CANADA
DEPARTMENT OF MINES
HON. CHARLES STEWART, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

GEOLOGICAL SURVEY
W. H. COLLINS, DIRECTOR

ECONOMIC GEOLOGY SERIES
No. 5

Oil and Gas in Western Canada

BY
G. S. Hume

OTTAWA
F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1928

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PREFACE

The importance of developing in Canada a petroleum production sufficient to meet the needs of the country may be judged from the fact that the value of imports of petroleum and petroleum products for the year 1925 exceeded $40,000,000. The Ontario fields until that year yielded the greater part of the annual oil production and a few thousand barrels were produced annually in New Brunswick and Alberta. In 1925, however, the production from Alberta, due principally to the yield from Royalite No. 4 well in Turner Valley field, increased from less than 1,000 barrels in 1924 to more than 169,000 barrels, thus making Alberta the leading petroleum-producing province of the Dominion. The production from Wainwright area, as well as the further development of Turner Valley field, resulted in a further increase in production in 1926, whereas production in Ontario and New Brunswick declined and will continue to do so unless new fields are opened, a possibility that at the present time seems rather remote.

Oil and Gas in Western Canada

CHAPTER I

ORIGIN AND ACCUMULATION OF OIL AND GAS[1]

ORIGIN OF PETROLEUM

The origin of petroleum is discussed in almost every text book on petroleum geology and, therefore, only a brief outline of the subject need be given here. There are a number of theories and these may be grouped into two major classes: (1) inorganic; and (2) organic.

INORGANIC THEORIES

It has been suggested that water acting on metallic carbides in the earth might produce hydrocarbons. The objections to this theory are clearly presented by Stigand who states:

"The existence of improbably large quantities of metallic carbides, within access in the earth, would be required, if only to suffice for originating the amount of petroleum which has been produced, as the amount of metallic carbides demanded is very great in proportion to the petroleum that can be produced from them. Furthermore, the circumstances that large deposits of bitumen or petroleum are only found in the stratified rocks, that the deposits found in the strata of younger age predominate, and that very frequently barren porous beds are intercalated in the petroliferous beds, or the strata subjacent to an oil series do not contain petroleum, all tend to constitute evidence contrary to the supposition of deep-seated origin."

There are also other theories based on chemical reactions between various substances, but in most cases the objections to these theories are so convincing to the field geologist, that they are dismissed by him as being highly improbable.

ORGANIC THEORIES

Theories of organic origin assume that petroleum is formed by biochemical, geochemical, and geophysical agents acting on plant and animal detritus buried in sediments. There is much field evidence to support this assumption, and in the laboratory petroleum is readily formed by the distillation of certain animal and plant remains. Some difference of opinion exists regarding the character of the material from which the oil is supposed to be derived; in all probability the materials are not the same for different kinds of petroleum. Amongst other substances the following have been suggested: (1) marine animals such as molluscs, corals, etc., and, possibly, fish remains; (2) marine plant and animal micro-organism such as diatoms, algæ, and protozoa (foraminifera); (3) marine plants such as fucoids, etc.; and (4) terrestrial plants.

[1] Text books on petroleum geology: "Oil Finding," by E. H. Cunningham Craig; "Practical Oil Geology," by D. Hager; "Geology of Petroleum," by W. H. Emmons; "Outlines of the Occurrence and Geology of Petroleum," by I. A. Stigand; "Popular Oil Geology," by Victor Ziegler.

Since in most cases oil is associated with marine strata or can be shown to have possibly migrated from marine strata, it may be that salt water influenced the changes undergone by the source material before it was deeply entombed in the sediments. Anerobic bacteria work best in the presence of salt water. They destroy the cellulose of plants, leaving the waxy and fatty materials, and these are the substances that give rise to oil according to some exponents of the organic theory, the materials being spores, algæ, and fatty and resinous matter.

According to Rae:[1]

"Microscopic work on shales associated with oil deposits has shown the presence of an unknown, rich, dark, organic, ulmohumic groundmass. . . . . . Rivers and streams act as the concentrating agents for millions of tons of organic material, which are later incorporated into marine or inland lake deposits. By subsequent pressure, heat, or catalytic agents, the organic material is converted into petroleum".

Evidence has been brought forward to support the view that petroleum forms from each of the source materials suggested. In certain cases the close association of possible source materials with the petroliferous beds seems to offer almost conclusive evidence of origin. For example, the presence of an abundance of diatoms and foraminifera in the Eocene of California led Arnold to conclude that the oil in the overlying Miocene was derived from them. In other places the association of coal with petroleum has given rise to the suggestion that the petroleum as well as the coal has been derived from terrestrial vegetation, but, as pointed out by Stigand, it may be that it is marine vegetation that is involved for

"It is under shallow water conditions such as on littoral or estuarine tracts or in basins, that petroliferous strata have most frequently been formed. Furthermore, series of strata containing petroleum often exhibit evidence of former land surfaces the presence of which must have been preceded and followed by extensive shallow water conditions and shifting tidal regions; this would be more particularly significant in the case of formations containing successions of coal and lignite seams . . . . . . which indicate secular oscillations centring about sea-level."

Such conditions on tidal flats are favourable for the growth of marine vegetation that possibly may have been the source of petroleum in such cases.

Differences in the compositions of the source materials necessarily mean differences in composition of the petroleum formed from them. Changes in the composition of petroleum may arise subsequent to formation as a result of filtration during migration and of interactions between the petroleum and substances in the formations through which it has passed. There may be losses due to natural distillation and the escape of the lighter volatile materials. Thus the petroleum found in an oil-field may differ quite widely in composition from the petroleum as first formed, a fact that makes it very difficult to determine the character of the material from which the oil has been derived.

ACCUMULATION OF OIL AND GAS

Under any view of the organic origin of oil, the source material is widely distributed through the containing sediments and, therefore, the oil when first formed must also be widely disseminated. In order that oil-fields may form it is necessary that the oil should collect in porous strata within a limited area.

[1] Rae, Colin, C.: "Organic Materials of the Carbonaceous Shales"; Am. Ass. Petroleum Geologists, vol. VI, No. 4, pp. 340–341.

CAPILLARY THEORY OF ACCUMULATION

If a clean glass tube of fine bore is dipped into water, the water rises inside the tube to a higher level than the surface of the external water. This tendency of liquids to enter minute openings or pores, such as is illustrated by a glass tube or by the absorption of water by blotting paper, is the result of capillary action.

Experimental evidence led McCoy[1] to believe that capillarity is the main force causing oil in a water-saturated sand to migrate, thus making possible the accumulation of oil in reservoirs capable of retaining it. Washburne[2] has stated that, "since water has about three times the surface tension of crude oil, capillary action must exert about three times as much pull upon it. The amount of the capillary pull varies inversely as the diameter of the pore. Hence the constant tendency of capillarity is to draw water, rather than oil, into the finest openings, displacing any oil or gas in the latter." Shale contains much smaller pore spaces than sand and consequently any slow flow between shale and sand would drive oil from the fine pores in the shale and concentrate it in the coarser pores of the sand. Since gas is not drawn into capillary openings by the action of surface tension and there is no capillary resistance to its movement, it is much more readily concentrated in the coarser pores than oil. It is possible, according to Washburne, where there is no flow between shale and sand, that the force of capillarity alone would be sufficient to draw enough water into the shale to displace the oil and to concentrate it in the coarser pores of the sand. In water-free rocks, oil, because of capillarity, would be drawn into the finer pores and hence the result would tend to be diffusion rather than concentration.

There are limits to the sizes of pores in which capillarity can act. In pores greater than 0·508 mms. in diameter there is no capillary action in the case of pure water. The minimum diameter, according to Washburne, is more uncertain, but is usually placed at 0·0002 mms. In such small openings it has been shown[3] that the adhesion is so great that it overcomes the capillary force.

Though in the case of small pores the capillary attraction of water is, theoretically, three times as great as that of oil, certain conditions may greatly modify this force. The capillary action of water in a pore having a thin film of oil is not nearly as great as in a pore that contains no oil, therefore, where water is moving into a finely porous bed and displacing oil originally in that bed, the capillary force exerted by the water is not three times that of oil. Under such conditions the force of capillarity will not be nearly as effective in concentrating oil in the coarser pores as might be supposed.

HYDRAULIC THEORY OF ACCUMULATION

Experimental studies by Mills[4] led him to believe that capillary adjustments between oil and water in saturated strata are restricted to short lateral ranges and that wide movements of oil due to such forces are

[1] McCoy, A. W.: "Some Effects of Capillarity on Oil Accumulation"; Jour. of Geol., vol. 24, No. 8, pp. 798-805 (1916).

[2] Washburne, C. W.: "The Capillary Concentration of Gas and Oil"; Trans. Am. Inst. Min. Eng., vol. 50, pp. 830 (1914).

[3] Johnston and Adams: Jour. of Geol., vol. 22, pp. 1-15 (1914).

[4] Mills, R. Van A.: "Experimental Studies of Subsurface Relationships in Oil and Gas Fields"; Ec. Geol., vol. 15, pp. 398-421 (1920).

the exception rather than the rule. He concluded that the up-dip migration of oil and gas under the propulsive force of their buoyancy in water, as well as the migration of oil either up- or down-dip caused by hydraulic currents, is among the primary factors influencing the accumulation of oil. The movement of oil under the action of currents is what has been termed the hydraulic theory of oil and gas accumulation.

This theory was developed by Munn[1] and a general statement regarding it was published by Rich[2] who states:

"The principal cause of the migration of oil and gas is the movement of underground water which carries with it minute globules of oil and bubbles of gas, possibly as fast as they are formed. Accumulation results from the selective segregation of oil and gas, which on account of their buoyancy always tend to work their way upward as they are carried along and are caught and retained in anticlinal or other suitable traps.

The nature of the trap necessary to cause accumulation depends on the rate of movement of the water and corresponding texture of the sands or other medium through which it flows. Where the sands are porous and there is a strong hydraulic head a sharp anticline with large closure is necessary to retain the oil; in fact where the movement is especially rapid, even such a structure may be inadequate. Where the sands are fine and the water movement is slow, slight structural and textural variations are enough to arrest the movement of the oil and gas. Under such conditions broad, flat anticlines with very little closure, terraces, or even minor flattenings of the regional dip, are enough to cause accumulation."

According to this theory any condition which retards the movement of underground water carrying globules or bubbles of oil and gas, will tend to bring about the accumulation of the oil and gas. Such retarding conditions, according to Rich, may be assumed to be present: (1) in anticlinal traps, (2) where the size of rock pores decreases, and (3) where a decrease in the rate of water movements is caused under certain conditions. Rich points out that where oil and gas are carried to an anticline, the buoyancy of oil and gas in the water becomes effective and, as a result, they tend to rise to the top of the structure and to become concentrated there. In cases where the regional dip decreases in amount, giving rise to a terrace structure, there will be a slowing down of the movement of the circulating solutions, and this may be sufficient to cause an accumulation of oil and gas without any reversal of dip. A change from a relatively porous rock to one of less porosity will also cause at least a partial stagnation, allowing the oil and gas to accumulate in the more porous rock, as where a sand lens is surrounded by less pervious parts of the same stratum. It is probable, in such cases, that capillarity plays a considerable part in the accumulation of the oil and gas in the rock with larger pore spaces.

Mills and Rich[2] deduced from experiments that a strong water movement through an anticlinal trap might carry along with it all the oil and gas, allowing no opportunity for them to collect in the top of the trap. Moreover, a strong water flow through an anticlinal trap in which there had already been some accumulation of oil and gas might flush away the accumulated oil and gas or, if only a partial flushing resulted, the oil would probably extend farther down the dip on the lee side of the anticline than on the side by which the water entered. Where the water movement is slow, the oil and gas would first concentrate in the crest of the trap and later additions would be on the side from which the water comes. These

[1] Munn, Malcolm J.: "The Anticlinal and Hydraulic Theories of Oil and Gas Accumulation"; Ec. Geol., vol. 4, pp. 509-529 (1909).

[2] Rich, John L.: "Moving Underground Water as a Primary Cause of the Migration and Accumulation of Oil and Gas"; Ec. Geol., vol. 16, pp. 347-371 (1921).

two cases explain why in some instances the division between oil and water is not at the same level on the two flanks of an oil pool.

STRUCTURAL FEATURES OF OIL POOLS

Oil and gas accumulations are associated with various structural features.[1] The structures of the fields of western Canada are indicated in some detail on later pages, and in this place, therefore, only a generalized consideration is given to the subject, omitting all reference to types of structure not yet recognized in Canada.

ANTICLINAL OR DOMED STRUCTURE

An anticline is an arch-like or dome-shaped fold. If the angle of dip of the two sides or limbs is the same and in opposite directions, the fold or anticline is symmetrical. Any marked departure from this condition produces an unsymmetrical fold and names have been applied to different variations from the ideal form. A dome is a special form of anticline in which the beds dip away from the crest in all directions or quaquaversal fashion.

Regardless of the various theories advanced to account for the accumulation of oil and gas, it is generally agreed that one of the commonest structures in which oil and gas is found is the anticline. In order that oil and gas may accumulate in any anticlinal structure certain conditions are essential: (1) there must be a petroliferous stratum from which oil and gas can be derived. It is thought that oil and gas form from organic materials and originate, respectively, as small globules and bubbles. These must collect if a pool of oil or gas is to form and, no matter what explanation is adopted as the cause of movement, it is agreed that there must be migration of the oil and gas to points where structural conditions allow their accumulation. (2) There must be a porous horizon into which and along which the oil and gas may migrate and be collected in pools of commercial size. Migration for the most part must take place through the pore space of the rocks and the rock of the structural reservoir must be sufficiently porous to hold a large amount of oil and gas if an oil-field is to be formed. The amount of oil and gas at any point will depend, among other things, on the amount of oil and gas available, on the size of the reservoir, and on its efficiency as a retainer of the oil and gas. The size of the reservoir will, in turn, depend on the size of the structure and the degree of porosity of the strata. (3) There must be an impervious cap to prevent upward dissipation of the gas and oil after arrival in a structurally favourable reservoir. A highly suitable cover for an oil reservoir is a fine-grained, wet shale. It has been calculated[2] that at a depth of 1,500 feet the force necessary to make oil migrate through a wet shale (openings 0·01 micron) is about 4,000 pounds per square inch and, therefore, that there could be no migration of oil through such a shale.

In a symmetrical anticline under ideal conditions, the arrangement of gas, oil, and salt water in a porous stratum acting as a reservoir is as follows: the gas occurs on the crest of the fold, the oil underlies the gas and occurs

[1] Clapp, Frederick G.: Bull. Geol. Soc. Am., vol. 28 (1917).
Emmons, W. H.: "Geology of Petroleum," p. 123.
[2] McCoy, Alex. W.: "Principles of Oil Accumulation"; Jour. of Geol., vol. 27, p. 258 (1919).

in the limbs of the fold, and the salt water underlies the oil. This arrangement is such as would result from gravitational segregation. So symmetrical a disposition of the gas, oil, and water does not usually obtain in nature. The anticline may not be of symmetrical form and other factors governing accumulation may also lack symmetry, with the result, for instance, that the oil may be largely concentrated in one limb of a fold. Furthermore, in many oil-fields the high pressures revealed in the early stages of production indicate that much of the gas must be absorbed in the oil. As is the case in a number of western Canada gas-fields a structure may contain gas and salt water, but no oil. The lack of oil in such cases may be due to the fact that gas is much more mobile than oil and consequently may move much farther from its place of origin or may pass through beds so finely porous as to hold back any oil. Other explanations of the absence of oil might be given, as, for example, that metamorphism has proceeded to such a stage that only gas may be present. Regardless of what the explanation may be the fact remains that many of the gas-fields of western Canada yield only "dry" gas which shows no evidence of associated oil.

SYNCLINAL STRUCTURE

A syncline is a trough-like fold. If a porous stratum in such a fold contains oil and gas, but no water, the gas will tend to rise along the limb of the syncline and to segregate at the crest of the succeeding anticline, whereas the oil will tend to sink to the bottom of the downwarp or syncline, the movements in both cases being due to gravity. Such occurrences of oil in synclines are known in Canada, but are exceptional. It is probable that the movement of oil under the influence of gravity alone is relatively weak, because other forces, particularly that of capillarity in a fine-grained stratum, are much stronger. The action of capillarity alone in a water-free sand, is one of diffusion rather than concentration, but, acting in conjunction with gravity, there might be some concentration, especially in the case of a porous stratum having relatively easy channels of movement through large pores where the force of capillarity would be small. It is probable, however, that irregularities in the character of the pore spaces in a sand would tend to make concentration relatively incomplete.

SAND LENSES

It has already been stated that capillary attraction in the case of pores within the critical limits of size is three times as great for water as for oil and for this reason water will penetrate the finer parts of a sand and force oil to the coarser parts. This, probably, is the controlling factor governing the accumulation of oil in those parts of a porous stratum where the pore spaces are largest. These coarsely porous parts of a stratum usually have irregular forms, pinch out laterally, and are in general lens-shaped. Where gas and oil are concentrated in such coarser sand lenses, they may be under high pressure. It has been suggested that the pressure may be due to capillarity, but this idea has been refuted by Washburne.[1] Possibly it is partly due to hydrostatic pressure which in many gas- and oil-fields is nearly equalled by the gas and oil pressure. Sand lenses con-

[1] Washburne, C. W.: "The Capillary Concentration of Gas and Oil"; Trans. Am. Inst. Min. Eng., vol. 50, p. 852 (1914).

taining oil and gas may occur without any relation to other structural features. Since most such lenses are irregular, the gas and oil collect in the higher parts, as in anticlinal structures.

TERRACES

A local flattening of the strata in a region otherwise characterized by a uniform dip gives the terrace structure. Where water carrying along with it oil and gas is moving up the dip and where,[1] the movement is "so slow that, assisted by the gravity component of buoyancy, it is little more than able to move the oil with it, the flattening at the down-dip edge of a terrace might be enough to arrest the movement of the oil and gas and start an accumulation . . . . . . This pool would grow from accretions added on the down-dip side and in time might extend for a considerable distance down the dip from the edge of the terrace. In general a terrace should be able to cause oil accumulation only where the movement of the rock fluids is comparatively slow, so that slight obstacles suffice to arrest the movement of the oil globules."

Johnson and Huntley[2] in discussing the terrace structure assume that where there is a gravitational separation of oil and gas through water there is a critical gradient which will allow oil and gas to accumulate. Where the dip exceeds in amount the critical gradient, the oil and gas will be carried up the dip, but where the gradient falls below the critical gradient the oil and gas will tend to accumulate. It is stated, however, that "it is difficult to ascertain the critical gravitational gradient because of two variables: *(a)* degree and types of porosity, and *(b)* direction and effectiveness of the current within the reservoir"; the current is considered as generally flowing up dip. The terrace, these authors believe, must also be wide, otherwise the oil and gas may escape up the dip. These and other factors have led Johnson and Huntley to regard terraces as of low rank among favourable structures and especially so since structures that appear as terraces on the surface may be absent at depth. Small folds on a terrace structure, however, offer favourable conditions for accumulation, since they combine the anticlinal fold with the terrace structure.

FAULTED STRUCTURES

Earlier views that faulted structures were not favourable for the accumulation of oil and gas have been greatly modified by the discovery of many highly productive faulted structures and certain investigators have concluded that in some fields the accumulation of petroleum has occurred as a result of faulting. It has been stated[3] that "faulting is associated with, and probably is, the controlling structural feature of all the oil-fields in the relatively flat-lying beds of the Gulf Coastal plain, from the Lower Cretaceous up to the Pliocene." Faulted structures affording oil production are also known in many other oil-fields, especially the Rocky Mountain fields, where the accumulation is thought to be closely related to the faulting. Rich[4] has pointed out that too much emphasis may be placed on faulting and that although it may be beneficial in some instances it may be decidedly detrimental in others by providing a channel of escape

[1] Rich, John L.: "Underground Water as a Primary Cause of the Migration and Accumulation of Oil and Gas"; Ec. Geol., vol. 16, No. 6, p. 355 (1921).

[2] Johnson, R. H., and Huntley, L. G.: "Text Book Oil and Gas Production," p. 72, 1916.

[3] Pratt, W. E., and Lahee, F. H.: "Faulting and Petroleum Accumulation at Mexia, Texas"; Bull. Am. Ass. Pet. Geol., vol. 7, No. 3, p. 231 (1923).

[4] Rich, John L.: "The Hydraulic Theory of Oil Migration"; Bull. Am. Ass. of Pet. Geol., vol. 7, No. 3, p. 222 (1923).

for oil and gas that would have been retained in an anticlinal structure. Mills[1] states that:

"The escape of water through natural passages, such as fault fissures, has induced widespread hydraulic currents through the beds toward these points of diminished pressure and these water currents, plus buoyancy, have contributed largely toward the migration of oil to favourable rock entrapments in the vicinity of the faults. The propulsive force of expanding gas has been one of the contributing causes for the hydraulic currents.

Paradoxical as it may seem, the escape of gas with entrained oil through fissures has been an important factor in the migration and accumulation of oil in many faulted areas. Compressed gas is the propulsive force by which oil generally moves to producing wells. It is also one of the propulsive forces by which oil has moved with or even ahead of water under conditions of differential pressure brought about by faulting.

The concomitant formation of gas and oil, together with the diffusion of absorbed gas under high pressure throughout the underground water and disseminated oil, are assumed to have preceded the processes herein outlined and have made them possible. Absorbed gas tends to lower the viscosity as well as the specific gravity of the oil, especially where the absorbed gas expands sufficiently to form minute bubbles within the oil. Again under the propulsive force of water currents alone, the oil tends to move less readily than the water, as exemplified by the formation of water cones around producing wells, but where there are considerable proportions of rapidly expanding gas, the oil is propelled ahead of the water. There are, of course, limiting conditions beyond which the folding and fracturing, or even the erosion of petroliferous strata, have permitted the excessive loss of oil and gas. There are also conditions under which faulting has caused barriers to migration . . . . . . where open fissures cutting deeply buried petroliferous beds have formed channels for the migration of oil, gas, and water and have then become sealed sufficiently to retain a part of the oil and gas in the reservoir rocks, the processes herein outlined have evidently functioned. . . . . . . During the more or less extensive movements of oil, gas, and water toward producing wells, the gas and oil tend to segregate above the water into favourably situated parts of the sands. This has been termed induced segregation. It is mildly analogous to what happens when hard or lithified strata containing unsegregated gas, oil, and water under pressure are fractured by faulting or fissuring.

Another important analogy between the deep-seated effects induced by oil and gas wells and the effects of faulting is the deposition of practically the same minerals in the wells and in the natural fissures. Calcite, barite, and gypsum, with inclusions of waxy hydrocarbons, accumulate in such quantities in the wells of the Appalachian and Mid-continent fields as to cause serious production troubles. Calcite, gypsum, and waxy hydrocarbons occur in the natural fissures cutting petroliferous strata in many fields. The origin of both types of deposits, those in the wells and those in the rock fissures, can be traced to the escape of water, gas, and oil from petroliferous strata.

Where the gas originally accompanying the oil and water (primary gas) has escaped through the fissures, the accumulated oil may be practically devoid of gas. . . . . . . But where considerable gas under high pressure accompanies oil in faulted and fissured structures it seems probable that this gas is either primary gas retained by the early sealing of the fissures, or that it is secondary gas which formed in, or migrated to, the entrapment after the fissures were sealed. It is possible that both phases of gas accumulation are represented in many structures. That there has been an enormous escape of gas incident to the migration and accumulation of oil in most fields is indicated by the high concentration of salts in the waters associated with the oil. This concentration has undoubtedly been brought about through the removal of water vapour in escaping gases."

Discussing the question as to why all the oil and gas does not escape from faulted areas before the fissures are sealed, Mills writes:

"The question might just as well be asked: Why does all the oil not flow from a productive sand through the wells that tap that sand? In both cases, the flow ceases when the propulsive force becomes inadequate to propel the oil to the surface. Let it be remembered that under ordinary conditions of recovery, about 80 per cent of the oil originally contained in a productive sand may, and probably does, remain underground when an oil-field is abandoned. As is the case with wells, the complete escape of oil through open fissures has probably failed largely because of dissipated gas pressures, whereas the final retention of the oil is due to the sealing of the fissures before the gas pressures in the vicinity of the faults have again built up through regional adjustments."

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[1] Mills, R. Van A.: "Natural Gas as a Factor in Oil Migration and Accumulation in the Vicinity of Faults"; Am. Assoc. of Pet. Geol., vol. 7, pp. 14-21 (1923).

Fault fissures may be sealed by the minerals mentioned by Mills and also by tar or asphalt. It has been shown[1] that sulphate waters react with oil, the sulphates being reduced by the hydrocarbons of the oil or gas to sulphides and the oil and gas in part being oxidized. Hydrogen sulphide thus formed is readily oxidized to give sulphur which is quite soluble in petroleum. The high sulphur content of some oils may be in part at least accounted for in this way. As sulphate waters are much more common near the surface than at depth, this action is probably greater near the surface and as the lighter oils are changed into heavier oils by this action, and as evaporation and oxidation also take place near the surface, the oil may be changed to tar or asphalt and thus seal the avenue of escape. According to Pack[2] "the effect of the deeper waters on the oil is not so extensive as that of surface waters, but it is evident none the less, for in place after place (in the Sunset-Midway field) where water is found in the oil sand a deposit of tar or heavy oil separates the portion of the sand occupied by oil from that occupied by water." It is thus evident that in this case even at depth tarry materials can effectively seal off a channel of escape for oil.

RESERVOIRS RESULTING FROM INTRUSIONS

In Canada there are no known reservoirs of this type, but since oil occurs in Montana in structures that have been thought to be related to the intrusions of the Sweet Grass hills, structures of this type may have some importance in southern Alberta. In regard to the Sweet Grass intrusion Dawson[3] decribes the relationships thus:

> "The central masses of the buttes (three buttes of igneous rock compose the Sweet Grass hills) are composed of trappean rock and around them the previously horizontal beds of the plains have been tilted up, those immediately surrounding the igneous masses resting at very high angles. . . . . Dykes of eruptive material traverse the sedimentary rocks surrounding the buttes, in some places, and appear generally to have a direction radiant from the higher peaks."

The intrusions have been described[4] as laccoliths, sills, and dykes and it has been suggested[5] that their presence "in part at least, induced the folding of the Kevin-Sunburst dome or it may be that this large symmetrical dome is itself laccolithic in origin."

POROSITY OF RESERVOIR ROCKS

The commonest rocks acting as reservoirs for accumulations of oil and gas are: (1) porous sandstone, and (2) dolomites or dolomitic limestones. Other rocks are not of so great importance, although in some fields oil has been produced in quantity from crevices in shales.

The porosity of a sandstone depends on a number of factors, as for example the shape of the sand grains, the manner in which they are packed, the variation in size of the individual grains, and the amount of clay or silt or of calcareous or siliceous cement between the sand grains. If the grains are uniform in size and shape, the amount of pore space is the same no matter how small or large the grains may be, provided they are packed

[1] Rogers, G. S.: "The Sunset-Midway Oil Field, Calif."; U.S.G.S. Prof. Paper 117, 1919.
[2] Pack, R. W.: "The Sunset-Midway Oil Field, Calif."; U.S.G.S. Prof. Paper 116, 1920.
[3] Dawson, G. M.: Geol. Surv., Canada, Rept. of Prog. 1882-4, pt. C, p. 17.
[4] Kemp, J. F., and Billingsby, Paul: "Sweet Grass Hills, Montana"; Bull. G.S.A., vol. 32, pp. 437-78 (1921).
[5] Clark, F. R.: "The Kevin-Sunburst Oil Field, Montana"; Bull. Am. Assoc. Pet. Geol., vol. 7, No. 3, p. 271 (1923).

in the same fashion. If the grains are large there will be a comparatively small number of large pore spaces, if the grains are small there will be a large number of small pore spaces, but the total amount of pore space will be the same. Where the grains are arranged in the most compact manner, the amount of pore space is about 25 per cent of the whole volume; where the grains are arranged so as to give the maximum pore space this amounts to nearly 50 per cent of the whole.[1] As has been pointed out by Johnson and Huntley:[2]

"A distinction should be made between the theoretical porosity of a rock and its effective porosity. Owing to the fact that in many rocks a considerable proportion of the pores do not communicate, even though the theoretical porosity may be high, the yield (of oil) is necessarily very low. A rock with very small pores cannot be drained of its oil content even though such pores communicate, because of friction and where gas or water is also present because of capillarity."

Thus, although a fine-grained sand may have as much porosity as a coarse-grained sand, its effective porosity may be very small and in some cases may even be nil. As already indicated, if the grains of a sand are not uniform in shape and size, the smaller grains may fill part of the spaces between the larger grains and consequently reduce the porosity. Silt and clay or materials cementing the sand grains will also diminish the amount of pore space.

Next to porous sands, dolomites and dolomitic limestones form the most important reservoirs for oil and gas.

Analyses, published by Orton,[3] of rock from different parts of the Trenton formation first drew attention to the fact that in the Trenton oil-fields of Ohio the oil is associated with dolomite. Pieces of reservoir rock, dolomite, blown from the wells, are very porous, whereas the compact limestone with a low magnesium content holds little if any oil and gas. It has been thought that the porosity of the dolomite is due to its formation from limestone, since in the change of a relatively pure limestone to dolomite a shrinkage of as much as 12 per cent may take place. The view that the porosity is wholly due to dolomitization was questioned by Phinney[4] because "chips and larger masses thrown out of the wells by the force of gas show that even where the rock is hard and compact small cavities are scattered throughout in such a manner as to suggest that a part of its substance had been removed by solution." It is now generally known that porous limestones and dolomites in certain cases furnish suitable reservoirs for very large amounts of both oil and gas and the Royalite No. 4 well, Turner Valley field, is a good example of production from such a source.

Dolomite forms in several ways,[5] as for example by: (1) deposition, (2) replacement, (3) leaching. Twenhofel concludes that:

"Unless the environmental conditions in the seas of the geologic past were greatly different from what they are at present, there is little possibility that the dolomites were formed by primary organic or chemical deposition. On the other hand, sediments which originally were deposited on the sea floor as calcium carbonate, or with calcium carbonate as the most important constituent, are known to have become dolomitized a few feet below the surface. . . . . . . The high content of magnesium carbonate arose either from leaching or replacement of calcium carbonate.

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[1] Slichter, C. S.: "Theoretical Investigation of the Motion of Ground Water"; U.S.G.S. 19th Ann. Rept., pt. 2, p. 305 (1899).
[2] Johnson, R. H., and Huntley, L. G.: "Principles of Oil and Gas Production," p. 34, 1916.
[3] Orton, Edward: Geol. Surv., Ohio, vol. 6, pp 103-105.
[4] Phinney, A J.: "The Natural Gas Fields of Indiana"; U.S.G.S., 11th Ann. Rept., p. 658 (1889).
[5] Twenhofel, H., and Collaborators: "Treatise on Sedimentation," 1926, p. 257.

It has been commonly assumed that in the formation of dolomite by replacement, there is an increase in the porosity of the rock formed"

and that the reaction involves:

"A shrinkage of 12·30 per cent in volume. Many dolomites are porous and cavernous, and this characteristic has been assumed to be typical of all dolomites and to have arisen through replacement after solidification. However, many dolomites have more than the required pore space, while others, in essentially horizontal positions, have less than 0·1 per cent. It is difficult to explain these variations as due to replacement alone. Shells which have undergone partial or complete replacement by dolomite in numerous instances show no decrease in volume, and it is obvious that field observations do not support the view that dolomitization involves a decrease in volume. Although it has not been proved that the porosity of some dolomites is due to replacement it is probable that a part of it may arise in this way, but there is a variety of other factors which are determinants of the pore space, among which are the physical characters of the particles composing the original calcite sediments, the cementation, the leaching subsequent to deposition, and the pressure to which the sediments were subjected.

One feature in the distribution of dolomites which is of interest is the fact that the occurrence of dolomite very frequently is regional rather than local."

The increase in the pore space as the result of dolomitization of a limestone is illustrated by the dolomite of the Presqu'île formation of Great Slave lake. On the north side of the lake at Windy point and vicinity, in the dolomite are large cavities lined with dolomite crystals and many of the cavities are filled with a semi-liquid oil or tarry residue from it. Another example is the supposed late Palæozoic dolomite from which the deep production is being secured in Turner valley. This dolomite is, in places, very porous and in view of the large area in which drilling is being done Twenhofel's statement that "the occurrence of dolomite very frequently is regional rather than local" is of great importance.

According to Beal and Lewis:[1]

"Many geologists and engineers engaged in estimating, by the use of porosity, the oil content of sands in the Mid-continent field ordinarily use a factor of 17½ per cent. . . . . . The porosity of the ordinary oil sand in California is usually taken as about 25 per cent, undoubtedly a low figure, since sands as loose as those generally average 36 per cent or more in porosity. Porosity in the Appalachian field is estimated at 10 to 12½ per cent, but actually productive portions of the sands probably average at least 15 per cent."

RELATION OF OIL PRODUCTION TO GAS PRESSURE

The amount of oil recovered from oil sands by ordinary methods is by no means the total amount in the sand. Some estimates place the recovery at only 10 to 20 per cent. The amount recovered "depends mainly upon the porosity and size of the pores, upon the available energy within the sand for expelling the oil from the pores of the sand, and upon the efficiency of this energy." The gas dissolved in the oil under pressure is the main force that expels oil from a sand, although gravitation and water pressure are important in some instances. The failure of a well to produce more oil, even though only 10 to 20 per cent of the oil in the sand has been extracted, is not, according to Beal and Lewis, the result of exhaustion of the oil, but is due to the exhaustion of the gas associated with the oil. The conservation of gas in connexion with producing wells is thus of vital importance.

Beal and Lewis have discussed the effect of gas pressure on production, and the following statements are mainly based on their treatment of the

[1] Beal, Carl H., and Lewis, J. O.: "Some Principles Governing the Production of Oil Wells"; U.S. Bur. of Mines, Bull. 194, p. 7 (1921).

subject. Since the amount of gas that can be dissolved in the oil is proportional to the pressure, "doubling the pressure, therefore, doubles the quantity of absorbed gas and hence the energy, being the pressure multiplied by the gas volume, is quadrupled. The expulsive energy thus increases as the square of the pressure, provided there is enough gas associated with the oil to saturate the oil at the existing pressure." Some of the gases present are condensable at the higher pressures and thus go into solution as liquids. The effect in the field is that the expulsive energy may increase at even a greater ratio than the square of the pressure. It is essential, therefore, in the best interests of the life of an oil-field, that an amount of gas as small as possible be used to produce each barrel of oil. If large quantities of gas are allowed to escape freely in the initial stages of production it is obvious that the recovery of oil will be much less than the possible maximum.

In many fields the gas pressure is about equal to the hydrostatic pressure, a condition that has been explained[1] by the "fact that the weight of water in the rock pores resists the slow outward movement, and that equilibrium is established when the outward pressure is equal . . . . . . to the hydrostatic head." There are many instances however, where the gas pressure is much in excess of the theoretical hydrostatic pressure and Washburne believes this excess of pressure may be "assigned in general to greater freedom of communication underneath the sand . . . . . . to locally more active ascent of rock fluids from any cause, or to greater resistance above the sand." Pressures lower than the theoretical hydrostatic pressure may, on the other hand, be "assigned to the opposite causes, or to leakage, or to dryness of parts of the overlying rock." As proof of the origin from below of pressures in excess of the theoretical hydrostatic pressure Washburne cites[2] the fact that such excess pressures are most common in areas where fracturing is prevalent. Also, excess temperatures in oil-fields, excess of chlorine in associated waters, and the abundance of helium in some deep wells, point to the same conclusion. It has been shown that capillary pressure under certain conditions is quite large, but Washburne believes since there is no change in volume in capillary movement that capillarity itself could not produce any great pressure in an oil sand.

RELATION OF OIL PRODUCTION TO THE SPECIFIC GRAVITY OF THE OIL

A heavy oil being more viscous than a light oil requires more energy to expel it from the pores of a sand. Since in any reservoir there is only a certain amount of available energy due to the gas pressure, it follows, therefore, other factors being equal, that there will be a larger ultimate recovery of the oil if it is light than if it is heavy. For the same reason the initial flow of oil from a sand is likely to be smaller if the oil is heavy than if it were light. The general tendency, however, for an oil well producing heavy oil, is to decline less rapidly than one producing light oil under similar conditions.

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[1] Washburne, C. W.: "The Capillary Concentration of Gas and Oil"; Trans. Am. Inst. Min. Eng., vol. 50, p. 557 (1914).

[2] Op. cit., p 556.

RELATION OF OIL PRODUCTION TO SPACING OF WELLS

The relationship of production to spacing of wells has been discussed by Beal and Lewis,[1] and they point out that the closer the spacing of wells the greater the ultimate recovery of oil. The gas absorbed in the oil is the propulsive force driving the oil to a well and for each reservoir only a certain amount of energy is available. The energy due to the gas pressure may be dissipated in driving either a small amount of oil a long distance or a large amount of oil a short distance. It is desired, of course, to obtain the maximum possible recovery of oil and it is obvious that this end will best be accomplished where the energy is used in driving a large amount of oil a short distance, or in other words where the spacing of the wells is close. There are, naturally, limits to the close spacing of wells and for each field there is a certain spacing which is the most economical.

[1] Beal, C. H., and Lewis, J. O.: U.S. Bur. of Mines, Bull. 194, p. 25 (1921).

CHAPTER II

CARBON RATIOS OF COAL AS AN INDEX TO THE OCCURRENCE OF OIL AND GAS IN WESTERN CANADA[1]

The Carbon Ratio theory is based on the assumption that in the transformation of carbonaceous materials such as peat, to coals of various grades, the changes are both physical and chemical, and the grade of coal finally produced depends on the stage to which alteration proceeded. Those changes which are frequently spoken of as the results of metamorphism, are due to pressure with accompanying heat, and according to the amount of metamorphism to which the sediments with the included carbonaceous beds have been subjected there is supposed to be a gradation from peat to anthracite coal and even to graphite. The improvement in the quality of the coal as a result of metamorphism is due to an increase of the carbon content and a corresponding loss of the volatile constituents. This rise in the quality of the coal according to the degree of metamorphism is well illustrated by the coals of western Canada. In the Plains area, where the deformation and the attendant metamorphism of the sediments are comparatively small, the coals are lignites, whereas in the mountains where deformation has been severe the coals are semi-anthracites and in the intervening areas they are sub-bituminous and bituminous. The same general relationship between the quality of the coal and the degree of metamorphism holds true for the Appalachian basin of the United States where there is a progressive increase in the quality of the coals from west to east, that is, from an area of comparatively slight metamorphism to an area of marked deformation in the Appalachian Mountain region. But, although it is true that this relationship holds in a general way, it has been found that the increase in the quality of the coal is not always uniformly progressive and there may be local variations such that an area containing coal with a carbon content indicating low or medium metamorphism may be surrounded by areas in which the coals are of higher grade. These local variations in many cases can be explained and in no way detract from a general rule, namely, that in a region exhibiting a progressive increase in the quality of the coal from an area of low metamorphism to one of more marked deformation, the quality of the coal, i.e. the amount of fixed carbon in the coal, may be taken as an index of the degree of metamorphism of the coal as well as of the sediments in which it occurs. It has been pointed out[2] that certain coals such as cannels are unreliable indicators of the varying degrees of metamorphism because of the nature of the material from which such coals were derived. Such coals, however, are not known in western Canada and their behaviour need not here be discussed.

It has been pointed out by White[3] that in any area there is a relation between the character of the oil found and the character of the coal, and since:

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[1] Published originally in the Bull. Can. Inst. Min. and Met.

[2] Lilley, E. R.: "Coals as an Aid in Oil Exploration"; Eng. and Min. Jour. Press, vol. 117, No. 25, p. 1009 (1924). Russell, W. L.: "Relation Between Isocarbs and Oil and Gas Production in Kentucky"; Econ. Geol., vol. 20, No. 3, p. 249 (1925).

