lake."

In the northeast, channels of streams that were formed subsequent to the retreat of the ice-sheet and since abandoned are rather common features. The majority are short and of little consequence. The best-developed channel occurs in the northeastern part of the area where it was traced for a distance of about 60 miles. The average width of the valley is nearly a mile, and the depth about 150 feet. This old channel was first located just west of the town of Kerrobert, in tp. 23, range 24, W. 3rd mer. The channel apparently merges into an old glacial lake bottom at this point. The size of this lake, of which Shallow lake forms a remnant, is not known, but it extended considerably to the north of the area studied. The drainage channel was traced south from this point through range 24 to township 31. Here it passes to the west of the town of Driver and enters range 25. In township 30 a tributary channel enters from the west. This channel can be followed for many miles. The main channel swings back into range 24 and thence south to township 28 where it forks. One branch swings to the east into range 23 and thence south, ending abruptly in the southern

¹ Geol. Surv., Canada, Ann. Rept., vol. I, pt. C, p. 56 (1886).

part of township 26. The other branch turns to the west and is followed by the Canadian National railway as far as Flaxcombe. Here the channel swings to the southwest and terminates abruptly in tp. 28, range 27. The coulée may be followed on a map through most of its course by the succession of lakes and swamps which occupy the lower areas of the channel. No stream of any considerable size now occurs in any part of the valley. It is believed that the drainage through this old channel was to the north, and that the water emptied into the lake just west of Kerrobert. The name, Kerrobert coulée, is suggested to designate this channel.

An old drainage channel occurs to the west of Rapid narrows on South Saskatchewan river. This channel extends several miles west from the river and has several branches which apparently drained the large morainal area in that locality. It is believed to have been formed by the run-off from the ice-sheet.

Frenchman river heads in small glacial lakes drained by Oxarart creek, but its main source is Cypress lake. The lake basin was excavated in large measure by ice action, but the impounding of the water is due to the silting up of the lower part of Oxarart creek, through which the lake drained into Battle river, and by the raising of its eastward drainage channel by the inwash of large quantities of sediment by the waters of Sucker, Belanger, and Davis creeks, which descend by steep slopes from Cypress hills to the north.

Below Cypress lake, the valley of the Frenchman compares in many respects with Milk River gorge. It is canyon-like, about $\frac{3}{4}$ mile in average width at the bottom, and is 500 feet deep in many places. Its bottom is deeply buried by clay, silt, and sand over which the river meanders as far as Palisade coulée, 10 miles below Cypress lake. Below this the river has excavated a channel through the Pleistocene deposits as far as East End. Three miles below Ravenscrag the remains of the silt filling extend up the banks of the river 350 feet above the river-level. The present gradient of the river from the lake to Ravenscrag is about 7 feet a mile and from Ravenscrag to Eastend about 10 feet a mile.

From the north, many intricate deep valleys enter the main valley, those below Palisade coulée being in obsequent arrangement (that is trending upstream). A good example of this arrangement is the north branch of the Frenchman, and a still more interesting example is to be seen east of the area described, in the dry channel joining Frenchman valley at Eastend. This is occupied to the northeast by Swiftcurrent and Jones creeks, which flow northward and have tributaries in obsequent arrangement.

On the south a still more remarkable valley opens into Frenchman gorge north of Palisade station. It contains no stream, but is followed by the Weyburn-Manyberries branch of the Canadian Pacific railway. The floor of this coulée is almost level and opens to the south into an old shallow channel with southwest direction and slope. For convenience this ancient valley may be called Palisade coulée.

Excellent rock sections occur in the banks of the various gorges, but the lower portions of the beds of the side streams and the river-bed itself scarcely expose rock at any point.

The gorge cutting and subsequent silting up of the Frenchman system are to be explained in much the same way as in the case of the lower Milk River gorge. There are, however, special characteristics of the Frenchman system which need explanation, the most important being the east-west trend of the river from Cypress lake to East End, rather than down the slope to the south; and the apparent reversal of drainage between Palisade coulée and East End as indicated by recent down-cutting in Pleistocene silt, by obsequent tributaries which do not enter the river at grade, and by the ancient channel to the south, spoken of as Palisade coulée.

Moraines, kettles, boulders, and a general glaciated topography characterize the upland south of Ravenscrag and East End, indicating that an extensive ice lobe, diverted south by the elevation of Cypress hills, covered this region extending in a southwest direction. Through the Gap, another ice lobe evidently extended southeast at least as far as Cypress lake and perhaps farther. The first course taken by the runoff of these two lobes appears to have been between them through Palisade valley, and out onto the south-sloping plain in a wide, shallow depression, now followed by the railway, to the valley of Battle creek at Vidora. Under these conditions the flow from Cypress lake was as at present, but the flow from the northeast and west of East End was opposite that of today. As the "Gap" lobe retreated, part of the runoff found its way into Battle creek west of Cypress lake, which in its flooded condition probably flowed in part down Battle creek, although still maintaining its main easterly flow. As the ice retreated still farther and the flow of water slackened, huge deposits of silt and sand were swept into the stream valleys and out onto the southern plain where they are still to be seen. With the final retreat of the easterly ice lobe, the channel of the Frenchman below East End was developed, and due to its favourable grade it gradually extended its course headward through the alluvial filling of the valley west of East End, until by the capture of stream after stream the Palisade gap was reached and the headwaters of the modern Frenchman river were turned from their southerly course into their present direction of flow.

Besides the old valleys mentioned, other old channels have been recognized at various places. Among these is the central channel of the "gap" which intersects Cypress hills in a northwest-southeast direction some 6 to 12 miles east of the Saskatchewan-Alberta boundary. This channel connects Oxarart Creek valley with Battle Creek valley at the elbow west of Cypress lake. Watercourses of short duration also appear to have occupied the southwest trending valleys along the north and western sides of Cypress hills, and between Cypress hills and Eagle butte.

Among the interesting results of post-Glacial river development are the perched positions of Milk and South Saskatchewan rivers. The former flows through Milk River ridge and across the foothills of the Sweet Grass hills, at an elevation sufficiently great to make it the source of water for the Foremost artesian area to the north. In fact Milk river at the mouth of Pendant d'Oreille coulée is 34 feet above the old level of lake Pakowki to the north, and, a shallow excavation in the coulée for a short distance, would turn the river waters into the old lake basin.

Milk River valley was established while the continental glacier covered the country to the north, as already shown, and the present northward slope of Pendant d'Oreille coulée, which formerly conducted the glacial run-off southward into Milk River valley, may indicate an unwarping of the area including Milk River valley, relative to the Pakowki Foremost region. A more probable explanation is that the present level of Milk River valley is due to the late Pleistocene deposition which clearly took place in it to a greater extent than in the Pendant d'Oreille coulée. As the continental ice-sheet retreated, more water and sediment were carried by the main river, than by its tributary, as Milk river headed in mountain glaciers. The Pendant d'Oreille-Lake Pakowki valley was then a back-water, into the mouth of which sediment was deposited. Later down-cutting by Milk river has brought about modern conditions.

In the case of South Saskatchewan river, the land in the proximity of the river over a large part of its course is higher than the land at some distance from it. This feature is especially notable in that part of its course above Red Deer forks. This anomaly has been attributed to the great heaps of glacial moraine lying in the vicinity of the river. It is still left to be explained, however, why the river chose a course through an area of high relief when areas of lower relief existed beside it.

The solution of this problem undoubtedly lies in the post-Glacial drainage of this area when the ice-sheet still lay in the immediate vicinity. The position of the moraines, extending as they do in a general north-south direction along the river, seems to indicate that they were lateral in position and were deposited between two lobes of the glacier that lay on either side of the present river channel. The run-off from the glacier would be forced to cut a channel through this mass of moraine in seeking an exit to the south. Such old drainage channels are of common occurrence in the southern part of Alberta. After the departure of the ice-sheet and the subsequent adjustment of drainage the old channel through the moraine would probably offer the best course for drainage from the south through this area.

There is little direct evidence to substantiate this idea and there is certainly no evidence of the original post-Glacial valley existing anywhere along the present course of the river. However, the old valley may not have been as wide as the present valley, and so all evidence of its existence may have been erased.

Lakes

The main lakes of the area have already been mentioned. McConnell¹ has grouped the lakes into three classes:

- "(1) Lakes occupying portions of the abandoned channels of ancient streams.
- (2) Lakes occupying the depressions in the drift which have become the receptacle for the drainage of the adjoining higher land.
- (3) Lakes partaking of the character of springs."

Under the first class he includes Cypress lake, and here also might be placed former lake Pakowki, Crow Indian lake, Tyrrell lake, and the small playa lakes of Verdigris coulée.

¹Ibid., pt. C, p. 21.

Cypress is a fine, freshwater lake, about 7 miles long and $2\frac{1}{4}$ miles wide at its widest point. It represents a wide portion of the old Frenchman River valley which was formerly deeper than at present. The more rapid inwash below Cypress lake has filled the narrow valley faster than the lake expansion, thus damming back the lake water.

Lake Pakowki was a residual part of a much larger lake belonging to the old drainage systems, as already described. It appears to have been not more than 2 feet in depth when seen by Dawson, and has virtually disappeared since the dam was built at the foot of Crow Indian lake (or lake Johnson).

Under class 2 fall practically all the other lakes, large and small, although as McConnell says, springs may add to the supply in many cases. In fact classes 2 and 3 merge into one another without definite, distinguishing characters. The northern part of the area is devoid of lakes of any considerable dimension, with the exception of lake Newell. This lake, situated south of Brooks, is artificial and is used as a reservoir for irrigation purposes. Most of the other lakes are connected with interior drainage systems and are, for the most part, of the "alkali" type. During the hotter part of the summer, when the water-supply diminishes, these lakes may become nearly, or completely, dry.

The largest lake of this type in the area is Grassy Island lake in tp. 33, range 3, W. 4th mer. This lake, together with the smaller lakes in the vicinity, is a remnant of a much larger lake that occupied the area of several townships in this locality after the retreat of the ice-sheet. The lake was subsequently drained by Sounding creek cutting through the barrier of moraine to the north. On account of this drainage the lake is now fresh. Most of the lakes of glacial origin show evidence of greater extent during earlier times.

Sand-plains

McConnell has mentioned the sand-hills which cover large areas north of Cypress hills. The largest area is known as the Great sand-hills, and extends with a width of from 10 to 15 miles, from Crane lake north about 40 miles. At its southern end it sends narrow spurs west to Many Island lake, and east, with one or two breaks, almost to Swift Current station. The whole extent of this sandy waste amounts to over 500 square miles. Smaller sandy patches were observed near the mouth of Miry creek, and also 10 miles east from Red Deer forks, and about 6 miles south of Sandy point on the Saskatchewan, and a few scattered hills were found 6 miles north of Medicine Hat. The other more important sandy tracts occurring within the limits of the district are the Middle sand-hills, lying between Red Deer and Saskatchewan rivers, near their confluence. A much smaller area occurs in the vicinity of Fortymile coulée south of Bow island.

These deposits of sand appear to mark the location of lakes that existed during the final retreat of the continental glacier. The sorting action of the waves has probably been responsible for the formation of bars and sand dunes which have later been spread and modified by wind action.

All areas of sand-hills appear to be progressing slowly towards the east or southeast, the direction of the prevalent winds of the plains. The movement is plainly shown on the eastern side, by the hills being now underlain by a loamy or clay floor, and on the western side by the solitary sand-hills, which are occasionally met with far in the rear of the advancing mass.

Recent River Valleys

The typical rivers of the area are youthful in character, flow in deep, steep-sided valleys which are clearly post-Glacial and are down-cutting at the present time. The South Saskatchewan above Medicine Hat is a good example; here the stream averages less than $\frac{1}{8}$ mile in width, the valley is about 1 mile wide at the top and slopes to the water's edge with a depth of about 350 feet. Along the same river, from Rapid narrows to a short distance below Sandy point, the stream is narrow with high, steep banks, in places nearly perpendicular. The valley is best described, especially in its southern part, as a gorge. At Rapid narrows the banks attain a height of over 500 feet, but they gradually diminish down stream.

The valley of Red Deer river from range 15, where it enters the area, to range 8, is post-Glacial, and the underlying Cretaceous formations are well exposed in high banks along this part of its course. Post-Glacial streams may have reasonably straight courses or meanders depending upon their original courses over the glacial and outwash deposits. Oldman and Saskatchewan rivers meander notably through the pre-Glacial sections of their courses. On the latter river, sharply incised meanders are conspicuous at Rapid narrows, and at Sandy point. Incised meanders are also common in the valley of Red Deer, St. Mary, Waterton, and Belly rivers, where, independent of structure, various kinds of rock have been eroded into sinuous gorges.

