CANADA

DEPARTMENT OF MINES

SIR JAMES LOUGHEED, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

GEOLOGICAL SURVEY

W. H. COLLINS, DIRECTOR.

Summary Report, 1920, Part B

CONTENTS

OTTAWA
THOMAS MULVEY
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1921

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No. 1874

SUMMARY REPORT, 1920, PART B

MESOZOIC OF UPPER PEACE RIVER, B.C.

By F. H. McLearn

CONTENTS.

Illustration.

INTRODUCTION

The upper part of Peace river flows through the foothills of the Rocky mountains, approximately between meridians 122 and 123, and a little north of parallel 56. This area is entirely in British Columbia and west of the Peace River block. Parts of the section there exposed were studied in the field season of 1920. The north bank was examined from a point about 3 miles east of Twentymile creek west to Burns creek and from the west end of Brennans flat west to 5 miles west of Schooler creek. A reconnaissance examination was also made in the vicinity of Eightmile creek and the head of the Peace River canyon. An unusually rainy season somewhat hampered the progress of the work. Able assistance in the field was given by A. J. Childerhose, A. H. Bell, and A. B. McLay.

PHYSIOGRAPHY

Within the foothills there is a rugged mature topography of high hills rising about 3,000 feet above deep valleys. No flat tops can be observed, valley slope meets valley slope, or there are long gently sloping surfaces of structural origin. The smaller valleys and gorges extending 600 feet above the bottom of the main valley are V-shaped. Below 600 feet, however, the main and tributary valleys are bordered with terraces carved in fluvioglacial gravel, sand, some clay, and a little boulder clay. That the terraces exhibit curves and cusps points to normal fluviatile origin. In debouching on the plains the river does not flow through the old gap between Portage and Bullhead mountains, but turning to the right passes around the south end of Portage mountain, where it has cut a post-glacial gorge about 700 feet deep. The old gap appears to have been closed by a terminal moraine. The slow cutting down of the gorge of the canyon has necessitated a concomitant slow erosion of the drift deposits occupying the valley upstream and has made possible the production of the terraces. So far the cutting down has been in the glacial drift and has resulted in a comparatively even grade and an absence of rapids. But as soon as the river cuts down into the bedrock below the drift, rapids will begin to form in the present navigable stretches. Parle-pas rapid is only a recent feature and there is the beginning of what may result in a rapid about 5 miles above Schooler creek.

As to the extent and character of Pleistocene glaciation in the foothills, it is not safe, without further investigation, to say more than that in the last stage valley glaciers occupied the main and larger tributary valleys to a depth of about 600 feet and laid down outwash gravel, sand, etc., and some boulder clay, but there was no glaciation above this level. If in earlier stages of the Pleistocene glaciers were of greater magnitude, evidence of it has been destroyed or has not been observed in the foothills along the Peace.

Only the valley flats are amenable to culture and there are small ranches at the mouths of Carbon river, Burns creek, and Twentymile creek.

STRATIGRAPHY

Table of Formations

	System	Formation	Zone	Thickness	Lithology
Mesozoic	Cretaceous	Bullhead Mountain	Upper member Lower member	3,000+	s. s., sh., coal. Massive s.s.
	Triassic (Upper)	Schooler Creek	Zone of *Pseudomonotis*	100+	Purple arenac. l. s., calcar. s. s., sh.
			Zone of *Halobia*	400+	Grey and purple arenac. l. s., calcar. s.s.
			Zone of *Spiriferina-Terebratula*	2,100 +	Grey arenac. l. s., calcar. s.s.

Schooler Creek Formation. This formation, of Upper Triassic age and of marine origin, although not composed of well-marked lithological divisions that would serve as mapping units, can be divided into several faunal zones. In ascending order these are: first, the zone of *Spiriferina-Terebratula* including the *Nathorstites-Dawsonites* beds; second, the zone of *Halobia*; and third, the zone of *Pseudomonotis subcircularis*. In Canada the first zone has also been recognized on Liard river at the Rapids of the Drowned, and at Hell Gate[1]. Frech[2] considers this an Upper Triassic fauna of Karnic (probably Lower Karnic) age. It is known also on Bear island, near Spitzbergen, and has been collected in float at Hamilton bay, Kupreanof island, Alaska[3]. The fauna of the second zone has not yet been studied, but may be the equivalent of the Karnic zone of *Halobia* cf. *Superba* of various Alaskan localities[4], which underlies there the zone of *Pseudomonotis*. The third zone—that of *Pseudomonotis subcircularis*—has in Canada also been found on the upper Pine and Stewart rivers and at a number of localities on the Pacific coast. It is a widely spread upper Noric zone. The "coral-reef" and "chert" zones[5] of Alaskan localities are not present in the Peace River section. The question of the presence of a disconformity at the base of the *Pseudomonotis* zone, however, is best left until the age of the zone of *Halobia* is accurately determined. Details of sections of the Schooler Creek formation follow.

[1]McConnell, R. G., Geol. and Nat. Hist. Surv., Can., Ann. Rept., vol. IV, 1888-89 (p. 49 D).
Whiteaves, J. F., Contr. Can. Pal., vol. I, 1889, pt. 3, pp. 147-149.
[2]Frech, Fritz., Lethaea geognostica, Teil ii, Das Mesozoicum, Band I, pp. 488-491, 508.
Martin, G. C., Bull. Geol. Soc. Am., vol. 27, 1916, p. 707.
[3]Martin, G. C., Bull. Geol. Soc. Am., vol. 27, 1916, p. 707.
[4]Martin, G. C., Bull. Geol. Soc., Am., vol. 27, 1916, pp. 707-709.
[5]Martin, G. C., Bull. Geol. Soc. Am., vol. 27, 1916, pp. 709, 710.

Over 1,600 feet of beds of the *Spiriferina-Terebratula* zone outcrop on the hill east of Burns creek. At the bottom are slaty, calcareous and arenaceous hard shales with lenses containing *Dawsonites* and *Nathorstites.* Above are thick-bedded light and dark grey arenaceous limestones and calcareous sandstones with *Terebratula, Spiriferina, Nathorstites,* etc. Higher are light and dark grey thick-bedded calcareous sandstones and arenaceous lime stones with some *Terebratula, Spiriferina,* and pelecypods. These thick-bedded light and dark grey calcareous sandstones and arenaceous limestones, with occasional *Terebratula* and *Spiriferina* are very common in all the sections studied. They make up a large part of the formation. Overlying these beds and lithologically transitional to the rocks of the zone of *Halobia* are mixed grey and chocolate-brown to purple thick-bedded arenaceous limestones and calcareous sandstones with occasional *Terebratula* and very rarely *Spiriferina.* Some of these beds have numerous geode cavities lined with crystals of calcite and, very rarely, crystals of sulphur. About 500 feet are of this character, making the total thickness of the *Terebratula-Spiriferina* zone at least 2,100 feet.

The zone of *Halobia* is about 400 feet thick and is composed of thick-bedded chocolate-brown to purple arenaceous limestones and calcareous sandstones. It is exposed on the hills west of Brennans flat and on a hill about 5 miles west of Schooler creek.

The zone of *Pseudomonotis subcircularis* is found on the hill west of Schooler creek, where it immediately follows the zone of *Halobia.* Only about 10 feet of the base outcrops. From the top of the Pseudomonotis to the bottom of the nearest Bullhead Mountain exposure 1,000 feet of strata are unfortunately concealed.

A conservative estimate of the thickness of the Schooler Creek formation is 3,000 feet.

Bullhead Mountain Formation. This formation was described and divided into upper and lower in the Summary Report for 1917, part C. The lower member underlies all the hills bordering the north side of the valley from Bullhead mountain to within about 2 miles of Twentymile creek. It is also found in the upper part of the canyon from its head down to some distance above the mouth of Gething creek. A few beds of dark shale and thin coal seams were noted in this part of the formation. Most of this member is of nonmarine origin, but a few poor marine fossils, including *Inoceramus,* were found near the base.

The upper member outcrops on both sides of the canyon from above Gething creek to about midway between Johnson and Deep creeks, where it is overlain by the St. John formation. It is also found for some distance up Gething, Moose, and Johnson creeks where it is followed by the St. John shale. On the north bank of the Peace from Bullhead mountain to Twentymile creek it outcrops only on the highest hills remote from the river and almost inaccessible.

No satisfactory section has yet been found in which to measure the Bullhead Mountain formation; it is at least from 2,500 to 3,000 feet thick.

A collection of plants from the upper member collected in the canyon in 1917 was recently sent to Professor E. W. Berry of the Johns Hopkins University. He considers it a well-defined Kootenay flora of Lower Cretaceous age. His identifications are as follows:

Oleandra graminæfolia Knowlton
Clodophlebis sp.
Onychiopsis psilotoides (Stokes and Webb) Ward
Dicksoniopsis (?) sp.
Pterophyllum acutipennis (Heer)
Nilsonia nigræcollensis Willard
Nilsonia sp.
Podozamites lanceolatus (L. and H.) F. Braun
Sequoia smittiana Heer
Inolepis imbricata Heer
Torreya dicksoniana Heer
Ginko arctica Heer

STRUCTURE

The structure is unusual. Although there are some anticlines and synclines of normal type, the rocks are not thrown into the usual well-defined and consistent undulating structure of anticline and syncline. There are large areas where the strata are flat or gently dipping with smaller and more circumscribed areas where the strata are very steep. The thick massive beds of the Schooler Creek and Bullhead Mountain formations acted as very "competent" or resistant strata and could carry stresses for long distances. Faulting is also present with high angles and considerable magnitude. A fault about 2 miles east of Schooler creek is estimated to have a throw of 1,100 feet. Like the land forms and the stratigraphy, the structure of this region is on a large scale.

ECONOMIC GEOLOGY

Coal. The lower member of the Bullhead Mountain formation is not promising as a coal producer. Coal seams were noted on the lower part of Eightmile creek and at the head of the canyon. They are too thin and of too poor a quality to be of commercial importance. The upper member contains coal of high grade, low in ash and high in carbon, but many of its seams are thin. The 5-foot seam described in 1917 is now being explored. The distribution of this upper member described under Bullhead Mountain formation is important from the standpoint of prospecting and exploration.

Oil. The area extending along the Peace from Bullhead and Portage mountains on the eastern border of the foothills, westward to the mountains is too large to cover adequately in one season. The evidence so far gathered is not favourable to oil exploration. The writer knows of no place where a drill could be located, with possibilities of success as deduced from the geological conditions. Exploration should not be attempted unless further geological work yields unexpected, and as yet unknown, data that would justify drilling. The reasons for this decision are given below. The only horizon now known to the writer that would serve as a suitable oil reservoir is that of the geodal beds which lie in the chocolate-brown and grey strata below the zone of *Halobia*. The other beds, both of the Schooler Creek and lower Bullhead Mountain formations, are too firmly cemented and too massive to function as reservoirs. The structure is not favourable: there is no consistent and well-defined undulating structure of syncline and anticline or even of terrace structure; it is difficult to see how the peculiar structure of this region would promote concentration in pools; of course a few true anticlines are present as on Bullhead and Portage mountains; then there is considerable faulting, of large magnitude, and this is unfavourable to the preservation of oil pools. The rocks, too, have suffered too much metamorphism to admit of preservation of oil in any quantity; the very best that could be expected would be light oil in very small quantities, mere pockets; the high carbon content of the coal exposed in the canyon is a good measurement of the metamorphism that the rocks have undergone.

Placers. The fine gold obtained from the bars on the river flats is not thought to have a local source, i.e., from the Schooler Creek and Bullhead Mountain formations, but to have come from the schists and other older rocks within the mountains to the west. It has been transported by glacial action in Pleistocene time or normal fluviatile work in both Pleistocene and Recent time. In the working over of this transported gravel and sand, in the course of the excavation of the post-glacial valley, re-sorting and concentration of the gold particles have taken place so that some places at or near the surface of the flats and bars are rich in gold content as compared with the unsorted bulk of the material: this sorting and concentration of gold is continually going on, enriching certain parts of the surface of the bars. Only the upper parts of the river bars and flats are likely to be gold bearing and obviously if the gold is not of local origin it is useless to search for enrichment at bedrock. A very small amount of platinum has been found with the gold.

Landslides. The following applies to northern Alberta in general and the Great Plains area along the Peace, Smoky, and other rivers in particular. Landslides on valley slopes are common phenomena in this region. The valley slopes are considerably modified by them; the river terraces are destroyed and hummocky surfaces are formed. Susceptibility to sliding depends on the slope and on the character of the materials. Where the material is Cretaceous sandstone, movement rarely takes place. The Pleistocene sand, too, is rarely affected; but slides in it have been observed on very steep slopes; it moves in large blocks and leaves vertical scarps or cliffs. Interbedded clay in small proportion does not appear to have any effect, but in large amounts promotes sliding. The Cretaceous shales are very susceptible where exposed, absorb moisture and move down hill; they may migrate in blocks leaving behind fresh scarps of bare rock, or may actually flow; the slide has in places, evidently contracted in order to pass through an opening in a sandstone ridge bordering the river, and then has expanded in a large fan-shaped cone on the river bank. Where the shale is overlain by Pleistocene sand it may be protected from sliding. The most fruitful source of landslides is boulder clay. It covers a large part of the slopes of the pre-glacial valleys in the region.

The relative potency of the Pleistocene sand and boulder clay in the production of slides is demonstrated by their effect on the railway grade on the valley slope of the Peace, near Peace River. In order to carry the railway from the high plateau down almost to river-level at Peace River, it was necessary to locate it for several miles along the valley slope so as to obtain a practicable grade. Throughout this distance it is exposed to any slides on the valley slope. The geological relations of the valley side are shown in Figure 1A. The following remarks apply to the railway for a distance of about 1 mile above the town in the spring of 1920. It was found that where the cut was in the outer layer of boulder clay, considerable distortion of grade and track had taken place (Figure 1B), except where the valley slope is very low. But where the cut is carried through the boulder clay into the underlying Pleistocene sand, the grade and track were firm (Figure 1C). In one place, however, the track though covered with a slide of boulder clay from the top (Figure 1D), remained firm. Where the fills are on exposed Pleistocene sand, the grade and track were firm (Figure 1E). The only trouble here is from boulder clay sliding down from above. Where the fill is on the outer boulder clay film, the grade and track were out of place (Figure 1F). Obviously boulder clay would be poor material for fills in this northern country. This shows that the Pleistocene sand is relatively firm, whereas the boulder clay is in movement. The difficulties of locating a railway on such a surface are obvious. In places, carrying the cut into, and placing the fills directly on, the more solid sand below may be feasible; in other locations, particularly where the boulder clay is very thick, it would entail too much expense. The mobility of the surface layer of sliding boulder clay and the comparative stability of the Pleistocene sand, however, are worthy of the attention of railway engineers working in the north.

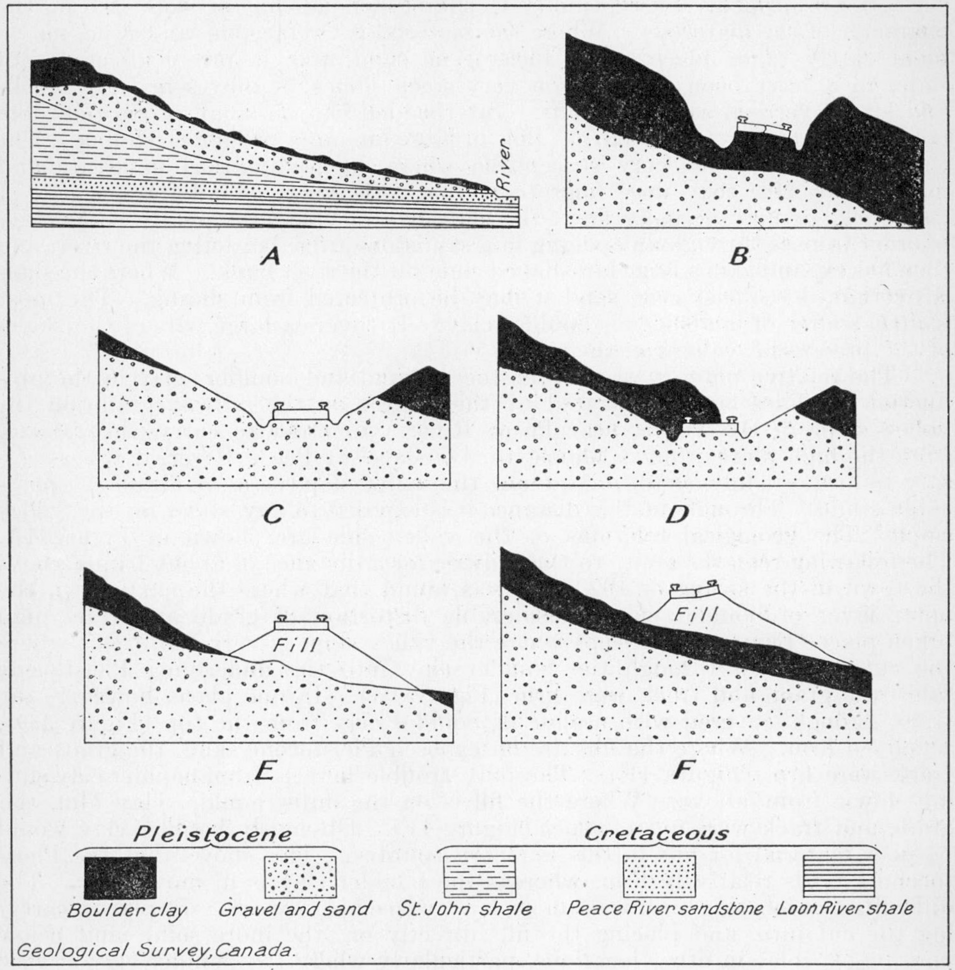

Figure 1. Diagram showing stability of Pleistocene sand and boulder clay mantle in relation to maintenance of railway grade.

A. Geological section of valley side at Peace river.

B. Cut in boulder clay, with distortion of grade.

C. Cut in sand, grade firm. D. Cut in sand, grade firm, but buried by slide of boulder clay. E. Fill on sand, grade firm. F. Fill on boulder clay, with distortion of grade.

UPPER ELK RIVER VALLEY, BRITISH COLUMBIA

By J. R. Marshall

INTRODUCTION

The field season of 1920 was occupied with structural and areal mapping of the coal-bearing and associated formations of the Upper Elk River valley, British Columbia. The duties of assistant were performed by H. F. Swann in a very capable and efficient manner. Sincere thanks are tendered Mr. Neal McQuarrie; Dr. Bruce Rose, and others for courtesies and useful suggestions.

GENERAL DESCRIPTION OF AREA

The Upper Elk River valley, drained by the Elk and Fording rivers and their tributaries lies immediately west of the continental divide in the Rocky mountains and north of 50 degrees north latitude. This portion of the valley varies in width from 2 miles at the head to 12 miles where it crosses the 50th degree of latitude. The valley is walled in by high limestone ridges that attain heights of 9,000 and 10,000 feet.

Between the limestone ranges, flanking both sides of the valley, and at somewhat lower elevations, is an important Cretaceous trough whose axis trends in a general northwest-southeast direction. The rocks forming this trough are arranged as a series of parallel ridges, the axes of which correspond very closely to the axis of the trough.

Elk river rises in the Elk lakes, approximately 4 miles north of 50° 30′ north latitude, and flows in a general southerly direction across the area. In the upper 10 miles of its course the river follows the base of the limestone ridge which has been thrust eastwards upon the eastern arm of the Cretaceous syncline.

About 17 miles south of 50° 30′ north latitude, it cuts across the axis of the Cretaceous syncline and again follows the base of the limestone ridge, which is here faulted upon the western limb of the syncline.

Separated from Elk river by the Green Hills range and only 2 miles distant from it, is Fording river, which for about 20 miles parallels the Elk. It then bends abruptly northwestward around the north end of the Wisukitshak range, and pursuing this course for about 2 miles, again turns south and joins the Elk about 8 miles south of 50 degrees north latitude. This abrupt bend is probably due to a tributary stream capturing the main Fording waters and diverting them around the Wisukitshak range.

GENERAL GEOLOGY

The area is underlain by a thick series of sedimentary rocks which, on the east side of the valley, are conformable one on the other; to the west there has been overthrust faulting. These sediments range from Devono-Carboniferous to Lower Cretaceous, the latter containing important seams of bituminous and semi-bituminous coal.

Table of Formations.

Pleistocene and Recent	Superficial deposits
Cretaceous, Upper	Elk conglomerates
Cretaceous, Lower	Kootenay formation
Jurassic	Fernie formation
Triassic	?
Devono-Carboniferous	Limestone, quartzite

Devono-Carboniferous. The great limestone series, which comprises a large part of the Palæozoic rocks of the Rocky mountains, is represented in the Upper Elk valley by rocks of Devonian and Carboniferous ages. In the extreme eastern part of the area examined the limestone forms the main range of the Rocky mountains and the divide between British Columbia and Alberta. The Devono-Carboniferous rocks consist of a well-defined, quartzite member, beneath which lies a limestone member. The base of the limestone is not exposed, since to the east, on the Alberta slope, this formation has been thrust over the upturned edges of the Cretaceous. There is also another limestone member much more crystalline than the limestone of the main range of the Rocky mountains.

The quartzite member, which lies conformably beneath the Fernie formation, is very fine-grained to dense, compact, and of light grey colour, resembling the Rocky Mountain quartzite of the Bow River section. It forms the lower western slope of the main range of the Rockies where it has a thickness of approximately 150 feet. The north end of the Wisukitshak range is underlain by a similar quartzite which carries Pennsylvanian fossils, and there the quartzite attains a thickness of at least 800 feet. The quartzite of the main range dips 70 to 85 degrees west, that of the Wisukitshak range 50 degrees east.

Underlying the quartzite of the main range of the Rocky mountains are massive, evenly bedded, light grey, slightly crystalline and arenaceous limestone of probable Pennsylvanian age. These are in faulted relations with the Cretaceous rocks on the Alberta slope.[1]

On the west side of the Upper Elk valley are massive, light-coloured, coarsely crystalline limestones and cherty limestones which may be Devonian. These have a persistent westerly dip and are thrust-faulted eastward over the Fernie and Kootenay formations.

Fernie Formation. Between the Palæozoic and the Kootenay formations is a thick series of shales referred to the Fernie formation, which has been described by Rose and others in the Crowsnest and adjacent areas.[2]

In the Upper Elk valley good sections of the Fernie are the exception. Where exposed in partial section, it consists of thinly-bedded, black and grey, platy and fissile shales. On a ridge between the heads of Aldridge and Weary creeks, the black fissile shales grade into a brown sandstone and finally into a quartzite, all of which is referred to the Fernie. In this particular section the formation attains a thickness approximating 900 feet.

Above the falls on Fording river are black banded shales and slates with interbedded quartzites. These carry fossil ammonites and are also referred to the Fernie. They appear to underlie the area westward from the Wisukitshak range across Elk river to the limestone, which has been thrust eastward upon the shales. The structural relations between these shales and the quartzite of the Wisukitshak range could not be definitely determined. Both have easterly dips, the quartzites 50 degrees, the shales at angles varying from 5 to 15 degrees.

