CANADA
DEPARTMENT OF MINES AND RESOURCES
MINES AND GEOLOGY BRANCH

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PAPER 45-29

RECENT EXPLORATORY DEEP WELL DRILLING IN MACKENZIE RIVER VALLEY, NORTHWEST TERRITORIES

(REPORT, MAP, AND FIGURE)

BY

J. S. STEWART

OTTAWA

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INTRODUCTION

Early in 1943 the writer was assigned to act as Liaison Officer between the Department of Mines and Resources and the United States Army on the Canol Project, and as supervisory petroleum engineer for the Department on the same project and since the termination of that project in May 1945.

The following account is based on observations by the writer in the field, and is concerned with conditions encountered and results obtained in a program of wildcat drilling in the Norman Wells region, commencing late in 1942 and continuing into September 1945. The exploratory or wildcat wells, seventeen in all, are scattered along Mackenzie River Valley, on either side of the proven Norman Wells oil field[1], from near Fort Norman on the south to Sans Sault Rapids on the north, a distance of about 125 miles.

[1] Stewart, J.S.: "Petroleum Possibilities of MacKenzie River Valley, Northwest Territories"; Trans. Can. Inst. Min. and Met., vol. XLVII, pp. 152-171 (1944).

The writer wishes to express his appreciation of the generous assistance given by officials of Imperial Oil Limited and the United States Army, the former providing free access to all Company files and reports.

The exploratory wells drilled in search for petroleum in the Mackenzie River region are the result of the success that attended the development of the Norman Wells oil field and the prosecution of the Canol Project by the United States Government.

The Norman Wells oil field is located on Mackenzie River, about 85 to 90 miles south of the Arctic Circle and about 50 miles downstream from Fort Norman at the mouth of Great Bear River (See Figure 1A). The Discovery Well was drilled in 1920, but the limited market for petroleum products in that region and its great distance from outside markets made further development unnecessary.

In 1942 the Japanese threat to Alaska, with the possibility of interruption of tanker shipments of vital petroleum products, caused the United States Government to enter into an agreement with the Government of Canada, which resulted in the Canol Project. This project had for its objects: (1) the development of the Norman Wells oil field by drilling wells sufficient to guarantee delivery of 3,000 barrels of crude oil a day in excess of local requirements; (2) the building of a pipe line from Norman Wells to Whitehorse, Yukon, a distance of some 600 miles, to transport the oil; and (3) the construction of a refinery at Whitehorse to process the crude oil from Norman Wells field.

The success that attended the early efforts to extend the oil field caused the United States authorities to raise the production objective from the original 3,000 barrels to 20,000 barrels a day, and to engage in a program of exploratory drilling and geological exploration to find other oil fields. After drilling four wildcat wells without favourable result, the United States Government confined their further drilling efforts to the proven oil field at Norman Wells.

New regulations governing oil and gas were issued by the Government of Canada on June 30, 1944. These removed the existing restrictions on prospecting for petroleum in the Northwest Territories, and made it possible for any company to obtain prospecting permits on a maximum area of 3,200 square miles with exclusive right to lease. The prospecting permits are issued for a period of 3 years with the possible extension for 3 more years, if conditions have been fulfilled. However, after each 18-month or yearly period the obligations become heavier and more expensive. Before, or by the end of, the life of the permit, leases must be obtained, if the permittee wishes to retain any of the permit area. Leases carry still heavier obligations than permits, and the maximum area that may be leased by one company is 350,000 acres, or about 547 square miles. Under these new regulations Imperial Oil Limited took up on their own account the maximum permit area. The company then began a program of geological and geophysical exploration and the drilling of wildcat wells, and have continued their efforts up to the time of writing. The following is a tabulated summary of the exploratory drilling in territory outside the proven Norman Wells oil field since the Canol Project started in 1942:

Designation of Well	Date of Completion	Completed Depth	Result
Hoosier Ridge No. 1	April 16, 1943	2,656 feet	Abandoned dry hole
Hoosier Ridge No. 2	August 9, 1943	2,718 feet	Abandoned dry hole
Bluefish Creek No. 1A	October 12, 1943	3,539 feet	Abandoned dry hole
Mac No. 1	November 6, 1943	3,146 feet	Abandoned dry hole
Mac No. 2	August 23, 1944	2,958 feet	Abandoned dry hole
Ray No. 1	September 8, 1944	3,817 feet	Abandoned dry hole
Morrow Creek	November 10, 1944	2,024 feet	Abandoned dry hole
Seepage Lake	January 11, 1945	1,636 feet	Abandoned dry hole
Loonex	March 8, 1945	4,564 feet	Abandoned dry hole
Loon Creek No. 1	March 30, 1945	5,452 feet	Abandoned dry hole
Vermilion Ridge No. 1	April 3, 1945	5,972 feet	Abandoned dry hole
Raider Island	May 4, 1945	2,190 feet	Abandoned dry hole
Sans Sault	June 28, 1945	3,291 feet	Abandoned dry hole
Loon Creek No. 2	June 30, 1945	5,093 feet	Abandoned dry hole
Canyon No. 1	July 24, 1945	2,066 feet	Abandoned dry hole
Judile No. 1	September 2, 1945	2,815 feet	Abandoned dry hole
Canyon No. 2	September 8, 1945	805 feet	Abandoned dry hole

TABLE OF FORMATIONS

The following is the table of formations, as established by geologists of Imperial Oil Limited, with the names in common use for the various stratigraphic units. It is a necessary preliminary for an understanding of the various rock types and formations that may be encountered by the drill.

Age	Formation or group	Character of Strata	Thickness[1] (Feet)
Pleistocene and Recent		Unconsolidated sands, gravels, clays, etc.	extremely variable
Tertiary	Undifferentiated	Conglomerate, sandstone, shale, and lignite	1,200
Upper Cretaceous	East Fork	Grey marine shale, with a little sandstone; shale, well bedded and plastic	850
	Little Bear	Conglomerate, sandstone, shale, and lignite	700
	Slater River	Black fissile shale, with ironstone concretions; also thin bands of bentonite	1,000
Lower Cretaceous	Sans Sault	Marine grey shales and sandstones	3,800
Upper Devonian	Imperial	Mainly sandstone and shale, with a little limestone	1,200
	Fort Creek	Upper shale member contains local lenses of sandstone and limestone	700
	Fort Creek	Bituminous shale member	100 to 400
	Fort Creek	Reef limestone member	Up to 450
	Fort Creek	Lower shale	540 (maximum)
Middle Devonian	Ramparts	Beavertail buff limestone; upper member Ramparts limestone and shale; middle member Hare Indian River greenish shale; lower member	2,000
Silurian or Devonian	Bear Rock	Dolomitic limestone, with some gypsum; characterized by a breccia composed of large angular blocks of dolomitic limestone	400
Silurian	Ronning	Hard, dense, cherty dolomitic limestone	1,500
Cambrian	Macdougal	Gypsum and salt overlain by shale and limestone characterized by reddish colour .	500 to 2,780

[1] In general the thicknesses given are the maxima that could be measured with any degree of accuracy.

	Macdougal	Shale and sandstone with some limestone and gypsum..	680
Cambrian or earlier	Katherine	Hard quartzitic sandstone with interbedded shales; sandstones are white to pink; shales are black, greenish and maroon to red.	450 +

The foregoing table deals with the sequence of strata that outcrop in Mackenzie River Valley between Fort Norman at the south and Fort Good Hope at the north. Within that distance the lateral variation of each formation both as to character and thickness is considerable.

DESCRIPTION OF FORMATIONS

CAMBRIAN

Strata of Cambrian or earlier age are exposed in Mackenzie Mountains, and probably the most easily accessible section is along Macdougal River (Dodo Canyon).

