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THE LOWER MACKENZIE RIVER AREA, NORTHWEST TERRITORIES AND YUKON

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PREFACE

Extensive exploration for petroleum and natural gas in Western Canada has shown the need for reports that bring together the available information on a wide regional basis. Following the abandonment of the Canol project in the Mackenzie River area at the close of World War II, the Geological Survey of Canada published Paper 45-16 containing an account of its own field work and that of the Canol geologists in that region. Subsequently, fourteen exploratory wells were drilled in the search for new petroleum sources.

The present report brings the geological information up to date by including the results of the more recent explorations, and assesses the data obtained by drilling in relation to the oil and gas prospects.

W. A. BELL,
Director, Geological Survey of Canada

OTTAWA, April 30, 1953

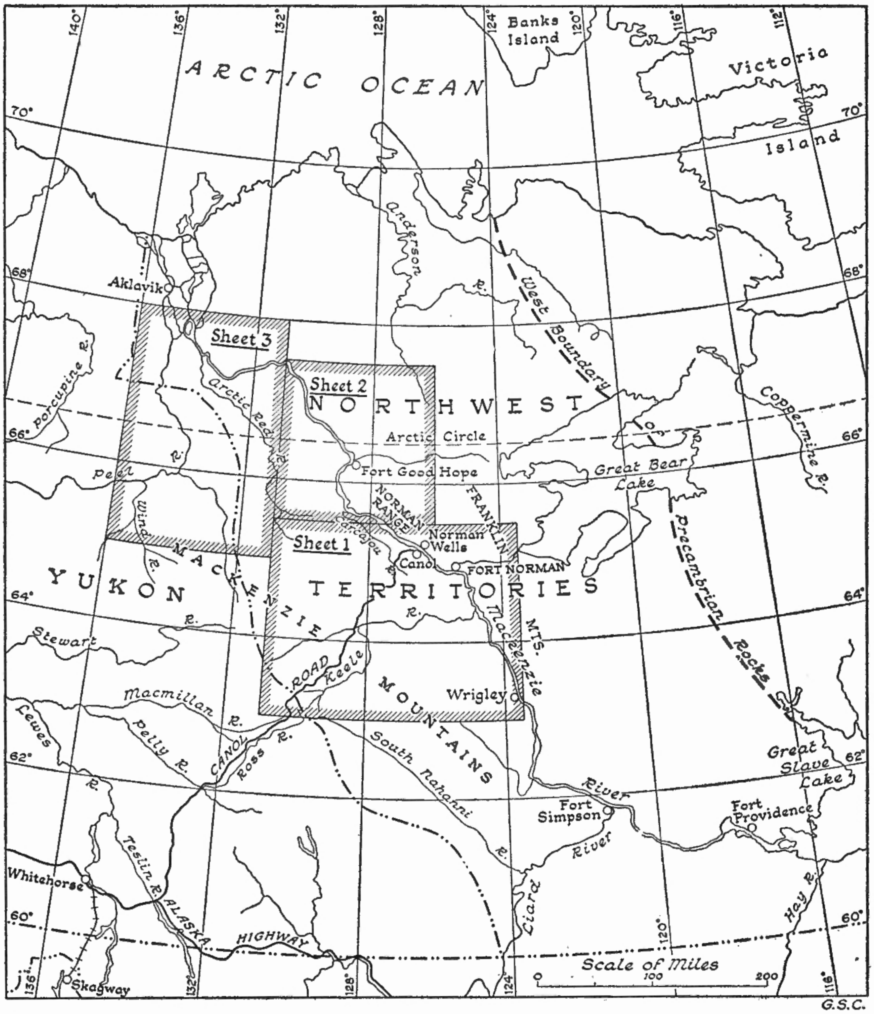

Figure 1. Index map of Mackenzie River basin, showing approximate areas covered by the accompanying geological maps (Sheet 1, No. 1032A; Sheet 2, No. 1033A; Sheet 3, No. 1034A).

The Lower Mackenzie River Area, Northwest Territories And Yukon

CHAPTER I

INTRODUCTION

The staking of oil claims in the Mackenzie River basin, followed by the drilling of wells and the discovery of oil at Norman Wells, in 1920, resulted in a minor oil boom. This led to repeated requests to the Geological Survey for information, and in order to meet the need Charles Camsell, in collaboration with Wyatt Malcolm, prepared a memoir (1921)[1] to which the senior author, out of a long experience in living and travelling in this sub-arctic and arctic region, made a large contribution. This report summarized the data as then known, but the oil interest not only led to much better communication facilities than had previously existed but also contributed a stimulus to further exploration encouraged by much more precise topographical and geological mapping on the part of various Federal Government departments. Thus within a few years, until the oil boom subsided, a very substantial amount of geographical and geological information was collected over an area mainly adjoining the larger rivers and routes of travel. During this time the Geological Survey issued summary reports[2] for the years 1920 to 1923, inclusive, on field investigations, and Mackenzie River, Great Slave Lake and its southern tributaries, and the Arctic coast west to the Alaska boundary were accurately mapped.

At the advent of World War II much of the Mackenzie basin, especially the areas a few miles distant from main routes of travel, remained unmapped and largely unexplored by scientific expeditions. With the oil at Norman Wells assuming strategic importance, the Royal Canadian Air Force and United States Air Force quickly mapped large areas from trimetrogon pictures mainly for air navigation, but certain other areas were covered by vertical photographs and the necessary ground control for accurate maps. Geological work proceeded on an extensive scale under the Canol agreement, and most of the accessible rivers tributary to the Mackenzie from Fort Wrigley northward were investigated. A summary of these reports[3] was published by the Geological Survey in 1945, showing the structures that had been discovered and the results achieved by drilling at Norman Wells. After the termination of the Canol agreement, Imperial Oil Limited drilled several exploratory wells in an effort to find further oil fields. A statement of these results, mainly as compiled by Stewart (1945, 1947) is included in this report. The northward exploration for oil and gas resulting from the discoveries in the Prairie Provinces since 1947 again make it desirable to include all available geological information in a single report, as was done by Camsell and Malcolm at the time of the first successful drilling in 1920.

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[1] Dates in parentheses are those of references listed in Bibliography at the end of this chapter.

[2] *See* Bibliography under Dowling, Hume, Kindle and Bosworth, Whittaker, and Williams.

[3] Hume, G. S., and Link, T. A.: Geol. Surv., Canada, Paper 45-16, 1945.

LOCATION OF, ACCESS TO, AND EXTENT OF THE AREA

The area described in this report centres around Norman Wells on Mackenzie River, 70 miles south of the Arctic Circle. Mackenzie River, from Great Slave Lake to the delta at the Arctic Ocean, is navigable by shallow draught steamer and motor boat throughout its length of about 1,000 miles. From late June to October the area can be reached from Edmonton by rail 300 miles north to Waterways on Clearwater River, near its junction with the Athabasca, and thence by boat via Athabasca River, Athabasca Lake, Slave River, Great Slave Lake, and Mackenzie River, a distance of about 1,200 miles. The only interruption to navigation on this route is the 16-mile portage from Fitzgerald at the northern boundary of Alberta to Fort Smith in the Northwest Territories. This portage is caused by rapids in Slave River, where in a succession of cataracts the river descends 125 feet in the 16 miles of the portage.

Access to the area is also by planes, for which there are established routes with beam stations. Travel from Edmonton may go via Fort McMurray, Fort Smith, Hay River, and Fort Simpson to Normal Wells; by Fort Smith or Yellowknife to Norman Wells and Aklavik; or by Grande Prairie, Fort Nelson, and Fort Simpson, at all of which places there are landing strips with airfield facilities. Float planes have been used, and are still used extensively in the north country. In winter these can be converted to ski-landing planes, and access may be had to any area where a suitable landing can be made. Owing to the prevalence of lakes and to the feasibility of utilizing watercourses for landing purposes, there are few places not within easy reach of a plane suitably equipped for travel under northern conditions.

Although the entire country west of Athabasca and Slave Rivers and south and west of Great Slave Lake has petroleum prospects this report describes only a part of the Mackenzie basin area, principally from Fort Wrigley to Fort Good Hope, where most of the Canol work has been concentrated, and to a much less extent the area along Mackenzie River from Fort Good Hope to the Mackenzie delta and the basins of Arctic Red and Peel Rivers to the west.

THE EXTENT OF THE MACKENZIE BASIN

Mackenzie River is one of the large rivers of the world, and on the North American continent second only in length of drainage area to the Mississippi. The main river system lies within the northward continuation of the Great Plains, but tributaries derive their water from within the Cordillera on the west and the Precambrian Shield on the east. The most southwesterly drainage of the Mackenzie River system originates in the Columbia ice-field. From this area waters flow to the Pacific, to the Arctic through Hudson Bay, and to the Arctic through the Mackenzie River system via such tributaries as flow northward to the Athabasca in the mountains of Jasper Park. To the northwest, the Peace River tributaries, the Parsnip and the Finlay, form the headwaters. Still farther northwest, the Liard has its headwaters in Frances River, at the divide with the Pelly in Yukon Territory, and is joined from the southwest by the Dease and from the southeast by the Nelson. In time of flood, the flow of water from the Liard into the Mackenzie at Fort Simpson exceeds the volume of water discharged into the Mackenzie from Great Slave Lake. In size, Great Slave Lake, with an area of 11,170 square miles, is smaller than Lake Superior or Lake Huron but larger than Lake Ontario or Lake Erie. To the east and northeast, it receives water from the Precambrian Shield. On the south its principal tributary is Slave River, which in turn originates in Lake Athabasca where the waters enter from the south and southwest, through Peace and Athabasca Rivers, and from the east through Fond-du-Lac River, which rises in Wollaston Lake in Saskatchewan, 250 miles east of the Alberta boundary.

To the north of Fort Simpson, at the mouth of the Liard, many rivers enter the Mackenzie in its 650 miles to Point Separation at the southern end of the delta, 75 miles from the Arctic Ocean. Among the larger of the tributaries are Keele River, flowing eastward, and the Arctic Red and Peel flowing mainly northward from the plains and mountains west of the Mackenzie; another is Great Bear River, which drains Great Bear Lake. This lake has a surface area of 12,000 square miles, only slightly larger than Great Slave Lake, but in spite of its size has relatively few significant streams of any size entering it; the main one is Camsell River, which enters from the south at the southeast end.

EARLY EXPLORATIONS

The early explorations in the Mackenzie River basin have been described by Camsell and Malcolm (1921), and its exploration and settlement by M. J. and J. L. Robinson (1946). The early explorations were mainly of geographical interest, although certain mineral deposits were noted. Thus, in 1770-72, when Hearne made his return journey from Fort Prince of Wales to Coppermine River, his purpose was to examine and report on native copper that had been reported from that area. Also Peter Pond, the first white man to cross from the headwaters of Churchill River to the Athabasca, via Methy portage and Clearwater River, noted the bituminous sands that centre around what is now Fort McMurray at the junction of Clearwater and Athabasca Rivers. Alexander MacKenzie's journey in 1789 to explore the lower Mackenzie River drainage, commencing at Fort Chipewyan on Lake Athabasca, was mainly made for geographical reasons, but the burning coal seams on the Mackenzie near the junction with Great Bear River were noted. The journeys of Franklin, Richardson, Back, Dease, and others between the years 1820 and 1850 added much to the geography of the region of the Mackenzie River basin, whereas the explorations of Thompson around 1800 and later contributed to the knowledge of the upper part of Athabasca River and the area around Lesser Slave Lake. The surveys of William Ogilvie of the Department of the Interior, from 1884 on, provided the first reasonably good maps of Athabasca and Peace Rivers, Great Slave Lake, and Mackenzie River, as well as part of Liard River and its tributary the Fort Nelson. These maps were supplemented by those made by McConnell, who descended Liard River in 1887, and who made extensive geological explorations in the vicinity of Great Slave Lake and later along Peace and Athabasca Rivers and in the vicinity of Lesser Slave Lake. McConnell's work added much accurate information to the geology of an area that had previously been explored mostly from the geographical viewpoint. During 1899, Robert Bell of the Geological Survey of Canada examined a part of Great Slave Lake, and the following year his assistant, J. MacIntosh Bell, accompanied by Charles Camsell, examined Great Bear River and the north and east shores of Great Bear Lake, making an overland trip to Coppermine River and returning from Great Bear Lake southward by a series of small lakes and Marian River, which flows south into the north arm of Great Slave Lake. The area southwest of Slave River, between it and the Peace, was examined by Charles Camsell in 1902, and the area in the vicinity of Wind and Peel Rivers in 1905. In 1907, Joseph Keele crossed over from the Yukon and descended to the Mackenzie by the river then known as the Gravel, which has subsequently been renamed the Keele. It enters Mackenzie River above Fort Norman at the mouth of Great Bear River.

In 1913, S. C. Ells began a study of the Athabasca bituminous sands, and these studies were continued by him for many years. The area of these sands was topographically mapped and the outcrops located and sampled, and recent developments are pointing the way to their commercial exploitation. In 1916, McLearn made an extensive examination of the exposed rock section along Athabasca River, followed in the succeeding years by similar work on sections along Peace River both in the Plains and Foothills areas. In 1919, the Northwest Company, a subsidiary of Imperial Oil Limited, began exploration and drilling in the Mackenzie River area, which led to the discovery in 1920 of the Norman Wells field, 50 miles north of Fort Norman. This search for oil stimulated work by the Geological Survey of Canada in the Mackenzie drainage basin, and work was undertaken and reports[1] issued in the years 1921 to 1924 by Kindle, Cameron, Williams, Whittaker, and Hume. As a further result of this interest, traverses of the Mackenzie River system were made by the Topographical Survey, Department of the Interior, and for the first time accurately surveyed maps of the main river route from Fort McMurray to the mouth of Mackenzie River became available. Interest was revived in the oil possibilities of the Mackenzie River basin with the outbreak of World War II in 1939, and in addition to considerable work on the bituminous sands by the Alberta Research Council, the National Research Council, and the Mines Branch, Ottawa, the Canol project for the development of the Norman Wells field was launched in 1942, with geological work over a wide area by several geologists. Interest was also renewed in the Peace River area, where drilling had begun in 1916. Considerable work was done along the Alaska Highway and in the Foothills of the Peace River area for the Geological Survey of Canada by Beach, Wickenden, Shaw, Stewart, Spivak, Hage, Williams, Kindle, and others, the results of which have been incorporated by McLearn and Kindle (1950) in Memoir 259. Additional information was available, too, from the Department of Mines, British Columbia, and from other sources.

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[1] *See* Bibliography.

THE CANOL PROJECT

The Canol development in the Northwest Territories and Yukon was the result of military necessity. Work began on the project in the early summer of 1942, the object being threefold, namely: (1) to explore and drill wells for oil in the Fort Norman and adjoining areas (*See* Figure 1); (2) to transport the oil by pipeline from Norman Wells to Whitehorse in Yukon, a distance of 598 miles; and (3) to build a refinery at Whitehorse, with a distribution system for petroleum products.

This report is concerned only with the first of these objectives, that is, the information obtained from the geological investigations and the results of drilling done under the Canol agreement. This agreement concerned the Canadian and United States Governments, and arrangements were made between Imperial Oil Limited and the United States Army in regard to the exploration and drilling, and between Imperial Oil Limited and the Government of Canada for securing the necessary concessions and leases of mineral rights. Considerable information on the Mackenzie area was available from Government and other sources prior to the beginning of the Canol project, but has been used in this report only in the correlation of the stratigraphy. The Canol project was undertaken with little time for adequate preparation, and under great climatic and transportation difficulties. This report has been compiled from Dr. Link's original reports and those made under his supervision, and submitted to the Government of Canada under the Canol agreement. The Canol reports are as follows:

Reports (listed from north to south)	*Geologist*
1[1]. Upper Peel River	C. R. Stelck
2. Lower Peel River	E. J. Foley
3. Lower Mackenzie River	A. W. Nauss
4. Arctic Red River	F. A. McKinnon
5. Mackenzie River between Sans Sault Rapids and the Ramparts	J. M. Parker
6. Hare Indian River	Lt. J. W. Harrison
7. Ramparts River area	F. A. McKinnon
8. Hume River	C. G. Moon
9. Mountain River Area	J. M. Parker
10. Gravel (Keele) River, East Fork of Little Bear River, and Kay Mountains	Lt. R. M. Hart
11. Redstone River	W. P. Hancock
12. Dahadinni River	Lt. G. D. Bath
13. Wrigley River and Johnson River	Lt. V. B. Monnett
14. Mackenzie River from Camsell Bend to Fort Norman	Lt. G. D. Bath
15. Nelson and Liard Rivers	A. W. Nauss

[1]These numbers are used in referring to the reports in the text.

In the vicinity of Norman Wells, the work was done in more detail, as outlined in the following reports:

1A[1].	Lower Carcajou River Area	Lt. G. D. Bath
2A.	Oscar Basin Area	Louis Desjardins
3A.	Oscar (Morrow) Creek Gap Area	J. M. Parker
4A.	Oscar (Morrow) Creek Area	L. R. Laudon
5A.	Slater River and Boggs Creek	E. J. Foley
6A.	Donnelly River	E. J. Foley
7A.	Mackenzie River from Norman Wells to Carcajou Rock	W. P. Hancock
8A.	Loon Creek	W. P. Hancock
9A.	Headwaters of Vermilion, Prohibition, and Nota Creeks	W. P. Hancock
10A.	Imperial River Area	L. R. Laudon
11A.	Great Bear River Area	L. R. Laudon
12A.	Mackenzie River from Hoosier Ridge to Mountain River	F. A. McKinnon
13A.	Canyon Creek	F. A. McKinnon
14A.	Upper Little Bear River	Lt. V. B. Monnett
15A.	Upper Carajou-Imperial River	A. W. Nauss
16A.	Carcajou Ridge-East Mountain Area	J. M. Parker
17A.	Carcajou and Little Bear River Divide Area	C. R. Stelck
18A.	Schooner Creek	C. R. Stelck
19A.	Bear Rock and Bluefish Creek	C. R. Stelck
20A.	Hanna River Area	H. T. U. Smith
21A.	Miscellaneous geological reports	Various authors
22A.	Fossil Accession Index.	

In addition, on the Norman Wells field there are the following reports:

1B[1].	The Subsurface Geology of the Norman Wells Pool	O. D. Boggs
2B.	Recoverable Oil Reserves from Norman Wells Pool	T. A. Link
3B.	Report on the Reflection Seismograph Survey in Norman Wells Area	Marvin Romberg

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CHAPTER II

STRATIGRAPHY

TABLE OF FORMATIONS

Age	Formation or group	Sedimentation	Fossils	Thickness, feet
Eocene.......	....	Imperfectly consolidated sands, clays, etc., with lignite.	Leaf and plant fragments.	600 (Stelck, 19A) 1,600 (Hart, 10)
		Erosional unconformity		
Cretaceous	East Fork...	Grey shales.....................	....	780-850 (Hart, 10)
	Little Bear..	Sandstones and shales with coal..	Large *Inoceramus*, *Scaphites*, *Watenoceras*, *Inoceramus labiatus*, etc. (Upper Cretaceous).	620 (Nauss, 15A) 780 (Monnett, 14A after Link)
	Slater River.	Dark grey to black shales, some siltstones and sandstones.	....	2,150 (Parker, 9) 200 (Foley, 5A)
	Sans Sault...	Fine-grained sandstone with glauconite; grey, sandy shales. Sandstone and conglomerate at or near base.	*Beudanticeras*, *Gastroplites*, *Hoplites*.	1,410 (Parker, 16A)
		Erosional unconformity		
Upper Devonian	Imperial.....	Green, fine-grained sandstone and shales; in part non-marine in certain areas.	*Spirifer disjunctus* fauna and other brachiopods, corals, etc.	1,465 (Nauss, 15A) 1,900 (Laudon, 10A) 437-700 (Boggs, 1B)
	Fort Creek..	Upper grey shales, thin sandstones; bituminous shales; coral reef and limestones; lower dark platy shales.	*Buchiola retriostriata*, Stromatoporoids, etc., *Leiorhynchus castanea*.	1,600 to 1,800 (Boggs, 1B)
	Ramparts...	Heavy massive limestones at top with or without coralline beds; limestone interbedded with shales in middle part; limestones in lower part.	Many corals and brachiopods in upper limestone member; *Proetus*, brachiopods, and corals in middle shale member.	245 (at Ramparts, Kindle and Bosworth) for upper limestone member; 300 ± feet (below Ramparts, Kindle and Bosworth) for middle shale member; 700 (Parker, 9) for middle shale member on Mountain River; 700 feet for lower limestone member in Mountain River area (Parker, 9).

TABLE OF FORMATIONS—*Concluded*

Age	Formation or group	Sedimentation	Fossils	Thickness, feet
Silurian or Devonian	Bear rock...	Brecciated dolomites and limestones, gypsum, and anhydrite.	None..........	250 (Stelck, 19A)
Erosional disconformity				
Silurian	Ronning group	Limestones with chert. Includes the Mount Kindle and Franklin Mountain formations of Williams and perhaps higher beds.	Niagara fauna (in places eroded off top). Fossils not abundant in lower beds.	1,400 (Stelck, 17A)
Ordovician	....	Argillites and shales.............	Graptolites....	1,500 (Stelck, 1)
Cambrian	Macdougal group	Limestones; greenish, chololate-grey, and black shales; sandstones, gypsum, etc. May be equivalent to Mount Cap and Saline River formations of Williams. May include gypsum beds at base of Bear Rock, Fort Norman.	*Ptychoparia*, *Paterina*, *Micromitra*, etc. (these are Middle or Upper Cambrian fossils found in lower beds of this group).	997 (Nauss, 6A)
Cambrian and/or older	Katherine group	Interbedded quartzites and black, platy shales.	No fossils.....	Base not seen (Nauss, 15A)

CAMBRIAN AND/OR OLDER

KATHERINE GROUP

The name Katherine group was applied by Link in 1921 to a series of interbedded quartzites and black, platy shales exposed in the upper Carcajou River area. The area is now accessible from the Canol pipeline route and was studied by Nauss (15A)[1]. The quartzites in the group are pink, buff, rusty, and white, and contain interbeds of black, platy, bituminous shales with some chocolate-coloured and green shales. The top of the group is placed at the base of a succession of chocolate-coloured shales. No fossils were found in these beds, but, as the overlying strata are Cambrian, their age is Cambrian or older. The base was not seen.

CAMBRIAN

MACDOUGAL GROUP

The name Macdougal was applied by Link in 1921 to rocks in the Macdougal Mountain area. The mountain received its name from that of the geologist James Clare Macdougal who was drowned in Great Slave Lake in 1920 while in the employ of Imperial Oil Limited.

[1] The numbers refer to the reports listed on pages 5 and 6.

The type locality for the Macdougal group is in Macdougal Creek Valley (Dodo Canyon) (Plate III). The group is divisible into several mapping units or formations, the base being placed at the bottom of 130 feet of chocolate-coloured, nodular, calcareous shale, and the top above 50 feet of evenly bedded limestone with shale partings. The succession, according to Nauss (6A), is as follows:

Description	*Thickness* Feet
Dark grey limestone	50
Interbedded grey, greenish grey, and chocolate-coloured shale with some siltstone	50
Gypsum beds—poorly exposed—reddish colour	200 (up to 500)
Interbedded black petroliferous shale, green silty shale, rust-coloured sandstone, and slate-coloured limestone beds	230
Blocky, rusty weathering, hard sandstone with interbeds of black shale	88
Hard, scarp forming limestone	200
Green shale and sandstone layers	15
Red, calcareous, nodular shale	14
Interbedded, red and green, calcareous, nodular shale	20
Chocolate-coloured, hard, smooth, calcareous shale with flattened ellipsoidal nodules on bedding planes; some green shale	130
Total thickness	997

In general, this section is somewhat similar to one described by Hume (1923a, p. 53) from Carcajou Canyon about 4 miles east of the Dodo Canyon exposures. The section in Dodo Canyon apparently exposes a few lower beds than those seen in Carcajou Canyon, and the uppermost 50 feet of limestones described by Nauss were not included in it, but, on a lithology somewhat similar to other overlying limestones, were assigned to the Silurian. The only fossils found in Carcajou Canyon were in the lower part of the section, and these were identified by Walcott as *Paterina* sp. and *Ptychoparia* sp. Their age is believed to be Middle or Upper Cambrian. The beds in which the fossils occur are represented in the lower part of the Dodo Canyon section by the 130 feet of beds described by Nauss, and it is on the basis of these fossils that he assigns all his Macdougal group to the Cambrian. Though it is not probable, part of the Macdougal group could be of Ordovician age.

In the Cap Mountains area northeast of Fort Wrigley, and in the vicinity of Clark Mountain 20 miles east of the confluence of Keele (Gravel) River with the Mackenzie, Williams (1923, p. 73, and Map 2022; Hume

1924, p. 4) mapped a thick section of Cambrian and possibly older strata, which he subdivided as follows:

Formation	Description	Thickness
		Feet
Saline River.......... (Middle Cambrian)	Banded calcareous shales *(Lingulella)* with interbeds of red and green shale................	300±
	Red and grey shale containing salt, gypsum, and selenite..................................	200±
Mount Cap.......... (Middle Cambrian)	Grey and green shales *(Lingulella?)*; red sandstone and shale *(Lingulella, Bathyuriscus, Ptychoparia, Saratogia)*..........................	200±
Mount Clark......... (Lower Cambrian)	Pink and red quartzite *(Scolithus)*..............	500+
	Red shale and ferruginous sandstone.............	50
	Hematite, red conglomerate, and sandstone.......	70+
(Precambrian?).......	Dark shales..................................	150
	Grey and drab shales..........................	225

The areas in which Williams obtained his information are 100 miles or more southeast of the upper Carcajou River area, and hence any attempt at correlation on the basis of description should only be regarded as tentative. The presence in each area of a fossil zone containing *Ptychoparia* in beds that are similar lithologically and that occur below a gypsum zone at least 200 feet thick, does, however, suggest that the Mount Cap and Saline River formations of Williams should belong in the Macdougal group of Nauss, and that the Mount Clark formation of pink and red quartzites is of the same age as the pink, buff, rusty, and white quartzites described by Nauss as belonging to the Katherine group. If this is a correct interpretation, it is evident that the red ferruginous sandstones, hematite, and conglomerate beds of the Mount Clark formation are lower than any strata seen by Nauss in the upper Carcajou area.

In the vicinity of Rouge Mountain, west of the headwaters of Little Bear River, Stelck (17A) has described a thick Cambrian section as follows:

	Description	*Thickness* Feet
(C5)	Dark, very fine-grained, iron-bearing limestone, weathering orange-red..	100
	Black, argillaceous limestone................................	70
	Green and maroon shales, and argillaceous limestones with maroon nodules...	40
	Green, and thin bands of red, shale...........................	30
	Maroon and green shales with limy nodules....................	75
	Maroon and green shales....................................	100
	Green shales and black limestone............................	30
(C4)	Black limestone and black shales............................	30
	Black shales and limestone with oolite bed at top...............	15
	Oolitic limestone and argillite................................	27
	Black shale..	30
	Red and green shale; thin sandstone..........................	18
	Pink to grey weathering sandstones and quartzites with conglomerate band at top; pebbles up to 8 inches in diameter.........	100
(C3)	Black shales and argillaceous limestone; weathers red; black chert at base..	150
(C2)	Hard, white to black weathering quartzites......................	800

The C4 group of this subdivision has been correlated by Stelck with the Katherine group of Nauss and with the Mount Clark formation of Williams in the Franklin Mountains. It is thus possible that the C3 group of Stelck is the equivalent of the beds assigned tentatively by Williams to the Precambrian. In this case the C2 group of Stelck is older than any strata hitherto reported from the Mackenzie basin.

In Stelck's opinion his C5 group represents the lower part of Nauss' Macdougal group, but the age of about 500 feet of poorly exposed and gypsum-bearing beds lying above the C5 group in the vicinity of Rouge Mountain are assumed to be Cambrian or Ordovician grading upwards into Silurian. He suggests a correlation of these gypsum-bearing beds with the Saline River formation of Franklin Mountains, which Williams on fossil evidence assigned to the Cambrian, and he also correlates them with the gypsum beds in the base of the section at Bear Rock[1], near Fort Norman.

On Imperial River, a branch of Carcajou River northwest of Dodo Canyon, Laudon (10A) observed 125 feet of quartzites at the base of the exposed Cambrian that he correlates, on lithologic grounds only, with the Katherine group of Nauss. Above these quartzites is a succession of beds reported as 1,839 feet thick correlated with the Macdougal group. Above this group again, and separated from it by a basal, hard, quartzitic, sandstone conglomerate, are 415 feet of black, algal limestones with interbedded black shale that may be Cambrian or Ordovician and that are said to have been included formerly in the Silurian.

The Macdougal group is reported by Laudon to comprise the following beds, from top to bottom:

Description	*Thickness* Feet
Green, red, black, tan, and grey shales, carrying in part much gypsum and some algal limestone layers	146
Green, red, and yellow, sandy shale with gypsum and shaly sandstone beds	135
Grey and green sandstone	60
Green, sandy shale and slaty limestone	19
Soft, black shale	85
Black, slaty shale interbedded with sandstone	47
Black and dark green shale	80
Quartz sandstone with some black to dark green shale	24
Hard, scarp-forming sandstone interbedded with green to red shales	350
Red and green shales alternating with sandstones	119
Light-coloured quartz sandstone	52
Red and green shale with sand lenses	14
Quartz sandstone, alternating with green, glauconitic shale	625
Red and green shales interbedded with grey to yellow quartz sandstones	83
Total thickness	1,839

No identifiable fossils were found in this succession.

Rocks of probable Cambrian and Ordovician (?) ages were observed by Parker (9) on Mountain River in the Mackenzie Mountains, but no measurements were made or detailed descriptions given.

[1] Williams (1922, p. 80) also suggested the correlation of these gypsiferous beds in the Bear Rock section with the Saline River formation.

In all these probable Cambrian rocks observed by Canol geologists in the Mackenzie Mountains south and west of Norman Wells no identifiable fossils were found. The assignment to Cambrian age is on the collection of fossils made in Carcajou Canyon[1] in 1922 by Hume (1923a, p. 53) and on the identification of *Micromitra superba* from a collection made by Link in Dodo Canyon in 1921, and identified for him by Professor Weller of the University of Chicago . As pointed out by Nauss, *Mocromitra* is a subgenus of *Paterina* and hence this fossil as found by Link is probably the same as *Paterina* sp. collected by Hume and identified by Walcott. The *Micromitra* of Link came from the 230 feet of interbedded, black, petroliferous shale, green, silty shale, rust-coloured sandstone, and slate-coloured limestone beds lying above the 88 feet of hard, rusty weathering sandstones, whereas the fossils collected by Hume were in beds correlated with the lower 130 feet of the Macdougal group as described by Nauss. Thus, on the basis of these fossils it appears that if any Ordovician is present in Dodo Canyon it must be very thin; Link's fossils came from the upper part of the Macdougal group, and those collected by Hume from the lower part.

In the upper Peel River area Stelck (1) observed 6,500 feet of slates and shales overlain by 500 feet of argillites with chert, occurring below beds identified as Ordovician because of the presence of the graptolite, *Tetragraptus*. It is thus assumed that the underlying beds are Ordovician and Cambrian, but the only fossils found in them were Tetractinellid remains (sponge spicules). No detailed study of them was made. They occur at the head of the lower canyon of Peel River (approximate longitude 134° 45′) and on Mountain River, which enters Peel River from the northwest a short distance above Bonnet Plume River (not the Mountain River that enters Mackenzie River at Sans Sault Rapids). On the lower part of Bonnet Plume River they are assumed to be present immediately under Tertiary strata, whereas farther up Peel River, toward the upper canyon, they are overlain by Ordovician, Silurian, and Devonian beds. At the head of the lower canyon of Peel River the alternate limy argillite bands weather white, giving a banding to the canyon wall above the whirlpool where the beds have a steep east dip or vertical attitude (Camsell, 1906, Pl. I). Above the canyon, however, the dip is considerably more gentle for the short distance the beds are exposed.

ORDOVICIAN

No rocks of Ordovician age have been identified positively in the vicinity of Norman Wells nor in Franklin Mountains, but it has been suggested that some beds may be of this age. Ordovician strata, as determined by Stelck (1), do occur in the upper Peel River area. They consist of shales and argillites 1,500 feet thick, in which two zones in the middle part of the section contain graptolites of which *Tetragraptus* is sufficient to indicate an Ordovician age. These beds outcrop in the lower canyon of Peel River, in an overturned section immediately above the whirlpool and in the upper canyon above the mouth of Wind River.

[1] For Fossil discussion *See* Kobayashi, Teiichi: Cambrian and Lower Ordovician Trilobites from Northwestern Canada; Jour. of Pal., vol. 10, No. 3, pp. 157-167 (April 1936).

Ordovician strata were reported by Keele (1910, p. 27) in Tigonankweine Range below the confluence of Twitya River with Keele (Gravel) River. Here the strata are almost horizontal and consist of 4,000 feet of alternating beds of argillite, dolomite, and limestone, above which are about 1,500 feet of sandstones lying on a diabase sill 100 feet thick. The sandstones become thicker eastwards, and opposite the mouth of Nainlin Brook Keele reports that they form, with only an occasional shaly parting, the entire mountain mass or about 4,500 feet of horizontal strata. The prevailing colour of the sandstone is reddish, but part of it is grey.

The only place graptolites were found by Keele was on Ross River about 7 miles below John Lake. They occur in black, indurated shale interbedded with cherty argillites and cherts.

SILURIAN

Silurian strata are widely distributed in the Mackenzie River area. They outcrop along the west side of the north arm of Great Slave Lake, in Franklin Mountains, as far north as and beyond Mount Charles on Great Bear River, in Nahanni Butte at the junction of South Nahanni and Liard Rivers, and northward at many places in Mackenzie Mountains. In the Norman Wells area not only do they occur on Bear Rock at the mouth of Great Bear River, but they form the core of Norman (Discovery) Range, and outcrop as well in the ridges north of Sans Sault Rapids and in various other places. It is proposed, for purposes of this report, to divide the Silurian rocks into a lower, Ronning group and an upper, Bear Rock formation[1].

RONNING GROUP

Most of the Canol geologists used the name Mount Ronning formation for all Silurian beds below the brecciated and non-bedded dolomites and limestones that lie immediately below Middle Devonian limestones and above probable Cambrian strata. The name was originally applied by Link (*See* Stewart, 1944) to a Silurian section on Mount Ronning named after the late Nelius Theodore Ronning, who, with James Clare Macdougal, after whom Macdougal Mountain and the Macdougal group are named, was drowned in Great Slave Lake in 1920 while in the employ of Imperial Oil Limited. From the reports, however, it is obvious that the various Canol geologists have included different beds in the Ronning formation in different localities without sufficient information being available for precise correlations. In order to obviate this difficulty, it is here proposed to use the name Ronning group for the succession of Silurian beds generally regarded as resting on Cambrian strata and overlain by the brecciated and non-bedded dolomites and limestones of the Bear Rock formation, as herein defined from the type section on Bear Rock at Fort Norman. The upper limits of the Ronning group are sharply delineated by a marked disconformity easily traced in a rock face, such as in Carcajou River Canyon, but the lower limits are less definite.

[1] As indicated in the discussion of the Bear Rock formation, the age is not definite.

In the Dodo Canyon (Macdougal Creek) area, Nauss (15A) includes 50 feet of limestone in the top of the Macdougal group. In the Imperial River area, a few miles to the northwest of Dodo Canyon, Laudon (10A) not only separated the upper limestone from the Macdougal group, but he also separated the lower 531 feet of cherty dolomites of Silurian age from the higher Silurian beds, whereas other geologists have included the entire assemblage in the one formation. In the Carcajou-Little Bear River Divide area, Stelck (17A) measured 965 feet of Silurian beds above the red and green gypsiferous shales, which he correlated with the Saline River formation of Williams, and below 450 feet of Middle Silurian beds. In these 965 feet of beds there is chert in the upper part and possibly some gypsiferous shales in the lower part. Stelck thinks these beds correlate with Laudon's cherty dolomite and with Williams' (1923, pp. 72-73) Franklin Mountain formation. He also thinks they represent all the Silurian beds that outcrop on Bear Rock below the brecciated and non-bedded limestones and dolomites. These correlations, however, can only be considered as tentative, as Stelck found no fossils, aside from a few poorly preserved gastropods that he says are not diagnostic. In the area of the Carcajou-Little Bear River Divide, Stelck measured 450 feet of massive, thick-bedded, porous and cavernous limestones of Middle Silurian age lying below typical Bear Rock brecciated beds. These strata are believed to be the equivalent of Williams' Mount Kindle formation, and contain *Conchidium, Halysites, Dawsonoceras, Favosites, Zaphrentis, Cyathophyllum,* and other corals definitely relating them to rocks of Niagaran age. No separate division is made for these Silurian beds by Nauss in the upper Carcajou River area, or by most of the other Canol geologists elsewhere. This undivided assemblage of Silurian rocks is, therefore, included here in the Ronning group.

In the Donnelly River area Foley (6A) included more than 1,000 feet of beds in the Silurian below the Bear Rock formation. He states that he found fossils within the upper 20 feet, and that these are typical Niagara fauna. The upper part of the formation is said to contain beds from 3 inches to 2 feet thick of white novaculite, but no mention is made of chert in the lower part, as observed by Laudon in the Imperial River area or by Stelck in the Carcajou-Little Bear River Divide area. A possible suggestion is that the equivalents of the Mount Kindle formation are very thin in this area, as Stelck (17A) regards them as missing in the Bear Rock section.