Kootenay Formation. The most important formation of the area from an economic viewpoint is the thick series of sandstones, shales, and intercalated coal seams called the Kootenay formation, which overlies the Fernie conformably. The bottom of the Kootenay is placed at the base of a massive, coarse, cross-bedded sandstone, above which occur black shales and coal seams with some conglomerate. Massive, coarse-grained, crossbedded, grey, brown, and reddish-brown sandstones predominate over grey, brown, and black friable shales. Throughout the area, the formation varies considerably in very short distances, in the proportions of sandstone to shale. These variations and the frequent alternating of sandstone, shale, and coal, indicate many and possibly rapid changes in conditions under which the Kootenay was laid down. The coal measures attain a thickness of 3,500 feet in the Green Hills range of the Upper

[1]Rose, B., Geol. Surv., Can., Sum. Rept., 1916, p. 109.
[2]Geol. Surv., Can., Sum. Repts., 1917–18–19, pt. C.

Elk valley. They are folded in the form of a syncline and occupy fully two-thirds of the valley east of Elk river.

Included in the Kootenay formation are a number of coal seams many of which have a thickness of 10 to 15 feet and some 20 feet. All of this coal is of a bituminous or semi-bituminous quality.

It is doubtful if the top of the Kootenay is exposed in any part of the Upper Elk valley. On the Alberta slope a prominent conglomerate band separates the productive Kootenay measures from the non-productive sandstones and shales above. But Rose reports more than one band of conglomerate in the Crowsnest area of British Columbia, and coal above the first band.[1] Therefore, it is doubtful if the band of conglomerate mentioned above marks the upper limit of the Kootenay in the Upper Elk valley.

Structure

Between the high limestone ranges which lie on either side of the Upper Elk River valley is a thick syncline of Mesozoic sediments in places 6 miles wide. On the extreme eastern edge of the valley these sediments lie conformably above the Palæozoic quartzite, and limestone. On the western side crystalline limestones of probable Devonian age have been thrust eastward upon both limbs of the syncline.

The axis of the syncline has a general northwest-southeast trend. North of 50 degrees north latitude, it follows very closely Fording River valley and crosses the Elk between the two prominent ridges that form the Green Hills range. North of this point only those measures outcrop which form the east limb of the syncline and these pass rapidly beneath the overthrust limestone.

About 2 miles north of latitude 50 Fording river leaves the syncline of Cretaceous rocks and bends around the north end of the Wisukitshak range which at this point is composed of quartzite of Pennsylvanian age. To the west of the Wisukitshak range, easterly dipping shales and slates, with fossil ammonites, outcrop in the bed of Fording river. These shales are referred to the Fernie formation, younger than the quartzite, but appear to pass beneath the quartzite. The north end of the Wisukitshak range may be part of an overturned block thrust upon the Kootenay, or there may be faulted relations between the Fernie and the quartzite of the Wisukitshak range, the latter thus occupying its normal position in the syncline. This could not be determined definitely.

ECONOMIC GEOLOGY

The Upper Elk River valley is occupied by a thick series of sandstones and shales which contain a considerable thickness of bituminous and semi-bituminous coals. As many as twenty-two distinct seams yielding a thickness of 175 feet of coal have been reported in the area.[2] In order to summarize briefly the coal of the Upper Elk valley the area may be divided into two sections, the Elk River section and the Fording River section.

Elk River Section

The bulk of the coal of the Elk River section is contained in the Green Hills range on the east side of Elk river. The coal measures here attain a thickness of 3,500 feet. At the Canadian Pacific Railway headquarters camp, two tunnels have been driven on the western slope of the Green Hills range. Two seams 12 and 15 feet thick were observed here. Higher on the slope indications of other good seams were observed. Immediately south of this location

[1]Rose, B., Geol. Surv., Can., Sum. Rept., 1917, pt. C, p. 30.
[2]Dowling, D. B., Geol. Surv., Can., Mem. 69, pp. 35–36.

on the same slope, Leach measured a section which gave 89 feet of coal in 3,386 feet of coal measures.[1] The Green hills here form the western limb of the syncline.

On Aldridge and Weary creeks intensive prospecting has revealed thick workable bituminous coal all of which occurs on the east arm of the syncline. A section measured by D. B. Dowling on the north side of Aldridge creek gives 175 feet of coal in 1,169 feet of coal measures.[2]

A partial section measured by the writer on the south side of Aldridge creek shows 60 feet of good coal in 900 feet of coal measures.

A sample from a 12-foot seam exposed in a tunnel on the north side of Aldridge creek and submitted for proximate analysis to the Fuel Testing station, Department of Mines, Ottawa, gave:

Moisture	1·2 per cent
Ash	8·2
Volatile matter	26·6
Fixed carbon	64·4

On Weary creek six seams gave approximately 80 feet of coal.

On the west side of Elk river coal seams have been uncovered at Hornickel (Iron) creek, and at Bleasdell creek, but in both places the westward extension of the coal measures passes beneath the limestone which has been thrust eastward upon the Kootenay.

North of Weary creek indications of coal were observed about 3½ miles south of the divide between the Kananaskis and Elk waters, and these indications continued at intervals across the divide into Alberta.

Fording River Section

On the south side of Ewing creek, east of its junction with Fording river, a number of entries have been driven along the trend of the coal measures. Many of these are now caved but coal seams ranging from 10 to 15 feet in thickness were observed. The measures here occur on the east limb of the syncline and are the southward continuation of those exposed on Aldridge and Weary creeks.

North from Ewing creek and east of Fording river indications of strong seams were found on many of the slopes as far as Henrietta creek. Thus there is every reason to believe that the seams exposed on Aldridge and Weary creeks are continuous at least to Ewing creek, and that a thickness of coal equal to that on the above-mentioned creeks (Aldridge and Weary) occurs here. An analysis of a sample selected from a 10-foot seam on the south side of Ewing creek shows the coal to possess fair coking qualities.

From the above summary it will be seen that there is in the Upper Elk valley a considerable thickness of workable bituminous and semi-bituminous coal. The seams are all pitching from 35 degrees to 50 degrees. The mining of this coal will not involve any serious difficulty as the methods used in the adjoining Crowsnest field will apply here, and the valleys of Elk and Fording rivers afford practical routes for a railway.

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[1]Leach, W. W., Geol. Surv., Can., Sum. Rept., 1901, p. 71.
[2]Dowling, D. B., Geol. Surv., Can., Mem. 69, p. 33.

REVIEW OF PROSPECTING FOR OIL ON THE GREAT PLAINS

By D. B. Dowling

CONTENTS

Illustrations

INTRODUCTION

Prospecting for oil in Alberta during the past season has been carried out in five distinct structural provinces (Figure 2); (1) the outer edge of the foothills of the Rocky mountains; (2) an elevated anticlinal strip in front of the Lewis and Clark ranges; (3) the Lewis and Clark ranges of the Rocky mountains; (4) the terrace structure along the northeast border of the Alberta syncline, the Peace River-Viking terrace, and its continuation to the Ribstone-Sounding Creek disturbed area; (5) the Bow Island anticline.

In Saskatchewan borings have been begun on the western edge of the basin which attains its greatest depth at Estevan. Oil has been found in this western edge where it extends into Montana; enclosing the Little Rocky and Bearpaw Mountains uplift. On the Canadian side of the basin no drillings have penetrated the oil-carrying beds, but a slight upthrust fault south of Consul near the boundary and a flat anticlinal arch exposed on South Saskatchewan river north of Rush Lake station on the Canadian Pacific railway are to be tested by the Imperial Oil Company. Drilling rigs are already installed.

Outer Edge of the Foothills

The larger prospecting operations in this field have passed into the hands of companies with sufficient capital to complete individual undertakings and to retain a staff of expert geologists. The results of the present drilling may, therefore, be looked forward to with more confidence than the sporadic work of 1913. A very small percentage of the first drill holes reached horizons in which there would be some chance of finding oil and many of the failures were made on unfavourable structures or in areas otherwise unfavourable. The success of the operations on the Turner Valley anticline on Sheep river has induced the geologists of the Imperial and Whitehall oil companies to search for similar structures in the foothills. In the northern foothills, as mentionned in the Summary Report, 1919, Part B, one anticlinal ridge was discovered last year in the region between Brazeau and Athabaska rivers, but no drilling has yet been done. South of Bow river it seems possible, that, were leases obtainable, prospecting might be resumed on the area near Jumpingpound creek, as it is known that some oil was obtained in the Moose Mountain well.

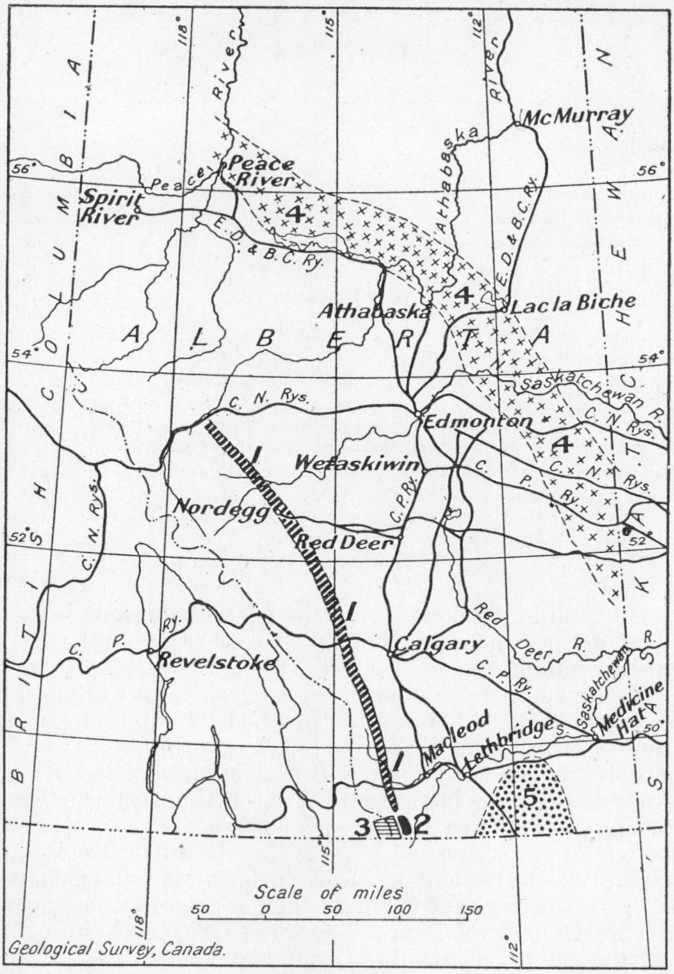


Figure 2. Index map showing the areas in Alberta where prospecting for oil is in progress.
1. Outer edge of foothills.
2. Elevated belt in front of Lewis and Clark ranges.
3. Lewis and Clark ranges.
4. Terrace structure along northeastern border of Alberta syncline.
5. Bow Island anticline.

The foothills from Sheep river to the International Boundary have been mapped by J. S. Stewart[1]. In this area several locations have been selected by various companies, and operations have been started this year at three localities by the Imperial Oil Company. These were visited and a study of the structure in each vicinity was made which in each case confirmed Mr. Stewart's surveys.

[1]Geol. Surv., Can., Mem. 112.

SHEPPARD CREEK, HIGHWOOD RIVER

(Figure 3.)

Well No. 2, Alberta Associated Oil Company. The operations for the present season seem to be under the direction of the Imperial Oil Company. This well

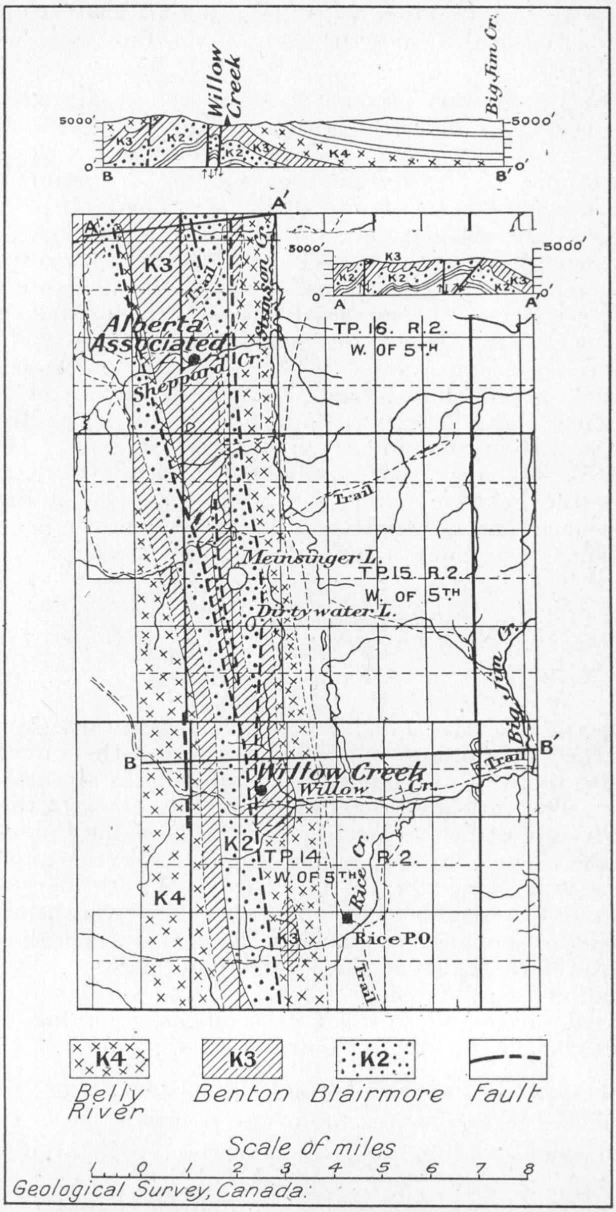


Figure 3. Diagram and sections of Sheppard and Willow creeks, Alberta.

is an unfinished prospect of 1916. No log is at hand but a note by Mr. Slipper[1] gives the following information. "This well, located on sec. 7, tp. 16, range 2,

[1]Geol. Surv., Can., Sum. Rept. 1916, p. 118.

W. 5th mer., was temporarily abandoned in 1915, but during the past season (1916) the hole was cleaned out and drilled deeper. A small seepage of dark green oil was found at 2,300 feet. Drilling was continued to a depth of 2,605 feet when work ceased for the winter. The hole was still in Benton formation at 2,605 feet."

It seems to be the intention to drill deeper to ascertain the character of the measures at the base of the Benton formation and whether there has been sufficient storage of oil in the sandy measures of the Dakota to warrant further drilling.

According to Mr. Stewart's section A-A the well is in a westward-dipping fault block that is split by several longitudinal faults, and at places shows also corrugations. It is separated from the eastward-dipping rocks by north and south overthrust faults. The section suggests that a distinct anticline was found first, and later broken by overthrust faults. The fault blocks are narrow and do not suggest large drainage areas. The drill holes have penetrated the beds at a high angle, but the thickness of the formation suggests a thickening by crumpling or repetition by overthrust faults. If a moderate amount of oil is found in this well, it may be supposed to have accumulated during the formation of the anticline and before the final faulting. The sandy measures of the base of the series, being exposed to the air along the eastern edge of the fault block, would subject this storage to a certain amount of evaporation of the lighter elements, and a heavier oil than that of the Sheep River field could be looked for. A certain amount of gas is known to be escaping in sec. 20, tp. 15, range 2, W. 5th mer., that is, about 4 miles south of this well. The fault—known as the Pekisko—which shears off the crown of the anticline, is thought to be inclined, and although for a distance the crown is not in evidence, there is a possibility of reaching it through the fault plane.

WILLOW CREEK

(Figure 3.)

Well of Imperial Oil Company. For 6 miles southward from the well on Sheppard creek the Pekisko fault cuts off the crown of the anticline. Thence it bears slightly to the west and a part of the anticline is revealed in the valley of Willow creek. The anticline is again seen on Rice creek to the south and is pitching southerly so that in two localities the rocks of the Colorado formation are exposed on the crown. In the arch on Willow creek, the Imperial Oil Company is sinking a well on sec. 29, tp. 14, range 2, W. 5th mer. This location appears structurally to resemble closely that on Sheep river, hence wet gas and probably light oil also should be obtained. The drill starts in the upper part of the Benton or the dark shales of the Colorado formation. The thickness of the whole formation is estimated at 2,000 feet, and the Blairmore formation beneath at 950 feet. In the Sheep River wells, oil has, according to Mr. Slipper, been obtained in varying amounts at four horizons.

(1) The uppermost bed of the Blairmore formation.

(2) Five hundred feet below the top of the Blairmore.

(3) One thousand, one hundred feet below the top of the Blairmore in the Kootenay.

(4) About 1,300 feet below the top of the Blairmore.

Anticline in Front of Lewis and Clark Ranges

(Figure 4.)

DRYWOOD RIVER

This branch of Waterton river flows from the mountains across a broad strip of foothills. The geological structure of the foothills at this place differs from that of the foothills to the north, in that the highly disturbed belt to the

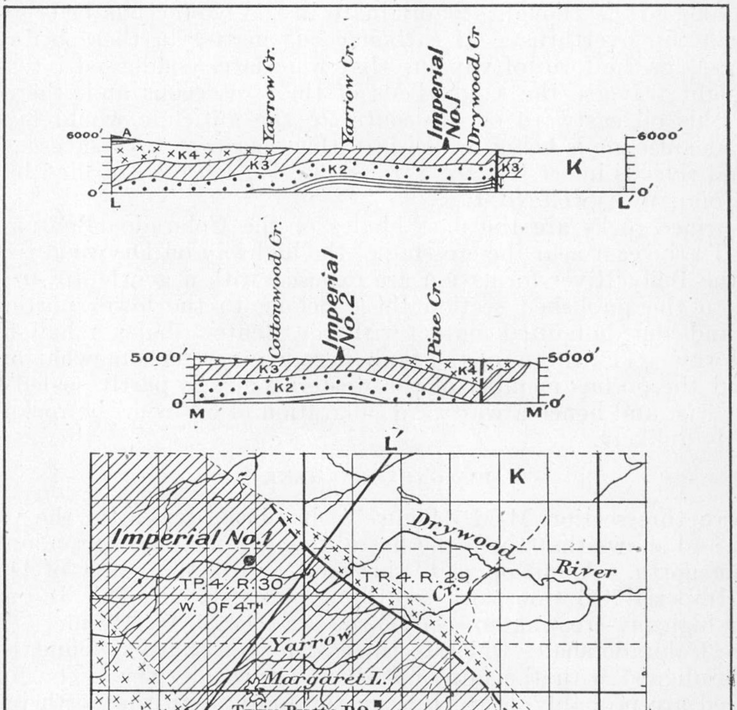


Figure 4. Diagram and sections of Drywood river and Dungarvon creek, Alberta.

north swings away from the mountains in tp. 5. It consists of a wide, rather flat anticline whose western limb is overridden by the limestone ranges of the mountains. To the east it is separated by a fault from another wide band whose structure is concealed by drift. The line of faulting which generally marks the foothill structure, lies still farther to the east and runs in a general northwest and southeast direction.

The rocks of the band in front of the limestone are elevated in comparison with those of the plains but must be separated from the Alberta syncline by the many faults of the outer margin. Mr. Stewart thinks the structure holds possibilities for the accumulation of oil. Oil is known in the mountains west of Waterton lake. It is thought to originate in the Cretaceous beds overridden by the mountain overthrust. If carbonaceous matter in these beds was distilled upwards in the form of vapours that were later condensed into oil, these vapours might traverse the sandy beds of the Cretaceous and, therefore, the storage of this oil eastward of the centre of the anticline would be possible.

The flat anticline is being drilled into this season at two places. The hole on Drywood river is in sec. 14, tp. 4, range 30, W. 4th mer., drilled by the Imperial Oil Company as well No. 1.

The surface rocks are the dark shales of the Colorado (Benton of some reports). To the east near the crossing of the highway on Drywood river, sandstones of the Belly River formation are exposed with a gentle dip to the east. According to the published section these belong to the lower portion of the formation and come in faulted contact with the Benton shales a half mile west of the highway. The throw of the fault here is given as somewhat over 1,000 feet, so that the porous member of the western block is partly sealed from the beds to the east and hence a westward migration of oil from the rocks beneath the plains is unlikely.

DUNGARVON CREEK

The structure section M-M[1] (Figure 4) has been drawn for the vicinity of Pine creek and shows that there the flat anticline has a more pronounced crest than farther north. About opposite this crest and in the valley of Dungarvon creek the Imperial Oil Company is drilling well No. 2. This is just to the west of the highway-crossing on sec. 21, tp. 3, range 29, W. 4th mer. The rocks exposed are Colorado shales which to the east form a sharp syncline, the centre of which is aligned with the fault noted on Drywood river. The formations to be pierced are probably as thick as in the foothills to the north but the oil horizons can not be predicted. The beds beneath the Colorado are known to be largely coarse-grained and possibly quite porous. Coal beds should be found in the Kootenay.

A well was started in 1891, just east of the road crossing in the same section. When visited by Dr. Selwyn in July of that year a derrick was being constructed. No indications of petroleum were found by him and he concluded that the venture was rather of the wild-cat order although the selection of the site was on the advice of an expert named Baring. This work was, probably, undertaken on account of the discovery of oil seeps the year previous on Cameron brook. Work did not continue, for, in the Summary Report for 1891, Dr. Selwyn adds "I subsequently heard that a copious flow of water had been struck and the boring abandoned."

Lewis and Clark Ranges, Rocky Mountains

(Figure 5.)

WATERTON LAKE AND CAMERON BROOK

Seepages of oil were reported on Cameron brook in 1890, and examined by Selwyn in July of 1891. They were found in the bed of the brook about

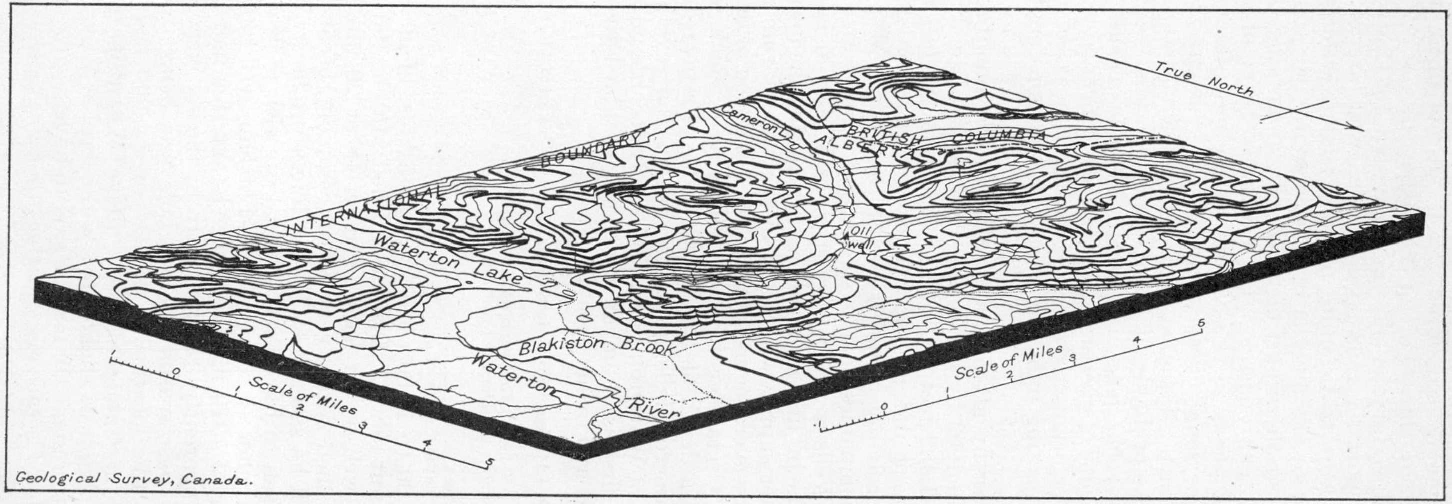


Figure 5. Isometric diagram of part of Waterton park, Alberta, looking southwest. Contour interval of 500 feet is shown only in half true relief.