Katherine Group

The Katherine group is well exposed in the crest of an anticline that is cut by Macdougal Canyon. The strata consist of quartzitic sandstones with lesser amounts of interbedded shale. The sandstones or quartzites are characterized by light colours varying from white to pink and buff. Many of the shales are dark grey, but near the top of the group they are maroon and greenish. A thickness of 400 feet assigned to this group is exposed in Dodo Canyon, and the base is not seen. No fossils were observed, and the age is inferred from the Cambrian age of overlying beds.

Macdougal Group

The Macdougal group is typically exposed along Macdougal River. The lowest member is a series of shales, mostly chocolate coloured, but with lesser amounts of interbedded, greenish shale. Flattened concretionary nodules are numerous and in places form continuous bands in the shale. These nodules range up to 8 inches in diameter and are fairly uniform in size. This chocolate and green shale member has a thickness of 130 feet, and is overlain by some 200 feet of hard, scarp-forming limestone. This in turn is succeeded by some 350 feet of shale with a few thin sandstone beds. The age is based on a few fossils found in outcrops, but more recently trilobites and brachiopods of Middle Cambrian age were found in cores taken at the Vermilion Ridge well from red shales that are thought to represent the Macdougal group.

In the Vermilion Ridge well, the upper 2,783 feet of the Macdougal group includes an abundance of evaporites, chiefly rock salt, and consists of alternating beds of gypsum, shale, and halite. Some beds of rock salt are very thick and of a high degree of purity, as evidenced by drill core samples. The lowest salt bed occurs about 200 feet above beds carrying Middle Cambrian fossils. No fossils have been found in this evaporite series in the Norman-Carcajou basin, either in outcrop or in well samples, and although it has been placed in the Macdougal group of the Cambrian[1] it may be of later age. It has been correlated tentatively with

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1 Hume, G.S. and Link, T.A.: Geol. Surv., Canada, Paper 45-16, p. 7 (1945).

the Saline River formation[1] on the basis of lithology and stratigraphic

[1] Williams, M.Y.: Geol. Surv., Canada, Sum. Rept. 1922, pt. B, pp. 72-78.

position, but the age of the Saline River is admittedly questionable. The evaporite or salt series apparently has its greatest development on the northeast side of Mackenzie River, because in Dodo Canyon, Macdougal River, where the entire Palaeozoic section outcrops, a thickness of only 500 feet of poorly exposed beds containing gypsum is assigned to this division of the Macdougal group.

SILURIAN

Ronning Group

The Ronning group directly overlies the Macdougal on both sides of Mackenzie River. It is commonly composed of dense, hard, and cherty dolomitic limestone, and is approximately 1,000 feet thick in Mackenzie Mountains. Its Silurian age is determined from contained marine fossils. The colony corals Halysites and Favosites are commonly found where this formation outcrops.

SILURIAN OR DEVONIAN

Bear Rock Formation

The Bear Rock formation is largely a breccia or fanglomerate and weathers into hoodoo forms. The breccia is made up of blocks of dolomitic limestone, some of them several cubic feet in size. The breccia is cemented in a calcareous matrix, and is often granular, saccharoidal, cavernous, and bituminous. The formation contains some bedded zones and some gypsum, and in places the breccia grades laterally into bedded dolomitic limestone. The age is inferred from overlying and underlying formations. The thickness of the formation is fairly constant and about 400 feet.

MIDDLE DEVONIAN

Ramparts Formation

The Ramparts formation includes formations that have previously been described as Beavertail and Hare Indian River. These beds are now all included in one formation because they can be mapped as a unit and no well defined division can be made in the field. The Ramparts formation directly overlies the Bear Rock, and consists of a thick lower series of dark grey and limy shales and limestones and an upper, massive, buff limestone. The thickness of the Ramparts formation is less than 400 feet in the upper Carcajou River and Fort Norman region, whereas to the northwest in the vicinity of Imperial Mountains it is 2,000 feet thick. The thinning to the northeast appears to be at the expense of the Hare Indian River shale member. The age is determined from contained fossils.

UPPER DEVONIAN

Fort Creek Formation

The Fort Creek formation directly overlies the Ramparts formation, and is essentially a series of shales of marine origin. However, local lenses of sandstone of appreciable thickness occur in the

region between Fort Norman and Norman Wells, whereas limestone lenses in the form of reefs with a maximum thickness of as much as 500 feet occur in the vicinity of Norman Wells. In the proven field such a reef forms the oil-bearing reservoir. The shales are dark grey, and a well defined zone of black bituminous shales occurs above the Reef limestone. The maximum thickness of the formation in the vicinity of Norman Wells is about 1,800 feet. The age is determined from contained marine fossils.

Imperial Formation

The Imperial formation directly overlies the Fort Creek and is given a new name[1] to replace the name Bosworth which has been found

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1 Hume, G.S., and Link, T.A.: Canol Geological Investigations in the Mackenzie River area, N.W.T. and Yukon, Geol. Surv., Canada, Paper 45-16, p. 34 (1945).

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to be pre-empted. The formation is well developed in Carcajou Valley and the type section is on the northeast flank of Imperial Mountain Range on Imperial River; hence the name. The strata consist of sandy shales and sandstones and in places a few thin limestone beds. At Norman Wells the Imperial beds exposed are pale greenish sandstones and may be seen in the river bank. In lower Carcajou Valley, where the formation is most fully developed, it has a total thickness of 1,200 feet. The age of the Imperial is determined from contained marine invertebrate fossils.

CRETACEOUS

The subdivisions of the Cretaceous made by Hume and Link[2] are

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2 Op. cit., pp. 39, 41 (1945).

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based mainly on field work by geologists for the Canol Project in 1943. Subsequently, in order to correlate the work of various geologists, critical areas were re-examined by F.A. McKinnon and W.P. Hancock for Imperial Oil Limited. This work made clearer the sequence, horizon guides, recognizable boundaries, and the thicknesses of the various stratigraphic units.

The present division of the Cretaceous into four units is roughly equivalent to A, B, C, and D divisions by Hume and Link. A principal difficulty in earlier geological work was, apparently, in defining the boundary between Upper and Lower Cretaceous beds. All strata of Lower Cretaceous age are here included in the Sans Sault group.

On the geological map accompanying this report, all Cretaceous strata are represented by one pattern, because of the difficulty in tracing the boundaries of the various separate units. Well exposed sections of these beds are few and scattered, due to the fact that the Cretaceous rocks generally underlie the lowlands, and are comparatively non-resistant to erosion.

In the region under discussion strata of Cretaceous age rest directly on Devonian beds with apparent structural conformity. The interval represented by the disconformity was a long one during which, no doubt, a large amount of bedrock was removed by erosion. It is known that the Cretaceous and Devonian formations that are in contact are

different in different localities. Either Upper or Lower Cretaceous beds may be found resting on Upper or Middle Devonian formations. The Cretaceous rocks have been subdivided in various ways by different workers, due to scarcity of fossils, to the lack of well marked lithologic units, and to the lateral variation of formation members within short distances. The sequence already given in the table of formations is the result of the latest information and discussion in the field. The names have all been previously used by geologists on the Canol Project, and the following is an attempt to define their limits and relations more clearly.

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 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.