In Gambill Mountains near the southern headwaters of Little Bear River, Monnett (14A) has assigned a thickness of 1,800 feet to Silurian beds below brecciated Bear Rock limestones. Few fossils were seen, and no detailed description is given. It is assumed the entire assemblage is included in the Ronning group.

Silurian beds have been described from various other areas by Canol geologists. With the exception of the area of Dodo Canyon, on the Norman Wells-Whitehorse road and pipeline, the Bear Rock section near Fort Norman is the most easily accessible, and has been subdivided by Stelck (19A) as follows:

Age	Formation	Description	Thickness
			Feet
Devonian or Silurian.	Bear Rock....	Brecciated dolomite................	175
		Dark grey, poorly bedded limestone or dolomite.....................	30
		Non-bedded, gypsiferous, massive dolomite or limestone..............	40 to 60
		Disconformity	
Silurian............	....	Thin-bedded limestone and dolomite with shales becoming more prominent toward the base, and with gypsiferous streaks...............	600
Silurian, Ordovician, or older..........	....	Red and green shales and gypsum...	190+

Kindle (1921) has described a composite section from the south and west slopes of Bear Rock, but it seems probable that he has duplicated at least part of the Silurian section below the Bear Rock formation, in which he included all strata below the Devonian. It is obvious from his table of formations (page 44) that he intended to include the brecciated beds, but in his detailed section he makes no mention of them. The thickness of 1,600 feet as given by Kindle is so much more than that given by Stelck that it is obvious a mistake has been made. Bear Rock is intersected by a number of faults, and it seems possible that Kindle measured part of a section repeated by faulting. In 1922 Hume[1] and Bain measured the Bear Rock exposures. Their section agrees with that of Stelck, except that they placed the division between the thin-bedded limestone with shaly partings and the gypsiferous beds somewhat higher, thus limiting the thickness of what Stelck calls Silurian to 470 feet. It can readily be appreciated, however, that this division, not being sharp, might easily be drawn at a slightly different place by different geologists, because, as pointed out by Stelck, the contact is chosen arbitrarily, and is conformable and transitional. In the light of this information, therefore, Stelck's section is accepted rather than that of Kindle, and, as later described, the Bear Mountain formation is discarded, as it obviously was intended by Kindle to include the brecciated limestones and all beds herewith described as those of the Ronning group.

[1] Hume, G. S., and Bain, G. W.: Geol. Surv., Canada, unpublished information.

Neither Kindle, Stelck, nor Hume found any Niagaran fossils in the beds assigned to the Silurian in Bear Rock. Their absence is strongly indicative that the Mount Kindle formation of the Franklin Mountain area, as described by Williams (1923, pp. 78-79) is not present. It is probable, therefore, that the Silurian represented in the Bear Rock section is to be correlated, as Stelck indicates, with the Franklin Mountain formation of Lower Silurian age.

Silurian strata similar to those found in Bear Rock occur along the east-facing escarpment of the Norman (Discovery) Range. Near the headwaters of Schooner Creek, 4 miles north of Norman Wells, Stelck (18A) reports that up to 100 feet of heavy, massive, crystalline, porous limestones containing a scant coralline fauna overlie the equivalents of the Silurian of the Bear Rock section beneath the brecciated beds. The upper contact of the limestone beds is erosional, and they are thought to be higher Ronning group beds than any present at Bear Rock, and, in fact, are correlated by Stelck with the lower part of the Mount Kindle formation. At the headwaters of Vermilion, Prohibition, and Nota Creeks, Hancock (9A) reported no Silurian beds equivalent to the Mount Kindle formation, but Lower Silurian beds are present. Farther northwest along the Norman Range, in the Oscar (Morrow) Creek area, Laudon (4A) mapped the Silurian as a unit, corresponding to the Ronning group as used here, and reported Niagaran fossils from it. Thus, it is inferred that beds of Mount Kindle age are present. Also, as already indicated, Foley (6A) found Niagaran fossils in the upper 20 feet of beds below the brecciated limestones in the Donnelly River area. Apparently these beds containing Niagaran fossils are much thicker in the Imperial River area, as Laudon (10A) states that a fauna of Niagaran age was found in one limited zone near the centre of the upper 450 feet of beds below the brecciated limestone. This included *Favosites, Diphyphyllum, Zaphrentis, Cyathophyllum, Syringopora, Halysites, Strombodes, Heliolites, Alveolites, Palaeocyclus,* and *Dawsonoceras.* As already indicated, in this area Laudon separated the Silurian into 531 feet of cherty limestones overlain by the 450 feet of beds in the central part of which the Niagaran fauna occurs. As pointed out by Stelck (17A) in his discussion of the Silurian in the Carcajou-Little Bear River Divide area, it is probable that the 531 feet of cherty limestones described by Laudon from the Imperial River area are equivalents of the Franklin Mountain formation, and that the overlying 450 feet represent the equivalents of the Mount Kindle formation. It is interesting to note that in the Wrigley-Mount Cap area Williams (1923, p. 73) included 500 feet of beds in his Franklin Mountain formation and 560 feet in his Mount Kindle formation, but above these had a thickness of 1,600 feet of beds, some of which are brecciated, cavernous, and gypsiferous limestones, that he included in the Lone Mountain formation. On Hare Indian River, Harrison (6) mapped about 750 feet of limestones in the upper part of which *Halysites* occurs. Neither the top nor bottom of these beds was seen, but the Bear Rock formation of brecciated limestones with gypsum overlies them. Similar limestones, underlain by red and green gypsiferous shales, were seen by Hume (1923A, pp. 6-7) on the edges of Brackett and Kelly[1] (Whitefish) Lakes; the latter 15 miles northeast of Norman Wells.

[1] *See* Norman Sheet, Air Navigation Edition, Hydrographic and Map Service, Ottawa.

No detailed description is given of the Silurian rocks observed by Parker (9) on Mountain River, nor by Moon (8) on Hume River, but on Arctic Red River, McKinnon (4) mapped 1,100 feet of limestones that would here be included in the Ronning group. He states they are overlain by 500 feet of massive, light grey limestone and dolomite that he correlates questionably with the Bear Rock formation. The Ronning group is stated to have a lower unit at least 400 feet thick containing chert in dolomitic beds, whereas the upper part 700 feet thick, with the top not exposed, is composed of limestones carrying a Niagaran fauna represented by *Favosites, Syringopora, Halysites, Orthoceras,* etc. No correlations with sections elsewhere have been given, but the description is so like that of other sections as to suggest that the lower cherty beds at least are the same as those correlated by Stelck in the Carcajou-Little Bear River Divide area with the Franklin Mountain formation, and the upper Niagaran beds are, in part, if not wholly, equivalents of the Mount Kindle formation.

Along Mackenzie Mountains south from the Norman Wells area the Ronning group of Silurian beds is not well known. In the Keele (Gravel) River area, Hart (10) records 600 feet of Ronning dolomites below the Bear Rock brecciated beds. These dolomites, however, are not described in detail, nor were any fossils reported from them. In the Dahadinni River area south of Keele (Gravel) River, Bath (12) observed 330 feet of grey to black dolomites and limestones interbedded with thin black shale beds lying below the brecciated Bear Rock limestones and with the base not exposed. The description and information available is insufficient to draw any conclusions in regard to these beds other than that they are Silurian.

Reference is made by Bath (14) to the Silurian beds of Lone Mountain at the mouth of North Nahanni River. These beds were described by Kindle (1921, p. 44) as the Lone Mountain formation[1], which he stated was 1,800 feet thick along the face of the escarpment to the west of Camsell Bend on Mackenzie River. In the Wrigley-Cap Mountain area Williams (1923, p. 73) described 1,600 feet of Silurian beds lying above the Mount Kindle formation of Middle Silurian or Niagaran age, and below Devonian limestones. Excluding 50 feet of beds with corals at the base of Kindle's Lone Mountain formation Williams correlates his 1,600 feet of beds with the Lone Mountain formation, and so describes them. He particularly emphasizes the brecciated character of some of the beds, and makes reference to Kindle's Bear Mountain formation, under which the Lone Mountain formation is supposed to occur. From the Canol explorations it seems evident that this is a wrong conception. As has been pointed out, the Silurian limestones below the brecciated beds, and above the red and green gypsiferous shales in the Bear Rock section, are probably Lower Silurian in age, and are the equivalent of the Franklin Mountain formation. At Bear Rock there are no strata of Mount Kindle age, and strata described as Lone Mountain by Williams are probably in part at least represented by the brecciated beds of the herein newly defined Bear Rock formation. On present information the correlation by Williams of the 1,600 feet of strata above the Mount Kindle formation in the Wrigley-Cap Mountain area with the upper 1,500 feet of beds in Kindle's Lone Mountain formation

[1] *See* Kindle, E. M.: Science, vol. 83, pp. 14-15 (1936), in which the name Lone Mountain formation was replaced by the name North Nahanni River dolomite.

from Camsell Bend can neither be substantiated nor disproved, but the correlation appears to have doubtful value, as Kindle's Lone Mountain formation (North Nahanni River dolomite) is poorly defined, and was meant to include all the Silurian beds in the North Nahanni-Camsell Bend area.

Laudon (11A) studied the Mount Charles area on Great Bear River about half-way between Mackenzie River and Great Bear Lake. Mount Charles is in the Franklin Mountain Range, which continues still farther northward. This area was also studied by Williams (1923, p. 74) and his section is as follows:

Age	Formation	Description	Thickness
			Feet
Upper Silurian	Lone Mountain[1].....	Thin-bedded, brown weathering dolomite..........................	190
		Brown, coarse-grained, sandy dolomite, brecciated in part..........	340
Middle Silurian	Mount Kindle......	Hard, light grey dolomite, thin bedded, cherty in lower 70 feet...........	180
		Chert, probably silicified dolomite...	60
		Unfossiliferous beds................	30
		Grey, magnesian limestone containing Niagaran corals..............	210
Lower Silurian	Franklin Mountain..	Grey, magnesian limestone..........	470
		Limestone and chert pebbles and grit in limestone matrix..............	75
		Grey limestone....................	120
		Cavernous limestone...............	200
Cambrian?....	Saline River........	Grey gypsum.....................	150+

[1] Probably the Bear Rock formation as here defined.

Laudon's (11A) section differs from this in one important respect, namely, that he puts "brecciated" beds below the gypsum that Williams places in the Saline River formation, and states that these beds, 250 feet thick, rest directly on thin-bedded, hard, dense, black limestone beds also 250 feet thick. Obviously these lower beds were not seen by Williams, but were seen by Hume and Bain[1] in 1922. Below the gypsum beds were 40 feet of conglomeratic limestones containing black, bituminous pebbles up to 4 inches in diameter, and below these, but not seen in contact with them,

[1] Hume, G. S., and Bain, G. W.: Geol. Surv., Canada, 1922, unpublished information.

were other dark, highly bituminous limestones dipping 12 degrees eastward and exposed in three cut-banks about three-quarters mile from the mouth of a small stream that enters Great Bear River above, but close to, the Mount Charles Range. In these beds a few ostracods (?) were found. Their age has not been determined.

In his section Laudon (11A) makes no mention of the cavernous beds described by Williams at the base of his Franklin Mountain formation, but these were seen by Hume and Bain with the gypsum beds immediately under them. The grey, magnesian limestones containing the abundant Niagaran coral fauna (Hume, 1923a, p. 54) form the top of Mount Charles, which here, as measured by aneroid, rises in a cliff about 625 feet above the level of Great Bear River.

The presence of two zones of brecciation in the Mount Charles area was previously noted by Hume (1923a, p. 53). The lower one is associated with the evaporites that Williams has mapped in the Saline River formation, and the upper one is in the base of his "Lone Mountain" formation. The latter is considered to be the equivalent of the brecciated and non-bedded limestones and dolomites of the Bear Rock section. It is widely distributed in the Norman Wells area, but the lower zone is only known to occur in the vicinity of Mount Charles.

SILURIAN OR DEVONIAN

BEAR ROCK FORMATION

All Canol geologists used the name Bear Rock formation to describe the brecciated and non-bedded dolomites and limestones lying below Middle Devonian strata and above a sharp disconformity with well-bedded Silurian limestones below it. The type section for the Bear Rock formation is at Bear Rock, Fort Norman (Plate I A). Details of the Bear Rock section have already been given under Ronning group. Stelck (19A) particularly notes the disconformity at the base, and states that there are two distinct divisions of the Bear Rock formation, a lower, lensing, gypsiferous division lying above the disconformity and variable in thickness according to locality, and an upper brecciated division. The basal division is a "white weathering massive tough gypsiferous dolomite that is absent on the south end of Bear Rock, but appears a short distance back from the southern scarp edge and rapidly thickens to 60 feet on the north side of Bear Rock. The hills north of Bear Rock are carved from this zone, and its total thickness there may be 100 feet. The basal division shows local bedding".

Also, according to Stelck (19A), "the upper division of the Bear Rock formation on Bear Rock consists of 175 feet of a breccia of brown, dolomitic limestone boulders in a matrix of dolomitic limestone. This is separated from the underlying white basal member by 30 feet of poorly bedded grey dolomite and limestone, and from the overlying Ramparts formation by 10 feet of bedded limestone and dolomitic breccia".

On Mount Charles the part of the section that presumably correlates with the Bear Rock formation consists, according to Williams (1923, pp. 80-81), of 340 feet of saccharoidal, coarse-grained, brown dolomites... overlain by 1,000 feet of thin-bedded, brown dolomites, in part brecciated. The top of the section was not seen. Three miles farther north the chert beds of the Mount Kindle formation are overlain by 500 feet of grey gypsum, which in turn is overlain by Middle Devonian limestones. Thus, according to Williams, the entire formation north of Mount Charles is composed of gypsum. The same condition was observed by Hume (1923a, p. 54) on the eastward extension of Carcajou Ridge where the Middle Devonian limestones were seen in contact with underlying gypsum beds, and below these were seen the hard arenaceous limestones of the Silurian.

On Canyon Creek, on the west flank of Norman (Discovery) Range, the cavernous limestone beds of the Bear Rock formation are underlain by sandstone and quartzitic sandstone[1]. In the cavernous limestone are quartzitic sandstone cobbles up to 6 inches in diameter together with other pebbles and cobbles of limestone. This is further evidence of the disconformity at the base of the Bear Rock formation, and shows that the breccia fragments in the Bear Rock formation are in part due to erosion, although the close association with gypsum suggests that the volume change of anhydrite to gypsum may have had some part in the fragmentation.

Stelck (19A) states that the Bear Rock formation is overlain conformably and transitionally by Middle Devonian limestones on Bear Rock. This condition, if definitely established, would have a direct bearing on the age of the Bear Rock formation, as the overlying beds are undoubtedly Middle Devonian. It would be impossible on this basis, therefore, to escape the conclusion that the Bear Rock formation is Devonian. In describing the Bear Rock strata Kindle included all the beds from the Devonian down to the base of the exposed red and green gypsiferous shales in his Bear Mountain formation of Silurian age, but did not record the disconformity at the base of the brecciated beds that are now defined as constituting the Bear Rock formation. The age of the brecciated beds at the top of the so-called Bear Mountain formation was considered, therefore, to be the same as lower beds of limestone from which Silurian fossils were obtained. In view of the erosional disconformity at the base of the Bear Rock formation, it is quite possible the beds above and below belong to different periods, and hence the Bear Rock formation may be Devonian. It is apparently regarded as Lower Devonian by some of the Canol geologists. The age has not been established by fossils and, in fact, the only known fossils found in this formation are reported by Laudon (10A) from the Imperial River area, where he states that in "the easternmost canyon south of Lake Florence, one dark limestone bed in the lower portion of the middle member carried large numbers of molds of a coral closely resembling *Diphyphyllum*. These were observed near the mouth of the canyon on the right canyon wall about 250 feet up from the floor". Unfortunately, these fossils have no diagnostic value as to the exact age.

The reported transitional contact of the Bear Rock formation on Bear Rock with overlying Middle Devonian beds has not been demonstrated at all other places where this contact has been observed. In Carcajou Canyon the contact is sharp (Hume, 1923a, Pl. II), and the irregularities along it were interpreted as indicative of a disconformity. A similar condition was observed by Monnett (14A) in Gambill Mountains in the upper Little Bear River area. The contact of the gypsum-bearing beds, where these replace the brecciated limestone, is also sharp with the overlying Middle Devonian

[1] Hume, G. S.: Geol. Surv., Canada, 1922, unpublished information.

limestones. It is, however, true that the disconformity at the base of the Bear Rock formation is everywhere very marked, and indicates a decided break in sedimentation. Thus, the age of the Bear Rock formation may be Devonian. The Silurian age, as given by Kindle (1921, p. 45), is based on fossils that occur below a marked erosional break at the base of the Bear Rock formation, and Stelck has reported a transition into Devonian beds at the top.

In the Norman Wells area, the Bear Rock formation is everywhere present, and except where it contains gypsum, it is rather uniform in thickness considering the character of the beds composing it. Laudon (11A) has described it as a fanglomerate, but Nauss (15A) points out that the variations in thickness and character of materials are not those of a fanglomerate. In all places where it has been described as consisting of brecciated and non-bedded limestones, it is porous. At certain places it is sufficiently porous to be described as cavernous, and in one place, on Sammons Creek, a branch of the Carcajou entering near the Rainbow Arch, the water according to Bath (1A) flows in "an underground channel for several miles in the fractures and other openings of the Bear Rock and adjacent formations". In a number of places it is bituminous.

The thickness as given by the various Canol geologists is as follows:

Geologist	Locality	Thickness	Character
		Feet	
Stelck (19A)	Type section—Bear Rock	215–295	Limestone breccia, gypsiferous beds
Stelck (18A)	Schooner Creek area	219	Brecciated limestones
McKinnon (13A)	Canyon Creek area	260	Brecciated limestones
Smith (20A)	Hanna River area	750–1,200[1]	Brecciated limestones with gypsum
Foley (6A)	Donnelly River area	720	Brecciated limestone and anhydrite
Foley (6A)	Hanna River area	500–800	Gypsum beds
Harrison (6)	Hare Indian River area	218+	Brecciated limestone and gypsum
Laudon (10A)	Imperial River area	406	Brecciated limestones and dolomites
Parker (16A)	East Mountain area	138+	Brecciated dolomites
Bath (1A)	Lower Carcajou River area	300	Brecciated dolomite overlain by interbedded dolomite and anhydrite beds
Parker (9)	Mountain River area	200+	Warm springs issue from a tightly compressed anticline in Mountain River gorge
Nauss (15A)	Upper Carcajou-Imperial River area	400–425	Brecciated dolomite and limestone
Stelck (17A)	Carcajou-Little Bear River Divide area	315–400	Brecciated dolomite and limestone
Monnett (14A)	Little Bear River area	400–500	Brecciated limestone
Laudon (11A)	Great Bear River area	175	Chert
Hancock (11)	Redstone River area	100	Brecciated dolomite and limestone
Bath (12)	Dahadinni River area	420+	Brecciated dolomite

[1] Part of this, according to Foley (6A), belongs in the overlying Ramparts formation.

The most southerly outcrop of Bear Rock brecciated dolomite noted by Canol geologists was on Amos Creek in the Blackwater River area north of Wrigley (Bath, 14). These beds are, presumably, in the part of the section called Lone Mountain formation by Williams on his map of this area (1924, Map 2022, opp. p. 4).

The high porosity of the brecciated dolomites and limestones of the Bear Rock formation makes them a favourable reservoir rock wherever they occur without anhydrite or gypsum. In places, as noted by various geologists, they are highly bituminous.

MIDDLE DEVONIAN

The Middle Devonian was subdivided by Kindle and Bosworth (1921) as follows:

Beavertail limestone
Ramparts limestone
Hare Indian River shales

As information has accumulated, it is apparent that these divisions are no longer applicable, and a new classification is here proposed that places all these beds in the Ramparts[1] formation, and divides it into:

Upper Ramparts limestone member
Middle Ramparts shale member
Lower Ramparts limestone member

The Upper Ramparts limestone member includes the Ramparts and Beavertail limestones of Kindle and Bosworth. These are placed in one member because ordinarily a division between them is not practicable. The Middle Ramparts shale member is the Hare Indian River shale of Kindle and Bosworth, but includes older beds that do not outcrop on Mackenzie River. The Lower Ramparts limestone member has not been described previously. It is well exposed on the flank of Imperial Range on Mountain River and it is proposed to consider this the type area for both the Middle Ramparts shale and Lower Ramparts limestone members.

RAMPARTS FORMATION

Lower Ramparts Limestone Member. This member has not been described previously as a unit. In many places in the vicinity of Norman Wells it is relatively thin, but it becomes more prominent to the northwest, and in all the sections studied by Canol geologists it is most prominent and best exposed in the area described by Parker (9) from the flank of the Imperial Range on Mountain River, about 30 miles above the junction with

[1] The name Ramparts as used here should not be confused with the Rampart group of Mississippian strata of the Tanana region of Yukon and Alaska. *See* Spurr, J. E.: U.S. Geol. Surv., 18th Ann. Rept., pt. 3, pp. 155-169 (1898).

Mackenzie River. In this area the section of Middle Devonian is much thicker than in the Norman Wells area. It consists of the following succession (Parker, 9):

Description	*Thickness* Feet
Upper Ramparts limestone member	
Limestone, grey, buff weathering, massive, many small *Cladopora*	80
Limestone, dark grey beds 0·6 foot thick and separated by black shale partings; limestone weathers grey and contains many large *Cladopora*	17
Limestone, dark grey, massive	10
Shale, black, earthy and limy, contains many large stromatoporoids and *Cladopora*	9
Limestone, black, massive, petroliferous	6
Limy shale, black to grey-brown, petroliferous; contains many large *Cladopora*	58
Total thickness	180
Middle Ramparts shale member	
Grey to green shales and limy shales with many thin limestone beds. In the lower 100 feet these thin limestone beds are commonly coquinoid. Fossils present are: *Reticularia, Productella, Proetus, Zaphrentis, Cladopora, Atrypa (spinosa), Cystiphyllum, Euomphalus, Palaeocyclus, Favosites, Syringopora, Schuchertella, Heliophyllum, Acervularia, Prismatophyllum, Pachyphyllum*	700
Lower Ramparts limestone member	
Limestone, dark grey to black, petroliferous beds 1 foot to 5 feet thick and with irregular and black shale partings; *Martinia, Atrypa, Productella*	100
Limestone and shale; thin, platy, dark grey to black limestone beds up to 6 inches thick with shale layer 3 inches thick; very fossiliferous particularly corals	135
Limestone, dark grey to black, massive at top and bottom and rubbly in central 2·5 feet. Very fossiliferous *(Acervularia, Cladopora, Paracyclas, Pugnoides)*	6
Limestone, dark grey, rubbly to platy and shaly; *Cystiphyllum*	129
Limestone, black, hard, brittle, very petroliferous, in beds ½ foot to 8 feet thick with black shale partings	75
Total thickness	445
Total thickness of Ramparts formation	1,325

Middle Ramparts Shale Member. This member, as indicated, is 700 feet thick in the type sections on the flank of Imperial Range in the Mountain River area. Formerly it was described by Kindle and Bosworth (1921) under the name Hare Indian River shales, with type sections at and in the vicinity of the mouth of Hare Indian River, below the Ramparts on Mackenzie River. At the Ramparts it occurs below the Upper Ramparts limestone member, and, owing to a southward dip, progressively more strata are exposed northward. At the mouth of Hare Indian River, however, the base is not seen. In many places in the Norman Wells area neither the middle shale nor the lower limestone member is sufficiently distinct to be mapped as a unit, and Kindle and Bosworth included both of them with the Ramparts limestones, whereas their Ramparts limestones at and below the Ramparts included only the upper limestone beds. Under these conditions, therefore, the name Hare Indian River shales is here dropped, and the name Middle Ramparts shale member substituted for it. Where no division is possible into members, the entire assemblage of beds constitutes the Ramparts formation.

Upper Ramparts Limestone Member. This limestone member, as used here, includes the Beavertail limestone of Kindle and Bosworth (1921) and all beds they called Ramparts limestones at the Ramparts section on the Mackenzie.

The type section of the Beavertail limestone as described by Kindle and Bosworth (1921) was at Beavertail Point, 12 miles below Sans Sault Rapids on the east side of Mackenzie River. A thickness of 300 to 400 feet was assigned to this formation, and the main exposures studied were on, and in the vicinity of, Carcajou Ridge. The character of the upper part of the limestone and its relation to the next higher shale formation was described from near the northern end of the exposures at Carcajou Ridge as follows:

Description	*Thickness* Feet
Shale, fissile, black, with interbedded limestones becoming more calcareous in upper 16 feet, and splitting into sheets of bluish black, bituminous limestone	65+
Limestone, grey	5
Shale, fissile, black	1
Dark, magnesian limestone of saccharoidal texture and bituminous odour	4
Limestone, hard, dark blue; with one or two thin bands of black slate in lower half	55

According to Kindle and Bosworth (1921) "about one mile up Mackenzie River from this section where the limestone stands vertical, about 260 feet of limestone is exposed. *Stringocephalus burtini* 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".

It is obvious that at Carcajou Ridge Kindle and Bosworth made the distinction between the Beavertail and Ramparts formations on the basis of fossils rather than on any differences in the lithology of the limestones. It was subsequently pointed out by Hume (1923a, p. 55) in the Carcajou Ridge section that the diagnostic *Stringocephalus burtini* of the Ramparts formation was found 60 feet below the Fort Creek-Beavertail contact, and that there was no clear-cut distinction between the overlying, hard, dark Beavertail limestones and the buff to grey Ramparts beds. The thickness of the upper limestones in this area down to the occurrence of *Stringocephalus burtini* would limit the thickness of the Beavertail beds to not more than 60 feet, and it is certain that in the 300 to 400 feet placed by Kindle and Bosworth in the Beavertail limestones some Ramparts beds are included. Parker (16A) restricts the Beavertail formation on Carcajou Ridge to 10 feet.

At Beavertail Point, from which the Beavertail limestone was named, only 30 to 35 feet of these beds, according to Parker (5 and 16A), are exposed. The limestones are composed largely of coralline beds. Corals may comprise at least 50 per cent of the rock, and along bedding planes they may form all of it. Bitumen is associated with or makes up the matrix.

Parker (16A) thinks that in their description of the Beavertail limestones Kindle and Bosworth included his Upper Ramparts limestone (i.e., the Ramparts formation of the Ramparts section), the Beavertail limestone, the Lower Fort Creek shale, and a reef limestone that, in the area of Beavertail Point—the type section for the Beavertail formation—may rest on what has elsewhere been called the Beavertail limestone. He suggested that the use of the name Beavertail should be restricted to those limestone beds below a bituminous, shaly, sedimentary phase that is characterized by the occurrence of a brachiopod, *Hypothyridina*[1] *castanea,* and above massive or shaly limestones that have the black, earthy, limy, and fossiliferous partings typical of the lower part of the Upper Ramparts limestone member. *Hypothyridina castanea* indicates an Upper Devonian age, and although in none of the Canol reports is this fossil listed as coming from Beavertail Point, yet it is apparent from Parker's description (16A) that he considers the Reef limestone at this place as resting on the true Beavertail limestone. From this it is inferred that the name Beavertail limestone is not applicable to the exposures described as the type section for this formation.

From the above statement it is obvious that if the Beavertail formation is to be retained, it must be re-defined at a new type section. There is also the difficulty of separating the limestones composing it from similar limestones on which it rests, and as these limestones are a lithologic unit, it seems preferable to include them in the same member, namely, the Upper Ramparts limestone member.

There is a further reason for discarding the name Beavertail and including all the upper limestones of Middle Devonian age in the Ramparts formation. Kindle and Bosworth (1921) described the section at the Ramparts of the Mackenzie, a few miles above Fort Good Hope, and included in the Ramparts limestones all beds below the Cretaceous and above beds that they named Hare Indian River shales. The section as given by them at the Ramparts is as follows (1921, p. 46):

Description	*Thickness* Feet
Disconformity with Cretaceous above it. Hard, cherty limestone cracking freely into small pieces, and weathering to a very irregular surface. Numerous spherical masses of stromatoporoid coral gives bedding an irregular appearance. Small branching corals and a large thick-shelled pelecypod are the only other common fossils	120
Black, calcareous shale with a *Cladopora* of branching type	1–4
Hard, knobby limestone full of stromatoporoid corals of spherical shale 2 to 3 inches in diameter—*Stringocephalus burtini* common in some beds. A drab, argillaceous limestone of fine texture, and an occasional 4- to 8-inch band of blue-black shale occasionally interrupts the bed of stromatoporoid limestone. Stromatoporoids comprise 80 per cent of the latter. Certain beds have an abundance of crinoid stems	30 ±
Grey, hard limestone, mostly in 6- to 10-inch strata. Stromatoporoids abundant; other corals much more varied and abundant than in the above 30 feet. *Rensselaeria* and *Stringocephalus* also common	95
Total	246–249
Hare Indian River shales	
Bluish grey, calcareous shale, in strata mostly 1 inch to 3 inches thick, with *Chonetes* and *Martinia* abundant. Base not exposed	95

[1]This may be a *Leiorhynchus.*

In describing the section in the Ramparts area, Parker (5) includes the upper beds in the Beavertail formation. Thus, he considers that Kindle and Bosworth have Beavertail beds in the section that they described as the type for their Ramparts limestone. He divides this upper part into two units, as follows:

Beavertail formation	
Limestone, light to dark grey, medium-grained, fairly regular beds with bitumen partings. All of the beds contain some corals and stromatoporoids, and some of the upper beds are composed of coral fragments in a bituminous matrix. *Megaloden* sp. is very abundant in some of these beds, and also in the unit below this one. Rubbly biohermal beds alternate with more regularly bedded limestones that weather and break to sharp angular edges	65
Limestone, light grey, medium-grained, contains coral fragments that are usually larger than the fragments in the above unit. The limestone is coarser grained than the above beds, and contains little bitumen except at the partings. The coral fragment content of one bed may vary from 10 to 90 per cent within a few hundred feet. The beds themselves are lensing and range from the vanishing point to 25 feet in thickness. Included in this unit are two or three lensing groups of dark grey, bituminous beds 10+ feet thick	130
Ramparts formation	
Limestone, dark grey, coarse-grained, petroliferous. This is a stromatoporoid limestone that contains many corals. The corals are generally much larger than those found in the Beavertail limestones. These beds contain dark grey, limy shales in irregular bands and around the individual stromatoporoid nodules. There are regular shale partings 18 to 24 feet above the base of this unit	32
Shale, black, earthy. The upper contact of this bed is an irregular biohermal zone. The shale contains abundant very large *Cladopora* and *Cystiphyllum* corals	2·5

Below this shale, Parker describes other limestones such as are indicated in the section described by Kindle and Bosworth.

It is obvious from Parker's description that the 2·5 feet of black, earthy shale containing *Cladopora* described by him is the same bed as the black, calcareous shale with a *Cladopora* of a branching type described by Kindle and Bosworth as 1 foot to 4 feet thick. This shale is a prominent marker, and hence is easily recognized in any detailed study of the Ramparts section. On the other hand, the division made by Parker between the Ramparts and Beavertail formations is so indefinite as to be of little or no value in mapping, for which purpose formations are commonly separated one from another. No evidence is given why such a division has been made, and no correlation on the basis of fossils has been included to show why the upper limestones of the Ramparts section are considered to be Beavertail.

Thus, as there is no real difference in the Ramparts section between the Beavertail and Ramparts limestones as described, and as the entire section was regarded as Ramparts in age by Kindle and Bosworth, it is here considered the type section for the Upper Ramparts limestone member. The Upper Ramparts limestone member, therefore, in the Ramparts section includes all limestone beds of Middle Devonian age below the Cretaceous and above the Middle Ramparts shale member, the beds of which were formerly called Hare Indian River shale by Kindle and Bosworth (1921, p. 45).

There are many areas in the Mackenzie River region where the Ramparts formation is exposed. As already indicated, in some of these it is divided into the three members, but in others it is more practicable to group all beds in one formation. In a few places where Middle Devonian limestones are overlain by Reef limestones, the division between the two is not sharp, and in some instances at least the Reef limestones were regarded by Canol geologists as Upper Devonian. The Carcajou Ridge section, described by Parker (16A), is an interesting example of the relationships of Reef limestone to the Upper Ramparts limestone member. The section is as follows:

Description	*Thickness* Feet
Reef limestone	6–70
Lower Fort Creek shale	0–21
Upper Ramparts limestone member (Beavertail and Upper Ramparts limestone of Foley)	60
Middle Ramparts shale member	745
Lower Ramparts limestone member	96+

In the northeast part of Carcajou Ridge the Reef limestone, according to Foley (6A), rests on the limestones of the Upper Ramparts limestone member, whereas farther west there is a shale intervening between the two, as indicated by Parker (16A).

In the above section it will be noted that the thickness of 745 feet for the Middle Ramparts shale member compares favourably with the thickness of 700 feet as measured by Parker (6) for the same beds in the Mountain River area, but the thickness of the Upper Ramparts limestone member is much greater in the Mountain River area.

In the Donnelly River area, which lies north of Carcajou Ridge, Foley (6A) mapped the Beavertail Mountain anticline extending eastward and slightly north from Beavertail Point into the West Virgina Hills and Mount Effie areas as well as the Bat Hills, and their eastward continuation into the Mount Dellis and Gibson Range area. Complete sections were not seen, but 220 feet of beds were considered to be "Beavertail" in the Bat Hills and Hanna River area and below this 1,171 feet were considered "Ramparts" in the Gibson Creek area. This would give a thickness of 1,391 feet for the Ramparts formation as here re-defined.

In the East Mountain area, north of Carcajou Mountain, Parker (16A) has described the following section:

Description	*Thickness* Feet
Limestone, dark grey, weathers grey to brown, petroliferous, mostly massive. *Cladopora* and stromatoporoids abundant. The upper 20 feet are very bituminous and petroliferous, and commonly these upper limestones are almost completly composed of ⅛-inch diameter *Cladopora* fragments in a bituminous matrix. Black shale partings are common throughout this unit. Some of the beds are banded and have a sandy texture	325±

The above section is thought by Parker to include both the "Reef limestone" and the "Beavertail" limestone. No distinct lower Fort Creek shale member is recognizable, and hence no division between the Reef limestone, which is considered Upper Devonian, and the "Beavertail" limestone of Middle Devonian age is possible.

Limestone, dark grey, rubbly and coralline with shaly partings; upper 20 feet more massive	60

This is considered to be the Upper Ramparts limestone (exclusive of "Beavertail") by Parker. It may be that it represents the top of the Middle Devonian, and that the coral reef limestone above it is all Upper Devonian.

The middle shale member is only partly exposed in the East Mountain area, according to Parker, and consists of the following:

Description	*Thickness* Feet
Covered interval	300 (?)
Limestone and shale, beds of thin, platy limestone, shaly limestone, and limy shale. *Atrypa reticularis* is the common fossil	200
Covered interval	65 (?)
Total	565 (?)
Lower Ramparts limestone member	
Limestone, dark grey, irregularly bedded to shaly; contains many stromatoporoids	200

The division between the "Reef limestone" and the beds formerly considered as Beavertail is as indefinite in other areas as it is on East Mountain.

In the Beavertail Point area the exposed part of the "Beavertail" consists only of reef limestone. Commonly the reef is a light grey, hard limestone that is made up almost entirely of stromatoporoids and *Cladopora*. In the vicinity of Bat Hills it is bedded, but usually has a typical massive appearance. In many places the limestone is very dark when freshly broken, and in fractures and coral interstices there may be films and blebs of asphalt and asphaltite (Parker, 6A).

In the Mountain River area, according to Parker (9), the "Beavertail" limestone, consisting of massive grey or buff weathering beds, is 80 feet thick. It is overlain by 10 feet of black, slaty shale in which some fragments of a brachiopod that might be *Hypothyridina* occur. This, in turn, is overlain by 380 to 585 feet of massive, buff weathering grey limestones that contain many *Cladopora*. This limestone is believed to be the equivalent of the Reef limestone, but no evidence is given for the belief that it is Upper Devonian other than the poorly preserved fossils seen in the black shale.

In the Carcajou-Little Bear River Divide area Stelck (17A) found no Reef limestone; the Upper Ramparts limestones are 139 feet thick and are underlain by 255 feet of Ramparts shale that lies directly and conformably on the Bear Rock formation. No mention is made of any Lower Ramparts limestones, which are obviously thin.

In the Gambill Mountains, in the upper part of Little Bear River, Monnett (14A) found 300 feet of Upper Ramparts limestone and Ramparts shale above the Bear Rock formation. The section of the Fort Creek was poorly exposed, but no Reef limestone was seen.