2 miles above the bend. The occurrence of oil in any large quantity in rocks of Lower Cambrian age was doubted and it was not until attention was called to the possibility of overthrusts along the eastern face of the Rocky mountains, that a possible source for the oil was suggested to Dawson. His comment in the Summary Report for 1898 no doubt renewed interest in the subject.

"It further appears to be quite possible that overthrusts of the kind referred to may serve to explain the otherwise somewhat anomalous occurrence of petroleum in the southern part of the Rocky mountains, between the Crowsnest and South Kootenay passes. The actual existence of small quantities of petroleum in several places in this portion of the mountains was verified, some years ago, by the personal observations of Dr. Selwyn. The petroleum was actually found in parts of the mountain region characterized at the surface by very ancient rocks probably of Lower Cambrian age. If it may be assumed however, that these rocks possibly overlie, in some places, those of the Cretaceous series, by reasons of overthrusts, it is easily conceivable that the petroleum in question may have originated in consequence of heat, at considerable depths in the earth's crust, acting upon the fixed hydrocarbons contained in the rocks of that series."

The first noteworthy attempt at drilling in the mountains near the known oil seep was made in 1903 by a company formed by John Lineham. This well was reported to be 1,400 feet. Oil was found at 1,080 feet and filled the well. The further deepening did not apparently increase the flow and difficulties developed which probably included loss of the tools. Many other holes were drilled by various companies on this stream but other horizons were not found to be oil-bearing. Wells were also drilled near Waterton lake on the anticline which crosses the lake in line with the prolongation of the lower part of Cameron brook, but no further supply was found in the rocks forming the lower part of this series. One, however, seems to have had a showing of oil and, it is thought, penetrated into the Cretaceous beneath. This well, which was bored probably in 1905-07, reached a depth of 1,984 feet. This is reported by R. A. Daly to have been near Cameron falls, probably one of the several that were bored within the townsite of Waterton park. The only records published are included in this note. The first is from an interview obtained by F. G. Clapp with the driller who lived at Pincher creek.[1]

"Surface elevation 4,140 feet (latest data gives Waterton lake 4,202 feet.)
Depth 1,984 feet.
Hard limestone 1,150 feet. Red sand at 1,200 feet.

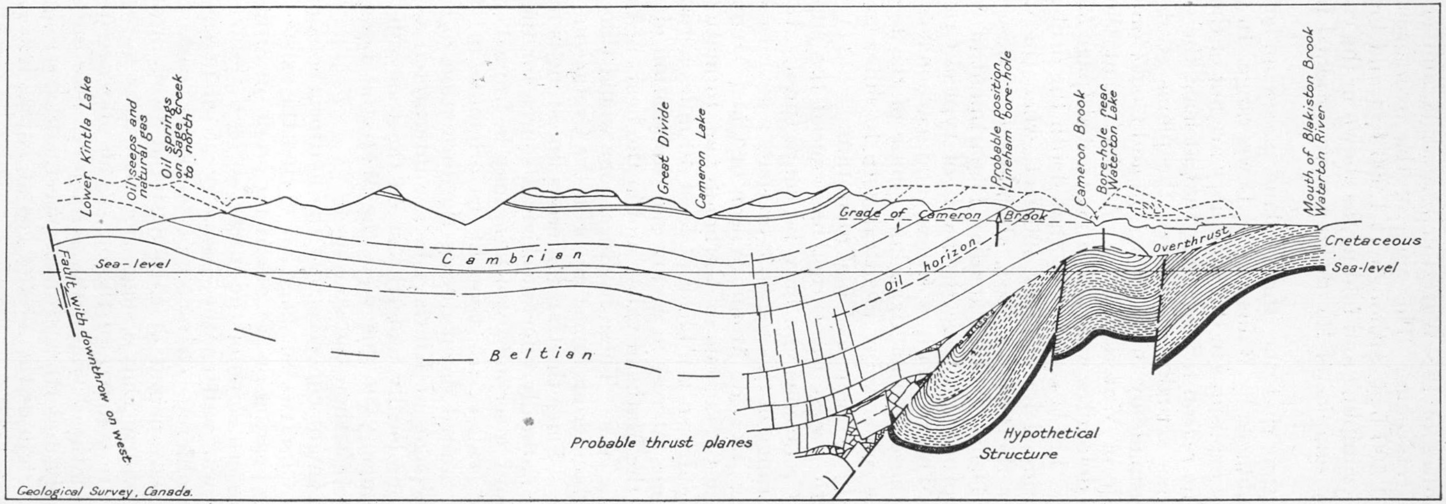
Blue marl 200 to 300 feet. Depth of bottom	1,460 to 1,560 feet.
Soft to about	1,800 "
Hard streaks 100 feet	1,900 "
Soft brown shale, caving, show of oil	1,984 "

"Baled from 6.00 to 12.00 o'clock about 5 bbls. of oil. Was not pumped and no tubing was put down. Drilling finished March, 1907.

"Stafford says well would have been an 18 or 20 bbl. producer, but lost tools and caved, fished for a year until company became disgusted. Says this is the only well he saw which looked like a producer."

All the wells seem to have been stopped up with tools or debris and many attempts have been made to clean out the Lineham well but with little success. During the summer of 1919 it was reported that this had been accomplished, but the cleaning apparently resulted only in the recovery of about 4 barrels of oil. During the past season another hole was being drilled nearby. The elevation given for this location is slightly over 5,000 feet which indicates a rise of 1,000 feet in Cameron brook above Waterton lake, so the oil seep was found in the well in beds slightly below the level of Waterton lake and in the beds of the Beltian terrane. Oil may be said to have been found at two horizons, one in the overridden Cretaceous and the other in the overlying beds of Cambrian quartzites.

[1]"Petroleum and natural gas resources of Canada," vol. II, p. 327, Pub. No. 291, Mines Branch, Dept. of Mines, Can.



6. Geological section from lower Kintla lake, Montana, to Blakiston brook, Waterton river, Alberta, showing hypothetical condition of overthrust of Cambrian on the Cretaceous.

In the well drilled near the lake there seems little doubt that the drill penetrated the dolomites of the Waterton formation and entered soft shales, which seem to be Cretaceous. The zone of the overthrust was apparently penetrated at about 1,500 feet, although at 1,900 feet and lower the beds were probably affected by crumpling and folding, as shown in the caving that stopped the work. Evidently samples of the drilling were obtained by Daly who thus reports on this well.[1]

"The demonstration that the thrust-plane passes under the Clark range is not as full as that adduced by Willis for the Lewis range. In the more westerly range the natural rock exposures in the Boundary are not of themselves sufficient to show the fact. The reason for believing that at least the eastern part of the Clark Range block has actually overridden the plains strata is found in the log of the deep boring made by the Western Oil and Coal Company at Cameron falls, on the west side of Waterton lake. At that point the drill penetrated 1,500 feet of siliceous dolomites which, as above noted (page 55) form the downward extension of the Lewis series. At that depth the drill suddenly entered soft shale which continued for another 400 feet, when the work was stopped and the bore-hole for the time at least, abandoned. These shales have been examined by Mr. T. Denis, of the Canadian Department of Mines, and by the writer; the material proved to have the habit of typical Cretaceous, probably Benton, sediments. Their colour, softness, and carbonaceous character are quite different from those characterizing any phase of the Lewis series; on the other hand the shales are sensibly identical with fossiliferous Cretaceous beds occurring below the thrust-plane at Chief mountain.

"How much farther west the thrust has caused the superposition of the Belt terrane on the Cretaceous can only be conjectured. It is not impossible that the entire Clark range in this region represents a gigantic block loosed from its ancient foundations, like the Mount Wilson or Chief Mountain massifs, and bodily forced over the Cretaceous or Carboniferous formations. In that case the thrust would have driven the block at least 40 miles across country. Such a speculation is of some interest in giving one explanation of the emanation of gas and petroleum in the Flathead valley and in the heart of the Belt-Cambrian rocks at Lower Kintla lake. These hydrocarbons would thus be considered as originating in the Carboniferous limestone or in the Cretaceous sediments underlying the thrust-plane. Since the Carboniferous limestone is highly bituminous, that formation would naturally offer an original source for the oil and gas.

"On the other hand, a second hypothesis may be framed, whereby the seepages in the Flathead valley are thought to originate in the Carboniferous limestone which was faulted down during the formation of the Tertiary fault-trough, while the seepages at Kintla lake are interpreted as emanations from Carboniferous limestone locally underthrust on the west side of the main syncline of the Clark range. On this view the Waterton Lake thrust need not extend much farther west than the lake itself.

"Or, thirdly, one might conceive that the hydrocarbons originated directly in the Beltian rocks themselves (see page 53) so that the existence of the seepages would have no direct bearing on, or afford no proof of, any large-scale thrust place beneath the western slope of the range."

Since the above was written the discovery of oil in the foothills farther north proves the petroliferous character of the lower part of the Cretaceous at least and the known amount of carbon stored away in these measures in coal seams tends to confirm Daly's suggestion that these measures and the Carboniferous limestone are a source of the oil. The presence of Cretaceous coal-bearing rocks in the Flathead valley was not then known but if the Cretaceous is considered as possibly underthrust on the west, added strength is given to his second theory of the origin of the oil and gas at Kintla lake and Sage creek.

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[1]Geol. Surv., Can., Mem. 38, pp. 90–91.

The presence of oil in these ancient rocks has been variously accounted for, but the light specific gravity of the oil suggests that it was introduced in the form of vapour which unlike oil did not need the presence of water in the rocks for its upward transference. These vapours, originating at depths, could readily penetrate the broken zones in the overlying thrust block and reach the bedding planes of the thin-bedded, though compact rocks of the overlying measures. The depth to which the overridden rocks were forced and the great load placed on them would provide the pressure and temperature for the distillation of the hydrocarbons of which the Cretaceous is known to have an abundance. The natural path of the ascending vapours would be along the porous beds of the Cretaceous if this path were not interrupted by fault displacements; hence the anticlines in front of the mountains are possible reservoirs. It is evident, however, that the overthrust cover of Cambrian received in its fractures some of the vapours and by means of the bedding planes and cleavages they were dispersed. The rock mass is very compact and would not apparently absorb much of the condensed oil.

The quartzites dip generally to the southwest and at the Interprovincial Boundary attain their greatest depression, thence westward along the Boundary they rise gradually. It seems probable that at the point of greatest depression, at the centre of the syncline, there is a concealed zone of vertical fracturing which would serve as a vent through which the vapours from the horizon of distillation might rise to the many interstices of the bedding planes above, and these being at higher elevation and subject to less pressure, would form condensing chambers. A vertical section across the beds (Figure 6) has been constructed from the published report of Daly, to which is added a suggested possible outline of the concealed understructure, in which this supposition of lines of upward transference is indicated. As rather less is known of the conditions at the western fault line no suggestion is made as to the character of the underthrust rocks which may have some influence in the production of oil and gas at Kintla lake. It is, however, to be noted that the oil occurs at elevations of from 3,000 to 5,000 feet above the sea and that buoying up of the oil by water can be counted on in only a narrow part of the section near the surface, and very rarely from profound depths.

The dispersal of the vapours would be from the deep-seated fractures Of these, two are indicated in the thrust faults at either side of the fault block

The eastern thrust plane could not be considered as an open vent; its low inclination precludes periods of relief of compression. As the centre of the syncline would appear to mark the extent of the overthrust, and may be the locus of submerged open fractures, this point is the most probable place for the dispersal of ascending vapours. From this place the deposition of petroleum along the bedding planes would be characterized by changes in specific gravity, the lighter oils being found at greater distances from the source of the vapours. The observations so far recorded are not at variance with this deduction. The oil found on Sage creek in British Columbia is of much lower specific gravity than that of Cameron brook, in Alberta, and suggests a dispersal towards the west, or from a median point which would be nearer Cameron brook than Sage creek. The analyses which follow though not complete, indicate this difference. [1]"The following are the results of an examination made of these oils by the Provincial Assayer:

[1]Rept. of Minister of Mines, B.C., 1903, p. 88.

No.	Where obtained	Specific gravity	Degree Baume	Remarks
1	From tubing of borehole in Alberta, 5 miles east of summit..................	0·879	30°	Dark coloured, heavy oil commences to distil over at 90° C.
2	From seepage at same point..............	0·879	30°	
3	From "Big Oil Spring" on Sage creek, B.C................................	0·828	40°	[1]Dark green oil; commenced to distil off at 90°C.; 90 per cent of oil distilled off below 200°C. leaving 10 per cent of thick dark oil containing tar, which latter is estimated at 5 per cent.
4	From bed of Sage creek near above (Leckie spring)........................	0·818	42°	Light amber-coloured oil; commenced to distil off at 90°C. leaving 2·5 per cent dark heavy oil containing some tar.

[1]Appliances were not available for complete or further fractional distillation.

The above analyses, though not conclusive, suggest either a condensate from the eastern source or if from a western source a condensate from material of different character.

Some of the debris from the denudation of these mountains has been preserved in the Flathead valley in the Kishinena formation. The minute particles of oil known to be present throughout this formation may have been derived from the surface evaporation of oil on the mountain sides then subject to erosion.

The present available supply is still not determined. Drilling has perhaps demonstrated that in the mountains the anticlines are not the structures most favourable to the retention of oil. On the assumption of condensation it would seem that the oil might be retained in the synclines or monoclines and where seeps occur they express a drainage from the beds projecting above the level and in some cases a buoying of the oil upward by surface water drained from higher parts of the same beds.

Northeastern Alberta

Prospecting on the Peace River-Viking terrace outside of the activities in the vicinity of Peace River, consists of an additional gas well in the Viking field; the building of a drilling rig at Ranfurly near Birch lake; the deepening of the Irma well in the valley of Battle river; the drilling of a well on Ribstone creek near Czar, and the placing of two drilling rigs near Monitor.

The structure of the Viking field is described in the Summary Report for 1916, Part C, as a monocline, but it is also noted that at Birch lake the exposed rocks are higher than the exposures at Pakan on the Saskatchewan. In other words the flattened part of the monocline which forms the terrace, dips nearly 6 feet a mile to the north from Birch lake. Southeastward the western part of the terrace probably maintains its elevation to Saskatchewan. A boring for oil or gas is to be made at Birch lake which is possibly the highest part of the terrace. This operation was well started this season but results can not be expected until next year. The deepening of the Irma well on sec. 4, tp. 45, range 8, W. 4th mer., resulted in a large flow of gas. In former published records of this well it is listed as a well at Hawkins and slight showings of oil were claimed at 1,215 and 1,582 feet. Last year the lower part of the well was redrilled and a good supply of gas was found at 1,745 feet. This is from the upper gas sand of the Viking wells. At 1,890 feet the lower sand was entered and a flow of 5,400,000 cubic feet a day was obtained.

Mr. Slipper, petroleum engineer for the Department of the Interior, measured the flow just before the well was closed in and found it as above. The gas is of very low specific gravity (0·57), so he concludes that it is dry, or contains no gasolene vapours. The sands from which the gas emerges contain showings of brown oil, but to penetrate deeper the gas pressure will have to be overcome.

The prospecting field at Czar is best illustrated by the small map inserted in Summary Report 1919, Part C. On this is shown crescentic lines of fractures on or near the crown of an anticline crossing the general structure and on the western edge of the terrace structure. The location selected by the Imperial Oil Company's geologists for a boring is on sec. 17, tp. 39, range 7, W. 4th mer. This is nearly in line with the anticline. The well in August was 2,350 feet deep and was in the dark shales of the Lower Colorado. What gas was coming had a strong petroleum odour.

Farther south at Monitor, two rigs were nearly ready to start. The one near the town was a California standard rig and the one about 4 miles south, a rotary.

Southern Alberta and Saskatchewan.

The general course of Milk river from its source in the Rocky mountains is around the north side of the Montana uplift. Its most northern bend where it crosses the Bow River anticline is north of the Sweetgrass hills. Several borings have been put down on this arch and indications of oil have been obtained.[1] Another attempt is being made by an independent company to bore south of Foremost. The location is near Crow Indian lake and appears to be somewhat higher on the anticline than the well formerly drilled on Etzikom coulee (United No. 3). The continuation southeastward of the Milk River valley passes north of Bearpaw and Little Rocky mountains. In this strip of Montana the elevation of these mountains is shown by the general uplift in proximity to them. From Bearpaw mountains to Cypress hills the strata form a gentle syncline in which there are many minor dislocations. These are described in a general way by Mr. Eugene Stebinger in the following paragraph:[2]

"On the plains surrounding the Bearpaw mountains for 30 or 40 miles on all sides there are many folds and faults in the nearly horizontal Cretaceous rocks that are irregular in their trend and distribution. The causes of this peculiar and irregular faulting are not well understood, but they are probably related to the extensive igneous intrusions in the Bearpaw mountains. The faults are all of the thrust type, older formations having been carried upward beside younger rocks that lie for the most part undisturbed. The largest of these faults average about 12 miles in length but most of them can not be traced for more than 4 to 6 miles."

As the country is well covered by drift these breaks and upthrusts are exposed only near the stream valleys; occasionally they are mapped as occurring on the upland and it is supposed that they may have made there an impress on the topography. The one instance of an upthrust noted in Saskatchewan is not shown by surface feature but altogether by the rock sections on the stream called Woodpile creek. No disturbance was noted on the streams lying to the east or west of it. The occurrence is along the northern boundary of sec. 4 and on secs. 8 and 9, tp. 1, range 27, W. 3rd mer., about 22 miles south of Consul. The Imperial Oil Company is boring on section 4 to the south of the upturned Belly River beds. Towards the Boundary the beds are horizontal and consist

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[1]Geol. Surv., Can., Mem. 116, p. 23.
[2]U.S. Geol. Surv., Bull. 641 C, p. 65.

of the characteristic grey shales of the upper Pierre, the Bearpaw shales of Montana. Near the well the base of the Bearpaw is not far below the exposures. In the upturn the dip increases to the north and the contact of the Bearpaw and lower rocks occurs where the dip is from 10 degrees to 30 degrees. The exposures extend at intervals along the banks for a quarter of a mile and in the report on the exploration of the Boundary line a detailed section is given in which it would appear that pits had been dug to obtain the details there recorded. This series, though probably not representing the complete section of the lower part of the Montana series, exposes some of the Pakowki shales, or the Claggett shales of Montana. The exposures are not clear enough to warrant a definite statement of the exact horizon, except that the stratigraphic relations point to an eastward extension of the Belly River series in which probably brackish-water beds replace the freshwater beds of the upper part. Indications of shallow water deposits and lagoon conditions toward the close of the period are shown by the sandstone beds and by the plant remains which at places seem to form thin lignite deposits.

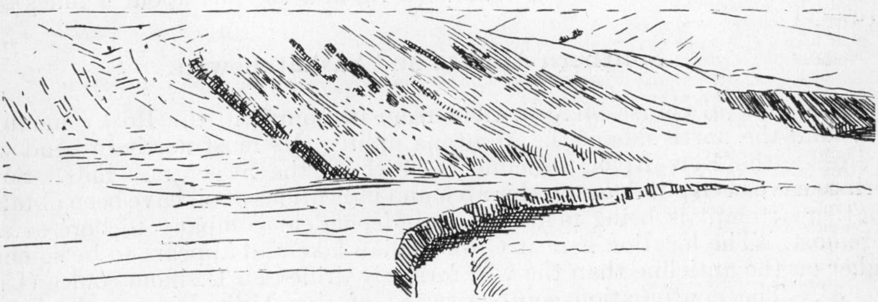


Figure 7. Sketch of upturned beds of Belly River formation, Woodpile creek, Sask.

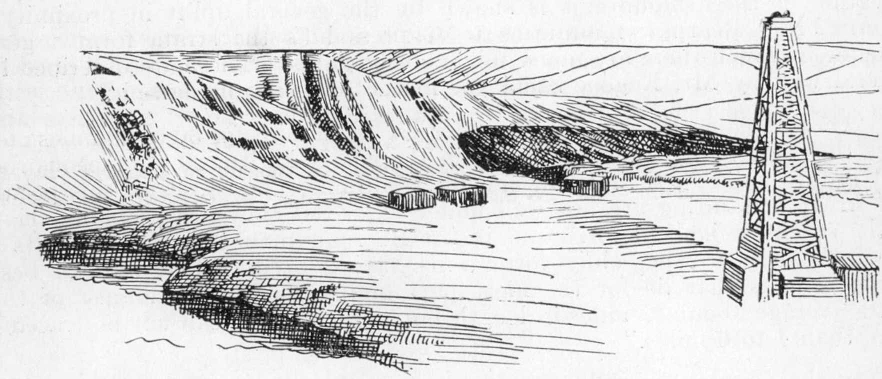


Figure 8. Site of well on Woodpile creek, Sask.

The section measured by Dr. G. M. Dawson in 1874 includes probably all the exposures of inclined beds. Farther up the stream apparently horizontal shales containing the same fossils as those exposed below the upturn are found. These include *Inoceramus, Cyprina ovata, Baculites compressus,* and *Placenticera whitfieldi.* As the boring for oil will penetrate the section at an angle, the log of the well will have to be adjusted for horizontal distance. For comparison and guidance to the drillers, Dawson's measurements are here added. The section is in descending order.[1]

"[1]Geology and resources of the forty-ninth parallel," p. 115. Ann. Rept., 1885, vol. I, p. 42 C.