TERTIARY

The Cretaceous shales above the mouth of the East Fork of Little Bear River are covered with conglomerates and sandstones. Cross-bedding probably yields exaggerated dips, but in general the true dip is thought to conform closely with that of the underlying Cretaceous shales. From the mouth of Tertiary Creek, a tributary of Keele (Gravel) River, for a distance of 18 miles, a series of gravels, conglomerates, sands, lignites, and shales is exposed. Some of the lignite beds are 8 to 10 feet thick. A total thickness of 1,200 feet of these beds was measured and is assigned to the Tertiary. The age of the beds is assumed from their stratigraphic relations and from fragmentary fossils that were observed but not collected or studied. In places the lignites and shales have been burned to a brick red colour. These Tertiary beds are overlain by unconsolidated sands and gravels of Pleistocene and Recent ages.

STRUCTURE

The rocks have been folded and in places faulted. The general trend of the structure is northwest-southeast, but there are notable variations from this general direction. The structure is also characterized by wide belts of gently dipping beds with dips of 10 degrees or less, and narrow belts of beds with steep to vertical dips. In some instances these steep limbs appear to be faulted, but the stratigraphic displacement is generally small.

DESCRIPTION OF WILDCAT WELLS[1]

[1] The wells are described in the order in which they were drilled.

In the following descriptions elevations given for wells are approximate only. An assumed elevation of 300 feet above sea-level has been given to the Discovery No. 1 well in the Norman Wells oil field, and all elevations are with reference to it. The elevations of wildcat wells at a considerable distance from the proven field are obtained by carrying elevations to the well from the nearest point on Mackenzie River, and assuming an average drop of 6 inches a mile in river level. The river level at Norman Wells is read every day. The elevations given for wells are for the top of the rotary table, which is generally about 12 feet above ground level. The elevation of Discovery No. 1 well, however, is taken at the top of the well head flange, and is practically at ground level.

Electrologs were taken at all the wells, so that in compiling the logs advantage could be taken of these records to supplement the information from rotary samples and cores.

HOOSIER RIDGE NOS. 1 AND 2 WELLS

Hoosier Ridge is a fairly flat-topped plateau about 3 miles long in an east-west direction and about 4,000 feet wide. The highest elevation, 800 feet, is about a mile east of the west end of the ridge. This topographic feature is controlled by the structure, being the result of erosion of an asymmetric anticlinal fold. The flat-topped ridge includes several minor ridges with a fairly uniform trend of north 45 degrees west. The minor ridges are due to glacial grooving and their trend does not conform to the strike of the strata. Bedrock exposures are all limestone and represent the Reef member of the Fort Creek formation. These exposures show the Hoosier Ridge structure to be a narrow, asymmetric anticline with steep northward dips up to 70 degrees and low dips of about 15 degrees or less southward (See Figure 1C). The south dip is normal for that part of the basin, and the beds probably continue to dip southward for a distance of 6 miles south of the surface trace of the anticlinal crest. The steep side of this asymmetric anticline faces the river. If this steep limb could be traced to subsea depths it is possible that overturned beds and perhaps overthrust faulting would be encountered. The location of Hoosier Ridge No. 1 well was made with such possible conditions in mind, and was made a sufficient distance down dip from the crest of the structure to avoid a possible low-angle thrust fault at shallow depths. It should not be overlooked, however, that the steep dip on the north limb may be in part at least depositional. Depositional dips in reef limestones up to 30 degrees are not uncommon. The location of the wells with regard to the structure is shown on the accompanying drawing (Figure 1C) by Dr. T.A. Link of Imperial Oil Limited.

The objective of the Hoosier Ridge No. 1 well was to test the Beavertail limestone and the Bear Rock dolomite. It was thought that if the north limb of the anticline were faulted, the fault might provide closure, on the up-throw side, for accumulations of petroleum. All the objectives were tested (See well logs). The structure shows closure along the strike both to the east and to the west. It has a length of at least 5 miles and may be as much as 12 miles long. The size of this structure and the probability of oil-bearing reservoir horizons at comparatively shallow depths made this structure very attractive. The reasoning for the tests was sound and the drilling justified.

Log of Hoosier Ridge Wells

Formation	Lithology	Depth in Feet No.1--Elev.530	Depth in Feet No.2--Elev.406
Pleistocene, etc.	Silts, etc.		0 to 50
Imperial	Sandstone and shale		50 to 150
Fort Creek	Upper grey shale member		150 to 850
Fort Creek	Bituminous shale member	0 to 20	850 to 926
Fort Creek	Beef limestone member	20 to 495	926 to 1,380
Fort Creek	Lower shale member	495 to 1,051	1,380 to 2,160
Ramparts	Lime and shale interbedded	1,051 to 1,220	2,160 to 2,300
Ramparts	Hare Indian River shale	1,220 to 1,515	2,300 to 2,570
Bear Rock	Dolomitic limestone	1,515 to 2,656	2,570 to 2,718

Cores have been preserved and are available from the following depths of the Hoosier No. 1 well: 830 to 838, 934 to 964, 1,012 to 1,024, 1,064 to 1,074, 1,110 to 1,118, 1,390 to 1,405, 1,541 to 1,556, 1,737 to 1,741, 2,023 to 2,033 and 2,337 to 2,347 feet.

The depth to which the Bear Rock dolomite extends in No. 1 well is not known. Towards the bottom of the hole this dolomite showed vertical dips, and so it is quite possible that the well was still in this formation when it reached its total depth of 2,656 feet. Also, difficulty was experienced in maintaining a straight hole, so the apparent excessive thickness is not the true thickness of beds penetrated.

Hoosier Ridge No. 2 well was drilled with the object of testing the downthrow side of what may be a faulted structure. It was thought that a fault on the updip side of the well might form a trap and possibly cause an accumulation of oil to gather in the Reef limestone, which at this location is buried and covered by shale; there were also possibilities in the upper or Beavertail member of the Ramparts formation and in the Bear Rock dolomite. The Reef limestone, however, contained only fresh water, with considerable hydrogen sulphide. The upper, Beavertail limestone member of the Ramparts formation yielded a slight oil showing when bailed, but acid treatment gave no further oil recovery. The Bear Rock dolomitic limestone yielded considerable water but no oil.

The thickness of the lower Fort Creek shale is abnormal in this well due to crumpling and fracturing. Core samples from depths of 2,018 to 2,107 feet showed considerable evidence of fracturing with slickensides cutting the bedding at angles of 60 to 70 degrees. Cores have been preserved and are available for study from the following depths: 928 to 958, 1,199 to 1,208, 2,018 to 2,028, 2,051 to 2,134 and 2,334 to 2,346 feet.

BLUEFISH NO. 1A WELL

This well is located at the mouth of Bluefish Creek about 9 miles downstream from Fort Norman. Structurally the well is located far down the west flank of a faulted major anticline that finds its topographic expression in the feature known as Bear Rock or Bear Mountain. This mountain rises to a height of 1,200 feet above the river. The structure in the vicinity of the well has a general northwest trend. About 2 miles downstream from the well Tertiary strata are shown faulted against the Imperial formation of Upper Devonian age. However, the great difference in age of the strata on opposite sides of the fault is no indication of the amount of stratigraphic or vertical displacement along the fault, because Cretaceous beds are known to rest unconformably on various Devonian formations in this general region. The geological maps show Tertiary beds in unconformable contact with Middle Devonian strata in the vicinity of Bear Rock, but this relationship is obscured by recent unconsolidated deposits.

The following is a summary log of Bluefish 1A well. The designation 1A was given this well because another had been started at the same location in 1921, and drilled to 495 feet where the tools were lost in the hole and the well abandoned.