CHAPTER VI

ECONOMIC GEOLOGY

NATURAL GAS

General Statement

So plentiful is natural gas in this region that the cities and most of the towns depend upon it for household fuel. There is also plenty for commercial requirements. At present many millions of cubic feet of gas are going to waste in Turner valley for lack of market.

Natural gas is obtained from the following fields within the map-area: Bow Island, Medicine Hat, Many Island Lake, and Foremost. The Rogers-Imperial well, with its 50,000,000 cubic feet of gas per day open flow, proves the presence of another field in the south and many other suitable structures are still untested.

Gas is known to occur in commercial quantities in the Milk River sandstone, lenses of sand in the Colorado formation, in the Kootenay-Blairmore formation, in the Upper Jurassic, and at or near the top of the Palæozoic limestone.

Bow Island Gas Field

The Bow Island gas field is northwest of Bow Island a village on the Crow's Nest branch of the Canadian Pacific railway midway between Lethbridge and Medicine Hat. The field is on a low dome of 50 feet closure superimposed on the Sweet Grass arch.

The first well in the Bow Island gas field was drilled by the Canadian Pacific Railway Company, but the Canadian Western Natural Gas, Light, Heat, and Power Company have done the major part of the development work. In 1911, they acquired the first well from the Canadian Pacific and since then have completed twenty-four others. In addition to those owned by the company there are two other wells in the field, one of them owned by the village of Bow Island, and the other by the Southern Alberta Land Company. A tabulated list of the wells with locations, open flow measurements, etc., follows.

Gas Wells in the Bow Island Gas Field

No.	L.S.D.	Sec.	Tp.	Range	Elevation	Depth to top of gas sand	Elevation of top of gas sand	Open flow cub. ft. per day
					Feet	Feet	Feet	
1.....	6	15	11	11	2,300	1,866	434	8,500,000
2.....	15	15	11	11	2,273	1,849	424	Abandoned
3.....	14	9	11	11	2,273	1,849	424	13,000,000
4.....	3	17	11	11	2,273	1,843	430	29,000,000
5.....	9	22	11	11	2,270	1,867	403	Abandoned
6.....	1	16	11	11	2,286	1,881	405	4,200,000
7.....	8	18	11	11	2,283	1,856	427	7,000,000
8.....	13	18	11	11	2,314	1,891	423	12,000,000
9.....	2	24	11	12	.....	.....	414	Abandoned
10.....	8	23	11	12	.....	.....	415	Abandoned
11.....	1	7	11	11	.....	.....	.....	7,300,000
12.....	13	7	11	11	2,467	1,958	409	16,000,000
13.....	3	9	11	11	2,521	.....	.....	18,000,000
14.....	1	1	11	12	2,548	2,100	448	7,000,000
15.....	13	12	11	12	2,581	2,170	411	4,000,000
16.....	4	4	11	11	2,554	2,134	420	Abandoned
17.....	1	25	11	12	2,594	2,207	387	Abandoned
18.....	4	1	11	12	2,663	2,230	433	Abandoned
19.....	16	25	10	12	2,531	2,076	455	3,000,000
20.....	16	30	10	11	2,550	2,100	450	Abandoned
21.....	1	30	10	11	2,564	2,127	437	Abandoned
22.....	14	31	10	11	2,544	2,100	444	1,300,000
23.....	16	17	11	11	2,396	1,981	415	2,300,000
26.....	15	33	10	11	2,559	.....	.....	Abandoned
27.....	4	20	11	11	2,496	2,092	404	1,300,000
Bow Island well	12	4	11	11	2,275	.....	.....	7,000,000
Southern Alberta Land Co.	9	24	11	12	.....	.....	.....	12,000,000

The best wells, Nos. 4, 13, and 12, have open flows of 29,000,000, 18,000,000, and 16,000,000 cubic feet per day respectively. The average well measures from 7,000,000 to 12,000,000, whereas the lowest, Nos. 22 and 27, measure 1,300,000. The total open flow capacity of the field at its maximum was between 150,000,000 and 175,000,000 cubic feet per day—a great deal higher figure than for Medicine Hat. This figure, has, however, decreased greatly in the last few years. The original rock pressure was between 700 and 800 pounds per square inch, but by 1923 had declined to 210 pounds. Mr. H. B. Pearson, formerly General Superintendent of the Gas Company, is the authority for the following statements.¹

"The capacity of the Bow Island-Calgary pipe-line is 39,000,000 cubic feet per day. The average amount of gas used by Calgary is 10,000,000 cubic feet per day. The maximum amount supplied to Calgary was 37,000,000 cubic feet per day during the cold weather of January, 1914. The lowest amount supplied was 4,000,000 cubic feet in one day."

The gas occurs in a porous sandstone band 35 feet thick in the Colorado shales about 1,300 feet below the base of the Milk River sandstone.

¹ Newspaper interview, 1916.

Owing to the thickness of the drift very few outcrops of rocks occur in the immediate vicinity of the field. The structure of the field is represented on Figure 3. It is not known how influential the irregularly shaped dome with a closure of only 50 feet has been in causing the accumulation of the large quantity of gas which has been obtained in the field. The accumulation of gas was undoubtedly aided by the fact that the small dome is situated on the crest of the Sweet Grass arch.

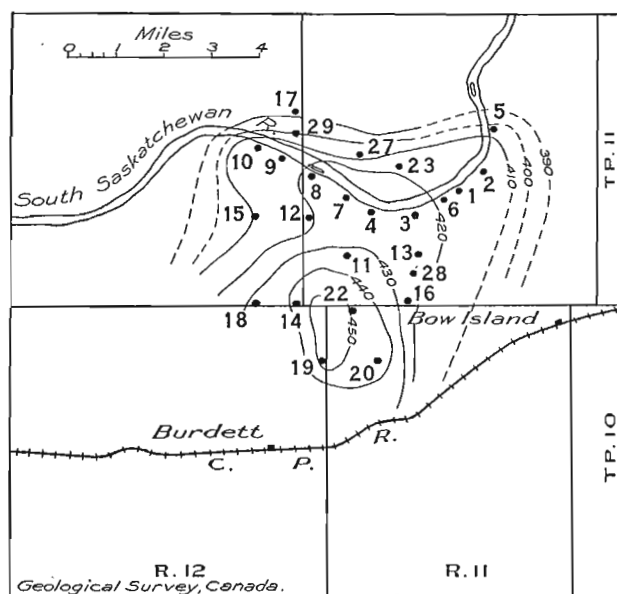


FIGURE 3. Bow Island gas field; structure contours represent top of the gas sand.

The extent of the field is not known exactly, but is probably not much larger than the dome shown on Figure 3. The field has passed its zenith and is now rapidly declining. Edge-water has appeared in several of the wells which have, consequently, been abandoned.

Barnwell Area

Eight wells were drilled in the small gas field near Barnwell 40 miles west of Bow Island, but only one struck a profitable flow of gas. The gas sand as at Bow Island and Foremost is a sandstone band near the base of the Colorado shales.

Medicine Hat Gas Field

The Medicine Hat gas field centres about the city of Medicine Hat and lies in the structurally low area to the east of the Sweet Grass arch.

Attention was first directed to the gas possibilities of the area by the seepages of gas in South Saskatchewan river; these are made evident by a

continuous stream of bubbles rising to the surface of the water. The first wells were drilled in 1901, but penetrated only to a shallow gas sand 700 feet deep, from which a very small production was obtained. In 1908 the Canadian Pacific Railway Company drilled to 1,000 feet and penetrated the Milk River sandstone which has proved the principal gas horizon in the field. From that time on all wells have been drilled to the deeper horizon and the shallow wells have been abandoned. The following table contains a list of the wells drilled in Medicine Hat with data concerning open flow measurements, depth of the gas sand, etc.

Gas Wells in the Medicine Hat Gas Field

No.	Name of well	Sec.	Tp.	Range	Elevation	Depth to Milk River sandstone	Elevation Milk River sandstone above sea-level	Open flow	Approx. thickness of Milk River sandstone
					Feet	Feet	Feet	Cubic feet	Feet
1	Main St.	SW. 1/4	31	12	5	2,202-95		2,225,000	
2	Armory	NE. 1/4	31	12	5	2,145-05		3,000,000	
3	Rosary	NW. 3/4	32	12	5	2,132-65		2,000,000	
4	Balmoral	SW. 1/4	32	12	6	2,128-95	905	1,224	85??
5	Electric Plant	NW. 3/4	35	12	6	2,167-75		4,000,000	
6	Craft	SW. 1/4	36	12	6	2,148-15	918	1,230	About 10
7	Industrial	NW. 1/4	18	12	5	2,346-95	1,094	1,253	35
8	Industrial	NE. 1/4	22	12	6	2,312-82	1,065	1,247-82	65
9	Stella	SW. 1/4	28	12	5	2,147-65	938	1,209-65	30
10	Hargrave	NW. 1/4	31	12	5	2,165-65		2,500,000	
11	Cousins and Sissons	NE. 1/4	25	12	6	2,269-44	1,075	1,194	
12	Central Park	NW. 3/4	30	12	5	2,262-87	1,030	1,232-87	28
13	Maple St.	NW. 2/4	29	12	5	2,131-35		2,500,000	
14	Powell	SE. 1/4	30	12	5	2,139-55		2,900,000	
15	Hackvale	NE. corner	6	13	5	2,336-53	1,080	1,256-53	38
16	Big Chief			12	5	2,133-55		2,800,000	
17	Ogilvie	NE. 1/4	30	12	5	2,137-16	904	1,233-16	35
18	Marlborough	SW. 1/4	30	12	5	2,151-65	915	1,236-65	
19	Wellington					2,171-05	975	1,196-05	
20	C.P.R. No. 1	SE. 1/4	31	12	5	2,178-65			
21	C.P.R. No. 2	SE. 1/4	31	12	5	2,179-54	970	1,209-54	45
22	C.P.R. No. 3	NE. 1/4	36	12	6	2,236-98	979	1,257-98	
23	Purmal	NW. 1/4	28	12	5			2,000,000	
24	Canada Cement Co. No. 1	Dauntless Sta.				2,360			
25	No. 2	NE. 1/4	28	12	6	2,330-96	1,095	1,235-96	70
26	No. 3	SE. 1/4	22	12	6	2,306-37	1,057?	1,249-37?	
27	No. 4	NE. 1/4	14	12	6	2,223-33	965?	1,258-33	
28	No. 5	SE. 1/4	28	12	6	2,291-86	1,058	1,240	28
29	Golden Valley Irrig. Co.	NW. 3/4	33	12	5	2,171-22	940	1,231-72?	
30	Roth No. 1	SW. 1/4	6	13	5	2,329-76	1,081	1,248-76	29
31	Redcliff South	NE. 1/4	5	13	6	2,450-88	1,187	1,263-88	
32	Redcliff East	NE. 1/4	9	13	6	2,413-04	1,150	1,263	4,000,000
33	Redcliff West	NE. 1/4	7	13	6	2,434-47	1,183	1,251-47	4,000,000
34	Redcliff Pressed Brick Co.	SW. 1/4	9	13	6	2,443-28		1,195??	1,800,000
34	Redcliff Brick and Coal No. 2	NW. 1/4	5	13	6	2,421-32		1,250-3	4,000,000
35	Redcliff Brick and Coal No. 3	NW. 1/4	5	13	6	2,247-04		1,224	2,000,000
36	Dom. Glass Co.	SW. 1/4	17	13	6				3,147,000
37	Redcliff Broadway	SW. 1/4	17	13	6				5,000,000
38	Dunmore Junc.	NE. 1/4	9	12	5				?
39	Dunmore	Townsite							?

The best wells in the field have open flows of nearly 5,000,000 cubic feet per day, and those under 2,000,000 are considered poor. The original total open flow capacity of the field was about 80,000,000 cubic feet per day, but it is reported that by 1922 this had decreased to 50,000,000 cubic feet. The rock pressure in the early history of the field was 550 pounds

per square inch; this had declined to 425 pounds in 1925. The open flow capacity is, therefore, falling more rapidly than the rock pressure. The rock pressure in Redcliff has always been higher than in Medicine Hat; in 1925 it was about 475 pounds. About one-half the wells are owned and used by the Municipalities of Medicine Hat and Redcliff; the remainder, for the most part, are owned and used by industrial concerns.