		Feet	Inches
1.	Some Cretaceous clay-shales. Division 4 M and H (Bearpaw)		
2.	Grey and yellow, arenaceous clays, with some remains of *ostrea* in the lower layers (about)	20	0
3.	Greyish-white, arenaceous clay with irregular sheets of ironstone	8	6
4.	Carbonaceous shale	1	6
5.	Grey, arenaceous shale	2	6
6.	Black, carbonaceous shale	2	0
7.	Dark shales with carbonaceous bands	12	6
8.	Carbonaceous shales with poorly-preserved plant remains	1	6
9.	Grey, arenaceous clay	30	0
10.	Brown shale with indistinct impressions of plants, a few inches		
11.	Grey, arenaceous clay	3	6
12.	Laminated carbonaceous shale with spots of amber and impressions of plants	2	0
13.	Grey and yellow, arenaceous clay	20	0
14.	Yellowish, arenaceous clay	11	0
15.	Grey, arenaceous clay	9	0
16.	Soft beds—probably yellowish, arenaceous clays, but not well exposed	35	9
17.	Grey sandstone, weathering yellow, and with many jointage-cracks	12	10
18.	Greyish, arenaceous clay	45	11
19.	Hard sandstone, breaking into large rectangular fragments and weathering into pot-holes	4	0
20.	Soft, arenaceous clays	12	10
21.	Fine-grained, grey-yellow sandstone with dendritic markings	2	0
22.	Grey and yellowish, arenaceous clay, with some thin sheets of ironstone	34	5
23.	Red-brown sandstone	2	0
24.	Soft, grey sandstone	6	5
25.	Nodular, brown sandstone	0	6
26.	Soft beds, with some thin sandstone layers	24	0
27.	Nodular, red-brown sandstone (about)	3	0
28.	Greyish and yellowish, arenaceous clays, well stratified, and with small fragments of some lamellibranchiste shell at base	88	5
29.	Greyish and yellowish, arenaceous clays, well stratified	121	10
30.	Sandstone	3	0
31.	Brownish, arenaceous clays, crumbling and rotten where exposed	134	4
32.	Grey sandstone (dip 45 degrees)	1	6
33.	Yellowish sandstone, thin-bedded and flaggy	34	0
34.	Purplish and brownish clays with evident stratification lines	47	7
35.	Impure ironstone	1	0
36.	Purplish shaly clays	127	3
37.	Impure ironstone	1	0
38.	Crumbling earthy clays	26	6
		893	7

The carbonaceous shales of beds Nos. 6 and 12 of the above section have been dug into both on the main valley and side gully to the east and it is evident that enough lignite has been found and extracted to supply some of the settlers with fuel. The general strike of the upturned beds is about 9 degrees north of east, astronomic. This direction was followed eastward to the valley of Battle river, but the exposures there appear to be mostly of boulder clay and reassorted or ground-up shales so that the line of upthrust could not be definitely traced.

UNDERLYING SEAMS OF THE SOURIS COAL FIELD, SOUTHEASTERN SASKATCHEWAN

By D. B. Dowling.

Coal mining in the Souris River coal area has been confined to the seams exposed in the vicinity of Estevan, Bienfait, and Taylorton which occur in beds that can be correlated with the freshwater Tertiary deposits of the Fort Union formation. Borings have demonstrated that beneath these naturally exposed seams there is a thickness of probably 400 or 500 feet, mostly shales, in which are several coal seams. The general character of the deposits and the thickness of the shales separating the coal seams indicate that these lower beds are probably not wholly of freshwater deposition and perhaps may be correlated with the Lance of Dakota.

The Fort Union beds of eastern Saskatchewan and Dakota occupy the eastern part of an irregular basin and dip towards the centre of this basin which is in Dakota and probably south of Estevan. The lower beds should, therefore, outcrop in Canada to the north of the Estevan field and to the east in the Souris valley and in Turtle mountain in Manitoba.

In Dakota the beds beneath the Fort Union outcrop in the valley of Missouri river. They, however, vary in character. In the west they are similar to the normal Fort Union but to the east are darker in colour and have in less degree the characteristics of continental deposition. In the vicinity of Bismarck the upper members contain marine fossils and the formation as a whole has less lignite. This upper series in western Dakota is called the Ludlow lignitic member of the Lance formation and merges to the east into the Cannonball marine member.

The lower beds in the Estevan district should, therefore, probably be correlated with the Ludlow member of Dakota on account of the amount of coal found in them, but include possibly a thin separating wedge of beds comparable to the Cannonball. The possible inclusion of marine beds is based upon the reported occurence of nodules or boulders containing marine fossils at a depth of 160 feet in a shaft at Lampman. As the specimens appear to represent forms characteristic of the Bearpaw rather than the Cannonball, it is assumed that they have been derived from the boulder clay which is very thick in places.[1]

The presence of coal seams below those exposed was first noted by Dr. Selwyn as the result of boring in the Souris valley in 1880. A 6-foot coal seam was found over 200 feet below the bed of the stream. Later reports state that wells drilled in the vicinity of the mines penetrated several of these lower seams. The section published by A. MacLean[2] includes all the natural sections and the various bore-hole records and shows that beside the four workable seams exposed there are three seams concealed. At 130 feet below the Taylorton seam, the lowest worked in the district, there is a 2-foot seam. At a farther depth of 207 feet or 337 below the Taylorton seam is one of 4 feet and 209 feet below this or 546 feet below the Taylorton seam, another seam 4 feet in thickness. The underlying measures beneath the latter seam were probed by a boring north of Estevan and show shales without coal for a distance of at least 500 feet.

The series should outcrop to the north and east but is concealed by a heavy mantle of drift. As the drift-covered rock surface was very irregular, probing for the seams through the drift is very uncertain. Occasionally wells reach

[1]Geol. Surv., Can., Sum. Rept., p. 43 C.
[2]Geol. Surv., Can., Sum. Rept., 1918, pt. A, p. 4.

the coal seams and show a continuity in the coal horizons but a great variation in the thickness. The outermost locations showing the presence of coal, thought to represent the lower seam, may be cited (on the authority of newspaper report only) and include the following. (1) On the farm of A. Cameron, about 4 miles south of Stoughton a seam of coal 20 to 21 feet thick lying 130 feet below the surface. (2) On Wm. Lee's farm, a 14-foot seam of coal, at a depth of 80 feet and another, penetrated for only 4 feet, at a depth of 102 feet. (3) Near Redvers, on sec. 3, tp. 8, range 32, W. 1st mer., an 8-foot seam of coal, at 250 feet. (4) On sec. 30, tp. 2, range 31, W. 1st mer., near Carrievale, a 6-inch seam of coal, at a depth of 251 feet.

Seams representing the middle horizon, or the seam at 337 feet below the Taylorton seam, are supposed to have been reached in wells near the Souris field, at Oxbow, for example; also a 6-foot coal seam reported from near Wauchope at a depth of 150 feet. A discovery near Lampman is more definite. On sec. 21, tp. 6, range 6, W. 2nd mer., about 8 miles north of Lampman, a seam lying about 210 feet below the surface was prospected by means of nine bore-holes and it was found that the seam varied from 4 feet to 15 or 16 feet. At about the centre of this lens of coal a double-compartment shaft was sunk to a depth of 176 feet, but work was stopped after the outbreak of war. The samples obtained from the drill hole were collected by Mr. E. J. Winger, of Regina and were analysed by Andrews and Cruickshank of Regina. The analysis made public by the operating company has some extraordinary features which may be due to the temperature used in making the test. The analysis gives moisture 0·6 per cent, volatile matter 16·30 per cent, fixed carbon 70·0 per cent, ash 13·10 per cent, B.T. U. 1260.

This analysis evidently does not give the moisture in the sample as mined and was probably made after drying at a very high temperature. Inquiry at the locality elicited the information that there was no opportunity for the samples to have been tampered with; or of substitution. The results will be better checked when the seam is reached by the shaft. In the meantime it is generally reported of these lower seams that their fuel value is higher than those of Estevan, although exact evidence in this regard is meagre. The following extract from Mr. Maclean's report[1] refers to the higher fuel value expected from these lower seams.

"Of the three lower seams, those of probable importance are marked 10 and 12 (in the table). The first seam, as analysed for Mr. Symond of the Western Dominion Collieries, showed a fixed carbon content of 42 per cent and the lowest a fixed carbon content of 48 to 51 per cent."[2]

Of the boring done by Dr. Selwyn the sample from the 6-foot seam which appears to be No. 10 above was analysed by Mr. Hoffmann and is as follows.[3]

	Slow coking	*Fast coking*
Hydroscopic water	17·78	17·78
Volatile combustible matter	29·51	32·70
Fixed carbon	44·36	44·17
Ash	8·35	8·35
	100·00	100·00

Considered as dried coal the analysis by slow coking would appear as below:

Volatile combustible matter	35·89
Fixed carbon	53·96
Ash	10·15
	100·00

[1]Op. cit.
[2]Geol. Surv., Can., Sum. Rept., 1917, p. 39 C.
[3]Ann. Rept., Geol. Surv., Can., 1879–80, p. 9 H.

The analyses on page 27 with that reported for the Lampman coal are all that are known of the lower seams in eastern Saskatchewan. Comparison can, however, be made of coals found in the Lance formation of Dakota.

In the Cannonball member a few small seams of coal are known and analyses of the coal are available. The two following seem to be typical.[1]

Coal from Haynes, N.D.

	As received from mine	Air dried	Dry coal theoretical	Ash free theoretical
Moisture	32·6	21·2		
Volatile	30·6	35·8	45·4	51·8
Fixed carbon	28·5	33·3	42·3	48·2
Ash	8·3	9·7	12·3	
Heating value, B.T.U.	7360	8600	10920	12460

From a Surface Prospect on Cedar Creek, N.D.

	As received from mine	Air dried	Dry coal	Ash free
Moisture	33·1	15·2		
Volatile	25·5	32·4	38·2	41·5
Fixed carbon	36·1	45·7	53·9	58·5
Ash	5·3	6·7	7·9	
Heating values B.T. U.	7470	9460	11160	12120

In its westward continuation, the Cannonball formation changes in character and contains more coal seams. In South Dakota the Ludlow member, which is at the top of the Lance formation, is the coal-bearing member for the state. Samples of the coals of this formation from the northwestern part of the state, have been examined and the following two analyses are selected as representing the wettest and the dryest of the mine samples.[2]

Phillips Mine, Sec. 7, Tp. 17N, Range 11E.

	As received from mine	Air dried	Dry coal theoretical	Ash free theoretical
Moisture	42·5	17·7		
Volatile	23·2	33·2	40·4	47·8
Fixed carbon	25·3	36·2	44·0	52·2
Ash	9·0	12·88	15·64	
B.T.U.	5950	8520	10350	12270

[1] U. S. Geol. Surv., Bull. 541, p. 256.
[2] U.S. Geol. Surv., Bull. 627, p. 42.

Nelson Mine, Sec. 29, Tp. 21N, Range 12E.

	As received from mine	Air dried	Dry coal theoretical	Ash free theoretical
Moisture	33·3	15·4		
Volatile	28·9	36·7	43·4	51·5
Fixed carbon	27·3	34·6	40·9	48·5
Ash	10·5	13·3	15·7	
B.T.U	6960	8830	10430	12380

In 1913 the State Engineer of North Dakota reported one hundred and sixteen mines in operation. Representative samples of the coal seams were taken from forty-eight mines. The analyses of these samples were made by Prof. E. J. Babcock and published in the Sixth Biennial report of the State Engineer.

The moisture in the coal varies from 27·32 per cent to 43·78 per cent, and for the lot the average is 35·98 per cent. On the dry basis the fixed carbon content varies from a minimum of 31·76 per cent for a dirty coal with 20·28 per cent ash to a maximum of 51·60 per cent for a coal with 6·11 per cent ash.

The average analysis for the 48 samples was:

Moisture	35·98
Volatile matter	29·13
Fixed carbon	27·90
Ash	6·99
	100·00
B.T.U	6691

With the moisture eliminated, the analysis would be:

Volatile matter	45·53
Fixed carbon	43·60
Ash	10·87
	100·00
B. T. U	10323

Analyses for coal as mined generally show higher moisture than would be found in the coal as used, owing to the loss of moisture in transportation. In fact, the coal as used may even reach the stage given as air dried. The calculations for dry coal and ash free are to facilitate comparisons between the coal substances of different seams and are not commercial ratings.

The heating value claimed for the Lampman coal and also the fixed carbon percentage are higher than any of the seams mined in Saskatchewan or North Dakota where coals of about the same age are to be found.

GREAT SLAVE LAKE AREA

By G. S. Hume

INTRODUCTION

The field season of 1920 was spent in exploring the north shore of Great Slave lake, special attention being given to the study of the North Arm. During the field seasons of 1916 and 1917 A. E. Cameron[1] studied and mapped the south shore of Great Slave lake westward from the mouth of Slave river to the Mackenzie; and the north shore eastward to Gypsum point at the south end of the North Arm. Material collected by Cameron and other members of the Geological Survey from the outcrops in this great stretch of country, together with collections from the Hay River section, includes the whole Devonian as it is found in this region. It was, therefore, deemed advisable to continue this work and discover what was to be found between the base of the Devonian and the top of the Precambrian and for this purpose the North Arm of the lake seemed to be the most favourably situated.

Owing to difficulties of transportation only six weeks were actually spent on geological work, and, in so large an area, detailed work was impossible.

The writer wishes to thank the officials and men of the various trading companies at the different posts on Great Slave lake. Transportation was furnished by the Northern Trading Company and by those in charge of Fairweathers' Limited post at Resolution. The writer is especially indebted to Mr. L. Roy of the Hudson's Bay Company. W. S. Dyer of Toronto ably acted as assistant.

DRAINAGE

It is rather remarkable that from Mackenzie river to the north end of the North Arm, no streams of any importance enter Great Slave lake. On the North Arm, the streams all head in sloughs and muskeg east of the high land which forms the Silurian cuesta on the headlands, and in no case can these streams be traced back for more than a couple of miles. The drainage for the area west of the North Arm is, therefore, to the west except for a narrow fringe close to the lake, and points to a regional slope in a general westward direction.

GENERAL GEOLOGY

Extent of the Silurian on the North Arm

In the map published with Memoir 108 of this Survey, a considerable portion of the country on the west side of the North Arm is shown as Silurian. This was inferred from the succession of strata but until last summer direct palæontological evidence was lacking. It has also been found that the Devonian does not appear again at the north end of the North Arm but that within the Silurian itself there is a change of sedimentation. The Silurian was traced as far north as the west side of lake Marian and there is reason to believe that it continues much farther to the north and in this distance separates the Precambrian on the east from the Devonian farther to the west. Only at one place near Fort Rae on the east side of the North Arm was any Silurian seen. However, here the Silurian is only of local occurrence because both to the north and to the

[1] ameron, A. E., Geol. Surv., Can., Sum. Repts. 1916 and 1917, pt. C.

south there are abundant outcrops of Precambrian. It is possible that other small outcrops will be found as outliers in the Precambrian but as time did not permit any investigation of the east shore, no others were seen.

Origin of the North Arm

Except in the northern part of the west side of the North Arm, the headlands are bounded by portions of a Silurian cuesta facing towards the lake, whereas the ends of the bays almost without exception are low and marshy and with muskeg for some distance inland. The cuesta has evidently resulted from the erosion of the Silurian towards the west, and the North Arm of the lake now occupies at least in part the eroded portion. There is some evidence that the Silurian dips to the west but this is not sufficient to explain the depression now occupied by the North Arm and it appears that a pre-Silurian valley in the Precambrian floor must have existed here. Towards the north end and on the west side of the North Arm, Precambrian rocks outcrop quite extensively near the shore and between the lake and the Silurian cuesta farther inland. These outcrops, particularly on a rocky headland called Pointe du Lac, rise in places 100 to 200 feet above the level of the lake, and in many places to the north, outcrops less high are frequent. Obviously, therefore, between these high knobs on the west shore and the outcrops on the east shore there is a part now under the lake in which the Precambrian is less elevated and which must have been a depression prior to the deposition of the Silurian sediments. It is noticeable that as soon as Precambrian rocks begin to outcrop on the west shore, islands become frequent. This is only further proof of the inequalities of the old Precambrian surface before it was covered by Palæozoic sediments, a feature that has been demonstrated for different parts of the shield where the Precambrian surface has been now re-exposed as a result of the erosion of the later sediments.

Character of the Silurian Cuesta

The Silurian cuesta along the west side of the North Arm is very much interrupted and broken. As has already been intimated, it appears on the headlands as an escarpment but at the ends of the bays continues only as elevated country at some distance back from the lake. At the south the escarpment when it occurs, is never high, and 50 feet makes a marked elevation in the otherwise very flat landscape. To the north, however, the escarpment becomes much higher and rises to as much as 250 feet above the lake at some distance back from the shore. At this elevation the escarpment has often a very marked cliff, 10 to 20 feet high at the top and a steep talus slope up to it.

Raised Beaches

A remarkable amount of evidence exists in many places of elevated beaches representing various heights up to about 60 feet above the present level of the lake. At Ninsti point, just south of Windy point, a small escarpment of Devonian rises to 60 feet above the lake. Below this escarpment there are evidences of numerous beaches as rows of shingle material. These for the most part are not very significant because they are all at approximately the same elevation and are apparently but slightly higher than what the wave action of the lake can produce. It would appear that at this point there is accumulation of material from along the shore and that the beaches are only indications of growth of the land surface out into the lake. However, on the top of the escarpment are several beaches that cannot be ascribed to this cause, and that can only represent a difference in the lake level of 60 feet. Such beaches can also be seen near Resolution, on the south side of the lake, the beaches showing here—as at Ninsti point—as interrupted ridges of limestone shingle on which there is seldom any vegetation. Perhaps the most striking beaches seen were on the North Arm at Le Gros point in front of the Silurian escarpment. Here on the gently sloping surface in about a mile from the escarpment or talus base to the water's edge, there are a number of beaches, each in the form of a broad, semi-circle roughly conforming to the present outline of the point. These, apparently were left as the lake receded, and the point was built farther lakeward by the accumulation of more material. In this case, as at Resolution, shingle prevents vegetation in the beaches, so that they appear as arcs of circles, the whiteness of which forms a striking contrast to the dark brown muskeg carrying an abundant growth of evergreen trees. At close view each beach appears as a rounded avenue with the trees on each edge forming a distinct boundary and the centre being almost entirely bare rock shingle. However, the beaches here do not represent as great an elevation for the former lake as is shown at Nintsi point. No detailed work has been done on these beaches and the factors controlling the subsidence of the lake-level are not known.

Structure

The Silurian on the North Arm exhibits very little structure. The rocks everywhere appear horizontal although the cuesta form and the distribution of the drainage of the area to the west, seem to point to a general westward dip. The greater height of the cuesta northwards indicates a southerly dip as well, rather than a more extensive erosion on a westward-dipping series—a set of conditions which would produce the same result on the height of the cuesta. To the south the Silurian is of softer material than in the north; hence, there is reason to assume that more erosion on the harder rock would not be probable. Some indication of the general dip was obtained from one locality about half-way up the North Arm. Here, between Spruce and High points about 4 miles distant, there is a deep bay on both sides of which are outcrops. On the west side, and 4 miles southwest of High point, there is a contact at the water-level between a shale and limestone member of the same formation. On Red Rock point, about 6 miles southeast of Spruce point, the same contact is exposed 43 feet above the lake and on High point the height is 25 feet. The dip represented by these three points of the triangle is less than one-quarter of a degree to the southwest. This is the only locality where the dip could be actually calculated and not much significance is attached to it because on the east side of the bay and 2 miles from one point of the triangle an outcrop of Precambrian rises 50 feet above the lake-level. Thus the dip may be locally affected by the irregular character of the Precambrian surface, and may be only in part due to the major structure. Cameron has clearly shown by a cross-section along Hay river that there is a regional dip to the south. This is evidenced by the succession of rocks in a north-south direction at the west end of Great Slave lake and there seems little doubt that this southerly dip extends to the North Arm.

On the north shore, at Windy point, a broad anticline which has its axis apparently slightly east of Windy point is not shown by recognizable change in dips but is rather to be inferred from the repetition of the formations on either side. At only one horizon in the Presquile formation, at Windy point, could fossils be found and these were all large gastropods. No definite horizons in this massive dolomite could be identified from place to place and for this reason very little information about the structure was obtained. At Windy point, near the Imperial Oil Company's drilling site, measurements of local dips indicated that the axis of the anticline was farther to the east. North of Sulphur bay an extensive outcrop of the Presquile dolomite forms some well-marked ridges that in a very flat country appear as prominent topographic features, although their elevation above the lake is less than 200 feet. The *Stringocephalus burtoni* zone of this formation might be expected to turn up here as on the south shore at Presquile point but, so far as the writer is aware, it has not yet been located.

Sedimentation—Silurian

Two formations apparently belong to the Silurian on the North Arm. What is thought to be the lower is represented by a very poor isolated outcrop mostly submerged and the only material available for study was a few scattered angular blocks thrown up on the shore by wave and ice action. The rock is a brownish dolomite that contains *Pycnostylus guelphensis* Whiteaves, and *P. elegans?* Whiteaves in abundance. The only brachiopod found appears to be a *Spirifer* nearest to *S. coralliensis* (Grabau). Dr. Foerste has examined some cephalopods from this horizon and reports two general species belonging probably to either *Gomphoceroids* or *Phragmoceroids* and an undescribed genus of *Poterioceroids*. These *Cephalopods*, according to Dr. Foerste, represent a horizon not far removed from Racine or Guelph age. This is quite in accordance with the age indicated by the corals belonging to the genus *Pycnostylus*. In New York State, *Spirifer coralliensis* comes from the Cayugan, but in the north fossils similar to the species in the Great Slave Lake collection come from the Fitzgerald dolomite of Fort Fitzgerald, at the northern boundary of Alberta.

About 2 miles north of this outcrop, on the North Arm, rocks appear at Gypsum point. These are red, arenaceous limestones and shales containing gypsum. The shore is composed of red pebbles making a striking contrast to the greys and browns of the other formations of the Silurian and the Devonian.

The best section of the red beds is found on the north side of Gypsum point. It consists of: 4 feet of brick red clayey shale with no gypsum (the material is soft, and with little bedding); 4 feet of harder-bedded, red shale containing gypsum. It is separated from the top part by a layer of green shaly material mixed with gypsum. At the base is a layer of pink gypsum varying from 2 to 6 inches in thickness. The contact both above and below this gypsum layer with the red shale is very irregular and in a number of places gypsum of the same sort extends for some little distance down into the lower beds. Within this zone symmetrical ripple-marks, but no mud cracks, were seen. Gypsum in small pieces is disseminated through this intermediate zone.

The lower part of the section, of which 3 to 5 feet is exposed, is more massive-bedded material than the intermediate zone. Stringers of white fibrous gypsum, both horizontal and vertical, are seen in many places. Usually these are only a fraction of an inch thick but a few are as much as 2 to 3 inches. Most of these stringers show a distinct parting of foreign darker material through the centre, clearly indicating that they are subsequent in origin to the deposition of the red beds that contain them and also that their mode of formation was comparable to vein filling. The red material of these beds is slightly dolomitic and arenaceous. At various places, too, the red rock becomes speckled by many small green particles. These green specks seem to be of similar material to the red material that encloses them, and it is thought they are due to incomplete oxidation of the iron, possibly as a result of some organic material being present.

At a few miles north of Gypsum point other sections are exposed. For a limited distance the character of the deposits was similar, and the zones as divided above were readily recognizable. It was found that below the lower zone, there were thin-bedded, finely-laminated, dolomitic shales still of a red colour. At various places, especially Gypsum point, pseudomorphs after gypsum were seen.

No indication was found of what came immediately under the red beds seen at Gypsum point, but to the north, small sections were exposed in many places of similar kinds of beds up to 105 feet above the level of the lake. To the north a more sandy material came in towards the base and more dolomitic material in the uppermost beds. No good section was seen, however, until Red Rock point 30 miles north of Gypsum point was reached. Here a complete section 33 feet high was exposed as a cliff on the shore of the lake and on the next point still farther north a section 55 feet was found.

The section at Red Rock point was as follows:

	Feet
Dull red, arenaceous dolomite without fossils and breaking up into very massive blocks	7
Dark grey shale, weathering very readily	10
Yellowish sandstone—a distinct contact with the shale above but grading down to greenish sandstone.	
Yellowish rusty sandstone.	
Purplish sandstone.	
Total thickness of sandstone	16

At the 55-foot section north of Red Rock point there were 33 feet of sandstones at the base and 12 feet of the red arenaceous dolomites at the top, the shales being still about 10 feet thick. In no part of this section were fossils found although in another small outcrop of greenish sandstone some fucoids were obtained.