Log of Bluefish 1A Well--Elev. 350 feet

Formation	Lithology	Depth in Feet
Recent	Sands and silts	0 to 30
Tertiary	Unconsolidated gravels, sands, etc.	30 to 360
Cretaceous	Shales and sandstones	360 to 1,150
Fort Creek	Upper shale member	1,150 to 1,620
Fort Creek	Jungle Ridge limestone	1,620 to 1,780
Fort Creek	Silty shale	1,780 to 1,907
Fort Creek	Limestone	1,907 to 1,913

Fort Creek	Shale	1,913 to 2,010
Fort Creek	Limestone	2,010 to 2,060
Fort Creek	Lower shale member	2,060 to 2,535
Ramparts	Beavertail limestone	2,535 to 2,650
Ramparts	Hare Indian River shales	2,650 to 2,910
Bear Rock	Dolomitic limestone	2,910 to 3,320
	Anhydrite	3,320 to 3,340
Ronning	Dolomitic limestone	3,340 to 3,539

No true reef limestone was encountered in this well. The limestone present above the lower shale is probably the basal limestone of the reef with shale partings. Also, there was no bituminous shale member.

The well was drilled to a total depth of 3,539 feet. Circulation was lost at 2,536 feet and a flow of water was encountered at 2,927 feet. Slight oil stains were found at 2,910 feet and at 2,480 feet. However, there were no indications of oil in commercial quantity, and the well was abandoned.

Although there appeared to be no favourable structure at this point, oil seepages occur at several places along the river bank both upstream and downstream from the well location.

Before the well was drilled it was known that the Norman Wells oil field was a stratigraphic trap, well down on the flank of a large anticlinal structure. The decision to drill was then made in the hope of striking:

1. Lenses of limestone or sandstone in the Fort Creek shale as follows:
   (a) The Jungle Ridge limestone
   (b) The Canyon sandstone
   (c) The Reef limestone
2. Porous lenses or beds in the Beavertail limestone.
3. Porous lenses or beds in the Bear Rock formation.
4. The erosional contact between the Bear Rock formation and the Ronning group.

The Jungle Ridge limestone is very impure, and it was thought might be porous. It is local in extent, and, hence, might easily form a stratigraphic trap. Likewise the Canyon sandstone is a local lens and in places was observed to be saturated with oil. As a possible reservoir rock the Reef limestone needs no comment, as it is the host rock for the Norman Wells pool. The Beavertail limestone is bituminous in many places, and the Bear Rock dolomite is commonly porous and bituminous. The erosional contact at the base of the Bear Rock formation is, from its nature, a possible reservoir.

The drill penetrated all the above objectives without favourable results, and, hence, the well was abandoned. In view of the number of possible reservoir horizons at comparatively shallow depth, the lens-like nature of many of them, and the proximity of oil seeps, the test appears justified.

Cores from Bluefish 1A were obtained and are available from the following depths: 840 to 845, 1,087 to 1,100. 1,228 to 1,245, 1,638 to 1,653, 2,056 to 2,066, 2,452 to 2,472, 2,553 to 2,565, 2,964 to 2,980 and 3,343 to 3,360.

MAC NO. 1 WELL

This well is located on the south bank of Mackenzie River about half a mile downstream from the Canol dock or landing. There are no outcrops of bedrock nearby. The well location was made on the basis of seismograph surveys in conjunction with information from wells drilled on Bear and Goose Islands. Interpretation of results of seismograph work indicated that the normal plunge of the Reef limestone to the east and southeast is interrupted by a flattening or terrace structure. A similar flattening was indicated at the top of the Beavertail limestone, and, hence, the terrace effect was thought to be structural and not due to a change of thickness in the reef. If this reasoning was correct, then some oil accumulation might be expected, and the possibilities seemed more favourable if there was a local thickening of the reef in this vicinity.

The well, however, was drilled to a depth of 3,146 feet without favourable result, and was abandoned.

Summary Log of Mac No. 1 Well--Elev. 297 feet

Formation	Lithology	Depth in Feet
Recent	Sands and clays	?
Cretaceous	Shales, etc.	? to 810
Imperial	Sandstone and shale	810 to 1,330
Fort Creek	Upper shale member	1,330 to 2,000
Fort Creek	Bituminous shale member	2,000 to 2,097
Fort Creek	Reef limestone member	2,097 to 2,589
Fort Creek	Lower shale member	2,589 to 3,130
Ramparts	Beavertail limestone	3,130 to 3,146

A comparison of this log with that forecast by the geological staff of Imperial Oil Limited before the well was drilled, is interesting.

Forecast Log of Mac No. 1 Well

	Feet
Loose surface material	0 to 50
Cretaceous shales	50 to 675
Imperial sandstone and shale	675 to 1,150
Fort Creek upper shales	1,150 to 1,975
Fort Creek Reef limestone	1,975 to 2,350

The reef was slightly deeper and much thicker than anticipated. A slight oil saturation was observed in cores in the uppermost section of the Reef limestone from 2,097 to 2,102 feet, but no oil in commercial quantity was encountered, and the well was abandoned.

MAC NO. 2 WELL

Mac No. 2 well was located about a mile southwest of Mac No. 1 and near the Canol Road. Its location and recommendation were determined solely on the strength of results of a seismograph survey. As a result of this work the reef condition was shown to extend farther down the dip in a southwesterly direction. The isopach time interval along this trend indicated the reef to be about the same thickness over the entire distance from Norman Wells to a point nearly 8 miles west of Mackenzie River at Mac No. 1 well. The well locations Mac No. 2 and Ray No. 1 were made along this trend for the purpose of testing the possibility of a stratigraphic trap due to local variations in porosity within the coral reef.

The well was drilled to a total depth of 2,958 feet. The estimated depth to the top of the Reef limestone before drilling, based on seismic data and results obtained in Mac No. 1 well, was 2,475 feet. The actual depth to the top of the reef proved to be 2,453 feet, so that the forecast was very close. The reef was thick, as the seismograph suggested, but there was no indication of oil saturation nor did a formation test indicate the presence of water. The reef here is apparently below the level of bottom water of the Norman Wells pool, but is of very low permeability, probably due to secondary cementation after the oil had been flushed up the dip. The well was consequently abandoned.

Summary Log of Mac No. 2 Well--Elev. 435 feet

Formation	Lithology	Depth in Feet
Recent	Surface sands and silts	0 to 100
Cretaceous	Shales, etc.	100 to 1,140
Imperial	Sandstone and shale	1,140 to 1,680
Fort Creek	Upper shale member	1,680 to 2,360
	Bituminous shale member	2,360 to 2,453
	Reef limestone member	2,453 to 2,935
	Lower shale member	2,935 to 2,958

Cores from Mac No. 2 well have been preserved and are available from the following depths: 2,449 to 2,464, 2,650 to 2,665, 2,803 to 2,822, and 2,940 to 2,958 feet.

RAY NO. 1 WELL

This well was located about 4 miles west of Mac No. 2 well, and near the northwest end of the Camp Canol airplane landing strip. Its location and recommendation were based entirely on the results of the same reflection seismograph survey and for the same reason as given for Mac No. 2 well. That is, a thick section of Reef limestone was indicated, and it was hoped that lensing of the reef and changes in porosity would produce a stratigraphic trap for petroleum. The well was drilled to a total depth of 3,817 feet.

Cores were taken at the following depths: 3,271 to 3,286, 3,380 to 3,396, and 3,683 to 3,701 feet.

Summary Log of Ray No. 1 Well--Elev. 576.5 Feet

Formation	Lithology	Depth in Feet
Recent	Sands, silts, etc.	0 to ?
Cretaceous	Shales	? to 1,900
Imperial	Sandstone and shale	1,900 to 2,520
Fort Creek	Upper shale member	2,520 to 3,176
Fort Creek	Bituminous shale member	3,176 to 3,266
Fort Creek	Reef limestone member	3,266 to 3,728
Fort Creek	Lower shale member	3,728 to 3,817

The top of the reef was found to be some 400 feet deeper than estimated. The seismograph survey results were interpreted as indicating a local thickening of the Reef limestone at this location, but this did not prove to be so. The indicated thickening was, however, based on isopachs that included the lower Fort Creek shale as well as the Reef limestone, and the effect could have been due to a local thickening of the shale.