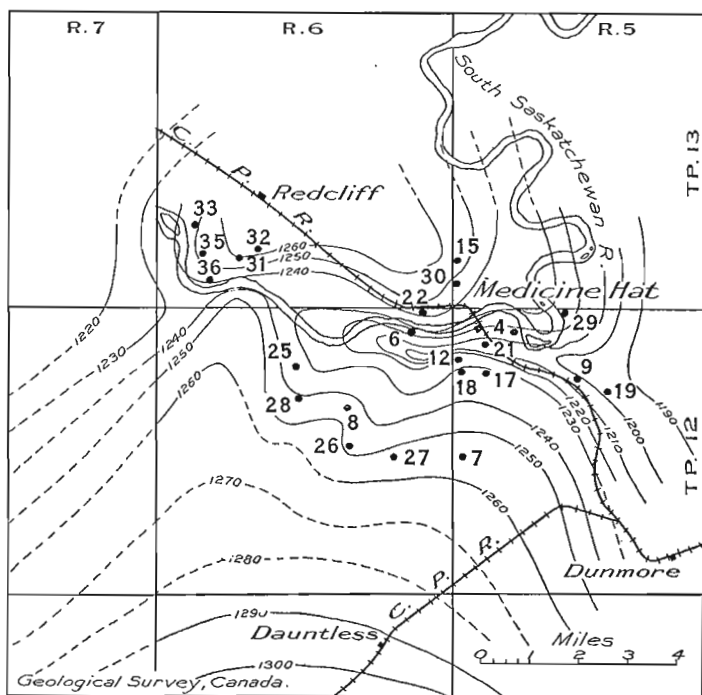


FIGURE 4. Medicine Hat gas field; structure contours represent top of Milk River sandstone.

The structure of the field as represented in Figure 4 is largely based on the data contained in the preceding table, but additional information was obtained by determining the strike and dip of the overlying rocks (Foremost beds) in the coal mines in the western part of the field and along the river valley opposite Redcliff. The structure that causes the accumulation of the gas is a low, broad structural nose of about 50 feet closure, which extends northward from the structurally higher land to the south. It is divided into two parts by an east-west trough which roughly parallels the river. The southern part of the field was developed first and has received most attention. A few good wells have been obtained in the trough. The northern part, however, holds out most promise for the future. It is higher than the southern part and the rock pressure also is greater. Some of the best wells have been drilled on it including the Huckvale well and the Broadway well at Redcliff.

In a paper by C. C. Ross¹ there appears a structure contour map of the Medicine Hat gas sand totally unlike the one included here. The difference largely depended upon the interpretation of the log of one well, namely "Cousins and Sissons", NE. $\frac{1}{4}$ sec. 25, tp. 12, range 6, W. 4th mer. In this well a flow of 2,800,000 cubic feet of gas per day was struck at a depth of 1,075 feet at the very bottom of the well. This is regarded as the top of the gas sand, although no sand is shown in the log at this depth. At a distance of 122 feet above this horizon at a depth of 953 feet a production of 60,000 cubic feet of gas is recorded. This was the horizon assumed by Ross to be the Milk River sandstone. The deeper horizon is regarded as being the Milk River sandstone, because from it the big production was obtained. The Milk River sandstone cannot extend for 122 feet between the two horizons, as it is nowhere over 50 feet thick in the field. The upper horizon is apparently a sandstone band in the Pakowki. According to the figures assumed herein as correct the top of the gas sand occurs at an elevation of 1,195 feet above sea-level. This figure agrees with the figures for the surrounding wells. Thus, in the Craft well the gas sand was obtained at an elevation of 1,230 feet, in the Central Park well 1,232 feet, in the Marlborough well 1,236 feet, in the C.P.R. well 1,209 feet, and in the Balmoral well 1,224 feet.

How far the field extends beyond the present proved area has not been determined. The Canada Cement Company's well at Dauntless is a very poor one and the field probably does not extend south of this point. Some gas was obtained at Dunmore, but the gas sand was thin and the field probably does not extend farther east. Nothing is known of the western extent of the field, but possibilities of obtaining good flow outside the structure shown on the map are not considered good. Future drilling may show that the field extends a considerable distance farther north and it is even possible that the rocks may rise in that direction.

The manner in which the rock pressure has kept up is remarkable and augurs well for the continued life of the field. Edge-water has appeared in but few of the wells in the central part of the city, namely in the Power Plant well and in Canada Cement well No. 2. With the wise conservation measures which have been, and are being, taken and with proper care in avoiding water troubles the field should last for a number of years to come, and there is always the hope of extending the field to the north or of finding new fields sufficiently close at hand for the gas to be piped to Medicine Hat.

In the summer of 1925 the drilling firm of Roth and Faurot by agreement with the city council of Medicine Hat commenced a search for oil in the rocks below the Milk River sandstone within the limits of the Medicine Hat gas field. For their first well they chose a location in the northern part of the city—L.S.D.4, sec. 6, tp. B, range 5, W. 4th mer. The Milk River sandstone was 39 feet thick and was reached at a depth of 1,081 feet; the Blairmore-Kootenay sandstone was struck at a depth of 2,520 feet, the Jurassic at 2,800 feet, and the Palæozoic at 3,000 feet. A flow of 2,600,000 cubic feet of gas per day under a pressure of 400 pounds

¹ Ross, C. C.: "Petroleum and Natural Gas Development in Alberta"; Bull. Can. Inst., Min. Met., No. 168, p. 487 (April 1926).

per square inch was struck in the Milk River sandstone and a flow of 10,000,000 cubic feet of gas which turned to water in one day was obtained at a depth of 2,845 feet. Other water sands occurred at depths of 2,175 feet and 2,525 feet.

Many Island Lake Area

This area is west of Many Island lake, within a mile of the Saskatchewan border. It is 12 miles north of the main line of the Canadian Pacific railway and 20 miles northeast of Medicine Hat. Attempts have been made by four companies to drill wells in the field, but two of these scarcely got past the stage of "spudding in". The Community Oil Company and the Many Island Oil Company, however, have had a certain measure of success.

At the last report the Community Oil Company's well was down to 2,500 feet where they had struck a flow of water in the Colorado shale. The Many Island Oil Company, under the management of C. W. Drazan, carried a well down 350 feet into Palæozoic limestone to a depth of 3,540 feet. The upper 1,870 feet was drilled by jetting machine, but the lower 1,670 feet by diamond drill; consequently no reliable information was obtained of the upper part, but the lower part has furnished one of the most instructive cores ever obtained in western Canada.

Comparing the log of the Drazan well with that of the Roth well in Medicine Hat it appears that the Blairmore-Kootenay sandstone is 100 feet lower in elevation in the Drazan well (299 feet below sea-level) than in the Roth well (190 feet below sea-level). There is, therefore, a low regional dip of 5 feet a mile to the east or southeast between these two wells. Comparing the elevation of the top of the Milk River sandstone in the Drazan well, 1,383 feet, with the same horizon in the Roth well (1,260 feet) we find that the Milk River sandstone is 123 feet higher in the Drazan well. This is chiefly due to the thickening of the Colorado formation eastward between the two wells of 157 feet.

The figures for the elevation of the contact between the Bearpaw shales and the Pale beds at several points around Many Island lake and Medicine Hat illustrate well the nearly horizontal attitude of the strata. Thus in an outcrop in sec. 34, tp. 16, range 8 (30 miles northwest of Medicine Hat), the elevation of this contact is 2,580 feet; in sec. 30, tp. 15, range 2 (15 miles north of the Drazan well and 20 miles north of Many Island lake) it is 2,547; in sec. 13, tp. 11, range 3 (4 miles south of Irvine) it is 2,631; in sec. 18, tp. 11, range 29, W. 3rd mer. (5 miles southeast of Walsh) it is 2,539. This shows a dip of 5 feet a mile to the east. In a well¹ drilled near Maple Creek on sec. 15, tp. 11, range 26, W. 3rd mer., in 1909, coal occurred at a depth of 196 feet, the elevation of the top of the hole being 2,507 feet, making the elevation of the coal 2,311 feet. If this is assumed to be the coal horizon between the Bearpaw and Belly River formations then the rocks may be assumed to dip eastwardly between Walsh and Maple Creek 228 feet in 25 miles or 9 feet per mile:

As concerns regional structure the Many Island area is situated similarly to the Medicine Hat field; but no local structure has been shown

¹Geol. Surv., Canada, Mem. 116, p. 46 (1919).

to exist in the former field. In the Drazan well the Milk River sandstone has almost wedged out and is represented only by sandy shale which does not produce gas.

Foremost Gas Field

This gas field is southeast of Foremost, and includes a part of Etzikom coulée and the adjoining plains. It centres approximately at the cross-roads separating townships 5 and 6, ranges 10 and 11, W. 4th mer.

Development started prior to 1919 with the drilling of United Oil Wells No. 3 in Etzikom coulée, SW. $\frac{1}{4}$ sec. 31, tp. 5, range 10, W. 4th mer., in which strong flows of gas were struck in two different sandstone lenses in the Colorado shale. In 1923 extensive development of this field was undertaken by the Canadian Western Gas, Light, Heat, and Power Company, Limited, with the result that C. C. Ross reports nine wells drilled in this field by April, 1926. He further states "The initial closed pressure ranged from 585 to 640 pounds per square inch and the open flow of gas was as high as 17,000,000 cubic feet per day." Since 1923 the major supply of gas for Calgary has been from this field and the Turner Valley oil field. During 1925, wells Nos. 5 and 6 of the Gas Company were completed. No. 5 flowed 11,000,000 cubic feet of gas and No. 6, 1,330,000 cubic feet of gas per day. The wells are from 2,070 to 2,250 feet in depth and obtain gas from sandstone lenses near the base of the Colorado shale.

The structure consists of a northward pitching anticline about 12 miles wide as measured between adjoining syncline axes. The sharp structure of the Rogers-Imperial well flattens out into a more regular northerly slope across Milk River valley, but the anticlinal character is assumed again at the Lucky Strike coal mines and continues northward through the Foremost gas field, losing its character in the northerly slope beyond Foremost. The dip of the axis of the anticline averages about 25 feet per mile in a direction north by east. The slope of the limbs varies between 30 and 50 feet a mile to the northwest and northeast. The Foremost gas field appears to be located on a flattened part of the axis of the anticline but no south closure is known.

OIL

History of Exploration

¹ No oil fields have yet been developed within the area here reported on, but a number of deep wells have been drilled and much information has been gained, which should be of service in developing promising structures.

The testing of the oil possibilities of southern Alberta received its first real stimulus from the discovery of an important oil field in the vicinity of Kevin-Sunburst, Montana, where oil was obtained from the "Kootenay," Ellis (Jurassic), and Madison (Palæozoic) formations, the last being at an average depth of 1,600 feet. The activity in this field in 1922 resulted in establishing it on a commercial basis and in extending its boundaries to within 12 miles of the Alberta boundary. As it was clear that the structure continued, although with decreasing elevation, into Alberta in the vicinity

¹ The developement of the Red Coulée oil field west of Coutts has taken place since this report was prepared.

of Coutts, leasing became active north of the Alberta boundary and drilling started on an extensive scale early in 1923. By autumn, two wells had penetrated the Palæozoic limestone, and two others, the "Kootenay" formation, without reaching the "Kootenay sand." The only encouragement came from the Red Coulée well drilled by the Northwest Company about 6 miles west of Coutts. This well penetrated the Palæozoic limestone at about 2,695 feet from the surface and struck a promising showing of oil in the "Sunburst sand" near the base of the "Kootenay" formation at a depth of 2,505 feet. This showing was not developed.

Later drilling in the vicinity of Coutts has added little new information, although the Urban well at Coutts has tested the centre of the field, and has furnished a standard log for the district.