The red, arenaceous dolomitic beds at the top are very hard and massive and the excellent sections exposed at many points along the shore are no doubt due to their resistance to erosion and the fact that they overlie soft sandstones and shales. The differences in the colour of the beds are very striking, making this the most picturesque part of the north shore.

About 8 miles north of Red Rock point fossils were obtained from the red beds themselves and from nodules of chert in the red beds. The fossils from the red beds were poorly preserved but those from the chert were somewhat better. At this point there were 15 feet of the red dolomitic beds exposed.

To the north, the sandstone occurs about the lake-level and several exposures were seen. Erosion has produced a great amount of loose sand and the escarpment in many places is at some distance inland. The shore is for the most part sandy, and large areas of white sand dunes and sand ridges are found between the shore and the escarpment. To the north also the dolomite becomes less red and finally the red is replaced by grey. This seems to be a lateral transition at about the same stratigraphic horizon although to the north the escarpment becomes much higher—up to 250 feet—with a much greater thickness of heavy, massive, grey, dolomitic beds at the top. At no place could any section be found to show what came between the top, massive dolomite beds and the sandstone found at the lake-level. However, in the grey dolomite a number of fossils were found in various places and although the fauna is meagre, it is a repetition of what was obtained from the red beds and chert nodules 8 miles north of Red Rock point.

This fauna consists of the following: *Receptaculites* sp. (two species were obtained); *Zaphrentis*—three species too poor to identify; *Halysites catenularia* (Linneus); *Palæofavosites asper* D'Orbigny; *Leptæna rhomboidalis* (Wilkens)?; *Leptaena* sp.; *Stropheodonta* nearest *varistriata* (Conrad); *Stropheodonta* n. sp.; *Stropheodonta* sp.; *Strophomena* n. sp.; *Strophomena* sp.; *Dalmanella* sp.; *Camarotœchia* sp. nov.; *Strophomena donnetti*? Salter; c.f. *Schuchertella interstriata* (Hall); *Orthis* sp.; *Lophospira bespiralis* (Hall); a number of gastropods too poor for identification; *Cyrtodonta* n. sp.; *Conularia* n. sp.; a number of cephalopods; *Illœnus* (*pygidium*); *Calymene* sp.

The fauna is without doubt Silurian but at what time in the Silurian is doubtful. A palæontological report is being prepared on these Silurian faunas and the problem of stratigraphic height will be discussed in detail in it. In the northern part Precambrian rocks occur in fairly close proximity to the Silurian where the lowest beds of the Silurian were sandstones. There are no outcrops that show the actual contact but no great interval would be permissible for any thickness of rock below the sandstones and above the Precambrian. In the south the outcrop containing *Pycnostylus*, etc., was separated from the nearest outcrop of red beds by several miles but it was thought the *Pycnostylus* beds were lower stratigraphically than the red beds. If this is the case no rocks containing the *Pycnostylus* fauna can come below the sandstones in the north, and this part of the section must either be absent in the north or be represented in age by the sandstones, which, as has been shown elsewhere in the case of the basal Palæozoic beds resting on Precambrian, may hold different stratigraphic heights at different places.

OIL POSSIBILITIES ON GREAT SLAVE LAKE

At Windy point on the north shore of Great Slave lake considerable interest is being taken in the possibility of obtaining oil in commercial quantities. At Windy point a number of oil seepages occur from the Presquile formation of Middle Devonian age. The Presquile formation is a porous dolomite containing caverns lined with dolomite crystals and partly filled with a thick heavy oil. Where fractures have occurred in the rock or where other factors have tended to concentrate the oil, small pools occur on the surface and where such seepages occur under the lake, the surface of the water is almost constantly covered by a thin film of oil. A black viscous substance derived from the oil stains the face of the rock and on a warm day, dark streaks of an oily mixture ooze out of the rock and slowly run down over the edges of the exposures. There is no doubt that this horizon contains oil in quantity but the outcrop of an oil horizon cannot be expected to be a very favourable location from which to obtain commercial quantities of oil by drilling. This is especially true of Windy point because the thickness of the Presquile formation is nowhere in this general locality more than a few hundred (100-300) feet at most and at Windy point the upper or Stringocephalus zone appears to be lacking.

Below the Presquile formation there is what is known as the Pine Point series of limestones and limy shales. In places these are bituminous especially on the south shore of the lake, but on the north shore from exposures seen just west of the North Arm nothing was discovered to indicate that this formation might contain oil in commercial quantities.

The possibilities of finding oil at some distance inland from Windy point are unknown. From what is known of the regional structure, the Windy Point anticline is a local fold on a much larger southwestward dipping structure. If this is the case higher beds than the Presquile formation ought to be found at some distance inland from Windy point. The formation immediately above the Presquile is the Slave Point formation mostly of limestones and above this is the lowest member of the Upper Devonian series—the Simpson shale. If favourable structures can be located in this region with a cover of Simpson shale, the possibilities of finding oil would seem to be very good. At present very little or nothing is known of the country inland from Windy point so that it is not known how far back it would be necessary to go before the Simpson shale would be found, but the character of Big island in Mackenzie river and the portion of the main land immediately northwest of it suggests it is underlain by Simpson shale. Below the Devonian, the Silurian red beds will be encountered and oil cannot be expected to be found in these.

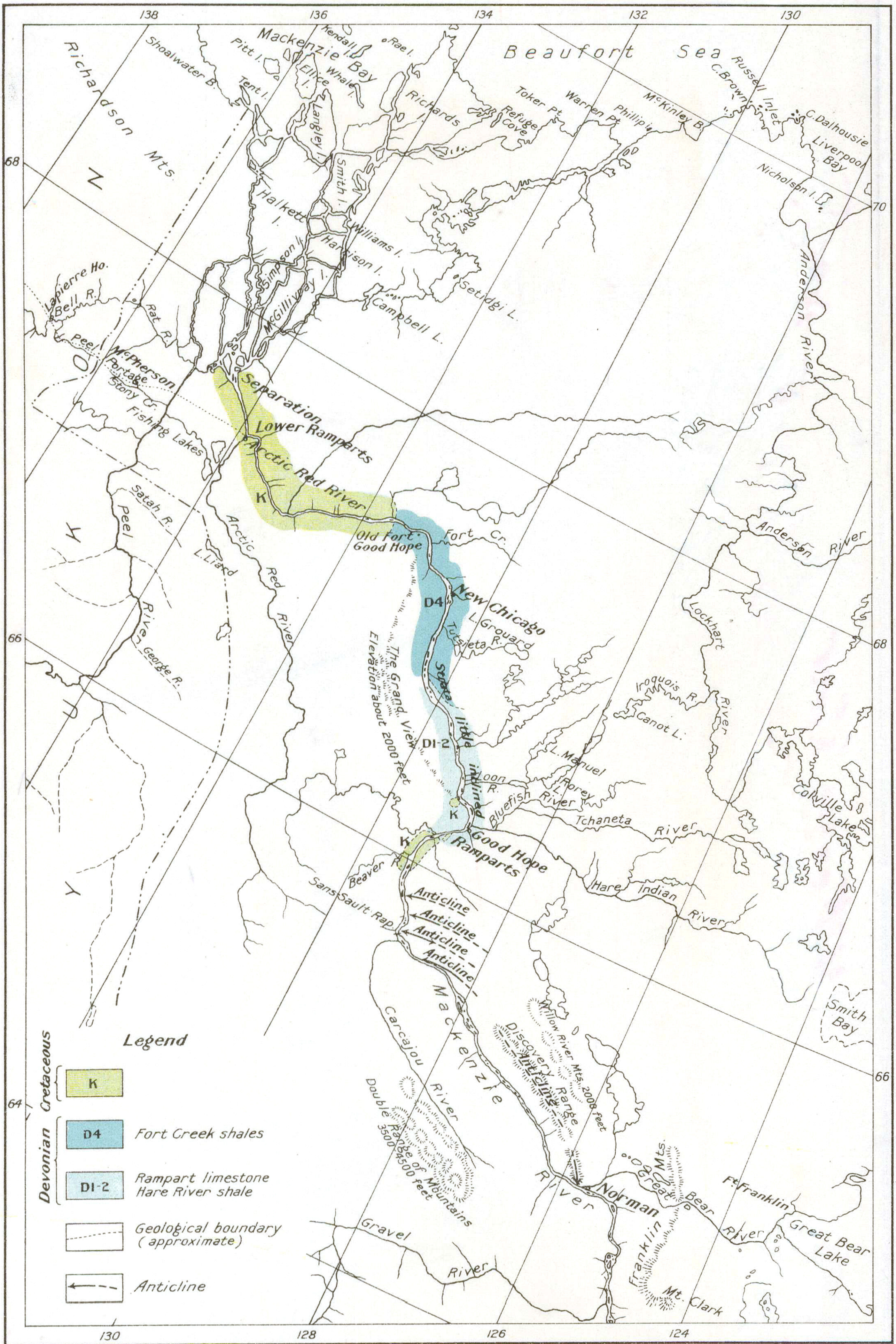
In connexion with Windy point, the sulphur springs of Sulphur bay ought to be considered. At Sulphur bay there is a small flood flat in proximity to outcrops of Presquile dolomites. Issuing from these dolomites are a number of small springs of sulphur water which are depositing gypsum and pure sulphur. The fetid odour of hydrogen sulphide is very pronounced in the vicinity and the water of Sulphur bay is a dirty milky white colour, due presumably to sulphur in suspension.

It is known from various oil fields that sulphate waters are not found in close association with oil. In the Sunset-Midway oil field of California, according to Rogers of the United States Geological Survey, there is a great amount of sulphate in the surface water but none in connexion with the oil horizons. The water associated with the oil field, on the other hand, shows the presence of alkali carbonate which is absent in the shallower waters where sulphate is present. The intermediate zone between the sulphate and carbonate zones shows the presence of hydrogen sulphide. It is, therefore, thought that the sulphate is reduced to sulphide by the chemical reaction of certain constituents in the oil and that oxidation conditions bring about the deposition of sulphur which is found in considerable quantities at some places in the Sunset-Midway field.

An analysis of one specimen of salt collected at Sulphur bay showed that it was composed principally of gypsum with some small amount of sulphur, whereas another sample collected only a few feet distant from the first showed 72 per cent of sulphur and the remainder of gypsum, small pebbles, and a little organic matter. The report given by the Mineralogical Department is as follows.

"Some of the little lumps of sulphur are almost pure, others are intimately associated with much gypsum". "The sulphur appears to have resulted from the reduction of gypsum."

It is known that the Silurian beds at the south end of the North Arm contain gypsum in quantity at certain horizons. Also it is thought that the general regional dip is to the west or slightly south of west. This being the case, the conditions at Windy point would be such that water at any horizon in the underlying Silurian would be under a hydrostatic head and hence, if opportunity was given would be expected to come from such depths carrying gypsum in solution. In passing up to the surface such gypsum-bearing waters would pass through the Presquile formation in which oil is present and hence it would reasonably be supposed that a reaction between the gypsum and certain constituents might readily take place resulting in the reduction of gypsum and the formation of hydrogen sulphide. The fact that gypsum is deposited on the surface from such solutions shows that the reduction is not complete. This may be because the amount of gypsum is in excess of the amount with which the reducing agent is able to react or simply because the gypsum-bearing solutions come in contact with the oil only in the upper horizon, and sufficient time is not given for the complete reduction of all the gypsum. Around Sulphur bay the number of sulphur springs represent a considerable amount of sulphur, although no great quantity is to be found in any one. All these springs are from the Presquile formation and as the action of sulphate water lowers the quality of oil, the specific gravity of any oil near here is likely to be heavy if it has come in contact with the sulphate solutions.



Geological Survey, Canada.

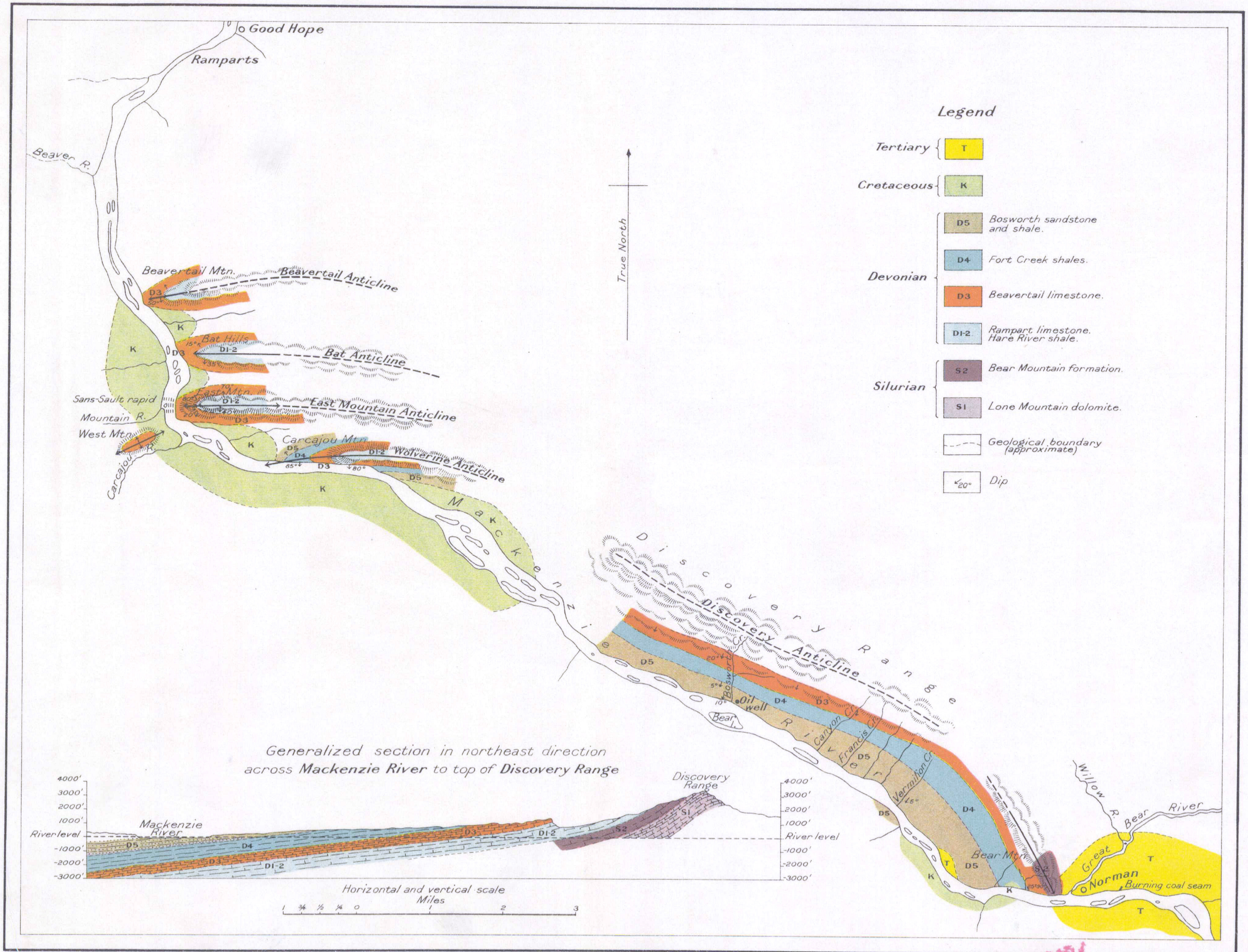
Publication No. 1873

Sketch map showing the geology along the **Mackenzie River** between the **Ramparts** and the **Delta**, Provisional District of Mackenzie.

To accompany Report by **T.O. Bosworth** and **E.M. Kindle** in Summary Report, Part B, 1920.

Scale of Miles
25 0 25 50

Geology by **T.O. Bosworth**, 1914, with additions by **E.M. Kindle**, 1919.
Formation boundaries provisional.



Geological Survey, Canada.

Publication No. 1872

Sketch map showing approximate geological structure of the **Norman-Good Hope** area, Mackenzie River, Provisional District of Mackenzie.

To accompany Report by E. M. Kindle and T. O. Bosworth, in Summary Report, Part B, 1920.

Scale of Miles

Geology by T. O. Bosworth, 1914, with additions by E. M. Kindle, 1919.

Formation boundaries provisional.

Mackenzie River
(Norman - Good Hope area)

OIL-BEARING ROCKS OF LOWER MACKENZIE RIVER VALLEY

By E. M. Kindle and T. O. Bosworth

CONTENTS

Illustrations

INTRODUCTION

The success of the first oil well drilled in the Mackenzie valley has created a demand for all the available geological data relating to the region. The desire to make this information available at the earliest possible moment for the use of prospectors and others interested in the region has led to the preparation of this report. Many features of the geology concerning which complete data are not yet available must be discussed in a provisional manner. But a report of this preliminary character which can be placed in the hands of the prospector early in the season following the "strike" is deemed of more value than would be a more exhaustive report at a later date.

The field work of the authors was done independently. The co-operation in its preparation was made possible through the courtesy of the Imperial Oil Company. Mr. Bosworth's maps and study of the stratigraphy and structure were made during 1914, since which time he has acted as chief geologist for the above-mentioned company.

Mr. Kindle has spent two seasons in the Mackenzie valley traversing by canoe the entire length of the part of the valley in which Palæozoic rocks occur, as well as parts of Great Bear, Root, North Nahanni, and Liard rivers. He is indebted to Mr. Theodore Link for the opportunity to examine many of the collections of fossils made by him for the Imperial Oil Co.

A convenient summary of previous work in the Mackenzie valley and a bibliography of the papers relating to the region will be found in Memoir 108 of this Survey.

It is a pleasure to the authors to acknowledge the many courtesies extended to them by the white men residing in the region. In this connexion they recall particularly Mr. Camsell, Mr. Harris and the representatives of the Northern Trading Company at Simpson, Mr. Caird at Fort Smith, and Inspector Anderson of the R.C.M.P.

LOCATION

The well at which the "oil strike" was made at the end of the season of 1920 is located on the bank of Mackenzie river, 40 miles north of Norman and about 100 miles south of the Arctic circle (Plate I A and B). It is about 60 miles farther north than the Klondike gold field which is separated from the oil well by 350 miles of little known mountain ranges.

The district covered by this report, and the accompanying maps (Nos. 1872 and 1873) includes the valley of Mackenzie river from the mouth of Great Bear river in latitude 64° 54′ and longitude 125° 45′ to a point a few miles below the site of old Fort Good Hope in latitude 67° 30′. These limits coincide with the disappearance of the Devonian rocks beneath a Tertiary basin on the south and a Cretaceous basin on the north. The total length of the part of the river valley covered by the maps is about 375 miles.

At Good Hope which is located near the middle of the area covered by the maps in longitude 128° 49′ and latitude 66° 15′ the easterly declination of the compass is 41° 38′. The compass needle at Norman points 41° 38′ east of north at one of the stations where the declination has been determined.

TRANSPORTATION

The river route by way of the Athabaska or Peace rivers affords the only practicable means of reaching this region.

Any approach by rail to these two great waterways leading toward Great Slave and the Mackenzie, must be through the city of Edmonton. This thriving modern city on Saskatchewan river was a very few years ago only an obscure trading post of the Hudson's Bay Company. A railway was completed a few years ago from Edmonton to Peace River Crossing, which is about 312 miles northwest of Edmonton. Amother railway extends north from Edmonton via lac La Biche to the head of navigation on Clearwater river. This railway ends near McMurray: from that point to the Arctic coast steamer navigation on the Mackenzie is interrupted at but one point, the rapids at Fort Smith, where there is a portage of 16 miles. It should be noted, however, that although the McMurray route is the more direct, the service beyond lac La Biche is frequently interrupted for considerable periods because of the condition of the road bed. The Peace River route is longer and involves a 4-mile portage at Vermilion chutes which the McMurray route avoids, but the railway transportation is more dependable. The distance from the end of the railway at Peace River Crossing to the oil well is about 1,500 miles, and from McMurray about 1,200 miles. Telegraph service extends to Peace River Crossing and to McMurray, but not beyond.

Two lines of steamers have for a number of years been engaged every summer in bringing out the winter catch of fur and taking in the yearly consignment of supplies to the trading posts located from 100 to 200 miles apart throughout the Mackenzie River system. A third line began operations in 1919. These steamers make only a single round trip to the most northèrly posts. Two or more trips are ordinarily made to points on the upper Mackenzie.

Away from the banks of the rivers the backs of men and dogs furnish the only transport-service known.

The navigation season on the Mackenzie extends from about July 1 to October 1. The river itself is free of ice for four months or more, but the ice in Great Slave lake generally lingers until about July 1.

The Mackenzie at Simpson, which is near latitude 62°, opens from May 4 to May 20, averaging from the 10th to the 15th, according to Captain Mills, who has spent several years at Simpson. Because of nearly dead water in the Mackenzie for a long distance, the head of the river opens two and a half or three weeks later than at Simpson. The opening of Great Slave lake generally occurs, according to Captain Mills, between June 16 and July 2, or six weeks later than the Mackenzie below Simpson. In winter the only communication with the outside world is by dog sledge which carries only first-class mail into the Mackenzie valley once a month.

A table showing the earliest and latest dates, based on records kept at the trading posts, of the appearance of the first drift ice, setting of the ice, and spring break-up, over a 17-year period, 1872 to 1888, is given below. Its importance from the standpoint of navigation in furnishing a synopsis of ice data is evident.

	McMurray	*Simpson*	*Norman*
First drift ice	Oct. 14 to Nov. 4	Oct. 11 to Nov. 12	Oct. 5 to Nov. 2
Ice finally set	Oct. 9 to Nov. 14	Nov. 18 to Nov. 30	Nov. 2 to Nov. 18
Ice broke	April 9 to May 4	May 1 to May 16 *Above Simpson* May 5 to May 27	May 9 to May 28

The above summary gives a good idea of average dates of the arrival and departure of winter conditions in the Mackenzie basin, but in some exceptional seasons the freeze-up comes earlier than these dates suggest. The writer encountered solid ice 1 inch thick on Quatre Fourches channel in Peace River delta, October 9, 1919. Floating ice necessitated abandoning a scow at McKay on the Athabaska, October 13 of the same season.

CLIMATE.

Although the new oil field lies in the latitude of south Baffin island and south Greenland, it has a far more genial summer climate than its latitude would suggest.

All traces of winter conditions have disappeared from the Mackenzie valley by the time the first steamer is able to get through Great Slave lake to the head of the river, which is usually early in July. Concerning the climate of early summer, Joseph Keele, who wintered near the head of Gravel river about 125 miles southwest of the new oil well, remarks that "June is a perfect summer month with practically no darkness and on fair days nearly twenty hours of bright sunshine; the temperature sometimes reaches as high as 90 degrees." The nearly continuous sunshine of June is the great factor in the exceedingly rapid development of vegetation. "Compared with Ottawa, Simpson has an average of three hours more sunlight daily for the summer months, which means about eighteen days of additional sunshine during the three months when sunshine is most important".[1]

The traveller in the Mackenzie valley who sees for the first time the limestone scarps and cliffs of the Mackenzie mountains so near the Arctic zone entirely free of snow in midsummer, is apt to be surprised when he recalls the glaciers and permanent snow fields which are familiar features of the same mountains many hundreds of miles farther south. The Nahanni mountains of the Mackenzie valley, which are quite free of snow in July, are in about the same latitude as the mouth of Frobisher bay, Baffin island, where one of the writers has seen a ship stuck for days in the ice floes, and experienced a snow storm late in July. The genial summer climate of the Mackenzie valley cannot fail to impress anyone who is familiar with the bleak coasts of north-eastern America which lie in the same latitude. Although the middle portion of the Mackenzie valley lies in about the same latitude as Baffin island, its summer climate bears a much stronger resemblance to that of the Gaspe peninsula in the gulf of St. Lawrence than it does to the Baffin Island summer.