[3] White, David: "Relations Between Coal and Petroleum"; Jour. of Wash. Acad. of Sci., vol. 5, p. 203 (1915).

"Petroleum is a product generated in the course of geodynamic alteration of deposits of organic debris of certain types buried in the sedimentary strata, the quantity and character of the oils generated are determined by: (1) the composition of the organic deposit at the beginning of the dynamo-chemical alteration of the organic substances; (2) by the stage in the progress of the dynamo-chemical alteration of the organic substances; (3) by the elimination under certain conditions of the heavier and more viscous hydrocarbons through filtration incident to migration."

Thus, although the

"Composition of the mother organic deposit largely regulates the types of oils, in general it is seen that the lowest rank oils of each type are found in regions and formations in which the carbonaceous deposits are least altered; that the oils in formations showing greater alteration of organic debris, as in sub-bituminous coals, are of higher rank, the oil being still more clearly of high rank in regions and formations of bituminous coals; and that in regions of still further alteration the oils are still better, the highest rank oils being, on the whole, found in regions where the carbonaceous deposits in the same or overlying formations have been brought to corresponding higher ranks."

Also, according to White, it appears that "the effect of progressive regional dynamic alteration is marked by a concentration of hydrogen in the distillates and a concentration of carbon in the residual debris (coal, carbonaceous shale, etc.)." Thus the oil is of light grade where the carbon content of the coal is high and the oil is heavy where the carbon content of the coal is low, but there is an upper and a lower limit to the amount of metamorphism that can take place and still permit oil to be present in the sediments so affected. If metamorphism has not proceeded to a certain stage the carbonaceous material which is the source of the oil and gas will not be sufficiently altered to cause the formation of oil and gas. On the other hand, if metamorphism has gone beyond a certain stage, the oil and gas will, to a large extent, be destroyed and according to Lilley[1] "dry gases composed almost entirely of methane and residual carbon are formed. Ultimately if the pressure becomes too severe, the methane is destroyed and the volatile hydrogen gas evolved. Because of the small size of the hydrogen molecule this gas easily escapes from the beds containing it to the atmosphere and is lost." These relationships between the coals, and oil and gas have been summarized by Fuller[2] as follows:

Carbon ratio[3]	Prevailing character of sands	Production
Over 70...........	Hard and tight......................	No oil nor gas, with exceptions.
70 to 65...........	Tight with a few porous spots.......	Usually only "shows" or small pockets. No commercial production.
65 to 60...........	Variable, with porous beds of limited extent.	Commercial pools rare, but oil exceptionally high grade when found. Gas wells common, but usually isolated rather than in pools.
60 to 55...........	Fairly continuous and open..........	Principal fields of light oils and gas.
55 to 50...........	Softer, less firmly consolidated, and more continuous and porous.	Principal fields of medium oils of Ohio-Indiana and Mid-continent fields.
Under 50..........	Sands usually saturated, often with fresh water to all depths reached by wells.	Fields of heavy coastal Plain oils and of unconsolidated Tertiary or other formations.

[1] Lilley, E. R.: "Coal as an Aid in Oil Exploration"; Eng. and Min. Jour. Press, vol. 117, No 25, pp. 1009-1012 (1924).

[2] Fuller, M. L.: "Relation of Oil to Carbon Ratios of Pennsylvanian Coals in North Texas"; Ec. Geol., vol. 14, p. 538 (1919).

[3] The carbon ratio is the recalculated percentage of fixed carbon in the coal after the ash and moisture have been eliminated.

These conclusions of Fuller are based on the relationships existing in regions bearing coal of Pennsylvanian age. A study of the relationships existing in the plains of western Canada where the coals are of Cretaceous age indicates that some modifications of the theory may be necessary, but the available data is rather limited and a satisfactory conclusion has not yet been reached. So far, however, it appears that the carbon ratios of the Cretaceous coals do seem to be an index of the degree of metamorphism and, consequently, afford a means of predicting where, other conditions favouring, oil may occur. The application of the carbon ratio theory fails, however, in some cases, in the matter of predicting the quality of oil that would be expected. Two cases may be cited, namely Wainwright and Peace River. In both of these areas the carbon ratios of most of the coals analysed fall between 55 and 60 and light oils might be anitcipated,[1] whereas heavy oils have been found. Two possible explanations of this apparent discrepancy can be suggested and although proof that either is correct is lacking it may be that both are valid. The first deals with the material from which the oil originated, and the second considers only alterations affecting the oil subsequent to its formation. In regard to the first explanation it has already been stated that the character of the material from which the oil is derived affects the quality of the oil produced. The materials that afforded the oils of the Cretaceous may have been quite unlike the organic material that formed the oil in the areas of Pennsylvanian strata, and, therefore, the significance to be attached to the carbon ratios of the coals of the two contrasted regions may be quite different. In regard to the second explanation, Rogers[2] points out that though surface waters may carry sulphates, on the other hand, waters associated with oil and gas rarely if ever do so and "it is generally supposed that the absence of sulphate is due to the reducing action of hydrocarbons, the sulphate being reduced to sulphide, which passes off as hydrogen sulphide . . . . . . " But though hydrogen sulphide "is found in many of the waters above the oil measures," the quantity present is so small as to suggest that "it is being removed from solution nearly as fast as it is being formed." Rogers concludes, since hydrogen sulphide is readily oxidized to sulphur, that "it is probable that considerable amounts of hydrogen sulphide are oxidized to sulphur and are removed by precipitation from the waters above the oil measures." The action of sulphur and also of oxygen which is carried in solution by most descending surface waters, is to cause the oil with which it comes in contact to become heavier. The action of sulphur on oil is explained by Rogers as follows:

"If paraffin or paraffin-bearing oil is digested with sulphur at moderate temperatures it becomes black and heavy and finally passes to a substance resembling solid asphalt. Similarly if a light asphaltic oil is treated with sulphur it becomes darker and more viscous finally becoming asphalt. . . . . . . The sulphur atom, by extracting two atoms of hydrogen from the oil, causes a condensation or polymerization of the hydrocarbon molecule and this change is reflected in the increase of the gravity of the oil itself as it approaches solid asphalt."

In the effects produced oxygen acts on oil to give much the same result, since, according to Rogers "oil exposed to the air for a long time becomes dark, heavy, and viscous and finally passes to asphalt. This

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[1] It should be borne in mind that oils from limestones have been found to be heavier than from sands of the same degree of metamorphism as indicated by the carbon ratio theory and, therefore, that for this second reason the oils of the two fields would be expected to be lighter than they have proved to be.

[2] Rogers, G. S.: U.S. Geol. Surv., Prof. Paper 117, pp. 27-31 (1919).

change is due chiefly to the evaporation of the more volatile constituents but partly to oxidation." Rogers has shown that in a general way the amount of sulphur in the oil gives an indication of the change that has occurred. The Peace River oil is notably high in sulphur and Camsell[1] records that waters issuing from a well 268 feet deep had a strong odour of hydrogen sulphide and that an analysis of the water showed hydrogen sulphide to be present in considerable quantity. In the case of Wainwright oil considerable sulphur is also present, an analysis of oil from No. 4 British Petroleums well made by the Fuel Testing Division of the Mines Branch showing a sulphur content of 1·98 per cent. Although the presence of sulphur in the oils of the Peace River and Wainwright fields is not proof of the mode of origin of the heavy character of the oils in these two fields, yet it is at least very suggestive of the action of sulphur on the oil, since the oils are heavy and asphaltic, whereas from the carbon ratio of the coals much lighter oils would be expected.

The second possible explanation of the failure of the application of the carbon ratio theory, to indicate the quality of the oil, is, as Fuller[2] has shown, that the carbon ratio of coal increases as the depth of burial of the coal increases, but the rate of increase is unknown. This suggests that the oils also should increase in quality with depth in any particular field, and White[3] has stated that "in general at a given point the oils found in successive underlying formations or in stratigraphically lower sands in the same formation are progressively higher in rank." As an example the Wainwright field may be again cited. It is believed there are two oil horizons in the Wainwright field. The upper of these in Colorado shales gives oil of approximately 12 degrees Baumé, whereas the lower one in presumably Lower Cretaceous sands yields oil of 19 to 20 degrees Baumé, the increase in quality with depth in this case being quite pronounced. However, as shown by Fuller,[4] although the downward increase in carbon ratios may be fairly uniform it is only so "within the limits of uninterrupted deposition . . . . . . Any important hiatus, whether or not represented by a recognizable unconformity, is likely to be marked by a rather sudden rise of the fixed carbon in passing downward across the break." For this reason, therefore, the carbon ratios indicated by coals of Cretaceous age would be an indicator for oils that occur, and which originated in Cretaceous sediments. These ratios probably would not correctly indicate the total degree of metamorphism that may have taken place below an unconformity such as that separating the Cretaceous and older rocks in certain parts of Alberta.

It must be remembered that where the carbon ratios of coal indicate a favourable degree of metamorphism for oil and gas, other conditions necessary for the accumulation and preservation of the oil and gas must be present to justify drilling to test such prospective areas. Thus, given suitable source materials for oil and gas under favourable conditions of metamorphism, there must also be porous horizons to contain the oil and gas when formed and these horizons must extend into structures that permit the accumulation of oil and its retention by an impervious cover.

[1] Camsell, Charles: Geol. Surv., Canada, Sum. Rept. 1916, p. 145.
[2] Fuller, M. F.: "Relation of Oil to Carbon Ratios of Pennsylvanian Coals in North Texas"; Ec. Geol., vol. 14, p. 537 (1919).
[3] White, David: "Relations Between Coal and Petroleum"; Wash. Acad. of Sci., vol. V, p. 211 (1915).
[4] Fuller, M. F.: "Carbon Ratios in Oklahoma Coals"; Ec. Geol., vol. 15, p. 227 (1920).

Unless all these conditions are present the carbon ratios have no value as indicating the presence of oil or gas. They are a valuable aid in separating the promising from the unpromising prospective areas as a preliminary step in the search for suitable structural conditions.

In applying the theory of carbon ratios to Alberta the analyses used are those given by Stansfield[1] and those published in various reports of the Geological Survey of Canada and the Mines Branch. Stansfield has grouped the analyses for each township. The townships are 6 miles square. The analyses for one township do not necessarily indicate the conditions of metamorphism which exist in other townships in the same coal area. It has already been stated that passing from the plains to the mountains there is a general rise in the degree of metamorphism and hence in the quality of the coals. This rise from east to west is, however, by no means uniform and especially in southern Alberta there is much variation. In this connexion it will be recalled that there are several hundred feet of Tertiary sediments, including conglomerate of Oligocene age, in the Cypress hills of Saskatchewan and Alberta. These sediments were undoubtedly derived from the mountains to the west and probably once extended westward to them, although now, except in the Alberta syncline, a great part has been removed. It is suggested, therefore, that the former thick cover of Tertiary sediments may have caused static metamorphism, which may in some degree account for the grade of coal found in certain areas of the plains where the folding seems to be very gentle and the carbon ratios of coals indicate a degree of metamorphism considerably higher than otherwise might be expected. Local variations in the amount of metamorphism, that is, in the carbon ratios, are not easily explained. But considering the lateral differences in character of the Cretaceous sediments it might be expected that the sediments in different areas would react differently to such deformative stresses as may have occurred. Also, it is known that coals found on anticlines are likely to possess a higher carbon ratio than coals occurring in basins, and it has been proved that near thrust faults where the compression has been relieved by the faulting, the coals are likely to have a lower carbon ratio than at some distance from the fault. Thus, local variations in the carbon ratios are suggestive of some structural condition that may have a very direct bearing on the accumulation of oil or gas.

Each carbon ratio in the following tables indicates the degree of metamorphism to which the sediments containing the coal have been subjected. The tables should be used in conjunction with the already quoted table of Fuller, showing the relationships between the carbon ratio and the oil and gas possibilities, but bearing in mind that Fuller's table is based on analyses of Pennsylvanian coals, and some modification of the table may be necessary when dealing with Cretaceous coals. The carbon ratios have been calculated from the analyses of coals by the use of the equation:

$$\text{Carbon ratio} = \frac{\text{Fixed carbon}}{\text{Fixed carbon} + \text{vol. material}} \times 100$$

[1] Allan, J. A., and Stansfield, E.; Bull. Can. Inst. of Min. and Met., p. 402 (April, 1925).

BELLY RIVER COALS

HALCOURT AREA (1)[1]

Township	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
70	11	6	12·9	9·6	32·0	45·5	58·6
70	10	6	14·2	9·4	31·0	45·4	59·4
70	7	6	13·7	9·5	31·2	45·6	59·4

In this area the carbon ratios are approaching the point where the occurrence of oil would be considered doubtful.

COALSPUR AREA (2)

Township	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
49	21	5	10·8	9·8	33·9	45·5	57·3
48	22	5	8·8	10·0	35·6	45·6	56·1
47	20	5	7·3	10·2	33·4	49·1	59·5
47	19	5	11·9	9·7	32·0	46·4	59·2
43	16	5	7·0	10·2	30·4	52·4	63·3

The carbon ratios of 56·1 and 57·3, in this area, indicate a degree of metamorphism favourable for oil and gas, provided structural and other conditions are also favourable. The Imperial Oil Company recently abandoned a deep test in township 49, range 21, without finding oil or gas in commercial quantities, although a number of small gas flows were encountered.

SAUNDERS AREA (3)

Township	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
40	13	5	9·3	10·0	32·7	48·0	59·5

PINCHER AREA (6)

Township	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
10	2	5	6·9	10·2	34·3	48·6	58·6
7	2	5	6·9	10·2	35·3	47·3	57·2
7	2	5	4·5	10·5	24·6	60·4	71·0

[1] Number of the coal area, in Figure 1.

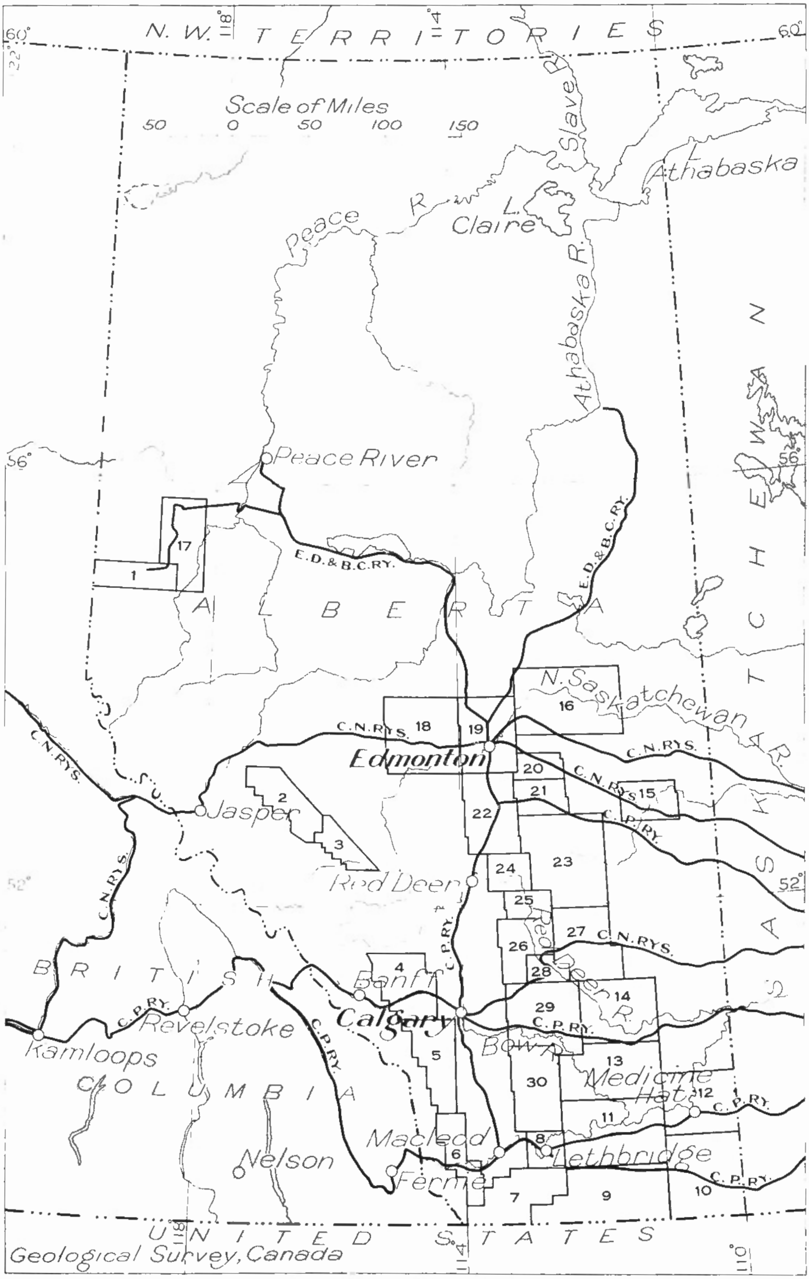

Figure 1. Index map showing location of coal areas in Alberta.

A marked divergence is noticeable in township 7, range 2. The Willow Creek Oils, Limited, drilled a well in township 8, range 2, to a depth of 1,686 feet, and a well in township 9, range 2, to a depth of 1,385 feet. These wells are hardly deep enough to be considered a fair test of the area. In view of the abnormally high ratio in township 7, range 2, structural details should be carefully studied. The Twin Butte wells of the Northwest Company are farther southeast, No. 1 being in tp. 4, range 30, W. 4th mer., drilled to 2,780 feet, and No. 2 in tp. 3, range 29, W. 4th mer., drilled to 4,392 feet. The results of drilling were negative.

MAGRATH AREA (7)

Township	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
2	26	4	7·6	10·2	34·5	47·7	58·0
1	26	4	7·0	10·2	35·7	47·1	56·9

The carbon ratios indicate a degree of metamorphism favourable for oil and gas, provided structural and other conditions are also favourable.

LETHBRIDGE AREA (8)

Township	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
10	22	4	10·0	9·9	35·0	45·1	56·3
9	22	4	9·9	9·9	34·7	45·5	56·7
9	21	4	10·5	9·9	34·6	45·0	56·5
7	21	4	10·3	9·9	35·9	43·9	55·0

Metamorphism indicated by the carbon ratios is favourable for the formation of oil and gas. The city of Lethbridge drilled a well in township 8, range 21, to a depth of 2,200 feet. The well was abandoned. The Geological Survey has recently completed a stratigraphic and structural study of southern Alberta, including this area. Well-defined structures should be favourable locations for drilling tests.

MILK RIVER AREA (9)

Township	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
3	16	4	13·4	9·5	31·5	45·6	59·1
3	11	4	20·1	8·8	29·0	42·1	59·2
2	16	4	13·4	9·5	31·0	46·1	59·8

The carbon ratios are rather high to be indicative of a favourable degree of metamorphism for oil, though perhaps not for gas. No other coal analyses are available and it is possible carbon ratios for other parts of the area might be lower. The Foremost gas-field in township 5, ranges 10 and 11, occurs within Milk River coal area, as does the Rogers Imperial well in township 1, range 11, in which a very large volume of gas and a few "shows" of oil were obtained. It may, therefore, be of some significance that the carbon ratios are more favourable for dry gas than for oil.

PAKOWKI AREA (10)

Township	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
9	5	4	29·4	7·8	29·2	33·6	53·5
8	8	4	24·6	8·3	28·9	38·2	56·9
8	4	4	32·9	7·4	29·4	30·3	50·7
8	3	4	37·5	6·9	28·5	27·1	48·7
7	2	4	33·0	7·4	28·8	30·8	51·7
2	6	4	22·5	8·5	29·6	39·4	57·1

These carbon ratios[1] are very favourable for the formation of oil and gas. The Sanctuary Oil Company drilled a well to a depth of 2,845 feet in township 5, range 8. Gas is reported to have been found at a number of horizons, the total flow being about 50,000 cubic feet. One oil show occurred at 2,725 feet. Structures suitable for oil and gas accumulation would be considered favourable locations for test wells.

TABER AREA (11)

Township	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
10	17	4	14·8	9·4	32·4	43·4	57·2
10	16	4	15·8	9·3	31·7	43·2	57·7
9	16	4	14·8	9·4	31·1	44·7	59·0
9	13	4	18·5	9·0	30·5	42·0	57·9
8	10	4	21·7	8·6	29·9	39·8	57·1

The Bow Island gas-field lies within this area, the presence of gas being in accord with predictions that would be made on the bases of the carbon ratio theory. Recently the Imperial Oil Company made a deep test of the Bow Island structure and an oil sand was encountered. The carbon ratios are favourable for oil, but the oil was heavy instead of light, as would be predicted on the basis of the Fuller table. The limitations of the application of the Fuller table to Cretaceous oils should be recalled.

REDCLIFF AREA (12)

Township	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
13	6	4	26·2	8·1	26·9	38·8	59·0

[1] Since the original publication of this article on "Carbon Ratios" in the Bulletin of the Canadian Institute of Mining and Metallurgy, the Devenish well in sec. 27, tp. 5, range 14, W. 4th mer., has encountered a commercial flow of oil. It will be noted that this well is considerably north of the area for which the carbon ratios are given here.

The Medicine Hat-Redcliff area, which has produced a large volume of gas, occurs in townships 12 and 13, ranges 5 and 6. Too much reliance should not be placed on the only analysis available, since local variations might occur, but it is perhaps significant that the carbon ratio is such that although gas would be predicted, the carbon ratio is approaching the limit where oil would not be expected. Recently two deep tests have been made in the Medicine Hat area, but the wells, Roth Nos. 1 and 2, have been abandoned so far as oil is concerned.

BROOKS AREA (13)

Township	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
17....................	17	4	17·6	9·1	31·7	41·6	56·7

The carbon ratio shown by the analysis indicates an area favourable for oil and gas, provided structural and other conditions are also favourable. The wells drilled within the area are as follows: Brooks, two wells, one of which gave a small flow of gas; Cassels, one well reported as 1,000 feet deep in which a small amount of gas was found; Alderson, one well with a small flow of gas at 1,155 feet; Suffield, one well reported as 1,200 feet deep, which gave a show of gas. No information is at present available regarding the relation of any well to local structure and all wells are shallow and not to be considered as tests of the oil possibilities.

WAINWRIGHT AREA (15)

Tp.	Range	Mer.	Moisture	Min. matter	Volatile matter	Fixed carbon	Carbon ratio
46	6	4	13·2	6·9 (ash)	35·3	44·6	55·8
			8·5	10·0 (ash)	39·1	42·4	52·0[1]
45	6	4	....	....	....	....	59·1[2]

The carbon ratios indicate favourable metamorphism for oil and gas. Gas has been found in several local folds within this area and oil in commercial quantities occurs in the Battle River-Wainwright anticline. The occurrences of oil and gas are, therefore, in accord with predictions that would be made on the basis of the carbon ratio theory, although light oil might be expected instead of heavy oil as found. Reasons suggestive of this departure from predictions regarding quality of the oil have already been discussed.

[1] South of Irma in a well at a depth of 110 feet.

[2] From No. 3B British Petroleums well, from 2,209 to 2,216 feet; average of five analyses.

PAKAN AREA (16)

Tp.	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
North Saskatchewan river, near Myrtle creek[1].			13·1 11·8	7·1 (ash) 9·2 (ash)	33·7 34·1	46·1 44·9	57·8 56·8
North Saskatchewan river, near Pakan[1].			13·6 12·6 11·9	5·2 (ash) 5·7 " 6·6 "	34·1 34·6 36·4	47·1 47·1 45·0	58·0 57·7 55·3

[1] Samples of coal from outcrops collected by G. S Hume and analysed by Fuel Testing Division, Mines Branch.

These carbon ratios are favourable for oil and gas if other conditions are also favourable. The Victoria well, drilled at a depth of 1,870 feet on sec. 12, tp. 58, range 17, W. 4th mer., obtained a small flow of gas at several horizons. The structure at this well is not known to be particularly favourable for oil or gas accumulation.

PEKISKO AREA (5)

Sec.	Tp.	Range	Mer.	Moisture	Ash	Volatile matter	Fixed carbon	Carbon ratio
[1] 19								
30	19	5	5	0·53	19·93	20·68	64·55	75·7
							Kootenay coal	
[1] 36	19	5	5	0·69	6·21	19·98	73·12	78·5
							Kootenay coal	
[1] 30	19	4	5	2·50	4·98	35·88	56·64	61·2
[1] 20	19	4	5	2·16	6·77	34·65	56·42	61·9
[1] 2	20	3	5	3·08	3·05	39·37	54·50	58 1
	20	2	5	8·0	10·1	35·0	46·9	57·3
	18	2	5	7·6	10·2	35·1	47·1	57·3
Five miles up North Fork Highwood river				6·12	12·08	31·92	49·88	60·9
7	22	3	5	3·76	5·96	33·91	56·37	62·4

[1] Dowling, D. B : "Coal Fields of Manitoba, Saskatchewan, Alberta, and Eastern British Columbia"; Geol. Surv., Canada, Mem. 53 (1914).

Turner Valley oil- and gas-field is in tps. 19 and 20, ranges 2 and 3, W. 5th mer. The carbon ratios from tps. 18 and 20, range 2, are favourable for oil and gas, as is also the carbon ratio from township 20, range 3. To the west, in township 19, ranges 4 and 5, the carbon ratios become progressively higher toward the west, that is in the direction toward the mountains where metamorphism would be expected to be more severe. Thus, on the carbon ratio theory, no oil or gas would be expected in township 19 from range 4 westward. This area lies within the "disturbed belt." In this connexion it should be remembered the carbon ratios apply only to the Cretaceous and a much higher degree of metamorphism would be expected in strata of late Palæozoic age, which is presumably the age of the lower dolomitic horizon productive in Royalite No. 4 well in Turner valley. Oil of 50 to 60 degrees Baumé has been found in the Cretaceous in a number of wells and this grade of oil is in accord with what would be predicted according to the metamorphism indicated by the carbon ratio for oil that originated in the Cretaceous. The fact that light oil is found in the Cretaceous in Turner valley, whereas heavy oil is found in the Cretaceous at other places under a degree of metamorphism slightly less than in Turner valley, might support the contention that the Cretaceous oil in Turner valley is a migratory product from depth, in which case it might be expected to be light regardless of the degree of metamorphism of the Cretaceous itself. On the other hand, it is possible there may be a relationship between the oil and the structure, because there seems no reason to assume oil could not have originated in the Cretaceous in Turner valley regardless of what occurs at depth.

MORLEY AREA (4)

Sec.	Tp.	Range	Mer.	Moisture	Ash	Volatile matter	Fixed carbon	Carbon ratio
[1] 7	23	5	5	9·3	13·38	35·59	41·72	53·96
[1] Stoney Reserve........................				1·26	8·84	41·30	48·60	54·05
[1] 19	25	4	5	5·0	7·07	52·10	35·20	40·32

[1] Dowling, D. B.: "Coal Fields of Manitoba, Saskatchewan, Alberta, and Eastern British Columbia"; Geol. Surv., Canada, Mem. 53 (1914).

The carbon ratio of the coal from Jumpingpound creek (Tower's mine) on township 25, range 4, is so very low that it should be checked by another analysis. The other two carbon ratios are favourable for the occurrence of oil. The Signal Hill and Cherokee Oil Companies are drilling in township 23, range 5, and the Imperial Oil Company is drilling in township 25, range 5. No results are yet available.

EDMONTON COALS

PEMBINA AREA (18)

Sec.	Tp.	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
	53	7	5	19·1	8·9	27·5	44·5	61·8
	53	4	5	21·9	8·6	27·7	41·8	60·1

The carbon ratios in this area are so high that the occurrence of gas in quantity is improbable and oil prospects are negative.

EDMONTON AREA (19)

Sec.	Tp.	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
	55	25	4	25·5	8·2	28·0	38·3	57·7
	55	24	4	26·3	8·1	26·9	38·7	59·0
	53	23	4	25·2	8·2	27·8	38·8	58·3
17	53	23	4	18·9	9·3	26·6	45·2	62·9
[1]18	53	23	4	17·6	8·0	27·8	46·6	62·6
[1]River lot 22.....		....	....	18·9	8·8	30·6	41·7	57·7
10	53	24	4	Av. of two analyses..........................				58·7
[1]Lot 17	53	24	4	Av. of seven analyses..........................				57·3
[1]Secs. 13, 24, 25	55	25	4	Av. of seven analyses..........................				56·4

[1] Stansfield, E., and Nicholls, J. H. H.: "Analyses of Canadian Fuels"; Mines Branch, Dept. of Mines Canada, Bull. 25 (1918).

The two analyses in which the carbon ratio is over 60 were made from coals from Clover Bar area. No explanation for these high carbon ratios is apparent. The remainder of the coals analysed came from the Edmonton and Cardiff-Namao areas in which the carbon ratios indicate favourable metamorphism for the formation of oil. As this area lies within the structural trough of Alberta the oil and gas horizons known from other parts of Alberta would be at a depth that would prohibit drilling even if there were local anticlinal structure of sufficient merit to warrant drilling. It is possible, however, in this great thickness of sediments there may be oil and gas horizons which are at present unknown, but in view of the fact that the upper sediments are non-marine the conditions may not be good.

CAMROSE AREA (21)

Tp.	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
48	20	4	27·0	7·9	28·4	36·7	56·4
48	19	4	26·6	8·0	29·1	36·3	55·5
48	18	4	25·0	8·3	28·4	38·6	57·2
46	20	4	25·4	8·2	28·4	38·0	57·2

These carbon ratios are favourable for the formation of oil and gas. In a well drilled to a depth of 1,235 feet, by the town of Camrose, on sec. 2, tp. 47, range 20, a flow of gas of approximately 150,000 cubic feet a day is reported to have been obtained. The local structure is unknown, as is the exact horizon from which the gas came.

CASTOR AREA (23)

Sec.	Township	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
	43	20	4	23·4	8·4	29·5	38·7	56·7
	41	16	4	26·4	8·1	27·5	38·0	58·0
	40	16	4	25·5	8·2	28·6	37·4	56·7
	39	15	4	27·4	8·0	28·2	36·4	56·3
	38	14	4	29·3	7·8	28·3	34·6	55·0
	40	15	4	25·8	8·2	28·6	37·4	56·7
	39	16	4	25·8	8·2	28·0	38·0	57·6
	37	14	4	29·2	7·8	28·1	34·9	55·4
[1]34	37	14	4	Average of two analyses				56·0

[1] Stansfield, E., and Nicholls, J. H. H.: "Analyses of Canadian Fuels"; Mines Branch, Dept. of Mines, Canada, Bull. 25 (1918).

The carbon ratios are within the limits where oil and gas are formed. In a well drilled to a depth of 1,455 feet by the town of Castor a small flow of gas was reported. The local structure is unknown.

ARDLEY AREA (24)

Township	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
38	23	4	20·1	8·8	27·7	43·4	61·1

The high carbon ratio of this analysis is indicative of metamorphism prohibitive for oil and gas.

BIG VALLEY AREA (25)

Township	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
35	20	4	21·7	8·6	28·8	40·9	58·7
34	22	4	18·8	8·9	27·4	44·9	62·1
34	21	4	19·7	8·8	28·5	43·0	60·2

Gas and oil prospects in this area are not good.

CARBON AREA (26)

Sec.	Township	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
	33	23	4	17·8	9·0	27·5	45·7	62·4
	33	21	4	19·5	8·9	29·9	41·7	58·2
	31	24	4	17·3	9·1	27·6	46·0	62·5
	29	23	4	16·5	9·2	30·3	44·0	59·2
[1]14	31	24	4	14·3	8·4 (ash)	28·5	48·8	63·1
[1]22	31	24	4	13·8	6·1 "	31·5	48·6	60·7
[1]36	31	24	4	14·5	8·2	29·3	48·0	62·9
[1]12	33	23	4	15·3	8·6	27·9	48·2	63·3
[1]14	33	23	4	15·4	8·5	28·1	48·0	63·1

[1] Stansfield, E., and Nicholls, J. H. H.: "Analyses of Canadian Fuels"; Mines Branch, Dept. of Mines, Canada, Bull. 25 (1918).

The carbon ratios are almost uniformly so high that prospects for oil and gas are negative.

SHEERNESS AREA (27)

Sec.	Town-ship	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
[1]18	29	14	4	21·2	9·4 ash	29·2	40·2	57·9
[1]12	29	13	4	20·0	4·7 "	29·3	46·0	61·1
[1]19	29	14	4	20·8	5·8 "	31·0	42·4	57·8

[1] Stansfield, E., and Nichclls, J. H. H.: "Analyses of Canadian Fuels"; Mines Branch, Dept. of Mines, Canada, Bull. 25 (1918).

The carbon ratios are inconclusive as regards oil and gas prospects.

DRUMHELLER AREA (28)

Sec.	Town-ship	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
1	29	20	4	18·7	9·0	30·1	42·2	58·4
1	28	20	4	17·8	9·0	31·1	42·1	57·5
1	28	19	4	18·7	9·0	30·5	41·8	57·7
1	27	18	4	20·9	8·7	28·9	41·5	59·0
2	28	19	4	19·6	8·9	29·1	42·4	59·3
5	29	20	4	19·7	8·8	29·2	42·3	59·2
5	28	19	4	19·6	8·9	28·7	42·8	59·8
7	29	20	4	18·5	9·0	29·1	43·4	59·8

In a rough way these carbon ratios show an increase with depth. Although the carbon ratios show metamorphism not prohibitive for oil and gas occurrence provided local structure is favourable, the approach of the lower seams to a carbon ratio of 60 indicates rather doubtful prospects.

TOFIELD AREA (20)

Sec.	Town-ship	Range	Mer.	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
	50	19	4	27·6	8·0	27·6	36·8	57·1
	50	19	4	28·5	7·9	27·4	36·2	56·9
[1]26.........	50	19	4	15·9	5·6	34·3	44·2	56·3
[1]26.........	50	19	4	11·7	6·9	36·7	44·7	54·9
[1]26.........	50	19	4	17·0	5·6	34·2	43·2	55·8
[1]26.........	50	19	4	16·8	7·2	32·4	43·6	57·4
[1]26.........	50	19	4	12·7	11·9	33·2	42·2	56·0
[1]35.........	50	19	4	15·8	6·7	32·4	45·1	58·2

[1] Stansfield, E., and Nicholls, J. H. H.: "Analyses of Canadian Fuels"; Mines Branch, Dept. of Mines, Canada, Bull. 25.

The metamorphism indicated by the carbon ratio is favourable for oil and gas, provided structural and other conditions are also favourable.

PEACE RIVER AREA

—	Moisture	Min. matter	Vol. matter	Fixed carbon	Carbon ratio
Heart river, near the town of Peace River[1]	14·2	13·9	28·9	43·0	59·8
Pine river, 5 miles above lower forks[2]	2·45	15·10	33·76	48·69	59·1
Pine river, Coal brook, 2½ miles east of forks[2]	7·83	5·87	34·21	52·09	60·4
	1·39	44·12	23·11	31·38	57·6
Pine river, east fork[2]	1·70	4·44	43·76	50·10	53·4
Smoky river, 5 miles below Little Smoky river[2]	11·52	4·18	34·83	49·47	58·7

[1]McLearn, F. H.: "Peace River Section, Alberta"; Geol. Surv., Canada, Sum. Rept. 1917, pt. C, p. 21.

[2]Dowling, D. B.: "Coal Fields of Manitoba, Saskatchewan, Alberta, and Eastern British Columbia"; Geol. Surv., Canada, Mem. 35 (1914).

Although these carbon ratios are not prohibitive for oil and gas over most of this area, it is surprising to find such a high ratio from Heart river from the Peace River formation. Oil of very heavy quality has been found in small quantity in a number of wells drilled on Peace river, but most of these are at some distance down the river from the town. The Peace River Petroleums, Limited, No. 1 well, was drilled close to Peace River town on R lot 9, sec. 31, tp. 83, range 21, W. 5th mer. Both oil and gas shows were encountered. The Pouce-Coupé well of the Northwest Company, drilled to a depth of 3,057 feet on sec. 26, tp. 80, range 13, W. 6th mer., encountered 10,000,000 cubic feet of gas at 1,675 feet. No oil was found.

The Peace River oil is very high in sulphur and it is suggested this may be an indication of action of sulphur on the oil, giving heavy oil where according to the carbon ratio theory lighter oil might have been anticipated.

CONCLUSIONS

A survey of all the carbon ratios in relation to the known occurrences of oil and gas seems to show that predictions regarding the occurrence of oil and gas can be made by means of the carbon ratios. This fact is, of course, of primary importance in prospecting, as the promising areas may be immediately separated from those of doubtful or negative value. In the promising areas, field studies to determine the locations of possible favourable structures should be considered essential before test wells are drilled.

As regards the character of the oil, predictions based on the carbon ratio theory are not so reliable for Cretaceous oil as, apparently, for Pennsylvanian oil. Since the character of the source material affects the original composition of the oil, it may be that the Cretaceous oils were originally different from Pennsylvanian oils or they may have been modified subsequent to formation by a different set of conditions inherent in the sediments. In this respect then, as indicating the grade of oil to be expected, the carbon ratios as applied to the Pennsylvanian may not be applicable to the Cretaceous, since in the case of the Cretaceous of the plains of Alberta the carbon ratios seem to indicate the presence of heavier grades of oil than are found in the mid-continent and Appalachian fields of United States under approximately the same degrees of metamorphism.

CHAPTER III

GEOPHYSICAL METHODS FOR LOCATING OIL

TORSION BALANCE

An instrument of considerable importance, designed by Baron Roland Von Eötvös, Professor of Physics at the University of Budapest, but modified and perfected to make it applicable to specific problems, has been used in recent years to find structures suitable for oil and gas accumulations. It is a gravity measuring apparatus which, however, does not measure the actual value of gravity, but indicates variations due to a deficiency or an excess of mass at any point where the instrument is used.

An account, by Captain H. Shaw and E. Lancaster-Jones,[1] describing the instrument and the principles governing its operation, is summarized here.

"The torsion balance is extremely simple and consists of an horizontal aluminium beam suspended by a very fine wire. At one end of the beam a weight of gold or platinum is fixed, while a second weight is suspended some distance below the other end of the beam. The wire usually employed is platinum alloyed with 20 per cent iridium, of 0·04 mm. diameter, but smaller wires and wires of other materials have been used from time to time. The whole suspended system must be adequately protected against all kinds of disturbance, and this is achieved by enclosing it completely in a double or treble walled metallic case, each case being thermally insulated from the others. The instrument is operated in a specially designed double-walled tent which provides additional protection from radiation. These precautions are necessary in order to minimize temperature changes and convection currents in the beam chamber on account of the extreme sensitiveness of the torsion wire. One of the main difficulties has been to prepare wires having a constant equilibrium position and it is of importance to maintain the temperature as nearly constant as possible during observations. With wires such as described above, it is possible to measure values of the order of one-billionth part of the total gravity, but in order to obtain such accuracy the wires require to be specially prepared. They are subjected to a baking treatment and are kept under constant tension for months or even years.

The mirror mounted on the middle of the beam enables its deflexion to be observed and this may either be read by means of a telescope or recorded photographically. Means are also provided for clamping the beam and relieving the tension from the torsion wire so that it may be transported from place to place without fear of damage."

The theory of the balance and its operation are as follows:

"Consider a light beam BC (Figure 2) to be accurately balanced by the weights B and D, and free to rotate in an horizontal plane about a fine suspension wire AO. It is well known that the weight of a body is the force with which the earth is attracting the body, and we are accustomed to regard these forces at neighbouring points as being parallel to each other. This, however, is only an approximation to the truth, for in reality the forces of the earth's gravitational attraction at points only a small distance apart are not absolutely parallel. If, for convenience, we consider the earth's gravitational force on B to be represented by a vertical line BF the corresponding force on the weight D will not be parallel to BF but will be inclined very slightly to that direction, say along DE. In the illustration this inclination is considerably exaggerated in order that it may be clearly represented in the drawing. This gravitational force DE may be resolved into three mutually perpendicular directions, giving forces P, Q, and R, the last named being parallel

[1] Shaw, H., and Lancaster-Jones, E.: "The Eötvös Torsion Balance and Its Application to the Location of Minerals"; Min. Mag., vol. 32, No. 1, p. 18 (1925).

to BF. Of the other two components P is the force parallel to the direction of the beam, but Q is perpendicular to the direction of the beam and tends to rotate the whole beam system about the suspension wire AO. The wire AO thus becomes twisted, until eventually a position of equilibrium is reached, when the torque due to the minute force Q is just balanced by the torsional force of the wire AO. The beam thus comes to rest in a definite position which can be ascertained by the reflection of a scale in the mirror carried at the middle of the beam. The whole beam system is now rotated into a different azimuth and the observation repeated. From observations of the equilibrium position of the beam in five different azimuths the variation of the gravity at that station can be calculated."