The wells drilled in Coutts area, Alberta, are as follows: The Red Coulée well of the Northwest Company on L.S. 6, sec. 5, tp. 1, range 16, W. 4th mer. The Urban well is on L.S. 2, sec. 4, tp. 1, range 15, W. 4th mer.; it finished 10 feet in the Palæozoic limestone at a depth of 2,570 feet. The Coutts-Sweetgrass Oils, Limited (McLean-Mitchell) well on SE. $\frac{1}{4}$ sec. 1, tp. 1, range 15, W. 4th mer., appears to have entered the Palæozoic limestone at 2,645 feet and finished at 2,852 feet; a showing of tar was reported from 2,700 feet and gas from near the bottom of the well. The Lethbridge Oils, Limited, well on SE. $\frac{1}{4}$ sec. 12, tp. 1, range 15, W. 4th mer., entered the "Kootenay" formation at about 1,965 feet and continued in it to the bottom at 1,985 feet, without penetrating the Sunburst sand. The Border Oil Company well drilled by diamond drill on SE. $\frac{1}{4}$ sec. 6, tp. 1, range 14, W. 4th mer., penetrated the "Kootenay" formation at 1,920 feet and finished at a depth of 2,020 feet without reaching the Sunburst "sand"; showings of oil were struck at 1,875 feet in a sandstone lens in the Colorado shale and again at the top of the "Kootenay" formation.

The drilling records confirm the surface indications as to the extent and northward plunge of the Kevin-Sunburst anticline in the vicinity of Coutts. They also show that the highest point for the upper formations is near the Red Coulée well 6 miles west of Coutts, although the highest structure of the Palæozoic limestone is at Coutts and appears to be due to the unconformity at the top of the Palæozoic limestone. The structure is revealed by the following data:

		Elevation above sea-level Feet
Red Coulée well.....	Top of Colorado.....	3,394
	Top of Palæozoic limestone.....	849
Urban well.....	Top of Colorado.....	3,320
	Top of Palæozoic limestone.....	900

In spite of the structure, the best oil showing for the field was obtained in the Red Coulée well.

Other drilling operations centred around the Canadian Oil and Refining Company's well (Rogers-Imperial) situated on the east bank of Deadhorse coulée in NE. $\frac{1}{4}$ sec. 29, tp. 1, range 11, W. 4th mer. When finished in 1924 this was "the largest gasser in Canada, with a flow of some 50,000,000

cubic feet per day and a pressure of 1,180 pounds per square inch."¹ This well penetrated Palæozoic limestone at about 2,720 feet in depth and was finished in it at about 2,797 feet. Gas was struck in the Colorado at 920 feet, in the Sunburst sand at the base of the "Kootenay" at 2,529 feet (about 25,000,000 cubic feet of gas), in the Jurassic at 2,538 feet and at 2,665 feet, and at the top of the Palæozoic limestone at 2,720 feet (about 22,000,000 cubic feet of dry gas). Because of the lack of market in Canada for this gas, the well has been capped.

The structure in the vicinity of the Rogers-Imperial well is a prominent nose extending north by west, and flattening out into the area of Milk River valley. This structure is subsidiary to that of West butte and it is quite clear there is no closure on the south side, although the gas sand is probably sealed by metamorphism, cementation, or contact with the igneous plug of West butte. It seems probable that the foothills on the Montana side are too much metamorphosed and disrupted by the intrusion to retain gas.

In the hope that the Rogers-Imperial gas pool might be flanked by an accumulation of oil, the Northwest Company drilled a well on L.S. 5, sec. 32, tp. 1, range 11, W. 4th mer. This well penetrated the Palæozoic limestone at a depth of about 2,573 feet and was finished at a depth of 2,578 feet. A good show of oil and gas was encountered in the limestone, but this was soon replaced by a heavy flow of "sulphur water." This well was drilled down the structure from the Rogers-Imperial well, the elevation of the top of the Palæozoic limestone in the two wells, as calculated from the well records, being, respectively, 496 feet and 426 feet above sea-level. The surface structure has a somewhat steeper dip.

Another well, known as Erickson Coulée well, was drilled by the Northwest Company on L. S. 13, sec. 8, tp. 1, range 12, W. 4th mer. This well appears to have penetrated the Palæozoic limestone at a depth of 2,800 feet and to have finished at a depth of 2,900 feet without economic results. As this well is situated still higher on the structure surrounding West butte than the Rogers-Imperial, the indications of oil or gas in this direction are unfavourable.

The Sanctuary Oil Company drilled a well in the bottom of former Pakowki lake on L. S. 16, sec. 10, tp. 5, range 8, W. 4th mer. This well was abandoned in a "water sand" of the Colorado formation at a depth of 2,065 feet.

The "Lethbridge well" was drilled some years ago near the Canadian Pacific Railway station. It stopped in the Colorado shale at a depth of 2,220 feet without reaching any of the important gas or oil horizons.

In southwestern Saskatchewan, the Imperial Oil Company drilled their Boundary well (Woodpile Coulée well) in Woodpile coulée, L. S. 4, sec. 9, tp. 1, range 27, W. 3rd mer., starting 150 feet above the base of the Bearpaw shale at the top of the thrust block elsewhere described. The well penetrated the Palæozoic limestone at about 3,940 feet and was finished at 3,960 feet. No commercial oil or gas was found. Contrary to anticipation² the well appears to have penetrated nearly horizontal beds,

¹ Ross, C. C.: *ibid.* p. 491.

² See Dowling, D. B.: *Geol. Surv., Canada, Sum. Rept. 1920, pt. B, p. 24.*

as the thicknesses of the formations recorded in the log correspond closely with the results of the measured section in the adjacent over-thrust block. As this well is located at the top of the thrust block, it is really in what is equivalent to the bottom of a syncline. A well drilled up creek from the fault block would tap the area beneath the thrust plane, and test for oil or gas sealed in by the fault gouge.

In the Drazan No. 1 well at Many Island lake, three shows of oil were met with, the uppermost in red shale of the Blairmore-Kootenay formation, the next in light grey, argillaceous limestone in the Jurassic (Ellis?) and the third in white, porous limestone also in the Jurassic. In the Roth No. 1 well at Medicine Hat a showing of oil and asphalt was found in the Jurassic (Ellis?) and heavy black asphaltic oil in sandstone at the contact of the Palæozoic and the Jurassic. A strong water flow was also met with in coarse-grained sandstone at the top of the Blairmore-Kootenay formation, which would indicate a good porous horizon suitable for a gas or oil reservoir. Heavy oil was found not far above the Palæozoic (probably in the Jurassic) in the Etzikom well in the SW. $\frac{1}{4}$ sec. 31, tp. 5, range 10, W. 4th mer. Two oil showings were found in the deep well drilled recently by the Imperial Oil Company near Burdett at depths of 2,912 and 3,340 feet, and oil showings were found in the Roth No. 2 well at Redcliff which has very recently been completed. A promising showing of oil has been reported from the Colorado sand lenses in the Devenish well on L.S. 5, sec. 27, tp. 5, range 14, W. 4th mer.

Several wells have been drilled in the northern part of the area in an attempt to locate oil and gas in commercial quantities. The greatest activity has been in the vicinity of Misty hills, where the sharp structural features early attracted the attention of prospective drillers. It has been mentioned elsewhere in this report that the structure so well displayed in these hills is believed to be superficial and, therefore, of no value for the accumulation of oil.

Only two wells have been completed in this region. One was drilled by the Imperial Oil Company in the NE. $\frac{1}{4}$ sec. 29, tp. 32, range 4, W. 4th mer., to a depth of 3,304 feet. No oil or gas was reported. The other was drilled by the West Regent Oil Company in sec. 19, tp. 34, range 4, W. 4th mer. This well reached a depth of 3,500 feet and traces of oil were reported. The well has been abandoned.

Another well drilled in the area is that of the Fuego Oil Company, Limited, in the NE. $\frac{1}{4}$ sec. 3, tp. 26, range 4, W. 4th mer. The well penetrated to a depth of 2,270 feet, but apparently failed to reach the base of the Colorado shales. Showings of gas were obtained at several horizons. Drilling has been suspended for the present. There are no outcrops in the neighbourhood of the drilling operations to demonstrate the presence of suitable structure.

Oil and Gas Possibilities

Oil and gas are so closely associated, that their future development is best considered together. As gas fields are already well established, the areas nearby, with similar structure and geological conditions, may

be looked upon as potential gas fields, with oil possibilities on the flanks of the structures. Untested areas of suitable structure have possibilities in both oil and gas.

A study of the Kevin-Sunburst Oil field of Montana sheds much light on oil possibilities in Alberta. There, commercial quantities of oil occur in the Sunburst sand near the base of the "Kootenay" formation, at the very base of the Ellis (Jurassic) formation, and to some extent within the Madison (Palæozoic) limestone itself. Of these, the Ellis sand¹ is the largest producer. The dome has a closure of more than 500 feet on its shallowest side, with dips varying between 60 and 100 feet to the mile. Drilling starts in the Colorado shale and averages about 1,600 feet to the Madison limestone. By last reports, more than 700 wells had been drilled in this field, a large percentage being producers. The average initial production was 200 barrels a day, but individual wells had initial production of 10,000 barrels a day.

The Kevin-Sunburst arch extends into Alberta at Coutts, but no dome occurs in this vicinity. The immediate problem is, therefore, that of finding suitable structure, for in Alberta nearly all the wells that have reached the lower formations have obtained shows of oil or gas, although in most cases they have been drilled on low structures. Should a structure approaching the Kevin-Sunburst dome be found in Alberta, there is no reason to think that oil in commercial quantities would not be obtained. The more favourable structures are described below.

Suitable Structures for Oil and Gas Accumulation

Suitable structures for oil and gas accumulation may occur in any part of the map-area, excepting over the area of the Alberta syncline, which borders the disturbed belt. This unfavourable trough is about 12 miles wide at the 49th parallel and there occupies tp. 1, range 23, and tp. 1, range 24, W. 4th mer. To the north it widens because the edge of the disturbed belt swings away to the northwest and the eastern flank of the syncline runs nearly north. Thus in the latitude of Lethbridge, the centre of the Blood Indian reserve is on the eastern edge of the syncline.

Terraces and subsidiary folds along the eastern border of the Alberta syncline may be favourable for oil accumulation. Attention is more particularly directed to the following structures.

A narrow anticline extends east and west through Shanks lake, along the north side of tp. 1, range 21. The Shanks Lake anticline appears to have no closure on the east and the Palæozoic limestone is estimated to lie about 4,700 feet below the level of Shanks lake.

A dome occurs in the western half of tp. 3, range 20, and a fold subsidiary to this, pitching westerly across the middle of tps. 3, ranges 21 and 22. This dome may be called the Lonely Valley dome. It appears to have a closure of more than 150 feet on the east, the trough on the south being several hundred feet deep. This dome and terraces to the east

¹ According to E. S. Perry, State of Montana Bur. of Mines and Met., Mem. No. 1, the Ellis sand "is at and the top of the Madison limestone."

are the most favourable structure discovered along the flank of the Alberta syncline. The Palæozoic limestone is estimated to be 4,400 feet below the bottom of a branch of Lonely valley where it crosses the top of the dome.

A narrow anticline extends west through Bradshaw to St. Mary river about at the mouth of Pinepound creek. This anticline is open on the east, but is a narrow, well-defined fold at St. Mary river. The Palæozoic limestone is to be expected about 4,900 feet below the surface at Bradshaw.

A structural nose at Welling pitches to the north of west and crosses St. Mary river above Pothole creek. The Palæozoic limestone may be expected at a depth of 3,900 feet at Welling.

A rather prominent pitching anticline extends northwesterly just south of Lethbridge. This anticline is a branch of the regional anticline to the east, and pitches toward the northwest. Just south of Lethbridge, the Palæozoic limestone may be expected to be at a depth of about 4,000 feet. As the thickness of the deeper formations are taken from wells drilled near Coutts this estimate is liable to greater error than those given for more southerly structures.

The Sweet Grass arch is known to extend far north into Alberta. That part of it extending from the Kevin-Sunburst oil dome north through Coutts to Conrad on the Lethbridge-Manyberries branch of the Canadian Pacific railway, may be called the Kevin-Sunburst arch. A subsidiary anticline on this arch extends north through Milk River town to Verdigris lake where it becomes a terrace from which a long low anticline appears to extend west along the northern boundaries of tps. 3, ranges 16, 17, 18, and 19. Most of this country is drift covered and the structure is projected from adjoining areas. In the SE. cor. tp. 4, range 19, however, well-defined outcrops occur. No closure is known on the eastern side and the dip to the south is derived from projected structure. The Palæozoic limestone has a probable elevation here of 100 feet above sea-level or 4,100 feet from the surface in sec. 2, tp. 4, range 19. From here the anticline descends to the northwest toward Raymond and is continued into the Welling anticline described above. The presence of gas in the Pale beds at shallow depth in the district west of Warner (e.g. on sec. 17, tp. 4, range 18, gas was struck at 140 feet sufficient for lighting buildings and for crackling feed) tends to confirm the structure determinations as given above.