Many varieties of flowers in bloom crowd the fire-cleared spaces of the lowland and the mountain slopes early in July. Ripe red raspberries were seen on August 7 on Bear mountain, which is about 80 miles south of the Arctic circle. Ripe blueberries were observed about the same date.

The gardens of the agents of the trading companies, which may be seen at intervals of 100 to 200 miles along the Mackenzie, show that excellent crops of all the more hardy garden vegetables may be grown in favourable seasons as far north as the Arctic circle.

At Wrigley, latitude 63° 14′, the first frost came September 1, 1919, at river level. Snow made its first temporary appearance on the summits of the mountains east of Wrigley on August 21. After September 7 the summit of Cap mountain above 4,000 feet was permanently snow-covered.

September is the ideal part of the year in the Mackenzie valley. The mosquito pest, which greatly abates late in August, disappears altogether with the first frost.

It may be well to remind prospectors who go into the Mackenzie valley expecting to stay there a year or more, that although they will find a genial summer climate, they will need to provide with some care for the sub-arctic winter conditions which follow the seductive smiling northern summers.

Probably no better authority for the character of the winter climate of the lower Mackenzie valley can be cited than R. MacFarlane, who spent many years in the region. He wrote as follows of the winter conditions at Good Hope in latitude 66° 15′.

"During the months of January and February, 1863, the thermometer was frequently as low as 50 degrees and 60 degrees below zero of Fahr.; it was also several times down to 65 degrees and 66 degrees, and once actually at 70 degrees; Notwithstanding this fearful cold, we trip all the same. I was travelling myself, accompanied by six loaded sleds, on the voyage from Good Hope, during this severe cold. Last winter, however, was by no means so severe; the thermometer was comparatively seldom at 50 degrees; it was once only at 55 degrees, and once also 60 degrees minus. In summer it is exceedingly hot at times".[2]

The break-up of the ice in spring begins in the small streams. Joseph Keele, who spent a winter in the Mackenzie mountains, describes it thus:

"In spring, the small side streams are the first to open, then the pressure from the increase of water in the main streams arches the ice-sheet and finally breaks it up. The broken ice usually jams at some point lower down, the pent-

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[1]Camsell, Charles, and Malcolm, Wyatt, "The Mackenzie River basin," Geol. Surv., Can., Mem. 108, 1919, p. 43.

[2]Macfarlane, R., "An account ofthe Mackenzie River district," Proc. Roy. Geog. Soc,. vol. 9, 1864-65, pp. 125-131, reference on pp. 129-130.

water behind the jam breaks out again and sweeps the river clear of ice. This operation is repeated until the entire river is open, no ice being left at the margins."

The formation of ice jams often leads to rapid and destructive rises in the northern rivers. At the mouth of Clearwater river a rise of about 30 feet, which was caused by an ice jam in the spring of 1919, resulted in the loss of a large quantity of provisions stored at McMurray. Alfred H. Harrison described the break-up as he observed it on Slave river as follows:

"The breaking up of the ice on these rivers is a grand sight. In the spring of that same year I happened to be encamped about 2 miles above a bend in the Slave river: in this bend the ice, which had broken in mid-stream, got jammed, and during that night the water, in three hours, rose 14 feet. Sometimes, indeed, the ice gets piled 20 feet high in places and seems to be solidly blocked right down to the bottom of the river; for as the ponderous fragments come along, they are drawn in underneath the pack, and it is only when the water has risen in this manner that the stream at length finds outlet and rushes away with a terrific roar, sweeping away the vast wreckage in its onset; and therewith the ice has wholly passed away for the season, saving only some isolated masses that emerge many days afterwards, covered with mud, from the river bed into which they have been driven by the enormous pressure from above."[1]

One of the authors observed in 1917 a remnant of one of these ice jams on the bank of the Mackenzie in latitude 63, which had a thickness of 25 feet in the last days of July.

GEOGRAPHY

The region covered by this report falls within the limits of two rather sharply contrasted physiographic provinces. The Mackenzie a few miles below Carcajou river passes out of a mountain province into a region bordered by a rolling plateau. The Ramparts gorge is cut through the southern portion of this plateau where hard limestones form the surface rocks. This plateau province is a region of moderate relief where the maximum elevation of the lands adjacent to the river is generally between 200 and 700 feet above it. The Mackenzie valley, from the southern margin of the plateau region above the head of the Ramparts to the mouth of Great Bear river, is, for 130 miles, within the confines of the Rocky Mountains system, which in this northeasterly region is called the Mackenzie mountains. In this area mountain topography alternates with basins floored with Tertiary and Cretaceous beds.

Mountains. Four distinct ranges with a northwest-southeast trend traverse the region northwest of the Great Bear and Gravel River valleys which in a general way limit the region on the south. The most northeasterly range is indicated on previous maps as Franklin mountains and crosses Great Bear river about midway between Mackenzie river and Great Bear lake. East of this range an undulating plain underlain by Cretaceous rocks extends to Great Bear lake. The geology of this range is known only from the Mount Charles section on the north bank of Great Bear river where the rocks are of Silurian age and the maximum elevation is in the neighbourhood of 1,800 feet.

A broad, lake-dotted plain, some 30 miles in width, separates this extreme eastern outlying range of the Rocky Mountains system from two closely associated mountain ranges, lying parallel with, and a few miles east of, Mackenzie river, northwest of Norman. The easternmost of these will be called Willow River mountains. They have an elevation of about 2,000 feet (Plate II A). Immediately southwest of these mountains lies the range which terminates abruptly in Bear mountain, near the mouth of Great Bear river (Plate I B).

[1]Harrison, A. H. "In search of a polar continent," 1905–1907, London 1908, pp. 17–18.

It is proposed to call it Discovery range from the Discovery well located at its western base. This range has a maximum elevation of about 2,500 feet. It is called on McConnell's map "limestone mountains" a term equally applicable to most of the ranges near the Mackenzie. About 30 miles southwest of the Bear mountain range is a double range of mountains with a maximum elevation of approximately 4,500 feet.

The regular northeast-southwest trend of Discovery range and Willow River range which continues for 80 miles northwest of Norman, gives place to a series of four ranges trending east and west which terminate on the east bank of the Mackenzie along the 30-mile stretch above and below the mouth of Carcajou river. These bear the names Beaver mountain, Bat hills (Plates II B and III A), East mountain, and Carcajou mountain. A single, isolated, short, anticlinal mountain—West mountain—stands on the west bank of the Mackenzie opposite East mountain (Map 1872).

No other mountains occur near the river to the north of these east and west ranges; but west of the stretch known as the Grand View, at a distance of perhaps 20 miles, a range apparently about 2,000 feet high can be seen trending northward.

Rivers. Within the limits of the mountain region the ranges exercise a definite control over the direction of some of the large streams. Reference to the map shows that Carcajou river, the "Long Reach" of the Mackenzie below Norman, and the line of lakes extending northwest from Willow river and Willow lake, are all parallel with the adjacent mountain ranges. The abrupt westerly deflexion of the Mackenzie at Carcajou mountain enables it to pass around the western end of this down-pitching, anticlinal mountain ridge. Where mountain structure is entirely wanting, as on the east side of the Mackenzie basin north of the Ramparts, many streams of good size join the Mackenzie at right angles without paralleling it for considerable distances as in the mountain region.

The Mackenzie is everywhere a majestic and impressive river. Ordinary rivers appear insignificant in comparison with it. Certain portions of the 375 miles of the river included in the maps are known by special designations. Some of these afford in themselves good brief characterizations of the essential features of the river along the portion to which they apply. The Long Reach is one of these (Plate II A). The name includes the nearly straight 80-mile stretch of river which skirts the foot of Bear range. This part of the river has an average width of 1 mile and a current rate of 3 or 4 miles an hour.

The Sans Sault rapids which are located a few miles north of Long Reach are formed by the river crossing the western end of the East Mountain anticline. Canoes should keep to the west side of these rapids.

The narrowest part of the river is found in the Ramparts, a gorge 100 to 180 feet deep and about 5 miles long cut through the nearly flat-lying limestone above Good Hope. Much of the rolling surface of the land adjacent to the Ramparts consists of nearly bare limestone which has been swept almost clear of whatever glacial debris may have been deposited on it. Only two small glacial boulders were found in a walk of a mile back from the river and no traces of gravel or sand or clay until a level of 200 feet or more above the river was reached.

The greatest width of the river is found at Grand View. This name applies "to an expanded portion of the Mackenzie, about twenty miles in length. The river here is almost straight, but curves gently to the north, and is from two to three miles wide. Its great width gives it more the appearance of a lake than a river, and in no other part of the Mackenzie is the magnitude of the mighty volume of water which this river carries to the sea impressed so forcibly on the mind. The banks are low and the sinuous shorelines show a succession of wooded points stretching out until concealed by the haze of the atmosphere. The bordering plains slope gently down almost to the water's edge, and are covered with a scattered growth of willow, spruce, and tamarack, with here and there patches of aspens on the drier ridges. The spruce along part of this reach presents a remarkably stunted and dwarfish appearance, but this is due more to the marshy character of the ground than to climatic severity, as the same tree, straight and well grown, was found much farther north."

Creeks. Since many of the best geological sections in the region are found along or near small unnamed streams entering the Mackenzie, it was desirable to give names to some of them. The northernmost, which has been called Fort creek, enters the Mackenzie from the east near where the river makes its abrupt bend to the westward above the site of old Fort Good Hope.

Four of the small streams which appear for the first time on the accompanying map (No. 1872) trench the western slopes of Discovery range and join the Long Reach section of the Mackenzie north of Norman. They are named in down-river order, Vermilion, Francis, Canyon, and Bosworth creeks.

STRATIGRAPHY

General Statement

In the lower Mackenzie valley the rocks of the Devonian system are the only Palæozoic formations exposed in the immediate vicinity of the river. The crests of some of the anticlines bring Silurian rocks to the surface a few miles from the river, and a great thickness of these older beds is exposed on Great Bear river 45 miles east of the Mackenzie. In the Gravel River region, about 100 miles southwest of Bear mountain, Ordovician and Cambrian terranes have been reported.

Silurian rocks are known to underlie the southern third of the region. Ordovician and Cambrian formations may also be present, but no evidence of their occurrence has yet been discovered.

No estimate of the total thickness of the pre-Devonian rocks is at present possible. Since the Silurian rocks are not known to be oil bearing they will be considered in the following discussion only in so far as they are related to the Devonian formations as representing the basal horizons of the sections.

The broader features of the stratigraphy of the region may be indicated by the list of geological systems present, together with a very brief summary of some of the most characteristic features of the lithology represented:

Tertiary	Shales, sandstones, and lignite.
Cretaceous	Clay shales and sandstones.
Devonian	Limestones, bituminous shales, and sandstones.
Silurian	Limestones, dolomites, gypsum

The Carboniferous, Triassic, and Jurassic systems are absent from the section throughout the Mackenzie valley.

The unconformity at the top of the Devonian brings different formations in contact with the Cretaceous in different parts of the region. As a result of non-deposition or erosion, or possibly both, the uppermost Devonian formation of one area may be wanting in another. This will be more fully shown in discussing the details of the stratigraphy.

The Devonian and Silurian rocks are divisible into the following lithologic units and will be described in order, starting with the lowest.

Table of Formations.

			Thickness Feet	Correlation with Great Slave lake and Upper Mackenzie
Upper Devonian	Bosworth sandstone and shale	Greenish and vari-coloured clay-shales and sandstones with marine shells and plant-fragments	2,000+	Hay River limestone and shale.
	Fort Creek shales	Bituminous shales, with thin seams of dark limestone and calcareous sandstone. Black or dark, but in places burnt brick-red. Plants and marine shells, common.	500–1,000	Simpson shale (with upper part).
Middle Devonian	Beavertail limestone	Hard, thick and thin, bituminous limestones with some shale partings. Black or dark grey.	350	Slave Point limestone.
	Ramparts limestones	Compact grey limestones, *Stringocephalus burtoni* and other fossils......................	250	Presquile dolomite
	Hare Indian River shales	Calcareous clay-shales with thin seams of limestone. Grey-green colour. Few fossils.	300+	Pine Point limestone
Silurian	Bear Mountain formation	Brecciated dolomite with hard grey limestone. gypsum, etc.	1,600	Fitzgerald dolomite
	Lone Mountain dolomite	Sandy magnesian limestone, dark grey and buff, without fossils.	1800	

Detailed Stratigraphy

Lone Mountain Dolomite. Near the mouth of North Nahanni river in the vicinity of the Great Bend of the Mackenzie the Palæozoic series is exposed for several miles in a nearly vertical scarp trending north from the Nahanni. This scarp exposes the edges of rock having a thickness of 2,000 feet or more and dipping west at an angle of about 35 degrees. The nearly vertical character of this scarp (Plate IV), made it necessary to study the same beds in a section on Lone mountain which is immediately south of Nahanni river. The following section is exposed on the sides and top of Lone mountain:

	Feet
d. Grey limestone somewhat lighter coloured than c. Fossils present...........	130
c. Dark grey limestone (Devonian). Fossils common. *Productella* sp. is the dominant species. Favosites and other corals rather common..............	80+
b. Light grey to dark, almost black dolomite and magnesian limestone, mostly fine grained but with some beds of saccharoidal texture..................... Fossils rare or absent.	1,500±
a. Massive dark grey limestone, some beds mottled with dark coloured dolomite. Corals present..	50+

Below the 210 feet of fossiliferous Devonian beds at top of mountains no fossils were found except in the basal 50 feet of the dolomitic limestones. These are chiefly poorly-preserved corals which appear to indicate a Silurian age for these beds. The beds below will be called the Lone Mountain dolomite.

The barren limestones which T. A. Link found in several of his traverses across Discovery range lie immediately below the richly fossiliferous Devonian limestones and bear apparently the same stratigraphic relations to the Devonian that the Lone Mountain dolomite bears to the Devonian in the Nahanni River district. This name is, therefore, applied to the beds at the base of the Discovery Range section. The base of this formation has not been seen.

The distribution of the formation is not indicated on the map. It may be stated in general, however, on the authority of Link, that its occurrence as a surface formation is mainly confined to that part of Discovery range near the anticlinal axis east and northwest of Bosworth creek.

Bear Mountain Formation. The southern end of Bosworth mountain shows a rather wide variety of sediments which will be called the Bear Mountain formation (Plate I B). These beds which are composed chiefly of limestones with some gypsum and shale lie immediately below a Devonian limestone correlated with the Beavertail. It is supposed to rest upon the Lone Mountain series but this formation is not exposed in Bear mountain. The character of the beds in this formation is indicated by the following section.

	Feet.
a. Grey jointed limestone with corals (Devonian)................................	100+
b. Hard grey limestone with occasional thin bands of dark shale. Fish teeth and plates and ostracoda in the latter (mostly on west slope of mountain)........	800±
c. Grey, thin-bedded limestone with banded appearance weathering buff (in south face of mountain)..	400±
d. Grey argillaceous shale interbedded with limestone which is sometimes cherty and has a few oolitic bands..	160
e. Drab clay shale with 1-foot band of iron ore near top with botryoidal upper surface and occasional thin limestone band..	100
f. Red, gypsiferous shale with bands of white selenite 1 inch to 3 inches thick......	30+
g. Thin-bedded limestone, shale, and covered..	100

The Bear Mountain formation includes all of the section below a.

The above section represents only the highly inclined beds exposed at the south and west slope of the mountain. Their exact relationship to the nearly horizontal beds east of the gypsiferous beds in the section was not determined.

Although careful search was made for fossils throughout the section, they were found in only one set of beds not more than 40 feet thick, located in the upper part of the section about 350 feet above base of Bear mountain. The fossils found include numerous ostracods, small fish remains, and some other poorly preserved specimens. The fauna is not yet well enough understood to fix the position of these beds in the geological scale with certainty. Provisionally they are placed in late Upper Silurian horizon. They are believed to represent about the same horizon as the Fitzgerald dolomite of Slave River valley. There is, however, nothing in common between the known faunas of the two formations. It is not impossible that the Bear Mountain formation may represent a special facies of the Lone Mountain formation.

The Bear Mountain formation is not known beyond Discovery range.

Hare Indian River Shale. At the lower end of the Ramparts gorge the heavy-bedded limestone which forms the walls of the gorge rests on a bluish-grey calcareous shale in strata 1 inch to 3 inches thick. The section on the east side of the river exposes 95 feet of these shales. The fauna is limited chiefly to a Chonetes and one or two species of Martinias which are abundant (Plate III B).

Good sections of this shale also occur at the mouth of Hare Indian river from which the formation is named, and in the cliffs below Good Hope. A shale considered to be the Hare Indian River shale forms the summit of a ridge on the river slope of Carcajou mountain and similar shales thought to belong to this formation occur in several anticlinal hills.

The base of this shale has not been observed and the thickness of ±300 provisionally ascribed to it is only a rough estimate.

Ramparts Limestone. This limestone is designated the Ramparts limestone because of the excellent exposure of it in the Ramparts section (Plate III B) just above Good Hope, where it lies between the Hare Indian River shales below and the Cretaceous shales above, and has a thickness of about 245 feet. The relations of this formation to the beds above and below are shown in the following section:

Ramparts Section

	Feet	Inches.
a.[1] Dark grey, soft shale with occasional thin band of iron ore and flattened spherical concretions. No fossils	120	
b. Iron ore band (best exposed in creek 5 miles above Ramparts)		10
c.[2] Band of shale	1	
d.[2] Thin-bedded, buff sandstones with shale in middle; bedding in basal part very irregular like wind-blown sand. Lowest beds in one case observed filling depression between low limestone knobs (a to d Cretaceous)	20	
Distinct disconformity.		
e. Hard, cherty limestone cracking freely into small pieces and weathering to a very irregular surface. Numerous spherical masses of Stromatoporoid coral give bedding an irregular appearance. Small branching corals and a large, thick-shelled pelecypod are the only other common fossils	120	
f. Black, calcareous shale witn a Cladophora of branching type	1–4	
g. Hard, knobby limestone full of Stromatoporoid corals of spherical shape 2 inches to 3 inches in diameter, resembles e but more knobby. *Stringocephalus burtoni* common in some beds. A drab, argillaceous limestone of fine texture and an occasional 4-inch to 8-inch band of blue black shale occasionally interrupts the beds of Stromatoporoid limestone. Stromatoporoids comprise 80 per cent of the latter. Certain beds have an abundance of crinoid stems.	30±	
h. Grey, hard limestone mostly in 6-inch to 10-inch strata. Stromatoporoids abundant, other corals much more varied and abundant than in g. Rensselaeria and Stringocephalus also common	95	
i. Bluish grey calcareous shale in strata mostly 1 inch to 3 inches thick with *Chonetes* and *Martinia* abundant	95	

Beds in upper 2 miles dip up stream at about 1 degree; the fall of the river makes them rise in the cliffs in descending the gorge rather rapidly, however.

All of the limestone beds in the Ramparts are quite free from small low folds or domes such as those seen on Athabaska river.

A more typical example of a disconformity than the contact between the middle Devonian limestone and the Cretaceous at the head of the Ramparts would be difficult to find. Not only are three geological systems—the Jurassic, Triassic, and Carboniferous—missing, but all of the Upper Devonian as well are absent from the section. The absence of the Devonian formations of later age is probably due to their erosion. The highly irregular surface of the top of the Ramparts limestone furnishes unmistakable evidence of the down-cutting of the limestone surface previous to Cretaceous sedimentation. Erosion in pre-Cretaceous times has in places cut out the whole of the Devonian limestone series. A section of the west bank of the Mackenzie, about 10 miles northwest of Good Hope, shows the Cretaceous shale and sandstone resting directly on the Hare Indian River shale, while the Ramparts limestone has on either side of this section its ordinary development except that it is thinner than in the Ramparts. The presence of the Upper Devonian shale in the sections both north and south of the Ramparts region indicates that its absence at the Ramparts is due to erosion.

The Ramparts limestone forms a scarp along the sides of the valley for several miles north of Good Hope. South of the Ramparts it has been recognized by its characteristic fossil—*Stringocephalus burtoni*—in the Bat hills and Carcajou mountain.

Beavertail Limestone. The thickness of this series is 300–400 feet. The strata consist of hard, thick and thin-bedded, bituminous limestones, with some shaly partings. They are so highly bituminous that their colour generally is almost black.

These rocks contain few fossils; but at the top there is a coralline bed which frequently forms dip-slopes. Its surface weathers grey, but where newly fractured it is seen to consist of grey corallites set in a black bituminous matrix.

A gradual transition upward from the Beavertail limestones into the Fort Creek shales, is well seen in the extensive cliff exposures along the south flank of the Wolverine anticline.

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[1]a is exposed in banks of creek on each side of river, 5 miles above the Ramparts.

[2]Exposed immediately above the Ramparts on east bank of river.

The Beavertail limestones, being considerably more resistant than the overlying formations, form the slopes of the ridges which mark the trend of each of the main anticlinal folds. They are conspicuously exposed in many places between Norman and the Ramparts.

On the banks of the Mackenzie they are well seen at Carcajou rock (Plate V B), East mountain, and Beavertail point: they are fully exposed on the hills, and up the creeks entering the Mackenzie between Bear mountain and Carcajou.

The character of the upper part of this limestone and its relation to the next higher formation are shown in the following section taken near the northern end of the riverside exposures at Carcajou mountain.

Carcajou Mountain Section

	Feet
a. Fissile black shale with interbedded bituminous limestone becoming more calcareous in upper 16 feet and splitting into sheets of bluish-black, bituminous limestone	65+
b. Grey limestone	5
c. Fissile black shale	1
d. Dark magnesian limestone of saccharoidal texture and bituminous odour	4
e. Hard, dark blue limestone with one or two thin bands of black slate in lower half	55

This section shows plainly the intergrading of the Beavertail limestone with the black shale of the Fort Creek shales. The beds to the east are considered to represent the upper part of this formation. About one mile up the river from the section, where the limestones stand vertical, about 260 feet of limestone is exposed. *Stringocephalus burtoni* occurs abundantly in the innermost or lowermost 60 feet of these rocks thus indicating the identity of a part or the whole of the limestones on the river bank at this point with the Ramparts series, which forms the base of the Beavertail limestone.

Fort Creek Shale. This series has a thickness varying from 500 to 1,000 feet, of which large parts are fully exposed in many places.

The strata are of very dark colour, often almost black. They consist chiefly of bituminous clay-shale, with thin seams of black limestone and calcareous sandstone. In some of the shales large plants are present, and the limestone bands contain some *Leiorhynchoids*, *Chonetes*, *Productella*, and other fossils.