In the Upper Carcajou-Imperial River area, Nauss (15A) divided the Ramparts beds (including "Beavertail") into groups similar to those of Parker in the Carcajou Ridge-East Mountain (16A) area and in the Mountain River area (9). The generalized section is as follows:

Strata	*Description*	*Thickness* Feet
Upper Ramparts limestones	Massive, hard, buff, petroliferous limestone with few shale breaks	50
	Massive, very fossiliferous, grey limestone	50
Middle Ramparts shales	Soft, thinly bedded, rubbly limestone with inter-beds of grey shale; very fossiliferous	310
Lower Ramparts limestones	Massive, buff limestones	90
	Total	500

The total thickness of the Ramparts formation in the Imperial River area is variable, decreasing toward the northwest from a maximum of 670 to 310 feet. *Proetus,* a fossil (trilobite pygidium) according to Nauss (3) characteristic of the Middle Ramparts shale (Hare Indian River shale), and found particularly abundant in the upper part of it in and north of the Fort Good Hope area, occurs also in the Middle Ramparts shale of the Upper Carcajou-Imperial River area. The correlation of this Middle Ramparts shale with the "Hare Indian River shale" in the area north of the Ramparts is well established.

In the Imperial River area somewhat farther west than the sections seen by Nauss (15A), Laudon (10A) used similar divisions to describe the Ramparts sequence:

Ramparts formation	*Description*	*Thickness* Feet
Upper limestone member	Hard, grey limestone	30
	Dark-coloured limestones	80
Middle shale member	Soft shale and thin limestone beds. Not completely exposed	250+
Lower limestone member	Thin-bedded, platy, dark-coloured limestones	90

On Hume River, on what would appear to be the strike of the Middle Devonian from the exposures on Mountain River, Parker (9) and Moon (8) measured 320 feet of shales with thin limestones overlain by 20 feet of irregularly bedded limestone. Still farther west on the strike of the formations McKinnon (7) observed limestones of Middle Devonian age on Ramparts River, but no detailed study was made of them. In the Arctic Red River area, however, McKinnon (4) found no "Beavertail" limestones, but divided the Ramparts formation as follows:

Description	*Thickness* Feet
Ramparts formation	
Limestone, thin-bedded, dark grey, fossiliferous	10
Limestone, rubbly, dark grey, 6- to 10-inch beds with thin black shale breaks; very fossiliferous	135
Limestone, light grey to buff, 8- to 12-inch beds with grey, limy shale breaks	65
Limestone, dark grey, 6- to 12-inch beds with 3-inch shale breaks	65
Total	275

This is a relatively thin section, but, as noted by Nauss (3) north of the Ramparts in the Lower Mackenzie River area, the Middle Devonian beds are bevelled off, and northward Upper Devonian progressively rests on older Middle Devonian beds. Thus, whereas, according to Parker (5), there are 195 feet of limestones formerly classified as "Beavertail" in the Ramparts area, 100 miles farther north at the type section of the Fort Creek shale, on Thunder River, the Fort Creek shales rest on the middle part of the Ramparts shale. This same condition was found by Stelck (1) in the upper Peel River area. On Mount Deception, at the junction of Hungry Creek and Wind River, about 500 feet of Middle Devonian beds occur. These consist of an upper part of hard massive limestones that resemble the Ramparts limestone of the Bear Rock area, and a lower part of more argillaceous beds, but lacking the abundant fossils of the Middle Ramparts shale as found elsewhere in the Mackenzie basin. Fifty miles northeast of Mount Deception, on Margery Creek, Stelck found Fort Creek shales resting on Middle Ramparts shales containing *Proetus, Atrypa, Paracyclas,* and the *"Acervularia"* fauna that tends to distinguish these beds. Margery Creek is about 15 miles east of the lower canyon on Peel River where, according to Stelck (1), a conglomerate carrying Ramparts fossils is overlain by Fort Creek shales, and underlain by Silurian strata. No Middle Ramparts shales were seen at this locality, and pebbles of Silurian limestone and shale occur in the basal Devonian conglomerate.

As already pointed out, there is a much thicker section of Middle Devonian in the vicinity of Carcajou Ridge than at the south end of Norman (Discovery) Range. At Bear Rock, according to Stelck (19A), the Ramparts section is about 350 feet thick. It outcrops along the south and west sides of Bear Rock and on the southwest flank of Norman Range. The upper massive limestones, heretofore called Beavertail, are similar in lithology to the underlying Ramparts limestones, but more shale appears in the lower part of the section. In a well drilled at Bluefish Creek the massive Middle Devonian limestones were 115 feet thick overlying 260 feet of shaly limestones of the lower part of the Ramparts formation. In Canyon Creek, which enters Mackenzie River about 10 miles southeast of Norman Wells, there are, according to McKinnon (13A), about 125 feet of massive, dense, crystalline limestones underlain by 255 feet of brown limestone with shale breaks. The whole constitutes the Ramparts formation. In the Schooner Creek area, about 4 miles north of the Norman Wells area, Stelck (18A) states that the Middle Devonian is 341·5 feet thick, consisting of 102 feet of limestones and 239·5 feet of shales. There are no essential lithological differences, although arbitrary divisions are made on the basis of fauna. The whole in reality constitutes one formation. Stelck points out that the "Beavertail" is poorly defined and that the Ramparts formation is based on a *Stringocephalus-Newberria* fauna that is of local occurrence. He suggested one formation name—the Ramparts—for the whole of the Middle Devonian as now defined in this report.

The section of the Ramparts formation on lower Schooner Creek, with the Fort Creek contact zone described from Bosworth Creek, is given by Stelck (18A) as follows:

Description	*Thickness* Feet
Fort Creek	
Section from Bosworth Creek	
Shale, black; with *Tentaculites*	
Argillite, black	2·0
Shale, black; with *Leiorhynchus*	0·25
Argillite, black; with *Leiorhynchus castanea*	0·25
Contact of Middle and Upper Devonian	
Upper Ramparts limestone	
Limestone, rubbly, brown, nodular and marly	7·5
Limestone, brown, with thin shale partings	11
Limestone, brown, bedded	10
Limestone, brown to grey	5
Limestone, brown, massive	4
Limestone, brown	7
Limestone, light grey, brown; with corals and porous zone at top	12
Shales; contact of "Beavertail-Ramparts" arbitrarily drawn here	0·25
Section below here from Schooner Creek	
Limestone, dark brown, massive, fine	13
Limestone, rubbly weathering	6·5
Limestone, dark brown, finely porous	4
Limestone, hard, buff-brown	1
Limestone, light brown, porous	3·5
Limestone, brown, bedded	6
Limestone, shaly, soft	2
Limestone, grey-buff, very fine	4
Limestone, brown, bedded	4
Limestone, thin-bedded, hard	1·5
Middle Ramparts shale (contact arbitrarily drawn with Upper Ramparts limestone)	
Limestone, fine-grained	1
Limestone, brown, rubbly weathering	5·5
Limestone, rubbly weathering; with interbedded marly shale	8·5
Limestone, heavier beds with very thin shales, large prismatophyllum bioherms	12
Limestone and shale, interbedded	4
Limestone and shale, nodular and marly	15
Shales and limestones, nodular and marly, more shaly toward the base	42
Shale, dark grey, calcareous	4
Limestone, shaly	6
Shale, dark grey	2
Limestone, light coloured, shaly; with shales	2
Limestone, and shales, lenticular weathering	2
Limestone, shaly, and soft shale	3
Limestone, rubbly weathering, and soft, brown, marly shale	18·5
Limestone, shaly	1·5
Limestone, soft weathering, brown, and marly shales	4
Coquina, hard	2
Shales, soft weathering, nodular, brown	5
Limestone, hard, dark brown	4
Shale and rubbly limestone, soft weathering	6
Stromatoporoid limestone	2
Shale and limestone, mainly covered	31
Shale and limestone, soft, marly, rubbly	5
Limestone, brown	1

Description	*Thickness* Feet
Limestone, soft, shaly	5
Limestone, hard, dark, rusty	3
Limestone, thin; even-bedded shale	3
Shale, limy, silty, crenulated bedding	2·5
Limestone, blocky, dark	2·5
Dolomite, dark grey, brown	7·5
Limestone, shaly, thin-bedded	4
Limestone, massive, dark	5
Limestone and shale, brown	2
Limestone, massive, dark	3
Limestone, black, argillitic	1
Shale, soft, brown; with limy bands	2
Shale, paper thin, brown	1
Shale, thin, brown; with limy bands	1·5
Shale, soft, thin-bedded, brown	1
Lower Ramparts limestone	
Limestone, black, shaly, fossiliferous	5
Limestone, shaly to slaty; with some soft grey shales	2·5
Fine conglomerate or breccia; usually absent	1
Disconformable (?) contact with Bear Rock formation	
Total thickness	341·5

In the series of anticlines on Carcajou River below its junction with the Imperial, Bath (1A) measured 255 feet of Middle Devonian beds. The lower part is limestones alternating with shaly beds overlain by heavier limestones. The upper 80 feet is massive, dark grey limestone overlain by Fort Creek beds containing *Hypothyridina castanea* (Plate I B).

South of Fort Norman, and 20 to 25 miles west of Old Fort Point on Mackenzie River in Kay Mountains[1], Hart (10) measured approximately 500 feet of Middle Devonian strata. The lower part, 400 feet thick, consists of thin to medium beds of limestone separated by highly fossiliferous, calcareous shales, and the upper part of about 100 feet of massive, dense, fossiliferous, grey limestone. The upper part of the limestones is dark and petroliferous.

Upper Middle Devonian limestones were seen by Hancock (11) in the Redstone River area, but were not described or measured. On Dahadinni River, Bath (12) included in the Middle Devonian 925 feet of grey to black limestones and dolomitic limestones with interbedded grey shale overlain by 100 feet of massive, dark grey limestone.

Farther south, at Lone Mountain near the mouth of North Nahanni River, Bath (14) describes 125 feet of massive limestones underlain by 175 feet of greenish grey, dense limestones. These he includes in the Middle Devonian, and below them describes 500 feet of grey and dark limestones as the upper part of the "Lone Mountain formation" of Kindle. The lower beds are very unfossiliferous, and the separation was apparently made only on the basis of lithology. A similar difficulty in separating the Middle Devonian from the "Lone Mountain formation" in this area was encountered by Hume (1922, p. 70). Near the top of Mount Camsell there is a small

[1] Called MacKay Mountains on some maps.

succession of shales between heavy-bedded limestones, and in these shales *Schuchertella chemungensis* occurs at the top of an exposed thickness of 1,550 feet of limestones. The same fossil occurs on Wrigley Rock at Wrigley and on the first mountain to the southwest of Wrigley. On Mount Camsell there is a coral zone about 20 feet above the shale zone, and this contains *Cyathophyllum, Favosites, Cladopora, Alveolites,* and stromatoporoids. On other mountains to the south of Mount Camsell about 500 feet more strata lie on top of the coral zone. This coral zone and the *Schuchertella* are probably Ramparts in age. The *Stringocephalus* fauna of the Ramparts formation of the Ramparts of the Mackenzie and the Presquile formation of Great Slave Lake was not found in the mountains in the vicinity of Camsell Bend, but the sections have been insufficiently studied. The Presquile dolomite on Great Slave Lake is very porous, and the oil seepages on the north shore, as at Windy Point, issue from it.

The Middle Devonian limestones of Franklin Mountains were not subdivided by Williams (1923, pp. 73 and 81). They consist of dark grey and in part argillaceous limestones estimated to be 2,000 feet or more in thickness. This thickness seems very large, especially as Laudon (11A) in the Mount Charles area of Great Bear River reports only 150 feet of limestones and shales, which he correlates with the Ramparts, overlain by 100 feet of dense, hard, biohermal limestones capped by thin-bedded, grey, marly limestones of the so-called "Beavertail" formation. The whole is now classified as Ramparts formation.

UPPER DEVONIAN

FORT CREEK FORMATION

The type section from which Kindle and Bosworth (1921, p. 47) named the Fort Creek formation is exposed on Thunder (Fort Creek) River not far from the site of old Fort Good Hope. This river joins the Mackenzie about 120 miles below the present site of Fort Good Hope. The shales are dark with limestone bands, and in places are so highly bituminous that they have been burnt to a brick-red colour.

The Fort Creek shales rest on heavy, massive limestones of Middle Devonian age in the Norman Wells area, and the contact[1] described by Stelck (18A) in the Bosworth and Schooner Creek areas is reasonably sharp. Stelck places the contact below beds containing *Leiorhynchus castanea.* On Outaratou River, 50 miles northwest of Fort Good Hope, Nauss (3) found 2 to 5 feet of calcareous quartz sandstone at the base of the Fort Creek formation, and this carried abundant *Hypothyridina*[2]. At Thunder River this lower sandstone is 45 feet thick and consists of fine-grained, black, flaggy, petroliferous sandstone with plant remains and a few brachiopods. On Vermilion Creek, in the Norman Wells area, a sandstone 50 to 70 feet thick occurs in the Fort Creek shales. Presumably this is a lenticular sand. It also occurs on the adjoining streams of this area (Heleva, Francis, Prohibition, and Canyon).

[1] *See* section under Middle Devonian.

[2] There is some confusion as to whether this is a *Hypothyridina* or a *Leiorhynchus.* Both are assumed to be the same fossil described by Stelck from the base of the Fort Creek. Fossils collected from this zone by Hume in 1922 are *Leiorhynchus,* that is, they have an internal septum. Some of them, howevér, in shape resemble *Hypothyridina.*

Drilling in the Norman Wells area has revealed the presence of a reef limestone in the Fort Creek shales. Boggs (11B) shows that the Fort Creek consists of the following:

Description	*Thickness* Feet
Upper Fort Creek shales	700–800
Bituminous zone	100–400
Reef limestones	0–410
Lower Fort Creek shales	385–540

In the Bluefish No. 1A well of Imperial Oil Limited, located near Bear Rock, 1,385 feet (Stelck 19A) of Fort Creek shales were drilled below Cretaceous beds. As it is doubtful if the overlying Upper Devonian formation was present in this well, it is obvious the thickness may not be the maximum for the Fort Creek formation, as some of it may have been removed by erosion prior to the deposition of the Cretaceous. The section as revealed by the well, according to Stelck (19A), is as follows:

Description	*Depth in Bluefish well* Feet	*Thickness* Feet
Sandy, micaceous shales, greenish and limy	1,150–1,618	468
Limestone, silty and shaly (Jungle Ridge limestone)	1,618–1,780	162
Shale, silty and micaceous	1,780–1,907	127
Limestone, dark brown, shaly (Kee Scarp zone)	1,907–1,913	6
Shale, dark grey (Kee Scarp zone)	1,913–2,010	97
Limestone, dark brown, shaly, and shales (Kee Scarp zone)	2,010–2,060	50
Shale, dark grey (lower Fort Creek shale)	2,060–2,535	475

The lower Fort Creek shales are hard, platy beds, which, in the Bluefish well, carried the fossil *Buchiola*. The limestones and shaly limestones between 1,907 and 2,060 feet are correlated with the Reef limestones in the Norman Wells area, and are locally known as the Kee Scarp member because of their outcrops on the flank of Discovery Range on what is known as Kee[1] Scarp. This zone in the Bluefish well, correlated with the Kee Scarp member, was not recognized by Stelck (19A) in outcrops in the vicinity of Bear Rock. In the wells of the Norman Wells field, as shown by Boggs (1B), the Reef limestones consist of 75 to 125 feet of bedded limestones overlain by true reef materials composed of stromatoporoids, corallites, and coral sand. It is the upper true reef part that is productive, whereas the lower bedded limestones are mostly barren. The basal part of bedded limestone is thought to outcrop on Bosworth Creek where it is 12 feet thick, but on Canyon Creek it was not recognized (McKinnon, 13A) and is believed to be replaced by a sandstone.

As shown by Stelck (19A), another but higher limestone member than the Kee Scarp was recognized in the Bluefish well. This member, known as the Jungle Ridge limestone, can be traced from Bear Rock northeast to Norman (Discovery) Range. It is approximately 200 feet thick in the outcrops and, as shown in the section, 162 feet thick in the Bluefish well.

[1] After the mythical Kee bird of the Canol project.

These limestones are undoubtedly local members within the Fort Creek formation. It has been pointed out by Boggs (1B) that the coral reef is probably a growth on top of the Kee Scarp limestone member. In the cores from the wells in the productive area of the Norman Wells field there is an abundance of fossil remains in a groundmass of coral sand in the true reef above the bedded limestone member. The fossils are commonly corals, bryozoans, and stromatoporoids. In some of the wells there has been a considerable thickness, up to 50 feet in one known instance, where the top of the reef was composed of fairly soft and coarse coral sand with few fossil remains. In a well outside the proved area 100 feet of this coral sand was present, but in other wells in the field it may be missing. Thus the coral reef not only shows wide variation in composition, but it is also variable in thickness. These conditions are what would be anticipated from a coral reef growth.

In various areas adjoining the Norman Wells area the Kee Scarp member may or may not be present. Reference has already been made to Canyon Creek where the member is thought to be replaced by a sandstone. In the anticlines near the junction of Imperial and Carcajou Rivers the Kee Scarp member may be represented by 5 feet of dark grey crystalline limestone containing many fossil fragments. This occurs about 170 feet above the base of the Fort Creek formation (Bath, 1A). Reference has also been made to the presence of the Kee Scarp or Reef member (Parker, 16A) in the Fort Creek formation on Carcajou Ridge. In the central part of the south side of this ridge the Reef limestone is 70 feet thick, whereas at the west end it is only 6 feet thick. Also, according to Foley (6A), the reef lies directly on Middle Devonian limestone in the northeast part of the ridge, whereas farther west there are 21 feet of lower Fort Creek shales (Parker, 16A). Some of the beds in the reef here are quite dense and impervious, but the upper part is very bituminous and petroliferous.

In the Mountain River area Parker (9) has placed only 10 feet of lower Fort Creek shales below the Reef limestone member, which is 380 to 585 feet thick. It is overlain by 90 feet of upper Fort Creek shales. This tremendous development of limestone in the Fort Creek formation is unusual, as is also the comparative thinness of the whole formation.

In the upper Fort Creek, in the Norman Wells field, Boggs (1B) has recognized a sharp differentiation, particularly in electrologs, between a lower, highly bituminous zone and higher grey shales. The thickness of the bituminous zone varies with the thickness of the underlying Reef member. Where the reef is thin the bituminous zone is thick, and vice versa. There is also a decrease in the combined thickness of the bituminous and Reef members away from the true reef (Boggs, 1B), but this to a large extent is compensated for by an increase in thickness of the upper non-bituminous zone. The total thickness within the Norman Wells field of the two zones of the upper Fort Creek shales plus the Reef member is 1,232 to 1,267 feet. Where the bituminous zone of the upper Fort Creek shales is thickest it becomes very dark in colour, almost coal-black in some places, and contains an abundance of pyrite and cherty materials that make the shales very hard (Boggs, 1B). The thickness of the bituminous zone in the Norman Wells field varies from 118 to 294 feet, and the combined thickness of the bituminous zone and Reef limestone from 426 to 567 feet (Boggs, 1B).

The upper or non-bituminous zone in the upper Fort Creek shales contains many thin sandstone beds, and grades upwards into the overlying Imperial[1] sandstone. The thickness of this upper part in the wells in the Norman Wells field is 670 to 840 feet.

The total thickness of the Fort Creek formation in the Norman Wells area is 1,600 to 1,800 feet. Near the mouth of Macdougal Creek, Nauss (15A) measured a section as follows:

Description	*Thickness* Feet
Soft, grey, flaky shales, some thin sandstone beds	1,140
Brown, platy shale	185
Bluish grey shale with two beds of rusty weathering, grey, clay ironstone 1 foot thick. This shale breaks into blocks 1 inch to 3 inches across. Sulphur stain	150
Brown, rusty weathering, black, platy shale; some concretions	150
Dark bluish grey, platy shale; petroliferous limestone concretions	90
Dark grey, platy shale; petroliferous limestone beds	20
Grey limestone with *Hypothyridina*	5
Disconformity	
Total thickness	1,740

This section is about as thick as that in the Norman Wells field, but differs in that the bedded limestone member at the base of the true reef of the Norman Wells field has not been recognized. The reef itself is missing. The section is thicker than some others of the same formation measured closer to Norman Wells. For example, on Canyon Creek McKinnon (13A) estimated that the whole of the Fort Creek formation was 900 feet thick, but did not include in this the sandstone member now thought to belong to it in the stratigraphic position of the Kee Scarp reef. On Schooner Creek much of the Fort Creek is concealed. However, according to Stelck (18A), a limestone member 100 feet thick overlain by 165 to 195 feet of coralline and brown limestone occurs above 450 feet of dark shales. The upper bituminous beds are covered. In the Hanna River area Smith (20A) estimated that the Fort Creek formation was about 470 feet thick, consisting of 270 feet of highly bituminous lower beds overlain by about 200 feet of soft, poorly exposed, non-bituminous beds with some thin, fine-grained sandstones. Reference has already been made to the presence of 5 feet of limestone of the Kee Scarp member in the anticlines near the mouth of Imperial River (Bath, 1A). This limestone is underlain by 170 feet of shales, and overlain by 625 feet of shales divisible into two members, consisting of a lower 265 feet of dark grey to black bituminous shales that in places have been burnt red, and an upper 360 feet of soft grey shales with numerous ironstone lenses. Thus, in this area the total thickness of the Fort Creek is 800 feet. This compares with a thickness of 850 feet reported by Hart (10) from Kay Mountains south of Bear Rock and west of Old Fort Point. The lower part there, also, is composed of black, hard, thin, slate-like beds that are strongly bituminous overlain by softer shales that weather greenish.

[1] Formerly called Bosworth; *See* new definition in this report.

In the Mountain River area attention has already been drawn to the unusual thickness of 380 to 585 feet of limestone in the Fort Creek formation (Parker, 9), and the comparatively small thickness of shales, amounting to 10 feet below it and 90 feet above it, making a total thickness of only 480 to 685 feet. In the Ramparts River area McKinnon (7) also assigns only 250 feet of beds to the interval occupying a similar stratigraphic position to the Fort Creek shales. The beds are black, platy shales with thin sandstone beds. On Hume River the Fort Creek beds are concealed by muskeg, and no estimates of thickness were made by Moon (8).

In the lower Mackenzie River area Nauss (3) reports that there are 50 feet of black, platy shales, in places burnt red, overlying the basal sandstone member in the Thunder and Outaratou[1] River areas. The maximum observed thickness of the upper part of the Fort Creek shale was 160 feet, but the top was not seen.

In the upper Peel River area Stelck (1) has mapped beds believed to be the equivalents of the Fort Creek formation of the Mackenzie River area. The Upper Devonian beds in this area may be 2,000 feet thick, and outcrops occur in the Hungry Lake area and on Peel River below the lower canyon to 8 miles below Snake River. At the base of the section at the lower canyon there is a conglomerate carrying Ramparts fossils. As pointed out by Stelck, this could be reworked material, and hence actually younger in age than Ramparts. The section is as follows:

Description	*Thickness* Feet
Shales and sandy shales, largely obscured	100
Limestones, thin, with *Cladopora;* interbedded with shale; contains tar	15
Limestone, and limestone breccia, and conglomerate, with *Cladopora*	60
Stromatoporoid reef, limestone conglomerates	3
Shales with thin coquina limestones containing *Acervularia, Favosites, Alveolites, Cladopora, Cystiphyllum,* and stromatoporoids (Ramparts)	45
Conglomerate of limestone and shale with boulders to 3 feet; *Tentaculites*	15
Limestone with *Favosites*	4
Limestone, grey, bedded, petroliferous	20
Shale with *Tentaculites* and *Lingula*	2–20
Biohermal limestone lens, with thin shale at base; *Acervularia,* stromatoporoids	0–10
Biohermal limestone lens with thin shale at base	10
Biohermal limestone lens	10
Limestone, grey, coarse, lenticular	8
Shale, hard, slaty, with *Conularia*	6
Shales with graptolites, contact hard to determine	
Total	303–331

On the basis of black interbedded shales carrying *Tentaculites,* Stelck (1) places these beds in the Upper Devonian, and hence the Middle Devonian fossils may be from transported materials.

On Margery Creek, 15 miles east of the lower canyon, there are no conglomerate beds, but there are 50 feet of shales below and 900 feet of shales above the Cladopora zone that are assigned to the Fort Creek formation, the top of which is at the base of a heavy sandstone bed considered the lowest bed of the overlying Imperial formation. The upper beds of the Fort Creek formation are platy, silty shales that are in places burnt rose-red by the combustion of petroliferous materials in them.

[1]This is spelled Cutaratou in Canol reports.

About 20 miles southwest of Fort McPherson, up Stony Creek in the Mount Toughenough area, Foley (2) found highly contorted black shales near a fault contact. It is suggested that this shale may be the equivalent of the Fort Creek. The thickness is difficult to estimate, but may be about 500 feet. East of this shale and east of a fault that bounds it are more dark grey shales with interbedded, brownish grey sandstones in beds 3 inches to 2 feet thick. These beds are presumably above the other black shales, and their thickness also may be as much as 500 feet. No fossils were found and, like the other shales, these are highly contorted.

South of the Norman Wells area the Fort Creek formation is easily recognized. In the Redstone River area Hancock (11) estimated that the Fort Creek shales may have a thickness of 1,500 feet. The part of the section observed by him, obviously from near the base of the formation, was composed of hard, black, platy, bituminous shale that weathers rusty to yellowish. In the Dahadinni River area Bath (12) reported approximately 1,000 feet of Fort Creek shales made up of an upper part of soft grey shales and a lower part of harder, more resistant, black, bituminous shales. In the vicinity and north of Wrigley, on the east bank of Mackenzie River, Williams (1923, p. 81) mapped Fort Creek beds, and it was from these that Kindle (1919, p. 3) described a fauna containing *Buchiola retriostriata, Buchiola dilata* n.sp., and *Tentaculites mackenziensis* n.sp., as well as other fossils. It was on the presence of *Buchiola retriostriata* that these beds were correlated with the Portage of New York. Attention was drawn by Monnett (13A) to the fact that the beds south of Johnston River and opposite the trail to Blackwater Lake belong to the Imperial formation. This was indicated by Hume (1923a, pp. 81-82), but on Geological Survey Map 2022 the beds are incorrectly shown as Fort Creek.

In the upper non-bituminous part of the Fort Creek shales in the Carcajou-Little Bear River Divide area, Stelck (17A) collected cyrtospirifers, and on the basis of these fossils makes a correlation of the upper Fort Creek with the Hay River shales of Great Slave Lake. Hitherto the Simpson shales of Great Slave Lake have been considered the equivalents of the Fort Creek shales of the Fort Norman area, due to the presence of *Buchiola retriostriata* in the type section of the Simpson formation on the northeastern bank of Mackenzie River opposite Fort Simpson, where about 140 feet of shales are exposed, and 5 miles above Rabbitskin River, where 65 feet of beds containing fossils occur. Kindle (1919, p. 2) states that beds immediately above these, in the Hay River section on the south side of Great Slave Lake, carry a *Spirifer disjunctus* fauna[1]. This fauna would be higher than the Fort Creek, that is, it would lie in the overlying Imperial formation of the Norman Wells area, but on Hay River no Simpson shales are exposed, and there may be a considerable interval of unexposed beds between Hay River[2] and Simpson exposures. On Bouvier River, which enters the Mackenzie about 25 miles below Mills Lake, a fairly complete section of the lower part of the Hay River beds is exposed, according to Whittaker (1923, p. 98). These beds lie entirely within the *Spirifer disjunctus* zone. In view of this it is difficult to understand Stelck's correlation, as the *Spirifer disjunctus* fauna is considered higher than any part of

[1] The *Spirifer disjunctus* may be *Spirifer whitneyi; See* Hume, 1922, p. 72.
[2] In the collections of the Geological Survey, *Spirifer (disjunctus) whitneyi* occurs in the Hay River shales from Hay River.

the Fort Creek shales. In this connection it should be noted that Laudon (10A) in the Imperial River area drew the boundary between the Fort Creek and the overlying Imperial formation at the top of the bituminous zone of the Fort Creek, and included the overlying, dark, non-bituminous and greenish shales with thin sandstone beds in the Imperial formation. No fossil evidence is given to support such a division. In the Schooner Creek area (18A) and in the Carcajou-Little Bear River Divide area (17A) Stelck also suggests that the Fort Creek formation should be terminated at the top of the bituminous zone, and that the name "Carcajou series" should be used to include the non-bituminous beds and the Imperial formation. In no case, however, was such a division followed for mapping purposes, and no type sections were indicated. It is quite apparent that everywhere the upper non-bituminous beds grade upwards into the Imperial formation by the inclusion of more sandstones, so that the boundary between the two is drawn arbitrarily. If there is any change in formational boundaries, therefore, the Imperial should be re-defined to include the beds now included in the upper part of the Fort Creek. These non-bituminous upper Fort Creek beds are those that Stelck (17A) in the Carcajou-Little Bear River area correlates with the Hay River shales. In the Imperial River area Laudon considers them to be 361 feet thick, whereas in the wells of the Norman Wells field Boggs (1B) logged them as the upper member of the Fort Creek formation, and shows that they have a thickness of 687 to 800 feet.

At present it is impossible to settle the question raised by Stelck and Laudon as to where the non-bituminous beds now included in the upper Fort Creek formation should be placed. Because for mapping purposes the Canol geologists have left these beds in the Fort Creek formation, this seems for the present to be the preferable and more practical thing to do.

The Fort Creek shale, by reason of its highly bituminous character, may have been an important source of oil. Its wide distribution, therefore, is a matter of great significance.

IMPERIAL FORMATION

The Imperial formation, also of Upper Devonian age, was originally named Bosworth formation by Kindle and Bosworth (1921) in their report for 1920. In 1921 Bosworth called these same beds Camp Creek series[1]. In 1936, Kindle[2] renamed the formation "Carcajou Mountain Beds" because he discovered that the name Bosworth had previously been used as a formation name by Walcott[3] for Cambrian strata in the Field area of British Columbia. In making this change Kindle suggested that the type section should be on the edge of Carcajou Ridge, 43 miles below Bosworth Creek. At this locality only a few hundred feet of these beds are exposed,

[1] Bosworth, T. O.: The Mackenzie Oil-field of Northern Canada; Inst. of Pet. Tech. London, vol. 7, p. 282 (1921).
[2] Kindle, E. M.: Science, vol. 83, pp. 14-15 (1936).
[3] Walcott, C. D.: Smithsonian Misc. Coll., vol. 53, No. 1804, pp. 2-3 (1908).

and it seems preferable, now that better sections are known, to make the type section on the northeast flank of Imperial Mountain Range on Imperial River, and, as suggesed by Link, to call these beds the Imperial formation. The area is 10 miles southwest of the junction of Imperial and Carcajou Rivers. The section has been described by Laudon (10A) as follows:

Description	*Thickness* Feet
Cretaceous sandstones and shales with a conglomerate at the base.......	
Imperial formation	
Soft, fine-grained, dark-coloured shales in lower part interbedded with thin, sandy and grey-brown limestone beds. The limestone beds are very fossiliferous, and contain *Atrypa, Cyrtospirifer, Cyrtina, Camarotoechia, Hypothyridina, Bellerophon, Pleurotomaria, Actinopteria*, and *Megistocrinus*. Some beds are almost completely composed of crinoid stems. The soft beds form mud slides..................................	450
Dark, soft, green shales alternating with green and shaly sandstones; some limy concretions in central and lower part.........................	251
Dark green shale and green sandstones with intraformational conglomerate zones with abundant fish teeth mostly in the upper and central parts; brown limestones with brachiopods and corals in the lower part.....	346
Green sandstones and shales with some ironstone concretions............	354
Green sandstones and shale with a brown, very hard, siliceous limestone at the top carrying a large gastropod fauna..........................	223
Green, sandy shale with subordinate amounts of green sandstones; a brown, limy sandstone bed at the top with brachiopods (*Atrypa, Spirifer, Camarotoechia*) and a large gastropod fauna......................	102
Soft, green sandstone and green, sandy shale, with a hard grey limestone at the top filled with corals and bryozoa..........................	262
Total..	1,988

In addition to the above beds Laudon included the upper non-bituminous part of the Fort Creek shales in the Imperial formation, because the division between these and the bituminous shales on which they rest is relatively sharp, whereas the non-bituminous shales of the upper Fort Creek contain some sandstones and grade upwards into the Imperial formation. As already explained, these non-bituminous beds have not been incorporated here in the Imperial formation, although further work may show that this should be done.

In the Norman Wells area the Imperial formation consists of green and fine-grained silty sandstones and shales. Some of these beds carry marine fossils, whereas others carry plant fragments and carbonaceous materials. There is a gradational contact from the underlying Fort Creek shales. The upper part of these beds contains thin sandstones, and the contact of the Fort Creek and Imperial formations is usually placed at the base of the first heavy sandstone bed or in beds that carry the distinctive *Spirifer disjunctus* fauna.

The Imperial formation comprises the youngest Palæozoic rocks in the Norman Wells area, and an erosional interval separates it from the overlying Cretaceous strata. In small isolated outcrops in some localities the Imperial strata are not easily distinguished from Cretaceous beds, although usually the two are sufficiently unlike to be recognized.

The green and fine-grained sandstones and shales of the lower part of the Imperial formation are replaced upwards by darker shales. The section as given by Nauss (15A) for the upper Carcajou River area is as follows:

Description	*Thickness* Feet
Bluish grey shale	600
Interbedded, fine-grained, flaggy sandstone and grey shale	200
Red and purple sandstone and grey shale	75
Interbedded, fine-grained, flaggy sandstone and grey shale	400
Massive, fine-grained, calcareous sandstone Covered—sandstone and shale Fine, grey, micaceous sandstone Silty, grey shale and some siltstone layers Grey, laminated, micaceous sandstones	190
Total	1,465

According to Nauss all measurements of the Imperial formation in this area were between 1,420 and 1,690 feet, or an average of approximately 1,500 feet.

In the vicinity of the mouth of Carcajou Canyon, Hume (1923a, p. 58) measured a section of 1,600 feet of Imperial sandstones and shales with an unexposed interval of 600 feet above it and below a Cretaceous sandstone outcrop. The sections of Imperial beds measured by Laudon (10A) in the Imperial River area at the edge of the mountains amounted to 1,988 feet, not including the upper non-bituminous zone 361 feet thick in this area ordinarily considered as Fort Creek, but thought by Laudon to be more closely related to the Imperial on account of the gradation upwards into it. These sections of Imperial strata described from the Carcajou-Imperial River areas are thicker than any others known in the Mackenzie basin.

In the area near the mouth of Imperial River, Bath (1A) describes 265 feet of fine-grained sandstone beds alternating with soft grey shale and thin sandstones in the lower part of the Imperial formation. The total thickness there is believed to be over 1,000 feet, with thin sandstones interbedded with shales, but grey shales predominating in the upper part.

In the Norman Wells field drilling begins in the Imperial formation, which outcrops on the delta of Bosworth Creek and in small exposures on the banks of Mackenzie River. On Goose and Bear Islands and on the west bank of the Mackenzie in this area Cretaceous beds cover the Imperial beds unconformably, so that the whole thickness of the Imperial formation has been penetrated by many wells. According to Boggs (1B) the thickness varies from 437 to 700 feet. This is taken as an indication of the amount of differential erosion preceding Cretaceous deposition in this very local area.

The Imperial beds outcrop between the Norman (Discovery) Range and Mackenzie River northward from Bear Rock to and beyond Norman Wells. In this area, however, only scattered outcrops occur, and no complete sections are exposed. The best sections are those already described from Carcajou Mountains. In the Mountain River area Parker (9) describes the Imperial beds. The lower part, 80 feet thick, consists of slightly sandy, dark grey shales with a few shaly sandstone beds. Although Parker does not say so, the description suggests that this is the upper member of the Fort Creek formation, concerning which there is some difference of opinion as to where it should be placed. Above this shale member is a sandstone member 630 feet thick containing an "intraformational, edgewise, limestone conglomerate" at the base. This is probably the lowest member of the Imperial formation in the Long Reach[1] area of the Mackenzie. It contains *Atrypa reticularis* and crinoid stems, but no other fossils are mentioned. It is overlain by 295 feet of massive, brown weathering, limy sandstones that contain abundant cyrtospirifers. The upper 100 feet of this member is exposed at the Whirlpool anticline, about 20 miles above the mouth of the river. This sandstone member is in turn overlain by 195 feet of black shale grading downward into a shaly sandstone in the basal 35 feet of beds. Only 15 feet of this member is present in the Whirlpool anticline where the remainder has been removed by pre-Cretaceous erosion. Thus the total thickness of the formation in the Imperial Mountains of the Mountain River area is 1,200 feet.

In the Arctic Red River area on Houston River, a branch entering Arctic Red River at the mountain front, beds assigned to the Imperial formation by McKinnon (4) were seen. The lowest member of these beds is a sandstone in contact with dark shale, presumably of the Fort Creek formation. No fossils were found. The top of the Devonian was not seen and outcrops are scarce. On the basis of the covered interval the Imperial formation was thought to be about 1,000 feet thick.

In the Upper Peel River area Stelck (1) mapped marine and non-marine beds, 1,050 feet thick, believed to be the equivalent of the Imperial formation. On Margery Creek, 15 miles east of the lower canyon of Peel River, there is a 20-foot sandstone bed, the base of which is considered to be the top of the Fort Creek formation. This sandstone is interesting also in that in an anticline, just below the mouth of "Calamites" Creek and 8 miles east of the lower canyon, it contains two dykes of bituminous materials. The section above the 20-foot sandstone is exposed on "Calamites" Creek and consists of the following succession:

Description	*Thickness* Feet
Siltstones with thin, interbedded shales with *Lepidodendron*	30
Marine shales with occasional thin, silty bands	340
Silty shales, ledge forming, petroliferous, burns red	40
Marine shales with ironstone bands	120
Limy, silty shales with plants; petroliferous	50
Shales with petroliferous dolomite nodules	200
Sandstone, crossbedded	20
Silty shales with *Calamites* flora, and shaly sandstone	250
Total	1,050

The 250 feet of beds below the 20-foot sandstone are presumed to be the equivalents of the upper non-bituminous beds in the Norman Wells area, so that the whole section here is described by Stelck as "Carcajou series".