A fold branches off, in tp. 4, range 18, from the north side of the east-west anticline just described, and extends northward past New Dayton, through tp. 8, range 18, towards Chin. In tp. 8, range 18, the fold is broad and apparently flat topped. The Palæozoic limestone has a probable elevation of 500 feet below sea-level, or a depth of 3,450 feet from the surface. The depth to the sands of the lower part of the Colorado shales, gas-bearing at Bow Island and Foremost, is estimated to be about 2,100 feet in Chin coulée in the southwest corner of tp. 9, range 18, W. 4th mer.

In the vicinity of Milk River town, a well-defined terrace exists and the sharp east dip near Coffins Ford even suggests partial closure on the southeast. At Milk River town, the Palæozoic limestone probably lies at about 450 feet above sea-level or 2,975 feet beneath the surface.

The above described structures constitute what may be termed the western branch of the extension into Canada, of the Kevin-Sunburst arch. An eastern branch extends northward to Verdigris coulée near the east side of range 15 where a terrace is also indicated. The eastern branch continues north past Verdigris coulée, is rather flat, and contains oil at the location of the Devenish well, as already noted.

Another structure, farther east on the Sweet Grass arch, is the Dead-horse Coulée-Foremost anticline which is gas producing at the south and north ends.

In the vicinity of the Lucky Strike coal mines (tp. 3, range 12, W. 4th mer.) the top of the Palæozoic limestone is probably near sea-level, and the depth below the surface is from 3,100 to 3,200 feet.

Small anticlines radiate from East butte toward lake Pakowki and Comrey (tp. 2, range 6) and Onefour (tp. 1, range 4) post office.

East of the Sweet Grass arch, the best defined structure is that of the Cypress Hills dome. For practical purposes, it may be considered as extending northeasterly from a gentle syncline west of the valley of Lodge creek and the headwaters of Manyberries creek, to the middle block of the Cypress Hills forest reserve, in tp. 8, range 26, W. 3rd mer. The estimated depths, based on the logs of deep borings at Medicine Hat, from the top of the Bearpaw to the various possible "oil and gas sands" in the Cypress Hills dome are as follows: Milk River sandstone 1,855 feet; Blairmore-Kootenay, 3,295 feet; Jurassic, 3,575 feet; and Palæozoic, 3,775 feet. According to the log of the Woodpile coulée well the depth from the top of the Bearpaw shale to the Palæozoic limestone is 3,800 feet.

There are strong indications of the existence of a closed, elongated, anticlinal structure with an axis extending northwesterly from the NE. cor. tp. 5, range 1, W. 4th mer., to sec. 28, tp. 6, range 3, W. 4th mer. The width of the closed area is estimated at 3 to 4 miles, the closure being about 150 feet. For this structure described, the name Thelma arch is proposed, as Thelma post office is situated on its northern flank and about 4 miles from its axis. The centre of the arch appears to include an area 1 to 1½ miles wide and extending from sec. 11, tp. 6, range 2, W. 4th mer., to sec. 26, tp. 6, range 3, W. 4th mer. This area is, however, only vaguely defined, excepting along its northern part where the structure is clearly shown in Willow creek. At the crest of the arch the Palæozoic limestone lies at an estimated depth of 3,800 feet below the surface of the upland or about 3,650 feet below the surface in the valley of Willow creek.

Another closed structure occurs in the northeastern part of tp. 8, range 1, W. 4th mer., and in the northern half of tp. 8, ranges 29 and 30, W. 3rd mer. This dome appears to be about 300 feet lower than the Thelma dome and has a probable closure of 100 feet. In this area, the surface formations are all above the Fox Hills sandstone and even in the coulees the depth to the oil and gas sands will probably be 250 feet more than in the case of the Thelma arch.

A favourable locality for drilling for oil or gas is in tps. 7, ranges 4 and 5, and in the southern part of tp. 8, range 4, W. 4th mer. Here, especially north and northwest of Eagle butte, the strata dip steeply along the northern side of the Cypress Hills arch. In tp. 8,

range 4, W. 4th mer., the Whitemud beds dip to the north 543 feet in 2 miles and in the NE. $\frac{1}{4}$ tp. 8, range 5, W. 4th mer., the dip to the north is 532 feet in 2 $\frac{1}{2}$ miles. Dyer believes that the structure has a closure of between 100 and 200 feet to the south. Williams, on the other hand, believes that no closure to the south exists and that the structure is a terrace. The depth to the Palæozoic limestone is not thought to be as great as farther east.

Eagle Butte well No. 1 drilled on L.S.D. 9, sec. 31, tp. 7, range 4, W. 4th mer., is reported to have struck a flow of gas estimated at 40,000,000 cubic feet per day. The horizon is thought to be at the top of the Blairmore formation.

The following log of the well has been prepared from the results of examinations, by D. C. Maddox, of drill samples.

Surface elevation 3,623 feet.

	Feet
Doubtful (brownish sands, containing some pebbles) may be Fox Hills, drift, or partly Bearpaw.....	0- 318
Bearpaw.....	318- 620
Belly River.....	620-1,220
	<hr/>
	Feet
Lethbridge coal horizon.....	620- 630
Pale beds.....	620- 870
Foremost beds.....	870-1,220
	<hr/>
Pakowki.....	1,220-1,890
Milk River.....	1,890-1,900
Colorado.....	1,900-3,070

COAL

In the southern plains of Alberta and southwestern Saskatchewan coal occurs in nine different formations; the Kootenay, the Milk River, the Foremost, and Pale beds of the Belly River formation, the Fox Hills, the Edmonton, the Paskapoo, the St. Mary River, the Estevan, and the Ravenscrag. The Kootenay coal seams are very thin and occur at too great depths ever to be mined, the seams in the Milk River, Paskapoo, and St. Mary River are also very thin and those in the Fox Hills, Estevan, and Ravenscrag though thick enough to be mined locally are of poor quality.

Belly River Formation

The transition beds between the Pale beds and the Bearpaw contain carbonaceous layers wherever they are exposed in this area, and in the western part, notably in the vicinity of Lethbridge and Eyremore, seams up to 5 feet in thickness occur which are mined by several companies.

LETHBRIDGE DISTRICT

In Lethbridge district, coal has been mined since the year 1882 and has been in demand as a domestic fuel, although the opening of other mines nearer the centre of population has seriously interfered with the output. In 1925, Lethbridge district was fourth in the list of coal-

producing districts of the province. The two largest mines operated are that of the Canadian Pacific Railway Company in Hardieville 2 miles north of Lethbridge and that of the North American Collieries, Limited, at Coalhurst 5 miles northwest of Lethbridge. Several other mines reported a small production in 1925.

Output of the Principal Collieries, Lethbridge District, 1923-25

	(Short Tons)		
	1923	1924	1925
Canadian Pacific Railway Co., Dept. of Natural Resources.	363,160	190,626	331,015
Chinook Coal Co., Ltd.	72,232	6,712	.....
City of Lethbridge Coal Mines.	12,490	12,574	10,791
Consolidated Diamond Collieries, Ltd.	.....	9,671	39,282
C. S. Donaldson Coal Co.	11,459	28,747	25,901
Lethbridge Coal Co., Ltd.	26,376	21,864	12,851
North American Collieries, Ltd.	162,444	122,205	234,589
All other operators.	5,829	9,815	11,888
Total.	653,990	402,214	666,317

The following sections near the C. S. Donaldson coal mine in sec. 36, tp. 8, range 22, W. 4th mer., give an idea of the coal seams.

	Feet	Inches
Overlying shales and boulder clay	.....
Coal	.....	6
Shale	8	
Draw slate	.....	8
Coal	1	8
Parting-clay	.....	1 to 2
Coal	2	10
Bone	1	4
White clay	.....	3
Shale	.....

The following section was measured when sinking No. 6 shaft of the Canadian Pacific Railway Company's mine at Hardieville.

	Feet	Inches
Coal	.....	10
Shale	.....	18
Coal	.....	16
Hard, blue shale	9	2
Ironstone	.....	3
Hard shale	4	6
Coal	.....	5
Shale	2	0
Ironstone	.....	6
Shale	1	0
Coal	.....	8
Shale	1	2
Coal	1	5
Fire-clay parting	.....	1
Coal	2	8
Black jack	1	6
Dirty coal	.....

} Worked

The section through the coal seams of the North American Collieries mine at Coalhurst follows:

	Feet	Inches	
Overlying slaty shale.....		2	
Coal.....	4	3	} Worked
Bone.....		8	
Coal.....		8	

Toward the north end of the field the main coal seams thin out.

The coal seams outcrop in many places along Oldman river immediately west of Lethbridge, at Diamond City, and for about 10 miles down stream from Diamond City. The Lethbridge seams are also mined or have been mined at the mouth of St. Mary river in secs. 2 and 11, tp. 8, range 22, W. 4th mer.; near the mouth of Pothole creek in secs. 2, 7, 8, and 18, tp. 7, range 21, W. 4th mer.; and at the Magrath mine and vicinity in secs. 1 and 2, tp. 7, range 22. Coal occurs in about 40 feet of measures, a seam about 20 feet below the Bearpaw shale, varying between 2½ and 5 feet in thickness, being the one most commonly worked. A seam about 10 feet higher varies between a few inches and 3 feet in thickness.

Coal of the Lethbridge horizon has also been mined in a very small way on the north side of Milk River ridge in sec. 10, tp. 4, range 19, W. 4th mer. The coal here, which is at the very top of the Pale beds, has a thickness of 49 inches including a 14-inch bed of clay about 15 inches from the base. It is probable that beds lower in the formation would be of better quality.

The Lethbridge coal is classed as sub-bituminous and is of good quality, better than other Belly River coals found on the plains.

EYREMORE DISTRICT

A coal seam occurring at the same horizon as at Lethbridge is being mined on Bow river at Eyremore. The production of the district in 1925 was 6,129 short tons. A section of the seam at the mine of the Kleenburn Collieries, Limited, the chief mine in the district, follows:

	Feet	Inches
Shale.....		
Coal.....	1	10
Clay.....	3	10
Coal.....	4	8
Clay.....		

The seam occurs about 10 feet above the water-level.

EASTERN DISTRICTS

In the eastern part of the area the same horizon, i.e. the transition beds between the Pale beds and the Bearpaw, is carbonaceous wherever it outcrops. The character of the contact on the side of the hill immediately south of Irvine is illustrated by the following section.

	Feet
Shale (Bearpaw).....	20
Pale yellow sands with very thin carbonaceous seams.....	110
Carbonaceous shales.....	1
Brown shale.....	5
Pale yellow sands.....	3
Brown shale.....	3
Carbonaceous shale.....	1
Brown shale.....	2
Yellow sands.....	2

A thin coal seam reported at a depth of 196 feet at the well drilled at Maple Creek, probably belongs to this horizon.

Coal is mined intermittently in sec. 6, tp. 5, range 4, W. 4th mer., in sec. 30, tp. 2, range 3, W. 4th mer., and elsewhere in this vicinity. At these localities lignite seams 2 feet or a little more in thickness are worked by stripping for local domestic purposes. The quality of the coal is inferior to that of coal of the same horizon nearer the mountains.

In southwestern Saskatchewan, coal has been dug for domestic purposes from the Pale beds in a branch of Battle creek on or near sec. 2, tp. 1, range 27, W. 3rd mer. Some coal had also been dug from this horizon in Woodpile coulee. The seams here are too thin and mixed with shale to give promise of commercial exploitation.

TABER DISTRICT

Many seams occur throughout the Foremost member of the Belly River formation, but the thickest are in the upper part. One of these, known as the Taber seam, outcrops along Oldman river for several miles in the vicinity of Taber and is mined at Taber, Barnwell, and Elean. The largest mine is operated by the Leland Coal Company which has recently taken over the property from the Majestic Collieries, Limited. This mine has been in operation since 1907. The thickness of the seam in the mine varies from 3 feet to 3 feet 10 inches. It is uniform of quality throughout and there are no clay partings. The floor is of clay and is very good unless it becomes wet when it swells and becomes sticky, but very little water is encountered in the mine. The roof is of grey sandstone and stands up well, little timber being necessary. In 1926 development work was being carried on by the new company, new entries were being driven, and a modified long wall method of mining was being introduced. When in full swing it is thought that the company will be able to produce in the neighbourhood of 1,000 tons a day.