These bituminous beds are seen throughout a considerable extent of the country between Norman and the northern limit of the map. They are exposed on the flanks of all the anticlines outcropping on the banks of the Mackenzie near Bear mountain, Carcajou rock, East mountain, and also in many tributary creeks.

About the latitude of the Arctic circle, and from thence northward, they occupy a large area, lying almost horizontal. Near the site of old Fort Good Hope they are much exposed in the river cliffs, and in Fort creek and elsewhere (Plate V A).

These shales are so bituminous that their odour is perceptible at a distance. In many places they are undergoing slow combustion and are burnt to a bright brick-red colour. (See also page 54).

By weathering, the cliffs of Fort Creek shales are often coated with sulphur, and there are many sulphur springs in the areas underlain by them.

The main oil horizon was encountered in the Discovery oil well, at 783 feet. It is believed to lie in the middle or lower portion of this series.

The following section taken at the type locality of these shales shows the upper part of the formation:

Fort Creek Section

	Feet
a. Black, bituminous, fissile shale with occasional ⅛ inch of cherty material....... *Styliolina*, *Conodonts*, and plant fragments.	120±
b. Black, bituminous, sandy slate or slaty sandstone. Sand grains very fine; strong bituminous odour. Splitting freely into large even sheets. Fossil plants common, one 6 inches in diameter (Pseudobornia ?), also a few Tentaculites..........	15
c. Black, bituminous sandstone similar to above but without the slaty cleavage and in beds 8 inches or 10 inches thick..........	5
d. Drab, argillaceous, soft shale with *Leiouhynchus* sp. *Productella* (large) *Chonetes* et cetera ?.......... (Lower part covered).	35

The base of a series of black shales considered to represent this formation is exposed on the northwest side of Bear mountain near the base in the bed of a small brook which heads on the mountain. Fissile black shale 50 feet thick rests on grey limestone, showing an abrupt transition, in sharp contrast with the transition seen in the Carcajou Mountain section (page 47).

Bosworth Sandstone and Shale. This important formation has a thickness probably exceeding 2,000 feet, though only the lower 1,000 feet have been found exposed.

The formation consists chiefly of grey-green clay-shales, sand-shales, and sandstones, with other vari-coloured strata. Some beds contain marine fossils such as *Atrypa reticularis* and *Acervularia*, in others there are plant fragments and carbonaceous matter.

The basal part, to the extent of some 200 feet, is largely of sandstone beds, and at other horizons also prominent green sandstones occur. At outcrops the sandstones give rise to seepages of oil.

On drilling into the outcropping Bosworth beds, small yields of oil were immediately procured.

These beds occur in the country north of Norman, occupying the synclines or lying low down on the flanks of the anticlinal folds.

The best sections are found in a number of creeks which enter the Long Reach of Mackenzie river from the northeast, in the 100 miles between Bear mountain and Carcajou rock.

Along the river side also, between these points, there are several small outcrops of the sandstones, causing seepages of oil. But the only large exposure on the banks of the Mackenzie is on the south flank of the Wolverine anticline, where a few hundred feet of these beds are seen just before the river turns westward, a few miles southeast of Carcajou rock.

The character of the beds exposed here is indicated in the following section:

Carcajou Mountain Section

	Feet
a. Hard, thin-bedded, grey siliceous limestone weathering brown, with numerous plant fragments, also some invertebrate fossils..........	5
b. Dark shale and covered..........	65±
c. Dark, lead-grey shale with much disseminated decomposing Fe_2 S and yellow sulphur-stained beds..........	150±
d. Thin-bedded, irregular, current marked sandstone..........	5
e. Duplicate of c..........	75
f. Sandy shale and thin-bedded sandstone with few rounded pebbles in upper beds 4 inches to 8 inches in diameter. Worm trails common..........	6
g. Dark shale with sandy bands..........	25
h. Hard, buff, thin-bedded, ripple-marked sandstone..........	15
i. Dark bluish shale..........	35
j. Buff sandstone..........	6
k. Shale and thin-bedded sandstone..........	75
l. Hard, bluish-grey shale..........	60
m. Fissile dark shale..........	100
n. Sandy, bluish-grey shale..........	150+

Age and Correlation

A discussion of the geological age and the correlation of the formations which are recognized and described here will be presented elsewhere.

The table given in the first part of this section indicates the correlation of the formations of this region with those of other parts of the Mackenzie basin. The palæontological evidence on which the table is based, will be presented in later papers.

It may be noted that although the region included in the maps has furnished no fossils from the formation forming the base of the section and here referred to the Silurian, an unmistakable Silurian fauna has been found by one of the authors in the Mount Charles section on Great Bear river, and in the Cap Mountain section, east of Wrigley. Such characteristic Silurian species as *Halysites catenulatus* and *Conchidium* sp. are present in these sections in dolomites which almost certainly represent the formation here called the Lone Mountain dolomite.

The youngest of the Palæozoic faunas in the section, the Fort Creek shales, has some interesting features among which are a *Pseudobornia* (?) resembling one in the Huron shale of the Ohio Devonian. A conodont fauna was also discovered in this shale—the first which has been found in northwestern Canada.

A large proportion of the faunas of the several formations are new and the discussion of their relation and characteristics must be deferred to a later paper.

GEOLOGICAL STRUCTURE

The Devonian rocks exposed in the Mackenzie valley are part of a great sheet of marine sediments which were laid over much of the northwest quarter of North America.

The original shore-lines of these deposits are, as yet, matter for conjecture and the mapping of the boundaries of the preserved portion of the resulting formations is far from complete.

The broader features of the structures developed in these formations by mountain-building forces will be outlined so far as they have been worked out.

Structure Between Norman and the Ramparts

Twelve miles before reaching Norman, the Mackenzie turns sharply northwestward, flowing along the south flank of Discovery range. This straight course known as the Long Reach (Plates I B and II A), is maintained for 75 miles, parallel with the range, and several miles to the southwest of it. The river then turns sharply northward, and in a distance of 25 miles it cuts across the trend of the mountains at their western end.

In this 100 miles of the Mackenzie valley, the Devonian formations are much exposed, and mountain-building folds which will now be described are revealed.

Anticlinal structure in this region was noticed first at Bear mountain (Plate I B), by McConnell, in 1888. The other folds were found and mapped by T. O. Bosworth in 1914. It was in this territory that the favourable indications and structural conditions were found which have led to the recent strike of oil.

Before a complete account of the tectonics can be written, much further geological work is necessary. The following represents but an imperfect preliminary impression.

The Devonian beds of the Discovery Range district have been thrown into a series of bold unsymmetrical folds, whose axes plunge up and down, steeply and frequently.

In the synclinals, the soft Bosworth sandstone and shale beds and Fort Creek shales, together with the overlying Cretaceous deposits, give rise to flat, low ground. But wherever the upward pitchings of the axes bring the arches of the Beavertail and lower limestones up above the general level of the land denudation has developed these arches as conspicuous anticlinal mountains.

In the area where the Mackenzie crosses the folds, there are four main anticlines, all pitching downward to the west. In order from south to north they have been named:

Wolverine anticline.
East Mountain anticline.
Bat Hills anticline.
Beavertail anticline.

The wave-lengths of the folds, from crest to crest, are about 7 miles. The amplitude from crest to trough must be of the order of 5,000 to 10.000 feet.

The four folds are approximately parallel. Where the river crosses them, their trend is a few degrees north of east, but east of the river they bend round to the southeast course, which is probably their more important direction.

Far back from the river little exploration has yet been done, and it is not known whether all of the four anticlines are continuous. In the district where their direction crosses the river, it is seen that, owing to their pitching up and down, they tend to cause four ranges of rather discontinuous hills.

Wolverine Anticline. (Plate V B and Figure 9 C and D.) The southernmost of the four anticlines was examined with the most care. It is thought that this axis of folding is continuous from Bear mountain (near Norman) to Carcajou mountain, with a length of about 100 miles. Throughout the greater part of this length, the axis lies 8 miles inland, parallel with the river; but a turn in its direction, at each end, brings it to the river bank.

At Bear mountain which has a height of 1,500 feet, the folding is complicated by faulting and is not yet fully mapped. The core of the arch consists of the limestones with reddish shales and gypsum shown in the section page 45 to which the name Bear Mountain formation is applied. On the west flank, the bituminous Beavertail limestone and Fort Creek shales are exposed.

About 12 miles south of Bear mountain on the opposite side of the river another hill, of similar appearance, is seen. Probably this is another anticlinal mass of limestone, which may belong to the same axis of folding as Bear mountain.

Passing inland from Bear mountain, the anticlinal axis at first follows a north-northwest direction, but soon swerves round a little to the northwest. It continues as a well-developed structure, parallel with the Long Reach. The dip-slope of the anticline is well seen from the river, all along this straight course (Plate II A). The crest of the ridge, which is about 8 miles back from the river, has a height of about 2,500 feet.

The river here flows along the strike of the soft Bosworth shales, and few rock exposures can be found in its low banks except by digging under the boulders and gravel. Ample exposures, however, are seen on ascending any of the tributary streams that flow down from the mountain range.

A traverse up Bosworth creek to the mountains was made in 1914, and several others have been made since. In all of them, the findings were much alike; and it is clear that the several formations of the Devonian crop out in successive bands, approximately as shown on the accompanying map. The dip generally is 5 degrees to 10 degrees near the river, increasing gradually inland to 20 degrees to 30 degrees, when the outcrop of the Beavertail limestone is reached, and to yet steeper inclinations as the axis is approached.

In the gently-inclined Bosworth Creek beds and Fort Creek shales many minor undulations were observed.

The outcrops of the Bosworth formation, Fort Creek shales, and Beavertail limestones, were clearly established, but as already explained in the paragraphs on stratigraphy, the identity of all the lower grey limestone members is not yet determined.

In this inland district the northeastern flank of the anticline has not been explored, nor have the farther ridges, which are thought to mark the position of the other anticlines, been reached.

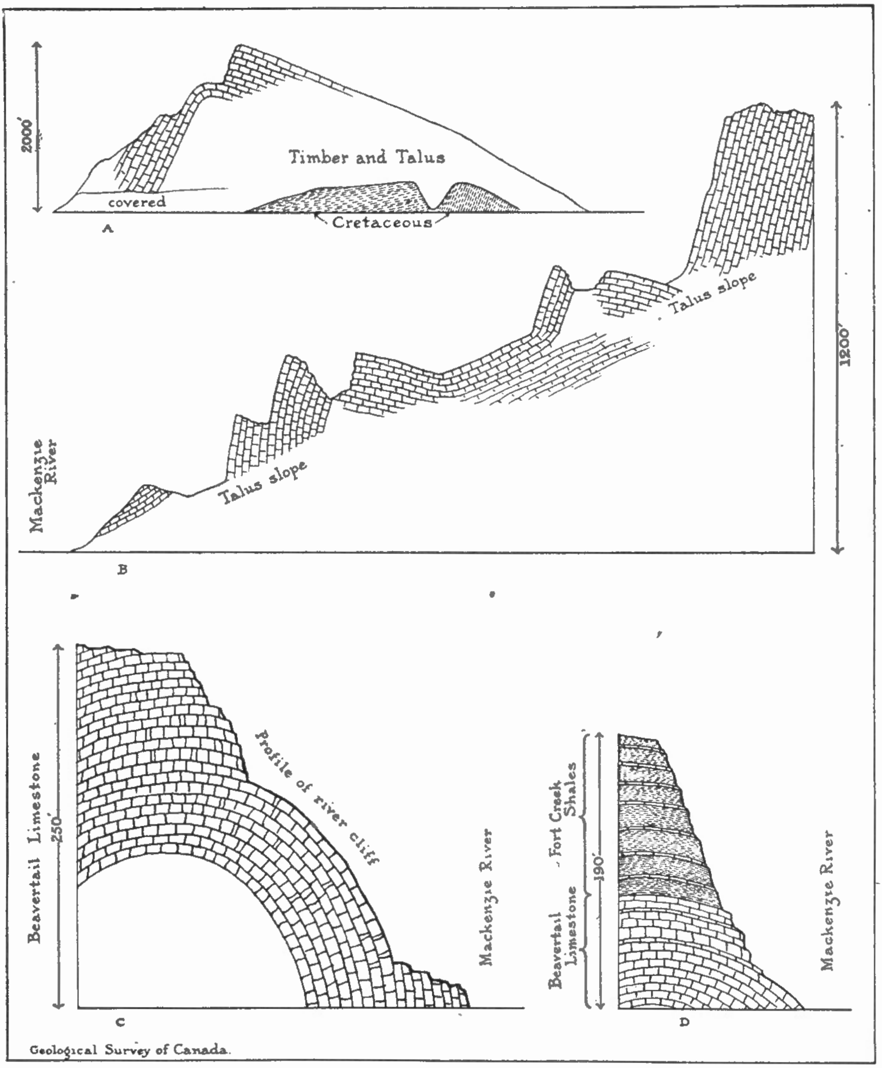

Figure 9. A. Profile sketch of East Mountain anticline from Mackenzie river.
B. Diagrammatic sketch of minor anticlinal arches superposed on the west flank of Discovery Range anticline.
C and D. South flank of Wolverine anticline as seen forming the river cliff west of Carcajou rock. C. View of the exposures west of the middle of the cliff. D. View of the exposure near the west end of the cliff.

Towards its northern end, the axis of this long anticline presumably turns westward and joins up with the conspicuous fold at Carcajou mountain, a bold limestone ridge on the north bank of the river, 1,000 feet in height. Here, for a distance of about 15 miles, the axis of the anticline trends along the north bank of the river, and the core is well exposed. The fold is very steep, and its south flank is seen as an almost vertical wall of Beavertail and Ramparts limestone, which has controlled the course of the stream, and now forms its cliff for about 10 miles. The crest of the arch is at the top of the cliff (See sketch Figure 9 A and B) and the north flank forms the slope of the hill, which faces inland. The top is nearly flat.

The fold pitches steeply westward, and, towards the west end of the cliff, the arch of Beavertail limestone passes underground. (Figure 9 B).

Lower limestones are exposed in the eastern end of these cliffs, on the axis of the fold. Provisionally they are considered to be the Bear Mountain formation.

East Mountain Anticline. (See Plates II B and III A). This anticline is about 6 miles north of the Wolverine anticline, and is very similar to it; though in this case the north side of the fold is the steeper.

East mountain, rising to a height of nearly 2,000 feet, on the east side of the river, is formed by the arch of limestones brought up by this anticline.

The dark bituminous Beavertail limestone is seen on the steep outer slopes; lower grey Ramparts limestones compose the core.

On the north flank of the anticline the limestones are inclined at 70 degrees, or even 80 degrees near the axis. On the south limb the dip is about 30 degrees to 40 degrees. (Figure 9 C and D.)

The axis pitches down towards the river, where the arch of Beavertail limestone passes underground.

Here the river floor is rough with outcrops of limestone, and there is swift water, known as the Sans Sault rapids.

The East Mountain anticline was traced inland only a few miles, but an impression was obtained that the axis pitches up and down, causing an irregular line of hills. It is thought that this anticline is continuous inland, behind, and parallel with, the Wolverine anticline. (Plate II).

West Mountain. On the west side of the river, an isolated anticlinal hill of Beavertail limestone, known as West mountain, has a height of about 1,000 feet. The relation of this mass to the four anticlines on the east side of the river is not yet known. It lies somewhat south of the direct continuation of the East Mountain axis.

Bat Hills Anticline. This anticline, which lies 7 miles north of the East Mountain anticline, appears to be of a similar nature, but was not closely examined. Apparently its arch of limestone was rather more elevated than those of the other folds, and has suffered more erosion.

The Beavertail limestones are well seen on either flank, and grey limestones occur in the core. Geologists who visited these hills in 1919 found *Stringocephalus* in the grey limestones on the axis of the fold, thus indicating the Ramparts limestones. In the core of the fold they found dolomites and red limestones, which they identified as Bear Mountain limestones.

Beavertail Anticline. This is the most northerly anticline found. It is similar to the others and is situated 7 miles north of the Bat Hills anticline.

The arch of limestones forms a ridge about 1,000 feet high. The south limb of the fold is the steeper, having dips of 40 degrees to 60 degrees.

At the river side the arch of Beavertail limestone is seen pitching down to pass westward under the river. This fold was not followed far inland, but the hills along its axis apparently continue parallel with the other folds.

Lowland Southwest of the Long Reach.

Southwest of the Long Reach low flat country extends back to the first range of Mackenzie mountains, whose summits, 3,000 to 4,000 feet high, are about 25 miles from the river.

Viewed from East mountain and from Bear mountain, this large expanse of lowland did not appear likely to afford much geological evidence. Only trees and water were seen. Probably its surface is formed chiefly by the soft Bosworth beds and by overlying Cretaceous deposits.

Possibly the four mountain-building anticlines described above, and others like them, extend into this area, making no topographic features because the arches of limestones are below the level of the lowland plain. Whether or not such folds as those occur, it is likely that there are many minor undulations.

The general structure of this lowland is probably a synclinal, though situated between the anticlinal axis of Discovery range and another anticline in the outer range of the Mackenzie mountains west of Carcajou river.

Period of Folding.

The above-described folding of the Devonian rocks did not take place all at one period. The greater part of it, probably, was pre-Cretaceous; for the Cretaceous beds that occupy the synclines and lie against the flanks of the anticlines, are much less steeply-inclined than the Devonian. Moreover the Cretaceous deposits are clearly composed of material derived by erosion from the Devonian rocks, particularly the Fort Creek shales.

But the attitude of the Cretaceous beds shows that folding along the same axes continued to an important degree also in post-Cretaceous times.

Structure between the Ramparts and Old Fort Good Hope.

No exposures of Devonian rocks are seen between their disappearance under the Cretaceous at Beavertail point and their emergence at the Narrows which lead into the gorge known as the Ramparts, a distance of 25 miles.

In the Ramparts the river is bordered by vertical cliffs, 150-200 feet high, which are formed by the Ramparts limestone, underlain by the Hare Indian River shales (Plate III B). These beds lie approximately horizontal, and from this place northwards no visibly folded rocks are found.

After emerging from the Ramparts, at Good Hope, the river turns to a general northwest course, which is maintained for 110 miles, to old Fort Good Hope.

Throughout much of this distance, cliffs of the Ramparts limestones and Hare Indian River shales are frequent. The attitude of the beds is nearly horizontal, and back from the river the limestone gives rise to plateau topography.

About 2 miles east of old Fort Good Hope, near where the Mackenzie changes from a northwesterly to a westerly course, cliffs composed of the black Upper Devonian Fort Creek shales appear with a gentle westerly dip which carries them below the Cretaceous shales a short distance below old Fort Good Hope (Plate V A). The exposures in the banks of the Mackenzie, and in Fort creek, do not directly reveal the relationship of these beds to the Ramparts limestones. But the evident westerly or northwesterly dip of the Fort Creek shales applies to the entire Devonian series below them, including the Ramparts limestone (if present so far north), which in the neighbourhood of Fort creek has passed below drainage.

A few miles beyond the site of the old fort, the Cretaceous beds occupy the surface and from there to the delta of the river, the Devonian rocks are no more seen.

We have, therefore, between the southeast border of the Cretaceous basin (which extends from the old fort to the delta) and the Cretaceous basin south of the Ramparts, a very broad and gentle arch with a north-south extension along the river of about 110 miles. It is probably shield-shaped with the longer axis parallel with this part of the river. It may be called the Grand View anticline. The almost negligible dips of this structure bear much the same relation to those of the sharp, narrow anticlines of the mountains south of it that the nearly imperceptible dips of the Cincinnati anticline of the Ohio valley bear to the structures of the Alleghany mountains.

At two or three places in the Mackenzie valley seepages of oil attracted the attention of early explorers, and have long been known. Inland from the river, other seepages were reported by the Indians.

The tar springs of the Athabaska region were noted as early as 1789 by Sir Alexander Mackenzie in the "Voyages through North America to the frozen and Pacific oceans." The first report of the Canadian Geological Survey on the Mackenzie valley described the oil prospects of the region. This report states that "The Devonian rocks throughout the Mackenzie valley are nearly everywhere more or less petroliferous, and over large areas afford promising indications of the presence of oil in workable quantities."[1]

The remarkable character of the rocks, and the discovery of advantageous structures, rather than the seepages, led one of the authors in 1914 to mark out certain areas as probable commercial oil fields.

Bituminous Limestones

Extending over a very large area, we have, within the Devonian, two thick and richly bituminous members.

The lower of these is the Beavertail limestone, having a thickness of 300 to 400 feet, which already has been described in the chapter on stratigraphy.

This limestone is more or less black with solid bituminous matter. It has a strong characteristic odour distinct from that of asphaltic or paraffin crude oils. It is thought that the bitumen is a fixed component of the limestone, and not a variable constituent, dependent on the migratory movements of the hydrocarbons in the rocks. In all the many exposures of Beavertail limestones at present known the rock is bituminous. All, however, are on the crests or flanks of anticlines.

No fluid oil was detected within these beds, and no oil seepages emanate from them.

All the way northward from Bear mountain to Beavertail point—a distance of 125 miles—this bituminous limestone is frequently conspicuous. Presumably it underlies a large area, extending far and wide throughout much of the country between Norman and the Arctic ocean.

Southward of Norman, also, it may be present, though it has not yet been identified at the surface.

The most accessible exposures of the Beavertail limestones are seen at the water's edge at Beavertail point, and near East mountain, and also in the river cliffs of Carcajou mountain.

This limestone is exposed on all the anticlinal mountains, and a few miles inland from the Long Reach, along the southwest flank of Discovery range; it has an outcrop 100 miles in length.

At depth, under favourable structural conditions, it is possible that some of the beds in this series may be found to hold accumulations of fluid oil.

Bituminous Shales.

Richly bituminous black shales—the Fort Creek shales—500 to 1,000 feet thick, overlie the bituminous limestones, and are spread over the same extensive territory.

When placed in a hot fire this shale will undergo some combustion, and sometimes will make a flame. The bituminous odour arising from the cliffs in some cases is so strong that it is noticeable at a distance of half a mile.

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[1]McConnell, R. G., "An exploration in the Yukon and Mackenzie basins, N.W.T." Geol. Surv. Can., Ann. Rept., new series. vol. IV, pt. D, 1888-89 (1890) p. 31.

On retorting a sample of this shale in a crude apparatus, in 1914, a small yield of oil was obtained.

Fluid oil was not seen in these rocks, and no seepages of oil rise from them.

At depth, however, under favourable conditions, it is likely that the sandy bands will carry oil.

The present main oil horizon (783 feet) in the Discovery well, is supposed to be within these beds.

These shales, being relatively soft, form low ground, and so are not conspicuously exposed. From the river they are best seen at Carcajou, and also near old Fort Good Hope, but inland, they are more fully displayed in the cliffs of many of the tributary creeks. They crop out low on the flanks of all the anticlines. Between Bear mountain and Carcajou, they have an outcrop about 100 miles in length.

In many places the bituminous shales are undergoing slow combustion at their outcrop, and are quite hot. In this process the bitumen is burnt out of them, and the shale acquires a bright brick-red colour. Some parts are burnt almost white, and become hard, so that they clink when struck.

In several places there are red cliffs of these burnt shales 100 to 200 feet high. Examples are seen up Fort creek (near old Fort Good Hope), and up Canyon creek, and Vermilion creek which enter the Long Reach, about 25 miles northwest of Norman.