Beds found in the lower 50 miles of Arctic Red River are considered by McKinnon (4) to be Imperial in age. These beds consist "mainly of sandstones, with less amounts of shales and sandy shales. The sandstones

[1] The Long Reach is the comparatively straight part of Mackenzie River, 80 miles long, between Bear Rock and Carcajou (Ridge) Mountain. *See* Kindle, E. M., and Bosworth, T. O.: 1921, p. 42.

are generally grey to brown in colour, evenly fine-grained, well indurated and micaceous and contain variable amounts of soft coaly remains and impressions of primitive plant forms. Fragments of brachiopods and crinoid columns were found in limy sandstones at two horizons near the base of the section". In the Appendix of McKinnon's report, which includes the tentative identification of fossils by Stelck, the plant remains are referred to the Cretaceous, and the brachiopod and crinoid fragments to the Cretaceous or Upper Devonian. Apparently, therefore, there is still some doubt as to the age of these beds. The general opinion, however, is that they are Devonian.

In the lower Mackenzie River area Nauss (3) maps beds previously considered Cretaceous as belonging to the Imperial formation. As pointed out by him, in an outcrop 10 miles above Tree River, which in turn is 40 miles above Arctic Red River, McConnell reported (1890, Map No. 7) *Inocerami* from what he considered Cretaceous beds. McConnell first noticed these beds 20 miles below old Fort Good Hope, and in the next 15 miles searched the outcrops for fossils, but obtained (Hume, 1923a, p. 111) only "an almost unrecognizable fragment of an ammonite which was found at the base of one of the sections". In his notes made at the time of his traverse of Mackenzie River in 1888 McConnell mentions having obtained a fossil in an ironstone nodule from the area mentioned by Nauss above Tree River. Evidently the identification of this fossil was made in Ottawa, and hence the name occurs on the map issued in 1891. Nauss states that he searched for fossils in this same area and found none, but at other places found ostracods, crinoid stems, and brachiopods, which led him to the conclusion that these beds are Devonian in age. In the Appendix to Nauss' report, where the fossils are tentatively identified by Stelck, the ostracods and crinoid stems are listed, but no reference is made to the brachiopods. The succession of beds for this area, placed in the Imperial formation by Nauss, is as follows:

Description	*Thickness* Feet
Smooth, grey, crumbly, homogeneous shale; some thin, fine-grained sandstone beds; crinoid stems, ostracods. Outcrop in Tree River area...	350
Interbedded, fine- and medium-grained, greenish grey, blocky and flaggy sandstone and grey, silty shale; exposed in the Lower Ramparts of the Mackenzie just above Arctic Red River and downstream to Point Separation; abundant plant remains, crinoid stems................	500
Grey, silty shale and argillaceous siltstone; some thin sandstone beds. Base not seen..	150+

It has been suggested by Link that, as in some areas the Imperial beds are not easily distinguished from the Cretaceous, strata of both ages may be present in this section.

East of Fort McPherson, up Stony Creek near Mount Toughenough, mention has already been made of 500 feet of shales, described by Foley (2) west of a fault, that are believed by him to represent the Fort Creek shales. East of the fault other beds, also perhaps as much as 500 feet thick and presumably higher stratigraphically, have thin sandstones interbedded with them. The age of these higher beds in the Devonian is uncertain. Along Peel River the oldest Devonian rocks seen were 50 feet of grey sandstones overlain by 10 feet of sandstone made up of subangular fragments of feldspar, ferromagnesian minerals, and a little quartz. Both of these sandtones contain tiny transported fragments of asphaltites. Fossil wood, *Atrypas*, and crinoid stems were found at the mouth of Tailinejeh River. These sandstones do not occur on Stony Creek and presumably were eroded before the Cretaceous was deposited. Above them there are 100 feet of grey shales with hard, dark grey sandstones. The lower sandstones, according to Foley (2), outcrop at Arctic Red River post, and thus must be the same as included by Nauss (3) in his intermediate member. The contact of the Upper Devonian with the overlying Cretaceous beds, according to Foley, occurs 6 miles up Stony Creek. The Devonian beds dip 3 degrees to the south, whereas the Cretaceous beds are horizontal.

South of the Fort Norman area the Imperial formation outcrops in the Gambill Mountains area (Hart, 10) east of upper Little Bear River. The outcrops, however, are poor and, although perhaps 700 feet of beds occur, the top is concealed. The lower shales, 50 to 100 feet thick, are soft, but overlying them is a sandstone approximately 50 feet thick containing an abundance of spirifers and other fossils. Above the sandstone are 500 to 600 feet of soft, grey, marine shales.

In Redstone River area, the full section of Imperial beds is not exposed, but Hancock (11) gives the following section:

Description	*Thickness* Feet
Shales, soft, grey, silty; sandstone beds up to 8 feet thick; contact with the overlying Cretaceous not exposed; pelecypods	90+
Shales, sandstones, and limestones; soft grey shales grading into fine-grained sandstones, interbedded with thin, dark grey limestones; coral, *Atrypa, Stropheodonta, Pugnoides*	140+
Unexposed—probably shales and sandstones	120+
Shale, soft, dark grey, flaky; small ironstone nodules; becomes sandy toward top; crinoid, pelecypod, *Cyrtospirifer, Atrypa*	180+
Sandstone and shale; fine-grained sandstone and shaly sandstone with brownish grey, micaeous shale; thin, dark grey, dense limestone in middle part of section; *Paracyclas*, coral, *Atrypa, Chonetes, Cyrtospirifer*, coniatite	390
Total	920+

The lower contact of the Imperial is here gradational into Fort Creek shales.

In Wrigley River area, Monnett (13) mapped a large anticlinal arch on the north branch about 20 miles from Wrigley. Nine hundred feet of beds exposed on this anticline are in the Imperial formation. The section is as follows:

Description	*Thickness* Feet
Grey shales and green to buff siltstone with shales prominent in the upper, and siltstone making up 50 per cent of the lower, part	650
Hard, brittle, dark grey, micaceous shale, with interbedded siltstone and fine-grained sandstone	250

The two sections given above, one from Wrigley River and the other from Redstone River, should be compared with the section from North Nahanni (Plate II A) and Root Rivers (Hume, 1922, p. 72), where the section is as follows:

Description	*Thickness* Feet
Shale, dark, fissile	100
Athyris angelica Zone—yellowish weathering limestone and interbedded grey shale containing *Athyris angelica, Leiorhynchus, Spirifer whitneyi, Productella, Ambocoelia, Hypothyris cuboides*	200 ±
Shale and limestone	
Red shale and interbedded limestone, *Spirifer* sp.	
Heavy bed of massive, unfossiliferous limestone.	
Thin, grey shales alternating with thin limestones.	
Fossils in the above section are *Leiorhynchus, Athyris angelica, Spirifer disjunctus (?), Spirifer whitneyi, Eatonia, Productella, Ambocoelia, Hypothyris cuboides*	1,000–1,200
Leiorhynchus Zone—alternating beds of limestone and shale with limestones predominating towards the top; *Leiorhynchus* (abundant), *Camarotoechia, Schizophoria, Spirifer disjunctus, Athyris angelica, Rhynchonella*	800–1,100

In the *Leiorhynchus* Zone a coral reef was found on Root River, and in it were many crinoid heads[1] as well as abundant corals and brachiopods.

The *Spirifer disjunctus*[2] and other fossils indicate that these beds are to be correlated with the Imperial formation of the Norman Wells area. The absence of sandstone and the presence of limestone in this section in comparison with the sandstone in the Imperial formation is particularly important as indicative of the change in sedimentation southward. These beds are correlated with the Hay River limestones of Great Slave Lake area, but, as noted by Whittaker (1922, pp. 52-3) on Trout River, there are higher beds there than in the Hay River section. This same condition apparently prevails in the North Nahanni-Root Rivers area where there are still higher Upper Devonian beds than described from Trout River, and as interpreted by Hume (1923a, p. 59) higher than any that occur in the Imperial formation of the Norman Wells area. Link found a goniatite, *Manticoceras intumescens,* in the Imperial formation, and this is regarded as in the lower half of the Upper Devonian. On Redknife River, a tributary from the south entering Mackenzie River 63 miles below Fort Providence, Whittaker (1923, p. 97) has described a coral reef similar to that seen by Hume (1922, p. 71) in the *Leiorhynchus* Zone in Root River area. These coral reefs are thus higher stratigraphically than the productive zone in the Norman Wells field, although all are Upper Devonian in age.

[1] These crinoids have been described by Springer, Frank: Geol. Surv., Canada, Mus. Bull. 42, pp. 127-132, Pl. XXIV (1926).

[2] As has previously been pointed out these fossils are not exactly similar to the type *Spirifer disjunctus.*

CRETACEOUS

The Cretaceous in the Norman Wells area disconformably overlies the older beds, and the erosion interval is very marked. Not only is the Imperial formation quite variable in thickness, locally due to varying amounts of erosion, but at the Ramparts of the Mackenzie both it and the underlying Fort Creek shales have been entirely removed, and Cretaceous strata are in contact with Middle Devonian limestones. Similar conditions occur on the ridges in the vicinity of Sans Sault Rapids and in Kay Mountains, 12 to 15 miles directly south of Bear Rock at Fort Norman.

In the Imperial syncline (Nauss, 15A) and in Mountain River area (Parker, 9) the Cretaceous has been divided into three parts, each of which is described.

When the original report (Hume and Link, 1945) on the Canol project was prepared the various parts of the Cretaceous could not be correlated precisely and, consequently, formational names were not introduced. The beds were, however, divided into four divisions, namely, A, B, C, and D. In 1945, formational names were used by Stewart (1945) and are now adopted. His description is as follows:

SANS SAULT GROUP

"The Sans Sault group rests disconformably on Devonian strata, and, in the locality from which the name is derived, it lies directly on lower Fort Creek, and in places, on the Ramparts formation. It includes all beds from the base of the Lower Cretaceous upward to the base of a non-sandy, thick shale series. In the type section of the Sans Sault the upper 114 feet contains ammonites of the *Beudanticeras* type and also bivalves of Lower Cretaceous age. The overlying thick shale series contains thin beds of bentonite. Individual beds are usually widely distributed and so form good key horizons. The bentonite beds in the shale overlying the Sans Sault formation are, hence, correlated with bentonite beds along Slater River which occur in strata of known Upper Cretaceous age. The Sans Sault group is then defined as being composed essentially of shales and sandstones of marine origin, and includes all Lower Cretaceous strata from the base upward to the first or lowest bentonite bed. The group shows its fullest development on Mountain River where the stream cuts across Imperial Range. Here the section of these rocks has a total thickness of 3,850 feet."

SLATER RIVER FORMATION

"The Slater River formation immediately overlies the Sans Sault. It is composed of thin-bedded, black, friable shales, with numerous ironstone concretions or concretionary layers. It also has thin, soft, white and yellow seams of alum and sulphur and occasional beds of sandstone. Its most distinguishing feature is, however, the presence of many thin bands of bentonite $\frac{1}{8}$ to 1 inch thick. A fish-scale horizon occurs in this section, and the fossils collected are thought to indicate an Upper Cretaceous age. A thickness of 1,000 feet is assigned to this formation on the basis of projected dips and structural evidence. Part sections of the formation may be seen on Mackenzie River below the mouth of Little Bear River, and on Mountain River."

LITTLE BEAR FORMATION

"The Little Bear formation, as its name suggests, has its type locality on Little Bear River. The strata consist of sandstone, some conglomerate, sandy shales, and coal seams. The beds are lenticular and so small and local in distribution that their correlation from place to place is difficult and uncertain.

"In general, any sandy series lying above shales of the Slater type may be tentatively correlated with the Little Bear. A full section of the formation has not been observed, as, where best exposed, all but the lower part has been removed by erosion. A thickness of 780 feet of sandy beds assigned to the Little Bear is exposed on Little Bear River. The age of the formation is determined from the evidence of marine, brackish, and freshwater fossils it contains."

EAST FORK FORMATION

"The East Fork formation directly overlies the sandstone series of the Little Bear formation. It consists of a series of well-bedded, grey, conchoidal, and plastic marine shale. The formation has a thickness of some 850 feet in the type locality on the East Fork of Little Bear River. Near the base are some thin, calcareous, sandstone members; and a thin coal seam, about 12 inches thick and containing fossil resin, was observed on a small tributary. The shales are very similar in lithology to those of the Slater River formation. The East Fork is not recognized north of Little Bear River. Its age is assumed from its stratigraphic relations and observed fossils, but no records of collection or study of these fossils are available."

Descriptions of individual sections were given in the Canol reports and the strata in the Imperial River area (Laudon, 10A) correlated with those on Slater River (Foley, 5A) and Little Bear River and are the same as described by Nauss (15A) in the same area as follows:

Description	*Thickness* Feet
Little Bear formation	
Grey, silty shale and fine-grained sandstone	600
Hard, medium-grained sandstone forming persistent ridge; *Inoceramus*	20
Slater River formation	
Grey, flaky shale; some thin sandstone beds near the top	1,400–1,500
Sans Sault group	
Fine-grained, white weathering, blocky sandstone; some thin shale breaks; ironstone concretions; *Beudanticeras, Inoceramus*	130
Soft grey shale, poorly exposed; fine-grained, glauconitic sandstone; fine-grained, crossbedded sandstone—petroliferous; grey shale, sandy; coarse quartz sandstone with thin conglomerate layers	860

The Sans Sault group was described by Parker (16A) from the west end of East Mountain and both sides of Mackenzie River at Sans Sault Rapids. It consists of a basal sand in places conglomeratic, a middle shaly member, and an upper sandstone, which causes Sans Sault Rapids. The following fossils indicating a Lower Cretaceous age were found in the upper sandstone of the type section: *Gastroplites, Pleuromya, Beudanticeras,* *Inoceramus, Lima, Pecten* (?), *Hoplites,* and *Pinna.* Part of the beds in the section are covered, so that the thickness is not exactly known but is given as 1,411 feet. The thickness on Mountain River is about the same, and the basal member has a pebble-conglomerate 1 foot to 2 feet thick with pebbles up to ¼ inch in diameter.

The Slater River formation was also described by Parker (9) from Mountain River in the area adjacent to Sperry Creek. This formation consists of dark grey to black shales with a few ironstone concretion bands and a few thin beds of siltstone and sandstone. No fossils were observed. The thickness in the Mountain River area is 2,150 feet. It is overlain by 355 feet of coarse-grained sandstones interbedded with dark grey to black shales of the Little Bear formation.

The Little Bear formation was described by Nauss (15A) from Link Bend on Imperial River, where 620 feet of beds of this age are exposed, but where the top of the division is not present. The *Inoceramus* present is similar to that from beds on Little Bear River (Hume, 1924, Pl. I) where a succession of sandstones with coal is overlain by dark, fissile shales.

The *Beudanticeras affine* fauna occurs in the Clearwater shale of the Athabasca area and the Moosebar shale of western Peace River area. The *Gastroplites,* according to McLearn (1945), is a northern fauna and is known from the Scatter formation of Liard River area and in the Hasler formation of Peace River. Both the *Beudanticeras* and *Gastroplites* faunas indicate Lower Cretaceous age.

On Slater River, which enters the Mackenzie from the west about 16 miles below Fort Norman, Foley (5A) mapped a succession of dark Cretaceous shales more than 200 feet thick. It appears as if this represents Division B of Parker and Nauss. There are some concretions and concretionary beds and many thin bands of bentonite. Fragments of a fossil, possibly *Inoceramus,* were seen. Overlying the grey shale is a grey, papery shale 5 to 20 feet thick with abundant fish scales. These form the surface at this locality.

On Little Bear River, Link, according to Monnett (14A), divided the Cretaceous into three divisions. The two lower of these are probably the Slater River and Little Bear formations, whereas the uppermost is the East Fort formation. They are composed as follows:

Description	*Thickness* Feet
East Fork formation	
Grey shale	
Little Bear formation	
Shales, sandstone, and coal	780
Slater River formation	
Grey shale	900

The Little Bear formation is well exposed on Little Bear River on the south limb of a large syncline northwest of Gambill Mountains. It can be divided into three members as follows:

Description	*Thickness* Feet
Sandstone and highly carbonaceous shales with coal seams from a few inches to several feet thick	100+
Sandstone with conglomeratic streaks and brown to grey shale with thin seams of lignite	350
Sandstone, greenish grey, with grey shale containing brown ironstone...	200

The East Fork formation is exposed on the east fork and along Little Bear River. It consists of 850 feet of shales, which, according to Hart (10), are similar in lithology to the Slater River shales.

In the Imperial River area, from which Nauss (15A) described the rocks of the Little Bear formation and other Cretaceous beds, Laudon (10A) mapped the same beds as Slater River and Little Bear formations. The Slater River formation, estimated by Laudon to be 1,324 feet thick[1], consists of the following succession:

Description	*Thickness* Feet
Soft, black and green shale, ironstone concretions	170
Green to grey, thin-bedded sandstone with soft, black, sandy shale; concretions	55
Soft, black, pyritic shales interbedded with a few shaly sandstone beds; a few limestone concretion beds	680
Soft, dark. sandy shale interbedded with sandstone; ironstone concretions	137
Soft, black shales with many concretions and a few sandstone beds....	150
Yellow to grey sandstone with large black flint nodules at top; underlain by soft, black shale and some sandstone with a coal bed; underlain in turn by shale and sandstone with a quartz-pebble conglomerate at base	132
Total	1,324

This succession of beds is overlain by the Little Bear formation, which Laudon (10A) measured as 569 feet thick, consisting of the following beds:

Description	*Thickness* Feet
Soft, green, brown, and tan sandstone beds interbedded with dark, sandy shales and containing a few limy concretions	295
Soft, black, pyritic, slightly sandy shales with minor sand beds and a few limestone concretion zones	210
Grey, green, brown, and tan, porous, relatively fine-grained quartz sandstone; very persistent in this area	64
Total	569

No fossils are given by Laudon from these beds, but it is obvious from the description that they are the same beds as Nauss (15A) described and which are believed to belong to the Little Bear formation. The thickness of the basal sandstone as given by Nauss is somewhat less than that given by Laudon, whereas the total thickness of the division as given by Nauss is somewhat greater than that given by Laudon. The above description of the Slater River by Laudon in the Imperial River area is similar to that for the Sans Sault and Slater River beds of Nauss.

[1]Division B as used here by Laudon probably includes Division A sandstones and shales.

The total succession of Cretaceous beds as understood at present appears to be as follows:

Description	*Thickness* Feet
East Fork formation	
Dark shales as on east fork of Little Bear River (Monnett, 14A, and Hart, 10)	850
Little Bear formation	
Sandstone, shale, and conglomerate, with coal, in Little Bear River area (Monnett, 14A, after Link)	780
Sandstone and shale with a 20-foot, hard, ridge-forming sandstone at base in Imperial River syncline (Nauss, 15A)	620
Slater River formation	
Grey, flaky shale with some thin sandstone beds near the top in Imperial River syncline (Nauss, 15A)	1,400–1,500
Dark shales with a few thin siltstone and sandstone beds in Mountain River area (Parker, 9)	2,150
Dark shales with thin, concretionary beds and many thin bands of bentonite on Slater River (Foley, 5A)	200+
Dark shales on Little Bear River (Monnett, 14A, after Link)	900
Sans Sault group	
An upper sandstone, a middle shale, and a lower sandstone that may be conglomeratic, in the vicinity of Sans Sault Rapids (Parker, 6A)	1,411
Sandstone and shale with glauconite and conglomerates in the lower part in Imperial River syncline (Nauss, 15A)	990

As already pointed out, the Sans Sault group contains the *Beudanticeras* and *Gastropolites* faunas of Lower Cretaceous age, whereas in the vicinity of Bear Rock, according to Stelck (19A), the only fossils found were *Watinoceras, Scaphites, Placenticeras, Inoceramus labiatus,* and fish remains. These are Upper Cretaceous, and are correlated by Stelck with the Kaskapau formation of the Smoky group, and are to be correlated with the Alberta group of the southern Foothills of Alberta. In the Bluefish No. 1A well of Imperial Oil Limited, drilled near Bear Rock, the Cretaceous occurred, according to Stelck, between 360 and 1,150 feet in depth. An arbitrary division in well cuttings gives a thickness of 550 feet to Little Bear formation and 240 feet to the underlying Slater River shales. At 1,100 feet in the well, that is in the Slater River shales, a considerable microfauna including *Haplophragmoides* was found. This genus of foraminifera has a long range, and unless it can be identified specifically is of little stratigraphic value. The fact, however, that outcrop fossils are Upper Cretaceous fixes the age of at least part of these beds. These are the only definite Upper Cretaceous fossils reported by Canol geologists in the Mackenzie River area.

According to Bath (1A) the shales exposed along lower Carcajou River belong to the Slater River formation. In this area these overlie 50 feet of sandstone. On the opposite side of Mackenzie River, in the upper Donnelly River area, Foley (6A) found the Cretaceous resting on Middle Devonian limestones. At the base of the Cretaceous there is 60 feet of sandstone with some conglomerate overlain by more than 300 feet of dark grey shale with concretions and bentonite layers. Fossil ammonities found in this shale included *Hoplites* and *Beudanticeras.* These fossils indicate a Lower Cretaceous age, and presumably the shale represents the Sans Sault group.

In the immediate vicinity of the Norman Wells field Cretaceous beds are exposed on Loon Creek (Hancock, 8A). There is a lower sandstone member from which a specimen of *Pleuromya* was obtained by Foley along the axis of the Loon Creek anticline. As in the lower part of the Cretaceous elsewhere, glauconite occurs in these beds and serves in part to help distinguish them from the underlying Imperial sandstones. Only 20 feet of the lower sand is exposed on Loon Creek. Above this sand is a shale member with bentonite, large ironstone concretions, and discontinuous concretionary bands. A large *Beudanticeras* was collected from near the base of these shales, which are thought to be about 500 feet thick. They are overlain by sandstones interbedded with shales more than 400 feet thick. Small, discontinuous coal seams occur with these beds.

In Hume River area, Moon (8) made no attempt to measure the thickness of the Cretaceous, but states that it would doubtless run into thousands of feet. To the west, in the Ramparts River area, McKinnon (7) shows the Cretaceous to be approximately 2,200 feet thick, and gives a composite section consisting of a lower member of 1,000 feet of dark grey shales with minor sandstones. Concretionary ironstone nodules are present, and in the lower 200 feet *Beudanticeras* and *Hoplites* occur, indicating a Lower Cretaceous age. The upper member of the Cretaceous here, 1,200 feet thick, consists of heavy sandstones and shales alternating with sandy shales.

In the Arctic Red River area (McKinnon, 4) by far the greater part between Mackenzie Mountains and the mouth of Arctic Red River is underlain by Cretaceous sediments. The section consists of a lower sandstone member, a middle shale member, and an upper sandstone member. The middle shale and the upper sandstone members are correlated with the two divisions seen on Ramparts River.

The lower member on Arctic Red River is composed mainly of massive sandstones with some alternating shales. Some conglomeratic beds occur near the base. It is about 500 feet thick.

The middle shale member contains some sandstone beds. It may be about 1,500 feet thick, but folding in it makes this estimate somewhat uncertain. In the lower part of Peel River the lower 300 feet of this member contains considerable gypsum and sulphur, and in places the shales are burned reddish by chemical action.

The upper member consists of a succession of heavy sandstones alternating with sandy shales. It is about 900 feet thick. A large *Inoceramus* was found in it.

In the lower part of Peel River, Foley (2) found an extensive area covered by Cretaceous beds, of which the following is a descending section:

Description	*Thickness* Feet
Grey shale, some concretionary layers with *Beudanticeras* and *Gastroplites*..........	800+
Shaly siltstone with sandstone containing *Liopistha* and *Tellina*..........	60
Light grey sandstone and shale..........	30
Dark grey shale..........	10
Green, thinly laminated sandstone with glauconite; *Tellina*..........	30
Dark grey shale interbedded with light grey to greenish sandstone; *Tellina*	200 ±
Grey sandstone weathering brown, yellow, and light red-brick; much fine conglomerate..........	40–200

It is obvious that all these beds are of Lower Cretaceous age.

On the higher part of Peel River, from near Snake River to some distance below Trail River, Stelck (1) found about 1,250 feet of Lower Cretaceous beds. These consist of 400 feet of soft argillaceous sandstones and sandy shales grading upwards into shales with thin siltstones about 850 feet thick. *Beudanticeras* occurs about 300 feet above the base.

It has already been pointed out that Nauss (3) considers the beds in the lower Mackenzie River area, including the lower Ramparts section, to be Upper Devonian rather than Cretaceous as formerly thought. The only beds reported as Cretaceous by Nauss in this area occur in an escarpment 12 miles northwest of Fort Good Hope. At this place there are 55 feet of crossbedded sandstone with a few streaks of conglomerate with angular black shale pebbles overlying the Middle Ramparts shales of Middle Devonian age.

Five and a half miles up Stony Creek, west of Fort McPherson, Foley (2) found a single belemnite at the base of a bank. This was from the lowest beds of Cretaceous age in this area, which here consist of 105 feet of sandstones with conglomerate near the base. The sandstone is overlain by about 100 feet of dark grey shale, and is, in turn, overlain by alternating sandstone and shales about 95 feet thick containing the fossil *Corbula*. These beds are again overlain by shales 180 feet or more in thickness.

As pointed out by Foley, O'Neill (1924) described the east face of Black Mountain west of Aklavik as consisting of 800 feet of interbedded sandstones and shales dipping west at about 12 degrees. Some of the sandstones are weathered reddish brown, and one stratum contains concretionary nodules. Some layers contain abundant fossils. These were identified by T. W. Stanton as *Pentacrinus, Pecten, Lima, Aucella* (very abundant), *Panopaea ?, Natica,* and *Pseudomelania*, and Stanton says that "the Aucella fixes the age as either Upper Jurassic or Lower Cretaceous, more probably the former". Nauss (3) describes this same section from Black Mountain and Donna River as follows:

Fine-grained, buff and rusty, blocky quartz sandstone containing glauconite, some conglomerate layers, a few silty shale beds, and *Belemnites*.
Dark grey, crumbly, silty shale, with abundant ironstone concretions and layers.

Camsell (1906, pp. 45-46) described a similar section from Mount Goodenough 20 to 30 miles farther south.

On Firth River, which enters the Arctic Ocean 35 miles east of the Alaska boundary, O'Neill also described shales, sandstones, conglomerates, and quartzites, in the top of which *Cadoceras*, indicating a Jurassic age, was collected. It is certain from this information that Jurassic beds are exposed in the Arctic, but it is more questionable whether those on Black Mountain are of this age or are Cretaceous.

South of Norman Wells area, Hart (10) has described the Cretaceous beds in the vicinity of Keele (Gravel) River, east fork of Little Bear River, and Kay Mountains. On Keele River 400 feet of Slater River shales were seen, but neither the top nor bottom is exposed. Little Bear formation beds occur in the vicinity of Kay Mountains, but are best studied on the lower part of Little Bear River. The East Fork formation 750 to 850 feet thick, is similar lithologically to the Slater River shales.

In Redstone River area, Hancock (11) found isolated outcrops of Cretaceous, but the complete section is not exposed. At the base, but not in contact with the underlying Upper Devonian beds, is an estimated thickness of 140 feet of sandstone with thin shale bands overlain by 90 feet of shale with crossbedded sandstone and coal seams. Above this is a covered interval of possibly 240 feet followed by 60 feet of sandstone overlain by 30 feet of shale.

On the flanks of an anticline about 8 to 9 miles from the mouth of Redstone River, 60 feet of sandstones, with a conglomerate band 2 to 3 feet thick, occur above 150 to 175 feet of shales alternating with sandstone beds up to 5 feet thick. The position of these beds in the Cretaceous section is not known.

On Dahadinni River, near Mackenzie River, Bath (12) placed the base of the Cretaceous at 30 feet of coarse-grained, grey sandstone with scattered pebbles and overlain by 40 feet of sandstones with some conglomeratic bands.

Cretaceous beds underlie the plateau surface of Horn Mountains, which rise to an elevation of about 2,000 feet south of Fort Providence. Only about 80 feet of beds were observed by Whittaker (1922, p. 54), and all of these consisted of brown-black, fissile shales that weather yellow. The beds are flat-lying and no fossils were found to determine their precise age.

TERTIARY

The Tertiary sediments of the Fort Norman area were noted by the early explorers on account of the burning coal seam a few miles south of Fort Norman on the banks of Mackenzie River. Plants collected from these beds indicate a lower Eocene age (1922, p. 76). These beds outcrop along Mackenzie River for several miles south from Great Bear River, and up that river to and beyond Brackett River. The thickness, according to Stelck (19A), may be as much as 600 feet, with a partial section of 330 feet drilled in Imperial No. 1A Bluefish well. The pebbles of the conglomerates are chert, quartzite, limestone, and sandstone, and interbedded with the soft clays are lignite seams.

Further deposits of Tertiary occur on Mackenzie River near Old Fort Point. They consist of soft sandstones and shales (Bath, 14). The exposed thickness is 125 feet and some lignite seams are present. Part of the deposit has been burnt red from the burning of the coal.

On Little Bear River, and tributaries, Hart (10) reports 1,600 feet of Tertiary beds. These consist of soft, coarse, carbonaceous sands, gravels, conglomerates, shales, and lignites. At the headwaters of East Fork River there are lignite seams 8 to 10 feet thick. For 18 miles along East Fork, near its headwaters, the high hills on both sides of the valley are made up of Tertiary beds with a measured thickness of over 1,200 feet. At the south end of Kay Mountains, the lignites and shales have been burnt red and dip 50 degrees to the northeast. Evidently these form a basin with the deposits at Old Fort Point, which dip toward the southwest.

The Tertiary beds of Wind River and Bonnet Plume areas were reported by Camsell (1906). According to Stelck (1), these are 1,050 feet thick and consist of gravels, sands, and shales with lignite beds. The Tertiary beds rest with high angular unconformity on the older formations. On Peel River about a mile above the delta of Bonnet Plume River, a lignite seam is burning. The beds include a basal conglomerate, and the basal part of the section with thick gravels is all that is left in the Hungry Creek section.

CHAPTER III

STRUCTURE

REGIONAL STRUCTURAL FEATURES

In the southern part of Western Canada the eastern Rocky Mountains trend northwest as far north as Liard River, where they are much less pronounced than farther south. To the east of them, and north of Liard River, Mackenzie Mountains appear. The eastern or Nahanni Range first becomes prominent in Nahanni Butte at the junction of South Nahanni and Liard Rivers, and is marked by an eastward-facing escarpment 800 to 1,000 feet high. This is a fault scarp. To the west of the main range the ridges are lower, all trending northerly about parallel with the main range and plunging northward largely to disappear in the area south of Dahadinni and Redstone Rivers. The eastern range is apparently unbroken from Nahanni Butte to the mouth of North Nahanni River. There it suddenly plunges northward, but in a very short distance again rises into a dome-shaped knob called Lone Mountain. Lone Mountain is south of Mackenzie River, and no mountain ridge is apparent for 40 miles farther north, to where the south-plunging end of Franklin Mountains (Williams, 1922, Map 1957) appears close to the junction of Willow Lake and Mackenzie River.

West of Lone Mountain, across the valley of North Nahanni River, the Camsell Range may be the northwest continuation or extension of the Nahanni Range. The trend is changed to northwest, but, as in the Nahanni Range farther south, the east side is a fault scarp, presumably the result of overthrusting from the southwest. This is a limestone ridge of Middle Devonian and older strata. It continues northwest for 50 miles to Root River, beyond which the trend is more northerly to the south side of Mackenzie River east of Wrigley River, which, in its lower part, parallels the west side of the ridge. The course of the ridge is interrupted by Mackenzie River Valley, but on the east side it is continued by Rock-by-the-River's-Side[1] Ridge and its northern extension. This ridge apparently dies out against the west flank of Franklin Mountains.

Fifteen miles west of Nahanni Range, in the area of North Nahanni River, another limestone ridge occurs along the west side of the south-flowing river for 20 miles. The river flows across the ridge at its north-plunging end, where the limestone disappears under younger strata. Farther north the ridge is no longer distinct. Unlike the Nahanni Range, however, this ridge is a fold, in places with very steeply tilted or vertical beds on its eastern face. Faulting is a minor feature in relation to the folding. The ridge illustrates the northward plunge of the regional structures in the country west of Nahanni Range and is also typical of many of the Mackenzie Mountains where folding rather than faulting becomes the predominant structural feature. This is in sharp contrast with the character of the eastern Rocky Mountains of southern Canada where the dominant feature is faulting, with fault blocks thrust onto one another from the west or southwest. Also, there are no foothills or disturbed belt in front of Mackenzie Mountains as in front of the Rocky Mountains. The Mackenzie

[1] The approved geographic name for this feature is Roche-qui-trempe-à-l'eau.

area north of Wrigley and south of Fort Good Hope is a basin between Mackenzie Mountains on the west and Franklin Mountains on the east. In the basin there are many gentle folds and only minor faults.

Franklin Mountains begin north of Willow Lake River close to Mackenzie River. The southern end is a plunging anticline, and the form northward is that of a gently rising arch. Along the trend to the north, however, the structure becomes more complex and faults occur. This mountain range continues 150 miles to Great Bear River, where Mount Charles is a prominent feature on it. North of Great Bear River it swings to the west, thus becoming arcuate in outline, and disappears south of Hare Indian River, which enters the Mackenzie at Fort Good Hope.

In the area south of Great Bear River, Franklin Mountains have two high peaks, Cap Mountain, northeast of Wrigley, which has an elevation (Williams, 1923, p. 70) of perhaps 5,000 feet above the sea, and Mount Clark, which rises to about 4,500 feet 20 miles east of the mouth of Keele River.

It has been pointed out by Dowling (1922, p. 85) that in the Mackenzie area the eastern mountains, including the Franklin Range, project almost across what has been called the Rocky Mountain geosyncline of more southerly areas. He also points out that "the Alberta mountains are formed from the fractured and folded extra thick beds of the western part of this geosyncline" whereas "the northern mountains, on the other hand, are formed from much thinner deposits that overlie the Precambrian and they present phenomena which suggest that in their formation a comparatively thin sheet of the stratified crust was crumpled by compressive strain".

Richardson Mountains west of the delta of the Mackenzie are said to trend almost north and south, and are composed of anticlinal ridges parallel with one another. Stelck (1) is of the opinion that the southern end is an anticlinorium, the eroded centre of which has been called Wind and Bonnet Plume River basins. He believes the two flanks of this anticlinorium are represented by the beds in the upper and lower canyons on Wind and Peel Rivers, with Cambrian and Ordovician rocks, in part unconformably overlain by Tertiary strata, occupying the intervening area.

McConnell (1890, p. 119) has described the mountains on Peel River as consisting "essentially of two ranges, separated by a wide longitudinal valley, and flanked on either side by high plateaus". On Rat River, west of Fort McPerson, the pass has an elevation of only 1,100 feet. The mountains in this area are low, with few prominent peaks.

Plateau areas are a striking feature of Mackenzie Mountains. The area in the vicinity of Dodo (Macdougal) Canyon has, in general, a very flat outline, but peaks rise above it. The Plains of Abraham south of Little Keele River, where the Norman Wells-Whitehorse pipeline reaches its highest elevation at 5,750 feet[1], is a plateau area where the folding is very gentle. There is also a remarkably flat-topped plateau area sloping northward in the area south of North Nahanni River and west of the Camsell Range. Stream valleys are deeply cut into this plateau, but very little information is available on the structure of the rocks composing it.

[1] *See* Norman Sheet, Air Navigation edition (8 miles = 1 inch), Hydrographic and Map Service, Ottawa.

Within and northwest of the Norman Wells area the structural trend is shown by two series of folds. The first of these begins in Kay Mountains[2], 20 miles south of Bear Rock at Fort Norman. These trend slightly northwest, but are sufficiently irregular that it is taken for granted the folding continues either directly or *en échelon* with the fold that again becomes pronounced in Bear Rock. Bear Rock trends nearly north, but the folding, with some faulting, continues to the northwest end of the Norman or Discovery Range, where again the folding, accompanied by faulting, becomes irregular in Cleaver, Richard, Thomas, and Paige Mountains. A sharp turn to the west in this vicinity is accompanied by four more or less parallel folds in a distance of 25 miles, south to north, as follows: (1) Carcajou Ridge (Mountain); (2) East Mountain; (3) Bat Hills, with their eastward extension into the Mount Dellis Range and their southeast continuation, the Gibson Range; and (4) Beavertail Mountains trending slightly northeast into the West Virginia Hills and eastward into the Mount Effie Range. These parallel folds all plunge westward and disappear at Mackenzie River, which flows around their western ends. Slightly north of the west end of East Mountain, Sans Sault Rapid in the Mackenzie is caused by hard Cretaceous sandstone on the north flank of East Mountain rather than by the core of the uplift. West of Mackenzie River the trend changes to the southwest, and again appears in West Mountain between Carcajou and Mountain Rivers, where a prominent anticline occurs in Middle Devonian strata. West Mountain is slightly oblique to either East Mountain or Carcajou Ridge, and lies between them. It, as all previous mountains herein described, has been uplifted and eroded sufficiently to expose Palæozoic rocks, but southwestward, as the folding continues into the Whirlpool anticline on Mountain River, there is no longer the distinct topographic expression of the folding, and the older Palæozoic rocks are concealed by overlying Cretaceous beds. The folding, however, continues, and the trend is northwest in Cretaceous beds across Hume, Ramparts, and Arctic Red Rivers. Farther north there is no precise information, but the folding may continue to and beyond Peel River.