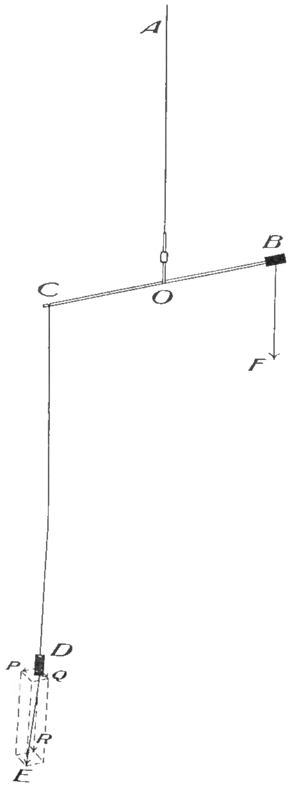

Figure 2. Sketch to illustrate the principle of the Eötvös torsion balance. (From The Mining Magazine, vol. 32, No. 1, page 19.)

To overcome the difficulty of taking readings in five different positions, Eötvös constructed a double-armed torsion balance (*See* Figure 3) which in reality is a combination of two instruments mounted on one pedestal and in which the arms are set in opposite directions. With this instrument observations are made in three positions. Since the construction of this instrument various improvements have been made, but the principles of operation are the same.

In a paper by Heiland[1] the methods for the discovery of mineral deposits are outlined. Since the torsion balance is very sensitive topographic irregularities within a certain radius have to be taken into account. It is on pronounced sensitivity that the value of the instrument depends and in the Gulf Coastal Plain of Louisiana, Texas, and Mexico, the instruments have been used with what must be considered remarkable success. The conditions under which oil occurs in the Gulf Coastal Plain are different from anything so far known in Canada, in that the oil occurs on the flanks of salt dome structures which are in many cases acres in extent. On the edges of the salt domes, which contain salt, gypsum, anhydrite, etc., the sediments are upturned against the salt dome mass and it is in these upturned beds as well as in the cap rock of dolomite that oil occurs.

The application of the torsion balance in these areas is directed toward finding the salt domes. Some of these had a topographic expression which led to the discovery of oil, but in other cases where there is no surface evidence of a dome and in fact where the dome may be buried at some depth below overlying sediments, the torsion balance has been used successfully to locate the salt domes. The salt in the domes has a lower specific gravity than the surrounding sediments, whereas the cap rock is heavier than the sediments and it is by determining these variations in gravity that the torsion balance has proved valuable. It is worthy of note that in these cases the differences in specific gravity are due to the salt dome mass and it is the presence of the salt dome that is recorded by measurements with the torsion balance, although in some instances the discovery of oil has followed because the oil occurs on the flanks of the salt domes.

It is claimed by exponents of the torsion balance that it can also be used for the detection of faults where there is even only slight differences in specific gravity of the sediments on the two sides of the fault-plane. There are large oil-fields in Texas and Mexico along fault-lines and it may be possible to apply the torsion balance to the search for further fields of this type.

The torsion balance can also be used effectively where a fold or anticline has a core of heavy material, the instrument measuring the difference in gravity between the heavy core and the flanking sediments. Such conditions are found in the case of igneous intrusions with which in certain instances oil is associated in Mexico. Also, it is understood that in Kansas the torsion balance is applicable to the location of folds in connexion with the buried Nehama mountains which have a granitic core overlain by Palæozoic and later sediments. The folded attitude of the strata lying on these buried mountains has been ascribed to differential settling, the minimum compaction occurring over the central core and the maximum in the thicker sediments away from it. Apparently the amount of compression is proportional to the weight of the overlying sediments and consequently the amount of folding is greater at depth than at the surface. According to Powers[2] the maximum known relief of the mountains is 1,400 feet in about 4½ miles, which is equivalent to about 4 degrees dip. In general, however, the dips are somewhat less.

[1] Heiland, C. A.: "Instruments and Methods for the Discovery of Useful Mineral Deposits"; Eng. and Min. Jour. Press, vol. 121, No. 2 (Jan., 1926).

[2] Powers, S.: "Reflected Buried Hills and Their Importance in Petroleum Geology"; Ec. Geol., vol. 17, p. 239 (1922).

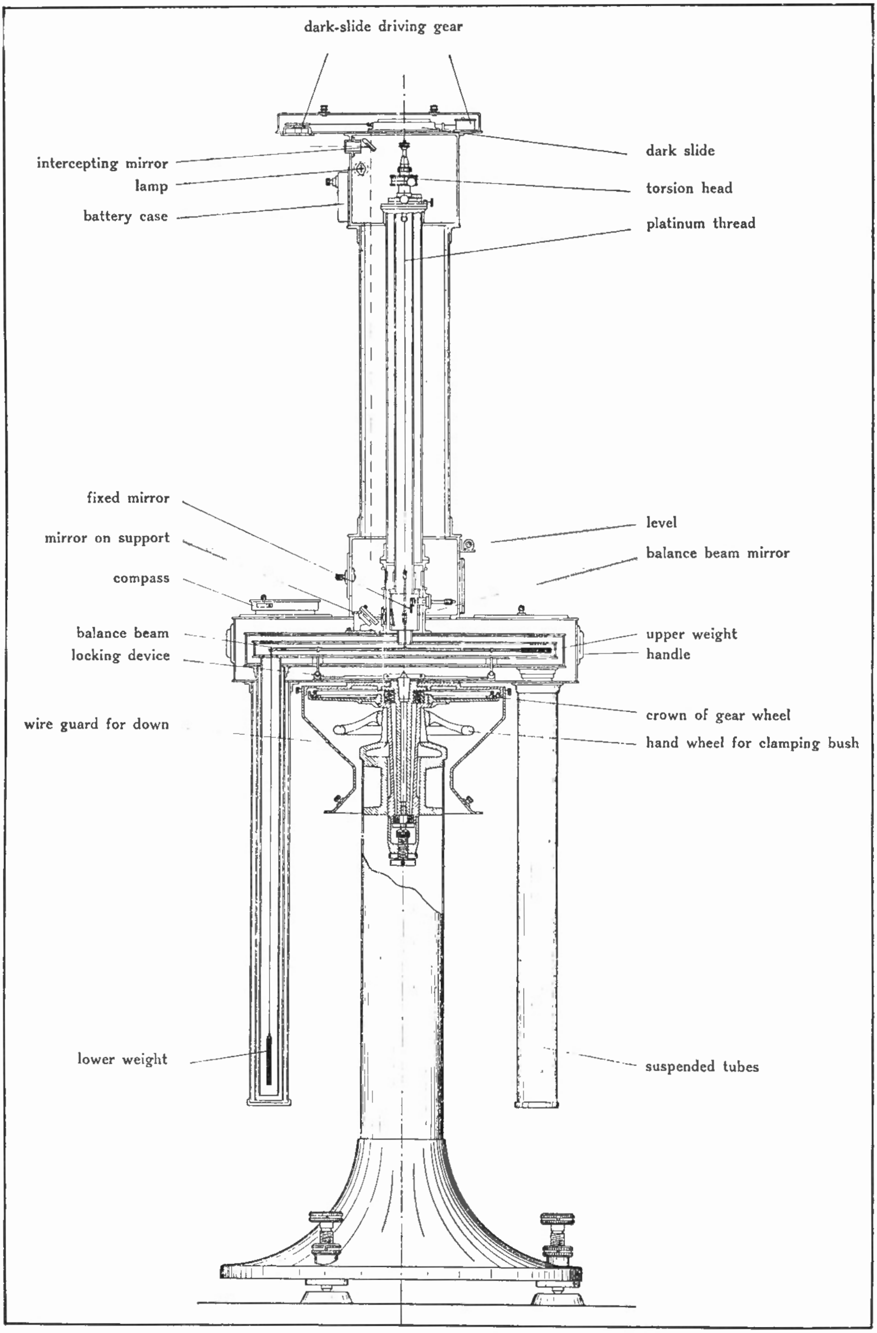

Figure 3. Sectional view of Askania-Werke torsion balance. (Published by permission of Askania Werke.)

It is known that there are Precambrian knobs protruding through Palæozoic sediments in Lake St. Martin district between lakes Winnipeg and Manitoba, and buried knobs of a similar type possibly occur along the eastern edge of the Palæozoics in the Manitoba lowlands and in north-eastern Saskatchewan. Prior to the deposition of the Palæozoics, the Precambrian surface had a relief measurable in hundreds of feet and it might reasonably be assumed that differential settling of the Palæozoics above and on the flanks of Precambrian knobs and ridges would produce a certain amount of doming. On account of the limited knowledge of conditions it is impossible at present to say whether these domes would be of sufficient magnitude to cause oil and gas accumulations within oil-bearing Palæozoic or later sediments. It is thought, however, that these buried knobs and ridges of Precambrian rocks could be detected by the use of a torsion balance, and such places would be the most likely to contain oil and gas in porous horizons at depths in a region where it is known that the general attitude of the strata is almost horizontal.

There are a number of factors which make the torsion balance difficult of application. Since the instrument is so sensitive the readings obtained from it must be corrected for deflexions due to topography. The instrument, therefore, can only be operated by a specially trained crew of men and the results should be interpreted by a geophysist. Also, it is expected some complications will be introduced by a cover of glacial drift such as that which on the plains of Canada in places has a considerable but variable thickness and is heterogeneous in character. Although exponents of the torsion balance claim that a cover of glacial drift does not make insurmountable difficulties it is thought the results obtainable might possibly be more subject to error than in unglaciated areas.

SEISMOGRAPH

The seismograph is an instrument to register and record earth tremors due to earthquake shocks. The instrument, however, has been adapted to the study of geological structures and its application has proved effective in locating salt domes in the Gulf Coastal Plain. A violent explosion is set off at some distance from the instrument and the waves transmitted through the earth are recorded on the instrument. In the case of salt domes it is understood the waves travel through the salt about three times as quickly as through the surrounding sediments. Hence, if a salt dome occurs between the point of explosion and the instrument, the presence of the salt dome becomes evident when the rate of transmission of the waves is calculated.

As pointed out by Stigand in "Outlines of the Occurrence and Geology of Petroleum," besides the waves that travel through the air and are weak there are three paths of transmission through the earth from the point of explosion to the instrument: (1) "along the surface through the looser deposits; (2) along the limits of the latter against the denser rock, from which deflected waves originate and can be recorded; and (3) through the deeper rocks." The surface wave is weak, whereas "the route through the border plane of the underlying strata and from it to the surface is longest. If, however, the distance of the receiving station is chosen far enough from the sending one, the waves running along the underlying strata will reach the receiving station first. The greater the distance along which this ratio prevails, the thicker the looser upper layer will prove to be."

Where shales and sands are underlain by dense limestones, the limestones will act as a high velocity medium and hence from the differences in the rate of transmission, data become available for the interpretation of the underground structure by calculating the depth to the high velocity beds.

VERTICAL AND HORIZONTAL FIELD BALANCES

It has been pointed out "that a mass of oil-impregnated rock surrounded by similar strata impregnated with water might be detected by plotting the density of the magnetic field, noting especially the vertical component. An oil-bearing area must necessarily be a poorer conductor than a water-bearing area and thus the density of the magnetic field should decrease over an oil-field."[1] It should be remembered, however, that other conditions than an oil-bearing area will give practically the same results, since a salt body is also less conductive than a water stratum and it may be necessary to use a combination of geophysical methods before a correct interpretation is possible.

As stated by Heiland,[2] in a magnetic survey "two component intensities are usually recognized, the horizontal and the vertical. The direction of the horizontal intensity forms an angle with the astronomical meridian and this is known as declination." For general purposes it is "sufficient to measure the horizontal and vertical intensity" and for this purpose instruments known as the Vertical and Horizontal Field Balances have been designed.

[1] Cunningham Craig, E. H.: Bull Am. Ass. of Petroleum Geol., vol. 9, No. 1, p. 166.

[2] Heiland, C. A.: "Instruments and Methods for the Discovery of Useful Mineral Deposits"; Eng. and Min. Jour. Press, vol. 121, No. 2 (Jan. 9, 1926).

CHAPTER IV

PHYSIOGRAPHY AND STRATIGRAPHICAL GEOLOGY OF THE GREAT PLAINS

PHYSIOGRAPHY

The Great Plains of western Canada lie between the Canadian Shield on the east and the Cordilleran mountains on the west (*See* "The Geology and Economic Minerals of Canada," by G. A. Young, Economic Geology Series No. 1, for maps and longer description). They extend from the International Boundary to the Arctic ocean and include part of Manitoba, much of Saskatchewan, nearly all of Alberta, a northeastern part of British Columbia, and a large part of Mackenzie River basin in North West Territories. Along their eastern border the Great Plains either merge into the Canadian Shield or else there is a sudden drop of a few score feet. Along their western margin, in Alberta, they are separated from the mountains proper by the narrow belt of the foothills, but farther north, in Mackenzie River basin, the plains sharply abut against the western edge of the Cordillera.

The Great Plains region consists of a number of physiographic subprovinces. Along the southern part of the east border lies the Manitoba lowland with an average elevation of about 800 feet above sea-level. The west edge of the lowland is an eastward-facing escarpment which forms the east edge of the Alberta upland. Drainage channels from the Alberta upland divide the escarpment into several plateau areas known respectively as Pembina, Riding, Duck, and Porcupine mountains, and Pasquia hills, the summits of which rise 500 to 1,000 feet above the Manitoba lowland. The Alberta upland on the whole rises gradually from its eastern edge to its western limit at the foothills of the Rocky mountains, rising from an elevation of less than 1,500 feet to more than 4,000 feet. Its northern edge is a well-defined, northward-facing escarpment overlooking the Mackenzie lowland. In its southern part the Alberta upland is divided in two by the eastward-facing escarpment of Missouri coteau, which, according to Rose,[1] forms the eastern boundary of the Wood Mountain-Willowbunch plateau which rises 200 to 800 feet above the prairie level. On the western side of Wood mountain there is a descent equal to the escarpment on the eastern side. To the west, partly in Alberta but mainly in Saskatchewan, lie Cypress hills, a plateau rising several hundred feet above the prairie level and like the Wood Mountain plateau representing an erosion remnant.

The Mackenzie lowland extends north from the escarpment of the Alberta upland, to the Arctic region. It

"Commences in the lower part of Peace river and the extreme western end of lake Athabaska, whence it extends as a narrow band down the valley of Slave river to Great Slave lake. Its eastern border here as well as north of Great Slave lake is the border of the . . . . . . (Canadian Shield). It embraces the basin of the western end of Great Slave lake and continues down the valley of Mackenzie river to the Arctic coast . . . . . .

[1]Rose, B.: "Wood Mountain-Willowbunch Coal Area, Saskatchewan"; Geol. Surv., Canada, Mem 89, p. 13 (1916).

its western (border being) Mackenzie mountains and the escarpment of the Peel plateau . . . . . . North of Nahanni river, however, the long narrow ridge of Franklin mountains divides the lowland into two parts by separating a strip 20 to 80 miles in width, through which the Mackenzie flows, from the main portion of the lowland lying in the drainage basin of Great Bear lake . . . . . . Rising above the general level of the lowland are a number of hills and mountain ranges varying in height from a few hundred feet to about 4,000 feet. Such ranges are: Horn mountain, northwest of Providence; Franklin mountains, between the Mackenzie and Great Bear lake; Grizzly Bear mountain and Scented Grass hills on the shores of Great Bear lake; Reindeer hills, east of the delta; and a number of other short ranges or isolated hills. . . . . . ."[1]

Peel plateau, which borders the Mackenzie lowland on the northwest,

"Extends south and west . . . . . . on either side of Peel river up to the base of the Mackenzie mountains . . . . . . On the north side, the Peel plateau forms an abrupt escarpment overlooking the lowland and rises gradually until it stands about 1,500 feet above the sea. Its surface is apparently flat, but is in reality made up of several long undulations . . . . . . Peel river cuts a valley in the plateau, ranging from 700 to 1,000 feet deep.[2]"

STRATIGRAPHY

Within the Great Plains region there is a wide diversity in the age of the rocks represented. The range is shown in the following table:

Recent and Pleistocene....	Mostly unconsolidated deposits consisting of boulder clay, gravel, and sand.
Tertiary..................	In central Alberta south of North Saskatchewan river a large area is covered by the Paskapoo formation represented in southwestern Alberta by the Willow Creek and Porcupine Hills formations. In southern Saskatchewan and Manitoba erosion remnants of Tertiary beds form Cypress hills, Wood Mountain-Willowbunch area, and Turtle mountain. In Mackenzie basin the Tertiary is represented by continental deposits in part of Peel plateau and in smaller areas in the Mackenzie lowlands where they lie unconformably on Cretaceous or Devonian rocks.
Mesozoic..................	*Cretaceous.* With the exception of those areas covered by Tertiary rocks, Cretaceous deposits cover all except the northern part of the Alberta plateau. East of the area covered by Tertiary rocks in central Alberta, the surface of the plains bevels the Cretaceous, so that on the whole, progressively older Cretaceous formations appear eastward, the eastern edge being the escarpment overlooking the Manitoba lowland. Cretaceous sediments cover large areas in the Mackenzie lowlands and Peel plateau.
	Jurassic and Triassic. Rocks of these ages outcrop only in the Rocky mountains and foothills where faulting and folding have brought them to the surface. They undoubtedly extend eastward for some distance beneath the Cretaceous and Tertiary strata of the Great Plains.
Palæozoic.................	*Carboniferous.* Rocks of this age are known only in the Rocky mountains and foothills. It is assumed that these also, like the Jurassic and Triassic, extend eastwards under the younger sediments of the plains, but their eastward limits are unknown.
	Devonian, Silurian, and Ordovician. These form the Manitoba lowlands, occupy large areas within the Mackenzie basin, and presumably extend westward beneath the younger strata of the plains. Devonian beds outcrop in the Rocky mountains.
	Cambrian. Rocks of this age are definitely known in small areas in the Mackenzie lowlands and included mountains. They are also known in the Rocky mountains west of the plains.
Precambrian..............	The Canadian Shield is composed of rocks of this age.

[1] Camsell, Charles, and Malcolm, Wyatt: "The Mackenzie River Basin"; Geol. Surv., Canada, Mem. 108, p. 20 (1921).
[2] Camsell, Charles, and Malcolm, Wyatt: op. cit., p. 19.

The Palæozoic formations overlap the Precambrian of the Canadian Shield, underlie the whole of the Manitoba lowland, occupy large areas within the Mackenzie lowland, and are extensively developed amongst the folded and faulted strata of the eastern ranges of the Cordillera. Palæozoic beds presumably everywhere underlie the younger strata of the Great Plains. Along the eastern and northern borders of the plains, the youngest division of the Palæozoic is the Devonian and it is unconformably overlain by Cretaceous beds and, in the Mackenzie lowland, by Tertiary strata also. The unconformity separating the Devonian and the Cretaceous, or the Devonian and the Tertiary, represents an exceedingly long interval of time, in which a large amount of erosion may have occurred in the east and north, but which in the west was, at least in part, a period of deposition, for there, Carboniferous, Permian, Triassic, and Jurassic rocks are known in the foothills and mountains. These beds were deposited in seas which overlapped the older sediments to the east for an unknown distance. Since everywhere, so far as known, the oldest Cretaceous sediments are continental deposits, it is assumed that preceding their deposition there was a period during which the area that now constitutes the Great Plains was above sea-level and undergoing erosion. It is probable that the sediments of Jurassic, Triassic, and Carboniferous ages were bevelled during this period of erosion and were entirely removed from the Mackenzie lowlands, if they were ever there. In the mountains of western Alberta, however, thick deposits of these ages are preserved and it is concluded these formations have a wedge-like form with the thick part of the wedge in the west and the thin edge at an unknown distance under the plains east of the foothills.

Following the erosion period of early Cretaceous and pre-Cretaceous time, continental deposits of Cretaceous age were widely developed over the Great Plains area. In these sediments, sands predominate over shales and in some areas conditions were favourable for the formation of coal. It is not assumed that the Lower Cretaceous sediments of the plains area are everywhere exact equivalents, for it is probable that the sediments in one part of the region represent only part of the time represented by sediments in other parts and the Lower Cretaceous sediments of one area may be younger or older than those of another area. Among the formations of Lower Cretaceous age are the Kootenay and Lower Blairmore of southwestern Alberta; the McMurray, Clearwater, and Grand Rapids of Athabaska area; The Loon River and Peace River formations of the eastern Peace River area; possibly the Bullhead Mountain formation of the western Peace River area; the basal Cretaceous sands of Manitoba area, etc. In certain parts of Mackenzie area sands and shales with some conglomerate and carrying thin coal seams form the oldest Cretaceous sediments, but their age is unknown.

The Lower Cretaceous strata are followed by Upper Cretaceous thick shale deposits of Colorado age of predominantly marine origin, although with them are local bodies of sands. Overlying the Colorado are the Montana formations consisting of alternating marine shales and non-marine, thick, extensive sands and shales. In Alberta non-marine sands of great thickness compose the Belly River formation which in the south is succeeded by the marine Bearpaw shale overlain in turn by the extensive, coal-bearing formation known as the Edmonton.

In central Alberta a disconformity[1] separates the Edmonton from the overlying Tertiary Paskapoo formation which occupies a wide area in southern central Alberta, extending from south of Bow river to a short distance south of Athabaska river northwest of Edmonton. There are also several, detached, smaller areas of Paskapoo, one on the watershed between McLeod and Athabaska rivers, and another, larger one north of Athabaska river and south of Lesser Slave lake in the vicinity of Swan hills. In southern Alberta the Paskapoo is represented by the Porcupine Hills and Willow Creek formations and possibly an upper part of the underlying St. Mary River beds. Later Tertiary rocks cap the Cypress hills of southern Alberta and Saskatchewan and are represented by the strata of Wood Mountain-Willowbunch area in south Saskatchewan and in Turtle mountain, Manitoba. These areas of Tertiary rocks are erosion remnants of once more extensive and, probably, continuous areas in the southern Great Plains.

It is certain that only part of Tertiary time was a period of deposition in the Great Plains area and prior to the Glacial epoch a great amount of erosion was accomplished. Following the Tertiary the whole of the Great Plains was glaciated. Two ice-sheets were involved in this glaciation: one from the mountains to the west, known as the Cordilleran ice-sheet, which, according to Coleman,[2] in southern Alberta at least, was older than the other or Keewatin ice-sheet from the northeast. The eastward limits of the Cordilleran sheet are unknown, but it probably covered a relatively small part of the plains area. Over the whole of the Great Plains, deposits of boulder clay and glacial materials were widely distributed and to a certain extent caused a rearrangement of the drainage. However, it has been demonstrated that at least a number of the main drainage channels antedate the ice-sheets. The amount of erosion that has taken place during and since the Glacial epoch is relatively slight in comparison with the erosion that was accomplished in Tertiary time.

STRUCTURAL FEATURES

The eastern ranges of the Cordillera began to form in Cretaceous time, although the major uplift probably did not take place until much later in Tertiary time. The mountain building took place in an area where a great thickness of sediments had accumulated and the deformation of these sediments in the eastern Rocky mountains gave rise to westward tilted fault-blocks overthrust to the east. In the foothills area along the east edge of the mountains, the rocks are intensely folded and faulted, but on a much smaller scale than in the mountains. In the Rocky mountains, erosion subsequent to deformation has to a large extent removed the younger rocks, leaving the older and harder Palæozoic rocks exposed. In the less elevated foothills area, erosion has resulted in the formation of elongated ridges which parallel the mountains. According to Stewart[3] "most of the ridges have steep slopes, in places as high as 30 degrees. The steeper slope is usually toward the east, owing to the westerly dips of the

[1] Allan, J. A.: "Geology of Alberta Coal"; Can. Inst. of Min and Met., No. 156, p. 396 (April, 1925).
[2] Coleman, A. P.: "The Drift of Alberta and the Relations of the Cordilleran and Keewatin Ice Sheets"; Royal Soc. of Can., sec. IV, pp. 3-13 (1909).
[3] Stewart, J. S.: "Geology of the Disturbed Belt of Southwestern Alberta"; Geol. Surv., Canada, Mem. 112, p. 12 (1919).

rocks. The difference in height of the ridges is due mainly to the relative hardness or resistance of the capping strata and some of the high buttes are clearly synclinal in structure." The main streams cut across the parallel ridges regardless of structure and clearly antedate the erosion that developed the longitudinal valleys between the ridges.

The folding and faulting that characterize the foothills gradually die out eastward and over much of the plains area the strata depart from the horizontal by only a few feet a mile. In Alberta, east of the foothills, a great syncline has been developed which, it is believed, to a large extent explains the preservation of the Tertiary rocks in central Alberta south of Lesser Slave lake. To the north this synclinal structure disappears and is not evident in the Peace River sections. In southern Alberta this syncline or basin is bounded on the east by the projection from the south of an anticlinal area known as the Sweet Grass arch, on which the Bow Island and Foremost gas-fields have been developed. In central Alberta the eastern edge of this syncline is supposed to be a line from Misty hills, south of Monitor, in the south, to west of Viking gas-field in the north. West of this line the strata dip in a southwestern direction into the Alberta syncline, whereas eastward, although the regional dip is in the same direction, it is much more gentle. Recent work has shown that this moderate southwestern regional dip is continuous from west of Viking to the Alberta-Saskatchewan boundary in the vicinity of Battle river, but on it are superimposed slight local folds causing gas and oil accumulations in the Viking-Irma-Wainwright area. East of the Alberta-Saskatchewan boundary, however, the dip becomes southeasterly and continues to be so almost as far east as Battleford, Saskatchewan, and for an unknown distance southeasterly. The structure, therefore, between Viking, Alberta, and Battleford, Saskatchewan, is a broad anticlinal fold modified to some extent by local folds. Since Lower Cretaceous formations appear to the east at the edge of the Manitoba escarpment, it is generally assumed that at some place in eastern Saskatchewan or Manitoba the dip must again change to a westerly or southwesterly direction, but a thinning of the formations eastward might obviate the necessity of any such change in the direction of dip. Details of the structure in eastern Saskatchewan and Manitoba are unknown, but in the Manitoba lowland it is thought that a general westerly dip is possessed by the Palæozoic formations.

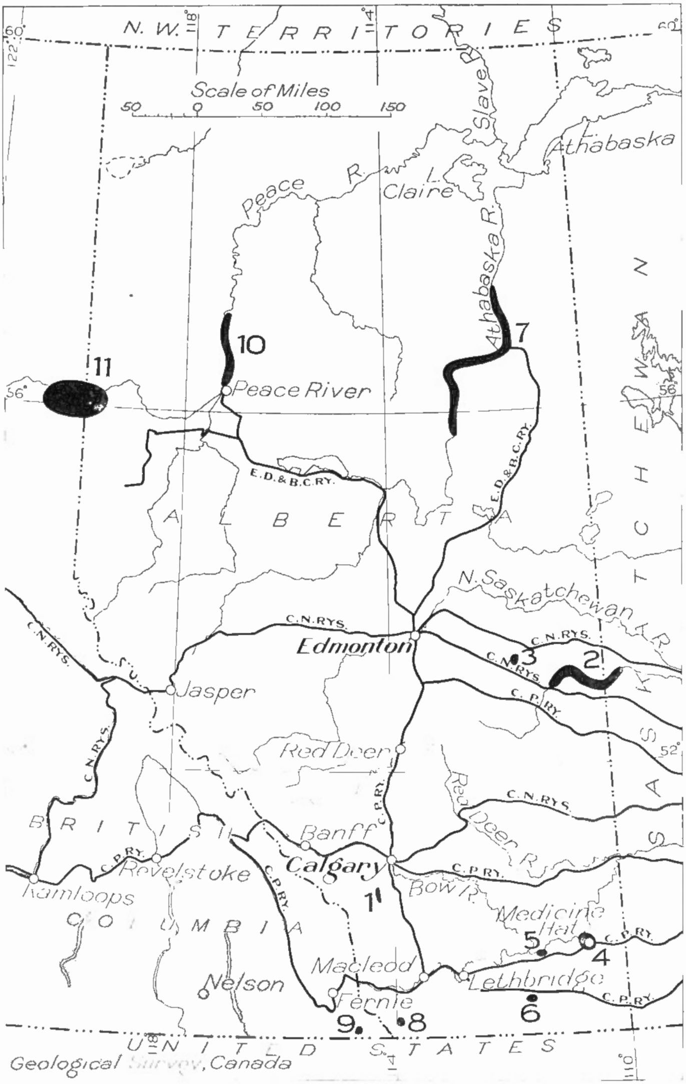

Figure 4. Index map showing location of oil- and gas-fields in Alberta and British Columbia:

1, Turner Valley field; 2, Battle River area; 3, Viking gas-field; 4, Medicine Hat gas-field; 5, Bow Island gas-field; 6, Foremost gas-field; 7, McMurray-Athabaska area; 8, Waterton lake and Cameron brook; 9, Flathead River area; 10, Eastern Peace River area; 11, Western Peace River area.

CHAPTER V

DESCRIPTIONS OF OIL- AND GAS-FIELDS

OIL AND GAS PROSPECTS IN ALBERTA SOUTH OF THE LATITUDE OF LETHBRIDGE

By M. Y. Williams

Reference: Dyer, W. S., and Williams, M. Y.: Memoir in preparation.

INTRODUCTION

Since the development of the Kevin-Sunburst oil-fields of Montana, in 1922, drilling has been actively carried on in southern Alberta. At first interest centred in the vicinity of Coutts, as it was hoped the oil pool would extend across the International Boundary from the proven territory only 10 miles south. Later, drilling was started just north of Sweet Grass hills, and renewed activity was manifested in the Foremost gas-field and in the wildcat well in Pakowki Lake district. The results have been gratifying from the standpoint of gas production, as the Foremost field is now proved to be of great value, and a new field has been opened up by the Rogers-Imperial well, with its various sands having an estimated production of about 50,000,000 cubic feet of gas a day. From the standpoint of oil production the results are inconclusive, but encouraging showings of oil have been struck in several of the test wells.

The region under discussion extends from the disturbed belt bordering the Rocky mountains, to the border of Saskatchewan on the east; and from the 49th parallel northward for 48 miles. With an average east-west dimension of 156 miles, the included area is 7,488 square miles. The region falls within the belt of treeless plains. Elevations vary between 2,680 feet where Milk river crosses the boundary into Montana and 4,800 feet in Cypress hills and 4,500 feet in the southern disturbed belt. The country is in general a rolling plain which slopes upward to Cypress hills in the northeast, Sweet Grass hills in the south, the hills of the disturbed belt in the west, and Porcupine hills in the northwest. Into the plain are entrenched the valleys of the Oldman and Milk River systems, including several dry coulées which served as temporary drainage channels during the melting of the continental glaciers at the close of Pleistocene time. It is in the sides of these drainage channels that most of the rock outcrops occur, as elsewhere the land surface is underlain by thick deposits of till and outwash sand and gravel.

GENERAL GEOLOGY

Rocks of early Tertiary and Upper Cretaceous age underlie the Glacial deposits and may be classified as in the following table, which also indicates the underlying strata whose presence has been revealed by drill records.

Table of Formations

Tertiary	Porcupine Hills sandstone, 1,000 feet Willow Creek shale, 1,000 feet
Upper Cretaceous	St. Mary River and Fox Hills sandstone, 1,600 to 1,800 feet Bearpaw shale, 800 feet Pale beds, 450 feet Foremost beds, 400 feet Pakowki shales, 250 feet Milk River sandstone, 200 to 300 feet Colorado shale, 1,900 feet
Lower Cretaceous	Kootenay sandstone and shale, 500 feet
Jurassic....................	Ellis sandstone, etc., 200 to 260 feet
Palæozoic..................	Madison limestone, 800 feet

These formations include three dark marine shales lying between sandstone formations which may be considered potential reservoirs of oil and gas. In fact, gas occurs in the Ellis sandstone, near Sweet Grass hills, in sandstone lenses in the Colorado shale at Dead Horse coulée, and Foremost; and in the Milk River sandstone at Medicine Hat; and oil occurs in large quantities in the top of the Madison limestone and the base of the Ellis sandstone at Kevin-Sunburst, and in small quantities at least in the Kootenay, Ellis, and Madison formations near Coutts.

The gentle structure of the southern plains of Alberta has been modified near the Montana line by the uplift caused by the intrusion of the igneous rocks forming the core of Sweet Grass hills. The general upwarp extends north into Alberta, where it is noticeable as a strong physiographic slope.

A few small minette dykes and two small stocks occur in Alberta as proof of the subsurface extension into Canada of the Sweet Grass igneous mass. Oil in this region has doubtless been affected by the igneous intrusion and the presence of large gas accumulations may well represent the distillation products of ancient oil pools. The radial dykes which extend 10 to 15 miles from Sweet Grass hills, may, under favourable circumstances, have brought about special accumulations of gas held back in its passage through the rocks by the dykes. It will be seen from these considerations that the Sweet Grass arch must be considered as a separate province, where conditions apply that are abnormal elsewhere in southern Alberta.

Descending from the Sweet Grass uplift there is a gentle structural slope eastward into Saskatchewan, and a steeper slope westward into the deep trough fronting the disturbed belt of the Rocky mountains. Locally the western slope is modified by gentle east-west terraces and folds of monoclinal nature.

AREAS OF EXPLORATION

Coutts

Within 6 miles east and west of Coutts five wells have been drilled. Of these, the Red Coulée well, drilled by the Northwest Company, near the 49th parallel and about 6 miles west of the town, penetrated the Madison limestone at a depth of 2,695 feet. A showing of oil of considerable promise was struck in the Sunburst sand of the Kootenay formation at a depth of 2,505 feet, but this was not developed.

The "Border" well, 6 miles east of Coutts, was drilled with a diamond drill and passed through a showing of oil at 1,875 feet in a sandstone lens in the Colorado shale, and again at 1,920 feet in the top of what is probably the off-shore phase of the Kootenay formation. The well was finished in the Kootenay at a depth of 2,020 feet.

The "Coutts-Sweetgrass" well, situated 4 miles east of Coutts, was drilled to a depth of 2,850 feet, which is probably 200 feet into the Madison limestone. Oil showings were reported at five horizons in the Kootenay and Ellis formations between 2,340 and 2,450 feet in depth.

The well drilled by the Lethbridge Oil, Limited, about 1 mile north of the Coutts-Sweetgrass well, penetrated the Kootenay formation at 1,950 feet and was finished at 1,985 feet without reaching the Ellis sandstone.

The Urban well drilled just east of Coutts has tested what was believed might prove a higher structure than that at the Red Coulée well. This is not the case, however, as the top of the Colorado shales is 70 feet lower in the Urban well than in the Red Coulée well. The Madison limestone in the Urban well was penetrated at 2,560 feet in depth. Sulphur water was struck in the Ellis sand and only small amounts of gas have been struck in the Madison limestone, which was penetrated 70 feet.

Dead Horse Coulée

The Canadian Oil and Refining Company's well, generally known as the Rogers-Imperial Dead Horse Coulée well, is situated 24 miles east of Coutts and 4½ miles north of the Montana boundary. This well is on a small structure subsidiary to the Sweet Grass dome. The Kootenay formation was penetrated at 2,100 feet and the well was finished in the Madison limestone at 2,797 feet. Gas was struck in large quantities in a sandstone lens in the Colorado shale at 920 feet, and in the Ellis sandstone at 2,538 feet, the total gas flow being estimated at 50,000,000 cubic feet a day. This well has opened up a new gas-field on the Canadian side of the Sweet Grass arch.

The Imperial Dead Horse Coulée well is situated about 3 miles northwest of the Rogers Imperial well, and down the dip of the rocks. This well penetrated the Madison limestone at a depth of 2,573 feet. The Sunburst sand at the base of the Kootenay formation was found to be saturated with oil, but the sand was very close. Heavy black oil was found in the calcareous sand and sandy limestone of the Ellis formation and some tarry oil was found in the top of the Madison limestone. The well was finished in the Madison limestone at 2,578 feet, where a show of oil and gas was followed by a copious flow of sulphur water.

Foremost (Locality 6, Figure 4)

The Foremost gas-field is situated from 4 to 6 miles southeast of Foremost, where the Canadian Western Gas, Light, Heat, and Power Company have six wells in Etzikom coulée and on the prairie to the north. Some of these wells started with a production of 10,000,000 to 25,000,000 cubic feet of gas a day, and in 1924 the field was connected with the Bow Island distributing line. The additional supply of gas has been a boon to

Calgary, Lethbridge, and the other towns drawing gas from the Bow Island and neighbouring fields.

The Foremost wells are from 2,070 to 2,250 feet in depth and obtain their gas from sandstone lenses in the Benton shales of the Colorado formation.

FUTURE POSSIBILITIES

The future possibilities of the area depend: (1) upon more complete testing of the large area under which the Madison limestone may be reached at 3,500 feet or less in depth; and (2) the testing of higher formations lying below the Pakowki and Bearpaw shales.

Recognizing the Foremost-Dead Horse Coulée region as potentially a gas-field, there is still room to explore the Madison and Ellis formations between the Milk River ridge and Lethbridge. A monocline in the vicinity of Kipp coulée is worthy of consideration, as is also another monoclinal fold about 5 miles south of Lethbridge. In Kipp coulée, west of New Dayton, the Madison limestone may be expected about 3,300 feet below the surface and is probably about 300 feet lower in the valley of Oldman river 5 miles south of Lethbridge. Other equally good areas may exist north of the Milk River ridge and between Lethbridge and Foremost. The possibilities of the Milk River sandstone and the Pale beds may be tested in the northeast corner of tp. 3, range 22, W. 4th mer., and in the Milk River valley in tps. 1 and 2, ranges 21 and 22, W. 4th mer., east and west of the highway bridge. The Madison limestone at these localities is probably about 4,000 feet from the surface, but the formations mentioned above should be penetrated between 700 and 2,100 feet in depth. Gentle domes are indicated at both locations named and the Bearpaw shale provides excellent cover for oil pools in the Belly River beds. Whether or not the Pakowki shale here is replaced by sandstone is a matter of conjecture. In case it is, the Milk River sandstone is not likely to retain oil pools; in this case the best chances are at shallow depth below the Bearpaw shales.

The Pale beds and Milk River sandstone are essentially freshwater deposits and the hope that they may contain oil depends upon the possibility of the descent of oil from the overlying Bearpaw and Pakowki shales of marine origin, or, in the case of the Milk River sandstone, of upward migration of oil from the underlying Colorado marine shale.

There are still possibilities of oil accumulation in sandstone lenses of the Colorado shale. Pools in such lenses are known farther east and south and the extent and thickness of the lenses are probably greater at those localities which are nearer the mountains and the source of the sediments.

From range 22 westward the formations sink into a deep syncline whose axis extends northwest-southeast through Woolford and Peigan stations. The western rim rises at the edge of the disturbed belt, and the whole syncline offers poor prospects for oil or gas accumulation.

In view of the showings of oil struck in Dead Horse Coulée and Coutts districts, there appears still to be a chance of finding favourable sand conditions for commercial oil occurrence. At Dead Horse Coulée, the Rogers-Imperial well is on the gas, and the Northwest Company's well is on the edgewater. Between these locations oil should occur and its quantity will evidently depend upon the porosity of the sand.

MEDICINE HAT, BOW ISLAND, AND MANY ISLAND LAKE GAS-FIELDS, SOUTHERN ALBERTA

By W. S. Dyer

References: Dyer, W. S., and Williams, M. Y.: Memoir in preparation.