Oil-Sands

Sandstones containing oil were seen at all the outcrops of the Bosworth beds that were examined.

In all cases they were beds of greenish sandstone, alternating with beds of clay-shale.

Some of these oil-sands were saturated with oil, but in others the oil was not visible except on breaking the rock under water.

The oil is light and almost colourless, and the odour of these oil-sands indicates a paraffin base and high gasolene content. It is quite different from the odour of asphaltic oils.

Some large blocks of this oil-sand are seen "in situ" on the shore near the mouth of Bosworth creek, where the Discovery well is situated.

Oil Seepages

All of the oil seepages discovered arise from sands in the Bosworth beds. Oil at the surface was found in five different localities. Further search probably will reveal many others.

Near the mouth of Bosworth[1] creek oil comes up in many places on the shore of the Mackenzie for a distance of 2½ miles. On digging in the gravel, the outcrops of the oil-sands are exposed, and oil can be collected in tins. Farther out in the river, oil in considerable quantity comes up to the surface of the water, and in the winter it collects in pools on the ice.

In some places on the delta of Bosworth creek there were dark patches of alluvium heavily impregnated with the residuum of oil. These were superficial only, and are due to the evaporation of pools of oil which had been carried ashore on the surface of the pack ice.

Further seepages were found in Bosworth creek.

Near Vermilion creek, about half-way between Norman and Bosworth creek, on the north bank of the Mackenzie, seepages similar to those at Camp creek, were found.

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[1]This creek was at first called Oil creek. It was renamed by the Director of the Survey "Bosworth creek" after Mr. Bosworth, who located it.

Four or five miles down stream from Bear mountain, on the bank of the river, small seepages were seen.

Cliffs East of Carcajou Rock

On the right bank, just before the river bends to flow along the side of Carcajou mountain, the Bosworth beds are seen dipping steeply away from the axis of the Wolverine anticline. No active seepage was found at this place, but the sands have an odour of petroleum and on crushing them under water, films of oil may be obtained.

About 16 miles beyond the west end of Carcajou cliffs Bosworth Creek beds are again exposed. Here also petroleum may be perceived in the same manner.

Gas Seepages

Gas is escaping at all the localities where the seepages of oil were found. The liberation of gas may be observed also in many places where the bituminous Beavertail limestone passes under the water.

Structures Favourable for Oil Accumulations

From the foregoing description of the geology it is evident that the conditions conducive to the formation of oil fields are here very favourably fulfilled.

Extending over a large area we have 1,000 feet or more of highly bituminous limestones and shales, from which an immense quantity of petroleum might readily be generated. And overlying these beds, there are 2,000 or 3,000 feet of clay-shales and sandstones from which numerous seepages of oil arise. Finally, this mass of petroliferous deposits is traversed by large, bold, anticlinal folds.

The high parts of the anticlinal hills are not now territory favourable for oil, since denudation has removed the oil-bearing formations from them. But these main anticlines pitch up and down, and probably in some parts of the low flat land, on the west side of the river, perhaps along the prolongation of these axes of folding, similar great arches of the petroliferous formations may be present underground. Such would be ideal situations for the accumulation of pools of oil.

Away from the crests, the dip slopes of the main anticlines present considerable possibilities; for changes in dip or porosity, faults, and minor flexures, may result in the accumulation of many oil pools at quite a distance from the main anticlinal axes.

Apart from the large folds, the minor undulations also may prove important. In such deposits as these it is probable in any case that oil accumulations will be formed. If large structures are not available the oil will find the small ones. These smaller structures, similar in dimensions, for instance, to the anticlines of the Oklahoma and Texas oil fields, probably occur throughout the territory, both on the dip-slopes and also at a distance from the axes of the main folds.

At present none of these small undulations have been mapped, and owing to lack of exposures their determination may be impossible unless by the use of well logs.

Discovery Oil Well

Discovery oil well is on the flank of one of the large anticlines, 8 miles distant from the crest. The location of this first test well was chosen in 1914, not as a spot where great production was hoped for, but as a site where a hole of moderate depth could not fail to penetrate the petroliferous formations which had been discovered.

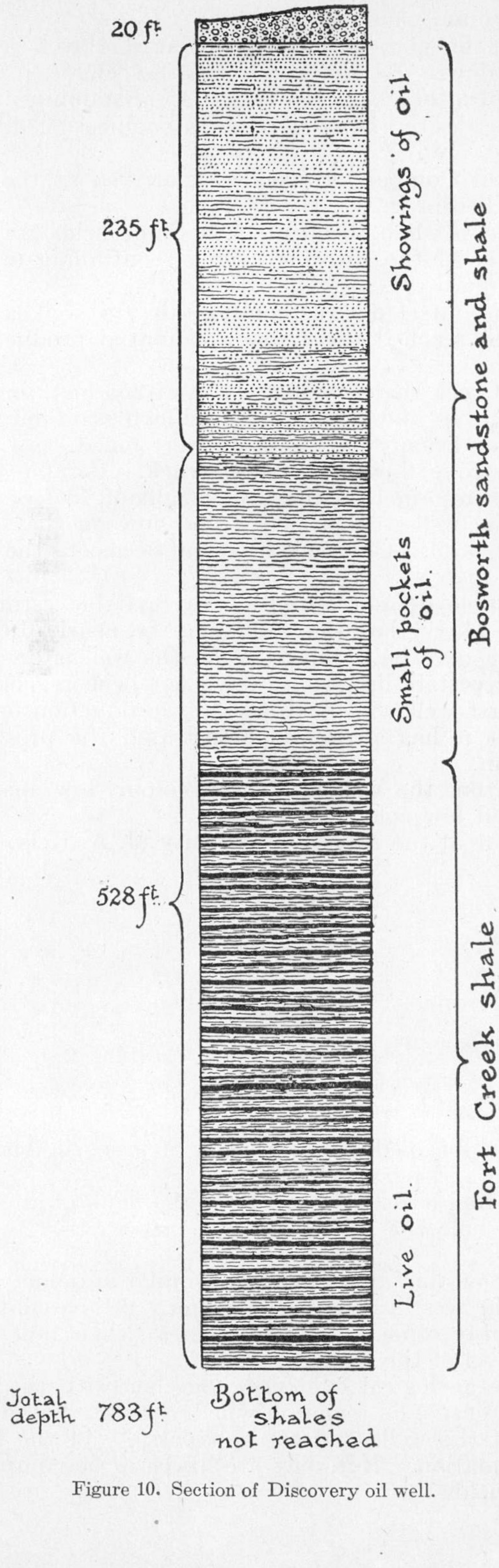


Figure 10. Section of Discovery oil well.

There was some evidence of a minor undulation at this place, and oil was seeping out of the ground plentifully.

It was clear that the oil rocks would lie rather shallow here, but by refraining from going farther down the dip, there was less chance of finding the beds occupied by water; also there was less risk of an abandonment of the operations without reaching the desired horizons, due to engineering difficulties in such a remote region.

The Imperial Oil Company's machinery arrived at the location in 1919, and the hole was drilled in 1920.

As soon as the drill had penetrated the superficial gravel it entered the lower sandy measures of the Bosworth series, continuing in them to a depth of about 255 feet (Figure 10).

Almost from the outset oil was coming into the well, and before a depth of 100 feet had been reached there was a potential production, estimated at 10 barrels a day.

The dark Fort Creek shales were reached at 255 feet, and continued to the bottom of the hole. In these beds, also, showings of oil were encountered almost throughout, and many barrels of oil were baled.

At 783 feet a strong flow of oil was struck. For ten minutes a column of oil spouted from the 6-inch casing to a height of 75 feet above the derrick floor, after which the well was capped. The flow on that occasion probably exceeded 600 barrels of oil. On two subsequent occasions the valve was opened, with similar results.

The data available do not admit of any reliable estimate of the well's capacity. It seems likely that the yield may be nearly 1,000 barrels a day. Increased production may be obtained when the well is deepened. It is considered that the Beavertail limestones have not been reached.

Whether this first well will yield a steady production or not is at present quite uncertain: but it has already demonstrated the prospect of important oil fields in the region.

The crude oil from the well is of light colour, low specific gravity, high gasolene content, and low cold test.

An analysis made at the Alberta University (J. A. Kelso), has been quoted as follows:

Specific gravity		0·845(36° Beaume)
Distillation	70°-150° C.	22·5 per cent.
	150°-300° C.	38·5 "
	300°-350° C.	33·9 "
	350°-375° C.	4·1 "
	Loss	1·0 "

Thus in commercial terms the oil consists of—

Gasolene	22·5 per cent.
Illuminating oil	38·5 "
Light lubricants	33·9 "
Medium lubricants	4·1 "

The seepage oil obtained by digging is of greenish black colour, having specific gravity "905 and paraffin base."

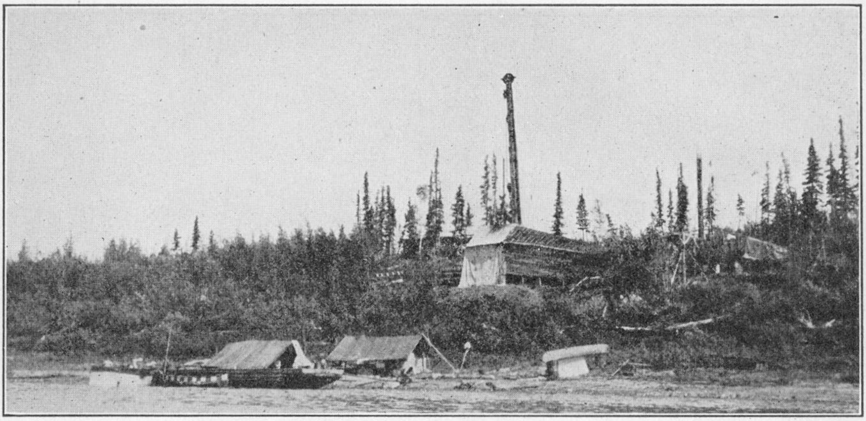
The present oil-well is situated far down the flank of an anticline 100 miles in length; and the whole 783 feet of strata penetrated by the drill are petroliferous.

North and east of this anticline other similar anticlinal hills occur, and in the flat ground to the west and north there may be the continuations of these anticlines (and possibly other anticlines besides), their limestone arches being below the general level of the land.

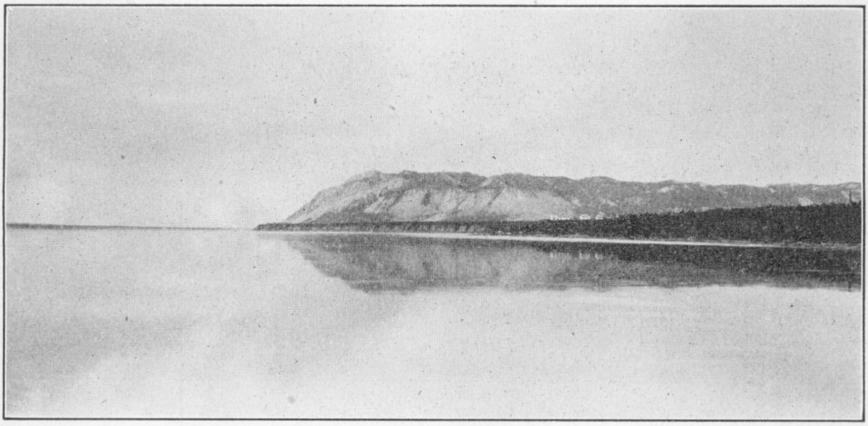
The sum of the geological evidence, together with the result of the test well, indicates an extensive oil region in which a number of oil fields may occur.

The capacity of the wells and the productivity of the fields, are matters beyond present calculation. But they are likely to be comparable to those of other Palæozoic oil fields

PLATE I.

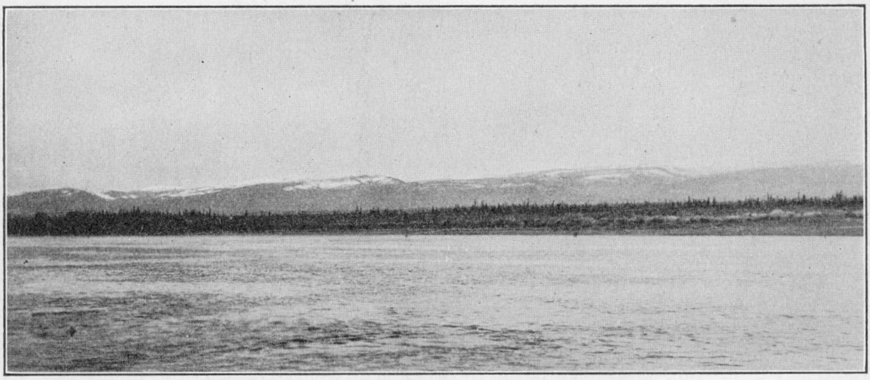


A. Discovery oil well, right bank of Mackenzie river, 40 miles below Norman. (Photo by Imperial Oil Company, 1919.)

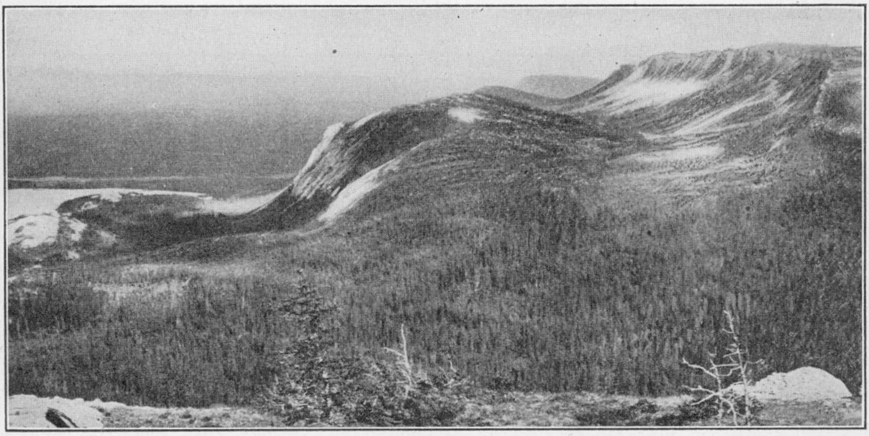


B. Looking down Mackenzie river showing Bear mountain about 10 miles distant and Norman on the right bank. (Photo by T. O. Bosworth.)

PLATE II.

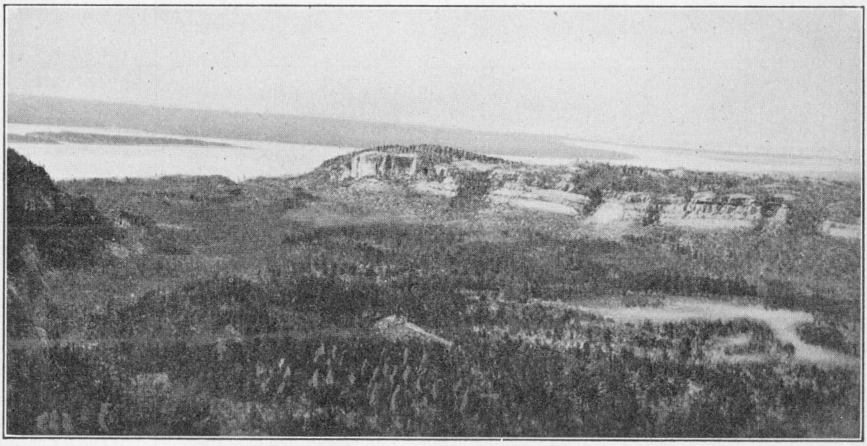


A. Right bank of Mackenzie river near the oil well, Discovery range in the background. (Photo by Imperial Oil Company.)

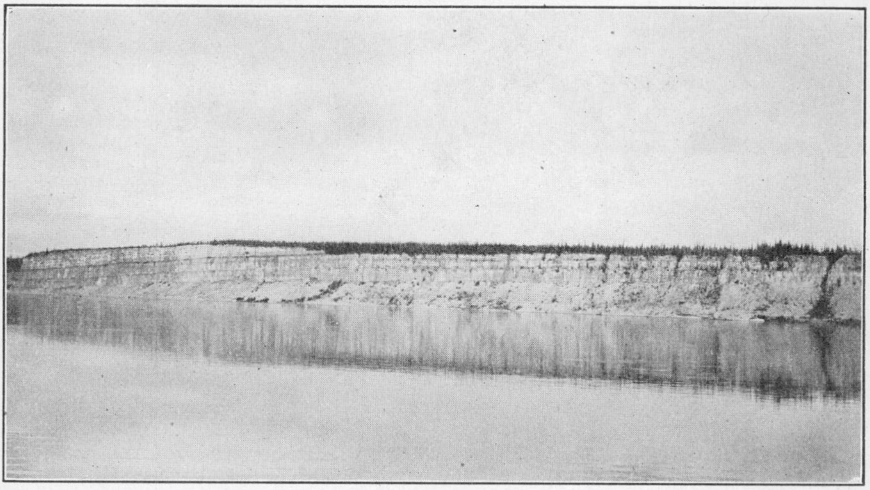


B. East Mountain anticline. View from the summit facing eastwards along the axis of the fold. The ridge in the middle is an arch of limestone, the anticlinal axis trending from background toward the observer and pitching down in the foreground. (Photo by T. O. Bosworth.)

PLATE III.

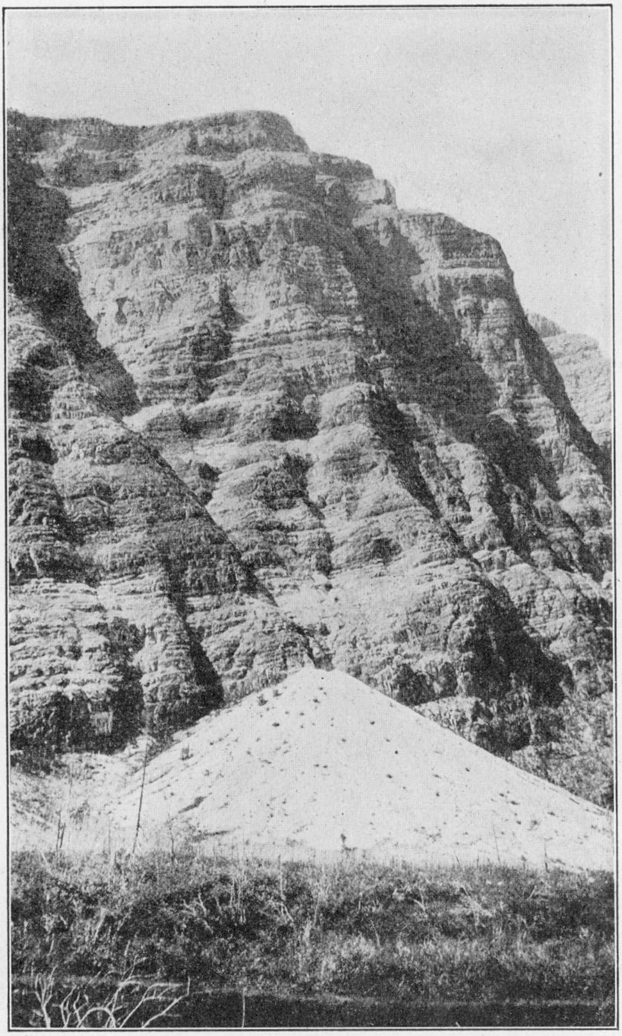


A. View of the northern scarp of the Bat Hills anticline, looking northwest from the southern scarp. Mackenzie river in the background. (Photo by Imperial Oil Company.)



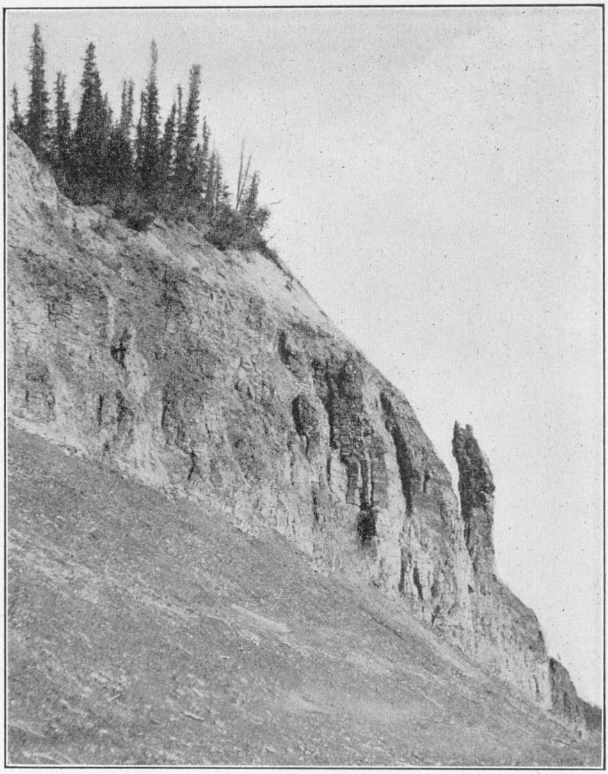
B. Ramparts limestone with Hare Indian River shale at the base partly covered by talus, west bank of Mackenzie river in the lower part of the Ramparts. (Photo by E. M. Kindle.)

PLATE IV.

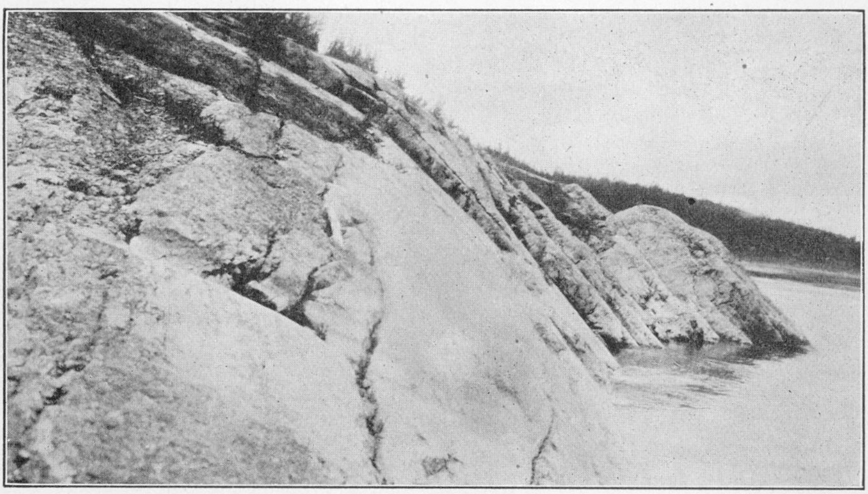


Lone Mountain limestone (Silurian), 3 miles north of mouth of Nahanni river. Top of cliffs capped with Devonian limestone. Alluvial cone partly conceals about 500 feet of the section. (Photo by E. M. Kindle.)

PLATE V.



A. Fort Creek shale at the mouth of Fort creek, Mackenzie river. (Photo by E. M. Kindle.)



B. Beavertail limestone on west side of Carcajou Mountain anticline, arching down on bank of Mackenzie river. (Photo by T. O. Bosworth.)

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INDEX—*Concluded.*

MEMORANDA.

The annual Summary Report of the Geological Survey is issued in parts, referring to particular subjects or districts, and each designated by a letter of the alphabet. A review of the work of the Geological Survey for the year with lists of reports and maps published during the year, forms part of the Annual Report of the Department of Mines.