The second series of folds roughly parallels the first to the south and west. It begins as the Imperial anticline trending northwest, and crosses Imperial River close to its junction with Carcajou River. For about 10 miles it roughly parallels Carcajou River and there breaks into a succession of folds from south to north, as follows: possible extension of Imperial anticline, Sammons anticline, Rainbow Arch anticline, and Shavetail anticline. These anticlines are in Palæozoic rocks, but to the east they plunge beneath Cretaceous beds. The folds also diverge eastward away from the curvature of the more southerly Imperial anticline, and are continued by further exposures of Palæozoic beds in Hoosier Ridge on the west bank of Mackenzie River. This is again continued, slightly *en échelon*, into the Morrow Creek anticline, which is inferred to cross Mackenzie River and shows on the east side.

To the west of the Carcajou River folds the Imperial anticline swings in a broad arc to the southwest and then to the northwest, exposing Palæozoic rocks on Mountain, Hume, Ramparts (*See* Map No. 1034A), and Arctic Red and Peel Rivers (*See* Map No. 1034A).

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[2] Called MacKay Mountains on some maps.

Folded Cambrian rocks are exposed in the Carcajou Range, extending northwest to cross Imperial and Mountain Rivers, but there is no exact information as to their further extension, although they again appear on Arctic Red and Peel Rivers (*See* Map No. 1034A).

Gambill Mountains, trending northeast at the headwaters of Little Bear River, seem to represent an uplift connected with the northeast-trending Little Bear syncline. They are thought to be continuous with the southeast end of Carcajou Mountains, and hence indicate a swing of these mountains to the northeast around the southern end of Little Bear River basin.

Thus the Mackenzie basin in the Norman Wells area is broken into more or less parallel but curving anticlinal ridges accompanied by a little faulting, but with folding predominating. Between these uplifted ridges, which in the main expose Palæozoic strata, there are limited basins of lowland country largely in Cretaceous strata but with Tertiary beds occupying them in part.

DETAILS OF STRUCTURAL FEATURES

AREA FROM KEELE RIVER NORTH TO THE ARCTIC

Kay Mountains (Hart, 10)

Kay Mountains rise abruptly 1,600 feet above the surrounding country. To the east is a broad, flat upland gently sloping toward the Mackenzie and, as usual in this northern country, covered by muskeg with stunted spruce trees and lakes of various size, some of them fairly large. Kay Mountains form a hogback 15 miles long, with a steep, east-facing scarp and a steep west dip-slope. Silurian rocks occur on the east-facing escarpment, but in a basin between this and Old Fort Point all older rocks are overlain by Tertiary gravels and clays with lignite seams. To the west of Kay Mountains is a high plateau, almost treeless, covered also by Tertiary deposits and ending at the edge of the rugged mountain front. In this western part there is another fold called Summit anticline with less steep dips than in Kay Mountains, but exposing a core of Bear Rock formation. The anticline has been incompletely mapped, but apparently trends northwest oblique to the northeast trend of Gambill Mountains east of Little Bear River. The north end may be cut off by a fault. Summit Creek flows southeast to Keele River, and Summit anticline lies to the southwest of its headwaters. The extent of the anticline to the southeast is unknown, and there is no information as to whether a fold on the projected trend is present on Keele River, 15 to 20 miles distant.

Little Bear syncline has been mapped crossing the East Fork of Little Bear River in Cretaceous strata near its junction with the main stream, and extending southwest across Little Bear River where the stream flows northward from the west side of Gambill Mountains. This is oblique to the more northerly trend of both Gambill and Kay Mountains. Four miles southeast, that is, at right angles to the trend of Little Bear syncline, the East Fork anticline parallels the syncline. Its east end may be cut off by a fault, and the entire anticline is in Cretaceous or younger beds. This appears to be the only possible oil prospect that has been observed in the vicinity of Kay Mountains (*See* Map No. 1032A).

Bear Rock and Vicinity (Stelck, 19A)

(*See* Figure 2)

Bear Rock, according to Stelck, is an elongate half anticline with several minor faults and folds. The half anticline is open to the east where Tertiary beds come in contact with Silurian or older formations, and it is not known whether or not a fault is present. On the top of Bear Rock, 5 miles north of Mackenzie River, an asymmetrical anticline parallels the trend of the Norman (Discovery) Range, and at the west side of Bear Rock this anticline is replaced by a fault with intense fracturing in the Middle Devonian limestones. Another fault in Bear Rock occurs on the northwest side beginning about 2½ miles north of Mackenzie River and trending slightly oblique to the northwest trend of the mountain. The upthrow side of this fault is to the east, in part thrusting strata of Bear Rock age against Ramparts limestones. The attitude of the fault plane is, presumably, steep. Some other faults in the southeast end of Bear Rock, unlike the one described above, seem to show thrusting from southwest to northeast, but the throw on these is, apparently, small.

To the west of Bear Rock, at Bluefish Creek, there is an anticline in lower Fort Creek shales. The trend of the anticline is northwest. Dips of 17 to 19 degrees occur on the southwest flank, and of 29 degrees on the northeast flank. On his map (1 inch=¼ mile) showing this anticline, Stelck indicates a small area of Beavertail limestone apparently in the river or low on the Mackenzie River bank on the southwest flank. This is not mentioned in his report. If such an outcrop is present, the structural relationships are such that faulting would be probable. Seepages of oil occur at the contact of the Fort Creek with the overlying Cretaceous beds.

Norman (Discovery) Range

(*See* Figures 3 and 4 and Map No. 1032A)

The Norman Range lies east and north of the Norman Wells field. It trends southeast, but in the vicinity of the headwaters of Vermilion Creek (Figure 4) turns more southerly and is separated by a fault from the northern end of Bear Rock. The strata on the Norman Range dip to the southwest, normally at 10 to 15 degrees, but steeper beds are present locally. There is a northeastward-facing escarpment. It is unknown whether this escarpment is a fault-line scarp or is wholly an erosional feature. To the northeast is a lowland, but in the vicinity of the west side of Kelly (Whitefish) Lake, hills composed of Silurian and possibly older rocks rise to as much as 1,800 feet above lake level. No Devonian has been reported at any place between the Norman Range and Kelly Lake, but the country is almost wholly unexplored. Thus, if the Norman Range is anticlinal, the position of the east flank is unknown. Explorations on the northwest end of the Norman Range by Canol geologists (Laudon; Parker) in the vicinity of Morrow Creek, which flows between the northwest end of the Norman (Discovery) Range and Morrow and Cleaver Mountains still farther northwest, show that the northeast flank of the range in this area is faulted, with the upthrow side to the southwest.

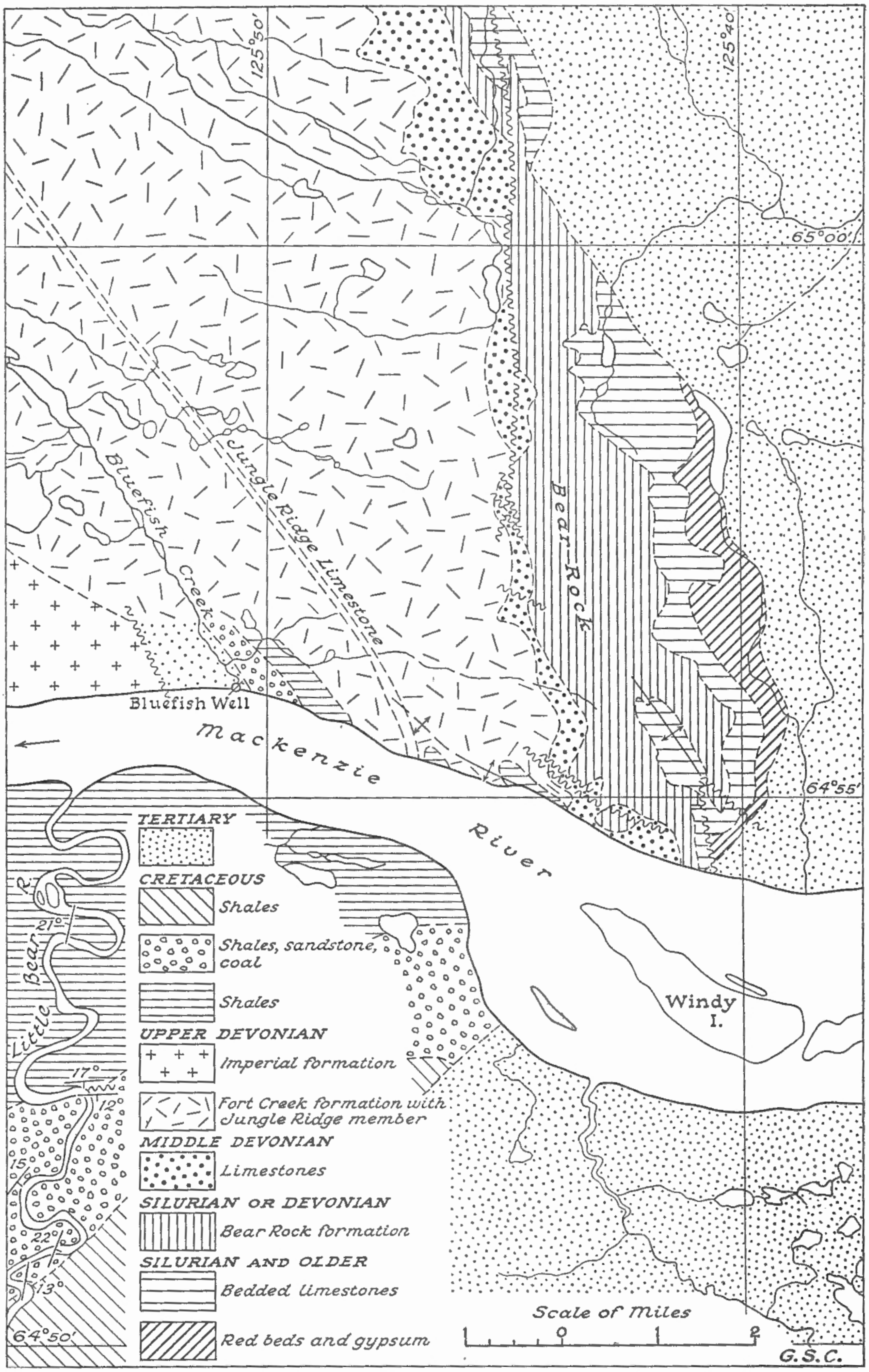


Figure 2. Bear Rock and vicinity.

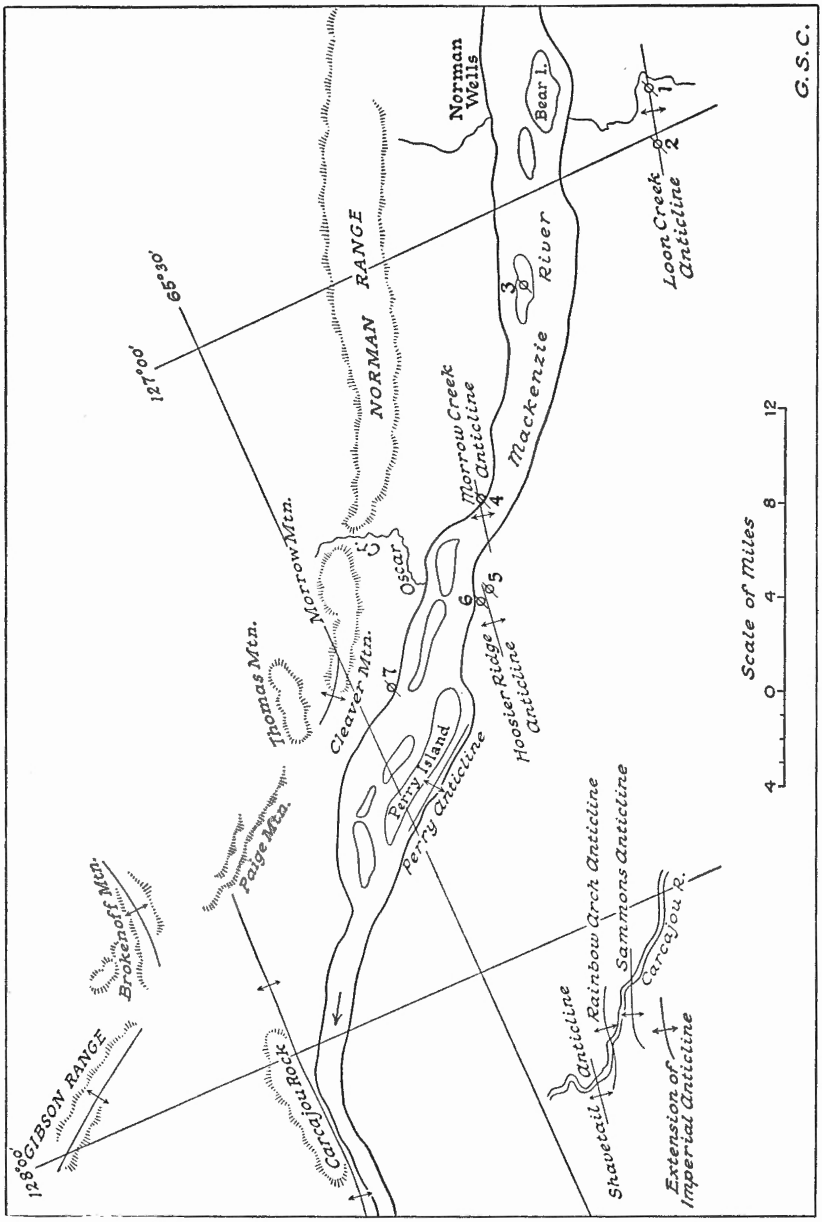


Figure 3. Structural trends, Norman Wells area: 1, Loon Creek No. 1 well; 2, Loonex No. 1 well; 3, Raider Island No. 1 well; 4, Morrow Creek No. 1 well; 5, Hoosier Ridge No. 1 well; 6, Hoosier Ridge No. 2 well; 7, Judile No. 1 well.

Vermilion Gorge Anticline (Hancock, 9A)

(*See* Figure 4 and Map No. 1032A)

Some minor folds occur on the southwest flank of Norman Range. One of the larger of these is in Fort Creek shale on Vermilion Creek 5 miles from Mackenzie River, and apparently extends 6 miles northwest to appear on Prohibition Creek (Figure 4). Where this anticline occurs on

Vermilion Creek a gorge has been cut, and the fold is thus named the Vermilion Gorge anticline. Another fold occurs on Vermilion Creek about 1½ miles above the first, but there is not sufficient information to suggest that it has any considerable magnitude.

Halfway Anticline? (Hancock, 9A; Foley, 5A)

(*See* Figure 4)

The north end of Halfway Islands in Mackenzie River is 3 miles south of the mouth of Vermilion Creek. Between these places there are beds on the west bank of the river showing a reversal from the normal southwest dip. There is a difference of opinion, however, about this supposed Halfway anticline in that the reversal, based on two outcrops within a distance of 100 feet, may be on beds that have been disturbed by ice action or slump. The anticline, if present, is quite small (Foley).

Oscar Basin (Laudon, 4A)

(*See* Figure 5)

Norman (Discovery) Range continues northwest into Morrow and Cleaver Mountains, but with a change in structure. The northeast edge of the Norman Range is faulted at the northwest end with the Silurian beds on the southwest overthrust to the northeast. Thus, the steep face of the Norman Range is to the northeast. The reverse is true for Morrow and Cleaver Mountains, where the faulted, steep face is to the southwest and the thrust from the northeast. Laudon explains these relationships by a hinge fault with pivot in the vicinity of Morrow Creek, but Parker (3A) considers that there are two faults.

To the north of Cleaver and Morrow Mountains, but trending eastward and thus diverging from the southeast trend of these ridges, are the Thomas and Richard Mountains. These also are faulted on the south and southwest, and the north side is thrust southward. To the south of these and northeast of Cleaver and Morrow Mountains is Oscar basin, largely underlain by Fort Creek shales. Few outcrops occur in this basin, and no anticlines have been observed in it.

Upper Hanna River Basin (Smith, 20A)

(*See* Figure 6)

To the north of Thomas and Richard Mountains in the upper Hanna River area is another basin open to the east, but bounded on the west by Paige Mountain and the east end of Carcajou Ridge, and to the north by Brokenoff Mountain. The mountain ridges are faulted, and apparently Brokenoff Mountain, like Richard and Thomas Mountains, is bounded by a fault along its southerly face. Silurian strata outcrop in these mountains, but the basin is underlain by Fort Creek shales in which there is an elongated, northwest-trending anticline, which, owing to a lack of outcrops, has rather obscure relationships on the southeast end. This anticline has been outlined by a limestone bed in the Fort Creek shale, but there are relatively few outcrops and the amount of closure if any, and other features are not available from surface information. The greatest width of the anticline is on Greenhorn Creek, which drains out of Moon Lake. The fold is thus known as Greenhorn anticline.

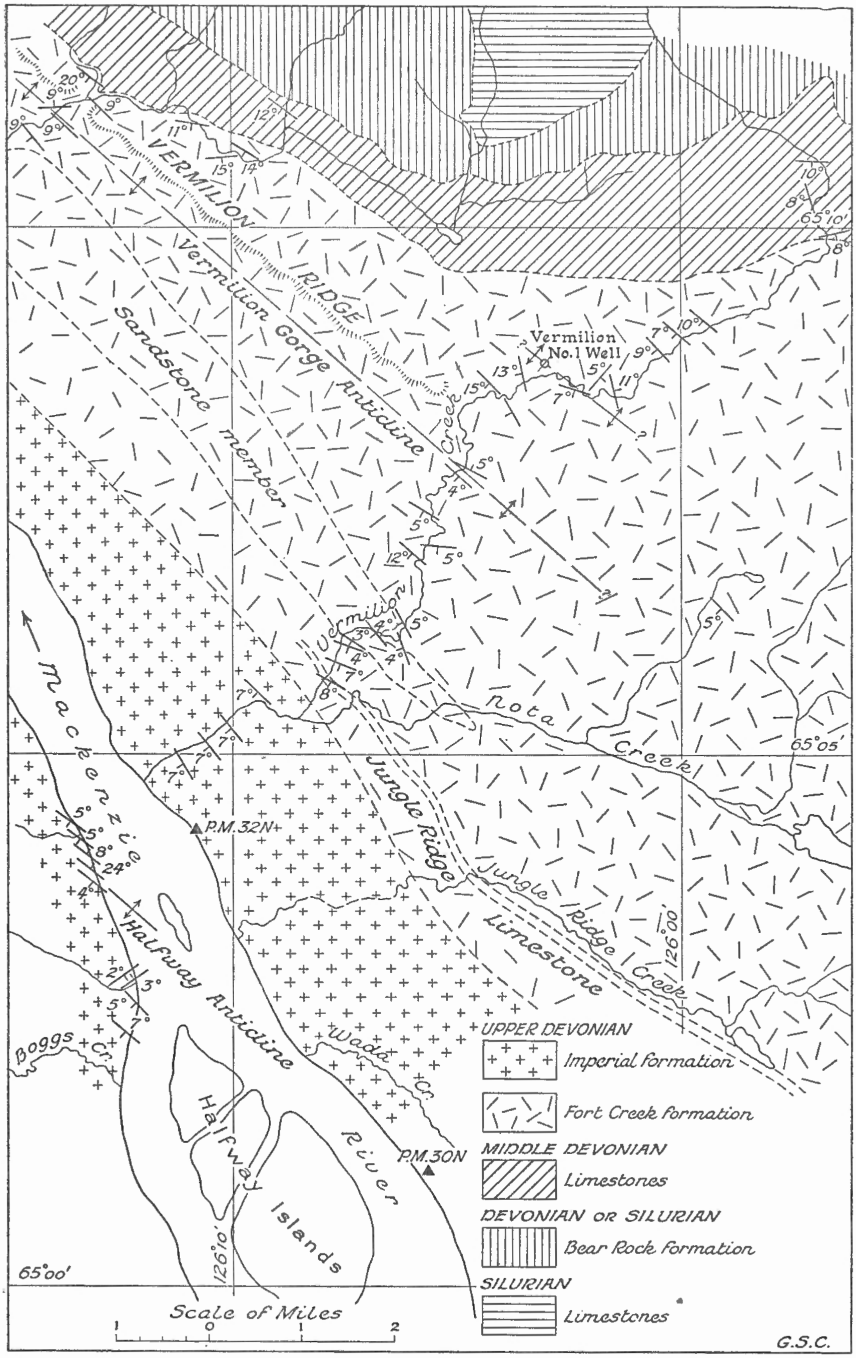


Figure 4. Vermilion Gorge and Halfway anticlines.

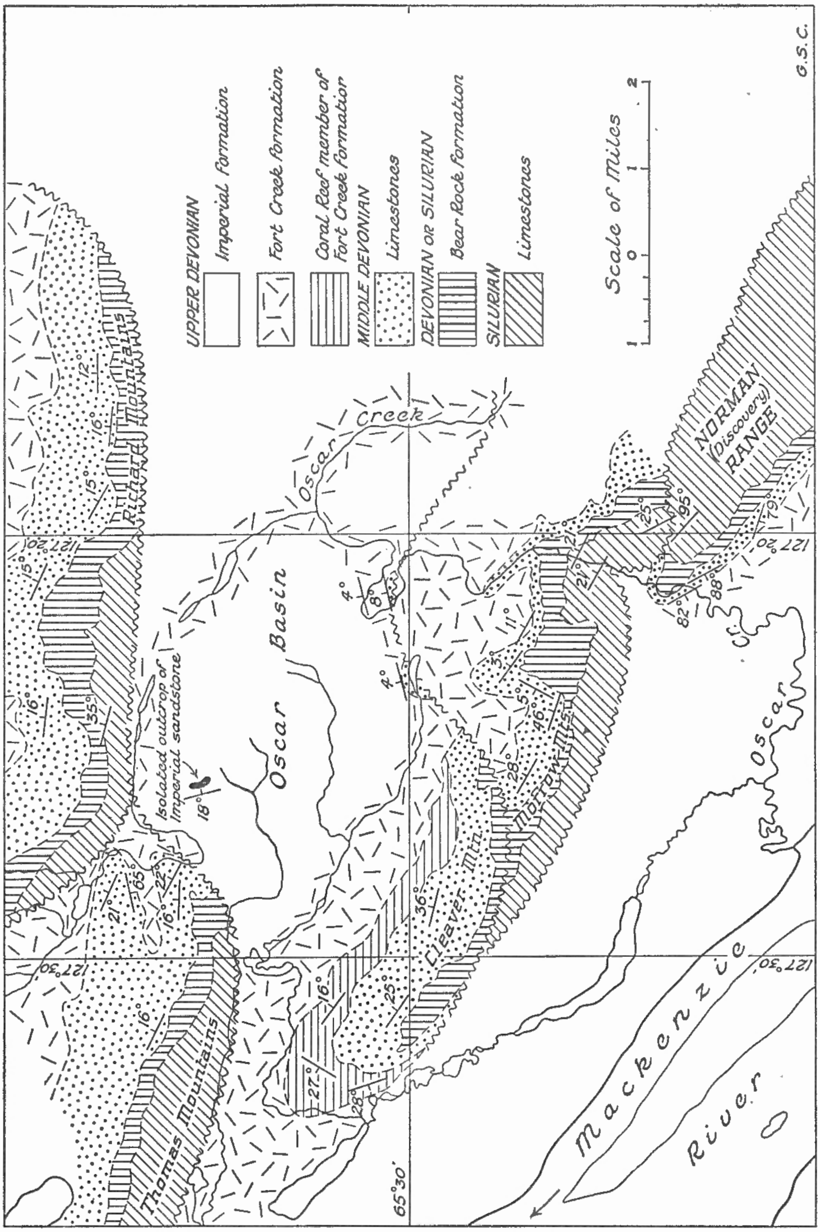


Figure 5. Oscar basin.

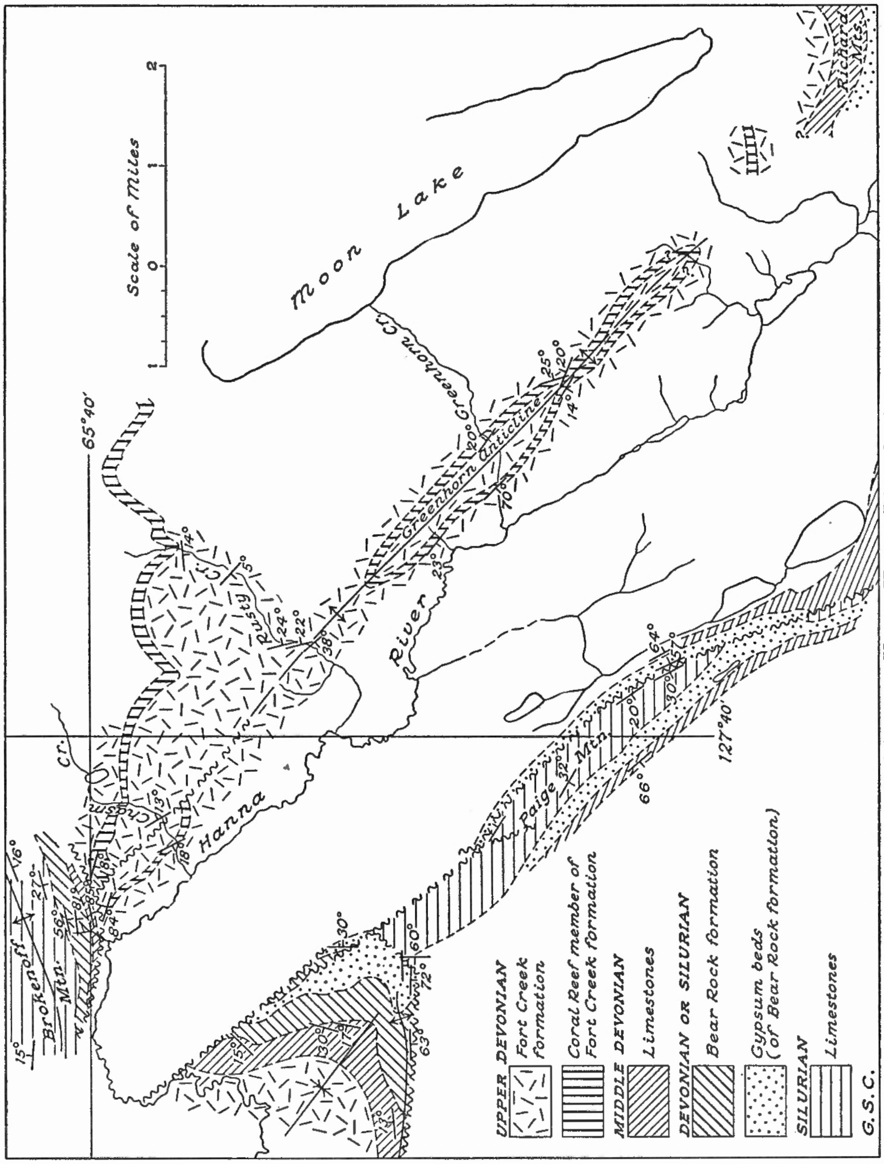


Figure 6. Upper Hanna River basin.

Lower Hanna River Basin (Parker, 16A) and
Donnelly River Basin (Foley, 6A)

(*See* Map No. 1033A)

Lower Hanna River flows north of Carcajou Ridge and East Mountain and south of Bat Hills, whereas Donnelly River is north of Bat Hills and south of Beavertail Mountain and continues eastward into West Virginia Hills and the Mount Effie Range. Chick Lake lies in the Donnelly River basin.

All of these mountains are anticlinal, with considerable faulting. All expose Bear Rock or older strata, with Cretaceous unconformably overlying the higher Devonian formations in the intermontane areas. All anticlines are at least in part strongly asymmetrical, but unlike Carcajou Ridge, the continuation of Bat Hills into Mount Dellis, the Gibson Range, and the eastward continuation of Beavertail anticline, which are steeply dipping on the south flank, East Mountain and the eastward part of Mount Effie Range are asymmetrical to the north. The eastward extension of Beavertail anticline with the fault on the south face is in contrast with the Mount Effie Range with a fault on the north face. The west end of Mount Effie Range is slightly to the north of the east end of the Beavertail anticline extension. There is also a slight change in trend, which is accompanied by faulting trending southeast, to cut off the northwest end of the Gibson Range.

No theory has been advanced by Canol geologists to explain the forces that caused this intricate structural pattern. It is obvious that compressive stresses acted both from the north or northeast and from the south or southwest, but the age relationships of all faults have not been well established.

In the lower Hanna River basin, occupied by Cretaceous strata, there are very few outcrops and no anticlines have been mapped. In the Donnelly River basin many outcrops occur in the Cretaceous west of Chick Lake, but aside from the basin structure itself, no minor folds have been observed. That such folds may be present in some of the large areas where there are no outcrops would be inferred from the occurrence of minor folds on the east bank of Mackenzie River northwest of Bat Hills. Also, in the vicinity of Sans Sault Rapids there are several small folds and faults in the Cretaceous on the north flank of East Mountain (Parker).

Sans Sault Anticline (Parker, 16A)

(*See* Figure 7 and Map No. 1033A)

On the west side of Mackenzie River two small anticlines are present in Cretaceous strata, whereas the dip of the rocks upstream and downstream from these anticlines shows that they are minor wrinkles on the top of a larger anticlinal structure (Parker). A well was drilled on this structure, but there was no oil production. The Bear Rock formation was reached.

Sans Sault Syncline (Parker, 9)

(*See* Map No. 1033A)

Included in this structure is all of Mountain River below the Whirlpool anticline, which occurs 20 miles above the mouth. The syncline is bounded on the south and east by West Mountain and the Whirlpool anticline, and on the east side by the Sans Sault anticline on the west side of Mackenzie River. Several small folds are present within this Cretaceous basin, and of these the most prominent anticline is one about 5 miles down Mountain River from the Whirlpool anticline. The structural relief of these small folds, according to Parker (9), is 50 feet or less, and little is known of the trend or extent of any of them.

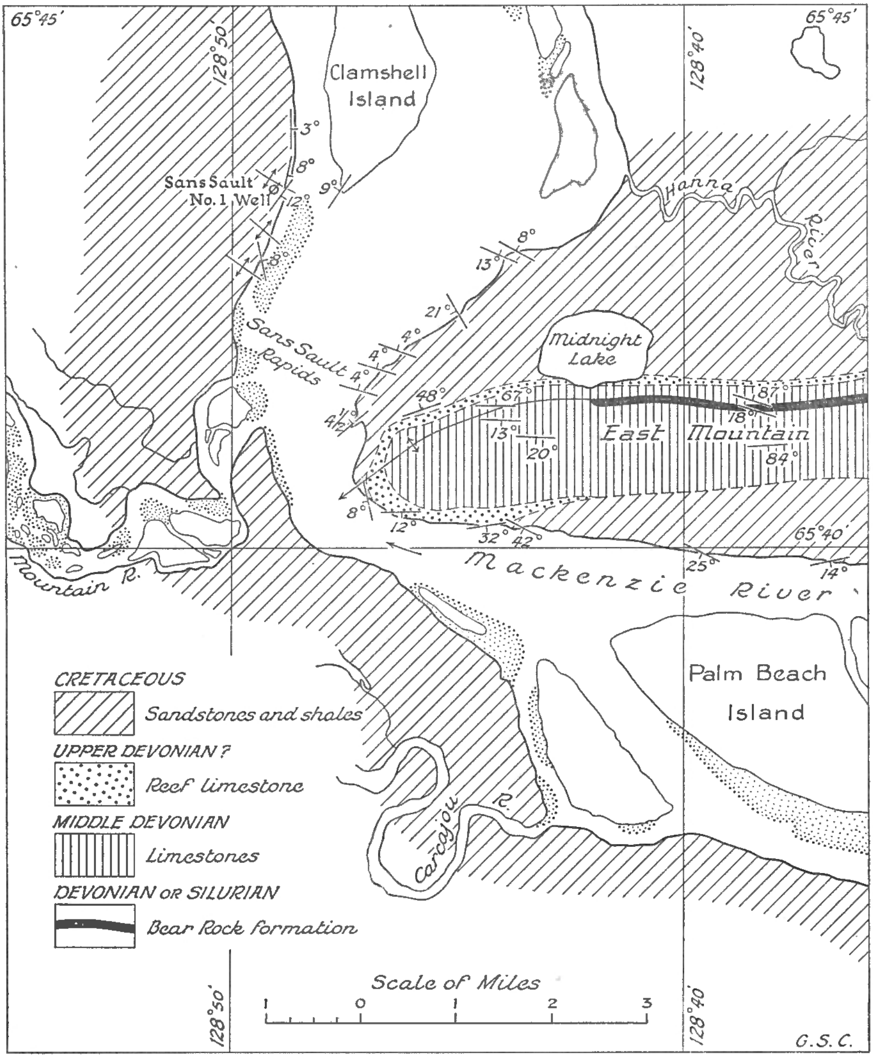


Figure 7. Sans Sault and East Mountain area.

Whirlpool Anticline (Parker, 9)

(*See* Figure 8 and Map No. 1033A)

This structure, located by Link, was mapped by Parker (9). It is a broad, gentle fold, and the oldest beds exposed on it are the Imperial sandstones and shales. Most of the outcrops on Mountain River are Cretaceous. The trend and form of the structure cannot be outlined accurately from the few rock exposures, but, according to Parker, the trend of the anticlinal axis is about east and west with a curvature to the northeast on the east side of Mountain River. Observations made in the vicinity of the anticline seem to show (Parker, 9) that the structural relief is about 1,000 feet, although regional studies based on the thickness of Cretaceous beds point to this being much larger. As with many structures in this country, there is little information available away from the river banks where the outcrops occur. East closure is indicated by the arrangement of the Cretaceous formations, but data on west closure are indefinite. As Imperial sandstones are exposed on the west side of the river, and as the indicated plunge is to the east, it may be the anticline opens up westward to expose more Imperial beds between Mountain and Hume Rivers. So far as the regional structure is concerned, it would appear as if the critical closure would, in all probability, be between the Devonian exposures on East and West Mountains and the Whirlpool anticline. The plunge eastward from the Whirlpool anticline, as indicated by the Cretaceous outcrops, appears to ensure a closure in this direction. The Whirlpool anticline thus becomes a very promising oil prospect as on the trend of the regional structure. An anticline on Cretaceous strata is present on Hume and Arctic Red Rivers.

Between the Whirlpool anticline and the Imperial Range is a syncline with a width of about 6 miles. Dips on the north side of the syncline in the Cretaceous are much steeper than those on the south side, but the central part is almost flat.

Hume River Anticline (Moon, 8)

(*See* Figure 8 and Map No. 1033A)

The anticline on Hume River is apparently the continuation of the Whirlpool anticline on Mountain River. Low dips occur in Cretaceous rocks and the anticline has relatively small closure. No information is available other than from exposures along the river.

Ramparts River Anticline (McKinnon, 7)

(*See* Figure 9 and Map No. 1033A)

About 25 to 30 miles northwest of the Hume River anticline is a more pronounced fold on Ramparts River. In front of the mountains is a syncline with its axis some 8 or 10 miles north of them. The southern flank of this syncline is the steeper, and, consequently, shorter than the northern limb where the dips vary from 3 to 5 degrees, becoming flatter northward. About 15 miles north of the synclinal axis is an anticlinal axis south of a large U-bend in the river parallel with the northwest trend of the structure. This anticline has at least a 5-mile width to the southwest, with dips of 4 to 6 degrees, but a shorter northeast flank, with dips of 2 degrees grading northward into flat-lying beds. Nothing is known of the extension of the anticline away from the river. The anticline is entirely within Cretaceous beds, which consist of dark grey, fissile shales with thin sandstones overlain by sandstones alternating with shales.