INTRODUCTION

The Bow Island (locality 5, Figure 4) and Medicine Hat (locality 4, Figure 4) gas-fields are the oldest and most important in southern Alberta. They have been developed rapidly within the last fifteen years until they have reached an advanced stage in commercial production. Several cities and towns, including Medicine Hat, Taber, Lethbridge, Macleod, and, until recently, Calgary,[1] derive their gas from these fields. The Bow Island field is situated northwest of the village of Bow Island on the Crowsnest branch of the Canadian Pacific railway midway between Lethbridge and Medicine Hat. The Medicine Hat field centres about the city of Medicine Hat, the junction point of the main line and the Crowsnest branch of the Canadian Pacific railway, 25 miles west of the Saskatchewan border.

GENERAL GEOLOGY

South Saskatchewan river, or the Oldman, as the same river is known above the mouth of its tributary, the Bow, flows in a general direction a little north of east from the Rocky mountains, past Lethbridge, Taber, and Bow Island, to Medicine Hat. At Medicine Hat its course is deflected to the north. In places the river has cut down its valley to depths of 300 feet and has uncovered large rock sections. The rocks exposed all belong to the Montana group of the Upper Cretaceous system, and, for the most part, to the Foremost and Pale beds—the fresh and brackish water portions of the "Belly River" of Dawson.[2] Near Lethbridge, however, large sections of the marine Bearpaw shales occur. The formations underlying the Foremost do not outcrop in the region and information regarding their character and thickness has been obtained from bore-holes sunk for oil, gas, or water.

Table of Formations

Formation	Lithological character
Fox Hills	Grey and buff sandstone and shale, brackish water, 400 feet
Bearpaw	Dark grey or black, fossiliferous, marine shales, 600 feet
Pale beds	Pale-coloured sands, clays, and sandy clays with freshwater fossils; coal seams at the top; 400 feet at Medicine Hat, 500 feet at Lethbridge
Foremost	Sombre-coloured sands, clays, and sandy clays with coal seams and fresh and brackish water fossils; 350 feet at Medicine Hat, 550 feet at Lethbridge
Pakowki	Dark grey or black, fossiliferous, marine shales; 700 feet at Medicine Hat, 200 feet at Lethbridge

[1] Calgary now obtains part of its supply from the Turner Valley field.

[2] Dawson, G. M.: "Report on the Geology of the Bow and Belly Rivers Region"; Geol. Surv., Canada, Rept. of Prog. 1882-1884, pt. C.

Table of Formations—Continued

Milk River..................	Sandstone or alternating sandstone and shale beds, freshwater; 30 feet at Medicine Hat, 200 feet at Taber
Benton (Colorado group).....	Dark-coloured, fossiliferous, marine shales with sandstone bands; 1,700 feet
Blairmore (upper part only)..	Grey sandstone and conglomerate

Gas has been obtained in quantity from two formations only in the part of southern Alberta under discussion, namely the Milk River and the Benton, and these two formations will accordingly be described in detail. The Milk River sandstone is thickest in the valley of Milk river near the International Boundary, where it forms precipitous cliffs over 200 feet in height, with characteristic castellated forms. From Milk River valley it spreads out over a large part of southern Alberta and has been penetrated in several bore-holes. It maintains a thickness of 200 feet as far north as Taber, but north, east, and west of this point it becomes much thinner; at Lethbridge it is 90 feet thick, at Bow Island 110 feet, at Alderson 115 feet. At Medicine Hat it is only about 30 feet, and has changed from a sandstone to a sandy shale with thin sandstone bands. It is probably present, though very thin, at Many Island lake, but north and east of this locality it fades out altogether and the Pakowki rests directly upon the Benton, giving a continuous series of shales nearly 2,500 feet in thickness. The Milk River is the gas horizon at Medicine Hat.

The Benton is a thick series of marine shales. Sandstone bands occur in the formation, many of which carry gas or water, but the main gas-producing horizon at Bow Island is a sandstone band 35 feet thick, 1,300 feet below the Milk River. Slipper[1] describes this sandstone as follows:

"The sandstone in which the gas occurs is medium-grained and light grey in colour; the grains are mostly white or of transparent quartz and are somewhat angular. There is no cement and the grains can be easily abraded by rubbing with the finger. It is very porous and pitted. The rock breaks into thin plates parallel to the bedding and the joint-planes are covered with a thin black scum or film."

The most prominent structural feature in southern Alberta is the Sweet Grass arch, a low, broad dome which extends southward halfway through the state of Montana and northward for at least 20 miles north of Bow Island. The arch centres about Sweet Grass hills, a series of laccoliths situated just south of the International Boundary. Many think that the upthrusting of the laccoliths caused the arch, but F. R. Clarke[2] believes that:

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

An oil-field of considerable importance has been found near Kevin and Sunburst in northern Montana on a smaller dome superimposed on the arch, but up to the present only minor structures have been found in Canada and no commercial pools of oil have been located. Certain of these small structures, however, have yielded gas in quantity.

[1] Slipper, S. E.: Geol. Surv., Canada, Sum. Rept. 1916, p. 133.
[2] "Kevin-Sunburst Oil Field, Montana"; Bull. Am. Ass. Pet. Geol., vol. 7, p. 271 (1923).

The northern part of the arch crosses South Saskatchewan river. Its broad, comparatively flat crest extends from Bow Island to Chin station on the Crowsnest branch of the Canadian Pacific railway. West of Chin the rocks dips westward at the rate of 35 to 40 feet a mile, into the Alberta syncline, and east of Bow Island they dip eastward at about the same rate.[1] At Medicine Hat the dip has decreased to less than 5 feet a mile to the east, which dip continues for many miles to the north and east.

The Bow Island field is on a low dome of 50 feet closure superimposed on the Sweet Grass arch, but the Medicine Hat field lies in the structurally low area to the east.

BOW ISLAND GAS-FIELD

(*See* Figure 5)

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

Gas Wells in the Bow Island Cas Field

No.	L.S.	Sec.	Tp.	Range	Elevation above sea-level	Depth to top of gas sand	Elevation of top of gas sand	Open flow, cubic feet per day
					Feet	Feet	Feet	
1	6	15	11	11	2,300	1,866	434	8,500,000
2	15	15	11	11	2,273	1,849	424	abandoned
3	14	9	11	11	2,273	1,849	424	13,000,000
4	3	17	11	11	2,273	1,843	430	29,000,000
5	9	22	11	11	2,270	1,867	403	abandoned
6	1	16	11	11	2,286	1,881	405	4,200,000
7	8	18	11	11	2,283	1,856	427	7,000,000
8	13	18	11	11	2,314	1,891	423	12,000,000
9	2	24	11	12	....	....	414	abandoned
10	8	23	11	12	....	....	415	abandoned
11	1	7	11	11	....	....	....	7,300,000
12	13	7	11	11	2,467	1,958	409	16,000,000
13	3	9	11	11	2,521	....	....	18,000,000
14	1	1	11	12	2,548	2,100	448	7,000,000
15	13	12	11	12	2,581	2,170	411	4,000,000
16	4	4	11	11	2,554	2,134	420	abandoned
17	1	25	11	12	2,594	2,207	387	abandoned
18	4	1	11	12	2,663	2,230	433	abandoned
19	16	25	10	12	2,531	2,076	455	3,000,000
20	16	30	10	11	2,550	2,100	450	abandoned
21	1	30	10	11	2,564	2,127	437	abandoned
22	14	31	10	11	2,544	2,100	444	1,300,000
23	16	17	11	11	2,396	1,981	415	2,300,000
26	15	33	10	11	2,559	....	....	abandoned
27	4	20	11	11	2,496	2,092	404	1,300,000
28	12	4	11	11	2,275	....	....	7,000,000
29	9	24	11	12	....	....	....	12,000,000

28=Village of Bow Island well; 29=Southern Alberta Land Company well.

[1] The top of the Milk River at Bow Island is 1,900 feet above sea-level and at Redcliff the same horizon is 1,200 feet above sea-level.

Wells Nos. 4, 13, and 12 have the remarkable open flows of 29,000,000, 18,000,000, and 16,000,000 cubic feet a day, respectively. The average well measures from 7,000,000 to 12,000,000 cubic feet; the lowest, Nos. 22 and 27, measure 1,300,000 cubic feet. The total open flow capacity of the field at its maximum was between 150,000,000 and 175,000,000 cubic feet a day—a much higher figure than for Medicine Hat. This figure has, however, decreased greatly in the last few years. The original rock pressure was between 700 and 800 pounds a square inch, but by 1923 had declined to 210 pounds. In connexion with the figures of the total capacity of the field it is interesting to note, according to Mr. H. B. Pearson, General Superintendent of the Gas Company[1], that

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

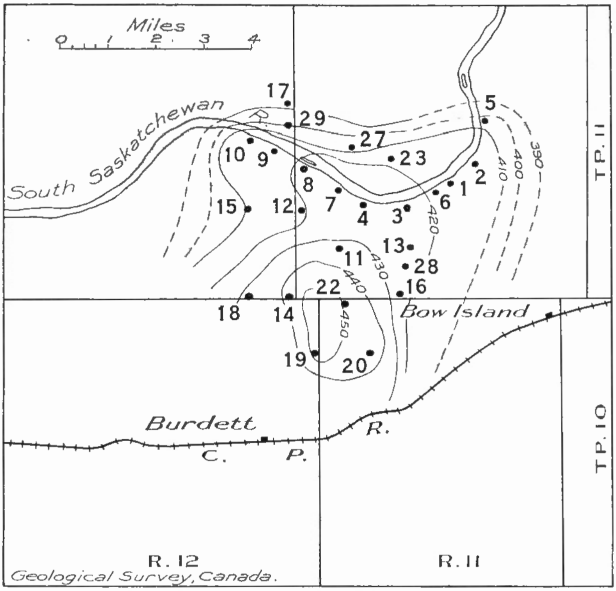

Figure 5. Bow Island gas-field; structure contours represent top of the gas sand; numbers designate the wells as given in the table, page 48.

No outcrops of rock occur in the immediate vicinity of the field. As already stated the gas occurs in a porous sandstone band 35 feet thick, in the Benton shales about 1,300 feet below the base of the Milk River sandstone. The structure of the field is represented in Figure 5 which is based on the data given in the preceding table. That the irregular-shaped dome with a closure of only 50 feet has been large enough to hold the large quantity of gas obtained in the field is surprising. Undoubtedly the reason is that the small dome is situated on the crest of the Sweet Grass arch.

[1] Newspaper interview, 1916.

The extent of the field is not known exactly, but is probably not much larger than the dome shown on Figure 5. The field has passed its zenith and is now rapidly declining. Edgewater has appeared in several of the wells, which have, consequently, been abandoned.

Other structures of a similar character occur not far away from Bow Island. The Foremost gas-field, 30 miles south of Bow Island, is probably on such a structure, as well as the small field near Barnwell 40 miles west of Bow Island. Eight wells were drilled in the latter field, but only one struck a profitable flow of gas. The gas sand is much the same as at Bow Island and Foremost, i.e., a sandstone band near the base of the Benton shales.

MEDICINE HAT GAS-FIELD

(*See* Figure 6)

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

Gas Wells in Medicine Hat Gas-Field

	Name of well	Sec.	Tp.	Range	Elevation	Depth to Milk River sandstone	Elevation Milk River sandstone above sea-level	Open flow cub. ft. per day	Approx. thickness of Milk River sandstone
					Feet above sea-level	Feet	Feet		Feet
1	Main st.	SW. ¼ 31	12	5	2,202·95	....	....	2,225,000	....
2	Armory	NE. ¼ 31	12	5	2,145·05	....	....	3,000,000	....
3	Rosary	NW. ¼ 32	12	5	2,132·65	....	....	2,000,000	....
4	Balmoral	SW. ¼ 32	12	5	2,128·95	905	1,224	2,500,000	85??
5	Electric Plant	NW. ¼ 35	12	6	2,167·75	....	....	4,000,000	....
6	Craft	SW. ¼ 36	12	6	2,148·15	918	1,230	3,264,000	About 10
7	S. Industrial	NW. ¼ 18	12	5	2,346·95	1,094	1,253	2,300,000	35
8	W. Industrial	NE ¼ 22	12	6	2,312·82	1,065	1,247·82	2,100,000	65
9	Stella	SW. ¼ 28	12	5	2,147·65	938	1,209·65	2,500,000	30
10	Hargrave	NW. ¼ 31	12	5	2,165·65	....	....	2,500,000	....
11	Cousins and Sissons	NE. ¼ 25	12	6	2,269·44	1,075	1,194	2,800,000	....
12	Central park	NW. ¼ 30	12	5	2,262·87	1,030	1,232·87	3,000,000	28
13	Maple st.	NW. ¼ 29	12	5	2,131·35	....	....	2,500,000	....
14	Powell	SE. ¼ 30	12	5	2,139·55	....	....	2,900,000	....
15	Huckvale	NE. corner 6	13	5	2,336·53	1,080	1,256·53	3,625,000	38
16	Big Chief	....	12	5	2,133·55	....	....	2,800,000	....
17	Ogilvie	NE. ¼ 30	12	5	2,137·16	904	1,233·16	3,000,000	35
18	Marlborough	SW. ¼ 30	12	5	2,151·65	915	1,236·65	1,850,000	....
19	Wellington	SW. ¼ 28	12	5	2,171·05	975	1,196·05	2,225,000	....
20	C.P.R. No. 1	SE. ¼ 31	12	5	2,178·65	....	....	....	....
21	C.P.R. No. 2	SE. ¼ 31	12	5	2,179·54	970	1,209·54	2.800,000	45
22	C.P.R. No. 3	NE. ¼ 36	12	6	2,236·98	979	1,257·98	2,995,000	....
23	Purmal	NW. ¼ 28	12	5	....	....	....	....	....

Gas Wells in Medicine Hat Gas-Field—Continued

	Name of well	Sec.	Tp.	Range	Eleva- tion	Depth to Milk River sandstone	Eleva- tion Milk River sandstone above sea-level	Open flow cub. ft. per day	Approx. thickness of Milk River sandstone
					Feet above sea-level	Feet	Feet		Feet
24	No. 1 Canada Cement Co.	Dauntless Sta.	....	....	2,360	....	....	2,000,000	....
25	No. 2 " "	NE. ¼ 28	12	6	2,330·96	1,095	1,235·99	2,338,000	70
26	No. 3 " "	SE. ¼ 22	12	6	2,306·37	1,057?	1,249·37?	2,117,000	....
27	No. 4 " "	NE. ¼ 14	12	6	2,223·33	965?	1,258·33	1,500,000	....
28	No. 5 " "	SE. ¼ 28	12	6	2,291·86	1,058	1,240	2,600,000	28
29	Golden Valley Irrig. Co.	NW. ¼ 33	12	5	2,171·22	940	1,231·22	....	....
30	Roth No. 1............	SW. ¼ 6	13	5	2,329·76	1,081	1,248·76	2,500,000	39
31	Redcliff, South.........	NE. ¼ 5	13	6	2,450·88	1,187	1,263·88	....	....
32	Redcliff, East..........	NE. ¼ 9	13	6	2,413·04	1,150	1,263	4,000,000	....
33	Redcliff, West..........	NE. ¼ 7	13	6	2,434·47	1,183	1,251·47	4,000,000	....
34	Redcliff Pressed Brick Co.	SW. ¼ 9	13	6	2,443·28	....	1,195 ??	1,800,000	....
35	Redcliff Brick and Coal No. 2.	NW. ¼ 5	13	6	2,421·32	....	1,250·3	4,000,000	....
36	Redcliff Brick and Coal No. 3.	NW. ¼ 5	13	6	2,247·04	....	1,224	2,000,000	....
37	Dom. Glass Co.........	SW. ¼ 17	13	6	....	....	.....	3,147,000	....
38	Redcliff Broadway.....	SW. ¼ 17	13	6	....	....	....	5,000,000	....
39	Dunmore Junc..........	NE. ¼ 9	12	5	....	....	....	....	....
40	Dunmore..............	Townsite...	....	....	....	....	....	....	....

The best wells in the field have open flows of nearly 5,000,000 cubic feet a day. Those under 2,000,000 cubic feet are considered poor. The original total open flow capacity of the field was about 80,000,000 cubic feet a day, but it is reported that by 1922 this had decreased to 50,000,000 cubic feet. The rock pressure in the early history of the field was 550 pounds a square inch; this had declined to 425 pounds in 1925. The open-flow capacity is, therefore, falling more rapidly than the rock pressure. The rock pressure in Redcliff has always been higher than in Medicine Hat; in 1925 it was about 475 pounds. About one-half the wells are owned by the municipalities of Medicine Hat and Redcliff; the remainder, for the most part, are owned and used by industrial concerns.

The structure of the field as represented in Figure 6 is largely based on the data contained in the preceding table, but additional information was obtained by determining the strike and dip of the overlying rocks (Foremost beds) in the coal mines in the western part of the field and along the river valley opposite Redcliff. The structure which causes the accumulation of the gas is low and broad with about 50 feet closure, and extends northward from the structurally higher land on the south. It is divided into two parts by an east-west trough that roughly parallels the river. The southern part of the field was developed first and has received most attention. A few good wells have been obtained in the trough. The northern part, however, holds most promise for the future. It is higher than the southern part and the rock pressure also is greater. Some of the best wells have been drilled on it, including the Huckvale well and the Broadway well at Redcliff.

In a paper by C. C. Ross[1] there appears a structure contour map of the Medicine Hat gas sand totally unlike the one included in this paper. The difference largely depends upon the interpretation of the log of one well, namely "Cousins and Sissons," NE. ¼ sec. 25, tp. 12, range 6, W. 4th mer. In this well a flow of 2,800,000 cubic feet of gas a day was struck at a depth of 1,075 feet, at the very bottom of the well. This is regarded as marking the top of the gas sand, although no sand is reported in the well-log at this depth. At 122 feet above this horizon, at a depth of 953 feet, a production of 60,000 cubic feet of gas is recorded. This is the horizon assumed by Ross to be the Milk River sandstone. The deeper horizon

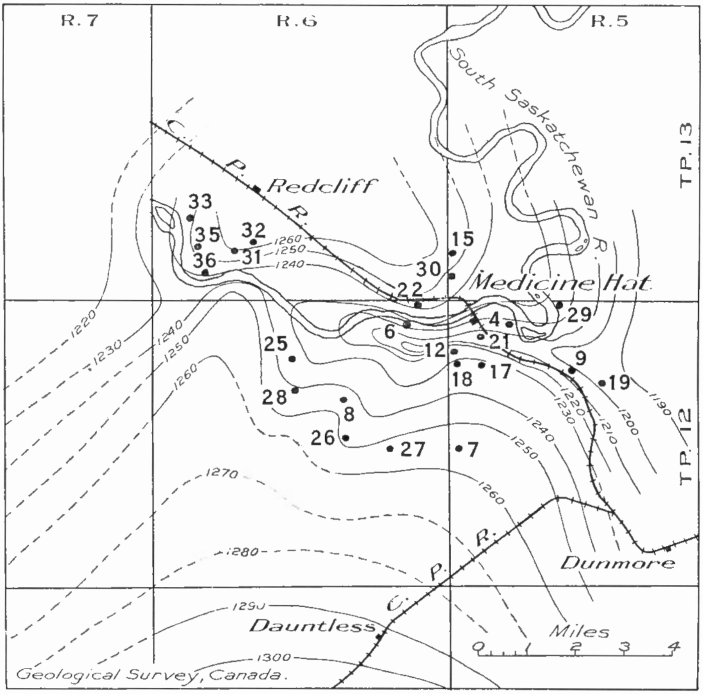

Figure 6. Medicine Hat gas-field; structure contours represent top of Milk River sandstone; numbers designate the wells as given in the table, page 50.

(1,075 feet) is now regarded as correct, because it was there that the large production was obtained and the Milk River sandstone, as it is only 30 feet thick in this field, obviously cannot extend for 122 feet between the two horizons. The upper horizon is apparently a sandstone band in the Pakowki. Another fact which bears out the correctness of the present interpretation is that, in drilling, the casing was carried down to a depth of 1,015 feet. Evidently the driller did not expect to strike gas sand until he was below this depth. According to the figure assumed herein as correct, the top of the gas sand occurs at an elevation of 1,195 feet above

[1] Ross, C. C.: "Petroleum and Natural Gas Development in Alberta"; Trans. Can. Inst. Min. Met., vol. 29, pp. 317-345 (1926).

sea-level. This figure agrees with the figures for surrounding wells. Thus, in the Craft well, the gas sand was struck at an elevation of 1,230 feet, in the Central Park well at 1,232 feet, in the Marlboro' well at 1,236 feet, in the C.P.R. well at 1,209 feet, and in the Balmoral well at 1,224 feet.

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

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

In the summer of 1925 the drilling firm of Roth and Faurot, by agreement with the city council of Medicine Hat, commenced a search for oil in the rocks below the Milk River sandstone within the limits of the Medicine Hat gas-field. For their first well they chose a location in the northern part of the city—L. S. 4, sec. 6, tp. B, range 5, W. 4th mer. This well is now drilled, but no oil has been struck. The Milk River sandstone where penetrated was 39 feet thick and was reached at a depth of 1,081 feet; the Blairmore-Kootenay sandstone was struck at a depth of 2,525 feet, and from last reports the drilling is still in the Kootenay. A flow of 2,600,000 cubic feet of gas a day under a pressure of 400 pounds a square inch was struck in the Milk River sandstone and a flow of 10,000,000 cubic feet of gas which turned to water in one day was obtained at a depth of 2,845 feet. Other water sands occurred at depths of 2,175 feet and 2,525 feet.

MANY ISLAND LAKE FIELD

This prospective field is west of Many Island lake and within a mile of the Saskatchewan border. It is 12 miles north of the main line of the Canadian Pacific railway and 20 miles northeast of Medicine Hat. Attempts have been made by four companies to drill wells in the field, but two of these scarcely got past the stage of "spudding in." The Community Oil Company and the Many Island Oil Company, however, have had a certain measure of success. At the last report the Community Oil Company's well was down to 2,500 feet, where they had struck a flow of water in the Benton shale. The company was at a standstill for lack of funds. The Many Island Oil Company, under the capable management of C. W. Drazan, carried a well down 350 feet into Palæozoic limestone to a depth of 3,540 feet. The upper 1,870 feet was drilled by jetting machine, but the lower 1,670 feet by diamond drill; consequently no reliable information was obtained of the upper part, but the lower part has furnished an instructive core. A log of the Drazan well appears on page 54.

Log of Drazan Well No. 1, of the Many Island Oil and Gas Company, NW. ¼, Sec. 34, Range 2, Tp. 13, West 4th Mer., Alberta; Elevation, 2,368 feet

—	Depth in feet	
	From	To
Recent		
Surface sands and gravels	0	55
Foremost		
Light-coloured clays and sandy clays	55	123
Grey sand, clay bands	123	159
Light grey and greenish clay, thin beds of sand	159	194
Brown, carbonaceous shale and coal	194	205
	205	219
Shale and clay, light grey, slightly sandy at intervals	219	289
Shale, grey, darker	289	335
Shale, grey and brown, coal seams and oyster beds	335	357
Shale, blue-grey	357	375
Sandstone, greenish grey	375	390
Pakowki		
Shale, blue-grey	390	460
Sandstone, hard	460	462
Shale, blue-grey	462	830
Shale, brown	830	842
Sandy shale, black	842	851
Shale, grey, dark, fissile	851	865
Shale, grey, dark, slightly sandy	865	885
Shale, blue-black, compact and fairly hard, containing some fine sand, thin bands of bentonite	885	985
Shale, blue-black, and fine sand, steel grey, intermixed in variable proportions	985	1,115
(Milk River sandstone probably occurs at base of this intrusive)		
Benton (Colorado)		
Shale, blue-grey, fissile, laden with iron pyrites	1,115	1,172
Shale, dark, compact	1,172	1,195
Shale, blue-grey, iron stained from pyrites	1,195	1,220
Shale, dark, compact, with fine sand partings yielding gas	1,220	1,247
Shale, dark, compact	1,247	1,275
Shale and fine sand. Gas	1,275	1,375
Shale, dark. Bands of bentonite	1,375	1,427
Shale and fine sand. Gas?	1,427	1,440
Shale, dark bands of bentonite	1,440	1,476
Dark, hard material	1,476	1,530
Soft, dark material, cavy, brown showing scum	1,530	1,550
Soft, dark brown material, slightly cavy	1,550	1,570
Hard, dark brown material, shale	1,570	1,575
Soft and muddy, dark brown material	1,575	1,591
Hard, dark brown material, oyster shale	1,591	1,592
Hard, dark, sandy material and shale	1,592	1,630
Grey, soft material, muddy	1,630	1,660
Hard rock, 2 feet very hard	1,660	1,662
Dark brown, soft material, muddy shale	1,662	1,670
Hard rock for 1 foot	1,670	1,671
Soft, dark brown, sandy material	1,671	1,680
Very hard rock	1,680	1,681½
Dark brown, not very hard, but coarse, sandy material	1,681½	1,720
Dark brown, hard and tough material, and fine sand	1,720	1,806
Hard, dark brown material, sand, some shale	1,806	1,810
Light brown, hard material, sand and some shale	1,810	1,820
Hard, brown material, sand and shale	1,820	1,830
Light brown, hard material, sand and shale	1,830	1,840
Brown, hard material, sand and shale	1,840	1,850
Light brown, hard material, turning grey, sand and shale	1,850	1,860
Hard, brown material. Very hard rock from 1,869 feet to 1870 feet	1,860	1,870

Log of Drazan Well No. 1—Continued.

—	Depth in feet	
	From	To
Benton (Colorado)—Continued		
Hard, grey rock. Hard sandstone on bottom. Diamond drill used from here to bottom of hole	1,870	1,882
Shale and sandy shale	1,882	1,925
Shale	1,925	1,962
Shale, mostly missing	1,962	2,010
Sand and shaly sand, not all recovered	2,010	2,033
Missing	2,033	2,040
Shale	2,040	2,083
Shale, in a few places grading to sandy shale	2,083	2,103
Only a few inches of shale recovered	2,103	2,121
Shale; a few inches of sandstone at 2,160 feet	2,121	2,160
Shale	2,160	2,184
Core lost except for a few inches of shale	2,184	2,208
Shale	2,208	2,232
Shale	2,232	2,272
Shale	2,272	2,294
Sandy shale to sandstone	2,294	2,298
Sandstone and sandy shale	2,298	2,335
Sandstone	2,335	2,360
Sandstone and sandy shale	2,360	2,417
Sandstone and sandy shale	2,417	2,425
Shale	2,425	2,430
Missing, except for a little shale and bentonite (?)	2,430	2,441
Sandstone and shaly sandstone	2,441	2,455
Sandstone and shaly sandstone. Bentonite reported at 2,456 feet	2,455	2,488
Sandy shale	2,488	2,520
Only 1 foot of shale recovered and some bentonite (?) at 2,530 feet	2,520	2,532
Shale, only part of the core recovered	2,532	2,582
Shale, dark	2,582	2,667
Blairmore-Kootenay		
Yellowish grey, crossbedded sandstone	2,667	2,754
Shale, green	2,754	2,761
Shale, grey, green, and reddish	2,761	2,793
Sandstone, grey	2,793	2,808
Shale, black	2,808	2,816
Sandstone, grey	2,816	2,818
Shale, red	2,818	2,822
Oil showing, 2,808 to 2,822 feet		
Shale, grey, sandy	2,822	2,835
Shale, chocolate red	2,835	2,840
Shale, grey	2,840	2,849
Shale, black	2,849	2,850
Shale, red	2,850	2,858
Shale, grey	2,858	2,870
Shale, black, carbonaceous in places	2,870	2,873
Shale, grey, sandy	2,873	2,889
Sandstone, grey	2,889	2,904
Coarse grey sandstone	2,904	2,937
Jurassic (Ellis?)		
Light-coloured, hard, sandy limestone	2,937	2,942
Grey shale	2,942	2,963
Grey, arenaceous limestone and some shale	2,963	2,967
" " "	2,967	2,971
Hard, grey shale	2,971	2,976
Grey shale with streaks of limestone and sandstone	2,976	2,986
White or light grey, argillaceous limestone very like Jurassic of Sweet Grass hills, but somewhat lighter in colour. *Showing of oil* between 3,005 and 3,018 feet	2,986	3,036
Grey, fine-grained argillaceous limestone. *Fossils*	3,036	3,045
Grey, fine-grained sandstone	3,045	3,058

Log of Drazan Well No. 1—Continued

—	Depth in feet	
	From	To
Jurassic (Ellis?)—Continued		
Light grey, hard, argillaceous limestone	3,058	3,065
Very hard, grey, sandy shale	3,065	3,067
Pale grey, argillaceous limestone	3,067	3,069
Black shale	3,069	3,070
Soft, black shale	3,070	3,071
Grey, argillaceous limestone	3,071	3,076
Shale and limestone, grey, hard	3,076	3,080
Dark grey, soft shale	3,080	3,082
Dark grey shale	3,082	3,083
Grey limestone, hard	3,083	3,086
Grey shale	3,086	3,087
Dark shale	3,087	3,091
Grey, sandy shale	3,091	3,099
Black shale	3,099	3,103
Green, sandy shale with pyrites	3,103	3,110
Light grey, argillaceous limestone, with crystalline quartz	3,110	3,113
White, rather hard limestone, very porous, with showings of heavy, black oil between 3,113 and 3,123 feet	3,113	3,140
White, chalky limestone, porous toward top	3,140	3,155
Green, soapy shale	3,155	3,163
Hard, white limestone	3,163	3,165
Green shale	3,165	3,166
Hard limestone	3,166	3,174
Softer limestone	3,174	3,176
Hard, white limestone	3,176	3,178
Soapy, green shale	3,178	3,183
Grey limestone	3,183	3,184
Greenish grey, soft shale	3,184	3,190
(3,190 feet marks beginning of Madison)		
Palæozoic (Madison?)		
Light grey limestone, crystalline	3,190	3,193
Somewhat mottled (brown and grey), very hard limestone	3,193	3,195
Grey and white crystalline limestone	3,195	3,221
Cherty limestone not crystalline—grey and brown, mottled	3,221	3,233
Grey, sandy shale	3,233	3,234
Cherty, mottled limestone, grey and brown	3,234	3,240
Grey limestone—crystalline in places	3,240	3,258
Grey, non-crystalline limestone, with crinoid columns	3,258	3,269
Ditto, somewhat more crystalline	3,269	3,272
Grey limestone with crinoid columns	3,272	3,290
Hard, grey limestone. Spirifer at 3,292	3,290	3,324
Hard, grey limestone, more crystalline. Large brachiopod-like *Productus* at 3,325 feet	3,324	3,328
Grey limestone with very numerous crinoid columns and sections of brachiopods	3,328	3,341
Grey, sandy limestone	3,341	3,345
Grey limestone full of crinoid columns and with some brachiopods, black chert from 3,353 to 3,354 feet	3,345	3,374
Dark, hard limestone with fossils	3,374	3,383
Dark grey shale—hard	3,383	3,390
Calcareous shale—hard	3,390	3,401
Calcareous shale—streaked with sandstone layers	3,401	3,435
Dark brown limestone	3,435	3,445
Grey, fine-grained, sandy limestone with black chert	3,445	3,540

Comparing the log of the Drazan well with that of the Roth well in Medicine Hat, it is found that the Blairmore-Kootenay sandstone is 100 feet lower in elevation in the first well (Drazan well, 299 below sea-level; Roth well, 195 below sea-level). There is, therefore, a low regional dip of

5 feet a mile to the east or northeast between these two wells. The figures for the elevation of the contact between the Bearpaw shales and the Pale beds at several points around Many Island lake and Medicine Hat illustrate well the nearly horizontal attitude of the strata. Thus, in an outcrop in sec. 34, tp. 16, range 8 (30 miles northwest of Medicine Hat), the elevation of this contact is 2,580 feet; in sec. 30, tp. 15, range 2 (15 miles north of the Drazan well and 20 miles north of Many Island lake), it is 2,547 feet; in sec. 13, tp. 11, range 3 (4 miles south of Irvine), it is 2,631 feet; in sec. 18, tp. 11, range 29, W. 3rd mer. (5 miles southeast of Walsh), it is 2,539 feet. This shows a dip of 5 feet a mile to the east.

As concerns regional structure the Many Island field is situated similarly to the Medicine Hat field, but no local structure has been shown to exist. In the Drazan well the Milk River sandstone has almost wedged out and is represented only by sandy shale which does not produce gas.

OIL POSSIBILITIES IN THE MILK RIVER SANDSTONE

The Milk River sandstone, which holds the gas at Medicine Hat, acts as an artesian water reservoir higher up the dip of the Sweet Grass arch. This artesian area has been delimited by Dowling.[1]

The Milk River sandstone where it outcrops on Milk river in ranges 12, 13, 14, and 15, west of the 4th meridian, is very porous and is capable of carrying underground water. If it came to the surface at a lower place a series of very strong springs would result. In the area under discussion, however, the porous sandstone instead of reaching the surface dips gently to the north at a rate only a little more than the slope of the surface. Being covered by impervious shales the water in the porous sandstone does not reach the surface but remains under a slight pressure. Drilling has shown that large quantities of fresh water are contained in the sand over the greater part of the crest of the Sweet Grass arch. Strong flows have been struck in Pakowki Lake region, in Foremost region, and in the country between Foremost and Bow Island, and as far north as Retlaw. Down the dip of the arch gas occurs, as at Medicine Hat. It is possible that the gas and possibly some oil were distributed originally more or less uniformly throughout the Milk River sandstone, but have been driven into the structurally low areas by the flushing action of the artesian water. Rich[2] says in his article on "Moving Underground Waters as a Primary Cause of the Accumulation of Oil and Gas":

> "If the oil is being carried along in a reservoir bed which pinched out into less pervious beds in the direction of movement, the oil and the gas should be screened out, and accumulated near the end of the pervious bed. There are two reasons for this. One is the greater friction on the oil globules as the texture of the rock becomes finer; the other is the effect of capillarity which tends to prevent oil leaving coarse, water-soaked beds to enter fine ones. Where the water movement happens to be up the dip the accumulation would be on the up-dip end of the pinching reservoir bed, where the movement is down the regional dip, however, the deduction would be that the oil accumulation should be at the down-dip end, unless there were anticlinal traps near the down-dip end, in which case most of the oil would doubtless be caught by them."

[1] Geol. Surv., Canada, Sum. Rept. 1922, pt. B, p. 104.
[2] Rich, J. L.: Econ. Geol., vol. 16, No. 6, p. 355 (1921).

It has also been suggested by Shaw[1] that:

"Near the limit of complete flushing, gas, on account of its greater buoyancy, would be retained by structures which were unable to hold oil. Starting from near the intake rim, the normal sequence would be: anticlines completely flushed; anticlines holding only gas; anticlines holding oil and gas."

Such conditions are undoubtedly present in the Milk River sandstone. Over the crest, and, perhaps, part way down the flanks of the Sweet Grass arch, the sandstone is filled with water. Around the sides of the artesian water area and beyond the influence of flushing, gas would be held in favourable structures. This gas would be under high pressure, since it is under a hydrostatic head of about 1,000 feet, which accounts for the fact that at Medicine Hat the pressure is greater than would be expected if natural hydrostatic conditions prevailed. If oil is present in the Milk River sandstone at all, it will be found only between the gas-field belt and the line to the north and east where the sandstone thins out and disappears. Since the "Milk River" virtually disappears at Many Island lake, the oil belt will be expected to lie between this point and Medicine Hat. If local structures be found and drilled on in this area some oil may be found. One difficulty is, however, that the drilling must be done completely in the dark, as a heavy mantle of drift covers the rocks for many miles without a break. Another difficulty is that the porosity of the Milk River sandstone is very low at Medicine Hat, perhaps too low to carry much oil, and the porosity apparently decreases to the east as instanced by the poor character of the sandstone at Dunmore.

OIL AND GAS POSSIBILITIES IN ROCKS UNDERLYING THE BOW ISLAND GAS SAND

The best places to drill for oil in southern Alberta are on minor structures superimposed on the crest of the Sweet Grass arch. Such a minor structure is the Bow Island dome, which may be too small to produce oil at any horizon. It would be better to locate some structure of greater dimensions on which to drill. On a larger structure oil might be found in sandstone beds in the Colorado (Benton), in the Kootenay, in the Jurassic (Ellis), or in dolomite in the Carboniferous (Madison). In Bow Island region the Dakota-Blairmore sandstone may be expected at a depth of about 2,500 feet and the Carboniferous at an approximate depth of 3,200 feet. A good place to locate a wild-cat well would be on the extreme western edge of the crest of the Sweet Grass arch, east of the point at which the rocks begin to dip steeply into the Alberta syncline. As far as can be conjectured at present this would be in the neighbourhood of Chin station on the Crowsnest branch of the Canadian Pacific railway. There has probably been a strong migration of oil and gas up the flanks of the arch onto its crest and this oil and gas would be trapped in anticlinal structures situated along the edge of the crest.

The fact that Medicine Hat is well down the flank of the Sweet Grass arch, if not off the structure entirely, dims the hope of obtaining oil in rocks underlying the Milk River sandstone at this point. It is only under special artesian conditions that gas occurs in the Milk River sandstone, so that in rocks in which these conditions do not hold, very little in the way of oil or gas is expected.

[1] Shaw, E. W.: Econ. Geol., vol. XII, pp. 610-628 (1917).

CYPRESS HILLS AREA, ALBERTA

Reference: Dyer, W. S.: "Geological Structure in the Western End of Cypress Hills, Alberta"; Geol. Surv., Canada, Sum. Rept. 1926, pt. B.
—Geol. Surv., Canada, Memoir (manuscript).

INTRODUCTION

The statements regarding Cypress hills are based entirely on the reports of W. S. Dyer, as the result of work done for the Geological Survey during the summers of 1925 and 1926. According to Dyer:

"Cypress hills are a prominent physical feature of the southern Great Plains. Beginning about 30 miles southwest of Medicine Hat they extend eastwardly for more than 80 miles. They reach their greatest altitude at the western end—Head of the Mountains—where they are 4,800 feet above the sea, or 2,600 feet above South Saskatchewan river at Medicine Hat. Eastward they sink until south of Swift Current they merge into the general level of the prairies. The central part of the hills, or the hills proper as McConnell[1] regarded them, is a plateau with the flat, featureless summit characteristic of this type of land form. The plateau is bounded by steep slopes which, in the western part of the hills, descend 800 feet to the more gently sloping country below. The summit of the plateau is treeless, but covered with rank-growing grasses upon which feed the stock belonging to the ranchers settled on the top of the hills. The steeper sides of the plateau are forested with poplar, spruce, and pine, and on them the Dominion Government has blocked out several square miles as a forest reserve. The country surrounding the plateau for distances of 15 or 20 miles is characterized by gradually diminishing slopes. It is, however, comparatively rugged, with many hills capped by the weathered product of the soft, underlying Cretaceous and Tertiary sands and shales, or by glacial drift. Near the plateau solitary buttes rise to elevations of 4,000 and 4,300 feet above the sea. Glacial erratics have been found as high as 4,300 feet, but above 3,800 feet the mantle of boulder clay is very thin.

Ready access can be had to almost any part of the hills. There are several dirt roads which are mostly in a fair state of repair, but after heavy rains are rendered almost impassable by the fine, clay character of the soil. An excellent road leads from Elkwater lake to the Canadian Pacific railway at Irvine, a distance of 20 miles, and another road leads directly from Eagle Butte to Medicine Hat, a distance of 35 miles.