A formation test of the Reef limestone between 3,284 and 3,347 feet yielded 40 feet of mud only, and no evidence of oil, water, or gas. The Reef limestone was barren throughout, and, apparently, of a very low order of permeability. The well was, therefore, abandoned.

MORROW CREEK NO. 1 WELL

Morrow Creek No. 1 well was located about 6 miles upstream from the Hoosier Ridge wells and on the opposite bank of the river. The location was made on what is thought to be a small anticlinal structure, but only one outcrop is shown with a northward dip of 11 degrees. The dip of the beds on all other exposures in that vicinity is southward, which is the regional dip from the Discovery Mountain Range. Gravimeter survey results suggested a structural high conforming well to that suggested by the surface outcrops. The results of seismograph work suggested the presence of reef limestone in the south flank of the structure, but poor reflections prevented a clear definition of the north side of the fold. There is little direct evidence of closure along the strike to the east and west, although recent gravimeter surveys indicate a westward plunge beneath the river and an eastward rise to a high anomaly about a mile along the strike from the well location. The well was drilled to a depth of 2,024 feet, and the depth to recognizable horizons was considerably shallower than expected. The presence of two possible oil reservoirs at comparatively shallow depths, the Reef limestone and the Bear Rock dolomite, was a favourable factor.

Summary Log of Morrow Creek No. 1 Well--Elev. 313 Feet

Formation	Lithology	Depth in Feet
Recent	Sands, silts, etc.	0 to 30
Fort Creek	Upper shale member	30 to 758
Fort Creek	Bituminous member	758 to 994
Fort Creek	Reef limestone member	994 to 1,064
Fort Creek	Basal limestone member	1,064 to 1,104
Fort Creek	Lower shale member	1,104 to 1,610
Ramparts	Beavertail limestone	1,610 to 1,767
Ramparts	Ramparts shale and limestone	1,767 to 1,965
Bear Rock	Dolomitic limestone	1,965 to 2,024

A strong flow of sulphur water was encountered at a depth of 2,024 feet, and the well was abandoned. This water flowed a full stream in the 7-inch casing with a pressure of 160 pounds per square inch at the surface. The temperature of the water was 90°F, and the flow was estimated at 24,000 barrels a day.

A complete analysis of the warm water from the Morrow Creek well gave the following result:

	Parts Per Million	Per cent Total Solids
Potassium (K_1)	Trace only	--
Sodium (Na_1)	8,600	32.2
Calcium (Ca_2)	978	3.7
Magnesium (Mg_2)	287	1.1
Iron and Aluminum (Al_3, Fe_3)	---	---
Chloride (Cl_1)	12,920	48.2
Sulphate (SO_4)	3,960	14.8
Hydroxide (OH)	--	--
Carbonate (CO_3)	--	--
Bicarbonate (H_2CO_3)	--	--

Free hydrogen sulphide-35.3 parts per million
Total solids by evaporation--27,100 parts per million
Specific gravity of the water at 60°F.--1.023

SEEPAGE LAKE NO. 1A WELL

This well was located about a mile northeast of the Discovery well of the Norman Wells field. The designation 1A was given because Seepage Lake No. 1 well was abandoned at a depth of 268 feet, and hence was not a test. The tools were lost in the hole, and a large bit was not recovered. The rig was then skidded 15 feet and well 1A was drilled. This well location was made because of an oil seepage on a small lake nearby, and, because the Reef limestone is known to extend up dip towards the well from the proven field. The well was drilled to a total depth of 1,636 feet. No evidence of oil or gas was encountered in the drilling. Cores and formation tests at various horizons proved that the zones tested were barren. It will be noted that the Reef limestone is very thin.

Summary Log of Seepage Lake No. 1A Well--Elev. 554 Feet

Formation	Lithology	Depth in Feet
Recent	Sands, silts, etc.	0 to 60
Fort Creek	Upper shale member	60 to 643
Fort Creek	Bituminous shale member	643 to 989
Fort Creek	Reef limestone member	989 to 1,035
Fort Creek	Lower shale member	1,035 to 1,545
Ramparts	Beavertail limestone	1,545 to 1,636

LOONEX NO. 1 WELL

Loonex No. 1 well was located about 5 miles due south of Mackenzie River (See map), on the plunging western end of the Loon Creek anticline. According to the evidence of the seismograph, it was expected that a thick development of Reef limestone underlay this site, and the Beavertail limestone plunges westward from Loon Creek No. 1 well. Actually the Beavertail limestone between Loon Creek No. 1 and Loonex No. 1 wells was found to plunge westward at about 200 feet to the mile, but the Reef limestone was entirely absent (See log).

Summary Log of Loonex No. 1 Well--Elev. 567 Feet

Formation	Lithology	Depth in Feet
Recent	Silt and clay	0 to 30 ?
Cretaceous	Shale and sandstone	30? to 1,325
Imperial	Sandstone and shale	1,325 to 2,230
Fort Creek	Upper shale member	2,230 to 3,080
Fort Creek	Bituminous shale member	3,080 to 3,580
Fort Creek	Lower shale member	3,580 to 3,990
Ramparts	Limestone and shale	3,990 to 4,377
Bear Rock	Dolomitic limestone	4,377 to 4,564

Formation tests were made in the limestone in the upper part of the Ramparts formation and also in the Bear Rock dolomite, but only drilling mud was recovered. There was no evidence of oil or gas, and the well was abandoned.

LOON CREEK NO. 1 WELL

This well was located on the west bank of Loon Creek about 4 miles south of its junction with Mackenzie River. The site is near the crest of a small anticlinal structure that is shown by exposures of Cretaceous sandstone and shale in Loon Creek. Here the regional southward

dip is interrupted for a short distance, and the beds dip northward at angles varying from 4 to 10 degrees. The anticlinal structure is verified by geophysical evidence. A seismograph survey indicated that the Loon Creek structure is a sharp nose with an east-west trend and westward plunge. Closure to the east was verified later by seismograph survey, and was re-checked and verified by the drilling of Loon Creek No. 2 well. The continuation of the anticlinal uplift was followed by the seismograph for 10 to 15 miles eastward from Loon Creek No. 1 well. The well was drilled to a total depth of 5,442 feet.

Summary Log of Loon Creek No. 1 Well--Elev. 512 Feet

Formation or Group	Lithology	Depth in Feet
Recent	Silts and clays	0 to 30?
Cretaceous	Shales and sandstones	30? to 485
Imperial	Sandstone and shale	485 to 1,095
Fort Creek	Upper shale member	1,095 to 2,215
Fort Creek	Bituminous shale member	2,215 to 2,612
Fort Creek	Limestone shale member	2,612 to 2,636
Fort Creek	Lower shale member	2,636 to 3,205
Ramparts	Limestone and shale	3,205 to 3,545
Bear Rock	Dolomitic limestone and anhydrite	3,545 to 3,970
Ronning	Dolomitic limestone	3,970 to 5,452

Cores were taken at the following depths: 381 to 391, 481 to 491, 515 to 533, 2,912 to 2,924, 3,191 to 3,219, 3,557 to 3,574, 3,613 to 3,674, 4,433 to 4,445, and 4,894 to 4,912 feet.

The drilling depths to various horizons verified predictions from surface observations and the seismic work. The formations were, however, found to be thickening to the west to a somewhat greater degree than anticipated. Seven different formation tests were made, extending from near the top of the Ramparts (Beavertail) limestone to near the base of the Bear Rock dolomite. No flow of gas, oil or water was evident, and the well was abandoned.