All the other mines are small and are worked only intermittently.

Output of the Principal Collieries in Taber District 1923-25

	(Short tons)		
	1923	1924	1925
The Bay Coal Co., Ltd.....	4,744	13,841	5,295
Canadian Block Coal Co., Ltd. (formerly John Oliphant and Regal Collieries, Ltd.).....	7,225	1,398	539
Co-operative Coal Co. (formerly Rock Springs Mines).....	4,309	9,084	5,932
Leland Coal Co. (formerly Majestic Collieries Ltd.).....	7,297	56,376	57,337
All other operators.....	4,155	9,833	13,754
Total.....	27,730	90,532	82,857

The coal is softer than at Lethbridge and of poorer quality, but compares favourably with the Drumheller coal.

OTHER OCCURRENCES IN THE FOREMOST BEDS

Five miles south of Grassy lake a coal seam about 2 feet 6 inches thick occurs at a depth of 30 feet. It is being worked in a small way for local use.

Two mines situated in sec. 36, tp. 11, range 11, northeast of Bow Island, have been worked intermittently; the seam is about 3 feet thick. At Winnifred a 5-foot seam has been reported as occurring at a depth of 276 feet. Farther down South Saskatchewan river in sec. 22, tp. 12, range 10, W. 4th mer., there is a small coal mine in which the seam is 4 feet 6 inches thick and in section 27 of the same township it is reported to be 5 feet 8 inches thick, but with 4 inches of bone 18 inches from the bottom of the seam.

From this point to Redcliff, coal seams are numerous in the banks of South Saskatchewan river, but have not been mined. At Redcliff several seams are exposed in the river banks. Two mines have been active in the district for a number of years, the larger, operated by the Ajax Coal Company (formerly J. T. Oliphant), is situated on the south side of the river opposite Redcliff. In 1925, its production was 30,816 short tons. The seam is 6 feet 6 inches thick, but there is a 6 to 8-inch parting of bone 2 feet from the top. The mine of the Redcliff Brick and Coal Company, Limited, is situated on the north side of the river in the town of Redcliff; it afforded a production of 13,821 short tons in 1925. The coal of Redcliff district is softer than the coal of the western part of the plains and poorer in quality than the Taber and Lethbridge coal.

The 7-foot seam reported at a depth of 292 feet in the well drilled at Maple Creek probably occurs in this horizon.

Over the large area underlain by the Foremost beds, many small mines and "gopher diggings" have been opened in the various coulées and river valleys, where the lignite horizon is exposed, and cheap fuel enabled many settlers to remain for years in the country, after their purchasing power had been greatly reduced by repeated crop failures. Local mining has been carried on in Fortymile, Sevenpersons, Chin, Etzikom, and Verdigris coulées, in Milk River valley, and Coal creek. Most of the lignite mined has been of very low grade and from seams 2 feet or under in thickness. More extensive mining, of a better grade of lignite, has been carried on near Milk River town and in the Lucky Strike field. The Milk River mines are situated in sec. 6, tp. 3, range 15; sec. 31, tp. 2, range 15; and sec. 26, tp. 2, range 16, W. 4th mer. The more northeasterly mines are worked by entrances from a small coulée, and the section of lignite is as follows, in ascending order: $3\frac{1}{2}$ feet of clean lignite; $2\frac{1}{2}$ to 3 feet of shale; 20 inches of lignite; 9 to 10 inches of shale; 14 to 16 inches of lignite; 4 inches of shale; 25 feet of soft sandstone; 1 foot of hard sandstone, followed by various thicknesses of overlying beds and glacial deposits. On sec. 26, tp. 2, range 16, the Hollander mine is operated by a tunnel over 250 feet long. The coal section is as follows in ascending order: 6 inches of lignite; 2 inches of shale; 12 inches of lignite; 6 inches of "dirt"; 6 inches of coal; 4 inches of clay overlain by clay shale. A shaft sunk to the north of the mine struck the lignite horizon 80 feet from the surface. The "coal" of the Milk River mines slacks badly and is somewhat higher in ash than the Lethbridge coal.

The Lucky Strike coal field is in the SE. cor. tp. 3, range 12, and the S. $\frac{1}{2}$ tp. 3, range 11, W. 4th mer. Mining has been carried on principally in sec. 1, tp. 3, range 12, and secs. 3 and 10, tp. 3, range 11. Entrances have been driven in from coulees and stream valleys. In range 11, a number of mines have been worked, the section in the Taylor mine in L.S. 7, sec. 10, tp. 3, range 11, is typical and is as follows in ascending order: 2 $\frac{1}{2}$ feet of good lignite; 6 inches of "bone"; 16 inches of good lignite; 4 feet of sandstone; 45 feet of blue shale to top of air shaft. The Lucky Strike coal field serves a large area of ranching and farming country far from the nearest railway station.

Considerable mining has also been carried on along the lower part of Milk River valley. The greatest development is near Comrey on sec. 9, tp. 2, range 6, W. 4th mer., where lignite seams well down in the Foremost beds have been mined by stripping. The seams are generally thin.

Edmonton Formation

Most parts of the Edmonton carry workable coal seams and several mines are situated on it at widely scattered points. The most important mining district is that of Drumheller which has been very fully reported on by Allan.¹ Eleven seams occur in the district. In 1921 mines were being operated on four of the seams. The deep seam, or Drumheller seam, the second from the base of the formation, is the thickest and ranges from 6 to 7 feet. This seam is characterized by a band of pure bentonite varying in thickness from a fraction of an inch up to 20 inches. The third seam from the bottom of the formation varies in thickness from 22 inches up to at least 40 inches with $\frac{1}{2}$ inch of bone about the middle of the seam. In places the seam consists of clean coal from roof to floor. Probably the most important seam in the district is seam No. 5 which is the sixth seam above the bottom of the formation. It was formerly known as the top seam or New Castle seam. Its thickness varies between 3 feet 6 inches and 5 feet 5 inches, but where mined its average thickness is about 4 feet 8 inches of clean coal. Seam No. 7, the eighth from the bottom of the formation, is mined by one company only. The thickness of the seam varies from 1 foot to 6 feet 8 inches, but the latter thickness includes a shale parting 24 inches thick; at the Brooks mine the seam is 42 inches thick with a 13-inch parting of bone.

In the year 1925, the output of coal from Drumheller district was second in the province of Alberta, being exceeded by a very small amount by Crowsnest district. In 1923, production from the district was 821,717 short tons; in 1924, 669,010 short tons; in 1925, 1,109,596 short tons.

The coal from Drumheller district is blocky and bright when freshly mined, but assumes a dull lustre on exposure to the air. The most prominent physical feature of the coal is its tendency to slack when unprotected from the air due to the high moisture content. On exposure the moisture evaporates and the difference in volume between fresh and air dried coal is represented by numerous cracks.

¹ Allan, J. A.: "Geology of Drumheller Coal Field"; Sci. and Ind. Res. Coun. of Alberta, Rept. No. 4, 1922.

Coal seams in the Edmonton are mined in very numerous localities along Red Deer river and its tributaries. Coal seams are also found in the Edmonton formation on Bow river, but have been left practically undeveloped. The thickest seam outcrops on the south bank of the river south of Towers siding on the Canadian Pacific railway. The section is as follows:

	Feet Inches	
The yellow sand.....		
Coal.....	6	
Brown shale.....	5	
Coal.....	9	6
Grey, soft sand.....	2	
Yellowish, soft, but massive sandstone (to water-level).....	30	

In the lower seam there is a 2-inch parting of yellow sand with some bentonite. The upper 2 feet of the seam is bony. About 5 miles southwest of Bassano in the Blackfoot Indian Reservations, coal seams have been mined sporadically in a few places. These seams occur in the base of the Edmonton formation. The principal coal seam is $8\frac{1}{2}$ feet thick with a 4- to 6-inch parting of bentonite and shale from 3 to 4 feet above the base of the seam. The upper part of the seam has been burnt over most of the surrounding country, giving a red appearance to the outcropping shales and leaving masses of clinker and ash.

An Edmonton coal seam is mined in a small way at a number of points in the vicinity of Champion, west of the Calgary-Lethbridge branch of the Canadian Pacific railway. In the small mine in secs. 24 and 25, tp. 16, range 23, W. 4th mer., the seam is $2\frac{1}{2}$ feet thick and is overlain by 30 feet of grey sandstone and glacial drift. In secs. 8 and 9, tp. 16, range 23, W. 4th mer., a 4-foot seam occurs 50 feet below the surface. One mile to the southeast the same seam is found in another mine at a depth of 91 feet. In still another mine immediately to the east the coal is at a depth of 50 feet and the seam is $4\frac{1}{2}$ feet thick. On the west side of lake McGregor in sec. 27, tp. 15, range 21, a coal seam of poor quality in the Edmonton formation is 2 feet thick and on the west side near the south end of the lake what is probably the same seam is $2\frac{1}{2}$ feet thick.

In Wolf coulee, in sec. 36, tp. 14, range 21, W. 4th mer., a coal seam 2 feet 3 inches to 2 feet 6 inches thick is being mined near the base of the Edmonton and sold locally. A section measured at this point follows:

	Feet Inches	
Alternating pale grey sandstone and brown shale in beds varying from 2 inches to 6 inches.....	10	
Pale grey, soft sandstone with elliptical sandstone concretions.....	25	
Grey shale with plant fragments.....	5	
Lignite.....	2	6
Grey shale with plant fragments.....	2	
Pale grey sandstone.....	15	
Alternating beds of pale grey sandstone and brown shale.....	15	
Pale grey sandstone with ironstone concretions.....	10	

Thin seams of lignite outcrop at several points along Little Bow river. In the NW. $\frac{1}{4}$ sec. 1, tp. 15, range 22, W. 4th mer., a seam 1 foot thick outcrops 85 feet above water-level and 1 mile to the west what is probably the same seam is $1\frac{1}{2}$ feet thick and outcrops 27 feet above water-level.

The production for the whole Champion district in 1925 was 10,183 short tons.

Fox Hills Formation

The Fox Hills sandstone of southwestern Alberta consists of a few feet of sandstone and shale resting on Bearpaw shale, overlain by massive sandstone about 140 feet thick; above this, a 3-foot seam of lignite or lignitic shale commonly occurs, but is very lenticular. Several attempts to mine the lignite have resulted in the production of a small tonnage of poor coal. On the McIntyre ranch on the west half of sec. 24, tp. 3, range 22, W. 4th mer., the lignite seam has been operated by means of two tunnels driven into the hillside. An exposure some distance to the east showed about 3 feet of lignitic shale. It is reported that the coal was very dirty and in small lenses.

St. Mary River Formation

Coal seams are not numerous in the St. Mary River formation. Most of those that have been reported by previous authors are in reality from the Fox Hills sandstone. The 16-inch seam exposed at Scabby butte probably belongs to the formation and the 10 feet of coal reported at a depth of 505 feet in the well drilled 1 mile west of Monarch is probably from the same horizon. In the foothills Stewart reports as follows:

"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 shale.¹ Exposures of this horizon showing coal seams may be seen on all of the main streams from Oldman river southward to the International Boundary."

Stewart lists occurrences in which the seam varies from 1 foot to 9 feet in thickness.

Paskapoo Formation

The Paskapoo formation carries little coal. Some of the beds are dark and carbonaceous and Dawson² records a 3-inch seam on Highwood river near the mouth of the Bow and on the Bow immediately above the mouth of the Highwood.

Estevan Formation

The Estevan, the chief lignite-bearing formation of southern Saskatchewan, occurs in Cypress hills, Old-man-on-his-back plateau, and Boundary plateau, where it carries thin lignite seams.

Two small mines on Bullshead creek in sec. 2, tp. 9, range 5, W. 4th mer., have made a small recovery of coal from the seam in this formation. The lignite is of poor quality.

The Estevan formation as developed in the western end of Cypress hills and the vicinity of Eagle butte, contains about 130 feet of lignite-bearing measures between an horizon 225 feet above the base of the formation and a second horizon about 60 feet from the top. The upper 20 feet

¹ These beds are probably correlatable with the Fox Hills formation.

² Rept. of Prog. 1882-83-84, pt. C, p. 83.

of these lignite-bearing measures contain the best lignite, and seams within this zone have been mined intermittently in a small way, from Elkwater lake southwest through Medicine Lodge coulee, and southeast to Thelma on Willow creek. Red, baked clay, at many places on the hillsides, marks former outcrops of the lignite consumed by spontaneous combustion.