STRATIGRAPHY

The rocks exposed in the western end of Cypress hills clearly show the gradual transition from marine to freshwater deposits, which occurs in the uppermost part of the 'Mesozoic' in many parts of the northwestern United States and the Prairie Provinces of Canada. The lowest beds exposed are marine shales of Bearpaw or Upper Pierre age, and above them follow without a break sandstones representing the shallow-water, near-shore phase of the retreating Pierre sea. These in turn gradually pass upwards into freshwater beds of sand or sandy clay, with fragmentary plant remains and lignite, which continue nearly to the top of the section. These freshwater beds are clearly divisible into three formations which agree with the three-fold division made by Davis[2] of the rocks of the same age in Saskatchewan, i.e., in descending order, the Ravenscrag, Whitemud, and Estevan. The terminology used by Davis is, therefore, extended to include the beds of the west end of the hills. The Estevan beds are undoubtedly of Lance age, as Lance dinosaurs have been found in them on Rock creek in Saskatchewan. The Lance dinosaur 'Triceratops' has also been reported by Sternberg from the Whitemud beds.[3] No dinosaurs have been found in the Ravenscrag beds, but plant remains and invertebrates of Lance or Fort Union age have been found in them. The upper slopes of the hills are covered by talus and by vegetation, and outcrops are rare. Toward the top of the plateau, however, silts and sands of uncertain age have been found, and capping the plateau there is a 25-foot bed of conglomerate which has yielded mammal remains of Oligocene age at localities north of East End, Saskatchewan.

[1] McConnell, R. G.: Geol. Surv., Canada, Rept. of Prog. 1885.
[2] Davis, N. B.: Mines Branch, Dept. of Mines, Canada, No. 468, p. 9.
[3] Sternberg, C. M.: Can. Field Nat., vol. 38, No. 4, p. 69.

Table of Formations

Geological time	Formation	Character and thickness of formations
Tertiary or Cretaceous..	Ravenscrag.....	Yellow, crossbedded sandstone (continental). Thickness 128+ feet
	Whitemud......	Light grey clays and fine sands weathering white (continental). Thickness 25 feet
Cretaceous..............	Estevan.........	Grey, buff, and brown sands, and sandy clays with lignite (continental). Thickness 235 feet
	Fox Hills.......	Crossbedded, grey and brown, ledge-making sandstone (marine). Thickness 150 feet
	Bearpaw........	Dark grey, soft shales (marine). Thickness 500 to 550 feet

Bearpaw. The Bearpaw shales are exposed on both the north and south sides of Cypress hills, but especially well on the north side where highly fossiliferous outcrops can be found on any of the small creeks draining the hills, such as Boxelder, Ross, Gros Ventre, and Bullshead creeks. Within the area included on the accompanying Figure 2 they outcrop at two points only. On the upthrown side of the fault, in sec. 11, tp. 9, range 5, W. 4th mer., a thickness of 100 feet was found on the north bank of Bullshead creek, and a small exposure was seen in Medicine Lodge coulée west of Thelma, in sec. 8, tp. 7, range 3, W. 4th mer. They probably, however, form the bottom of a large part of Medicine Lodge coulée. They consist of dark grey or greenish grey, soft shales and contain marine fossils of Cretaceous age. At the outcrop on Medicine Lodge coulée a fragment of *Placenticeras* was found, and at the outcrop on Bullshead creek the following fossils were found: *Baculites ovatus, Baculites compressus, Placenticeras whitfieldi, Corbicula* sp., and *Pteria linguiformis.* The thickness of the formation is difficult to determine owing to the lack of exposures in the hills, but evidence was obtained on the creeks on the north side of the hills which made possible an estimate of the thickness. Certain fossil zones were found which were correlated from creek to creek and on certain creeks the distance of the lowest zone above the base of the formation and the highest zone below the top of the formation was determined.[1] In this way a thickness for the formation of between 500 and 550 feet was worked out.

Fox Hills. This formation is best exposed in Medicine Lodge coulée. Sandstone ledges referred to it flank the hills on both sides of the coulée for several miles, but owing to the large amount of outwash from the hills they are exposed in only a few places. The best exposure is perhaps on the east side of the coulée in sec. 6, tp. 8, range 5, W. 4th mer. They also outcrop in a gully in the S.E. ¼ sec. 30, tp. 9, range 1, W. 4th mer. The formation consists of grey, medium-grained, massive-bedded, quartzose sandstone with a large biotite content. Crossbedding is prevalent, and the sand is sufficiently coherent to form ledges. Gentle slopes occurring between the steep sandstone ledges suggest the presence of shale, but the shale itself is nowhere exposed. Toward the base the sandstone becomes soft and shaly and passes gradually into Bearpaw shale. Toward the top the sands are incoherent and light grey and cannot be distinguished from the overlying Estevan beds. The upper part contains silicified wood and is probably continental in origin. Thinner bedded, calcareous sandstone in the middle of the formation yielded the following marine fossils of Fox Hills or Bearpaw age: *Linearia formosa, Inoceramus* sp., *Protocardia borealis, Mactra warrenana, Yoldia evansi, Protocardia subquadrata, Pteria nebrascana, Scaphites* sp., *Nucula* cf. *subplana.* Stanton[2] reports finding the following additional species at the same locality: *Tancredia americana, Callista nebrascensis, Scaphites nodosus* var. *quadrangularis.* He says, 'Part of these species are in the Fox Hills beds in other regions and most of them occur in the Pierre and Bearpaw shales. It has long been known that the faunas of the Fox Hills and the Pierre are too closely related to be considered really distinct.'

[1] This work will be described in full in a later publication.
[2] Stanton, T. W., and Hatcher, J. B.: U.S. Geol. Surv., Bull. 257, p. 55.

Estevan. The Estevan beds overlie the Fox Hills sandstone in Medicine Lodge coulée. They are also found along the road south of Elkwater lake, on the north side of the west arm of Elkwater lake, on Bullshead creek, and on Willow creek near Thelma. They consist of grey, buff, and brown sands and sandy shales with occasional rows of brown ironstone concretions. In the lower part of the formation beds of compact, grey clay are found which on exposure weather to a bright red. Seams of lignite are present. The chief one, 2 feet in thickness, occurs about 175 feet above the base of the formation and 60 feet below the Whitemud beds.

This series of beds is placed in the Estevan of Davis because of its position between the Fox Hills sandstone and the Whitemud beds, and because of its continental origin. It differs somewhat from the Estevan beds of the more typical Saskatchewan localities in being more sandy, lighter in colour, and without the fine banding of clay and sandy clay, so characteristic of the beds in Saskatchewan. The thickness of 235 feet represents the interval between the ledgy sandstones of the Fox Hills and the Whitemud beds.

Whitemud. Numerous outcrops of these beds were found in Medicine Lodge coulée; and in the long, narrow, coulée which extends from the western end of Elkwater lake to the small lake in sec. 7, tp. 8, range 3, W. 4th mer., and thence southwestward to Medicine Lodge coulée. They are also found on Bullshead creek on the downthrown side of the fault, and at various points on Eagle butte. Owing to the pure white colour of the beds on exposure, they show up very plainly and serve as an ideal horizon marker for structural work. They were used for most of the structural work in the hills. Beds referable to the same formation have been found at many widely scattered points in southern Saskatchewan,[1] and at many localities the clay part of the beds is refractory. At Clay Bank they are made use of for the manufacture of fire-brick. No analyses have been made as yet of the clays in the western part of the hills, and it is not known whether they are refractory or not.

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

Section Through the Whitemud Beds

	Feet
Soft, light grey clay, weathering pure white	10
Black or dark brown (bentonitic?) clay	1
Yellowish green bentonite	½
Light grey, soft, very fine-grained sand, weathering pure white	10
Light grey clay apparently grading downward into the buff-coloured sands of the Estevan	4

Ravenscrag. The yellow sands of the Ravenscrag formation were found above the Whitemud beds at numerous localities throughout the hills. They are exposed to best advantage, however, in Medicine Lodge coulée in sec. 31, tp. 7, range 3, W. 4th mer., and a good section was also obtained on the road south of Elkwater lake on the north side of the hills from 175 to 255 feet above the lake.

The formation consists of yellow and brown, crossbedded, medium-grained sandstone, and in many places includes sandstone concretions of large size. Beds of intraformational conglomerate consisting of clay pellets and pebbles of sandstone are also present. The contact with the Whitemud beds is not seen clearly, but in a gully on the north side of Eagle butte in the S.E. ¼ sec. 20, tp. 8, range 4, W. 4th mer., beds of hard, grey shale and dark brown, soft, clay shale lie between the Whitemud beds and the yellow sands of the Ravenscrag. At the base of the formation the following freshwater fossils were found: *Campeloma producta, Campeloma cypressensis* (n. sp.), *Thaumastus limnaeiformis tenuis, Hydrobia recta, Unio* sp., and *Sphaerium* sp. These at least indicate a post-Bearpaw and probably a Fort Union age.

The greatest thickness measured for the Ravenscrag was 128 feet; but it is probably much greater. The upward extent of the beds could not be seen, as the upper slopes of the hills are talus covered and afford very few outcrops."

PROSPECTS FOR OIL AND GAS

According to Dyer, Cypress hills are in part at least structural in origin, representing an uplifted area from which the strata are known to dip northward and eastward and probably to a less degree southward,

[1] Dyer, W. S.: Geol. Surv., Canada, Sum. Rept. 1926, pt. B, p. 33.

although such southward dip has only been noted at one place, namely, Medicine Lodge coulée. To the westward there is a regional rise in the strata and closure on the west of the Cypress Hills structure depends on the presence of a northeast-southwest fault which Dyer has described and which he believes has a throw of 400 to 550 feet.

According to Dyer:

"The Cypress Hills structures should prove to hold oil or gas provided the underground conditions are right. These include the presence of porous sands suitable for reservoirs, and beds capable of generating petroleum. The Milk River sandstones which hold so much gas at Medicine Hat might quite possibly be oil-bearing in this more pronounced structure. Other favourable horizons would be sandstone beds in the Colorado, the Blairmore-Kootenay sands, the Jurassic (Ellis) sand or limestone, and the Palæozoic (Madison) limestone, all of which can be reached at reasonable depths. Oil showings were met with in the Drazan well in the Many Island field, in the Blairmore-Kootenay, and in Jurassic. In the Roth well at Medicine Hat oil showings were found in the Ellis and at the top of the Palæozoic, and several strong flows of water indicating porous horizons were struck in the Colorado, Blairmore-Kootenay, and Palæozoic. These wells were both located on very much flatter structure.

It would require deeper drilling than at Medicine Hat to reach the same horizons in Cypress hills, owing to the higher stratigraphic position of the beds exposed. At Medicine Hat the Roth well No. 1 was started about 100 feet above the top of the Foremost beds. It reached the Milk River sandstone at a depth of 1,080 feet, the Blairmore at 2,520 feet, the Jurassic (Ellis) at 2,800 feet, and the Palæozoic at 3,000 feet. Adding 775 feet to these figures, which represents the distance between the horizon at which the Roth well was started and the top of the Bearpaw, figures are obtained showing the depths at which the various horizons would be reached in a well started at the top of the Bearpaw on Cypress hills, assuming there is no change in the thicknesses of formations. Thus the Milk River sandstone would be reached at a depth of 1,855 feet, the Blairmore at 3,295 feet, the Ellis at 3,575 feet, and the Palæozoic at 3,775 feet."

WATERTON LAKE AND CAMERON BROOK[1]

By D. B. Dowling

Seepages of oil were reported on Cameron brook (locality 9, Figure 4) in 1890, and examined by Selwyn in July of 1891. They were found in the bed of the brook about 2 miles above the bend. The occurrence of oil in any large quantity in rocks of Lower Cambrian age was doubted and it was not until attention was called to the possibility of overthrusts along the eastern face of the Rocky mountains, that a possible source for the oil was suggested to Dawson. His comment in the Summary Report for 1898 no doubt renewed interest in the subject.

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

The first noteworthy attempt at drilling in the mountains near the known oil seep was made in 1903 by a company formed by John Lineham. This well was reported to be 1,400 feet. Oil was found at 1,080 feet and filled the well. The further deepening did not apparently increase the flow and difficulties developed which probably included loss of

[1] Reprinted from Geol. Surv., Canada, Sum. Rept. 1920, pt. B, pp. 16-22.

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

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

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

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

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

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

In the well drilled near the lake there seems little doubt that the drill penetrated the dolomites of the Waterton formation and entered soft shales, which seem to be Cretaceous. The zone of the overthrust was apparently penetrated at about 1,500 feet, although at 1,900 feet and lower the beds were probably affected by crumpling and folding, as shown in the caving that stopped the work. Evidently samples of the drilling were obtained by Daly who thus reports on this well.[2]

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

"How much farther west the thrust has caused the superposition of the Belt terrain on the Cretaceous can only be conjectured. It is not impossible that the entire Clark range in this region represents a gigantic block loosed from its ancient foundations, like the Mount Wilson or Chief Mountain massifs, and bodily forced over the Cretaceous or Carboniferous formations. In that case the thrust would have driven the block at least 40 miles across country. Such a speculation is of some interest in giving one explanation of the emanation of gas and petroleum in the Flathead valley and in the heart of the Belt-

[1] "Petroleum and Natural Gas Resources of Canada," vol. II, p. 327, Pub. No. 291, Mines Branch, Dept. of Mines, Canada.
[2] Geol. Surv., Canada, Mem. 38, pp. 90-91 (1912).

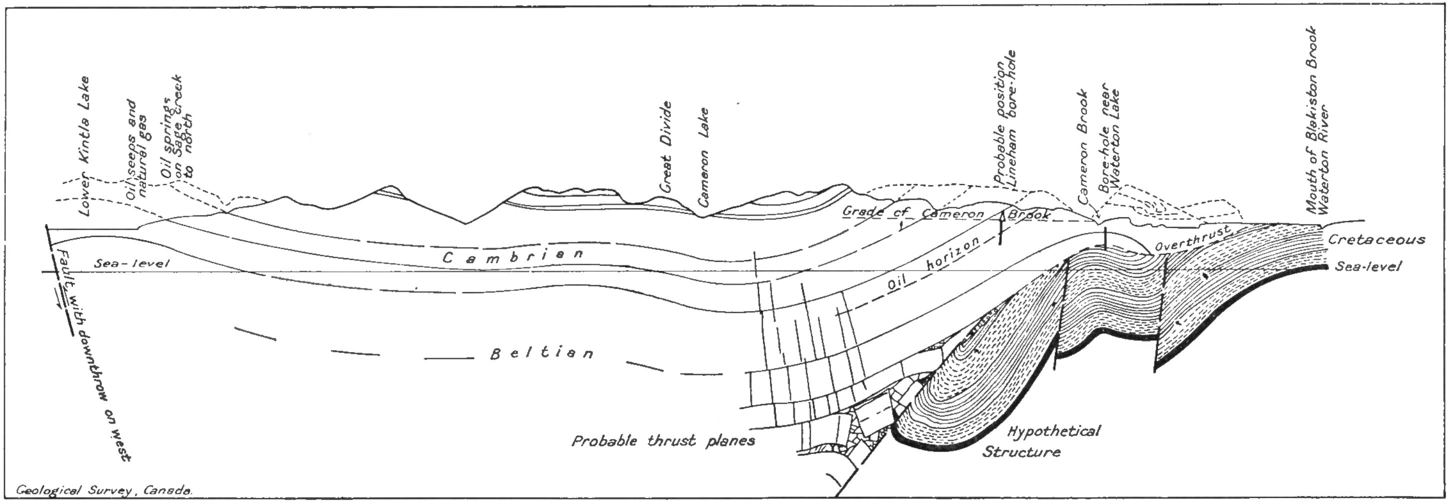

Figure 7. Geological section from lower Kintla lake, Montana, to Blakiston brook, Waterton river, Alberta, showing hypothetical condition of overthrust of Cambrian on the Cretaceous.

Cambrian rocks at Lower Kintla lake. These hydrocarbons would thus be considered as originating in the Carboniferous limestone or in the Cretaceous sediments underlying the thrust-plane. Since the Carboniferous limestone is highly bituminous, that formation would naturally offer an original source for the oil and gas.

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

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

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

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

The quartzites dip generally to the southwest and at the Interprovincial Boundary attain their greatest depression, thence westward along the Boundary they rise gradually. It seems probable that at the point of greatest depression, at the centre of the syncline, there is a concealed zone of vertical fracturing which would serve as a vent through which the vapours from the horizon of distillation might rise to the many interstices of the bedding planes above, and these being at higher elevation and subject to less pressure, would form condensing chambers. A vertical section across the beds (Figure 7) has been constructed from the published report of Daly, to which is added a suggested possible outline of the concealed understructure, in which this supposition of lines of upward transference is indicated. As rather less is known of the conditions at the western fault line no suggestion is made as to the character of the underthrust rocks which may have some influence in the production of oil and gas at Kintla lake.

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

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

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

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

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

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

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

TURNER VALLEY FIELD

By G. S. Hume

References: Slipper, S. E.: "Sheep River Gas and Oil Field, Alberta"; Geol. Surv., Canada, Mem. 122 (1921).
Hume, G. S.: "Turner Valley Oil Area, Alberta"; Geol. Surv., Canada, Sum. Rept. 1926, pt. B (1927).
McLearn, F. H., and Hume, G. S.: "Stratigraphy and Oil Prospects of Alberta"; Bull. Am. Ass. of Pet. Geol., March, 1927.

(*See* Figure 8)

INTRODUCTION

Turner Valley field (locality 1, Figure 4) is about 35 miles southwest of Calgary and lies within the foothills belt of folded rocks. The field has been described in Memoir 122 by S. E. Slipper. In 1926, the present writer made a further study of the structure in relation to the wells then drilling and a report on this work constitutes part of Summary Report 1926, part B. The general outline of the stratigraphy and structure, and the details of drilling as given here, contain the information available up to the end of the year 1926.

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

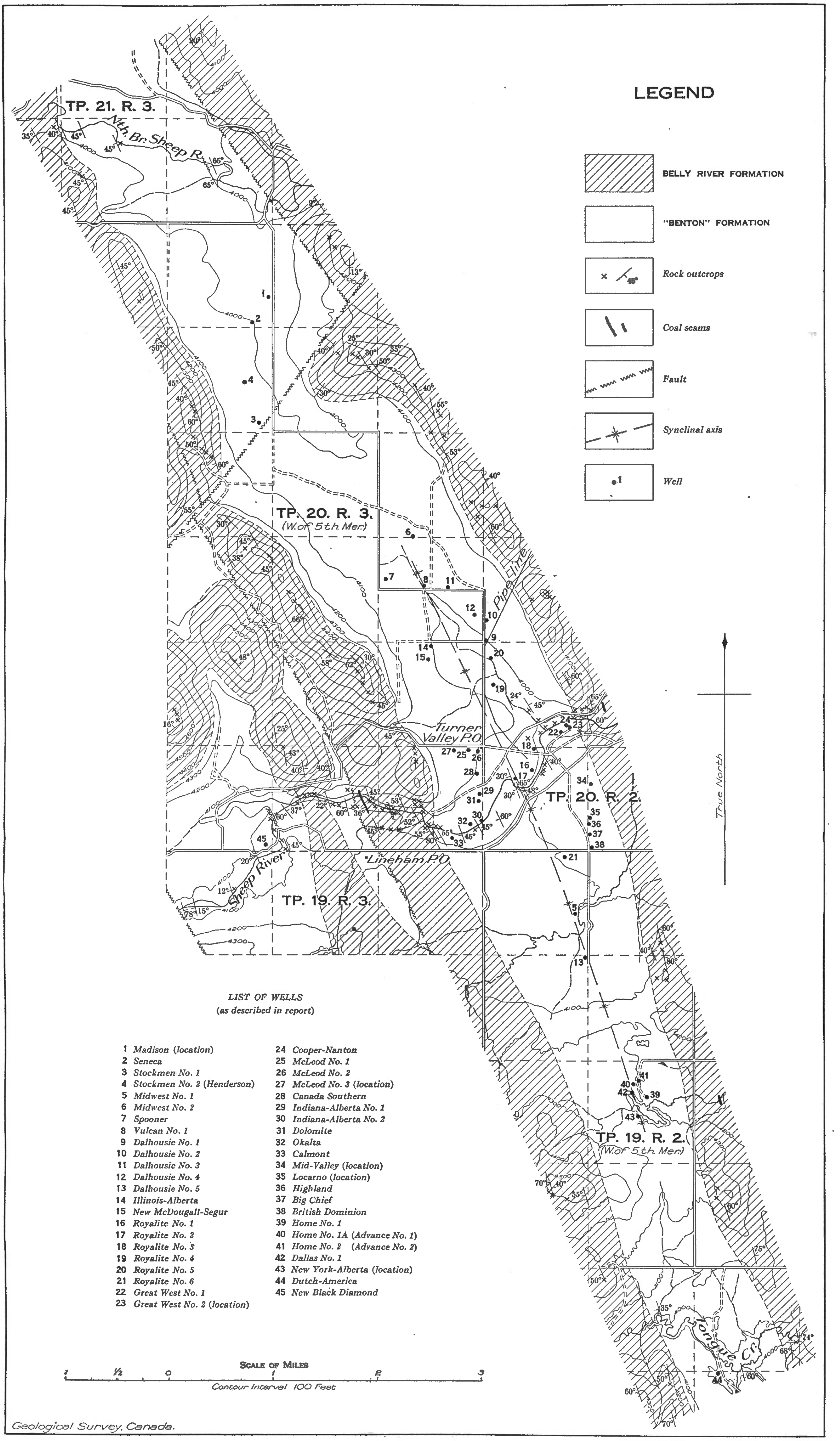

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Figure 8. Turner Valley field.

Table of Formations

Age	Formation	Lithology	Deposit	Topographic expression	Thickness	Remarks
Tertiary	Paskapoo	Light, ash-coloured, massive, sandstone beds, greenish clays and shales	Freshwater	Eroded into irregular hills and depressions	Feet 4,000±	In certain places a conglomeratic sandstone with quartzite pebbles up to 3 inches in diameter is exposed at what is considered the base of the Paskapoo. Below the conglomeratic sandstone is green clay shale presumed to be Edmonton. The division is not made on fossil evidence
Cretaceous	Edmonton	Dark green clays with hard, greenish sandstones. A carbonaceous horizon at base	Brackish and freshwater	Underlies a broad depression formed in upturned beds east of Turner valley and extending northwestward to Priddis	1,300±	
Cretaceous (Montana)	Bearpaw	Black shales, carbonaceous in places	Marine			Not definitely known to be present in Turner Valley area
Cretaceous (Montana)	Belly River	Light grey clays and shales, light grey and greenish, massive, and thin-bedded sandstones. A coal seam at the top of the formation	Brackish water	Upturned beds form prominent ridges	1,800 to 1,900	
Cretaceous (Colorado)	"Benton"	Blue-black shales with several thin sandstone members	Marine	In contrast with the Belly River rocks these are easily eroded and form valleys	2,500 to 3,000	Fossils from the upper part of the "Benton" appear to be Montana in age, whereas lower down Colorado fossils are common
Cretaceous	Blairmore	Thin-bedded, variegated shales, massive and thin-bedded, green and grey sandstones	Land and freshwater (plants)	Form ridges	Blairmore and Kootenay	In Blairmore area there are two floras, an upper dicotyledon flora of Upper Cretaceous age and a lower cycad flora. Only the lower has so far been found in Turner valley
Cretaceous	Kootenay	Coal, black shales, and hard sandstones	Continental	Does not outcrop in Turner Valley area	1,000±	A conglomerate of varying thickness occurs at the base of the Blairmore. It is not known to have been recognized in well samples

Pre-Kootenay Sediments. In a former report[1] the sediments underlying the Kootenay of Turner valley were assigned to the Fernie of Jurassic age and the belief was expressed that there were 400 to 500 feet of these strata. It was assumed also that these Fernie strata rested directly on Palæozoic limestone and dolomite, although it was suggested some Triassic might be present. These deductions regarding the pre-Kootenay sediments were the result of information obtained from the section of pre-Kootenay strata exposed on Canyon creek on the east side of Moose mountain about 25 miles northwest of Turner valley. This is the nearest section to Turner valley available for convenient study.

At Canyon creek the section is as follows:

Kootenay formation..................	This consists of sandstones, shales, and carried some coal seams near the top. The top is defined by heavy beds of conglomerate at the base of the Blairmore formation. The thickness of the Kootenay is 250 to 275 feet.
Erosional unconformity...............	This is quite marked in one exposed section, but no measurements of the amount of erosion are available.
Fernie formation.......................	This consists mostly of marine dark shales with some limestone bands. In various places Belemnites are present in profusion. The thickness is 200 to 225 feet.
Erosional interval......................	The character of this erosional interval is not known, since the contact of the Fernie with the underlying limestones was not observed. It is thought, however, that at this place the two formations are conformable.
Palæozoic limestones and dolomites...	The upper bed consists of very dark cherty limestone which passes downwards into more shaly limestones. At an horizon within this formation there are several bands of highly porous dolomites separated by more dense layers. Below the dolomites the limestones are dense and white, but cavernous in places. The dolomite horizon is thought to correspond to the productive horizon in Royalite No. 4 and other wells in Turner valley. The age of the limestones and dolomites is not definitely known, but a few poorly preserved corals are present and these apparently are Palæozoic.

The only other section that has been studied with which Turner valley may be compared is in Banff area about 60 miles to the northwest of Turner valley. At Minnewanka lake near Banff, according to Shimer[2], the section is as follows:

		Feet
Mesozoic	Jurassic—Fernie formation...........................	
	Triassic—Spray River formation...........................	1,500
Palæozoic	Permian—Rocky Mountain quartzite.................	500 to 600
	Pennsylvanian..... and Mississippian....... } Rundle formation................	1,450 to 1,500
	Mississippian—Banff formation.......................	1,200
	Devonian—Minnewanka formation....................	2,500

[1]Hume, G. S.: "Turner Valley Oil Area, Alberta"; Sum. Rept. 1926, pt. B.

[2]Shimer, H. W.: "Upper Palæozoic Faunas of the Lake Minnewanka Section near Banff, Alberta"; Mus. Bull. No. 42 (1926).

The section in the vicinity of Banff[1], according to Warren, is as follows:

		Feet
Mesozoic	Cretaceous—Kootenay Jurassic—Fernie	
	Triassic—Spray River	3,400?
Palæozoic	Pennsylvanian—Rocky Mountain quartzite	700
	Pennsylvanian? and Mississippian—Rundle	2,400
	Mississippian—Banff	1,400
	Devonian—Minnewanka	
	Upper part	1,000
	Lower part	1,900

It will be noted that Shimer assigns the Rocky Mountain quartzite to the Permian, whereas Warren assigns it to the Pennsylvanian. Although this seems to be a contradiction it is, in reality, not a very serious difference, since the age determination is dependent on the value assigned to various fossils. The difference tends to emphasize the closeness of the age relationships between the Permian and the late Pennsylvanian, and Warren[1], although contending that the fossil evidence indicates Pennsylvanian age for the lower part of the Rocky Mountain quartzites, admits that the upper part may be Permian.

In a pamphlet[2] recently prepared for the Second (Triennial) Mining and Metallurgical Congress by the Petroleum section of the Canadian Institute of Mining and Metallurgy the sand productive of oil in Home No. 1 and Dalhousie No. 5 wells in Turner valley is tentatively assigned to the Rocky Mountain quartzites. If this is so all the strata below this horizon must necessarily belong to the Palæozoic. This would greatly restrict the thickness of the Fernie, to which in Summary Report 1926 the writer assigned a thickness of 400 to 500 feet, but in view of the absence of proof of the exact age of these lower strata it seems preferable for the present to leave the question open until fossils from the cores of pre-Kootenay strata taken from Dalhousie No. 1 well can be studied in detail. It should be remembered that present information regarding the Fernie of the foothills indicates that in both lithology and faunal content the Fernie is widely different in various localities and no explanation of this fact has as yet been formulated, McLearn in dealing with this question states:[3]

"It is difficult to explain why the Fernie formation carries faunas of different age or composition in almost every locality. Two faunas that can be dated have not so far been found in any one section and locality. Was the Fernie a shifting sea or a sea in which the site of deposition shifted from one place to another, i.e., do the Fernie strata represent different ranges of time in different localities, or have the strata at all localities approximately the same, and a long time range, and is it by chance that a fauna of only one horizon and age has been preserved and found at any locality."

Added to this peculiar faunal distribution of the Fernie there are also the differences in the lithological character of the Fernie at different localities. Any decision regarding the age of pre-Kootenay strata in bore-

[1]Warren, P. S.: "Banff Area, Alberta"; Geol. Surv., Canada, Mem. 153, p. 37 (1927).
[2]Republished in "Oil News" (London), vol. XXII, No. 774, pp. 330-1 (Oct. 1, 1927).
[3]McLearn, F. H.: "Some Canadian Jurassic Faunas"; Trans. Royal Soc. Can., vol. 21, pt. 1, sec. 4, p. 70, (1927).

holes where fossil evidence is not obtainable or is inconclusive should take these facts into consideration, and although it seems much more reasonable to compare the Turner Valley section with the nearest studied outcrops, i.e. at Canyon creek, Moose mountain, present information would point to the expectation that differences in lithology and faunal content should occur in the Fernie of these two places rather than that there should be any marked similarity, although in both cases the age might be Jurassic. These difficulties regarding the amount of strata that should be assigned to the Fernie in Turner valley are also increased by our lack of knowledge of the distribution of the Triassic and late Palæozoic rocks. Thus, although there is a thick section of Triassic in Banff area, none has so far been recognized in the Canyon Creek, Moose Mountain section 40 miles to the southeast. From this it might be inferred that no Triassic is present in Turner Valley area some 25 miles still farther southeast, but this does not necessarily follow. Also the age of the limestones and dolomites underlying the Fernie in the Canyon Creek section is not definitely known owing to the scarcity and poorly preserved character of the fossils, although it appears to be Palæozoic. Its exact equivalents in Banff area are, therefore, a matter of doubt, although judged on stratigraphic position and such fossils evidence as is available it would be inferred that it probably is Rundle in age.

Blairmore-Kootenay Formations. The Blairmore was originally called Dakota, but it is now known that the formation is of pre-Dakota age. The name Dakota, therefore, is not applicable and the name Blairmore, from Blairmore area in southwest Alberta, is used here. In Blairmore area, a basal member of cherty conglomerate separates the Blairmore from the underlying Kootenay, but since this conglomerate has not been recognized in well samples in Turner valley no satisfactory division between Blairmore and Kootenay is possible. The absence of the conglomerate in Turner valley is rather surprising, because, according to Stewart,[1] the conglomerate has been traced from Castle mountain in Crowsnest district northward to Bow river, a distance of 120 miles. Since this conglomerate forms a good horizon for structural mapping in the foothills the following description by Stewart is worthy of attention.

"The conglomerate is made up of well-rounded pebbles of black, white, and greenish chert, set in a hard, siliceous matrix. The pebbles have been well sorted and are of even size, averaging from 1 to 1½ inches in diameter. The bed averages from 6 to 10 feet in thickness and reaches 30 feet in places. The contact with the underlying Kootenay formation is conformable and in most places the conglomerate grades into sandstone upward and downward, and in the eastern part of the Blairmore area, horizontally also. The conglomerate in places is 50 feet above the uppermost coal seam of the underlying Kootenay formation, and in other places it practically forms the roof of the seam."

It is worthy of notice that in Blairmore area the conglomerate grades horizontally in an eastward direction into sandstone. A similar condition may be the explanation of the apparent absence of conglomerate in Turner valley, but the horizon may occur there locally and it has been seen by the writer in the foothills to the west.

The Blairmore and Kootenay consist on the whole of variegated green, chocolate, and red shales with green and grey sandstones. One coal seam has been noted in a number of wells in the Kootenay of Turner valley. In the vicinity of Macabee creek, a tributary of Sheep river, a volcanic tuff

[1] Stewart, J. S.: "Geology of the Disturbed Belt of Southwestern Alberta"; Geol. Surv., Canada, Mem. 112, p. 28 (1919).

about one foot thick has been recognized. The volcanic tuff corresponds in position to the Crowsnest volcanics of southwestern Alberta, but since the volcanic tuff is of very local occurrence within Turner Valley area it probably is not important as an horizon marker.

"Benton" Formation. Dark shales with a few sandstone bands of variable thickness occur immediately overlying the Blairmore formation. Fossils from the lower part of these shales are Colorado in age, but large Baculites and other fossils in the upper part are Montana in age. Since elsewhere the Benton is Colorado in age, the name Benton is not strictly applicable to these sediments, although on account of the local usage the name is retained here as "Benton." In Moose Mountain area Cairnes[1] found 150 to 300 feet of dark shales which he called Claggett, overlying the Cardium sandstone containing Colorado fossils. There is little doubt that the so-called Claggett of Cairnes, which is Montana in age, corresponds to the top part of the "Benton" in Turner Valley area, although at present there is no data to show whether or not these shales should be correlated with the Claggett of Montana. The Cardium sandstone is not recognizable as such in Turner Valley area, so that no division of the "Benton" for mapping purposes is possible.[2]

Within the "Benton" of Turner valley are a number of thin pebble zones rarely more than 1 to 2 inches thick. So far it has not been possible to correlate the logs of wells by means of these pebble zones, although pebbles have been found in a number of wells. The pebbles are mostly about the size of peas, although a few up to ½-inch in diameter have been found. They consist of black, grey, and greenish chert.

The thickness of the "Benton" has not been definitely determined, owing to the fact that variable dips are encountered in the wells drilled in Turner valley, but the thickness is considered to be more than 2,500, and less than 3,000, feet.

Belly River Formation. In southern Alberta, Dowling included all strata from the base of the Milk River formation to the top of the Pale beds in the Belly River. This has some objectionable features and lately Dyer and Williams have redefined the Belly River to include only Pale and Foremost beds. The Pakowki underlying the Foremost is considered to be Claggett. If the top of the "Benton" of Turner valley should prove to be Claggett, as suggested in the report of D. D. Cairnes, the Belly River of Turner valley would then be equivalent to the Belly River of southern Alberta as redefined by Dyer and Williams, that is would include the strata lying between the Bearpaw above and the equivalents of the Claggett shales below. Before this correlation can be definitely established, further palæontological work must be done.

In Turner valley the Belly River formation includes about 2,000 feet of non-marine strata consisting of light grey, massive, and crossbedded sandstones and greenish and dark grey shales. At the top of the formation is a commercially important coal seam and another coal seam of smaller

[1] Cairnes, D. D.: "Moose Mountain District, Southern Alberta"; Geol Surv., Canada, Mem. 61 (Second Edition) (1914).

[2] Further field work west of Turner valley has demonstrated the presence of the Cardium conglomerate and sandstone in this general area and it is now possible to recognize this horizon in Turner valley where it occurs as a sandstone.

size occurs in the upper part of the formation. The uppermost coal seam is mined in a number of places. A few small conglomerate bands are also present in various localities. The sandstones of the Belly River resist weathering and, therefore, form prominent ridges in the foothills area.

Bearpaw Formation. The Bearpaw formation has not been definitely recognized within Turner Valley area, although dark shales overlying the Belly River coal seam may be of this age. To the south of Highwood river, Bearpaw shales are present and the thickness increases eastward.

Edmonton Formation. In the southern foothills, according to Stewart,[1]

"The St. Mary River formation overlies the Bearpaw without any evidence of a break, the shales passing gradually upward into sandstones, some of which are so highly calcareous as to be practically limestones. Within the lowermost 100 feet there is always at least one bed composed largely of oyster shells with other brackish-water fossils in lesser amounts."

The brackish water beds are correlated with the Fox Hills of the south, but on account of difficulties of separation Stewart included them in the St. Mary River formation. In Turner Valley area the Edmonton includes all beds above the dark shales which may represent Bearpaw, and below the Paskapoo, that is, it is the equivalent of the St. Mary River formation as described by Stewart. It is not known if the brackish, oyster-bearing beds are present, since the lowest beds are for the most part concealed, but Slipper[2] reported oyster-bearing beds at this horizon on Highwood river and included them in the Edmonton formation. It is, therefore, probable that the Edmonton of the foothills includes the equivalents of the Fox Hills sandstone.

According to Slipper[3] the Edmonton has an estimated thickness of 1,300 feet in Turner Valley area. The best-exposed section is on the south branch of Sheep river in the vicinity of the Black Diamond bridge and northwards. The beds consist of "a series of dark green mudstones with yellowish and hard, greenish sandstones, the mudstones predominating." In the higher part of the formation there are numerous horizons of freshwater Unios and Vivipari.

Paskapoo Formation. The division between the Edmonton and Paskapoo is made on lithological differences, and although the Paskapoo is considered to be Tertiary, whereas the Edmonton is at the top of the Cretaceous, it is not always possible to make a satisfactory division. In a section exposed east of the bridge over Fish creek at Priddis, a conglomeratic sandstone with quartzite pebbles up to 3 inches in diameter overlies greenish clay shales of Edmonton age. It is thought the conglomeratic sandstone represents the base of the Paskapoo and may be of more than local significance, since Allan[4] has reported that an erosional interval separates the Paskapoo and Edmonton in the Plains region.

STRUCTURE

The structure of Turner Valley field as described by Slipper[5] is an

"Anticlinal fold which is topographically indicated by Turner valley and its continuation southwest . . . . . . The crest has been eroded to a considerable extent, forming

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[1] Stewart, J. S.: "Geology of the Disturbed Belt of Southwestern Alberta'; Geol. Surv., Canada, Mem. 112, p. 43 (1919)

[2] Slipper, S. E.: "Sheep River Gas and Oil Field, Alberta"; Geol. Surv., Canada, Mem 122, p. 13 (1921).

[3] Slipper, S. E.: "Sheep River Gas and Oil Field, Alberta"; Geol. Surv., Canada, Mem. 122, p. 10 (1921).

[4] Allan, J. A.: "Geology of Alberta Coal"; Can. Inst. Min. and Met., p. 396 (April, 1925).

[5] Geol. Surv., Canada, Mem 122, p. 11.

a central valley up to 2 miles wide in which the underlying Benton shale is exposed. The Belly River beds form two parallel ridges on the flanks. The beds on the east limb have a general dip of 60 to 70 degrees and on the west of 50 to 60 degrees; but these dips vary considerably along the fold. . . . . . . North of Sheep river, the Belly River beds on the eastern limb show irregular structure and farther north the strata exposed on the ridge which is apparently the eastern limb, dip west. North of the North branch there are four northwest-trending sandstone ridges on the strike of the valley, all dipping 35 to 40 degrees west. It would seem, therefore, that the anticlinal structure of Turner valley is replaced by a series of overthrust faults at a point 4 or 5 miles north of Sheep river."

A study of the outcrops on the eastern flank of the Turner Valley anticline reveals a decided, local change in both dip and strike on the nose of a hill which extends westward from the main ridge to the centre of sec. 26, tp. 20, range 3. Southwest of this place the ridge forming the western flank of Turner valley is broken in sec. 22, tp. 20, range 3, by a deep cross-valley, and the ridge north of the break is offset slightly to the east. These conditions are explained by assuming that a normal fault with down-throw to the north crosses Turner valley northeastward from about the centre of section 22 and passes north of the nose of the hill in section 26, such a fault being later than the folding of the Turner Valley anticline. From the increase in dip on the eastern Belly River ridge, from south to north toward the fault, it is thought that considerable drag-folding is involved with the faulting and it is possible drag-folding along a definite line of dislocation may predominate over actual faulting within the "Benton" shales. The conditions resulting from faulting may be explained in two possible ways: (1) by a normal fault downthrown to the northwest, that is with the plane of faulting dipping in the direction of the down-thrown side; (2) by a thrust fault overthrust to the northwest. Both of these explanations would give the eastward offsetting of the western Belly River ridge, but on account of the assumed position of the fault and other data from drilling, it is much more logical to assume a normal fault. This transverse normal fault divides Turner valley into two distinct types of structure. To the southeast is the Turner Valley anticline and to the northwest is a westward-dipping fault block with a thrust fault forming the division between the "Benton" and the Belly River on the eastern flank.