VERMILION RIDGE NO. 1 WELL

This well was located about 25 miles east of Norman Wells and about 5 miles from Mackenzie River in a direct line. The well is near the base of Discovery Range, a broad anticlinal structure, the well site being far down the southwest flank where a reversal of dip in the Fort Creek shales suggested a minor anticline. The regional or normal dip of the strata is toward the southwest, and the reverse or northeast dip extends for a very short distance and probably represents crumpling in the shale and not more than a slight flattening, if any, in the more deeply buried and competent limestones. It was hoped that this structure might form traps for accumulation of petroleum in the Reef limestone, the Ramparts-Beavertail, or the Bear Rock brecciated dolomite. The well, however, started below the Reef limestone and therefore deeper in the section than was anticipated. These upper horizons having failed to produce oil, the well was drilled to the Cambrian strata in order to test all likely horizons for petroleum, but without success.

The Vermilion Ridge No. 1 well, however, was drilled deeper both vertically and stratigraphically than any previous well, and at the time of writing is the deepest well in the Northwest Territories.

Noteworthy in the log is the thick section of rock salt and the salt series. Supplementing the rotary drill samples, in the making of the log, are numerous core samples and an electrolog.

Summary Log of Vermilion Ridge No. 1 Well--Elevation 1,055 Feet

Age	Formation	Lithology	Depth in Feet
Upper Devonian	Lower Fort Creek	Dark brownish grey shales	0 to 470
Middle Devonian	Ramparts	Mainly limestone with lesser shale	470 to 853
Silurian or Devonian	Bear Rock	Dolomitic limestone with pyritic nodules; carbonaceous partings; anhydrite in lower part.	853 to 1,297
Silurian	Ronning	Dolomitic limestone, hard and dense; interbedded with anhydrite and green shale	1,297 to 2,799
Cambrian	Macdougal	Green and red shale with dolomite and gypsum, shale and gypsum at the base ...	2,799 to 3,369
	"	Salt Series: Mainly rock salt, 3,369-4,402; limy siltstone with salt and gypsum, 4,402-4,470; mainly salt with lesser amounts of limy and silty beds, 4,470-4,656; mainly siltstone with lesser 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 to 5,582
Middle Cambrian	"	Greenish grey shale ...	5,582 to 5,788
	"	Shale, greenish grey and purple, finely laminated and calcareous; fossils abundant, chiefly small trilobites.....	5,788 to 5,972

Cores were taken at the following depths: 480 to 506, 845 to 945, 995 to 1,072, 1,333 to 1,353, 1,819 to 1,839, 2,103 to 2,121, 2,374 to 2,394, 2,650 to 2,668, 2,801 to 2,821, 4,450 to 4,470, 5,255 to 5,275, and 5,788 to 5,806.

Formation tests showed no evidence of oil, water, or gas and the well was abandoned.

RAIDER ISLAND NO. 1 WELL

This well is located on Raider Island about 7 miles downstream from Norman Wells and the proven field. The location of the well was made entirely as the result of geophysical work. Seismograph results were inconclusive, but the gravimeter suggested a thickening of the Reef limestone. Hence the well was drilled in the hope of finding oil in this limestone. The gravimeter showed a low anomaly over Raider Island, which much resembled the gravity low over the proven field, and the two lows have similar trends. This similarity was interpreted as probably representing a reef, underlying Raider Island. The strata in the vicinity have a general southwest dip of about 5 degrees. No reversal to this is known, and so the hoped for condition here was a stratigraphic trap similar to that at Norman Wells. The well was drilled to a total depth of 2,190 feet. The Reef limestone was found to be extremely thin, and hence, the low gravity anomaly was due to other causes.

Apparently, only basal limestone of the Reef member was encountered. This was cored for 40 feet, and revealed low permeability. A formation test yielded drilling fluid only, and the well was abandoned. The following is a summary log:

Log of Raider Island No. 1 Well--Elev. 331 Feet

Formation	Lithology	Depth in Feet
Recent	Sands, silts, etc.	0 to 50
Cretaceous	Mainly shale, some sandy shale	50 to 312
Imperial	Sandstone and shale	312 to 810
Fort Creek	Upper shale member	810 to 1,795
Fort Creek	Bituminous shale member	1,795 to 2,035
Fort Creek	Basal Reef limestone member	2,035 to 2,080
Fort Creek	Lower shale member	2,080 to 2,190

SANS SAULT NO. 1 WELL

This well is located on the left bank of Mackenzie River at Sans Sault Rapids, about 70 miles downstream from Norman Wells. At this site an anticlinal structure is well exposed in an outcrop of Lower Cretaceous shales on the left bank of the river.

The axial trend is about north 80 degrees west, and the dip of the strata does not exceed 5 degrees. Eastward closure along the strike is clearly indicated, but closure to the west is assumed but uncertain. Small faults are seen in the Cretaceous outcrops, but it is thought that the more deeply buried and competent Devonian limestones are unaffected. This anticlinal structure at the well site is, however, a minor feature, and lies between two major uplifts, East Mountain and West Mountain. In the crest of these major uplifts Middle Devonian strata are exposed within a distance of 5 miles. The objective of this well was to test three horizons:

1. The Reef limestone member of the Fort Creek formation, reported to be highly bituminous in outcrops.

2. The Beavertail limestone, porous and permeable in that region.

3. The Bear Rock formation of fractured and brecciated dolomite, which is often petroliferous. It is commonly porous, sometimes cavernous, and would form an excellent reservoir.

The drilling disclosed less than 100 feet of the Fort Creek formation. Apparently the rest of the Fort Creek beds had been removed by erosion before the overlying Cretaceous strata were laid down; hence there was no reef and this eliminated one possible reservoir. No oil or gas was encountered in the Beavertail limestone. A formation test of the Bear Rock formation yielded water only. Analysis of the water showed sufficient sodium chloride to suggest that the Bear Rock dolomite at Sans Sault carries formation water, but in small amount. The well was drilled to a total depth of 3,291 feet and abandoned.

It was originally planned to test the more deeply buried formations in this well; but mechanical difficulties, and the negative results obtained in the prospective horizons penetrated, resulted in this project being abandoned.

Summary Log of Sans Sault No. 1 Well--Elev. 318 Feet

Formation or Group	Lithology	Depth in Feet
Sans Sault	Mainly shales	0 to 1,337
Fort Creek	Lower shale member	1,337 to 1,408
Ramparts	Beavertail limestone member	1,408 to 1,845
Ramparts	Shale and limestone member	1,845 to 2,925
Bear Rock	Brecciated dolomitic limestone	2,925 to 3,291

Cores were taken at the following depths: 1,409 to 1,424, 1,710 to 1,728, 1,955 to 1,991, 2,531 to 2,544, 2,783 to 2,801, and 3,086 to 3,123 feet.

LOON CREEK NO. 2 WELL

This well site is about 16 miles upstream from Norman Wells, and about 3 miles inland from the south bank of Mackenzie River. It lies in an area of low relief in which there are no outcrops of bedrock, and no topographic features that might suggest the trend of the rock structure. The location of the well was based entirely on the results of reflection seismograph surveys. These indicated the presence of a structural high trending eastward from Loon Creek No. 1 well. A seismic survey had previously been made of the region between Loonex No. 1 well and Loon Creek No. 1 well, and the drilling of these wells provided a check on the calculations. As a result of this work it was possible to map an anticlinal structure running eastward toward Loon Creek No. 2 location. Calculations of the depth to the reflecting horizon indicated that it was considerably higher at the Loon Creek No. 2 location than at Loon Creek No. 1. Actually the Beavertail limestone member of the Ramparts formation was 1,386 feet higher structurally at No. 2 well than at No. 1 well. Possible oil reservoir horizons that might be encountered were porous limestone or sandstone lenses in the Fort Creek formation, and also the Bear Rock formation. The anticlinal structure also made it a favourable location for testing the more deeply buried older formations. The well was drilled to a total depth of 5,093 feet without favourable results, and was abandoned. A formation test was made at 1,804 to 1,850 feet.