The Elkwater Lake mine illustrates the northern occurrences. It is situated on a small promontory jutting into the northwestern side of the lake in L.S. 16, sec. 23, tp. 8, range 3, W. 4th mer. The coal seam outcrops about 30 feet above the lake and is mined by a tunnel over 300 feet long. The annual output is about 360 tons. The coal seam lies nearly flat, and is about 5.7 feet thick with 6 inches of clay partings 2.1 feet above the base.

A 2-foot seam of coal outcrops on the eastern side of Medicine Lodge coulee on sec. 6, tp. 8, range 3, W. 4th mer., and elsewhere in the vicinity.

The only mine on the southwest side of Cypress hills with a continuous output during recent years is at Thelma in the SW. $\frac{1}{4}$ sec. 18, tp. 7, range 2, W. 4th mer. The beds dip 6 degrees northwest, although the dip is probably less away from the outcrop. The coal is mined by stripping, about 30 feet of overlying silt, sand, and till caving down each season, and being removed by scrapers before the autumn mining activity begins. The section is as follows in ascending order: 6 feet of lignite; 6 inches of shale; 6 inches of lignite; 3 inches brown shale; 2 feet of lignite; 3 inches brown shale; 3 feet of lignite; 4 feet soft, grey shale; 6 inches of white fire-clay; 25 feet of Pleistocene sand and silt, covered with 3 or 4 feet of till. The cover is much thicker deeper into the hillside, due both to the rising surface of the land and to the northwest dip of the beds.

Coal has also been mined by open-cut at Thelma (sec. 12, tp. 7, range 3) from seams occurring from 45 to 60 feet below the main seam, but these operations appear to be abandoned. The lower lignite seams are rarely more than 1 foot thick and are interbedded with much shale.

Estevan lignite has been mined periodically, in a small way, in Cypress hills along the west side of the Gap, and elsewhere. Caved in diggings have been noted on secs. 1 and 27, tp. 8, range 29, and secs. 19 and 32, tp. 7, range 28, W. 3rd mer. The lignite is generally brown and weathers to "slack". In some of the mines, the seam is probably 5 feet thick.

Farther east, coal of this formation has been dug on sec. 24, tp. 8, range 28; on sec. 15, tp. 8, range 26; and sec. 28, tp. 7, range 24, all W. 3rd mer. The only mine in working condition in the summer of 1926 was that on Belanger creek on the central block of the Cypress Hills forest reserve (sec. 15, tp. 8, range 26, W. 3rd mer.). Here a tunnel was driven into the east bank of the stream for 50 feet. It was well timbered, 4 feet wide and 6½ feet high, and both roof and floor appeared to be in lignite. The section consists of brown lignite with 3 to 4 inches of clay 18 inches from the floor and again 2 feet from the roof.

In the west bank of the stream a strong spring of water issues from beneath a 9-foot seam of lignite, with 2-inch clay partings 2 feet above the base and again 5 feet above the base. This coal was formerly mined by a shallow open-cut.

No lignite was seen in Old-man-on-his-back-plateau, but the lower beds of the Estevan formation are present, and lignite seams are probably present.

Coal was reported on sec. 31, tp. 1, range 23, W. 3rd mer., but no indication of it could be found. Lignite doubtless also occurs in the Estevan formation as exposed in the flanks of Boundary plateau.

Ravenscrag Formation

Several seams of lignite occur within the lower 150 feet of the Ravenscrag formation as represented in the type section above the Whitemud of Ravenscrag butte. These seams are generally under 2 feet thick and of very poor quality, but at some localities lenses of suitable quality and thickness have been mined for domestic fuel. Workings were noted on secs. 10, 11, and 12, tp. 7, range 23; and on sec. 36, tp. 6, range 22, W. 3rd mer. At the former locality, a 4-foot seam of poor quality lignite had been mined by tunnel and stripping; and at the latter locality a 4-foot seam of fair lignite, with some clay partings, had been mined from two tunnels driven into the hillside. The seam is probably about 40 feet above the Whitemud.

In the western end of Boundary plateau, lignite seams, and red burned shale occur above the Whitemud formation.

SODIUM SUPHATE

The sodium sulphate deposits of the western plains have been investigated by L. H. Cole¹ and the reader is referred to his report for information regarding these deposits.

SHALE AND CLAY FOR BRICKMAKING

Clays and shales suitable for the manufacture of various kinds of ceramic products are widely distributed. The more important of these deposits have been described by Ries and Keele², or by Davis³.

BUILDING STONE

Most of the rocks outcropping on the southern plains are soft and quite unsuited for building, but certain beds of sandstone of the Paskapoo, Porcupine Hills, and St. Mary River formations are quarried in the vicinity of Calgary, High River, and Monarch. Parks has given a full account of these stones in vol. 4 of his report on the "Building and Ornamental Stones of Canada" published by the Mines Branch in 1916.

BALL MILL PEBBLES

The Cypress conglomerate is composed for the most part of well-rounded quartzite pebbles, which are commonly mixed with grit and sand and set in a calcareous cement. At many places, however, practically no cement is present and large quantities of pebbles lie scattered on the talus slopes fronting the conglomerate cliffs. Although varying much in size at the same locality and also from place to place, pebbles of almost

¹ "Sodium Sulphate of Western Canada"; Mines Branch, Dept. of Mines, Ottawa, No. 646 (1926).

² Geol. Surv., Canada, Mem. 24.

³ "Report on the Clay Resources of Southern Saskatchewan"; Mines Branch, Dept. of Mines, Ottawa.

any size desired up to 6 or 8 inches in diameter, could be obtained. The pebbles are smoothly worn, are thick, discoid or ovoid in shape, and are of exceedingly tough quartzite of cream or pink colour. The lighter coloured pebbles are covered with well-developed chatter-marks. The characters of these pebbles suggest their use for pebble mills.

Large quantities of Cypress pebbles occur on the talus at the foot of a 70-foot cliff of Cypress conglomerate in sec. 10, tp. 8, range 3, W. 4th mer.; and other conglomerate cliffs with more or less loose stone occur on secs. 4 and 15, tp. 8, range 1, W. 4th mer.; sec. 3, tp. 8, range 2, W. 4th mer.; and on sec. 23, tp. 8, range 30, W. 3rd mer.; secs. 11 and 22, tp. 8, range 30, W. 3rd mer.; secs. 1, 8, 9, 15, 17, tp. 8, range 29, W. 3rd mer.; sec. 21, tp. 9, range 25, W. 3rd mer.; and elsewhere. Besides the talus pebbles from the Cypress conglomerate, large areas of country have deposits of the same pebbles scattered over the surface as loose gravel. Such an area occurs in the vicinity of Belanger post office along the Maple Creek road, north of Cypress lake. Much coarse gravel lies upon the benches bordering Frenchman river between Ravenscrag and Cypress lake. Part of this gravel appears to represent loose beds of Cypress conglomerate, but much of it has been reworked by glacial ice, and mixed with some granite and other foreign material. The most favourable localities for "pebbles" of suitable character for mills are along the outcrops of the Cypress conglomerate formation.

Six bags of pebbles of the smaller sizes were collected by L. H. Cole in 1926, from the outcrop in sec. 10, tp. 8, range 3, W. 4th mer., and were run in comparison with commercial Danish pebbles of the same size. Cole states¹ that.... "The results obtained..... show that the amount of work done by the Canadian pebbles..... was practically the same as that for the Danish pebbles".....

ARTESIAN WATER

Artesian water is obtained from the Milk River sandstone over a large region in southern Alberta. The area includes the basin of Pakowki lake in the southeast, and extends northwestward between Chin and Bow Island to Oldman and South Saskatchewan rivers, the most northwesterly well being near Barnwell in sec. 28, tp. 11, range 17, W. 4th mer.

The development of artesian water was due to the advice and efforts of the late Dr. D. B. Dowling, who supervised the drilling of three wells by the Department of Mines in 1916-1918. After these wells had come in with flows of 4,000, 3,000, and 11,000 gallons of water a day, and so had demonstrated the presence of large quantities of potable water in this region of scant surface supply, independent enterprise continued to develop the field. For a full account the reader is referred to Dowling's² report which is accompanied by maps giving the approximate depth to the water sources, the structure of the water-sand in the artesian area, records of wells, etc.

¹ "Silica in Canada", pt. 2, pp. 30-31, Mines Branch, Dept. of Mines, Ottawa.

² "Artesian Area of Southern Alberta"; Geol. Surv., Canada, Sum. Rept. 1922, pt. B, p. 104-123.

VOLCANIC ASH

Volcanic ash has been found at two horizons within the area described in this report. In the coulée in sec. 29, tp. 28, range 22, W. 4th mer., an 8-inch bed was found near the top of the Edmonton formation. The section at this locality follows:

	Feet	Inches
Yellow and grey sand and sandy clay gradually changing into harder, ledgy sandstone typical of the Paskapoo.....	50	
Grey sand (Edmonton).....	5	
Black colloidal mud.....	15	
Grey volcanic ash, porous, with many of the pores filled with chalc-dony.....		8
Black, colloidal mud.....	25	

On the south side of Gros Ventre creek in the southwest corner of sec. 16, tp. 11, range 3, W. 4th mer., 115 feet above the bottom of the creek and about 100 feet above the base of the Bearpaw formation, there is a 2-foot band of peculiar white material [with specimens of *Liopistha undata* and an abundance of *Pteria* cf. *linguiformis* (dwarf forms)], which resembled volcanic ash. Samples were submitted to Mr. F. J. Fraser of the Borings Division, Geological Survey, who reported on them as follows:

"Dull, cream white, powdery, and dusty. Coherent lumps break with a sub-conchoidal fracture, have a somewhat greasy feel, and adhere strongly to the tongue. Little, if any, swelling in contact with water. Plasticity low. The wet paste gives a slight suggestion of grittiness to the fingers, but not to the teeth. The wet paste is easily reduced between the fingers to pass a 200-mesh sieve leaving a few calcareous sand grains, biotite flakes, and an occasional rounded quartz grain on the heads.

Under the microscope are seen mainly fine, jagged grains and very fine particles which are for the most part isotropic or with a poor aggregate polarization. The largest fragments—up to 0.06 mm.—are clear, isotropic, and with a low refractive index—less than 1.54.

The general appearance and characters of the material, the isotropic character of the grains, absence of swelling in contact with water, and low plasticity suggest a volcanic ash."

The full extent and thickness of the bed could not be determined as the exposure occurs on the top of a knoll and the upper part of the bed is eroded. Excavations in the main bank of the creek may reveal its presence there. What is probably the same bed was located 18 miles to the southwest in Petrified coulée in secs. 25 and 26, tp. 9, range 6, W. 4th mer. This bed may prove to be a useful horizon-marker in future drilling, as no other beds of a similar character were found in the district, and as volcanic ash beds are usually of great lateral extent.

Volcanic ash has found its greatest usefulness in the trade in the manufacture of cleansers such as "Old Dutch", and as a substitute for powdered pumice. A volcanic ash bed occurring in the bed of Swift-current creek near Waldeck, Sask., is made use of in the manufacture of "Old Sal" cleanser. It is possible that the volcanic ash beds of southern Alberta may in time be put to such a use.

BENTONITE

Bentonite has been shown by Hewett¹, Wherry², Nelson³, and Ross and Shannon⁴ to be a product of devitrification, with partial decomposition, of glassy volcanic ash. The properties of the resulting material are in many

¹ Jour. Wash. Acad. Sci., vol. 7, p. 89 (1917).

² Jour. Wash. Acad. Sci., vol. 7, p. 576 (1917).

³ Bull. Geol. Soc. Am., vol. 33, p. 605 (1922).

⁴ "The Minerals of Bentonite and Related Clays and their Physical Properties"; Jour. Am. Ceram. Soc., vol. 9, pp. 77-96 (1926).

respects like those characteristic of colloidal gels—it absorbs dye and other materials from solution and swells markedly and becomes plastic when wet. Ross and Shannon¹ by special methods of purification obtained material which they examined optically and chemically; they showed that bentonite consists of one or two definite minerals which have characteristic optical properties and to which they could apply a formula. The most common mineral was called montmorillonite and its formula given as follows: $(\text{MgCa})\text{O} \cdot \text{Al}_2\text{O}_3, 5\text{SiO}_2, n\text{H}_2\text{O}$. A second mineral commonly found was called beidellite², its formula being as follows: $\text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2, n\text{H}_2\text{O}$.