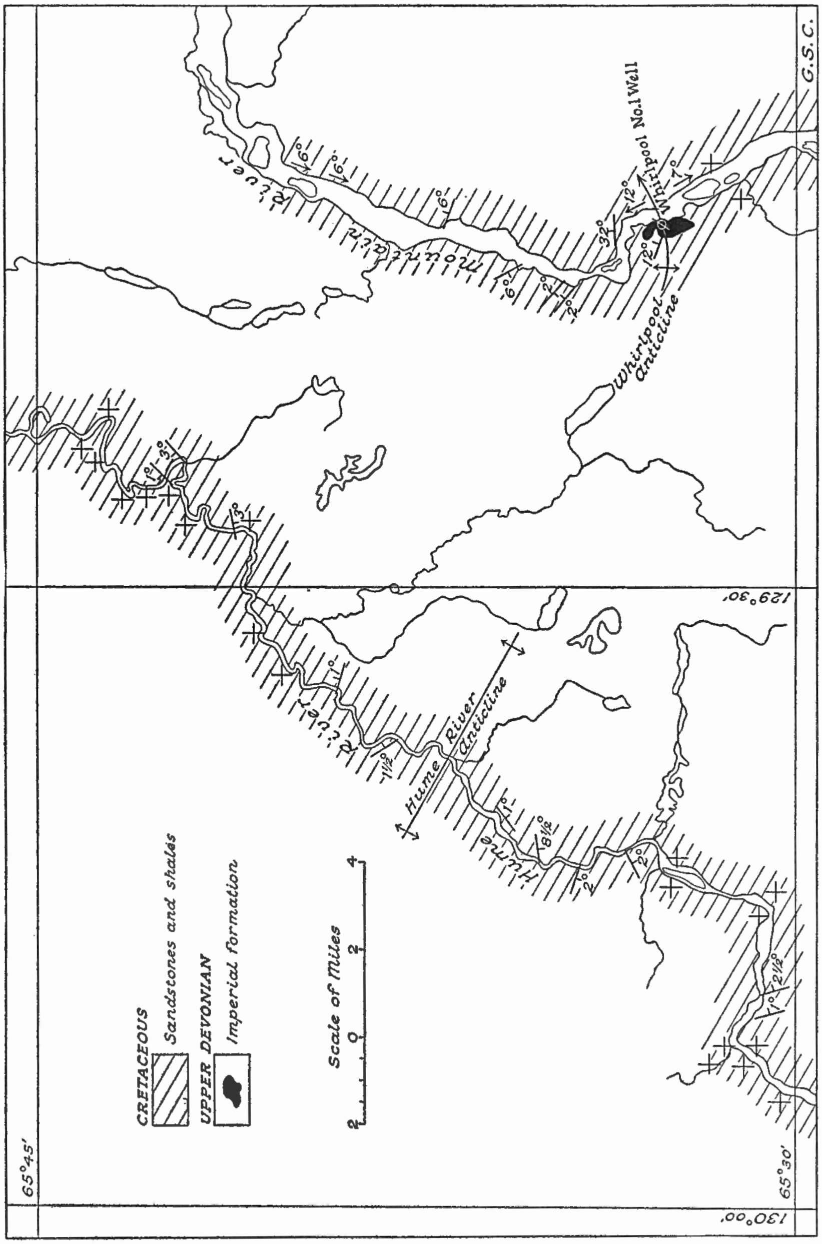


Figure 8. Whirlpool and Hume River anticlines.

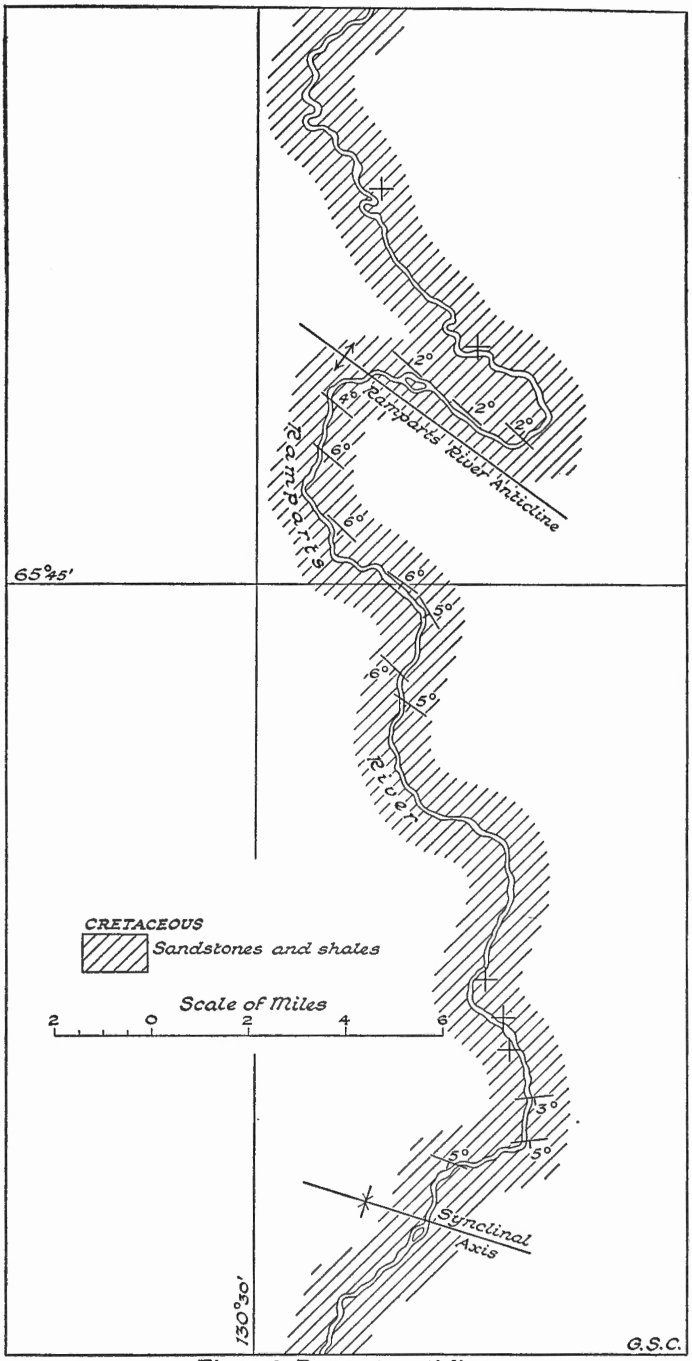


Figure 9. Ramparts anticline.

Arctic Red River Anticline (McKinnon, 4)

(*See* Map No. 1034A)

For 25 to 30 miles from the mountain front, Arctic Red River flows northward, and then turns to the northwest. On Mount Edith, at the junction of the Houston with Arctic Red River, there is some faulting, with Silurian strata thrust onto Devonian. In front of the fault the Devonian is overlain by Cretaceous beds, and this condition continues for many miles downstream. In front of the mountains is a shallow synclinal basin, the axis of which is about 12 miles distant. On the south limb of the syncline the beds dip 15 to 20 degrees northward, and on the north limb the dip is 2 to 4 degrees for about 6 miles, when flat beds, apparently on the crest of an anticline, occur. The reversal on the north flank is shown by only one exposure of shale, where the dip is 2 degrees to the north. This outcrop is nearly a mile north of the supposed crest of the anticline. About 2 miles north of the crest southward dips again appear, and for 8 miles are up to 8 degrees. From this place north the south dip still continues, but at the rate of about 20 feet to the mile. Four miles above the mouth of Arctic Red River are Upper Devonian non-marine beds, dipping southwestward at 2 degrees. Similar beds occur on Mackenzie River in the vicinity of Arctic Red River post.

From oblique air photographs it is considered that the small anticline on Arctic Red River is the continuation northwestward of a similar fold on Ramparts River. The amount of closure in the Cretaceous on the north flank of this anticline is small.

Lower Peel River Basin (Foley, 2)

(*See* Maps Nos. 1033A and 1034A)

The basin comprising the lower part of Peel River also includes the lower parts of Arctic Red, Ramparts, Hume, and Mountain Rivers. This is the Cretaceous basin extending westward from Mackenzie River north of the Ramparts and east of the mountains to the Arctic coast. The anticlines already described from Arctic Red and Ramparts Rivers are reasonably close to the mountains and are parts of a trend beginning south of Bear Rock and extending through the Norman Range, East and West Mountains, to the Whirlpool anticline on Mountain River. Apparently this anticline becomes less pronounced northwestward. There are some anticlines on Peel River below the lower canyon, but it is not known if these are connected with the folds on Arctic Red and Ramparts Rivers close to the mountain front.

The rocks on lower Peel River show a very gentle southward regional dip, so gentle in fact that in local areas the rocks appear to be horizontal.

Along Stony Creek, west of Fort McPherson, there are some minor undulations, but none of them is sufficiently large to be an oil structure. About 2 miles east of Mount Toughenough there is a fault, with the downthrown side to the west. East of the fault the dip is eastward. About 1¼ miles west of this fault is a highly deformed zone bordering the mountains. South of Mount Toughenough the Devonian shales are vertical or overturned southward, and in places are highly contorted and thrust-faulted.

In the valley of Vitrekewan (Road) River, about 3 miles above its junction with Peel River, a small fold in the Cretaceous is overturned to the northeast. The shale beyond the immediate vicinity of the fold is horizontal.

The upper part of Trail River was not reached.

Upper Peel River Area (Stelck, 1)

(*See* Map No. 1034A and Figure 10)

Wind and Bonnet Plume Basin. According to Stelck, the upper part of Peel River basin is a broad anticlinorium. The west limb exposes Devonian strata on Mount Deception, and, in the upper canyon and the east limb 30 miles distant, includes the overturned Devonian beds of the lower canyon. The axis lies somewhat east of the junction of Peel and Wind Rivers, and Cambrian beds are exposed in the anticlinal crest on Wind River. It is these Cambrian beds that in the basin of Wind and Bonnet Plume Rivers are covered by non-marine Tertiary strata. Formerly the basin of Wind and Bonnet Plume Rivers was regarded as a prospective oil area. The facts of the stratigraphy as given by Stelck completely destroy this conception. The axis of the anticlinorium plunges northward, ultimately to involve Cretaceous beds. Its trend is approximately north, and it is believed to be continuous with the Rat River anticline of Richardson Mountains west of Fort McPherson.

Hungry Lake Area. West of Mount Deception (*See* Map No. 1034A), at the mouth of Hungry Creek on Wind River, there is a syncline extending northward into a mountain area. Immediately west of this, on Hungry Creek, is a south-plunging anticline showing some faulting. Farther west, the structure around Hungry Lake is not well understood. To the south the structures appear to follow an east-west trend, whereas the structures to the north appear to trend northwesterly.

Area East of Lower Canyon of Peel River (*See* Figure 10). East of the lower canyon of Peel River there is a broad arch plunging northward. For 5 miles east of the foot of the lower canyon the beds dip southwesterly, and then change to a northeasterly dip for 7 miles. The anticlinal crest, which trends somewhat north of west, occurs in the vicinity of the mouth of Calamites Creek, where fracturing has given rise to dykes of pyrobituminous material cutting sandstones. The beds on Calamites Creek are thought to be non-marine equivalents of the Imperial formation. At the crest of the anticline the beds are almost everywhere petroliferous.

On Margery Creek, which enters Peel River about 10 miles below Calamites Creek, there is another anticline with axis trending slightly west of north and quite oblique to the one farther west. This anticline is plunging northward, and the southern closure, if any, has not been determined. Middle Devonian rocks are exposed in the central part of this anticline.

East of the Margery Creek anticline the dip of the Devonian beds is gentle and to the southeast. About 10 miles down Peel River from the mouth of Snake River, Cretaceous rocks overlie the Devonian, and although the dips near the contact are as much as 15 degrees, they flatten eastward to only a few feet a mile. To the east and north lies the large Cretaceous basin of the lower Peel River.

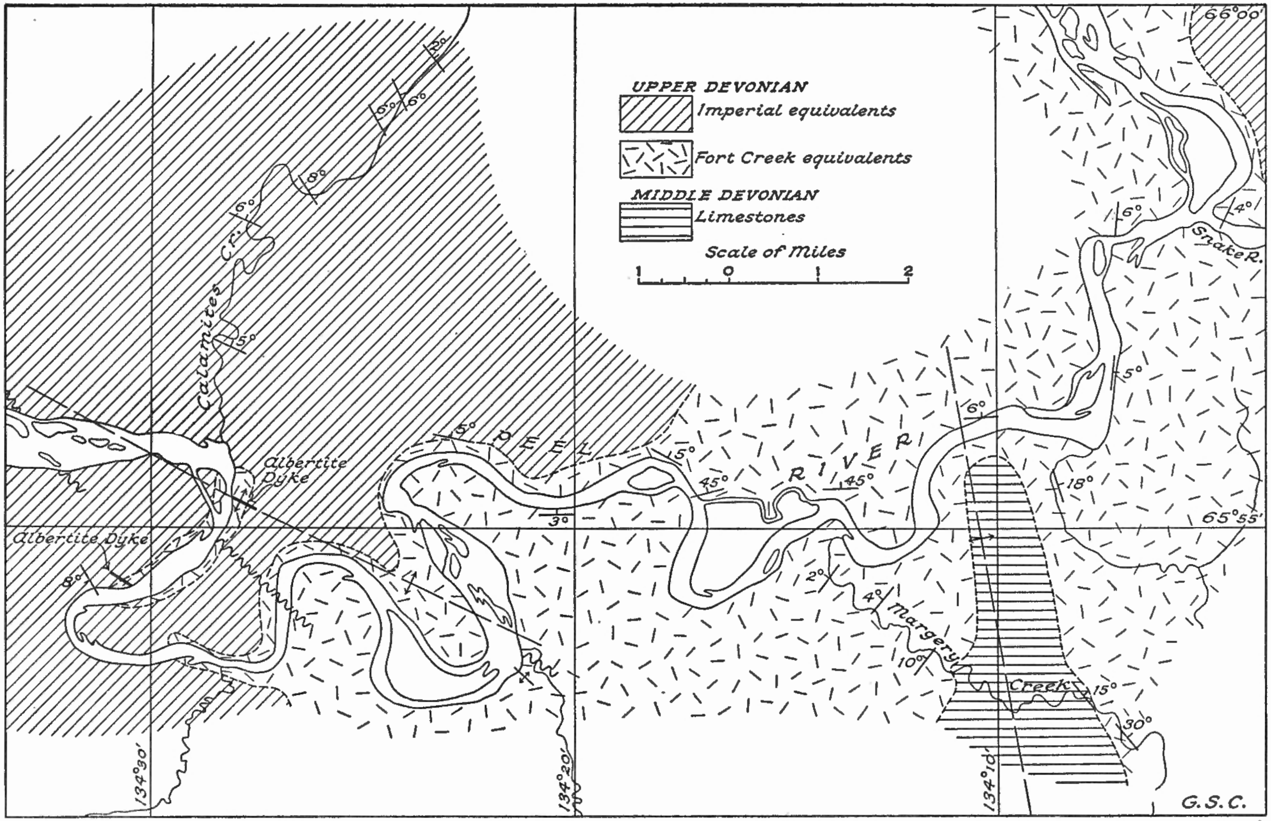


Figure 10. Upper Peel River area.

Point Separation Anticline (Nauss, 3)

(*See* Map No. 1034A)

From Arctic Red River north toward Point Separation the dip of the beds exposed along Mackenzie River is southward. At about half a mile south of Point Separation a reversal or north dip occurs. The apparent closure along Mackenzie River is only 50 feet, but the northward dip may continue for some distance under the Mackenzie Delta.

Richardson Mountains (Nauss, 3)

Very little information is available on Richardson Mountains west of the Mackenzie Delta. The top of the mountains forms a plateau that has an elevation of about 1,500 feet above sea-level. It is entirely above tree line, with only bushes and brush.

Several miles north of Black Mountain, west of Aklavik, an anticline 1 mile wide, trending north and south, forms the mountain front at the edge of the Mackenzie Delta. The dips do not exceed 20 degrees, and are mostly gentle.

West of this first anticline the dips are again eastward for 2 or 3 miles, and form the east flank of another parallel anticline.

It thus appears that Richardson Mountains consist of a series of north-trending anticlines with gentle dips.

The oldest beds observed by Nauss on these anticlines were Mesozoic, and at least one anticline had no older beds than Mesozoic exposed on its crest. The anticlinal conditions observed in Richardson Mountains extend over a wide area.

AREA FROM KEELE RIVER SOUTH TO FORT SIMPSON

Redstone River Area (Hancock, 11)

(*See* Figure 11)

Big Bend Anticline. Redstone River has the appearance of having captured the headwaters of Dahadinni River. It is a river with a wide valley east of the mountains, and, except at the headwaters of Dahadinni River where it flows north, its main drainage is eastward. From the mouth for 28 miles southwest, only Cretaceous strata occur, but it is evident that these are gently folded. One rather pronounced fold appears 7 miles above the mouth of the river at a large bend, and for this reason has been named the Big Bend anticline. On the river the plunge of the anticline is to the south, and closure on the north end is assumed but has not been observed. The dips of the Cretaceous beds on both flanks are 5 to 7 degrees, and the anticline appears to have a width of at least 2 miles with perhaps 250 feet of closure across the trend, that is, in a northeast-southwest direction.

Other Structures Crossing Redstone River (*See* Map No. 1032A). West of the Big Bend anticline the dips of the Cretaceous beds appear to be somewhat steeper, and at the contact with the Devonian beds, 28 miles west of the mouth of the river, the dip is approximately 25 degrees. West of the Big Bend anticline, but within the Cretaceous beds, a second anticline is

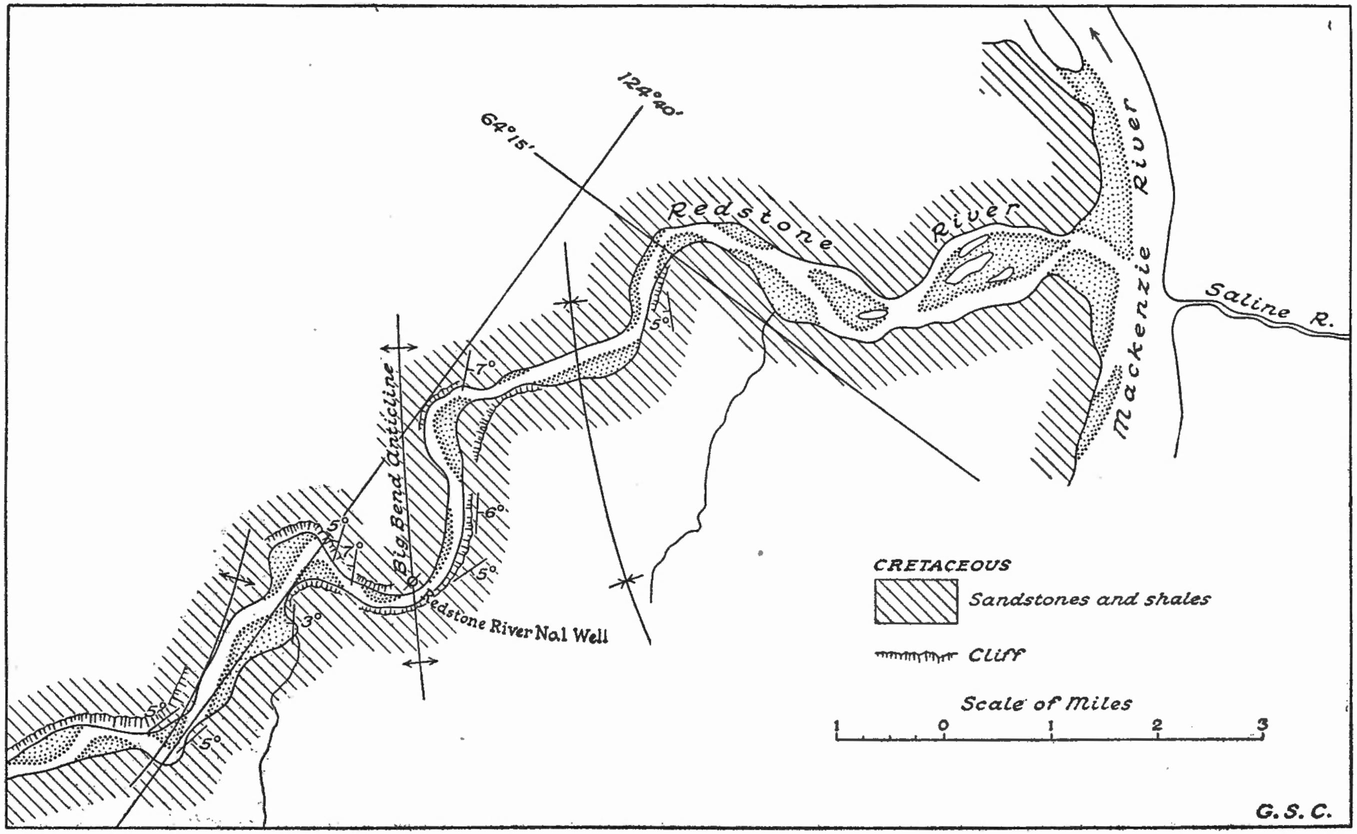


Figure 11. Big Bend anticline, Redstone River area.

suggested from a study of air photographs, although the anticline was not observed on the surface. The width of the Cretaceous basin is such that as no Devonian beds outcrop through it, the dips must be relatively low or folds must occur. Outcrops are relatively scarce, so that folds other than those observed may be present.

West of the Cretaceous basin several folds were observed in Devonian rocks, and some faulting occurs in the area east of the mountain front. The front fold in the Dahadinni area to the south is farther east than the mountain front on Redstone River, and it is thought that one anticline observed on Redstone River is the plunging north end of this Dahadinni fold. This anticline on Redstone River exposes Devonian strata flanked to the east by Cretaceous beds. The dips on the west flank in Devonian rocks are 40 to 60 degrees, and the reversal where it occurs is sharp. The anticline is assumed to open up southward, due to the north plunge, so that it is unlikely that south closure occurs.

West of this anticline there is a wide syncline in upper Devonian beds, and this also is plunging northward. To the west of it there is another anticline with conditions suggesting faulting on the west flank. Still farther west, another anticline shows dips up to 75 degrees on the west flank and gentle dips of 12 degrees or less on the east flank. There is a structural relief of at least 500 feet on this anticline in an east-west direction, but closure to the north and south is unknown. Upper Devonian strata are exposed in this anticline, whereas the front fold of the mountains brings Middle Devonian strata to the surface.

Dahadinni River Area (Bath, 12)

(*See* Figure 12)

Crescent Ridge Anticline. At the mouth and for some distance from it, Dahadinni River Valley is covered by recent deposits that hide all bedrock. The first Cretaceous outcrops that occur are dipping west at 1 degree to 3 degrees. About 10 miles from the mouth, however, Upper Devonian rocks occur from beneath the Cretaceous, and the dip is to the east at about 9 degrees. Thus the structure of the Cretaceous is synclinal, and the Devonian occurs in a fold that, on account of a ridge that it forms, is known as the Crescent Ridge anticline. The trend of the anticline is apparently northwest, but very little information is available on the west flank other than that the Devonian again becomes overlain by Cretaceous and hence a westerly dip is indicated. The information, however, is insufficient to outline the structure, and nothing is known of the plunge either to the north or the south.

Other Structures on Dahadinni River. About 30 miles above the mouth of the river, which in its lower part flows northeast, there is another large fold that has been called the Dahadinni anticlinorium because of its composite nature. On Dahadinni River this fold brings the Bear Rock dolomite to the surface, and the plunge is to the north. A few miles west of the axis of the first fold of the anticlinorium the course of the river is from the south for 30 miles, or roughly parallel with the axial trend of the anticlinorium. In this part of the river other anticlines have been observed, and the trend of these is apparently slightly oblique to the one just described, with a divergence to the northwest.

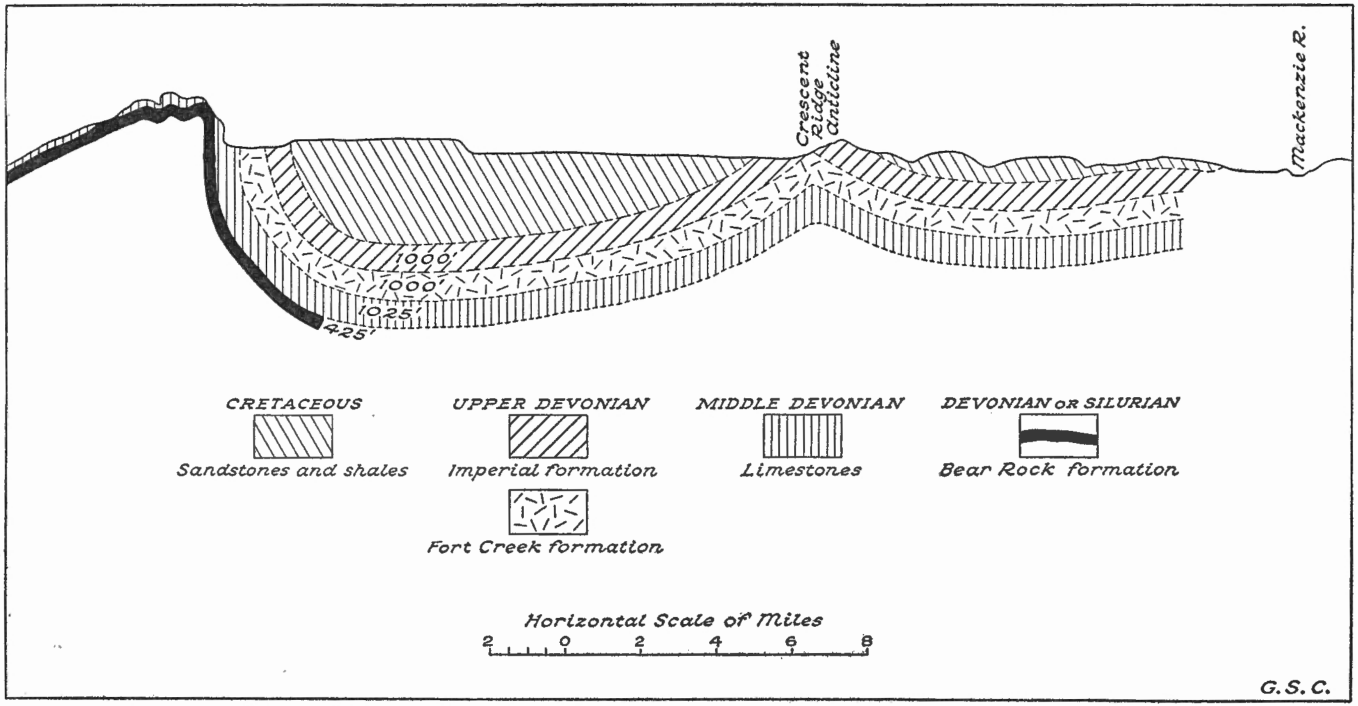


Figure 12. Structure-section along Dahadinni River.

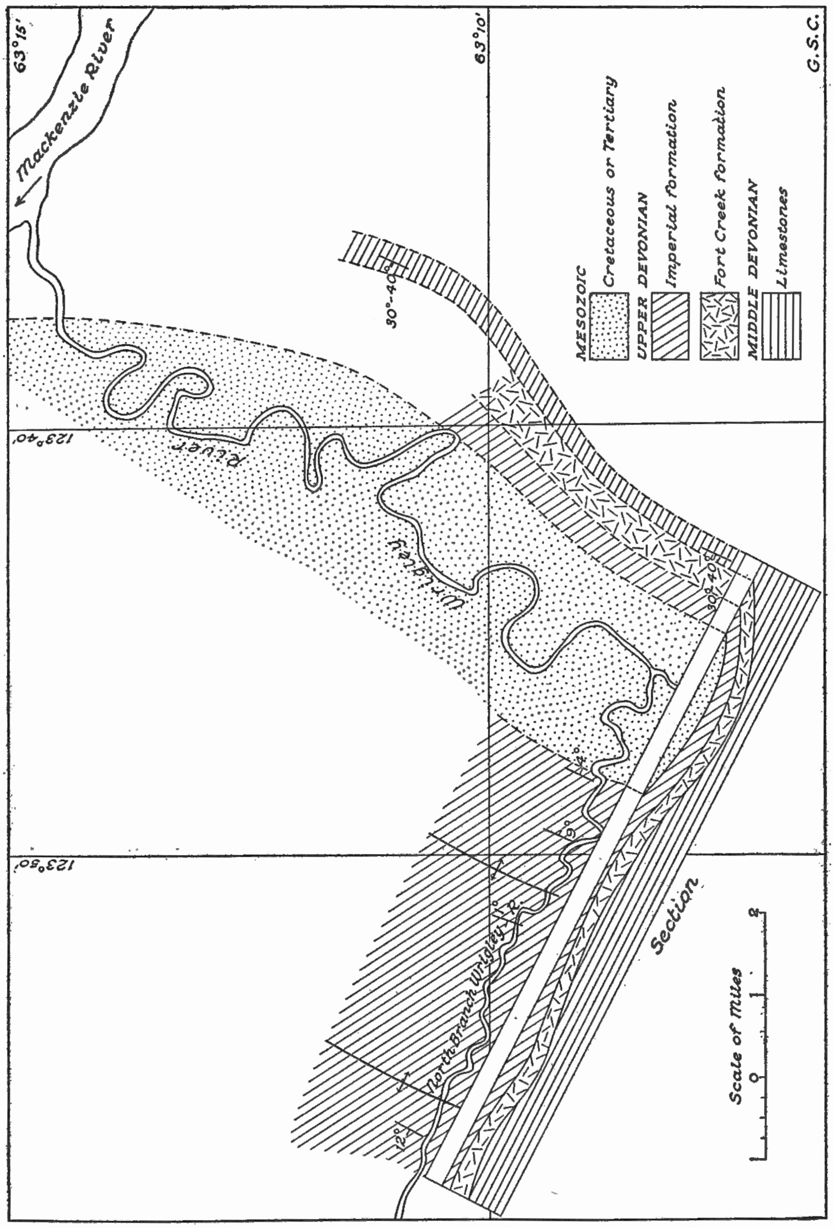


Figure 13. Wrigley River area.

This Dahadinni anticlinorium, as has been indicated, is plunging northward and is apparent only on Redstone River to the north as a small fold. Obviously any oil prospects on the fold on Redstone River would be dependent on closure between Dahadinni and Redstone Rivers, and concerning this there is no available information.

Wrigley River Area (Monnett, 13)

(*See* Figure 13)

Rock-by-the-River's-Side (Plate II B), which rises to a height of about 1,500 feet on the east side of Mackenzie River about 1½ miles below Wrigley (*See* Map No. 1032A), is an anticline in Devonian strata. The anticline itself is somewhat faulted, and, along the trend of the structure to the northeast, the southeast flank is highly tilted in comparison with the northwest side. On the west side of Mackenzie River the ridge of Devonian limestones can be traced southward, with a scarp on the east face and a dip-slope to the west. Wrigley River runs along the foot of the ridge for many miles on the west side, and 4 miles up the north branch, which flows from the west and joins the main stream about 20 miles from its mouth, there is a double-crested anticline in Upper Devonian beds. The trend of this anticline parallels the main ridge to the east, but nothing is known of the character of the anticline except on the cross-section along the river valley. It is probable that very little information could be obtained from the interstream areas, and the only satisfactory method of completely outlining the anticline would be by geophysical means.

Structures South of Wrigley

(*See* Geol. Surv., Canada, Sum. Rept. 1921, pt. B, Map 1957)

It is known that structures occur in the vicinity of Root and North Nahanni Rivers in Upper Devonian strata. Only a very limited amount of information on them has been obtained, and so far as is known, no attempt has ever been made to outline them for the purpose of evaluating their oil prospects.

CHAPTER IV

ECONOMIC GEOLOGY

PETROLEUM SEEPAGES

In many reports on the Mackenzie River area it is stated that Alexander Mackenzie observed oil seepages on his journey from Fort Chipewyan on Lake Athabasca to the Arctic Ocean and back, in the summer of 1789, a trip that was accomplished in 102 days. At only one place, namely, the lower Ramparts, did Mackenzie record a substance that he called "petrolium", and it is extremely unlikely that this has any connection with either oil or oil seepages. Mackenzie's description[1] of the lower Ramparts and the "petrolium" is as follows: "The bank is high, steep and soft rock, variegated with red, green and yellow hues. From the continual dripping of water parts of it frequently fall and break into small, stony flakes like slate, but not so hard. Among them are found pieces of petrolium which bears a resemblance to yellow wax, but is more friable".

The age of these beds may be still somewhat doubtful. Formerly they were assigned by McConnell to the Cretaceous, and as such they appear on Geological Survey maps. Nauss, however, considers them to be non-marine Devonian strata, and they are shown as such on maps with this report. The beds are non-marine and contain many plant fragments. Beds presumed to be of similar age carry fossil resin. This is a yellow substance that is quite friable, and hence is probably what Mackenzie referred to as "petrolium". No oil seepages or oil are known in these non-marine beds in this area.

It is to be presumed that the presence of seepages along Mackenzie River at the mouth of Bosworth Creek and below Bear Rock were known to the Indians and early Hudson's Bay Company traders. McConnell, however, seems to have been one of the first to recognize the importance of seepages and to record their presence, but apparently the only seepages that came under his observation were those on the north shore of Great Slave Lake, although he records (1890, p. 31) that "near Fort Good Hope several tar springs exist, and it is from these that the Hudson's Bay Company now obtain their principal supply of pitch. The springs are situated at some distance from the river, and were not examined". Petitot also records "asphalt in great quantity" in "several of the marshes in the neighbourhood of Good Hope"[2]. McConnell noted "bituminous limestones at Rock-by-the-River's-Side, at Bear Rock, at the Ramparts, and at numerous other places" and states that "in the vicinity of old Fort Good Hope the river is bordered for several miles by evenly bedded dark shales of Devonian age which are completely saturated with oil. The shales have been reddened in many places by the burning of the oil which they contain".

On his map of the lower Mackenzie River, Nauss shows the occurrence of Middle Ramparts shale (Hare Indian River shale of Kindle and Bosworth) almost to Thunder River, below which Mackenzie River swings to the west. At Thunder River the Fort Creek shale is exposed, and, according

[1] Mackenzie, Alexander: Voyage from Montreal on the River St. Lawrence through the Continent of North America to the Frozen and Pacific Oceans in the years 1789 and 1793.

[2] Petitot, Emile: The Great Mackenzie Basin; Reports of the Select Committees of the Senate 1887-1888.

to Nauss, about 45 feet above its base includes 50 feet of "black, platy sulphurous bituminous shale. In places it is burnt red by forest fires. On Outaratou River this member contains a light oil in considerable quantity. Small droplets of oil occur at the outcrop and give it a brown color". It is probable that these are the same strata to which McConnell refers as "completely saturated with oil".

None of the early explorers of Mackenzie River was aware of the oil seepages at the site of the present Norman Wells oil field. The discovery of the seepages was made in 1911 through J. K. Cornwall of the Northern Trading Company, who sent an Indian named Karkesee to search for them because of his knowledge that float containing oil had been found along the river banks in the area below Fort Norman. From observations that had been made, the general area where the oil-stained rocks originated was suspected. The Indian found small pools of oil in the gravel and later guided Mr. Cornwall to the location. A sample of oil collected in a sealer at that time was submitted through the Royal Bank, Edmonton, to the Barber Asphalt Company of Pittsburgh for analysis. The similarity to Pennsylvania oil was noted in the report made by this company.

At the time of the interest in oil in Turner Valley in 1913, J. K. Cornwall, J. H. Woods of the *Calgary Herald,* and Fred Lowes of Lowes and Company, Real Estate, Calgary, acting as a syndicate consulted Dr. T. O. Bosworth, Geologist, who happened to be in Calgary on his way to England from South America where he had been employed by the Shell Oil Company. Dr. Bosworth agreed to return the following summer and to examine and stake the far northern oil prospect. This was done and the arrangements for transportation from Waterways were made by Mr. Cornwall.

Following the staking of the claims, attempts were made to interest oil companies in the discoveries and the property was bought by Imperial Oil Limited during World War I while Colonel Cornwall was overseas. Development by the Northwest Company, a subsidiary of Imperial Oil Limited, followed in 1919 and 1920.

The area staked included the seepages although Bosworth states "it was the remarkable character of the Fort Creek shales and Beavertail limestone rather than the seepages, which led to a favourable view of the prospects of this field". Bosworth pointed out the bituminous character of the Fort Creek shales, and noted the oil in the overlying sandstones of what is now called the Imperial formation. He states that "the principal seepages occur on the shores of the Long Reach where the river flows for seventy-five miles along the outcrop" of the Imperial formation. He also points out that near the mouth of Bosworth Creek "the seepages are conspicuous for a distance of two and a half miles. On digging in the river gravel, the outcrops of the green oil-sands are exposed and the oil could be collected in considerable amount. Further out in the river much oil rises to the surface of the water, and in winter it collects forming pools on the ice".

Link studied these seepages in 1919. He noted that "about one mile upstream along the shore of Mackenzie River, oil is seen to come to the surface of the water in small, black globules, which when reaching the surface, break and spread as thin iridescent films of oil. Gas bubbles are also found rising to the surface of the water in great profusion wherever oil seepages are found". In order to get samples of seepage oil, Link dug four pits, 2 by 3 feet, and lined them with clay. In 3 days 2⅙ gallons of oil were collected from these four pits, or at the rate of 6·3 barrels a year. It is likely that several hundred barrels of oil are escaping in this area in a year, as the number of vents from which oil is escaping is considerable. The seepages are said by Link to occur 1 mile upstream from Bosworth Creek and about 1,500 feet out into Mackenzie River.

In 1920 a second seepage area was found by Link at Seepage Lake, 1½ miles inland from Mackenzie River. This seepage is believed to be coming from the Fort Creek shales from the zone that gave the large flow of oil in Discovery No. 1 well at 783 feet.

There are several oil seepages along the north side of Mackenzie River below Bear Rock (Stelck, 19A). These occur at or near the contact of the Fort Creek and Cretaceous beds and presumably come from the Fort Creek shales. The oil stains the mud and shale dark brown, but free oil is not commonly present. Seepages are present within a half mile downstream from the west side of Bear Rock, and are found for some distance beyond this. Franklin[1] described Bear Rock "composed of limestone and from the cliffs which front the river, a dark bituminous liquid oozes and discolours the rock. There are likewise two streams of sulphureous water that flow from its base into the Mackenzie". McConnell (1890, p. 102) mentions that Franklin saw the seepages, but apparently he, himself, did not observe them.