Cores were taken at the following depths: 1,804 to 1,824, 2,152 to 2,170, 2,266 to 2,284, 2,630 to 2,648, 3,764 to 3,777, 4,032 to 4,047, 4,585 to 4,596, 4,772 to 4,792 and 5,077 to 5,093 feet. Hydrogen sulphide gas was noted at 2,250 to 2,270 feet.

Summary Log of Loon Creek No. 2 Well--Elev. 493 Feet

Formation or Group	Lithology	Depth in Feet
	Sands, silts, etc.	0 to 150
Imperial	Sandstone and sandy shale	150 to 440
Fort Creek	Upper shale member	440 to 1,100
	Canyon member, shale and sand	1,100 to 1,210
	Lower shale, and sand	1,210 to 1,805
Ramparts	Beavertail limestone member	1,805 to 1,940
	Shale and interbedded limestone	1,940 to 2,275
Bear Rock	Brecciated and bedded dolomitic limestone; much anhydrite near base	2,275 to 2,615
Ronning	Dolomitic limestone, hard, dense and cherty; streaks of anhydrite near the top, and some shaly beds near the base	2,615 to 4,610
Macdougal	Red and green shales becoming silty; with gypsum streaks near the base .	4,610 to 4,775
	Salt Series: rock salt with brown and green shales and siltstones ...	4,775 to 5,093

CANYON NO. 1 WELL

This well is located on the northeast bank of Mackenzie River, about 15 miles upstream from Norman Wells, and on the southwest flank of Discovery Range, a major uplift. The structure at the site is monoclinal, and the dip of the beds is gentle, probably less than 5 degrees toward the southwest. The location was chosen for the purpose of testing the Canyon sandstone and the possibility of finding a limestone reef in the Fort Creek shales. The Canyon sandstone is a local lens that has been mapped in the area between Canyon Creek and Vermilion Creek, but was not found farther upstream at the Bluefish No. 1A well, nor downstream in the Norman Wells oil field. The Canyon sandstone does, apparently, extend southwest and is represented in the Loon Creek No. 2 well by some 110 feet of sandy beds. This sandstone horizon occurs in the rock sequence immediately above the bituminous shale member of the Fort Creek formation, and is fully developed on Prohibition Creek where, in early estimates, a thickness of 300 feet was reported, and in places it shows a slight oil saturation. The primary purpose of the Canyon No. 1 well was, therefore, to test this Canyon sandstone where most fully developed and at some distance down the dip from its line of outcrop. The well was drilled to a total depth of 2,066 feet. Cores were taken at the following depths: continuous cores from 1,236 feet to 1,363 feet, also 1,390 to 1,400, 1,860 to 1,874, 2,027 to 2,046, and 2,046 to 2,066 feet. Formation tests were made at 1,236 to 1,276, 1,276 to 1,332, and 2,027 to 2,066 feet. These yielded only drilling fluid, and as there was no evidence of any flow of oil or gas, the well was abandoned. The Canyon sandstone was fine-grained, with many shale bands, and yielded only an odour of petroleum.

Summary Log of Canyon No. 1 Well--Elevation 310 Feet

Formation	Lithology	Depth in Feet
Recent	Sands and silts	0 to 10
Imperial	Greenish sandstone and shale	10 to 325
Fort Creek	Dark grey shale with limy bands	325 to 1,231
Fort Creek	Canyon sandstone member; fine-grained sandstone and sandy shale; certain streaks have a strong petroleum odour	1,231 to 1,328

Fort Creek	Dark grey shale with some sandy shale ..	1,328 to 1,585
	Black bituminous shale with limy streaks and some pyrite at the base	1,585 to 2,025
Ramparts	Beavertail limestone member	2,025 to 2,066

JUDILE NO. 1 WELL

This well was located on the northeast bank of Mackenzie River about 30 miles downstream from Norman Wells. In that vicinity, on Judith and Perry Islands, anomalous dips in Cretaceous strata suggested local folding. Gravimeter survey parties reported gas that would burn, in seeps on the right bank of Mackenzie River near the well site.

A seismic survey party reported similar gas in shallow (50-foot) shot holes on the left bank of the river, opposite the upstream end of Perry Island. A study of the geology in that locality showed that there were three possible reservoir horizons, commonly bituminous, underlying the site selected; and that these horizons lay at reasonably shallow depth and could be tested by a hole 3,000 feet deep.

1. The Reef limestone of the Fort Creek formation is the shallowest. It outcrops and is quite thick in the Hoosier Ridge structure nearby, but on the opposite side of the river.

2. The Beavertail limestone member of the Ramparts formation is reported to be reef-like and bituminous in that region.

3. The Bear Rock formation was porous and permeable in the Morrow Creek and Hoosier Ridge wells, but carried water only. It was thought, however, it might carry oil if drilled on a structural trap.

The well was drilled to a total depth of 2,815 feet. No oil or gas was encountered, and the well was abandoned. All the objectives were penetrated without favourable results. The depth to the Bear Rock formation was only 50 feet less than predicted in the projected log. A considerable thickness of Reef limestone was encountered in the Fort Creek formation, but it yielded no oil. Likewise the Beavertail member of the Ramparts formation and the Bear Rock formation apparently had no appreciable porosity or permeability, and were barren.

Summary Log of Judile No. 1 Well--Elevation 437 Feet

Formation	Lithology	Depth in Feet
Recent	Sands, silts, etc.	0 to 60
Cretaceous	Shales, mainly	60 to 315
Imperial	Sandstone, mainly	315 to 653
Fort Creek	Upper shale member	653 to 1,252
	Bituminous shale member.....	1,252 to 1,305
	Reef limestone member	1,305 to 1,835
	Lower shale member	1,835 to 2,306
Ramparts	Beavertail limestone member	2,306 to 2,500
	Lower shale member	2,500 to 2,608
Bear Rock	Dolomitic limestone and anhydrite	2,608 to 2,815

CANYON NO. 2 WELL

This well was located on the right or northeast side of Mackenzie River about 18 miles upstream from Norman Wells, and about 2 miles back from the river on Prohibition Creek. This general area lies on the southwest flank of Discovery Range, which forms the southwest limb of a major uplift. The underlying strata in the vicinity of the well site are Upper Devonian in age, and have a monoclinal dip of about 7 degrees toward the southwest.

The sole object of this well was to test the Canyon sandstone member of the Fort Creek formation. The Canyon sandstone is known to be a lens of very limited distribution, and it outcrops on Prohibition Creek. At this outcrop the sandstone, with numerous interbedded shale bands, was originally estimated to have a considerably greater thickness than is found in the Canyon No. 1 and No. 2 wells. It also shows some oil saturation, and was described as an oil sand. Showing such evidence of the presence of oil at the outcrop and in Canyon No. 1 well, it was decided to test the area between, in the hope that a lens with oil in commercial quantity might be found.

The well was drilled to a total depth of 805 feet. The Canyon sandstone was encountered at 667 feet. Cores were taken at 664 to 765 feet continuously and from 795 to 805 feet. Although some of the more sandy but thin bands showed a slight saturation of light petroleum there was no flow, and a formation test yielded drilling fluid only. Consequently the well was abandoned.