In the central part of Turner valley, in the vicinity of Sheep river, the anticlinal structure is well shown by outcrops of "Benton" shales on the banks of Sheep river, as well as by the flanking ridges of Belly River rocks extending northwest from the river. The anticlinal structure is, however, modified by a sharp syncline on sec. 6, tp. 20, range 2, which is clearly visible in outcrops of "Benton" shale on the river banks. To what extent faulting, if any, accompanied this synclinal folding is not evident from the outcrops. In the Vulcan well, drilled close to the centre of sec. 13, tp. 20, range 3, the Palæozoic limestone and dolomite were penetrated at a depth slightly more than 1,400 feet greater than in Royalite No. 4 well which was drilled on the west side of sec. 7, tp. 20, range 2, and an examination of the Vulcan well samples shows no evidence of any structure not explainable as due to sharp folding. It is concluded, therefore, that the Vulcan well was drilled in a continuation of the syncline visible on Sheep river and this conclusion is supported by the fact that a straight line joining the Vulcan well and the axis of the syncline on Sheep river corresponds in direction to the strike of the rocks outcropping on Sheep river. It is further concluded that for this part of the field the position of the synclinal axis can be plotted with a fair degree of accuracy. Northwest of the Vulcan well there is no available data regarding the course of the synclinal axis, but since the direction of the anticline swings somewhat to the west in the vicinity of, and as a result of, the transverse fault, the synclinal axis also probably swings to the west and is thought to reach the transverse fault almost due south of the Stockmen well. Since the folding preceded the transverse faulting, the extension of the Vulcan syncline is undoubtedly present in the fault block north of the transverse fault, but offset by it to the east. South of Sheep river the syncline cannot yet be definitely traced owing to the absence of outcrops and insufficient drilling, but its presence at the Dallas well on sec. 20, tp. 19, range 2, is strongly suggested by the thickness of "Benton" encountered in that well. It is shown on the map, therefore, as extending from Sheep river to the Dallas well, but its position as shown should only be accepted as being approximate.

Drilling already done in the central part of Turner valley has demonstrated that the Vulcan syncline divides Turner Valley field into two anticlines, on both of which the prospects for oil and gas are excellent. It seems, however, from well data, that each of these anticlines is asymmetrical with a westward-dipping axial plane and it is suspected that a similar condition holds with respect to the central syncline. If this is the situation, the dip of the strata will vary from top to bottom of a well and the apparent thickness of the beds will differ from well to well. In wells drilled east of the axis of the eastern anticline the dip will increase with depth, whereas in wells west of the western anticline the dip will decrease with depth, provided the well does not penetrate the axial plane. Thus it seems probable that a well on the west side of the main structure and comparatively close to the western Belly River ridge would reach the same stratigraphical horizon at the same depth as a well east of the main structure but much farther removed from the eastern Belly River ridge.

New Black Diamond Anticline. The New Black Diamond anticline is named after the New Black Diamond Oil Company which is drilling a well on it in sec. 3, tp. 20, range 3. The fold occurs within Turner Valley map-area, although it is a structure entirely distinct from the Turner Valley anticline and lies about 2 miles west of it on Sheep river. It is separated from the Turner Valley fold by a thrust fault which brings "Benton" rocks into contact with the top of the Belly River formation, indicating a throw of about 2,000 feet. The crest of the anticline appears near the northeast corner of sec. 34, tp. 19, range 3, and although the anticline is presumed to be approximately parallel to the Turner Valley structure it cannot be traced north or south of Sheep river due to an absence of outcrops. The strata on the east flank near the crest dip 45 degrees or more to the northeast and about a quarter of a mile northeast of the New Black Diamond well is a small fault or zone of disturbance which, however, is probably of minor importance. To the west of the crest for over a mile southwest, the angles of dip are rarely over 20 degrees, but a very short distance west of sec. 34, tp. 19, range 3, there is a strongly disturbed area in which both Blairmore and "Benton" outcrop.

Since the folding on the New Black Diamond anticline is less sharp than on the Turner Valley anticline, the base of the "Benton" should be reached in the former structure at a less depth than in the wells being drilled in Turner valley. It would seem that the anticline is of considerable prospective value as an oil- and gas-field.

OIL DEVELOPMENTS AND PROSPECTS

Royalite No. 4 well, which in the autumn of 1924 struck a productive horizon in the supposed Palæozoic dolomitic strata at a depth of 3,740 feet, has continued to produce more than 500 barrels of 72° to 73° Baumé naphtha a day, with an increased yield in 1926 as compared with that of 1925. The production consists of a flow of 17,000,000 to 20,000,000 cubic feet of gas a day, from which the naphtha is extracted in two Smith separators. During 1926 the Vulcan Oil Company's well on sec. 13, tp. 20, range 3, reached a productive horizon in the central syncline of the main anticlinal structure at 5,004 feet in the Palæozoic and the daily initial yield amounted to between 100 and 150 barrels of naphtha. Illinois-Alberta well on sec. 12, tp. 20, range 3, also reached a productive horizon in the same series of rocks in the west anticline at a depth of slightly more than 3,800 feet. This well has a production of nearly 100 barrels a day. The only other well within this area so far drilled into the Palæozoic is McLeod No. 2, on sec. 1, tp. 20, range 3, and although some production has been secured drilling is being continued at the time of writing. An important development in Turner valley in 1926 was the discovery of a productive horizon yielding 70 to 100 barrels a day of approximately 55° Baumé oil, in the Blairmore, by the New McDougal-Segur well on sec. 12, tp. 20, range 3. The depth of the productive horizon is slightly less than 2,600 feet and its discovery gives rise to the hope that other wells may meet with similar success. Prior to the drilling of Royalite No. 4 well, all the production within Turner valley came from several horizons of the Blairmore-Kootenay which yielded oil and wet gas and had been encountered in a number of wells; the yield of the New McDougal-Segur well is the largest flow obtained from recent drilling from the Blairmore-Kootenay horizon.

The maximum depth at which production will be secured on the flanks of the Turner Valley anticline cannot at present be predicted. The Vulcan well drilled in the syncline in the centre of the main fold, obtained a yield in the Palæozoic limestone and dolomite encountered at about 4,865 feet or about 850 feet below sea-level, and it is reasonable to expect the flanks of the main anticline to be productive to the same depth, although it is realized production may not extend for an equal distance down each flank. It is, of course, unknown how far below the depth of the Vulcan well a yield may be expected. It seems likely that the extent of the productive area in a northwest and southeast direction will depend mainly on the extent of the productive horizon, as structural conditions seem to be favourable from the transverse fault in the north end of Turner Valley field, to at least the vicinity of the Home wells in the south and, possibly, to the south of Tongue creek where the anticline is plainly discernible, although a southward plunge is suggested by the disappearance of the "Benton" under later rocks at the south end of the map-area.

No predictions can be made regarding the prospects within the fault-block structure northwest of the transverse fault in the northern part of

Turner Valley field. It seems probable that the strike fault along the east side of the fault block may have caused an accumulation, against the fault, of oil and gas in the westward-dipping strata. The position and extent of any accumulation may be modified by the extension of the Vulcan syncline into the fault block or by other features such as small faults, but although the existence of such features makes it more difficult to predict the conditions within the fault block, it would not destroy the value of the areas as a prospective oil- and gas-field.

The Seneca well on sec. 27, tp. 20, range 3, is being drilled in this fault-block structure in the northern end of Turner valley. Since fault-block structures of this type occur in many places in the foothills, a successful result in the case of the Seneca well will undoubtedly greatly increase the possible areas where prospects for oil and gas would be considered favourable.

VIKING GAS-FIELD

By G. S. Hume

References: Slipper, S. E.: "Viking Gas Field, Structure of Area"; Geol. Surv., Canada, Sum. Rept. 1917, pt. C, pp. 6-7.
Elworthy, R. T.: "Gas in Alberta"; Mines Branch, Dept. of Mines, Canada, Pub. No. 616 A, p. 17 (1924).

(*See* Figure 9)

Viking gas-field (locality 3, Figure 4) is west of Irma-Wainwright district and north of the town of Viking on the Canadian National railway. The country is for the must part flat or gently rolling and is covered to a

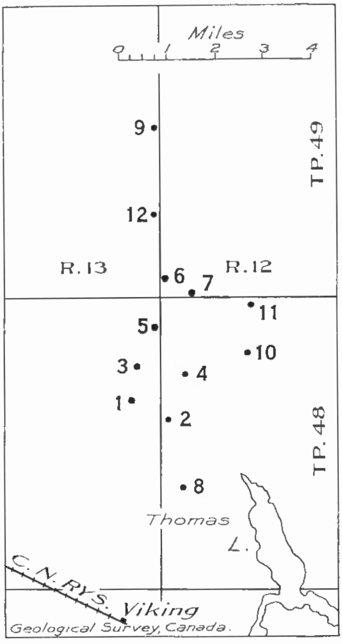

Figure 9. Viking gas-field; numbers designate the wells as given in the table, page 77.

large extent with glacial till. There are no large streams and in consequence outcrops are rare. Such as do occur belong to the Pale-Variegated series of sediments.

West of Viking field the strata plunge downwards into the Alberta syncline and in consequence the field is limited in that direction. To the east the structure is not known in detail, but there is reason to suspect a syncline to the northeast between Viking and Birch lake. Reconnaissance work carried out in 1924 points to the conclusion that the strata in the vicinity of Birch lake and for some considerable distance to the northeast, dip southwesterly. This is contrary to the idea that Birch lake is on the axis of a broad fold. The Talpey-Arnold well on the west side of Birch lake apparently was drilled in strata dipping in one direction for a long distance both east and west of the drilling site. Such a structure would not be favourable for oil or gas accumulation and this conclusion is in accord with the results of drilling. It is believed the gas from Viking field has in a large measure been prevented from migrating up the dip towards the Talpey-Arnold well by a syncline separating Birch Lake and Viking areas.

As far as can be told, therefore, from data at present available, Viking gas area is a local fold developed on the eastern edge of the Alberta syncline. Although an oil show was reported in one well, the dry character of the gas does not lead to the hope that oil is present. The extent of the gas-field to the north and south is unknown, but the fold seems to plunge downwards in both directions.

Production[1]

Well No.	L.S.	Sec.	Tp.	Range	Elev.	Depth	Rock press.	Open flow
					Feet	Feet		
1..........	13	24	48	13	2,285	2,435	All wells	9,000 M.
2..........	5	19	48	12	2,289	2,373	about	2,700 M.
3..........	10	25	48	13	2,290	2,365	800 lbs.	5,000 M.
4..........	3	30	48	12	2,306	2,343	....	1,350 M.
5..........	8	36	48	13	2,290	2,220	....	6,286 M.
6..........	5	6	49	12	2,287	2,203	....	7,617 M.
7..........	1	6	49	12	2,303	2,215	....	7,000 M.
8..........	2	18	48	12	2,275	2,430	....	2,000 M.
9..........	8	24	49	13	2,262	2,340	....	3,250 M.
10..........	16	29	48	12	2,316	2,220	....	3,000 M.
11..........	16	32	48	12	2,279	2,152	....	7,000 M.
12..........	9	12	49	13	2,254	2,125	....	9,000 M.

[1] Elworthy, R. T.: "Natural Gas in Alberta"; Mines Branch, Dept. of Mines, Canada, Pub. No. 616A, p. 17 (1924). (Table in part from this publication with additions.)

The gas from Viking field is piped to Edmonton, about 80 miles to the northwest, and supplies not only Edmonton but several other centres of population between Edmonton and Viking. The gas is a dry gas, with methane as the chief constituent and no sulphur.

An analysis[1] of the gas from No. 6 well is as follows:

	Per cent
Methane CH_4	92·5
Ethane C_2H_6	3·5
Carbon dioxide CO_2	0·5
Carbon monoxide CO	......
Oxygen O_2	0·1
Nitrogen N_2	3·4
Sulphuretted hydrogen H_2S	......
Helium He	0·006
Specific gravity	0·64
Calorific value B.Th.U. at 0°C. and 760 mm	1,051

According to Elworthy the supply in the immediate field is calculated to be over 60,000,000 cubic feet of gas.

Log of Viking Well No. 1

	Feet	
Light grey clay	0	—85
Light grey shale	85	120
Light grey shale, somewhat sandy	120	140
Very fine, sandy shale	140	165
Light grey to brown, fine, sandy shale	165	170
Light grey shale with coal fragments	170	210
Dark grey, carbonaceous shale	210	243
Coal	243	245
Dark grey, carbonaceous shale	245	252
White, fine-grained sandstone	252	272
Light grey, sandy shale	272	280
Dark grey shale	280	340
Dark grey shale with specks of coal	340	360
Grey shale (contains shells)	360	370
Grey shale	370	395
Grey and greenish shale, light grey sandstone	395	465
Fine-grained sandstone with carbonaceous matter	465	485
Chocolate-coloured and grey shale	485	515
Dark grey carbonaceous shale	515	530
Dark grey shale with some coal	530	535
Dark grey, carbonaceous shale	535	655
Chocolate brown shale	655	690
Comparatively coarse, light grey sandstone. Water	690	740
Blue-grey shale	740	885
Blue-grey shale, sandy in places	885	890
Brown, carbonaceous shale	890	895
From driller's record:		
Brown shale	895	1,210
Hard lime shell	1,210	1,215
Blue shale	1,215	1,400
Brown shale	1,400	1,605
Sand with grey clay	1,605	1,610
Dark grey, rusty shale	1,610	1,860
Upper gas sand at 2,180 feet.		
Dark grey shale	1,860	2,202
Dark grey, rusty shale	2,202	2,340
Lower gas sand at 2,335 feet.		

[1]Elworthy, R. T.: "Natural Gas in Alberta"; Mines Branch, Dept. of Mines, Canada, Pub. No. 616A, p. 17 (1924).

The sandstone carrying water encountered at 740 feet in depth is believed to represent the base of the Ribstone Creek formation, whereas the fine-grained sandstone at 465 to 485 feet is thought to be at the base of the Birch Lake formation. The chocolate and dark grey shale between 485 and 535 feet probably belongs to the Grizzly Bear formation. It is impossible to make a division between the Pale and Variegated beds at the top of the well and the Birch Lake formation below, although from the log of the well the Birch Lake would be assumed to begin between 395 and 465 feet in depth. The shales from 740 downwards are thought to be Lea Park and Benton with the productive gas sands at the base of the latter.

BATTLE RIVER AREA, ALBERTA

By G. S. Hume

References: Allan, J. A.: Geol. Surv., Canada, Sum. Rept. 1917, pt. C.

Dowling, D. B., Slipper, S.E., and McLearn, F. H.: "Investigations in the Gas and Oil Fields of Alberta, Saskatchewan, and Manitoba"; Geol. Surv., Canada, Mem. 116 (1919).

Hume, G. S.: "Oil and Gas Prospects of the Wainwright-Vermilion Area, Alberta"; Geol. Surv., Canada, Sum. Rept. 1924, pt. B.

—"Oil Prospects in the Vicinity of Battle River at the Alberta-Saskatchewan Boundary"; Geol. Surv., Canada, Sum. Rept. 1925, pt. B.

(*See* Figure 10)

INTRODUCTION

Battle River area, as the name is here used, includes an area extending from Irma east to the Saskatchewan boundary. The country is flat or rolling, with a covering of glacial till which obscures most of the underlying rocks except along stream valleys where erosion subsequent to the Glacial period has removed part of the glacial deposits.

The drainage is toward the east, Battle river and tributaries providing the main drainage channels. North of the area the drainage is to North Saskatchewan river which also flows eastwards. Both North Saskatchewan and Battle rivers have wide valleys which in many places are several hundred feet deep and, considering the low relief of the remainder of the country, are marked topographic features. It can be proved that parts of both valleys antedate the Glacial epoch and probably this is the case throughout most of their length within this area. They have been cut in Cretaceous strata and on Battle river at least some of the bends of the river have been controlled by structural features in the underlying rocks, a condition which could be possible to any considerable degree only in an area where the river valley antedated the Glacial age.

STRATIGRAPHY

Table of Formations

Age		Formation	Thickness	Description	Oil and gas
Cretaceous	Montana	Bearpaw	Feet 600 to 700 Not exposed in this area	Marine, dark grey shale containing large quantities of selenite and ironstone nodules. Within these shales is the Bulwark sandstone which is hard, massive, and brown	
		Pale Beds	About 500	Pale, incoherent, crossbedded sandstone and green clays. Ironstone bands and coal seams occur. Contains fresh-water fossils	
		Variegated Beds	200	Interlayered sands and shales with thin coal seams	
		Birch Lake	60 to 100	Massive, crossbedded, buff sandstone with some shales. At Birch lake a marine member has been reported. Mainly brackish water deposits	
		Grizzly Bear	100 to 40	Dark blue-grey marine shale containing ironstone and sandstone nodules; some sand beds present	
		Ribstone Creek	225	Greenish yellow, massive, soft sands with some hard sandstone beds. Green and carbonaceous shale with coal. To the east in Saskatchewan it contains a marine horizon. Mainly brackish water deposits	Unimportant gas showings have been found in wells in this formation
		Lea Park	Lea Park and Benton 1,500 to 1,600	Marine, blue-grey shale and sandy shale with selenite and ironstone nodules. Fossils	Gas showings
	Colorado	Benton		Marine, grey shale with some sandstone beds and nodules	Oil and gas
	Lower Cretaceous		150	Mostly sands with some shale. Continental deposit	Oil and gas
Devonian				Limestones, marine	Oil showings

Benton Formation. The Benton is not exposed in Battle River area, but has been penetrated in a number of wells and is known to consist of dark marine shales with numerous ironstone bands. At the base are sand horizons carrying gas in Viking field, and oil and gas in Wainwright area. Since the Lea Park, which overlies the Benton, is marine shale, similar lithologically to the Benton, no division can be made between these two formations in well logs. The Lea Park, however, is Montana in age and the Benton is Colorado and each carries a distinctive fauna. The combined thickness is 1,500 to 1,600 feet.

Lea Park Formation. The type section of the Lea Park formation is at Lea Park, Alberta, on North Saskatchewan river. At this place the formation consists of dark shales and sandy shales with nodules and discontinuous layers of ironstone. Fossils of Montana age are plentiful in some localities. The thickness of the formation has been given by Slipper[1] as 700 feet and by Allan,[2] who studied the North Saskatchewan section, as considerably less. The difference in the estimates of the thickness may be due to the fact that the Benton is distinguishable from the Lea Park only on the basis of fossils.

Ribstone Creek Formation. The Ribstone Creek formation is named from Ribstone creek, a tributary of Battle river in Alberta near the Saskatchewan boundary. At this locality it is readily separated from the underlying Lea Park formation by the fact that the lower beds of the Ribstone Creek formation are soft, greenish yellow, crossbedded sands, whereas the upper beds of the Lea Park are dark grey marine shales. The thickness of the sand beds at the base of this formation is somewhat variable, from only a few feet to more than 20 feet, and several hard sandstone beds occur in outcrops within this sand zone. In wells these sands are in many places water-bearing and where the sands outcrop along stream or river valleys springs are of common occurrence. Most of the information on the character of the central part of this formation has been derived from well records and outcrops are rare because the formation consists of easily weathered soft shales. Where outcrops occur the shale is not easily distinguishable from the higher Grizzly Bear shales or the lower beds of the Lea Park formation. The Ribstone Creek shales, as far as known, however, carry no fossils and the formation is considered to be predominantly non-marine, at least in Alberta. Above these shales there is another sand zone at the top of the formation, which also carries in outcrops a number of hard bands and nodules. It is thought that these hard bands are largely a surface feature and are due to cementation of the sand by circulating waters carrying minerals in solution, since in well logs not many hard sandstone bands are encountered. In certain localities carbonaceous layers and even small coal seams occur in the upper part of the formation. On the banks of Battle river near the mouth of Buffalo coulée a coal seam has been mined to a slight extent for local use. The thickness of the whole formation is approximately 200 to 225 feet, thinning eastwards.

Grizzly Bear Formation. The Grizzly Bear formation consists of dark grey marine shale and carries Montana fossils. It is thought that the Ribstone Creek non-marine beds grade upwards into the Grizzly Bear marine beds and although in a general way a division can be made, owing to the fact that the top of the Ribstone Creek formation is sand, whereas the base of the Grizzly Bear is predominantly shale, there is a 10 to 15-foot zone in which shale and sand beds alternate and carry marine fossils as well as an abundance of selenite in crystals and flakes. This

[1] Slipper, S. E.: Geol. Surv., Canada, Sum. Rept. 1917, pt. C, p. 8.
[2] Allan, J. A.: Geol. Surv., Canada, Sum. Rept. 1917, pt. C, p. 11.

zone is thought to represent the change from non-marine to marine sedimentation. It seems very probable that the seas depositing the Grizzly Bear shales were very shallow, since the formation in various places carries small nodules made up almost entirely of selenite crystals, and in one well at least, in shales that were thought to belong to this formation, a very thin seam of carbonaceous or coaly material was encountered, although the formation is considered predominantly marine.

Birch Lake Formation. The Birch Lake formation, named from Birch lake, Alberta, consists mostly of massive, crossbedded, brownish, and grey sandstones with some softer sand and shales. The contact with the underlying Grizzly Bear shale has not been observed by the writer, but at what is considered to be approximately the base of the formation a bed of oyster shells, in places 3 feet thick, occurs. This oyster shell bed has been found over a wide area and is considered to represent the change from marine conditions in Grizzly Bear time to brackish water conditions in Birch Lake time. It is probable that the brackish water beds of the Birch Lake were deposited almost at sea-level, since the presence of marine fossils[1] in this formation at Birch lake attest to at least one invasion of the sea.

Variegated and Pale Beds. Although it was found impossible in the field to make a sharp division between the Variegated and Pale beds, in a general way the two formations are dissimilar, the Pale beds being composed of light grey and whitish sands interbedded with darker shales, whereas the Variegated beds are somewhat darker in colour. Both formations contain thin, unimportant coal seam and carbonaceous layers and the Pale beds are characterized by numerous bentonitic layers. Ironstone nodules are common in both formations. The total thickness as given by Slipper[2] is 700 feet, but from well logs in Monitor area, where the top of the Pale beds is exposed, the thickness is believed to be somewhat greater.

Bearpaw Formation. The Bearpaw, which overlies the Pale beds, consists of dark marine shale with a sandstone member (Bulwark sandstone) in the area south and southwest of Wainwright. Shales of this age occur on Battle river southwest of Hardisty, but not within the area under consideration. The Bearpaw represents the top of the Montana series of rocks and in central Alberta is overlain by the non-marine beds of the Edmonton.

STRUCTURE

Eastward from the edge of the Alberta syncline west of Viking the strata dip southwesterly, but at angles decreasing in size eastward. In the vicinity of Wainwright a regional southwesterly dip is still recognizable, although it is modified in places by small folds superimposed on the major structure; but east of the Alberta-Saskatchewan boundary, in the vicinity of Battle river, the dip changes to a southeast direction. The major structure between Viking, Alberta, and Battleford, Saskatchewan, is a broad anticline, the highest point of which is somewhere in the vicinity of the mouth of Ribstone creek. On this major structure a number of minor folds are known and although the occurrences of oil and gas may in a general

[1] Warren, P. S.: Trans. Roy. Soc. of Canada, vol. 20, p. 9 (1926).
[2] Slipper, S. E.: Sum. Rept. 1917, pt. C, p. 8.

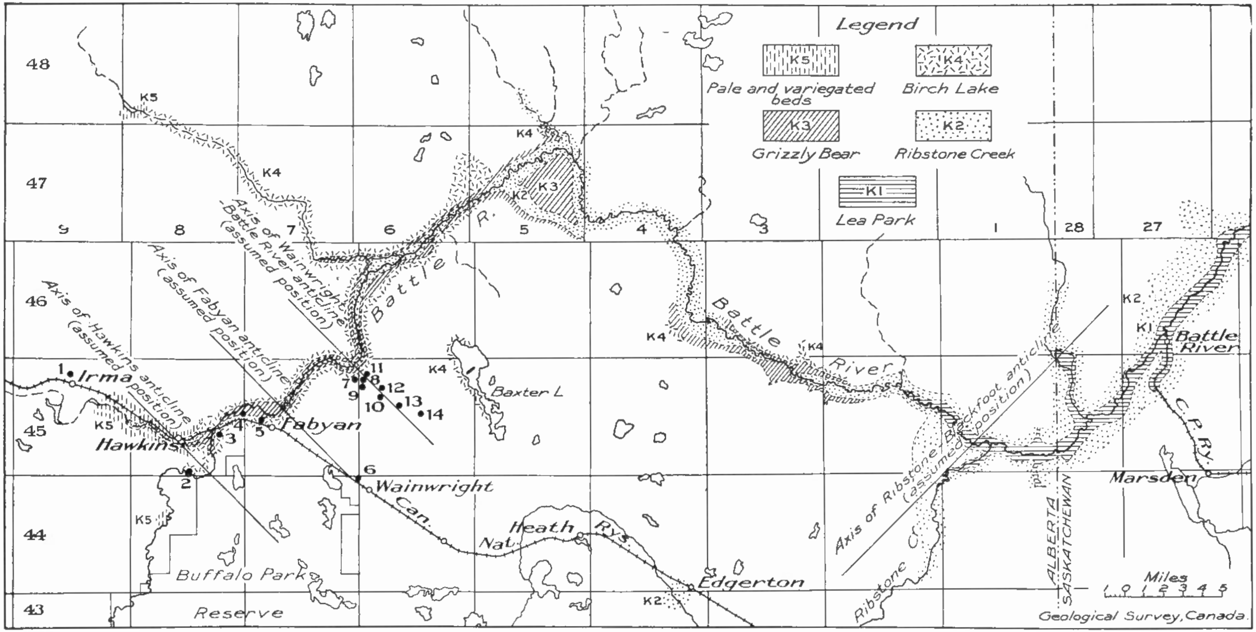

Figure 10. Battle River area, Alberta:

1, Irma Oil Development Co. (drilled by Edmonton-Wainwright Oil Co.); 2, Gratton No. 1; 3, Imperial Oil Co. No. 2; 4, Maple Leaf Oil Co.; 5, Imperial Oil Co. (Fabyan) No. 1; 6, Interior Oil Co.; 7, British Petroleums No. 1; 8, British Petroleums No. 2; 9, British Petroleums No. 4; 10, British Petroleums No. 3B; 11, British Petroleums No. 5 (location); 12, Edmonton-Wainwright No. 1; 13, Western Consolidated Oil Co.; 14, British Wainwright Oil Co.

way have resulted from the larger structure, they occur on the minor folds. The determination of these minor folds, therefore, is the most important consideration in locating drilling sites, for past experience has proved beyond doubt that wells that are not located on the minor folds have small chances of striking commercial supplies of oil or gas. The major structure, which embraces a very large area in an east-west direction, may be taken as roughly outlining the territory in which oil and gas may occur, but it is only the much smaller areas of local folding that may be expected to be productive.

Hawkins Fold

A cross-section of this fold appears on Map 2058 which accompanies Summary Report 1924, part C. If the writer's interpretation of the stratigraphy is correct, the Birch Lake formation forms the crest of an anticline whose axis is assumed to extend in a southeast-northwest direction. Gratton No. 1 well in sec. 4, tp. 45, range 6, W. 4th mer., was drilled on the southwestern flank of this fold and gave a fair flow of gas. Since it is assumed that gas fills the crest of the fold and that oil, if present, occurs down the flanks, any well drilled nearer the crest of this fold would be a gas well. As the Gratton well is a considerable distance down the southwestern flank of the fold it is, therefore, assumed that the fold contains only gas. If the fold extends northwest, the axis will pass east of Irma and the well of the Irma Oil Holdings Company will be on the southwestern flank.

Fabyan Fold

It is believed a fold crosses Battle river northeast of Fabyan station. The available information is not sufficiently definite to outline the extent or magnitude of this fold, although data obtained by accurate levelling leave little doubt that a fold is present. It is thought the crest of the fold lies east of the Imperial (Fabyan) No. 1 well, sec. 18, tp. 45, range 7, W. 4th mer., in which a flow of gas, estimated at 10,000,000 cubic feet a day, with some heavy oil, was obtained. If, as is presumably the case, gas fills the crest of the fold, any well drilled between Imperial (Fabyan) No. 1 well and the crest of the fold would be a gas well. Maple Leaf No. 1 well was drilled on the west flank of the fold and obtained gas with an initial flow of 2,500,000 cubic feet a day at a depth of 1,705 to 1,720 feet. The lower horizon that gave the large gas flow in the Imperial (Fabyan) No. 1 well at a depth of 1,870 feet was apparently not penetrated by the Maple Leaf well. Since gas with a small amount of oil is present in the Imperial (Fabyan) No. 1 well it is reasonable to assume that if oil in quantity is present in the fold it will occur down the dip to the west of this well. The western limit of the structure is unknown, but since Imperial No. 2 well on sec. 14, tp. 45, range 8, is a dry hole, any oil present must be northeast of this location. The drilling of the Maple Leaf No. 1 well to a greater depth would more closely limit the part of the fold that may hold oil and might be considered a fair test of the oil prospects about midway between the Imperial (Fabyan) No. 1 well on sec. 18, tp. 45, range 7, and Imperial No. 2 well on sec. 14, tp. 45, range 8. During 1926 Fabyan Petroleums, Limited, commenced a well slightly north of Maple Leaf No.

1. This well has not yet been drilled to a sufficient depth to reach any possible productive horizons and its relation to the structure is approximately the same as Maple Leaf No. 1 well.

The oil found in Imperial (Fabyan) No. 1 well is heavy, having a gravity of approximately 12° Baumé. The well contains much salt water which is forced out with a small amount of oil, in the form of an emulsion, by the gas pressure when the well is opened. The value of the present Imperial well, therefore, is entirely dependent on the value of the gas that can be obtained from it.

Wells Drilled on the Fabyan Fold

Imperial (Fabyan) No. 1, sec. 18, tp. 45, range 7, W. 4th mer., contains gas with small amount of oil.

Maple Leaf No. 1, sec. 24, tp. 45, range 8, W. 4th mer., contains gas which is now piped to Wainwright.

Fabyan Petroleums, sec. 24, tp. 45, range 8, W. 4th mer. (drilling).

Interior,[1] sec. 36, tp. 44, range 7, W. 4th mer. (drilling).

Battle River-Wainwright Fold

A number of wells which constitute what is generally known as the Wainwright field, have been drilled on this fold. It crosses Battle River at the northeast corner of range 7, tp. 45, and is thought to extend in a northwest-southeast direction.

Between the Battle River-Wainwright and the Fabyan folds there is a syncline, the magnitude of which is unknown. It is presumably sufficiently deep and wide to prevent the main body of gas struck in Imperial (Fabyan) No. 1 well on the Fabyan anticline, migrating northeastward into the Battle River-Wainwright fold. On the northeast flank of the Battle River-Wainwright fold a dip of 40 feet in about half a mile was measured. The distance the dip continues at this rate and with this direction is not known, but is not thought to be great, since the regional southwest dip becomes apparent again some distance southwest of the mouth of Buffalo coulée.

The width of the productive part of the Battle River-Wainwright fold has not been determined and will only be known when more drilling has been done. The crest of the anticline is thought to be wide and flat. The length of the field in a northwest-southeast direction is also unknown, but the finding of oil in British Petroleums No. 3 B well on the SW. ¼ sec. 29, tp. 45, range 6, leads to the assumption that this well is on the southeast extension of the fold. In a northwest direction there is reason to assume that the fold crosses Battle River valley. A considerable volume of gas, much larger than so far encountered in any well to the southeast, is reported to have been struck in BritishPetroleums No. 2 well on sec. 30, tp. 45, range 6. This suggests that the well is structurally higher than the wells farther southeast, but the validity of this surmise has not been proved, owing to the difficulty of correlating the wells. If correct, then the large flow of gas could be explained by assuming that the anticline plunges southeast at a low rate. If this is the situation there should be a corresponding rise to the northwest and British Petroleums No. 1 well on sec. 36, tp. 45,

[1] Interior Oil Company's well is on the strike of the fold several miles to the southeast of the other wells.

range 7, should be stratigraphically slightly higher than British Petroleums No. 2 well. It was reported that British Petroleums No. 1 well when being drilled struck a larger flow of gas than was encountered in British Petroleums No. 2 well. If this were true it confirms the suggestion that the anticline plunges southeasterly. That this is the case is also suggested in another way. At each of the three folds, namely Hawkins, Fabyan, and Battle River-Wainwright, there is a southward bow in the river. This apparent relation between drainage pattern and structure can scarcely be merely a coincidence, and since in each case the river makes a southward bow, it is probable that the anticlines plunge in the same direction. If the folds plunge southeast they probably continue to rise to the northwest across Battle river. Wells located on the strike of the anticline northwest of Battle river will, if these conditions prevail, be higher structurally than any so far drilled. As rock outcrops are confined to Battle River valley, a knowledge of the structure can be obtained by drilling either for oil or shallow holes to determine structure only. The sand horizons of the Birch Lake formation should be relatively close to the surface of Battle river and would afford suitable datum planes whereby the structure could be determined.

Wells Drilled on the Battle River-Wainwright Fold

British Petroleums No. 1, sec. 36, tp. 45, range 7, W. 4th mer.—Abandoned
" " No. 2, sec. 30, tp. 45, range 6, W. 4th mer.—Gas and oil
" " No. 3, sec. 29, tp. 45, range 6, W. 4th mer.—Abandoned
" " No. 3B, sec. 29, tp. 45, range 6, W. 4th mer.—Oil
" " No. 4, sec. 30, tp. 45, range 6, W. 4th mer.—Oil
" " No. 5, sec. 31, tp. 45, range 6, W. 4th mer.—Location
British-Wainwright No. 1, sec. 22, tp. 45, range 6, W. 4th mer.—Location
" " No. 2, sec. 20, tp. 45, range 6, W. 4th mer.—Drilling
Emerald, sec. 30, tp. 45, range 6, W. 4th mer.—Drilling
Edmonton-Wainwright No. 1, sec. 29, tp. 45, range 6, W. 4th mer.—Oil
National Exploration, sec. 30, tp. 45, range 6, W. 4th mer.—Gas
Western Consolidated No. 1, sec. 20, tp. 45, range 6, W. 4th mer.—Temporarily shut down
Western Consolidated No. 2, sec. 30, tp. 45, range 6, W. 4th mer.—Oil, abandoned
Wainwright-Dome, sec. 31, tp. 45, range 6, W. 4th mer.—Drilling
Wainwright-Petroleums, sec. 30, tp. 45, range 6, W. 4th mer.—Location

Oil and Gas Horizons. Great difficulty is experienced in correlating the strata penetrated in the various wells of Wainwright area. It is thought, however, that two oil and gas horizons are present, of which the higher seems to be in the base of the Colorado shales and is the oil and gas-producing horizons in British Petroleums Nos. 2 and 4 wells. The oil from the upper horizon has a specific gravity of 12° to 14° Baumé. The lower horizon is supposed to be in sands of Lower Cretaceous age and is the productive horizon in British Petroleums 3B, Edmonton-Wainwright, and Western Consolidated No. 2 wells. The oil has a gravity of about 19° to 20° Baumé. The higher horizon at the base of the Colorado shales failed to yield oil in these wells.

Analyses of Oil. An analysis of the oil from British Petroleums No. 4 well, by the Fuel Testing Division, Mines Branch, is as follows:

Sample taken at well, September, 1924
Specific gravity at 60°F. = 0·973
" " = 13·9° Bé.
Water................7·4 per cent (volume)
Sulphur...............1·98 per cent

Distillation range—	Per cent
Up to 150° C. (Naphtha)	—
150° to 300° C. (Illuminants)	12·9 (vol.)
300° C. and up (Lubricants)	68·2 (vol.)
Coke and residue oil	14·1 (wt.)

An analysis of oil from British Petroleums No. 3B well made by P. V. Rosewarne, Fuel Testing Division, Mines Branch, is as follows:

Sample taken from initial production of well

	Per cent
Specific gravity at 60° F. = 0·940	
" " = 18·9° Bé.	
Water	0·7
Sulphur	1·6
Distillation range—	
Up to 150° C. (Naphtha)	2·1 (vol.)
150° to 300° C. (Illuminants)	21·3 "
300° C. and up (Lubricants)	69·0 "
Coke and residue oil	10·9 (wt.)

Log[1] of British Petroleums No. 3 Well

Elevation: 2,304·3 feet
Location: L.S. 4, sec. 29, tp. 45, range 6, W. 4th mer.
Method of drilling: Rotary rig with core barrel used for part of log

	Feet
Surface material	0 to 130
Shale, dark grey	130 to 210
Sandstone, with hard layer on top	210 to 230
Shale, soft, grey	230 to 251
Sandstone, hard, grey	251 to 285
Shale, sand, grey	285 to 302
Shale, grey, sticky, sandy in part	302 to 343
Shale, grey	343 to 370
Shale, blue	370 to 383
Sandstone, hard, grey	383 to 386
Shale, coal fragments	386 to 412
Shale, grey, hard	412 to 479
Sandstone, hard	479 to 480
Shale, blue, soft	480 to 501
Limestone, hard. (Probably ironstone bands or sandstone)	501 to 504
Shale, grey	504 to 507
Limestone, hard. (Probably ironstone bands)	507 to 509
Shale, sandy, dark grey	509 to 580
Shale, grey, soft	580 to 588
Limestone, blue. (Probably ironstone)	588 to 589
Shale, blue	589 to 624
Shale, blue, hard	624 to 784
Shale, grey, hard	784 to 897
Limestone, hard. (Probably ironstone band)	897 to 898
Shale, grey, soft	898 to 997
Shale, blue	997 to 1,045
Shale, blue, hard	1,045 to 1,073
Limestone. (Probably ironstone band)	1,073 to 1,074
Shale, grey, hard	1,074 to 1,189
Shale, sandy, grey	1,189 to 1,239
Shale, black, pyrite	1,239 to 1,277
Shale, black, hard streaks	1,277 to 1,300

[1]Lcg supplied by British Petroleums, Ltd.

Log[1] *of British Petroleums No. 3 Well*—Continued

	Feet	
Shale, black, sandy. Gas	1,300	to 1,352
Shale, black, soft	1,352	to 1,427
Shale, sandy, dark grey. Gas	1,427	to 1,481
Shale, black, hard and soft alternating	1,481	to 1,657
Shale, dark grey. Glauconitic sand, 1,800 to 1,804 feet	1,657	to 1,804
Limestone. (Probably ironstone band)	1,804	to 1,804·5
Shale, black, sandy	1,804·5	to 1,820
Shale, sandy, with pyrite	1,820	to 1,836
Shale, black, hard	1,836	to 1,838
Limestone, hard. (Probably ironstone band)	1,838	to 1,838·5
Shale, grey, hard	1,838·5	to 1,852
Lime, sandy, hard, grey	1,852	to 1,852·5
Shale, black	1,852·5	to 1,879
Lime, sandy, hard	1,879	to 1,879·5
Shale, black, soft	1,879·5	to 1,895
Sand, hard	1,895	to 1,896
Shale, black, hard	1,896	to 1,903
Shale, black, sandy	1,903	to 1,931
Sand, blue-grey, hard	1,931	to 1,931·5
Shale, sandy, black	1,931·5	to 1,939
Sand, brown, soft, with shale partings. All saturated with oil. Gas	1,939	to 1,942
Shale, sandy, soft, brown, containing oil and gas	1,942	to 1,953
Sand, brown, soft, saturated with oil and gas	1,953	to 1,956
Shale, black, sandy layers	1,956	to 2,008
Lime, grey, soft. (Probably ironstone band)	2,008	to 2,009
Shale, hard, dark	2,009	to 2,021
Lime, grey, very hard. (Probably ironstone band)	2,021	to 2,022
Shale, black, hard	2,022	to 2,038·5
Lime, grey, hard. (Probably ironstone band)	2,038·5	to 2,039·5
Shale, black	2,039·5	to 2,056
Sand, coarse, white, soft. Bentonite band	2,056	to 2,058
Shale, black	2,058	to 2,074
Sand, blue	2,074	to 2,075
Shale, black	2,075	to 2,085
Shale, with streaks of soft, brown sand impregnated with oil. Gas	2,085	to 2,093
Shale, black, hard	2,093	to 2,096
Lime, grey, hard, with pyrite. (Probably ironstone bands)	2,096	to 2,096·5
Shale	2,096·5	to 2,098
Sand, soft, brown, impregnated with oil. Gas	2,098	to 2,106
Shale, sandy. Oil and gas	2,106	to 2,109
Sand, brown, soft. Oil and gas	2,109	to 2,111
Shale, brown, sandy	2,111	to 2,113
Shale, brown, sandy	2,113	to 2,118
Sand, showing oil	2,118	to 2,120
Sand, hard, showing oil	2,120	to 2,151
Sand, hard, shale partings	2,151	to 2,152
Shale, grey	2,152	to 2,155
Shale, grey, with some sandy streaks	2,155	to 2,157
Sand, hard, coarse	2,157	to 2,158
Shale, grey, sandy	2,158	to 2,160
Shale, grey, sticky	2,160	to 2,161
Sand, hard and coarse, grey	2,161	to 2,165
Sand, grey, with streaks of asphaltic material	2,165	to 2,166
Shale, brown, with streaks of asphaltic material	2,166	to 2,171
Shale, grey, sandy	2,171	to 2,178
Asphaltic material	2,178	to 2,183
Shale, grey, sandy, asphaltic material	2,183	to 2,188
Sand, hard, coarse	2,188	to 2,190
Sand, grey, with streaks of shale	2,190	to 2,200
Shale, grey	2,200	to 2,208
Coal	2,208	to 2,217
Shale, sticky, grey	2,217	to 2,222
Shale, black, with sand partings. Oil and gas	2,222	to 2,223·8
Lime. (A part of this was tested by the Borings Division, Geological Survey, showing it to be ironstone)	2,223·8	to 2,224·8

NOTE. The glauconitic horizon at 1,800 to 1,804 feet in this well correlates with a similar horizon at 1,684 to 1,688 feet in No. 1 B.P. well and at about 1,705 feet in Maple Leaf No. 1 well.