Gas seepages were also reported by Link 4 miles upstream from Discovery well near the mouth of Joes Creek. These occur in the lower part of the Imperial formation for a distance of about a mile along the river front. Another oil seepage was noted from the Imperial formation upstream from Carcajou Ridge.

SULPHUR SPRINGS

In many places sulphur springs have been found, and sulphur deposits have been observed particularly on the Fort Creek shales. On Bosworth Creek, near the contact of the Fort Creek shales and the underlying Middle Devonian limestones, three sulphur springs were noted by Link. The sulphur deposits are on the rocks adjoining the spring.

In the Vermilion Creek gorge, about 6½ miles from Mackenzie River, several springs issue from the gorge face (Hume, 1923a, pp. 61-2). These springs are also from the Fort Creek shales.

Slightly less than a mile below Bear Rock, sulphur water comes from the upper Middle Devonian limestones. These springs were reported by Franklin, and are seen at low water only. McConnell noted their occurrence, but did not see them.

In many places the Fort Creek shales contain sulphur stains, and other rocks give off a fetid odour when struck by the hammer. These are probably due to the reduction of sulphates by the bituminous materials contained in the rocks. This may be the explanation why sulphur springs and sulphur stains are so widely associated with the highly bituminous Fort Creek shales.

[1] Franklin, Sir John: Narrative of a 2nd Expedition to the Shores of the Polar Sea in the Years 1825, 1826, and 1827, p. 19 (1828).

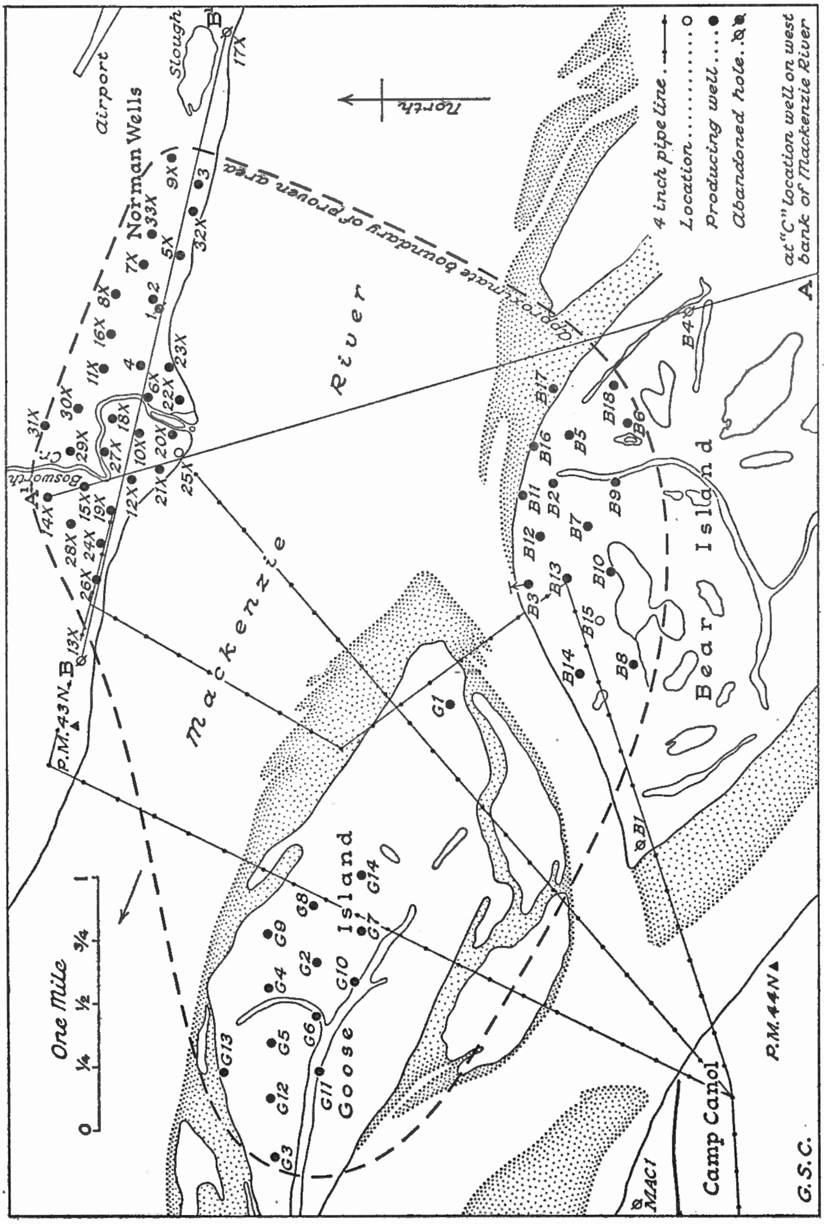


Figure 14. Norman Wells field.

THE NORMAN WELLS FIELD

(*See* Figures 14-16)

DRILLING PRIOR TO CANOL PROJECT

The discovery well in what has now become known as the Norman Wells field was located in 1919 by T. A. Link for the Northwest Company, a subsidiary of Imperial Oil Limited, near the site of the seepages on the delta of Bosworth Creek. Drilling was done in 1920. A star cable-tool rig was used. Bedrock was encountered under frozen glacial materials at a depth of less than 20 feet, and consisted of sandstones and shales of the Imperial formation. At a depth of 83 feet a flow of fresh water was encountered, and below this, in a sandstone, the first show of oil occurred. Other shows of oil were found and oil taken from the well as follows: 112 ft., 132 ft. (15 gals.), 147 ft. (12 gals.), 167 ft. (12 gals.), 183 ft. (8 gals.), 198 ft. (180 gals.), 199 ft. (30 gals.), 202-215 ft. (100 gals.), 212 ft. (80 gals.), 216 ft. (20 gals.), 220 ft. (15 gals.), 225 ft. (12 gals.), 227 ft. (12 gals.), 231 ft. (12 gals.), 235 ft. (12 gals.), 249 ft. (12 gals.), and 255 ft. (gas).

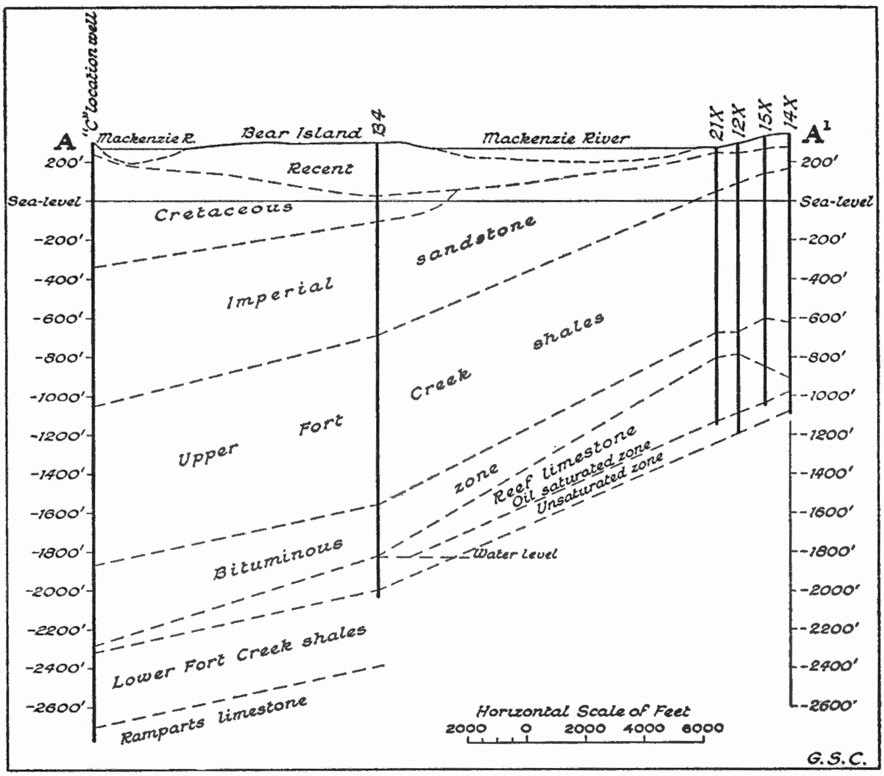


Figure 15. Cross-section A-A¹, Norman Wells field.

The Imperial formation was 255 feet thick, and from the above showings it is apparent that oil was everywhere present in the sands composing it. At 285 feet, in the Fort Creek shales, 40 gallons of oil, and at 317 feet, 150 gallons of oil, were obtained. At greater depths the Fort Creek shales became darker and somewhat harder, and below 400 feet oil again began to appear in the hole as follows: 400 ft. (36 gals. in 36 hrs.), 435 ft. (1 bbl.), 455 ft. (1 bbl. oil and gas), 475 ft. (1 bbl. oil and gas), 530 ft. (more oil and gas), 535 ft. (5 bailers of oil in 36 hrs.), 505 ft. (1 bbl. oil), 575 ft. (½ bbl. oil), 606 ft. (36 gals.), 625 ft. (75 gals.), 669 ft. (55 gals.), 705 ft. (12 bbls. in 36 hrs.), 720 ft. (3 bbls.), 740 ft. (100 gals.), 760 ft. (10 gals.), 783 ft. (well flowed by heads rising 75 feet in the air through 6-inch casing).

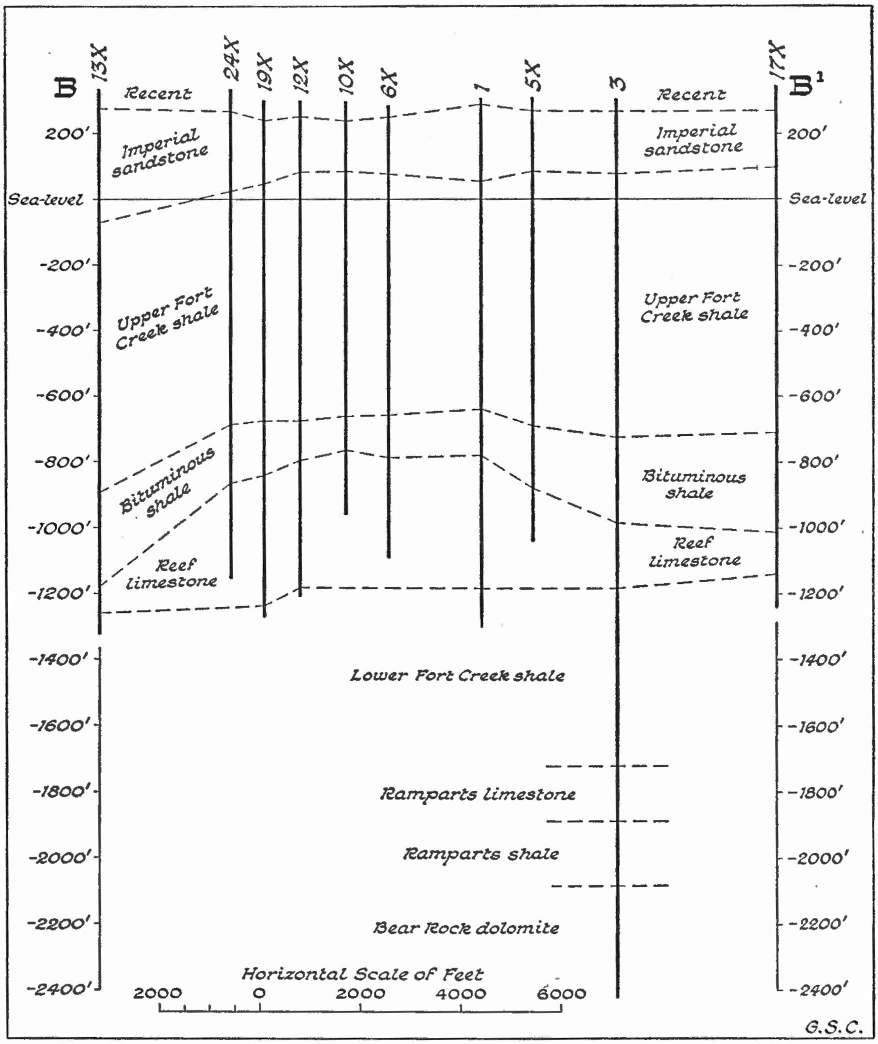


Figure 16. Cross-section B-B¹, Norman Wells field.

Initially the well flowed through the 6-inch casing for 10 or 15 minute intervals, and after it was capped it was capable of flowing whenever it was released. This was surprising in view of the fact that the bottom of the well was in black Fort Creek shales, where only fractured zones were capable of producing the necessary reservoir conditions.

In 1923 this well was deepened to 1,025 feet, and a further flow of oil was found, the former one having largely ceased because of cavings or the exhaustion of the oil at this level. The bottom of the hole, at 1,025 feet, was still in the Fort Creek shales. This well was abandoned in 1944, as it had gone largely to gas and the fractured character of the shales in it were likely to prove a source of dissipation for any gas that was put back into the field by re-pressuring.

In 1921 the Northwest Company drilled Bear Island No. 1 well on the west point of Bear Island. This well obtained shows of oil at 1,948, 1,975, and 2,000 to 2,010 feet, but encountered salt water at 2,060 feet. The well was drilled to 2,304 feet. It was thought formerly that this well reached the top of the Middle Devonian limestones at 1,945 feet, but a re-interpretation of the samples by O. D. Boggs, after considerable information had been derived from the Canol drilling, indicates that they came from the top of the Reef limestones in the Fort Creek shales, and that the well at 2,304 feet was still in this zone. The log of the well, as re-interpreted by Boggs, is as follows: 0 to 80 feet, surface sand; 80 to 660 feet, Cretaceous beds; 660 to 1,140 feet, Imperial formation of sandstones and shales; 1,140 to 1,840 feet, Upper Fort Creek shales; 1,840 to 1,945 feet, bituminous zone of Fort Creek shales; 1,945 to 2,304 feet, Reef limestones. When this well was opened at the time of the Canol activity in 1943, it was found to contain considerable oil. It is now known to be on the southwestern edge of the Norman Wells field.

In 1921 the Fort Norman Oil Company drilled a well to a depth of 1,512 feet about 8 miles up Mackenzie River from the Northwest (Discovery) No. 1 well. Some gas was encountered, but no oil was obtained.

In 1921-22 the Northwest Company drilled "C" location on the southwest side of Mackenzie River opposite the upper end of Bear Island. The first well was abandoned because of mechanical troubles, and a second well, drilled to 3,057 feet, got only slight shows of oil and was abandoned as a dry hole. Neither of these wells nor the Fort Norman Oil Company well can be considered as part of the Norman Wells area, but like Bear Island No. 1 well were drilled in an effort to determine how far the field extended.

The "C" location well samples have been examined and re-interpreted by O. D. Boggs, after considerable information became available from drilling under the Canol project, as follows: 0 to 60 feet, no samples; 60 to 650 feet, Cretaceous beds; 650 to 1,350 feet, Imperial formation of sandstones and shales; 1,350 to 2,160 feet, upper Fort Creek shales; 2,160 to 2,570 feet, bituminous zone of Fort Creek formation; 2,570 to 2,605 feet, Reef limestone beds. The limestone had no oil saturation, and probably represents only the basal beds with no true Reef limestones. No water was encountered; 2,605 to 2,990 feet, lower Fort Creek shales; 2,990 to 3,057 feet, Middle Devonian (Ramparts) limestones. These limestones were not porous, and contained no water.

In 1924-25, the Northwest Company drilled No. 2 well, 150 feet from No. 1 well, to a depth of 1,602 feet. The log, according to Boggs, is as follows: 0 to 30 feet, surface deposits; 30 to 260 feet, Imperial formation, with a show of oil at 122 feet; 260 to 950 feet, Upper Fort Creek shales with gas at 272 and oil at 792 and 895 feet (estimated at 25 barrels a day); 950 to 1,086 feet, Fort Creek bituminous zone with oil and gas at 1,060 feet (flow estimated at 50 barrels a day); 1,086 to 1,490 feet, Reef limestones with oil saturation to 1,310 feet, lower part barren; 1,490 to 1,602 feet, lower Fort Creek shales. In 1944 this well was re-worked. An attempt was made to pull the $8\frac{1}{4}$-inch casing, but this was found impossible; $5\frac{1}{2}$-inch casing was run inside to a depth of 1,329 feet and cemented. The casing was finally gun perforated from 1,115 to 1,140, 1,155 to 1,205, and 1,220 to 1,310 feet. The well was then acidized. Initial production was 140 barrels a day through a $\frac{6}{32}$-inch choke, with a gas-oil ratio of 686 cubic feet to the barrel.

Northwest No. 3 well was drilled in 1939 to 1,830 feet, and was deepened in 1940 to 2,702 feet with no apparent change. It is up river approximately half a mile from Nos. 1 and 2 wells. The log, according to Boggs, is as follows: 0 to 20 feet, surface deposits; 20 to 230 feet, Imperial sandstones, with an oil trace at 140 feet and gas show at 155 feet; 230 to 1,020 feet, upper Fort Creek shales, with gas shows at 448 and 555 feet; 1,020 to 1,280 feet, bituminous zone of Fort Creek formation, with oil show at 1,163 feet; 1,280 to 1,475 feet, Reef limestones with oil saturation to 1,310 feet, and from 1,340 to 1,360 feet; 1,475 to 2,011 feet, Lower Fort Creek shales; 2,011 to 2,180 feet, Middle Devonian (Ramparts) limestones; 2,180 to 2,370 feet, Middle Devonian (Ramparts) shales; 2,370 to 2,702 feet, Bear Rock dolomite. Water at 2,385 feet was said to be about 2 gallons an hour.

Northwest No. 4 well was drilled in 1940, slightly less than a quarter mile down river from Nos. 1 and 2 wells, to a depth of 1,384 feet. The log is as follows: 0 to 30 feet, surface materials; 30 to 250 feet, Imperial sandstones, with slight oil show at 150 feet and a slight gas show at 190 feet; 25 to 940 feet, upper Fort Creek shale, with oil shows at 485, 510, and 710 feet, and gas shows at 270, 285, 335, 385, and 710 (large flow) feet; 940 to 1,090 feet, bituminous zone of the Fort Creek shale; 1,090 to 1,215 feet, Reef limestone with oil and gas flow 1,092 to 1,150 feet.

The above wells were drilled with cable tools, and from the samples, without having any cores, the true character of the reservoir rock was not understood until drilling with rotary rigs commenced under the Canol project in 1942, and cores were taken. It was then recognized that the producing zone was a reef limestone in the Fort Creek shales.

DRILLING UNDER THE CANOL PROJECT

Under the Canol project sixteen wells were drilled in 1942. All of these wells were on the northeast side of the river, and are wells 5X to 23X inclusive, with the exception of 15X. Nos. 13X and 17X wells proved to be outside the limits of the field, but the remaining wells all obtained oil in varying amounts. Because of the fact that the true character of the reservoir rock was not recognized prior to this drilling, many of these wells did not penetrate the full thickness of the porous beds, and in 1943 twelve of them were deepened. These included all of the wells drilled the previous year excepting 5X, 13X, 16X, and 17X. In addition, twelve new wells were drilled in 1943. These included 15X, 19X, 22X, and 24X on the northeast bank of the river; Bear Island Nos. 2, 3, 4, 5, and 8, on Bear Island; and Goose Island Nos. 1, 2, and 3. Bear Island No. 3 well was directional, as shown on Figure 14, and in a depth of 2,394 feet deviated 969 feet horizontally. In addition to these, Mac No. 1 well was drilled to a depth of 3,146 feet on the southwest side of the river. This proved to be a dry hole, as was also Bear Island No. 4 well. In 1944, thirty wells were drilled as follows: 26X to 33X inclusive (25X was not drilled) on the northeast bank of the river, Bear Island Nos. 6 to 18, except Nos. 8 (drilled in 1943) and 15, and Goose Island Nos. 4 to 14 inclusive. Water occurs in some of the wells on the edge of the field on Goose Island, but all wells drilled are capable of producing oil. In 1944, No. 1 Discovery well was abandoned because it was not drilled to the reservoir rock, and was likely to cause leakage from the reservoir when re-pressuring was commenced. It had also largely gone to gas. Also No. 18X well, largely a gas well, was made into a gas intake well. Thus, in the Norman Wells field at the end of 1944 there had been sixty-two wells drilled, and at the end of the year fifty-six of these were oil producers. The dry holes were 13X, 17X, and Bear Island Nos. 1 and 4. Oil was put in the pipeline in December 1943. This pipeline, which goes to Whitehorse across the Mackenzie Mountains, is 598 miles long, of which all but 140 miles of 6-inch pipe on the Whitehorse end is 4 inches in diameter. There are ten pumping stations on the line. The capacity of the line was estimated at 3,000 barrels a day, but it has exceeded that amount.

SURFACE GEOLOGY OF NORMAN WELLS FIELD

Rock outcrops of Imperial sandstone occur on the estuary of Bosworth Creek and along Mackenzie River in the immediate vicinity. All outcrops are relatively small. No outcrops are known on Bear or Goose Islands, and on the southwest side of Mackenzie River Cretaceous beds occur. To the northeast of the Norman Wells field the Norman Range lies at a distance of about 5 miles. Silurian limestones outcrop on the top and east side of this range, and the successive higher formations are found to the southwest. These are the Bear Rock dolomites, the Ramparts shales and limestones, the Fort Creek shales, and Imperial shales. Along Bosworth Creek the dip of the beds on the Imperial formation is 4 to 12 degrees, whereas on the Ramparts formation it is locally higher, but the general dip is about the same. At the mouth of Bosworth Creek the dip is variable both in direction and amount, and although some crumpling seems to be indicated, there is no reversal on the general southwest slope. It is possible, however, the crumpling may have caused some local fracturing of the subsurface beds, allowing oil to escape as seepages over the area previously described.

Cretaceous strata completely cover all older rocks on the southwest side and in the vicinity of Mackenzie River. They dip into a basin in which, in part, Carcajou River flows in a direction only slightly oblique to the Mackenzie for a very considerable distance. Beyond and along Carcajou River the dip is in general to the northeast and the older beds emerge from the basin to form Carcajou Mountains.

Thus the Norman Wells oil field is on a monoclinal structure on the southwest flank of the Discovery Range, and on the northeast limb of the Carcajou basin. In the field itself, as revealed by drilling, the dip is 4 to 5 degrees to the southwest. There is no reversal of dip to the northeast.

SUBSURFACE GEOLOGY OF NORMAN WELLS FIELD (Boggs, 1B)

The youngest strata drilled within the Norman Wells field are Cretaceous beds. Southwest of these, on the west bank of Mackenzie River, in the few exploratory wells drilled to date, still thicker Cretaceous sections occur. The basal part of the Cretaceous within the field, according to Boggs (1B), is a sandstone about 100 feet thick that is easily recognized in the electrologs of the wells. Boggs gives the thickness of the Cretaceous, in wells drilled up to the end of 1944, from 70 feet (Bear Island No. 11 well) to as much as 300 feet (Goose Island No. 3 well). The Cretaceous is overlain by glacial material and recent silts and sands. The depth to it is, consequently, variable, but in most wells it is 100 to 200 feet deep, and in several wells is as much as, or even more than, 300 feet (Bear Island No. 13 well—310 feet).

In Mac No. 1 well, drilled on the southwest bank of Mackenzie River, no samples are available down to 300 feet. Below this the beds are soft, platy, dark grey to black shales to 470 feet. From 470 to 520 feet there is much bentonite, followed by 70 feet, that is, to 590 feet, of light grey sandstones with glauconite. Below this, for 120 feet, to 710 feet, the beds are shales with glauconite, and these in turn are underlain by 100 feet of sandstones and sandy shales, with much glauconite and with small rounded quartz grains near the bottom.

Imperial Formation

As already indicated, sandstones of the Imperial formation outcrop on the northeast bank of Mackenzie River, but are covered by Cretaceous beds to the southwest. The top of the Imperial formation is an erosional unconformity, and hence the formation shows considerable variation in thickness. The base of the Imperial formation is gradational from sandstones into the shales of the Fort Creek formation, and hence the formation boundary is drawn arbitrarily. It may be that the upper sandy beds of the upper Fort Creek formation should be included with the beds of the Imperial formation, as the division between them and the underlying bituminous shales is reasonably sharp. However, until further information becomes available, the base of the Imperial formation has been placed at the beginning of the predominantly sandy beds into which the shales grade upward. In several of the wells Boggs noted that the lower 400 feet of the Imperial formation is largely sandstone, whereas the higher beds are much more shaly.

The wells on the northeast bank of Mackenzie River that commenced in the Imperial formation show a thickness for these beds of approximately 150 to 225 feet. No. 13X well, which was drilled outside the field at the northwest or down river end, showed a thickness of 320 feet. On Goose and Bear Islands, where the Imperial formation is overlain by Cretaceous beds, Boggs shows the thickness to be 425 to 570 feet, whereas at Mac No. 1 well, on the southwest bank of the river, it is 520 feet, and in the "C" location well it is 700 feet thick. This thickness is relatively small in comparison with that on Imperial River from which the section has been described in this report.

Fort Creek Formation

In the Norman Wells field Boggs (1B) has divided this formation into four members as follows:

(1) Upper non-bituminous member.

(2) Bituminous shale member.

(3) Reef limestone member, divisible into two parts: (a) the producing zone of true Reef limestones; and (b) a lower, bedded limestone on which the reef has been built.

(4) Lower shale member.

Upper Non-bituminous Member. This member contains some sandstone toward the top, and there appears to be a gradation into the heavier sandstones of the overlying Imperial formation. For this reason these non-bituminous beds may belong with the Imperial rather than with the Fort Creek formation. However, *Spirifer disjunctus* is thought to belong exclusively in the Imperial formation, and so far as known, it is not in these non-bituminous shales. In fact, its occurrence with the sandy beds has been used as an aid in dividing the two formations. For the present, therefore, it seems preferable to leave this non-bituminous member as the upper part of the Fort Creek formation. Where the Reef limestone is missing the non-bituminous member is as much as 840 feet thick (Bear Island No. 4 well), and as little as 660 feet thick (No. 20X well) where the limestone is fully developed (Boggs, 1B).

Bituminous Member. This member is noticeably darker than the overlying non-bituminous beds, and in the electrologs of the wells there is an abrupt and large increase in the impedance curve. According to Boggs, these beds are almost coal-black where this member is thick, and are hard, with an abundance of pyrite. They overlap the reef and hence vary in thickness within the Norman Wells field from 100 feet, where the reef is fully developed, to as much as 300 to 400 feet, where only the basal limestones of the reef are present. This is illustrated by the following table (Boggs, 1B) for wells drilled to the end of 1943:

	Number of wells	*Average thickness of bituminous member* Feet
Reef limestones more than 400 feet thick........	17	118
Reef limestones from 200 to 400 feet thick.......	10	197
Reef limestones less than 200 feet thick..........	7	294

At "C" location, based on samples only, Boggs gives the thickness of the bituminous member as 410 feet.

The variation in the combined thickness of the Reef limestones and the bituminous member is given by Boggs for wells drilled to the end of 1943 as follows:

	Number of wells	*Combined thickness of Reef limestones and bituminous member* Feet
Reef limestones more than 400 feet thick.........	7	567
Reef limestones 200 to 400 feet thick............	5	529
Reef limestones less than 200 feet thick..........	7	426

In a few of the above wells, where the complete thickness was not drilled, Boggs made an estimate. He notes that the combined thickness of the Reef limestones and bituminous member is about 140 feet greater where the reef is fully developed than it is where the true reef condition has disappeared. The thinning occurs outward from the true reef and is, to a large extent, compensated by a thickening of the upper non-bituminous member as previously described. That such is the case is shown by Boggs in the following table:

	Number of wells	*Combined thickness Reef limestones, bituminous member, and non-bituminous member* Feet
Reef limestones more than 400 feet thick.............	7	1,267
Reefs limestones 200 to 400 feet thick...........	5	1,264
Reef limestones less than 200 feet thick..........	7	1,232

This table also suggests that the net compaction effect of the shales above the Reef limestones may be some such figure as 30 feet, although, as Boggs states, the number of wells is too few to draw any certain conclusion.

Reef Limestones. When the early wells were being drilled it was thought that these limestones were Middle Devonian, but later drilling revealed that they were coralline limestones within the Fort Creek formation, and, consequently, of Upper Devonian age. The shape and thickness of the reef can be seen from cross-section, shown in Figures 15 and 16. As already stated, the reef can be divided into an oil saturated, true reef, the upper part resting on a bedded limestone 70 to 160 feet thick. This lower part is generally impermeable, but in a few wells, possibly due to fracturing, it has some saturation. On Bosworth Creek, where the Fort Creek shales outcrop southwest of the Norman Range, the lower bedded limestone is thought to be represented by only 12 feet of limestone strata. On Canyon Creek it was not recognized. This lower limestone, however, is believed to have a fairly wide distribution in the vicinity of the Norman Wells field, and Stelck suggested that one of the limestone members in the Bluefish well may be the equivalent of the basal Reef limestone of this field. It is apparently the foundation on which the true reef was built. Some wells, as 13X and 17X, outside the limits of the producing area on the northeast bank of Mackenzie River, found only the lower bedded limestone and hence obtained no production. In Goose Island No. 3 well, Boggs reports a definite division between the true reef and the underlying limestones. In this well a core was taken about 85 feet above the base of the lower limestone, and showed conglomeratic Reef limestone grading into 2 or 3 feet of shale that overlies the bedded limestones. At "C" location on the west bank of the river, the true reef was missing, and only 35 feet of basal limestones were present.

According to Boggs, the true reef part of the limestone varies in thickness from 0 to 350 feet in the Norman Wells field, and may be as much as 400 feet thick on the south bank where it contains water. It is composed of heterogeneous materials, such as corals, bryozoans, and stromatoporoids, and where cores have been obtained they show an abundance of fossil remains in a groundmass of coral sand. In Goose Island No. 2 well the reef was composed of fairly soft and coarse coral sand with few fossil remains. Lower in the section there was an abundance of fossil fragments. In Goose Island No. 3 well this non-fossiliferous coral sand was missing, and in Mac No. 1 well, drilled on the southwest bank of the river, a coral sand 100 feet thick was encountered, but was hard and evidently of low permeability. Boggs thinks that the character of the reef changes within short distances, and illustrates this by reference to No. 4 well, which found only traces of oil in the uppermost 50 feet of the reef, whereas No. 6X well, drilled only 600 feet distant, flowed strongly as soon as the top of the reef was touched by the drill. Boggs also points out that the true reef is generally oil-bearing where it is structurally favourable, but within it there may be barren zones and also considerable variation in degree of the saturation. Porosity determinations made from the more porous parts of the reef show 8·7 to 23·6 per cent, with an average of 17 per cent (eight samples).

The wells drilled to the end of 1943 are listed by Boggs as follows:

Well	Depth to top of limestone	Over-all thickness of Reef limestone	Amount of limestone penetrated	Notes
	Feet	Feet	Feet	
Discovery—				
No. 1	....	....	....	Limestone not reached.
2	1,086	224	404	
3	1,280	80	195	Not saturated 50 feet.
4	1,092	236	(292)[1]	
5X	1,175	115	(155)	
6X	1,065	232+	(301)	
7X	1,207	93	260	
8X	1,208	112	(258)	Best saturation to 52 feet.
9X	1,265	45	158	Net saturation 20 feet.
10X	1,050	320	(375)	Best saturation to 260 feet.
11X	1,170	230	(271)	
12X	1,088	302	(408)	
13X	1,505	0	75	
14X	1,250	60	170	
15X	1,186	179	(203)	
16X	1,208	82	(105)	
17X	1,340	0	125	
18X	1,120	240	365	Slight saturation to 310 feet.
19X	1,135	285	395	Best saturation to 225 feet.
20X	1,076	332	(343)	
21X	1,074	336	(351)	
22X	1,083	372	(383)	Best saturation to 302 feet.
23X	1,040	370	386	Best saturation to 330 feet.
24X	1,190	250	(284)	
26X	1,285	160	(235)	
27X	1,133	232	(241)	
28X	1,230	130	(150)	
29X	1,194	136	(161)	
30X	1,185	125	(155)	
31X	1,215	95	165	Basal limestone 70 feet thick.
32X	1,232	58	(138)	
33X	1,245	55	(115)	
Bear Island—				
No. 1	1,945	75	(359)	Net saturation 15 feet.
2	1,706	244	(329)	
3	1,669	334	(422)	Vertical measurements; best saturation 290 feet.
4	2,110	0	170	
5	1,725	305	(331)	Best saturation 300 feet.
6	1,893	87	(202)	
7	1,775	215	(354)	
8	1,890	135	(275)	Net saturation 115 feet.
9	1,821	154	(152)	
10	1,817	163	(183)	
11	1,640	340	495	Basal limestone 155 feet thick.
12	1,700	260	(267)	
13	1,764	226	(236)	
14	1,747	223	(228)	Best saturation 193 feet.
15	....	....	....	Not drilled.
16	1,648	257	(327)	
17	1,739	181	(227)	
18	1,879	61	(121)	
Goose Island—				
No. 1	1,663	312	(312)	Net saturation 182 feet.
2	1,592	388	(432)	
3	1,785	195	381	Net saturation 145 feet.
4	1,641	254	414	Basal limestone 160 feet thick.
5	1,686	289	(296)	
6	1,665	265	(301)	
7	1,666	294	(334)	
8	1,560	320	(369)	
9	1,555	335	(385)	
10	1,668	(262)	(262)	
11	1,755	(170)	(170)	
12	1,767	(168)	(168)	
13	1,783	165	(167)	Best saturation 66 feet.
14	1,610	290	(320)	
Mac No. 1	2,097	3	492	
"C" location	2,570	0	35	

[1] (292) Figures in parentheses indicate depth of penetration when not completely drilled.

From the above it is seen that the maximum reef thickness of 388 feet was found in Goose Island No. 2 well, although several other wells had a thickness of more than 300 feet. In Goose Island No. 2 well the upper 50 feet was coral sand with few fossils. In Mac No. 1 well, coring showed the upper 100 feet was coral sand, but only the upper 3 feet had any oil saturation. In this well the total thickness of the reef, including the lower bedded limestone, was drilled, and the thickness was approximately the same as in Bear Island No. 11 well, namely 490 to 495 feet, whereas on the northeast bank of Mackenzie River the maximum thickness exceeds 400 feet, and, according to Boggs, may be about 450 feet.

Lower Shale Member. The lower shale member of the Fort Creek formation has been reached in a number of wells in the Norman Wells field, but has been penetrated by only three in and on the edge of the field, as follows:

Well	Depth to top of lower shale member	Thickness of lower shale member
	Feet	Feet
Discovery No. 3 well	1,475	536
Mac No. 1 well	2,589	541
"C" location	2,605	385

Outside the vicinity of the Norman Wells field several wells have drilled the complete Upper Devonian section. The thickness of the lower shale member of the Fort Creek in three of these is given by Boggs as follows:

	Feet
Bluefish No. 1A well	475
Hoosier Ridge No. 1 well	556
Hoosier Ridge No. 2 well	780

In the Hoosier Ridge No. 2, however, the shales may have been deformed, and hence the drilling thickness may considerably exceed the stratigraphic thickness.

Coral reefs have been reported by various Canol geologists from different areas. The tendency has been to refer to these as the Kee Scarp member, which is correlated with the producing reef of the Norman Wells field. It is unlikely that these all occur at the same stratigraphic horizon. At Beavertail Point, for example, the beds formerly assigned to the Beavertail formation, that is, Middle Devonian age, are composed mainly of coralline material, and although the age of this may be questionable, it is very doubtful if it is equivalent to the Reef limestone of the Norman Wells field. The drilling of the Sans Sault well on the west bank of Mackenzie River might have been expected to solve this problem, as this well commenced in Cretaceous strata. Unfortunately, the well passed into Fort Creek shale under the Cretaceous without drilling either the equivalent of the Kee Scarp reef or higher beds. If it is assumed that the part of the Fort Creek beds drilled belong to the lower member, then the reefs at Beavertail Point and on East Mountain may not be equivalents of the Kee Scarp member, although they resemble it in character.

Ramparts Limestones

In the Norman Wells area the Ramparts formation was reached in only three wells, namely, Discovery No. 3, Mac No. 1, and "C" location, and of these only Discovery No. 3 well completely penetrated these beds. This well showed the Ramparts formation to be 359 feet thick, of which 169 feet is Upper Ramparts limestone. In the Bluefish and Hoosier Ridge Nos. 1 and 2 wells the Ramparts formation was 295, 270, and 260 feet thick, respectively.

Bear Rock Formation

Only one well in the Norman Wells field, namely Discovery No. 3, reached the Bear Rock formation. The top was reached at a depth of 2,385 feet. Water was encountered 15 feet within this formation. As the well is on the monoclinal slope into Carcajou basin, and as highly porous dolomites outcrop up-dip from the well on the southeast flank of the Norman Range, the presence of water serves only to emphasize the porosity of these beds.

SIZE AND PRODUCTION OF NORMAN WELLS FIELD

The Norman Wells field has now been outlined by drilling, and is calculated to contain approximately 4,325 acres, of which 370 are on the northeast bank of Mackenzie River, 462 on Bear Island, 1,473 on Goose Island, and 2,020 under the water of Mackenzie River. By directional drilling a part of this under-river area will be reached, but it will be impracticable to drill from piers built in the river because of the severity of the ice shove during spring break-up. Link has estimated an inaccessible area of 1,180 acres beneath Mackenzie River.