As in Canyon No. 1 well, the cores of the Canyon sandstone showed that the arenaceous beds were very fine-grained, with much shale interbedded. This local sandy member of the Fort Creek formation was apparently much overrated as a possible petroleum reservoir, and there seemed to be no closure of the sandy lenses on the up-dip side of the monocline.

Summary Log of Canyon No. 2 Well--Elevation 463 Feet

Formation	Lithology	Depth in Feet
Recent	Sands, silts, etc.	0 to 10
Fort Creek	Upper shale member	10 to 667
	Canyon sandstone member	667 to 760
	Dark grey shale, some black and bituminous	760 to 805

SUMMARY AND CONCLUSIONS

Indications of petroleum in the rocks along Mackenzie River were noted by McConnell in his report of 1888-89, and oil seeps on the north bank of the river led to the staking of claims at Norman Wells in 1914.

In 1920 the first well was drilled and oil in commercial quantity discovered. Later a small refinery was built to supply the local demand for motor fuel.

Prior to the start of the Canol Project in 1942, four producing wells had been drilled. These were sufficient to supply the local demand. Distance from outside markets precluded any expansion in that direction.

Under the Canol Project sixty productive wells and three dry holes were drilled in the Norman Wells field. The No. 1 Discovery well had been plugged and abandoned in the summer of 1944, because it had gone largely to gas and was located only 150 feet from the No. 2 well, so that when the Canol Project was terminated there was a total of sixty-three potentially productive wells in the proven field. These wells completely outlined the productive area, and showed that it extended beneath the river and across to Bear and Goose Islands.

The oil occurs in the Reef limestone of the Fort Creek formation. The structure is monoclinal, the strata dip about 4 degrees toward the south or southwest, and the oil is contained by a stratigraphic trap, the reef wedging out up the dip. According to latest estimates, the productive

section of the reef covers an area of approximately 4,010 acres of which 1,870 acres underlie Mackenzie River. The true reef, with saturated sections varying from 0 to 388 feet thick, attains a maximum thickness of 400 feet.

This true reef has grown on a barren, basal limestone about 100 feet in thickness, and extends over a wide area beyond the limits of the productive field. Oil saturation in the reef is irregular both horizontally and vertically. It is estimated that a total of 460 of the 1,870 acres covered by Mackenzie River can be drained by directional drilling. This gives a total drainable area of 2,600 acres in the proven field. Early estimates of recoverable oil reserves of the Norman Wells field were of necessity by the porosity-area method and were based largely on assumptions. These estimates varied all the way from 30 to 63 million barrels. Drilling and production of oil for the Canol Projects ended in March 1945, after which a bottom hole pressure survey was made of the field. With the additional data available from this survey an estimate by the pressure-decline method gave approximately 36,250,500 barrels of recoverable oil reserves. When the Canol agreement was terminated, the field was producing at the rate of about 4,000 barrels a day. With the end of the contract, the pipe line and the refinery at Whitehorse ceased operations. This closed the outlet for the bulk of the crude. Estimates of crude requirements for the local refinery, to supply products for the local market in the coming year, are only 75,000 barrels, plus crude requirements of the Norman Exploration program.

To reach outside markets and meet competitive prices, the development of petroleum on an economic basis in Mackenzie River Valley is dependent on finding oil reserves in sufficient quantity to justify a large pipe line. The distance from outside markets is so far and the terrain so rough and difficult that transportation costs will be high. The per barrel cost can only be cut down by large scale production sufficient to assure a supply of 40 to 50 thousand barrels a day. This production would have to continue a sufficient time to permit earnings to amortize capital expenditures and interest charges as well as costs of operation and maintenance. It is for this reason that the Norman Exploration Branch of Imperial Oil Limited have continued the search for new fields, by means of geological and geophysical surveys as well as by exploratory deep wells.

The results of wildcat drilling to date have been extremely disappointing. The bituminous nature of many of the beds and the occurrence of petroleum seepages gave reason to believe that accumulations of petroleum would be discovered when drilling tests were made in favourable localities. Difficulties of transport at present restrict freedom of choice of drilling locations. For example, summer locations must be made close to navigable rivers; this practically means close to Mackenzie River, because few tributary streams are navigable, with heavy equipment, for any appreciable distance. Travel overland in summer is not feasible, as the lower Mackenzie Valley is largely muskeg, and road building costs would be prohibitive unless the success of drilling operations were assured. Consequently, exploratory drilling any appreciable distance from Mackenzie River must be done during winter when the ground is frozen. This in turn means that a base camp must be established at the nearest point on the river, and all heavy equipment and supplies shipped there by river boat during the season of river navigation. All this slows up work, and there are still a few known favourable locations that are planned to be tested.

Several of the exploratory wildcat wells have been drilled on monoclinal structures in the hope of finding stratigraphic traps. In most instances these locations were drilled as a result of gravity or depth anomalies discovered by geophysical methods. Although the tests have been unsuccessful, they were necessary in order to explore all possibilities.

The Bear Rock formation of Middle Devonian age appears to be the most promising reservoir horizon. It is essentially a dolomite with coarse breccia in places and in places is petroliferous. In the outcrop at least, it is commonly very porous and in part cavernous. It is fairly regular in thickness and widespread in distribution. Consequently high hopes were entertained of finding oil accumulations in structural traps. The results so far have been negative, and the only indication of high porosity was at Morrow Creek No. 1 well where the Bear Rock formation yielded a large flow of warm sulphur water. In other wells drilled on known structural highs the Bear Rock dolomite appeared to have low permeability and yielded no oil and little or no water. For comparison a summary log of a typical well in the proven field is given.

Summary Log of Bear Island No. 5 Well--Elev. 296 Feet

Formation	Lithology	Depth in Feet
Glacial and Recent	Sands, clays, etc.	0 to 240
Cretaceous (Undifferentiated)	Mainly shales	240 to 340
Imperial	Sandstone and shale	340 to 850
Fort Creek	Upper shale member	850 to 1,595
Fort Creek	Bituminous shale member	1,595 to 1,725
Fort Creek	Reef limestone member	1,725 to 2,056 +

On March 8th, 1945, when all drilling and oil production for the Canol Project was stopped, the following was the status of the wells completed in this region by Imperial Oil Limited, or under their supervision:

	Canol Project Wells	Imp. Oil Ltd. Pre-Canol Wells	Imp. Oil Ltd. Norman Exploration	Totals
Producers	60	4	--	64
Edge well failures	3	1	--	4
Wildcats	4	1	4	9
Totals	67	6	4	77

On October 1st, 1945, the wildcat drilling program of Imperial Oil Limited had extended the area tested and added 9 to the number of completed wildcat wells, giving a total of 87 wells drilled in this region.

Although the drilling to date in Mackenzie River Valley has discovered no oil fields other than the Norman Wells pool, it cannot be said that the region has been adequately tested. The area to be explored is large, and not only contains rocks in which petroleum commonly originates, but direct evidence in the form of oil seepage and saturation occurs in many places. As recently as the summer of 1945, a seepage of tarry oil was discovered some 60 miles north of Fort Good Hope. It occurs on a hillside covering several hundred square feet and can be seen from a plane. This seepage has, apparently, been known to local native trappers for a long time, and may be the tar springs mentioned by McConnell[1], but which he did

[1] McConnell, R.G.: Geol. Surv., Canada, Ann. Rept. vol. IV, pt. D, p. 31 (1888-89).

not visit because of their distance from the river.

Any region within easy reach of markets and modern transportation facilities, showing similar promise in the way of oil seeps and bituminous matter in the rocks, would certainly have been much more thoroughly tested years ago.