[1]Log supplied by British Petroleums, Ltd.

It is difficult to divide the well logs into stratigraphic horizons, but the following division is approximately correct for No. 3 well.

	Feet
Glacial material	0 to 130
Variegated beds and Birch Lake formation	130 to 285
Grizzly Bear formation	285 to 383
Ribstone Creek formation	383 to 580
Lea Park and Benton	580 to 2,100 (?) (approximately)
Lower Cretaceous	2,100 to (bottom of well).

Ribstone-Blackfoot Fold

Outcrops indicating the position of the Ribstone-Blackfoot anticline occur along the banks of Battle river and its tributaries Ribstone and Blackfoot creeks. Elsewhere the country is covered by a heavy mantle of drift which conceals the underlying sediments. Lines of levels run along definite stratigraphic horizons outcropping along Battle River valley from range 3, west of the 4th meridian, to slightly east of the Alberta-Saskatchewan boundary, and in the vicinity of Unwin on the Canadian Pacific railway indicate a northeast-southwest strike of the strata. The southeasterly dip of the east limb of the anticline is indicated by the outcropping of higher formations to the southeast. The contact of the Ribstone Creek and Lea Park formations on Ribstone creek, 2 miles from Battle river, has an elevation of approximately 1,900 feet, whereas the same contact in the Imperial Muddy Lake well, 50 miles southeast, is at an elevation of 1,340 feet, indicating a dip of about 500 feet or roughly about 10 feet to the mile. On the northwest flank of the anticline in sec. 4, tp. 46, range 3, W. 4th mer., the contact between the Grizzly Bear and Ribstone Creek formations is exposed on the north bank of Battle River valley at an elevation of 1,825 feet, and since the Ribstone Creek formation is at least 200 feet thick, the Ribstone Creek-Lea Park contact at this point cannot be at a higher elevation than 1,625 feet. The dip northwest, therefore, from the Ribstone Creek-Lea Park contact on Ribstone creek is about 275 feet in 12 miles, or approximately at the rate of 23 feet to the mile. This is the average value of the dip from the crest of the anticline to the axis of the small syncline to the northwest, and the dip on the flank of the anticline is probably considerably higher.

Oil and Gas Prospects. A water well 315 feet deep, on the farm of Mr. Garton, sec. 24, tp. 46, range 1, W. 4th mer., gave at 290 feet a flow of gas sufficient to supply fuel for Mr. Garton through the winter of 1923-24. On sec. 24, tp. 48, range 28, W. 3rd mer., on Mr. Charles Marren's farm, there is a supposed oil seepage in a water well. The writer examined this seepage in the summer of 1926 and oil in considerable quantity was undoubtedly present. The water was pumped for about an hour, after which time it was presumably lowered below the casing in the well and a couple of pails of a mixture of water and oil were secured. Upon stirring, the oil readily separated from the water and about a third of a pail of light amber coloured oil was obtained. A test of this oil showed that it was very light gravity and consisted principally of kerosene and gasoline and hence was not what would be expected from a seepage. However, since the oil is present in considerable quantity it hardly can be derived from an unknown outside source. This supposed seepage is on the northeast extension of the Ribstone-Blackfoot anticline, but its position with reference to the crest of the structure is unknown.

Since the Ribstone-Blackfoot anticline is a subsidiary fold on a much broader anticline, the crest of which corresponds to the local structure, there is no reason to assume that the major anticlinal conditions have not been effective in concentrating oil and gas toward the crest of the structure and that this concentration would be greatly aided by the local structure. Outcrops on the northeast or northerly extension of the Ribstone-Blackfoot anticline are very scarce and are not such that definite information regarding structure can be obtained from them. On Big gully, Saskatchewan, marine sandstones outcrop from tp. 51, range 27, W. 3rd mer., to tp. 49, range 23, W. 3rd mer. These are thought to be a marine phase of the Ribstone Creek formation.

In the Imperial Ribstone No. 1 well drilled on sec. 5, tp. 44, range 1, W. 4th mer., a large flow of gas was encountered at a depth of about 1,400 feet. Between depths of 1,870 and 1,900 feet about 8 feet of oil-saturated sand was struck, but exhaustive bailing tests only yielded 4 to 5 barrels of 18 Baumé oil a day. The failure of this sand to produce a larger quantity of oil is ascribed to two conditions: (1) absence of a strong gas pressure in the oil stratum; and (2) fineness of the sand. It seems reasonable to conclude that at points structurally higher, greater gas flows might be obtained and if coarser sands should exist favourable conditions for commercial oil production would be present. If no closure is present along the anticline in a northeast direction the fineness of the sand would effectively prevent migration of oil. Since the presence of an oil stratum is now proved, production of oil on this anticline would be expected on higher structural parts if coarser sand lenses occurred within the fine-grained sand horizon. The conditions within the oil-saturated horizon can only be determined by drilling, but it is considered that further drilling is justified by the finding of favourable indications in the Imperial well.

McMURRAY-ATHABASKA AREA

By G. S. Hume

References: McConnell, R. G.: Geol. Surv., Canada, Ann. Rept., vol. V, pt. D (1893).
McLearn, F. H.: Geol. Surv., Canada, Sum. Rept. 1916.
Dowling, D. B., Slipper, S. E., and McLearn, F. H.: Geol. Surv., Canada, Mem. 116 (1919).
Ells, S. C.: "Bituminous Sands of Northern Alberta"; Mines Branch, Dept. of Mines, Pub. No. 632 (1926).

(*See* Figure 11)

PHYSIOGRAPHY

Athabaska river is the largest of the southern members of the Mackenzie River system. It rises in the mountains to the west, in the region of Yellowhead pass, and flows northeastward across the plains area almost to the eastern edge of the Cretaceous rocks in the vicinity of McMurray, and from there northward to Athabaska lake. From the town of Athabaska to McMurray, the river flows through a valley 300 to 500 feet deep, and is marked by a number of rapids. Below McMurray the valley is broad with gentle slopes and a low gradient, but above McMurray the valley is narrower with more abrupt slopes and in part is gorge-like. Away from the river the region as a whole, according to McLearn,[1] consists of "a number of plateau-like surfaces which, along the river, become lower in altitude northward. They are underlain by gravel, sand, and clay, and are poorly drained, with large areas of swamp and muskeg." The country as a whole is wooded and rock exposures occur only where streams or rivers have cut valleys through the surface drift.

STRATIGRAPHY

Table of Formations[1]

			Thickness in feet	
		Drift		Gravels, sand, and clay
Cretaceous	Montana?	LaBiche formation	1,100	Grey and black shales with layers of concretions at various horizons. Marine
	Colorado	Pelican sandstone	35	Crossbedded sandstone, conglomeratic at top. Central part continental. Top and base marine
		Pelican shale	90	Black shale. Marine
	Lower Cretaceous	Grand Rapids formation	280	Sandstone. Upper part continental, with thin coal seams. Lower part concretionary, carrying marine fossils
		Clearwater formation	275	Soft, grey shale, black shales, grey and green sandstones with some concretionary layers. Marine
		McMurray formation	110 to 180	Sandstone, massive and crossbedded. In certain places conglomeratic and more rarely clay and shale are found at the very base. Parts are highly impregnated with bitumen. Continental
		Unconformity		
Devonian			220+	Limestones

[1] McLearn, F. H.: Geol. Surv., Canada, Sum. Rept. 1916, p. 146.

STRUCTURE

The structure is described by McLearn[1] as follows:

"The structure from Athabaska to point Brûlé is simple, consisting of a half-fold or homocline with a low south dip. From Grand Rapids to Pelican rapids the rate of dip is about 5½ feet per mile, and north of Grand Rapids the dip flattens considerably. But south of Pelican rapids to carry the strata to their position in the Athabaska bore-hole requires a dip of about 10 feet per mile. This greater dip below may be due, in part, to the southwest course of the river near Athabaska. Indeed the true dip is probably west of south, rather than directly south, and hence steeper on sections in the former than in the latter direction.

The section exposed between point Brûlé and McMurray is almost at right angles to the above and shows a low anticlinal structure (Athabaska anticline). The axis lies near Crooked rapids and the dips on either side are exceedingly low, only about 3 or 4 feet per mile.

Below McMurray the land on either side of the valley is low, so that the top of the McMurray formation soon ceases to be exposed in the cliffs. Since the bedding of this formation is not reliable for structural purposes, the dip cannot be accurately determined there. It probably does not depart very far from the horizontal, but may have a slight north or northeast dip. This section is best adapted for demonstrating the structure of the limestone and the nature of the unconformity.

In addition to sharing with the Cretaceous sediments of the above described Athabaska anticline and the long half-fold to the southwest, as a major structure, the limestone is warped into low domes of much smaller magnitude."

Drilling has been done on some of these minor warpings, but the structures are too small to be important as structures suitable to contain commercial amounts of oil or gas.

OIL AND GAS HORIZONS

The McMurray formation, composed of massive and crossbedded sandstones, is to a considerable extent impregnated with bitumen. The bituminous content varies from place to place and even in different layers of the same exposure. The richest parts contain more than 20 per cent bitumen, but the average bituminous content is considerably less. The bituminous sands outcrop in thick sections in many places along Athabaska river from Boiler rapids to some distance below McMurray, and on many of the tributary streams. Southward the dip carries them below younger deposits. At Pelican, about 70 miles southwest of McMurray, they were encountered in a drill-hole at a depth of approximately 750 feet.

It has been assumed that the bituminous sands represent "an upwelling of petroleum to the surface . . . . . . but the more volatile and valuable constituents of the oil have long since disappeared."[2] On such an assumption it was considered that oil might be found away from the outcrop and under suitable cover. To test this idea several wells were drilled, but in the central and southwest part of the district "no liquid oil has so far been found, nothing more than the asphaltum or at best semi-liquid maltha content of the tar sands."[3] In a well drilled by the Geological Survey in 1897,[4] at the mouth of Pelican river on the Athabaska, a strong flow of gas was encountered at the bituminous sand horizon and tarry-like material

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[1]McLearn, F. H.: Geol. Surv., Canada, Sum. Rept. 1916, p. 148.
[2]McConnell, R. G.: Geol. Surv., Canada, Ann. Rept., vol. V, pt. D, p. 66 (1893).
[3]McLearn, F. H.: Geol. Surv., Canada, Sum. Rept. 1916, p. 149.
[4]Dawson, G. M.: Geol. Surv., Canada, Ann. Rept., vol. XI, p. 28 (1901).

filled the bottom of the hole to such an extent that further drilling was impossible. Other evidence of natural gas in this area is afforded by gas seepages, and according to McConnell[1]:

"The most important natural gas spring in the district occurs on the Athabaska at the mouth of Little Buffalo river (point Brûlé). The gas here forces its way up through the tar sands, through 250 feet of the Clearwater shales, and issues from the surface in numerous small jets distributed over an area 50 feet or more in diameter. Some of the jets burn steadily when lighted until extinguished by heavy rains or strong winds, and afford sufficient heat to cook a camp meal.

A second spring was noticed on the left bank of the Athabaska about 13 miles below the mouth of Pelican river. The volume of gas escaping here is less than at the mouth of Little Buffalo river and in order to reach the surface it is obliged to penetrate 570 feet of shales and sandstones which here overlie the tar sands." "Explorations to date indicate that the McMurray formation (tar sands) is the only source of gas that promises to be of commercial importance."[2]

The most prominent structure, according to McLearn,[3] is the low, broad Athabaska anticline and the long half-fold (homocline) to the southwest. Evidence from gas seepages and drilled wells led McLearn to conclude that:

"The anticline and half-fold as far down the dip as Pelican are gas-bearing rather than oil-bearing" (Only liquid oil is here considered). . . . . . . "As far as the homoclinal structure is effective, ... the possibilities for the occurrence of oil southwest of Pelican (i.e. down the dip) are better than for its occurrence north or northeast of Pelican (i.e. up the dip)."

In the northeastern part of the district, according to McLearn:

"The wells of the Athabaska Oils, Limited, opposite the mouth of Dover river, ... record the presence of oil, although of low gravity. The wells are all shallow and the tar sands themselves outcrop so that the conditions of cover do not exist."

The oil at this place has collected

"In a hollow of the Cretaceous-Devonian unconformity. This depression is 12 miles long in the direction of the river and opposite the mouth of Dover river, at the wells of the Athabaska Oils, Limited, has a depth of about 85 feet below the river and about 140 feet below the limestone rim."

This is an interesting occurrence of oil since it records the presence of oil in a syncline, the strata being "dry" as far as the presence of water is concerned.

A sample of gas collected from the Pelican well by Elworthy[4] in 1916 and analysed by the Mines Branch, gave the following analysis:

		Per cent
Methane	CH_4	83·5
Carbon dioxide	CO_2	1·0
Oxygen	O_2	2·9
Nitrogen	N_2	12·6
Calorific value per cub. ft. at 60° F. and 760 mm		850 B. Th. U.

As will be noted from the above analysis the gas is dry, i.e. contains no gasoline.

FUTURE PROSPECTS

The discovery in other areas of oil in Lower Cretaceous sands occupying the same position stratigraphically as the Lower Cretaceous of the Athabaska area has led to the hope that sands comparable in thickness to the McMurray formation will be found over a large area at some distance

[1] McConnell, R.G.: Geol. Surv., Canada, Ann. Rept., vol. V, pt. D, p. 64 (1893).
[2] McLearn, F. H.: Geol. Surv., Canada, Sum. Rept. 1916, p. 151.
[3] McLearn, F. H.: Geol Surv., Canada, Sum. Rept. 1916, p. 148.
[4] Elworthy, R. T.: "Natural Gas in Alberta"; Mines Branch, Dept. of Mines, Canada, Pub. No 616A, p. 21 (1924).

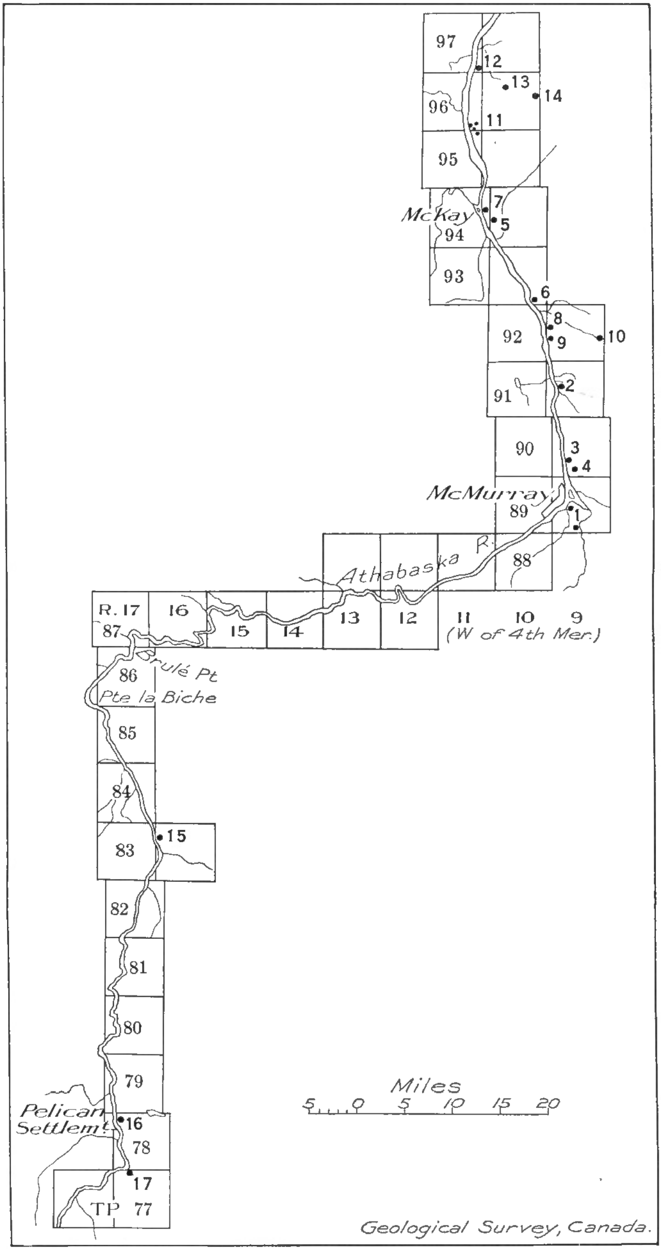

Figure 11. McMurray-Athabaska area, showing positions of wells drilled for oil and gas:

1, Northern Alberta Exploration Co.; 2, 3, and 4, Athabaska Oil and Asphalt Co.; 5 and 6, Fort McKay Oil and Asphalt Co.; 7, 8, 9, and 10, A. von Hammerstein; 11, Athabaska Oils, Ltd. (8 wells); 12, Spokane-Athabaska Oil Co.; 13 and 14, Alcan Oil Co.; 15, Edmonton Athabaska Oil Co., Ltd. (2 wells); 16 and 17, Pelican Oil and Gas Co., Ltd.

from Athabaska river. According to McLearn[1] "the Lower Cretaceous includes . . . . . . in the Athabaska section the McMurray tar sands, Clearwater formation, and Grand Rapids formation." These formations hold the same stratigraphic position in the Athabaska section as do the sands between the base of the Benton and the top of the Palæozoic limestones in Wainwright area. Other than that both are of Lower Cretaceous age no definite correlation is at present possible. In Athabaska area the Clearwater formation, 275 feet thick, is, according to McLearn, entirely marine and "the lower concretionary member" of the Grand Rapids sandstone "is marine," although the "upper part is of subaerial origin as demonstrated by the presence of small coal beds."[2] In Wainwright area the Lower Cretaceous sediments have been considered to be entirely non-marine, although no proof of this is available. The non-marine character is inferred from the presence of a number of coal seams logged in various wells. Coal and carbonaceous shale 9 feet thick were found in British Petroleums No. 3 and No 3B wells, not far below what is considered to be the base of the Colorado shale. It is possible the coal is of about the same age as the coal seams in the upper part of the Grand Rapids formation, but such a correlation is questionable and unreliable. If there are no marine shales in the Lower Cretaceous of Wainwright area, then the marine phases represented by the Clearwater formation and the lower part of the Grand Rapids formation on Athabaska river must thin out entirely before reaching Wainwright area. If this is the situation, the marine phase in Athabaska area must have a shore phase toward the southeast where there would be some alternation of marine shales and sands, and such a place under suitable structural conditions would be a very favourable location for oil accumulations. It has already been demonstrated by British Petroleums No. 3B well, in Wainwright area, that the Lower Cretaceous contains oil of economic importance, so that the area northwestward should offer equally as favourable, if not more favourable, opportunities for oil, provided, of course, other conditions such as structure, etc., are equally as good as in Wainwright area.

According to McLearn,[3] "the Colorado group includes . . . . . . in the Athabaska valley the Pelican shale, Pelican sandstone, and Lower LaBiche formation," whereas the Upper LaBiche is "of Montana age." The Pelican shale, Pelican sandstone, and Lower LaBiche are thus of the same general age as the Benton in Wainwright area. The Lea Park formation in Wainwright area is Montana in age (Lower Pierre) and possibly is a correlative of the Upper LaBiche, since both are marine shales. The combined thickness of the Pelican shale, Pelican sandstone, and LaBiche formation is less than the thickness of the Lea Park and Benton in Wainwright area, and part of the Pelican sandstone in Athabaska area is non-marine. Subaerial conditions seem to have prevailed farther west as the Pelican sandstone,[4] only 35 feet thick on Athabaska river, is correlated with the Dunvegan sandstone on Peace River area, 530 feet thick. Thus, westward from Athabaska area there is an appreciable thickening of the

[1] McLearn, F. H.: "Investigations in the Gas and Oil Fields of Alberta, Saskatchewan, and Manitoba"; Geol. Surv., Canada, Mem. 116, p. 127.
[2] McLearn, F. H.: "The Athabaska River Section"; Geol. Surv., Canada, Sum. Rept. 1916, p. 148.
[3] McLearn, F. H.: "Investigations in the Gas and Oil Fields of Alberta, Saskatchewan, and Manitoba"; Geol. Surv., Canada, Mem. 116, p. 30.
[4] McLearn, F. H.: "Cretaceous, Lower Smoky River, Alberta"; Geol. Surv., Canada, Sum. Rept. 1918, pt. C, p. 4.

subaerial deposits, whereas southeastward there is an increase in the thickness of marine deposits. The situation thus suggests that possibly during Colorado time a sea continuously occupied Wainwright area, with a shore-line for part of the time southeast of Athabaska area, where subaerial deposits were formed, and hence it is possible that somewhere between Athabaska and Wainwright areas there may be alternations of marine shales and sands, as should occur towards the shore-line which represents the southeastern edge of the subaerial deposits of the Pelican sands. Oil and gas have already been found in Wainwright-Viking area in sands near what is considered to be the base of the Colorado. The Pelican sands in Athabaska area are only 90 feet above the base of the Colorado which consists of marine shales. The Pelican sands thus hold a stratigraphic position somewhat similar to that of the sands from which oil and gas have been produced in Wainwright-Viking area, although it cannot be said that they represent the same horizon. Their presence, however, justifies the expectation that sand beds in the marine formation may be found over a wide area between Wainwright and Athabaska areas. Such sand beds under favourable structural conditions would offer favourable locations for oil and gas accumulations.

As indicated above it is possible that two oil horizons may underlie large areas between Athabaska and Wainwright districts. One horizon is in the Colorado and the other in the Lower Cretaceous. At any location in this area there is a possibility that both horizons may be present, but the thickness and oil content are likely to vary widely. Drilling to test the possibilities of the region should be done only where there is a local structure of sufficient magnitude to cause oil or gas accumulations.

The McMurray, a non-marine formation, is not likely to maintain over a wide extent the thickness displayed on Athabaska river, for part of this formation at least is a delta deposit that apparently thins to the southwest to a very small thickness, as is shown by the log of the Pelican well. Its extension in other directions is unknown. It is believed that the oil that gave rise to the bituminous sands migrated to the sands in which it is now found. There is a much greater development of marine beds in the Lower Cretaceous in Athabaska area than in Wainwright field and a location on a favourable structure at some distance from Athabaska river would seem to offer the best possibilities to test what is considered to be the better of the two horizons in which oil has been found and which have been developed to some extent in Wainwright field. Wells located where there is no local structure are not likely to be successful in finding oil or gas in commercial quantities.

ORIGIN OF THE OIL IN THE "TAR SANDS"

The presence of oil in the bituminous sands of the McMurray formation is well known. McConnell[1] regarded the bitumen as derived from the underlying Devonian limestones, as is shown by the following sentence from his report: "The amount of petroleum which must have issued from the underlying limestones . . . . . . cannot now be estimated, as the conditions of oxidation and the original composition of the oil are unknown."

The contact of the Palæozoic limestones with the overlying McMurray formation is an erosion surface and many cracks and joints in the lime-

[1] McConnell, R. G.: "Report on a Portion of the District of Athabasca River North of Lesser Slave Lake"; Geol. Surv., Canada, Ann. Rept., vol. V, pt. D, p. 65 (1893).

stone are filled with bitumen. This has been interpreted as meaning that the bitumen came from below, but it seems more reasonable to suppose the cracks and joints were filled by seepages from above. The limestone as a whole is dense, white, and free from bitumen. It is difficult to understand how such a great migration of oil could take place unless along fissures. If a migration from below did take place then there must be a reservoir in the limestones or below them from which the oil was derived and of which evidence should still be available. In the vicinity of McMurray two wells, of which cores were obtained, were drilled through the limestones in the search for salt.[1] The records of two wells drilled to the granite at the mouth of Horse creek at McMurray are also available. In none of these wells was there any indication of an oil reservoir from which the oil in the bituminous sands could have been derived. In the log of the salt well at McMurray there is a sharp change at a depth of 500 feet, from massive, mottled limestone to gypsum and anhydrite, which with salt and thin interbedded shales, continue for 185·5 feet (depth of 685·5 feet), at which point drilling was stopped. No indications of oil were found. In the log of salt well No. 2 drilled at Waterways the limestone-anhydrite[2] contact was found at a depth of 415 feet. An alternation of gypsum, anhydrite, and a slight amount of salt with dolomite beds continued to a depth of 782 feet and at 785 feet the Precambrian was encountered. As in No. 1 well no indications of oil were found. Thus it is highly improbable that the oil now found in the bituminous sands came from a reservoir either in the limestones or below them.

As indications of oil occur in Lower Cretaceous strata in Wainwright and other areas it is much more reasonable to assume that the bitumen in the bituminous sands originated in the Lower Cretaceous strata of which the McMurray formation forms a part and that any bitumen now filling cracks and joints in the upper part of the Devonian limestones is due to downward seepage under gravitational influences. Such a conception of origin implies that the Lower Cretaceous strata have been capable of forming a very large amount of petroleum and that the bituminous sands are the residue left as a result possibly of evaporation of the lighter constituents of the oil at the outcrop, the oxidation of the oil, and changes due to contact with sulphate waters, etc.

In a well drilled at the mouth of Horse creek the top of the limestone has an elevation of about 800 feet above sea-level,[3] whereas at Pelican, 75 miles southwest, the elevation of the top of the limestone is about 400 feet. The dip of the surface of the limestone is, thus, about 400 feet in 75 miles, or slightly more than 5 feet a mile. This is not the dip of the Palæozoic strata, since the top of the limestone is an erosion surface. In the Pelican well the part of the McMurray formation represented by sands is very thin, whereas it is 110 to 180 feet in the Athabaska section. The dip of the Cretaceous beds would be the dip of the limestone surface, i.e. about 5 feet a mile, if the sands at Pelican in which heavy oil was found were equivalent to the basal beds of the McMurray formation at McMurray. If, however, the oil-bearing beds at Pelican are equivalent to the highest

[1] Second Ann. Rept. of the Min. Res. of Alberta, 1920, pp. 111-112.

[2] Fourth Ann. Rept. of the Sci. and Indust. Res. Coun. of Alberta, 1923, p. 50.

[3] Investigations in the Gas and Oil Fields of Alberta, Saskatchewan, and Manitoba"; Geol. Surv., Canada, Mem. 116, p. 83.

beds of the McMurray formation at McMurray the dip would be about 8 feet a mile. It may be safely concluded, therefore, that the regional dip between McMurray and Pelican is a southwest dip at a rate of between 5 and 8 feet a mile. Such a regional dip could cause the migration of oil toward the outcrops if there were any movement of water up the dip. Assuming that the hydraulic theory is applicable, water would enter Lower Cretaceous rocks in the foothills area and move slowly toward the lower elevations of the outcrops of these formations in the plains area. The movement would be eastward or northeastward toward the outlet at the outcrops of the Lower Cretaceous on Athabaska river and any oil and gas in the water-bearing horizons would be flushed towards the outcrop and the bituminous sands would result from the alteration of oil at the outcrop due to the loss of the lighter constituents by evaporation, to oxidation of the oil, and, possibly, to changes resulting from the contact of the oil with sulphate-bearing waters. It should be remembered, also, that a migration in Athabaska region would be up the dip, that is in the direction that oil and gas would tend to move on account of their buoyancy and any effect from this cause would aid the flushing effect due to moving waters. Huntley[1] explained the bituminous sands as due to oil produced in the "Dakota" formation as a result of deformation and caused to migrate by the flushing effect of water. No flora of the typical Dakota formation has yet been found in Canada,[2] so that all Huntley's contentions may not necessarily hold, but it is interesting to note that he regards the concentration of oil at the outcrops on Athabaska river as having resulted from the flushing effect of underground water movement.

EASTERN PEACE RIVER AREA, ALBERTA

By C. S. Hume

References: McLearn, F. H.: Geol. Surv., Canada, Sum. Rept. 1917, pt. C; Geol. Surv., Canada, Sum. Rept. 1918, pt. C.
Dowling, D. B., Slipper, S. E., and McLearn, F. H.: Geol. Surv., Canada, Mem. 116 (1919).

(*See* Figure 12)

PHYSIOGRAPHY

Peace river flows from the British Columbia-Alberta boundary eastward to the town of Peace River and from there northward to Vermilion. At the town of Peace River the river valley is about 800 feet below the level of the bordering plateau country, but the depth of the valley gradually decreases northward, until at Vermilion chutes where limestones of Devonian age form ledges in the river the banks are quite low. Along the part of the river between the towns of Peace River and Vermilion, the "Ramparts of the Peace" occur, the steep valley walls being formed of beds of sandstone. West of Dunvegan, sandstone beds of the Dunvegan formation form high cliffs which in places weather into castellated forms, but in other parts the valley sides are more rounded, and in places terraces occur. The country away from the river is plateau-like, part of it is open prairie, but the larger part is wooded. At some distance from Peace river, the tributary streams flow on the prairie level, but close to the river they have cut deep valleys.

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[1] Huntley, L. G.: "Oil, Gas, and Water Content of Dakota Sand in Canada and United States"; Trans. Am. Inst. Min. Eng., vol. 52, p. 343 (1915).
[2] McLearn, F. H.: "Peace River Canyon Coal Area, B.C."; Sum. Rept. 1922, pt. B, p. 6.

STRATIGRAPHY

Table of Formations[1]

				Description
Cretaceous	Montana	Wapiti	900 feet +	Thick, massive, crossbedded sandstone, with some grey to dark carbonaceous shales. Thin coal seams, one of which is 180 feet, and another 580 feet above the base of the formation. Continental
	Colorado	Smoky River 300 feet	Upper shale	Dark, friable shale with thin beds of sandstone near the top. Ironstone concretionary bands
			Bad Heart sandstone	Coarse sandstone weathering reddish brown, 10 to 25 feet thick. Marine
			Lower shale	Thin-bedded sandstone and shale at the top, below which are dark, friable shales and paper-thin carbonaceous shales with concretions. Marine
		Dunvegan	440 feet in the Smoky River section (estimated) 530 feet in the Peace River section	Massive, concretionary, and crossbedded sandstone, with shale, alternating with thick zones of thin-bedded sandstone and shale. Some thin coal seams in the continental deposits. Subaerial and marine
		St. John	560 feet (estimated) on Smoky river, much thicker in the western sections of Peace river	Dark, friable, and paper-thin carbonaceous shale, with some ironstone bands and concretions
	Lower Cretaceous	Peace River	Upper sandstone 130 feet (max.)	Massive, white to cream-coloured, crossbedded sandstone with a discontinouus lignite seam. The upper sandstone thins northward on Peace river, where the upper part is replaced by bedded sandstone and shale of marine origin
			Middle shale 30 feet	Blue, black, friable shale. Marine (?)
			Lower sandstone 160 feet (max.) Thins northward	Top is massive and crossbedded with large, spherical concretions passing downwards into bedded sandstones and shales which are marine. The top may be subaerial
		Loon river	1,100 feet below town of Peace River. May be thicker on Smoky river	Dark blue to dark grey, friable shale with some ironstone concretions. Where penetrated by wells near town of Peace River sediments are arenaceous near the base of formation. Where exposed the shale is marine
Palæozoic limestone series				

[1]McLearn, F. H.: Geol. Surv., Canada, Sum. Rept. 1918, pt. C, p. 2.

STRUCTURE

The structure within Peace River area has been described by McLearn[1] as follows:

"Eastward to several miles below St. John the structure seems to be almost flat. Near the North Pine river and downstream the structure steepens with an east dip, so as to bring the Dunvegan sandstone almost to river-level a few miles below the mouth of Kiskatinaw river. From here to the bend at Montagneuse river the structure is flat. The section is east-west to this point. From the mouth of Montagneuse river southward a north-south section is cut and here a small south dip is revealed. Where the river turns east past Dunvegan an east-west section is again exposed and flat structure indicated. Beyond the mouth of Burnt river the Peace turns to the northeast and so continues to Peace River. Here the strata rise downstream and the inclination near Peace River amounts to some 40 feet per mile to the south.

From Peace River northward a north-south section is exposed and at first reveals a south dip of 10 feet per mile. In the vicinity of No. 2 well and extending to Tar island the structure is practically flat, although there is probably a slight rise of 1 or 2 feet per mile. Downstream from here there is a slight dip north of a few feet per mile to a point about 10 miles below the mouth of Cadotte river. Beyond this there is a gentle rise and a final flattening out. The above structure applies to that observed above river-level. It is possible, however, owing to the thinning of the Loon River shales northward and the consequent rise of the limestone contact, that the lower strata below river-level, which would be reached by drilling, would be slightly tilted southward as compared with the overlying strata above river-level. This applies particularly to the section north of Tar island."

To the south of Peace River, on Smoky river, McLearn[2] describes the major structure as:

"A south dipping homocline or half-fold, the north side of a large synclinal basin whose axis is south of Bezanson." "No undulating structure of anticline and syncline is superposed on the major structure. There is considerable change of dip, however, and a few miles above the mouth of the river a rather poorly defined terrace. Details of the dip are given in the table below. Attention is called to the almost flat structure revealed by the east-west section from Bad Heart river to the great bend one mile east of the east boundary on range 25; this shows that the general strike is practically east-west."

	Dip to south Feet per mile
Mouth (Smoky river) to 1 mile south of north boundary of tp. 81	12
Latter to south boundary of tp. 81	Flat
" middle of tp. 79	25
" south of Smoky river	50
" south boundary of tp. 77	20
" within one mile east boundary range 25	12
Mouth Bad Heart river to Puskwaskau river	60
Latter to horseshoe bend above Puskwaskau river	15
" 2 miles below Kleskun creek	30
" middle of tp. 72	45
" ferry below Bezanson	60
	Dip to east Feet per mile
Mouth Bad Heart river to 1 mile east of east boundary range 25	1

From this it would appear that the structure in Smoky River area, as well as along Peace river, is very gentle and nowhere has a dip of as much as one degree been noted. Since from the town of Peace River northwards the dip is southward this southward dip is probably a continuation of the southward dip noted in Smoky River area. North of Tar island, on Peace river, there is a northward dip of a few feet a mile, so that the crest of this broad structure is somewhere in the vicinity of Tar island, although the strata at this place are practically flat. The crest of the structure is, thus,

[1] McLearn, F. H.: Geol. Surv., Canada, Sum. Rept. 1917, pt. C, pp. 18,19.
[2] McLearn, F. H., Geol. Surv., Canada, Sum. Rept. 1918, pt. C, p. 5.

probably quite broad, but it is interesting to note its occurrence in this locality in view of the fact, according to Camsell[1]:

"A spring of natural gas is situated at Tar island on Peace river about 25 miles below Peace River crossing. The gas rises with salt water and some tar among the gravel and boulders at the upper end of the island. The flow of gas was roughly calculated to be about 3 or 4 cubic feet per minute."

The occurrence of gas and tar at this point may be due to the broad structure already described.

OIL AND GAS HORIZONS

In 1917 oil was struck in No. 2 well of the Peace River Oil Company, about 15 miles below Peace River. The oil, according to McLearn,[2] occurs in two sandstone horizons "near the base of the Loon River and not far above the limestone contact." The upper sandstone was encountered from 842 to 948 feet in the drill hole.

"Above 852 feet this bed yielded gas; from 852 to 905 feet it contained a highly viscous oil; from 905 to 910 feet it carried salt water; and from 910 to 948 feet was firmly cemented and barren of oil, gas, or water. Below this is a 14-foot shale bed, followed below from 962 to 1,032 feet by a second oil sand. This is impregnated with oil of a somewhat better quality. This horizon would produce a few barrels per day."

Also, according to McLearn:

"Oil of similar gravity was found at the corresponding horizons in the No. 1 well 1½ miles downstream. The two sandstones are of less thickness here and the shale between thicker. The thinning of these oil sands northward no doubt limits the possibilities of exploration in that direction, since with their disappearance there would be no reservoir to contain oil."

In the Smoky River section McLearn[3] found no structure especially favourable for oil. He described a terrace in township 81, range 23, but with low dip on the north side. This is the only structure in this area that approaches a suitable structure for oil or gas accumulation, but the dips are so gentle that its value is rather doubtful.

Since the drilling of the wells by the Peace River Oil Company, a well was completed in 1923 by H. L. Williams and Company, Limited, on SE. ¼ sec. 11, tp. 85, range 21, W. 5th mer., and a depth of 2,810 feet was reached. The Devonian limestone is reported to have been encountered slightly above a depth of 1,400 feet and below this limestone and shale of Palæozoic age occurred to the bottom of the hole. No flows of oil or gas were reported from the Palæozoic rocks. In 1916, according to Camsell:[4]

"At Vermilion chutes a drill-hole was driven to a depth of 860 feet, but at that depth an accident happened to the stem of the drill which prevented the hole being driven any farther and drilling ceased without having struck oil. The rocks cut in this drill-hole are Devonian limestones and shales which have a slight dip to the westward. The upper beds are porous and impregnated with bitumen, and at two or three points in the neighbourhood heavy black oil comes to the surface in springs."

Thus, drilling to date in Peace River area has shown the presence of oil in sandstone beds at the base of the Loon River formation of Cretaceous age and also the presence of oil has been recorded in certain places in the upper part of the Devonian. No well so far drilled has, however, found oil in commercial quantities.