Bentonites are usually light in colour, ranging from cream to olive green, but in some cases they are coloured darker by carbonaceous materials. The outcrops exhibit characteristic weathered surfaces, having a crinkled appearance due to the alternate swelling and shrinking of the material upon repeated wetting and drying out. A bentonite exposure is rare, and quite noticeable.

In the area herein described, bentonite occurs in thin beds throughout the Bearpaw formation and in some localities in the Edmonton formation. It is found sparingly in the Belly River formation. Gumbo clay owes its peculiar characteristic to the small percentage of bentonite which it contains.

Spence described three deposits of bentonite in the present area as follows:

"At Rosedale the bentonite seams in the working of the Rosedale Coal Companies mine measure 6 to 10 inches in thickness and the material compares favourably in point of colloidalilty with a type Wyoming clay. It is, however, of not quite so good a colour and contains grit. Formerly the system followed in mining the coal resulted in the removal of bentonite as lumped clay and the considerable tonnage of clean material went to the waste pile. Under the present method of mining only the upper seam is taken down, the cutters being run in the bentonite partings. This results in the bentonite being broken in small pieces and contaminated by slack and dust. Possibly this waste could be avoided and the bentonite saved clean, but no attempt to do this is likely to be made until a favourable market for the clay is sure."

Thin seams of bentonite were found in the coal seams outcropping south of Bow river in the eastern end of the Blackfoot Indian Reservations. These seams and the seam in which bentonite occurs in the Rosedale's mine are near the base of the Edmonton formation and are very probably correlatable.

"At Knollys in sec. 17, tp. 6, range 22, W. 3rd mer., an 8-foot bed of bentonite is exposed in the side of Frenchman River valley about $\frac{1}{2}$ mile south of the railway. The bed may possibly be picked up at other spots along a distance of several miles up and down the valley, there being numerous cut banks exposed in good section of the Cretaceous sediments. A second bentonite bed is exposed on the other side of the valley near Eastend just below an adit recently driven for coal. This bed may possibly be the same as that at Knollys. The clay of both these outcrops is of yellowish green cast when damp, drying to a cream shade, in this respect resembling the Wyoming bentonite; its degree of colloidalilty has not yet been determined.

An outcrop of about 18 feet of impure bentonite containing large crystals of selenite and nodules of chalcedonic quartz occurs 8 miles south of Dunmore in sec. 14, tp. 11, range 4, W. 4th mer."

¹ Loc. cit.

² Larsen, E. S., and Wherry, E. T.: Jour. Wash. Acad. Sci., vol. 15, pp. 465-467 (1925).

On Little Bow river in the NW. $\frac{1}{4}$ sec. 14, tp. 12, range 20, W. 4th mer., the following section showing bentonite was measured:

Yellow, shaly silts very fine-grained, may be bentonitic.....	Feet 4
Brown shale.....	1 $\frac{1}{2}$
Clay ranging from dark greenish colour at bottom to lighter greenish yellow toward top. This may all be bentonite. Seams purer going upward. The last 6 inches is greyish and quite pure bentonite.....	15

Large selenite crystals are found toward the top of the section in the brown shale and clay underlying them. The horizon is the lower part of the Bearpaw formation.

Spence says:

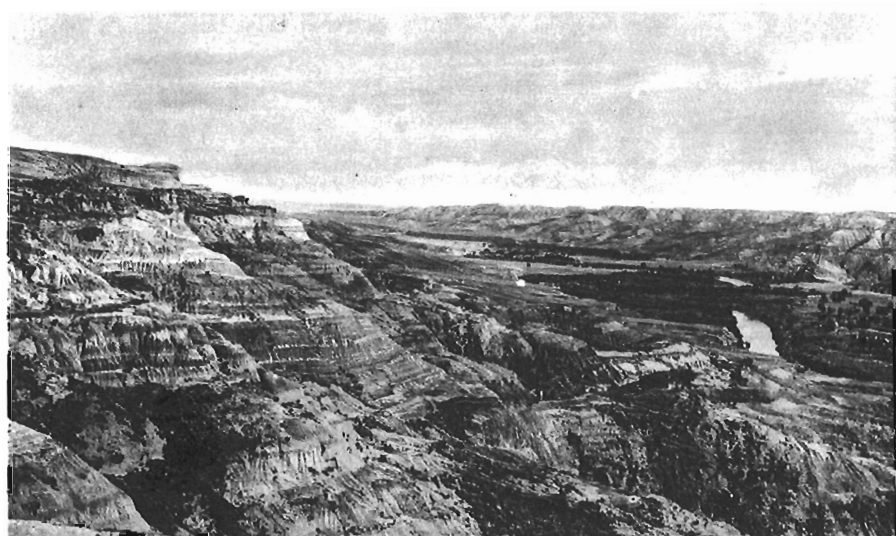
"Thus far, the established field of usefulness for bentonite in industry and the arts is a limited one, and progress in developing new uses for the material has been slow for several reasons. In the first place high freight rates are inevitable, since the known deposits are situated at a considerable distance from the important industrial centres. This acts as a deterrent to industries that might contemplate the possibility of using the material, and more often than not kills at the outset any suggestion of research upon it."

Several possible uses of bentonite are then outlined by Spence which are uses that have suggested themselves from the study of the physical characteristics of the material. A few of those mentioned are:

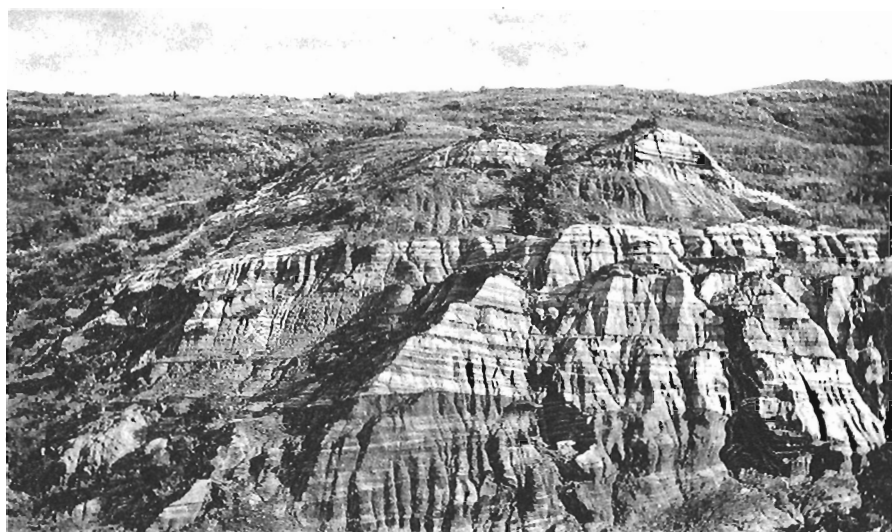
1. In cement and plasters.
2. Ceramics.
3. As a dewatering agent.
4. In the dye industry.
5. Emulsion.
6. Explosives.
7. Fertilizers.



A. Upper Milk River sandstone, lower Verdigris coulée, Alberta.



B. Milk River gorge near Comrey, Alberta; depth 450 feet;
Foremost beds in foreground.



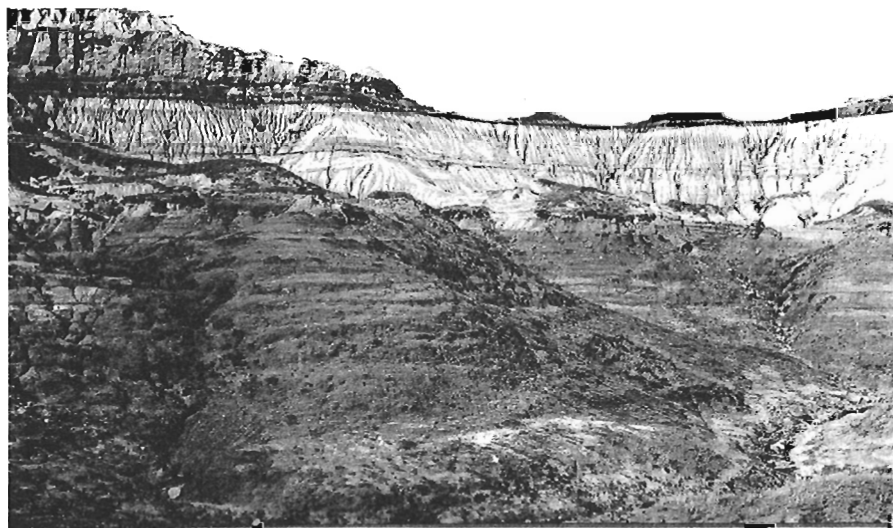
A. Foremost beds, Chin coulée, Alberta.



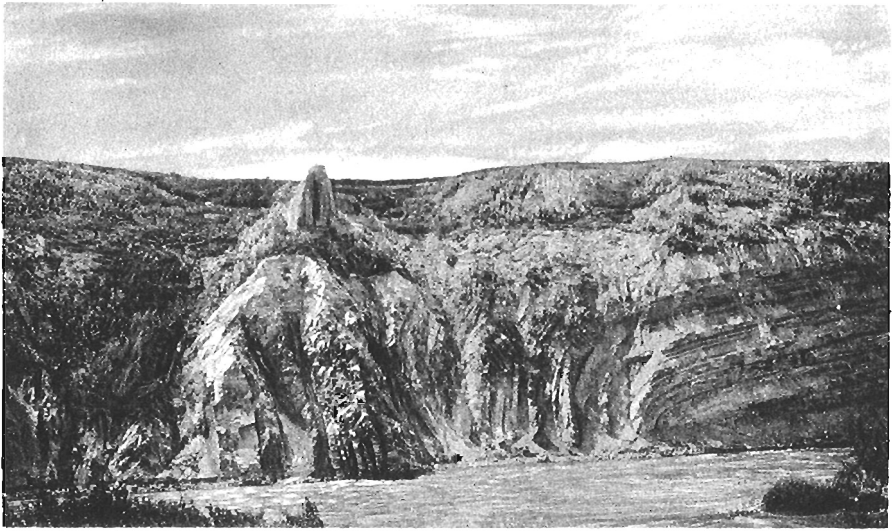
B. Pale beds, South Saskatchewan river, 15 miles west of Medicine Hat.



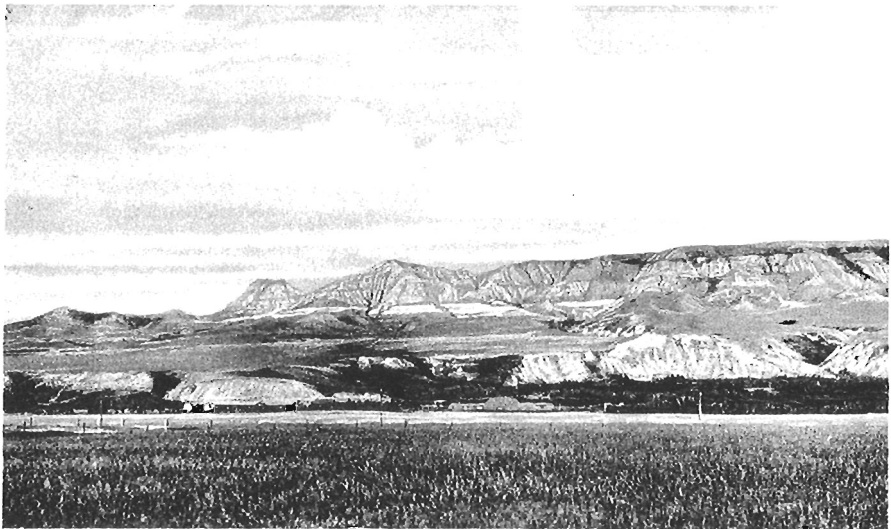
A. Pale beds showing crossbedding, south of Irvine.



B. Edmonton sandstone overlying Fox Hills sandstone, near Bassano, Alberta; the Fox Hills sandstones are the darker beds in lower half of picture.



A. St. Mary River sandstone at edge of disturbed belt, St. Mary river, above Kimball, Alberta.



B. Whitemud and Ravenscrag strata, Ravenscrag butte, Saskatchewan.



A. Crossbedded Ravenscrag sandstone, Cypress hills south of Elkwater lake.



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