It is difficult to give an accurate figure for the potential production of the wells drilled, as this is greatly altered by the amount of acidization. Boggs estimated a potential of 215 barrels a day for the wells drilled in 1942. As reported by Stewart (1944), one of the best wells, on being allowed to flow wide open, produced 1,000 barrels in 23 hours, whereas another well flowed 875 barrels in 19 hours after acid treatment. Some of the wells, however, previous to acidization, were capable of less than 50 barrels a day. The porosity and the thickness of the oil-saturated zone within the producing area also show considerable variation. In making calculations of reserves Boggs uses an average porosity of 17 per cent for the saturated zone. There is, however, considerable connate water. Various estimates of the reserves in the Norman Wells field have been made. Boggs, at the end of 1943, calculated the recoverable oil might be about 57,000,000 barrels, a figure that approximately corresponds with Stewart's estimate of 60,000,000 barrels. Link, however, gives a much more conservative estimate, based on the same data, of 30,000,000 barrels. Later, W. D. C. Mackenzie, Petroleum Engineer for Imperial Oil Limited on the Canol project, estimated the recoverable oil reserve at 36,250,000 barrels from a drainable area of 2,600 acres. This, according to Stewart (1948), includes 460 acres beneath Mackenzie River that can be drained by directional drilling, and gives an average of nearly 14,000 barrels an acre. It leaves 1,410 acres of potentially proven territory beneath Mackenzie River that are considered at present not economically drainable.

The reservoir pressures have been given by Stewart, and are considerably above hydrostatic pressures. Bottom hole pressures in wells shut in for a considerable time are given for various wells as follows: depth 1,330 ft.—693 lbs.; 1,340 ft.—675 lbs.; 1,399 ft.—720 lbs.; 1,705 ft.—833 lbs.; 1,840 ft.—895 lbs.

CHARACTER OF NORMAN WELLS OIL

(Stewart, 1944, pages 152-171)

Specific gravity at 60°F	0·833
Degrees A.P.I.	38·4
Pour point below	60°F.
Viscosity seconds	
Saybolt Universal at 70°F	41·6
" " 15°F	88·0
" " 0°F	142·0
" " −15°F	239·0
" " −30°F	525·0

Sulphur by weight 0·55 per cent
Water and sediment by volume, per cent—trace
Base of crude—intermediate (wax bearing)

Previous to the Canol project there was a small refinery at Norman Wells, capable of supplying local needs. The capacity of this refinery was about 850 barrels a day, but it was operated only for a few months in the summer, and alkalate was taken to the refinery from other sources to provide 87 octane gasoline for aeroplane use. In 1943, when the need for products increased, certain improvements in the refinery brought the capacity up to 1,100 barrels and, according to Stewart, the amount of products obtained from the oil are as follows:

(a) When the refinery is making aviation base stock:

	Per cent
Aviation base gasoline	18½
Heavy naphtha	14
Light diesel fuel	27½
Reduced crude	36½
Loss	3½

(b) When the refinery is making motor gasoline:

Motor gasoline	30
Light diesel fuel	31
Reduced crude	37
Loss	2

A heavy diesel fuel is made by blending reduced crude, heavy naphtha, and crude oil. The products made are such as to meet the requirements of local needs in the Northwest Territories, where there is considerable mining activity on Great Bear and Great Slave Lakes.

PRODUCTION OF NORMAN WELLS FIELD

When the Canol contract was terminated, sixty-four productive wells had been drilled in the field, four of them before the time of the Canol project. The production of the Norman Wells field is as follows:

Year	Production	Cumulative production
	Barrels	Barrels
Prior to 1942	118,895	118,895
1942	82,324	201,219
1943	266,882	468,101
1944	1,229,310	1,697,411
Jan. 1 to Mar. 8, 1945	279,931	1,977,342

The Canol agreement terminated on March 8, 1945. The large production in 1944 was due to the operation of the Canol pipeline and to the completion of the Whitehorse refinery, which began operating April 30, 1944.

Year	Production	Cumulative production
	Barrels	Barrels
Mar. 8 to end of 1945	65,240	2,042,582
1946	177,282	2,219,864
1947	227,474	2,447,338
1948	350,541	2,797,879
1949	155,528	2,953,407
1950	186,729	3,140,136
1951	227,449	3,367,585
1952 (est.)	301,000	3,668,585

Total to end of 1952 is, thus, 3,668,585 barrels.

EXPLORATORY WELLS AND PROSPECTS

The wells that have been drilled outside the Norman Wells field are as follows:

Well	No.	Year drilled	Depth Feet	Notes
Fort Norman	No. 1	1921	1,512	
Camp "C"	No. 1	1922	1,704	On approximately same location
Camp "C"	No. 2	1922	3,057	
Bluefish	No. 1	1922	495	On approximately same location
Bluefish	No. 1A	1943	3,536	
Mac	No. 1	1943	3,146	
Mac	No. 2	1944	2,958	
Hoosier	No. 1	1943	2,656	
Hoosier	No. 2	1943	2,718	
Morrow Creek	No. 1	1944	2,024	
Ray	No. 1	1944	3,817	
Canyon	No. 1	1945	2,066	
Canyon	No. 2	1945	803	
Judile	No. 1	1945	2,815	
Loon Creek	No. 1	1945	5,452	
Loon Creek	No. 2	1945	5,093	
Loonex	No. 1	1945	4,564	
Raider Island	No. 1	1945	2,190	
Sans Sault	No. 1	1945	3,291	
Seepage Lake	No. 1	1945	268	On approximately same location
Seepage Lake	No. 1A	1945	1,636	
Vermilion Ridge	No. 1	1945	5,972	
Redstone	No. 1	1946	4,874	
Whirlpool	No. 1	1946	6,417	

These wells thus tested twenty-one locations in various parts of the Mackenzie River area, all without success.

REDSTONE AREA

(*See* Figure 11)

Redstone River enters the Mackenzie from the west about 125 miles upstream from the Norman Wells field. Its mouth is some 12 miles south of Keele River, which is one of the larger tributaries. About 7 miles above the mouth there is a pronounced anticline in Cretaceous strata, with dips of 3 to 7 degrees on each flank as shown on Figure 11. This was regarded as a very promising structure, and Redstone River No. 1 well was located to test the prospects.

Redstone No. 1 Well. The log of this well is as follows:

Age	Formation	Lithology	Depth in feet
Recent		Sands and gravels	0–35
Cretaceous		Shale and sandstone	35–565
Devonian	Imperial	Sandstone and shale	565–1,705
"	Fort Creek	Dark shales	1,705–2,675
"	Ramparts	Mainly limestone	2,675–3,508
Devonian or Silurian	Bear Rock	Dolomitic limestone	3,508–4,160
Silurian	Mount Kindle.	Limestone and anhydrite	4,160–4,874

No oil or gas was found, and the well was abandoned.

BLUEFISH AREA

(*See* Figure 2)

In 1921-22 a hole was drilled to a depth of 495 feet at the mouth of Bluefish Creek. This is only a short distance below Bear Rock and in an area where there are seepages. The well was abandoned because of mechanical difficulties, and a new well to a depth of 3,539 feet was drilled under the Canol project at approximately the same location.

The log of Bluefish No. 1A well was as follows (Stelck, 19A; Stewart 1945, p. 10):

Age	Formation	Lithology	Depth in feet
Recent		Sands and silts	0–30
Tertiary		Unconsolidated gravel, sands, etc.	30–360
Cretaceous		Shales and sandstone	360–1,150
Upper Devonian	Fort Creek	Upper shale member	1,150–1,620
	"	Jungle ridge limestone	1,620–1,780
	"	Silty shale	1,780–1,907
	"	Limestone (Kee Scarp member)	1,907–1,913
	"	Shale (with *Buchiola*)	1,913–2,010
	"	Limestone	2,010–2,060
	"	Lower shale member	2,060–2,535
	Ramparts	Beavertail limestone	2,535–2,650
	"	Hare Indian River shales	2,650–2,910
Devonian or	Bear Rock	Dolomitic limestone	2,910–3,320
Silurian	"	Anhydrite	3,320–3,340
Silurian	Ronning	Dolomitic limestone	3,340–3,539

As pointed out by Stewart, the Fort Creek formation contained no bituminous shale member at this location, and no reef limestone was encountered. The limestone above the lower shale member is that on which the reef was built in the Norman Wells field. Obviously the Beavertail limestone member was porous, as circulation was lost while drilling at a depth of 2,538 feet. The Bear Rock dolomite was also porous, as water was encountered at a depth of 2,927 feet. Shows of oil were seen in shales at depths of 2,480 and 2,910 feet, but these were not significant. The test, therefore, would seem to be fairly conclusive that no production is to be expected in this area.

AREA ADJOINING NORMAN WELLS FIELD

Fort Norman No. 1 Well (*See* Map No. 1032A). This well was drilled in 1921 about 8 miles up Mackenzie River from the Norman Wells field. It reached a depth of 1,512 feet, and although it encountered some gas it discovered no oil.

"C" Location Well. In 1921-22 the Northwest Company drilled "C" location on the southwest side of Mackenzie River opposite the upper end of Bear Island. The first well was abandoned because of mechanical difficulties, and a second well, drilled to a depth of 3,057 feet, obtained only slight shows of oil and was abandoned. The log of this well was re-interpreted by O. D. Boggs, after considerable information became available from the Canol drilling, and is as follows:

Age	Formation	Lithology	Depth in feet
Recent			60–650
Cretaceous		Sandstone and shales	650–1,350
Devonian	Imperial	" "	1,350–2,160
"	Fort Creek	Upper shale member	2,160–2,570
"	"	Bituminous shale member	2,570–2,605
"	"	Lower shale member	2,605–2,990
"	Ramparts	Limestone	2,990–3,057

The Middle Devonian Ramparts limestone was not porous.

Seepage Lake Wells. About a mile northeast of No. 1 well in the Norman Wells field there is an oil seepage on the edge of a small lake. The Reef limestone was known to extend in this direction, for it occurs as a thin band in outcrops on Bosworth Creek. Thus, there seemed to be justification for the assumption that reef conditions might be found by drilling. The first well, Seepage Lake No. 1, encountered mechanical difficulties at 268 feet and was abandoned. A second well, Seepage Lake No. 1A, was drilled 15 feet from the first location. The log was as follows:

Seepage Lake No. 1A Well
(Elevation[1], 354 feet)
(*See* Map No. 1032A)

Age	Formation	Lithology	Thickness in feet
Recent		Sands, silts	0–60
Devonian	Fort Creek	Upper shale member	60–643
"	"	Bituminous shale member	643–989
"	"	Reef limestone member	989–1,035
"	"	Lower shale	1,035–1,545
"	Ramparts	Beavertail limestone	1,545–1,636

The well encountered no oil or gas, and was abandoned.

[1] The elevations for wells are calculated from the elevation of the casing head of No. 1 or Discovery well in the Norman Wells field, which was assumed at 300 feet.

Mac No. 1 Well (Elevation, 297 feet). In 1943, the Mac No. 1 well, located on the south bank of Mackenzie River about ½ mile down stream from the landing dock, was drilled on the basis of seismic surveys. The log (Stewart, 1945, p. 12) was as follows:

Age	Formation	Lithology	Depth in feet
Recent		Sands and clays	0–810
Cretaceous		Shales	
Devonian	Imperial	Sandstone and shale	810–1,330
“	Fort Creek	Upper shale member	1,330–2,000
“	“	Bituminous shale member	2,000–2,097
“	“	Reef limestone member	2,097–2,589
“	“	Lower shale member	2,589–3,130
“	Ramparts	Beavertail limestone	3,130–3,146

The Reef limestone was much thicker than had been anticipated, and although slight oil saturation occurred in that part of the reef between 2,097 and 2,102 feet, no production was secured.

Mac No. 2 Well (Elevation, 435 feet). In 1944, this well was drilled a mile southwest of the Mac No. 1 as the result also of seismic surveys. The reef was interpreted as extending farther down dip to the southwest than elsewhere, and this test and Ray No. 1 well were drilled to determine the possibilities of stratigraphic traps within the reef due to variations in porosity. The log of Mac No. 2 well was as follows:

Age	Formation	Lithology	Depth in feet
Recent		Surface sands and silts	0–100
Cretaceous		Shales	100–1,140
Devonian	Imperial	Sandstone and shale	1,140–1,680
“	Fort Creek	Upper shale member	1,680–2,360
“	“	Bituminous shale member	2,360–2,453
“	“	Reef limestone member	2,453–2,935
“	“	Lower shale member	2,935–2,958

The reef had low permeability, and contained neither oil nor water.

Ray No. 1 Well (Elevation, 576·5 feet). This well was drilled in 1944 at a location about 4 miles west of the Mac No. 2 well. The location was based on seismic survey data as no outcrops occur in the immediate vicinity. A thick section of reef limestone was anticipated, and it was hoped to find changes of porosity that would provide a stratigraphic trap for oil accumulation.

The log of the well was as follows:

Age	Formation	Lithology	Depth in feet
Recent		Sands and silts	0–1,900
Cretaceous		Shales	
Devonian	Imperial	Sandstone and shale	1,900–2,520
“	Fort Creek	Upper shale member	2,520–3,176
“	“	Bituminous shale member	3,176–3,266
“	“	Reef limestone member	3,266–3,728
“	“	Lower shale member	3,728–3,817

The Reef limestone proved to be less thick than expected, and no evidence of either oil or water was obtained.

Loon Creek Anticline

Loon Creek enters Mackenzie River opposite Bear Island. About 4 miles south of the mouth a small anticline is exposed in Cretaceous strata where, for a short distance, the regional south dip is interrupted by north dips of 4 to 10 degrees. The anticlinal structure was verified by seismic surveys and appeared to afford favourable conditions for possible oil accumulation. The anticline was determined to have a length of about 15 miles with a westward plunge, and closure to the east was indicated.

Three wells, namely, Loon Creek Nos. 1 and 2 and Loonex No. 1, were drilled on this structure, but none encountered any oil or gas. The logs were as follows:

Loon Creek No. 1 Well (Elevation, 512 feet). This well was located on the west bank of Loon Creek about 4 miles south of its junction with Mackenzie River. The log was as follows:

Age	Formation	Lithology	Depth in feet
Recent		Silts and clays }	0–485
Cretaceous		Shales and sandstones: }	
Devonian	Imperial	Sandstone and shale	485–1,095
"	Fort Creek	Upper shale member	1,095–2,215
"	"	Bituminous shale member	2,215–2,612
"	"	Limestone-shale member	2,612–2,636
"	"	Lower shale member	2,636–3,205
"	Ramparts	Limestone and shale	3,205–3,545
Devonian or Silurian	Bear Rock	Dolomitic limestone and anhydrite	3,545–3,970
Silurian	Ronning	Dolomitic limestone	3,970–5,452

No oil, gas, or water was encountered in the well.

Loon Creek No. 2 Well (Elevation, 493 feet). This well was located on the northeast end of the anticline about 15 miles from Loon Creek No. 1 well. The log was as follows:

Age	Formation	Lithology	Depth in feet
Cretaceous		Sands, silts	0–150
Devonian	Imperial	Sandstone and sandy shale	150–440
"	Fort Creek	Upper shale member	440–1,100
"	"	Canyon member—shale and sand	1,100–1,210
"	"	Lower shale and sand	1,210–1,805
"	Ramparts	Beavertail limestone member	1,805–1,940
"	"	Shale and interbedded limestone	1,940–2,275
Devonian or Silurian	Bear Rock	Brecciated and bedded dolomitic limestone; much anhydrite near base	2,275–2,615
Silurian	Ronning	Dolomitic limestone, hard, dense, and cherty; streaks of anhydrite near the top; some shale beds near base	2,615–4,610
Cambrian	Macdougal	Red and green shales becoming silty, with gypsum streaks near the base	4,610–4,775
"	"	Silt series—rock salt with brown and green shales and siltstones	4,775–5,093

In this well the Beavertail limestone member was 1,386 feet higher structurally than at No. 1 well. No oil or gas was encountered, and the well was abandoned.

Loonex No. 1 Well (Elevation, 567 feet). This well was located on the plunging southwest nose of the Loon Creek anticline about 6 miles from Loon Creek No. 1 well.

The log of the well was as follows:

Age	Formation	Lithology	Depth in feet
Recent		Silt and clay	0–1,325
Cretaceous		Shale and sandstone	
Devonian	Imperial	Sandstone and shale	1,325–2,230
"	Fort Creek	Upper shale member	2,230–3,080
"	"	Bituminous shale member	3,080–3,580
"	"	Lower shale member	3,580–3,990
"	Ramparts	Limestone and shale	3,990–4,377
Devonian or Silurian	Bear Rock	Dolomitic limestone	4,377–4,564

In this well the top of the Beavertail limestone member of the Ramparts formation lay at a depth of 3,990 feet, whereas in Loon Creek No. 1 well it was encountered at a depth of 3,205 feet, thereby indicating an apparent structural difference of 730 feet, when the difference of 55 feet in surface elevation is allowed for. This difference was, however, in part due to the fact that in this well the Reef limestone was missing and the whole of the Fort Creek formation was 350 feet less thick than in the Loon Creek No. 1 well; the remainder of the difference is presumed to be structural.

This well, drilled to test the possibility of a stratigraphic trap on the plunging nose of the structure, failed when none was found. Consequently, the well was abandoned.

Vermilion Ridge Anticline

(*See* Figure 4)

Vermilion Ridge No. 1 Well (Elevation, 1,055 feet). In 1945, Imperial Oil Limited drilled this well to a depth of 5,972 feet on the north side of Vermilion Creek northeast of the Vermilion Gorge anticline. The log of the well, according to Stewart (1945, p. 17) was as follows:

Age	Formation	Lithology	Depth in feet
Upper Devonian	Lower Fort Creek	Dark brownish grey shales	0–470
Middle Devonian	Ramparts	Mainly limestone, with less shale	470–853
Silurian or Devonian	Bear Rock	Dolomitic limestone with pyritic nodules; carbonaceous partings; anhydrite in lower part	853–1,297
Silurian	Ronning	Dolomitic limestone, hard and dense; interbedded with anhydrite and green shale	1,297–2,799
Cambrian	Macdougal	Green and red shale, with dolomite and gypsum; shale and gypsum at the base	2,799–3,369
		Salt series—mainly rock salt, 3,369–4,402; limy siltstone with salt and gypsum, 4,402–4,470; mainly salt, with less amounts of limy and silty beds, 4,470–4,656; mainly siltstone with less amounts of salt and gypsum, 4,656–5,225; mainly rock salt, 5,225–5,275; siltstone, shale, and salt, 5,275–5,530; chiefly rock salt, 5,530–5,582	3,369–5,582

Age	Formation	Lithology	Depth in feet
Cambrian	Macdougal	Greenish grey shale	5,582–5,788
		Shale, greenish, grey, and purple, finely laminated and calcareous; fossils abundant, chiefly small trilobites	5,788–5,972

There was no evidence of any oil, gas, or water in the well, and it was abandoned.

The thickness of the salt beds through more than 2,200 feet is a feature of the Cambrian, which, together with the character of the beds above and below the salt, makes it improbable that any oil can be expected from rocks of this age in this general area.

It is surprising that no water was reported from the well, as on Vermilion Creek, where the brecciated dolomite of the Bear Mountain formation is exposed, large springs of sulphur water occur (Hume, 1923, p. 51). In many places the dolomitic beds of this formation are somewhat bituminous and, although no oil has yet been found in any well in them, there seemed to be a reasonable expectation that under proper structural conditions oil might occur. In this particular area the beds are exposed, and it would seem that there has not been sufficient structural closure to allow oil to accumulate and be retained.

Canyon Creek Area

In 1922, Hume (1923, p. 61) reported a sandstone member 50 to 70 feet thick in the Fort Creek formation on Canyon Creek. At that time, Discovery No. 1 well in the Norman Wells field was at a depth of 783 feet and the oil was coming from shales. It was thought that if the well was deepened it might encounter the sandstone and hence give reason to expect that an extensive oil reservoir might be present. Consequently, No. 1 well was deepened in 1923 to a depth of 1,025 feet, but the sandstone was not encountered.

Canyon Creek Nos. 1 and 2 Wells. The Canyon Creek sandstone member, however, offered a possible reservoir rock and Canyon Creek Nos. 1 and 2 wells were drilled to test it in the area where it was known it would be encountered. As the sandstone is lenticular within the Fort Creek shales it was thought that it might act as a stratigraphic trap in which the up-dip side would be sealed off by the shales. This hope seemed justified in that on Prohibition Creek the sandstone is about 300 feet thick and shows some oil stain in outcrops. The wells were drilled on the southwest flank of Discovery Range about 15 and 18 miles respectively upstream from Norman Wells. The structure at the wells is monoclinal, and the southwest dip of the strata is not more than 5 to 7 degrees.

The log of the Canyon No. 1 well (elevation, 310 feet) is as follows:

Age	Formation	Lithology	Depth in feet
Recent		Sands and silts	0–10
Devonian	Imperial	Greenish asndstone and shale	10–325
"	Fort Creek	Dark grey shales and limy bands	325–1,231
"	"	Canyon sandstone member of fine-grained sandstone and sandy shale; some oil stain	1,231–1,328
"	"	Dark grey shale with some sandy shale	1,328–1,585
		Black bituminous shale with limy streaks and pyrite	1,585–2,025
"	Ramparts	Beavertail limestone member	2,025–2,066

The following is the log of the Canyon No. 2 well (elevation, 463 feet):

Age	Formation	Lithology	Depth in feet
Recent		Silts and clays	0–10
Devonian	Fort Creek	Shales, sandy shale, and limestone bands	10–667
"	"	Canyon sandstone member consisting of greenish grey, fine-grained sandstone with oil-stained streaks	667–724
"	"	Dark shales, in part bituminous	724–803

Raider Island

Raider Island No. 1 Well (Elevation, 331 feet; *See* Figure 3). A well known by this name was drilled on Raider Island about 7 miles down stream from Norman Wells. According to Stewart (1945, p. 18), gravimetric work suggested a thickening of the Reef limestone, although results given by seismic work were inconclusive. It had been found that a gravimeter survey of the Norman Wells field gave a low anomaly and, hence, a similar condition over Raider Island suggested reef conditions as in the producing oil field. The structure, so far as known, is monoclinal, and the dip is to the southwest at about 5 degrees. The well log was as follows:

Age	Formation	Lithology	Depth in feet
Recent		Sands, silts, etc.	0–50
Cretaceous		Shale and sandy shale	50–312
Devonian	Imperial	Sandstone and shale	312–810
"	Fort Creek	Upper shale member	810–1,795
"	"	Bituminous shale member	1,795–2,035
"	"	Basal Reef limestone member	2,035–2,080
"	"	Lower shale member	2,080–2,190

Apparently there was no reef above the limestones on which in other places reef conditions occur. The limestone has low permeability and, hence, failed to yield on test. The well was abandoned.

Judile No. 1 Well (Elevation, 437 feet; *See* Map No. 1032A). This well was located about 30 miles downstream from Norman Wells in an area where dips on the Cretaceous suggest some folding. According to Stewart (1945, p. 22), gas seepages were noted.

The log of the well was as follows:

Age	Formation	Lithology	Depth in feet
Recent		Sands and silts	0-60
Cretaceous		Shales	60-315
Devonian	Imperial	Sandstones and shales	315-653
"	Fort Creek	Upper shale member	653-1,252
"	"	Bituminous shale member	1,252-1,305
"	"	Reef limestone member	1,305-1,835
"	"	Lower shale member	1,835-2,306
"	Ramparts	Beavertail limestone member	2,306-2,500
"	"	Lower shale member	2,500-2,608
Devonian or Silurian	Bear Rock	Dolomitic limestone and anhydrite	2,608-2,815

No oil or gas was encountered in the well, which was abandoned.

Morrow Creek Area

Morrow Creek is about 15 miles below the Norman Wells field on the northeast side of Mackenzie River. It is a few miles up river and on the opposite side from the pronounced Hoosier ridge fold. In the vicinity of the well the dips are in general southward but there is a local fold with a north reversal of dip. Gravimeter surveys confirmed the structural conditions and seismic surveys suggested the presence of the reef limestone on the south flank but were more indefinite in regard to the north flank.

Morrow Creek No. 1 Well (Elevation, 313 feet; *See* Figure 3). This well, close to Mackenzie River, was drilled to a depth of 2,024 feet, and the log is as follows:

Age	Formation	Lithology	Depth in feet
Recent		Sands and silts	0-30
Devonian	Fort Creek	Upper shale member	30-758
"	"	Bituminous member	758-994
"	"	Reef limestone member	994-1,064
"	"	Basal limestone member	1,064-1,104
"	"	Lower shale member	1,104-1,610
"	Ramparts	Beavertail limestone member	1,610-1,767
"	"	Ramparts shale member	1,767-1,965
Devonian or Silurian	Bear Rock	Dolomitic limestone	1,965-2,024

At 2,024 feet a strong flow of sulphur water was encountered. The flow rate was estimated at 24,000 barrels a day. The temperature of the water was unusually high, namely, 90°F.

HOOSIER RIDGE AREA

(*See* Figure 3)

Hoosier Ridge occurs on the south side of Mackenzie River about 20 miles below the Norman Wells field. It is a sharply folded anticline, presumably on the continuation of the folds that occur on Carcajou River some 30 miles above its mouth. The trend is to the west, but Hoosier Ridge plunges sharply downward along its axis, and there is an intervening saddle between it and the Carcajou folds. The ridge rises to an elevation of 800 feet and is about 3 miles long. It is an asymmetrical fold, with north dips up to 70 degrees and south dips of 15 degrees or less.

The strata exposed on Hoosier Ridge are of Devonian age, the central core being the Reef limestone of the Fort Creek formation, with Fort Creek shales overlain by Imperial sandstones and shales on the flanks. The outlying areas are covered with Cretaceous shales.

Hoosier Nos. 1 and 2 Wells. The prospects for oil in this structure are obviously only in strata below the Reef limestone of the Fort Creek formation. The first well was located down the south flank in harmony with the view that the north flank might be overturned at depth and perhaps faulted. When this well failed, a second well was located on the north flank in the hope that a fault at depth might provide closure. The logs of the two wells are as follows:

Age	Formation	Lithology	No. 1 well (elevation, 530 feet) Depth in feet	No. 2 well (elevation, 406 feet) Depth in feet
Recent..........	....	Silts, etc.................	....	0-50
Devonian........	....	Sandstone and shale.....	....	50-150
"	Fort Creek......	Upper grey shale member	....	150-850
"	"	Bituminous shale member	0-20	850-926
"	"	Reef limestone member..	20-495	926-1,380
"	"	Lower shale member....	405-1,051	1,380-2,160
"	Ramparts.......	Limestone and shale.....	1,051-1,220	2,160-2,300
"	"	Shale....................	1,220-1,515	2,300-2,570
Devonian or Silurian........	Bear Rock.......	Dolomitic limestone.....	1,515-2,656	2,570-2,718

In No. 2 well, the Beavertail limestone member of the Ramparts gave a slight oil show. The Bear Rock formation contained water. The thickness of some of the members of the Fort Creek is abnormal and is due to drilling these beds at a high inclination. Toward the bottom of the No. 1 well, the Bear Rock beds were vertical.

SANS SAULT AREA

Sans Sault is a rapids in Mackenzie River formed by rock ridges. In its vicinity there is pronounced folding in East and West Mountains on the east and west sides of Mackenzie River respectively, and the cores of these anticlines expose Devonian rocks with the Bear Rock dolomite occurring in East Mountain. It is known that Cretaceous beds unconformably overlie the Devonian, and in drilling the well the Cretaceous was found to rest on the lower part of the Fort Creek formation below the Reef limestone.

Sans Sault No. 1 Well (Elevation, 318 feet). At the well site on the southwest bank of Mackenzie River the exposed beds are Cretaceous and there is a gentle anticlinal fold. The log of the well is as follows:

Age	Formation	Lithology	Depth in feet
Cretaceous....................	Sans Sault.....	Dark shales..................	0-1,337
Devonian......................	Fort Creek....	Lower shale member..........	1,337-1,408
"	Ramparts.....	Beavertail limestone member..	1,408-1,845
"	"	Shale and limestone member...	1,845-2,925
"	Bear Rock....	Dolomitic limestone...........	2,925-3,291

Water occurred in the Bear Rock formation, and as no oil or gas was encountered the well was abandoned.

WHIRLPOOL AREA

Mountain River enters Mackenzie River about 75 miles below Norman Wells oil field. The well-marked Whirlpool anticline crosses it about 25 miles above its mouth and about 10 miles southwest of East Mountain. This anticline is largely in Cretaceous strata, but there is an exposed core of sandstones and shales of the Imperial formation (*See* Figure 8).

Whirlpool No. 1 Well. This well was drilled on the west side of the river and encountered the Devonian immediately below recent sediments. The log is as follows:

Age	Formation	Lithology	Depth in feet
Recent		Sands and silts	0–50
Devonian	Imperial	Sandstone and shales	50–920
"	Fort Creek	Marine shales	920–955
"	Ramparts	Limestones and shales	955–2,828
Devonian or Silurian	Bear Rock	Dolomite	2,828–3,266
Silurian	Ronning	Cherty dolomite	3,266–5,426
Silurian?		Dark grey limestone with shaly interbeds	5,426–6,417

No oil, gas, or water was encountered, and the well was abandoned.

SUMMARY OF RESULTS

In view of the production from the Norman Wells field and the bituminous character of the sediments over a wide area of the Mackenzie River basin the results of exploratory drilling were very disappointing. Most of the wells drilled were within 25 miles of the Norman Wells field, and although the structures on which some of these were drilled were none too well defined, others in such a petroliferous area would be considered excellent. The negative results, therefore, are difficult to explain, as oil accumulations in addition to that in the Norman Wells field were to be expected. It is true that in most of the wells outside the immediate vicinity of the Norman Wells field the reef conditions were not represented, but there was every expectation that the upper part of the Ramparts formation and the Bear Rock formation would prove sufficiently porous to be productive. In a few wells, as proved by the flows of water, the Bear Rock formation was porous, but the few oil shows that were encountered in drilling were much smaller than would have been anticipated. Particularly in areas considerably removed from the Norman Wells field, as at the Whirlpool anticline on Mountain River and at the Big Bend anticline on Redstone River, the prospects prior to drilling were considered very favourable, but the results were negative. It seems very improbable that further attempts will be made in the near future to find oil in new areas in the vicinity of the Norman Wells field, but it is expected that other parts of the Mackenzie River basin will come under active exploration.

CONCLUSIONS

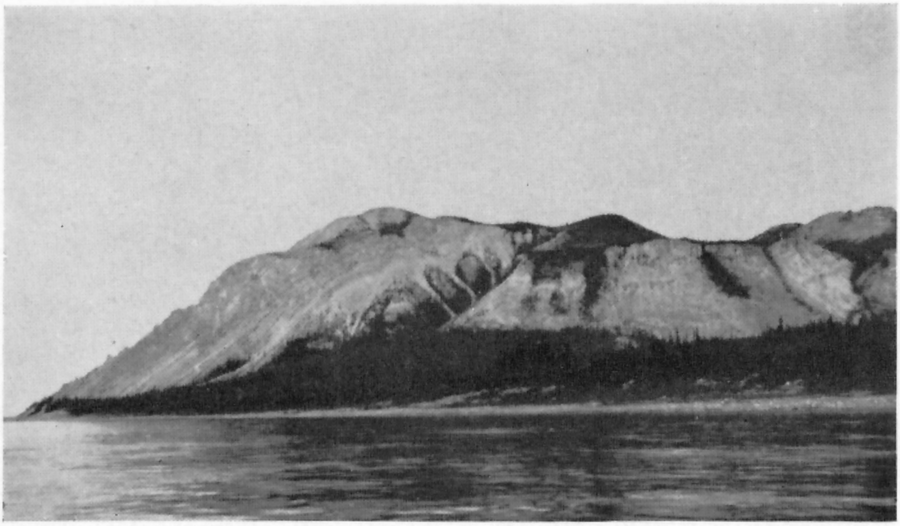
The fact that oil was found in a coral reef in the Norman Wells field led to the hope that other discoveries would be made in the immediate vicinity. In this connection the seepages at the mouth of Bosworth Creek provided the key to discovery, and without them the presence of an oil field on the monoclinal slope of the east flank of the Carcajou basin would not have been suspected. The Reef limestone was found, however, to give good seismic reflections and, hence, investigation by geophysical methods provided further hope of discovering more reef fields. The drilling done to date has not, however, revealed any other reefs in the immediate vicinity of the Norman Wells field. It is apparent, though, that besides the Kee Scarp member there are other reefs elsewhere in the Devonian formations, and that under favourable conditions any of these might become an oil reservoir rock. The anticlines that have been drilled in the Mackenzie River area have, to some extent, shown porous rocks, although the oil shows have been relatively scarce. There are sandstones at the base of the Cretaceous and in the Imperial formation that could act as reservoir rocks, although in general the Imperial sands seem to be rather fine grained and silty. In the original wells drilled in the Norman Wells field these sands contained oil that had seeped up into them under conditions of fracturing, and the fact that they did not contain oil down the dip under less favourable structural conditions has no significance. It has been pointed out in this report that the upper beds of the Middle Devonian Ramparts formation are commonly coralline, and that at Beavertail Point, in particular, as well as at other places, this zone is highly petroliferous. Undoubtedly, by far the most porous rocks in the area are the Bear Rock dolomites. These are extremely porous, and have yielded flowing water in several exploratory wells. In places, however, the position of the porous Bear Rock dolomite is occupied by gypsum and anhydrite beds, and under these conditions porosity may be lacking, as has already been proved to be the case in at least one exploratory well. The Bear Rock formation is perhaps the most widespread porous rock in the Mackenzie Valley area, and is known to extend at least as far south as Wrigley. In places it is quite bituminous, and in other places yields springs of water.

In the Silurian strata below the Bear Rock formation the upper beds representing the Niagaran coral zone are in places quite porous. The Bear Rock formation rests with erosional unconformity on the Ronning group of the Silurian, and, as has already been pointed out, the Niagaran coral zone of the Silurian may have a variable thickness or be missing in certain localities. For instance, it is not known in the Bear Rock area, but at the headwaters of Schooner Creek, on the Norman Range, it has a thickness of 100 feet, according to Stelck, who states that the beds composing it are coarsely crystalline and very porous, and would serve as excellent reservoir strata.

So far as known, the remainder of the Silurian beds below the Niagaran coral zone are fairly dense limestone, but in many places there is upwards of 1,000 feet of beds, and detailed studies of this succession have not been made. The age of some of the beds below the Silurian is open to question. In some areas, as at Bear Rock, red and green gypsiferous shales occur that have been regarded as equivalent to the Saline River (Upper Cambrian) of the Cap and Clark Mountain areas of Franklin Mountains. In Dodo Canyon, in Mackenzie Mountains west of Fort Norman, 1,000 feet of strata included in the Macdougal group have been studied by Link and Nauss, and in the upper Carcajou River area still older Cambrian beds belonging to the Mount Katherine group are reported to contain black, platy, bituminous shales. However, these are associated with chocolate and green shales and quartzites, a succession that does not give rise to much optimism in regard to oil prospects.

In summary, therefore, it appears that the best prospects for oil are in the Devonian and Upper Silurian beds, with less favourable conditions in the older Silurian and Cambrian strata.

PLATE I



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A. Bear Rock at the junction of Great Bear and Mackenzie Rivers at Fort Norman. (Page 20.)

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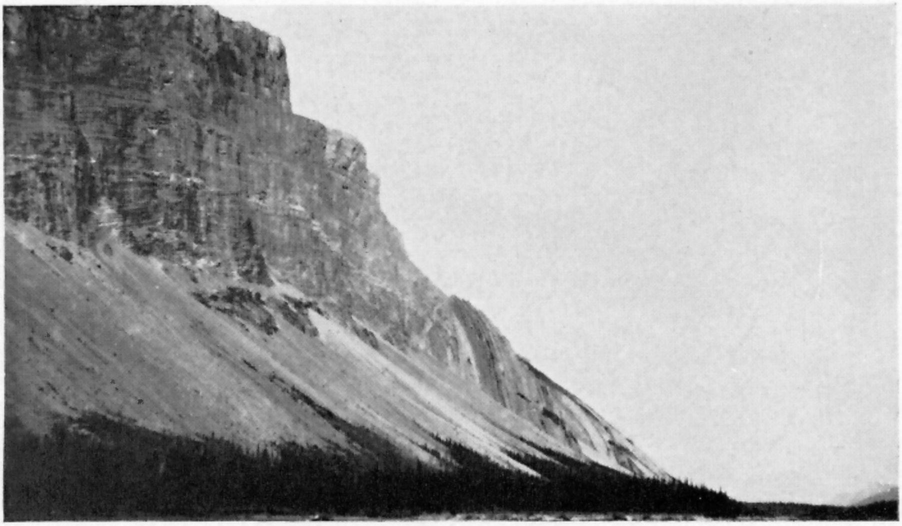
B. Rainbow Arch on Carcajou River, showing the contact between Middle Devonian limestones and Upper Devonian shales. (Page 33.)

PLATE II



52308

A. Folded Middle Devonian rocks on North Nahanni River a few miles west of Mackenzie River. (Page 46.)

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B. Rock-by-the-River's-Side, near Wrigley, showing folds in Middle Devonian rocks. (Page 80.)

PLATE III

Dodo (Macdougal) Canyon in Carcajou Mountains on the Norman Wells-Whitehorse pipeline route. (Page 10.)

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