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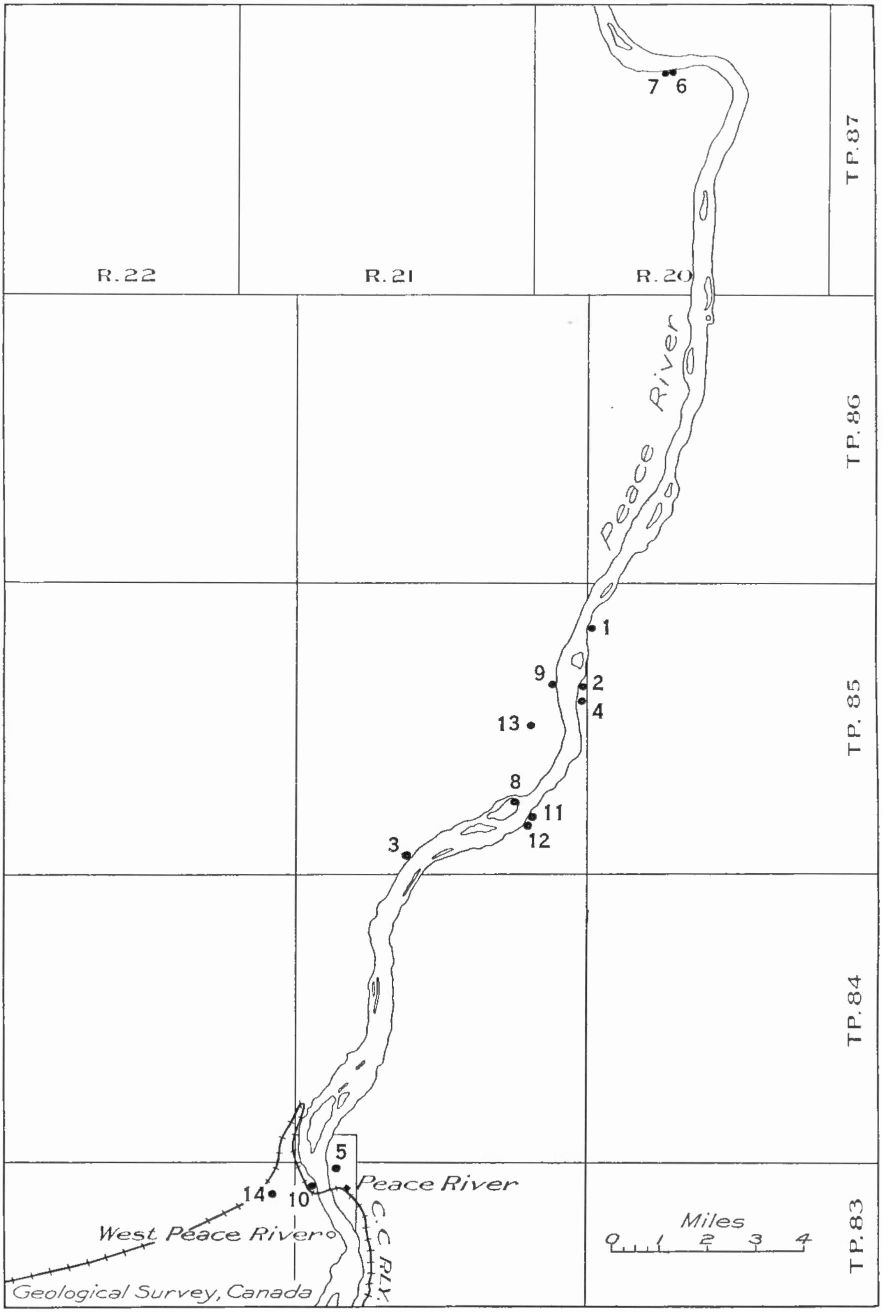
[1] Camsell, C.: Geol. Surv., Canada, Sum. Rept. 1916, p. 148.
[2] McLearn, F. H.: Geol. Surv., Canada, Sum. Rept. 1917, pt. C, p. 19.
[3] McLearn, F. H.: Geol. Surv., Canada, Sum. Rept. 1918, pt. C, p. 6.
[4] Camsell, C.: Geol. Surv., Canada, Sum. Rept. 1916, pp. 144-145.



F'gure 12. Eastern Peace River area, Alberta, showing positions of wells drilled for oil and gas; numbers designate the wells as given in the table, page 103.

Character of the Oil. A sample of oil from well No. 2 Peace River Oil Company, collected by F. H. McLearn and analysed by the Mines Branch, gave the following results:[1]

Specific gravity at 60° F.	981
Distillation test—	
Below 150° C.	2 % by volume naphtha
150° to 200° C.	4·87
200° to 250° C.	5·3
250° to 300° C.	56·2
300° to 325° C.	5·2
Residue and loss	26·5 %

According to McLearn,[2] "the oil from Peace River 'cracks' at abnormally low temperatures. This phenomenon begins at 200 degrees and is particularly active between 250 and 300 degrees."

FUTURE PROSPECTS

The crest of a broad structure occurs in the vicinity of Tar island and it is surely more than a coincidence that a seepage of tar and gas occurs on Tar island and that some oil was found in suitable sandstone horizons in the Loon River formation in wells drilled in this area. McLearn[3] has pointed out:

"As far as structure is . . . . . . effective (in concentrating oil) it should be noted that it is of a gentle nature north of the wells (Peace River Oil Company), with very low dips. The conditions obtaining at the wells, therefore, might be expected to prevail over a considerable area from the wells north, limited in that direction more particularly by the wedging out of the sandstones."

Since, however, the structure is so gentle the results from the wells already drilled may be taken as a fair indication of what might be expected to be found by drilling over a much wider area. From what is at present known of the structure no area more favourable than the one which has been tested can be outlined. It is unfortunate that more pronounced folding does not exist in this area, for, excepting the structure, other conditions appear favourable for oil.

No.	Well	Location					Depth
		L.S.	Sec.	Tp.	Range	Mer.	Feet
1	Peace River Oil Co., No. 1	4	31	85	20	5	1,136
2	Peace River Oil Co., No. 2	16	24	85	21	5	1,125
3	Peace River Oil Co., No. 3	6	4	85	21	5	1,282
4	Peace River Oil Co., No. 4	9	24	85	21	5	305
5	Peace River Petroleum Ltd., No. 1	R.L. 9	31	83	21	5	1,162
6	Peace River Pertoleum Ltd., No. 2	9	28	87	20	5	897
7	Peace River Petroleum Ltd., No. 3	9	28	87	20	5	890
8	North Pacific Oil Co.	10	11	85	21	5	850
9	Tar Island Oil and Gas Co.	14	24	85	21	5	1,087
10	Victory Oil Co., No. 1	11	31	83	21	5	1,807
11	Canadian Petroleum Ltd., No. 1	SE. ¼	11	85	21	5	1,275
12	Canadian Petroleum Ltd., No. 2	SE. ¼	11	85	21	5	3,008
13	H. L. Williams	SE. ¼	23	85	21	5	—
14	P. M. Oil Co.	7	36	83	22	5	130

[1] McLearn, F. H.: Geol. Surv., Canada, Sum. Rept. 1917, pt. C, p. 19.
[2] McLearn, F. H.: Geol. Surv., Canada. Sum. Rept. 1918, pt. C, p. 6.
[3] McLearn, F. H.: Geol. Surv., Canada, Sum. Rept. 1917, pt. C, p. 19.

WESTERN PEACE RIVER AREA

By G. S. Hume

References: McLearn, F. H.: "Peace River Section, Alberta"; Geol. Surv., Canada, Sum. Rept. 1917, pt. C, pp. 14-21.

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McLearn, F. H.: "Peace River Canyon Coal Area, B.C."; Geol. Surv., Canada, Sum. Rept. 1922, pt. B, pp. 1-47.

Spieker, E. M.: "The Petroleum Geology of a part of the Western Peace River, B.C."; Am. Ass. Pet. Geol., vol. 6, pp. 112-138 (1922).

(*See* Figure 13)

INTRODUCTION

The following account is based wholly on published information, a bibliography of which is given above. The "Western Peace River Area" includes the country north and south of Peace river and extending eastwards from the "disturbed belt" east of the mountains in British Columbia, to the plateau country of Alberta. Within this area is the Peace River block of British Columbia and, to the south of the Peace River block, the country east of the "disturbed belt" drained by Moberly, Pine, Kiskatinaw, and Pouce-Coupé rivers. The area includes a belt of moderately folded rocks, which lies east of the disturbed belt and passes eastward into the plateau area in which the rocks are relatively little disturbed.

Peace river, according to Spieker (1920),[1] occupies a valley about 800 feet deep, which in the vicinity of Hudson Hope, on the western edge of the Peace River block, is 2 to 3 miles wide. The higher land adjacent to the valley is more or less flat, but from Moberly lake southeastwards the surface is broken by hills and dissected by river valleys. According to Stewart (1919) this part of the area:

"Is well timbered, rough, and hilly. A relief of 1,500 feet is common and in places the higher ridges rise over 3,000 feet above the adjacent river valleys. Peace river being the main waterway to which all the streams of the region are tributary has the lowest elevations, the higher altitudes are attained by the most westerly ridges. Eastwards the uplands gradually become less irregular and blend into a high level plateau. The main streams flow for the most part in deep, narrow, V-shaped valleys and except in a few places, at time of low water, are too deep to be forded."

[1] *See* Bibliography.

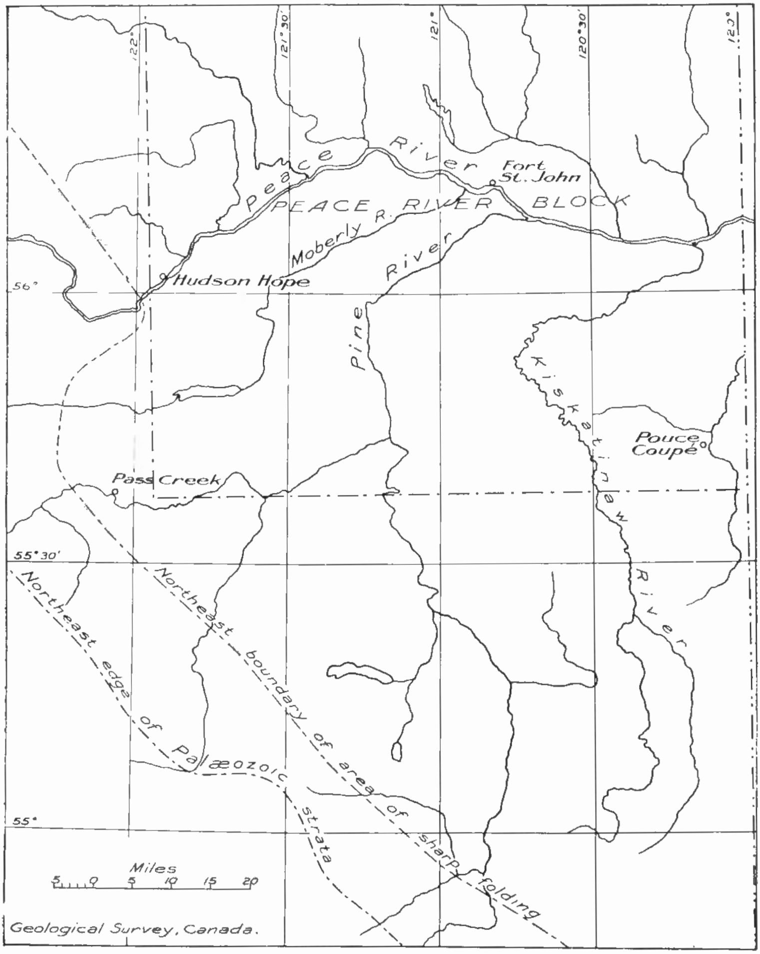

Figure 13. Western Peace River area, British Columbia.

STRATIGRAPHY

Table of Formations[1]

System	Group	Formation	Character	Thickness in feet
	Montana	Wapiti	Subaerial sandstone, massive, cross-bedded, with shales and lignite	900+ (Top not exposed)
		Smoky River	Dark, friable shales, marine with median sandstone member	800
		Sukunka member	Coarse, subaerial sandstones, hardened continental muds, green shales, lignite	1,000+
Upper Cretaceous	Colorado	Dunvegan	Massive to thin-bedded sandstones, varying in origin from littoral to subaerial, with some shale and a few thin seams of lignite	1,000+
		St. John	Black marine shales, usually arenaceous, with intercalated sandstone bands and marine sandstone locally	1,400 to 2,500
Lower Cretaceous		Bullhead Mountain	Hard, green-grey conglomerates, coarse-grained massive sandstones and shales, with many seams of high-grade coal	1,500 to 4,400+
Jurassic?		Pine River	Blue black marine shales with intercalated limestone and some sandstone	300+ (Base not exposed)
Triassic			Purple limestones and fine-grained sandstones; limestones vesicular near top	3,000 in the foothills

[1] From Spieker (1920) and various reports by McLearn.

Triassic. Rocks of Triassic age have not been observed in the area, but it is presumed they occur underlying younger formations, since they were seen by McLearn (1917) on Peace river west of Peace River canyon where they consist of limestones, hardened sandstones, and shales, all of which are marine. The total thickness is approximately 3,000 feet (McLearn 1920), but since the Cretaceous rests on the Devonian in the eastern Peace River area the Triassic must wedge out eastwards.

Jurassic (?). Spieker (1920) found blue-black clay shales interbedded with bands of limestone and sandstone, on Pass creek, a tributary of Pine river. To this series Spieker applies the name Pine River formation and assumes it belongs to the Jurassic, although the few fossils found are not sufficient to indicate a definite age.

Bullhead Mountain Formation. The Bullhead Mountain formation, according to McLearn (1922), consists of an upper and a lower member in Peace River canyon and westwards. The upper member is composed of conglomerates, grits, and coarse sandstones, with smaller amounts of medium to fine sandstones and shales. Large-scale crossbedding is present in some of the grits and sandstones and some layers are ripple-marked. The lower or Gething member consists of medium to fine sandstone, shale, clay ironstone, and a number of coal beds. The thickness of the upper member is over 3,000 feet, and the lower member is more than 1,400 feet.

On Pine river, at the mouth of Commotion (Boulder) creek, Spieker (1920) found the top of the Bullhead Mountain formation to consist of 130 feet of extremely hard, resistant conglomerate, the pebbles of which are almost uniformly one-eighth to one-quarter of an inch in diameter and are flint, chert, and quartz. Below the 130 feet of conglomerate are 600 feet of sandstone, which decreases in hardness downwards. The bottom part, also 600 feet thick, consists of less massive sandstones and possibly shales with coal. The total thickness is thus only 1,300 feet, although the area examined by Spieker on Pine river is only 20 miles almost directly south of the area at Peace River canyon and westwards where the formation is more than 4,400 feet thick. McLearn (1917) correlated the Bullhead Mountain formation "with the Peace River and probably also the Loon River formation of the eastern succession" on Peace river.

St. John Formation. According to McLearn (1917) the St. John formation where seen on Peace river consists of two, thick, shale members separated by a thin sandstone member. The lower shale member in the vicinity of Peace River canyon is 800 feet thick and consists of dark, thin-bedded, slightly arenaceous shale. The middle sandstone in the same locality consists of 50 to 80 feet of massive, crossbedded sandstone representing subaerial conditions of deposition. The upper member in the vicinity of Cache creek, a tributary of Peace river, is 1,300 feet thick; the bottom part is dark, friable shales with concretions overlain by black, paper-thin shales, above this are thin-bedded arenaceous shales with several large sandstone lenses, and higher still are thin-banded sandstones and shales. The series contains fossils which according to McLearn indicate marine conditions of deposition.

Outcrops of St. John shales are widely distributed over the area under consideration. They form the valley slopes of Peace river in the vicinity of Hudson Hope and of many of the tributaries including Moberly, North and South Pine, Halfway, Kiskatinaw, and Pouce-Coupé rivers for long distances from Peace river. Some of the lower plateau surfaces to the east expose these shales, but mostly the plateaux are capped by the harder, more resistant, Dunvegan sandstone.

On Smoky river the St. John shales have an estimated thickness of 560 feet (McLearn 1918). In Moberly River area the thickness is placed by Stewart (1919) in excess of 2,200 feet. This indicates a thinning eastwards of about 1,640 feet in about 150 miles.

Dunvegan Formation. On Peace river (McLearn 1918) the top of the St. John formation grades upwards into the Dunvegan by an increase in thickness of the sandstone layers, thus giving a gradation to the massive sandstones at the base of the Dunvegan. The Dunvegan formation outcrops on Peace river in the vicinity of Dunvegan and westwards and the sandstone weathers into peculiar castellated forms in the cliffs along the river. To the south of Peace river on the Sukunka branch of Pine river Spieker (1920) found a series of shales, hardened muds, and sandstones overlying the Dunvegan. These beds have not been observed elsewhere and according to Spieker may represent the westward phase of the lower Smoky River formation, but he classified them tentatively under the name Sukunka formation, as the upper member of the Dunvegan. According to Spieker (1920) the Dunvegan formation on Sukunka river, including the Sukunka beds, is 2,000 feet thick, although the Dunvegan as measured by McLearn (1917) near the mouth of Cache creek and eastwards is only 530 feet thick, representing a very considerable increase in thickness in about 50 miles in a north and south direction.

Smoky River Formation. On Smoky river (McLearn 1918) the Smoky River formation is composed of marine shales with thin bands of sandstone near the top. The formation appears on Peace river at and west of Dunvegan where shales underlie the adjacent plateaux. According to Allan and Cameron's map (1921) these shales form the plateau surface some distance east of Pouce-Coupé river, although the plateau in the vicinity of the river exposed the Dunvegan formation. The Smoky River formation does not appear in the area examined by Spieker just east of the "disturbed belt."

Wapiti Formation. The Wapiti formation does not occur in the area under consideration, but has been described (McLearn 1918) from Wapiti river, a tributary of Smoky river. In that locality it is composed of cross-bedded sandstones and shales with coal seams. It is thus non-marine in origin. The thickness is about 900 feet.

STRUCTURE

To the east of the "disturbed belt" bordering the mountains there is an area of moderately folded rocks in which a number of possible oil and gas structures have been outlined. Since the lower formations occur in the west and the higher in the east it may be assumed that there is a general eastward or southeastward dip. Such a conclusion, however, may be erroneous because of the thinning eastwards of such formations as the St. John and the equivalents of the Bullhead Mountain. Allan and Cameron (1921) describe an eastward and northeastward dip for Pouce-Coupé area. In the vicinity of Smoky river, McLearn (1918) has shown that the dip is southward towards the synclinal area to the south of Wapiti river, although in township 81, on Smoky river, there is a poorly defined terrace. The structure along Peace river is indicated by McLearn (1917) as follows:

"The transition from foothills to plains structure is very abrupt and takes place where the Portage Mountain anticline is succeeded by an area of gentle undulation and overthrust faulting extending as far as the Gates. From there to Cache creek there is a low east dip, under one-half degree, with a local west dip equally low near the mouth of Cache creek. Eastwards to several miles below St. John the structure seems to be almost flat. Near the North Pine river and downstream the structure steepens with an east dip, so as to bring the Dunvegan sandstone almost to river level a few miles below the mouth of Kiskatinaw river. From here to the bend at Montagneuse river the structure is flat. The section is east-west to this point. From the mouth of Montagneuse river southward a north-south section is cut and here a small dip is revealed. Where the river turns east past Dunvegan an east-west section is again exposed and flat structure indicated. Beyond the mouth of Burnt river, the Peace turns to the northeast and so continues to Peace River. Here the strata rise downstream and the inclination near Peace River amounts to some 40 feet per mile to the south."

Thus the structure as indicated by a study of the Peace River section is exceedingly flat for the plains area and the prospects for finding suitable structural reservoirs for oil and gas are not bright.

To the south, in Pouce-Coupé area, Allan and Cameron (1921) believe there is a terrace structure on the west side of the Alberta syncline. According to them:

"The high land just east of Kiskatinaw river shows a very flat tableland capped by the Dunvegan formation, while east of Pouce-Coupé River valley a gentle easterly dip causes the appearance of the Smoky River formation. The dip in the strata is in all cases very gentle and nowhere has been observed to exceed 25 feet to the mile."

According to Dresser (1920):

"Two broad anticlines appear on the banks of Peace river in the first 15 miles east of the foothills. The first is near Hudson Hope and the second at the 'Gates' of the Peace, a rock-enclosed narrows some 7 miles east of Hudson Hope. In these the dip, which elsewhere is commonly less than 5 degrees, rises very perceptibly on both limbs of the folds."

According to Spieker (1922), the Hudson Bay anticline is a low fold of small extent and although little is known of the axial extent of the fold it is presumed to be continuous with a faulted fold exposed in the west fork of Maurice creek, and dies out southward. The lower member of the St. John shale is exposed at the crest of the fold and the top of the Bullhead Mountain formation is supposed to be 600 to 700 feet in depth. Spieker (1922) thinks:

"The Hudson Hope anticline is hardly pronounced enough to have been thoroughly effective as a reservoir structure and the comparatively small thickness of hopeful beds beneath it within ordinary drilling depth emphasizes the decision that it is not to be considered with the best anticlines of the region."

On Red river, about 20 miles northwest of Hudson Hope, Dresser (1920) found a well-marked anticline.

In the area of gently folded rocks south of Peace river and east of the "disturbed belt" Stewart (1919) and Spieker (1920) both noted a number of local folds. These are outlined in detail on the map issued with Spieker's report.

OIL AND GAS HORIZONS

In eastern Peace River area, north of the town of Peace River, several wells have been drilled (*See* Figure 12) and indications of oil and gas have been obtained. According to McLearn (1917) the oil in No. 2 well of the Peace River Oil Company "occurs at two horizons, beds of sandstone in both cases, near the base of the Loon River and not far above the limestone contact." The Loon River formation lies on the Devonian limestone at this locality, but west in the western Peace River area Triassic beds occur in part or all of the area. The Peace River sandstone and probably also the Loon River formations of the eastern succession are, according to McLearn (1917), to be correlated with the Bullhead Mountain formation of the western succession. In a later report McLearn indicates a doubt as to the validity of this correlation, but if it is correct it indicates a change from marine conditions in the eastern area to non-marine conditions in the localities where the Bullhead Mountain formation occurs. The thick, heavy, massive sandstone beds of the Bullhead Mountain formation do not give much promise of holding oil and gas, but if there was an interfingering of marine beds, conditions would be much more favourable. In the area under consideration no evidence of the existence of marine beds in the Bullhead Mountain formation has been noted at any point and, therefore, the chances of finding an oil horizon equivalent to that in the Loon River formation are not considered good.

In Pouce-Coupé area the Imperial Oil Company drilled a well on sec. 26, tp. 80, range 13, W. 6th mer., to a depth of 3,057 feet. The well began in St. John shales. On Smoky river the St. John shales are estimated by McLearn (1918) to be 560 feet thick, whereas in Moberly River area Stewart (1919) estimated the thickness to be at least 2,200 feet and on Peace river near Cache creek McLearn (1917) estimated the thickness to be 2,150 to 2,180 feet. The thickness in Pouce-Coupé area would, therefore, be between 560 and 2,180 feet. In the Pouce-Coupé well a gas flow estimated at 10,000,000 cubic feet a day was struck at 1,675 feet, with other insignificant gas shows at 2,000, 2,372, and 2,736 feet, respectively. Salt water was encountered at 1,730 to 1,740 feet. The interpretation of the Pouce-Coupé well log is very difficult, but it is possible the large gas flow was struck near the base of the St. John formation and that the lower small flows of gas are in strata equivalent to the Peace River and Loon River formations of the eastern succession. These strata are not the same as the Bullhead Mountain formation farther west. In Pouce-Coupé area Allan and Cameron (1921) report a terrace structure. It is considered that such a structure may be sufficient to cause gas accumulation, whereas oil accumulations would, it is thought, demand a much more pronounced structural trap. The fact that an oil seepage is reported by Allan and Cameron (1921) on Pouce-Coupé river suggests that the St. John formation might be oil-bearing if more favourable structural conditions existed. According to Spieker (1922) an oil seepage occurs near Rolla, B.C., on Pouce-Coupé river; this is probably the seepage referred to by Allan and Cameron. Gas seepages are common, according to Spieker, in the vicinity of the oil seepage and another oil seep is known on Moose creek about 4 miles north of Peace river.

If, as has been assumed, the Bullhead Mountain formation is entirely non-marine west of Pouce-Coupé, this formation would not appear to offer favourable opportunities for oil accumulation even if proper structure were present, and the only formation within the Cretaceous worthy of prospecting would be the St. John which contains considerable sands as well as shales. There is, however, the possibility that rocks below the Cretaceous, i.e. Triassic, may be suited to act as oil and gas reservoirs. As these rocks have been seen only on Peace river west of Peace River canyon nothing is known regarding them except that they probably are all marine. Where seen they are in part arenaceous limestone and calcareous sandstones containing numerous geode cavities. To the eastward they probably would be less metamorphosed than where seen. The thickness diminishes eastwards from a maximum of 3,000 feet (McLearn 1920) in the foothills to zero in the eastern succession of Peace river where the Cretaceous rests on Devonian limestones.

OTHER AREAS IN ALBERTA

A large number of wells have been drilled in Alberta in areas where details of the geological structure are not definitely known. In many wells small flows of gas and shows of oil have been encountered, but in a number of cases the horizons giving these have not been studied in detail, so that little is known about their value as oil or gas reservoirs. The information from these wells shows a wide distribution of gas in Alberta and it is possible when the geological structure is better known that certain areas from which small gas flows are now reported may be sufficiently promising to warrant further drilling. A list of wells supplied by the North West Territories and Yukon Branch, Department of the Interior, is given in the appendix. This list indicates, so far as known, all the wells that gave oil or gas "shows," but with the data at present available it is impossible to indicate the promising areas except in so far as has been done in the case of the fields described on preceding pages.

FLATHEAD RIVER VALLEY, SOUTHEASTERN BRITISH COLUMBIA

By G. S. Hume

References: Dawson, G. M.: Geol. Surv., Canada, Ann. Rept., 1898.
Ann. Rept., Minister of Mines, B.C., 1903.
Dowling, D. B.: Geol. Surv., Canada, Sum. Rept. 1920, pt. B.
MacKenzie, J. D.: Geol. Surv., Canada, Mem. 87 (1916).
Ingall, E. D.: Geol. Surv., Canada, Sum. Rept. 1924, pt. A, p. 146.

Seepages of oil have long been known in Kootenay district, British Columbia, on Sage and Kishinena creeks, tributaries of Flathead river. The Sage Creek seepages were first reported by Selwyn in 1891 and occur 10 to 12 miles up the creek from Flathead river, in rocks regarded by Selwyn as of Cambrian age. The oil occurred in some abundance and gas was escaping from joints and cracks in the rock at the time of discovery. In recent years drilling has been done on Sage creek by the Crow's Nest Oil and Gas Company in Precambrian strata of the Lewis series, and drill samples to a depth of 3,000 feet[1] have been examined by the Borings Division, Geological Survey. According to a statement in the report of the Minister of Mines, B.C., 1903:

"The place at which the oil is found is at the top of an anticlinal in the formation . . . . . . the axis of the anticlinal crossing the creek in a northwest direction. From this point the beds dip up to the creek to the northeast and also down the creek to the southwest. The beds can be traced dipping to the northeast for about 3 miles, at first at a very flat angle, but gradually increasing until the dip reaches 35 degrees. At this point a fault occurs, with, to the east, a different dip to the rocks, while farther up the creek this is followed by other faults; hence it may be said that 3 miles above the 'spring' is the limit in that direction of this possible field of accumulation. To the southwest, that is, towards the valley of the Flathead, the beds dip at a very flat angle, probably not exceeding 10 degrees and apparently flattening out as they are lost to sight under the gravel and surface wash of the Flathead depression.

[1] Ingall, E. D.: "Deep Borings in British Columbia and the Yukon"; Geol. Surv., Canada, Sum. Rept. 1924, pt. A, p. 146.

On Kishinena creek, at a point where oil is reported, a similar anticlinal fold occurs, but with the axis running nearly northeast and southwest, or with the course of the creek, the beds dipping off at an angle to the northwest and southeast into the adjacent mountains."

It was suggested by Dawson[1] that the rocks from which the seepages issue may "possibly overlie, in some places, those of the Cretaceous series, by reason of overthrusts" and that the oil "may have originated in consequence of heat, at considerable depths in the earth's crust, acting upon the fixed hydrocarbons contained in the rocks of that series." As has been pointed out,[2] however, "if this explanation is the correct one, the overthrust must have been very great indeed to bring the Cretaceous beds underneath the present oil seepages, as the Cambrian beds extend eastward from 12 to 15 miles from this point, in fact over the summit into Alberta." It is further pointed out that:

"The oil might have travelled westward underground for some distance, but this is not probable, as a few miles to the eastward of the point of occurrence of the oil there are several faults which have the appearance of being profound and would, therefore, have allowed the gas and oil to rise to the surface through them, but of this there is no indication."

Detailed knowledge concerning the area in the vicinity of Sage and Kishinena creeks is very limited and the suggestion of Dawson that Cretaceous rocks underlie much older rocks as a result of overthrust has not been proved or disproved. To the east in Alberta, at Waterton lake, similar oil seepages occur and it is fairly well established that in that area Cretaceous rocks are overlain by older rocks as a result of overthrust. In a well drilled near Waterton lake, according to Dowling:[3]

"There seems little doubt that the drill penetrated the dolomites of the Waterton formation and entered soft shales, which seem to be Cretaceous. The zone of overthrust was apparently penetrated at about 1,500 feet, although at 1,900 feet and lower the beds were probably effected by crumpling and folding."

Flathead River valley, to the west of Sage creek, has been studied by MacKenzie[4] who reports that the Kishinena formation considered to be of Eocene (?) age shows considerable bituminous content. Regarding the oil content MacKenzie says:

"A marked characteristic of these rocks is their bituminous odour when struck or rubbed, and on joint-planes brownish stains are frequently seen which give a strong bituminous smell when heated . . . . . . some bands are impregnated more than others with the bitumen which serves to darken them . . . . . . Throughout all these rocks and with varying concentrations in different specimens are found impregnations of yellowish, brownish, and black material which is thought to be a residue from the evaporation of petroleum . . . . . . In many cases the bitumen takes the form of spheres . . . . . . The spheres are thought to represent drops of petroleum that have segregated under the influence of surface tension in the water-saturated rocks, yet were unable to migrate to any considerable distance owing to the very dense character of the enclosing material."

In summing up the conditions regarding the petroleum prospects of this area MacKenzie states:

"That bituminous material exists in the Kishinena rocks is without question, and its source may be with confidence assigned to the soft parts of the numerous mollusks with whose shells it is now so closely associated. Whether or not petroleum as such exists in these beds is not yet proved and chloroform tests of some of them furnish only negative results. However, the seepage of kerosene-like oil on Sage creek, east of Flathead valley, suggests the rather unlikely possibility that the oil may have been derived by migration from these bituminous Tertiary sediments. The porous, coarse nature of many of the

[1] Dawson, G. M.: Geol. Surv., Canada, Ann. Rept., vol. XI, pt. A, p. 23 (1901).
[2] Ann. Rept., Minister of Mines, B.C., 1903, p. 92.
[3] Dowling, D. B.: Geol. Surv., Canada, Sum. Rept. 1920, pt. B, p. 20.
[4] MacKenzie, J. D.: "Geology of a Portion of the Flathead Coal Area, B.C."; Geol. Surv., Canada, Mem. 87 (1916).

sands of the Kishinena formation would render them suitable for petroleum reservoirs, and although little is known of their structure in detail it is probable that local conditions of porosity or succession of strata might afford a gathering place for bodies of oil, although these assuredly would not be large. The small possible thickness of oil-bearing strata and their position near the surface render the finding of any considerable body of oil improbable, for if any had been present it would have readily escaped by natural channels and, furthermore, a sufficient gas pressure to make a field workable is unlikely at such shallow depths . . . . . . It is apparent that the chances of the occurrence of commercial deposits of petroleum in the Flathead map-area are very slight."

MACKENZIE RIVER BASIN

By G. S. Hume

INTRODUCTION

There are two areas—Great Slave Lake and Norman—in which drilling has been done within Mackenzie River basin. In Norman area the drilling has met with some measure of success, but in Great Slave Lake area only negative results have been obtained. There are other large areas presumably underlain by oil-bearing rocks, but owing to the inaccessibility of a great part, no tests have as yet been made. General information on Mackenzie basin is contained in the following reports:

Camsell, C., and Malcolm, W.: "The Mackenzie River Basin"; Geol. Surv., Canada, Mem. 108 (1921).

Kindle, E. M., and Bosworth, T. O.: "Oil-bearing Rocks of Lower Mackenzie River Valley"; Geol. Surv., Canada, Sum. Rept. 1920, pt. B, pp. 37-58.

Detailed information on restricted areas within Mackenzie basin is published in the following reports:

Cameron, A. E.: "Explorations in the Vicinity of Great Slave Lake"; Geol. Surv., Canada, Sum. Rept. 1917, pt. C, pp. 21-27.

"Hay and Buffalo Rivers, Great Slave Lake and Adjacent Country"; Geol. Surv., Canada, Sum. Rept. 1921, pt. B, pp. 1-45.

Whittaker, E. J.: "Mackenzie District between Great Slave Lake and Simpson"; Geol. Surv., Canada, Sum. Rept. 1921, pt. B, pp. 45-55.

"Mackenzie River District between Providence and Simpson"; Geol. Surv., Canada, Sum. Rept. 1922, pt. B, pp. 88-100.

Williams, M. Y.: "Exploration East of Mackenzie River between Simpson and Wrigley"; Geol. Surv., Canada, Sum. Rept. 1921, pt. B, pp. 56-66.

"Reconnaissance Across Northeastern British Columbia and the Geology of the Northern Extension of Franklin Mountains, N.W.T."; Geol. Surv., Canada, Sum. Rept. 1922, pt. B, pp. 65-87.

Hume, G. S.: "Great Slave Lake Area"; Geol. Surv., Canada, Sum. Rept. 1920, pt. B, pp. 30-36.

"North Nahanni and Root Rivers Area and Caribou Island, Mackenzie River District"; Geol. Surv., Canada, Sum. Rept. 1921, pt. B, pp. 67-78.

"Geology of the Norman Oil Fields and a Reconnaissance of a Part of Liard River"; Geol. Surv., Canada, Sum. Rept. 1922, pt. B, pp. 47-64.

"Mackenzie River Area, District of Mackenzie, N.W.T."; Geol. Surv., Canada, Sum. Rept. 1923, pt. B, pp. 1-15.

Maps of Mackenzie river and Great Slave lake are published by the Department of the Interior, Topographical Surveys, Ottawa.

NORMAN AREA

(*See* Figure 14)

Location and Physiography

Norman area lies north of latitude 65 and in the vicinity of longitude 127. Norman is at the junction of Great Bear and Mackenzie rivers and the area tested by drilling lies approximately 50 miles northwest.

The Mackenzie lowland through which Mackenzie river flows has a general northward slope. In the vicinity of Norman oil area the lowland occupies a relatively narrow strip of country between the Norman range of mountains on the east and Carcajou mountains on the west. The Norman range rises approximately 2,500 feet above Mackenzie river, whereas Carcajou mountains are higher and much more rugged. The country between the mountains is heavily forested with spruce, poplar, and alder, and is covered by muskeg in which there are innumerable small lakes. Looking northeastward from Carcajou mountains the country appears to be rather flat and one-quarter to one-fifth of the whole area is occupied by lakes and sloughs from which in many cases there are but poorly developed drainage channels. At a few feet below the muskeg surface, even in summer, a layer of ice is encountered in many places and presumably the ground at a slight depth below the surface is permanently frozen.

Stratigraphy

Rock exposures are almost entirely absent except along the larger streams and rivers and in the mountains. The following table of formations indicates the stratigraphic succession so far as it is known.

Age	Formation	Description	Thickness in feet
Eocene		Imperfectly consolidated sands and clays	
Erosional unconformity			
Cretaceous		Black, soft, fissile shales and greenish sandstones. Lower members with coal in some localities. Upper member marine, carrying ammonites	
Erosional unconformity			
Upper Devonian	Bosworth	Greenish sandstones and shales	1,600+
	Fort Creek	Mostly black shales	1,000 to 1,500
Middle Devonian	Beavertail and Ramparts	Limestones	400 (?)[1]
	Hare Indian River	Shales	300+
Silurian	Bear Mountain	Brecciated limestones	400 to 450
		Well-bedded limestone	1,000
		Red gypsiferous shales	770 (red gypsiferous shales; red shales, no fossils; red and greenish shales and sandstone)
Ordovician (?)		Red shales, no fossils	
Cambrian		Red and greenish shales and sandstone. Bottom not seen	

[1] In Geol. Surv., Canada, Sum. Rept. 1922, pt. B, p. 55, it was shown that the Beavertail limestone was only 60 feet thick at the Wolverine anticline. It is probable that in the measurements by Kindle and Bosworth part of the Ramparts limestone (*Stringocephalus burtoni* zone) was included in the Beavertail. The thickness of the Beavertail-Ramparts limestone is given by the log of Northwest Company's No. 2 well, but it is not known to what formation the shales under the limestones belong.

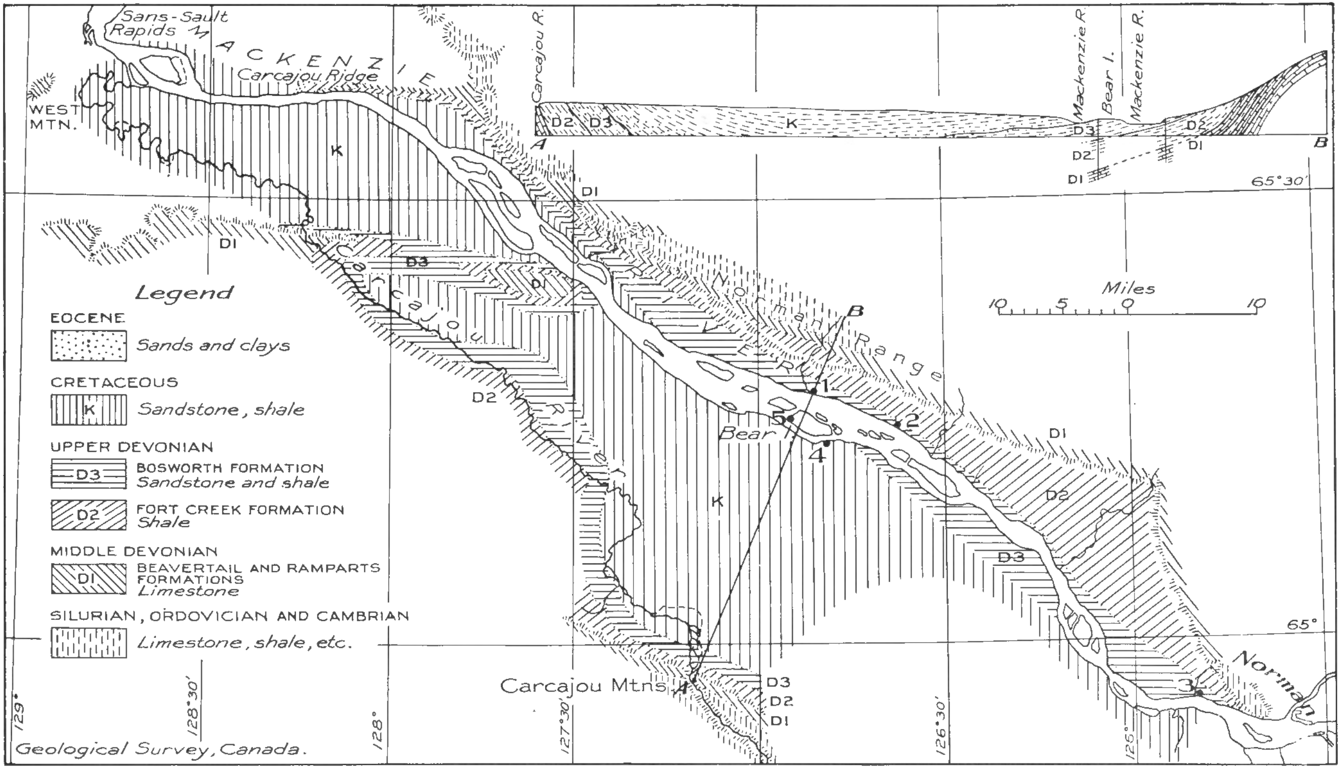

Figure 14. Norman area, district of Mackenzie:

1, Northwest Oil Co., No. 1 and No. 2; 2, Fort Norman Oil Co.; 3, Northwest Oil Co., Bluefish well; 4, Northwest Oil Co., "C" location; 5, Northwest Oil Co., "D" location (on Bear island).

Structure

The Norman mountains are anticlinal in form. The mountains east of the Northwest Company's No. 1 well represent the western half of a great fold, the axis of which has been eroded, leaving a deep valley with abrupt, eastward-facing cliffs. The mountain is composed of westward-dipping Silurian rocks, on the flanks of which, toward the Mackenzie, lie Devonian formations in ascending order, with the Bosworth formation outcropping at the east side of Mackenzie river at the Northwest Company's No. 1 well. On the west side of the river these beds are overlain by Cretaceous, and it is presumed the westward dip continues for some distance west. On the west slopes of the valley, Devonian limestones again appear at the surface at the eastern edge of Carcajou mountains, and westward in the mountains Silurian and Cambrian rocks occur indicating an eastward dip. The structure between Norman and Carcajou mountains in a section through the Northwest Company's No. 1 well is thus a large basin in the central part of which Cretaceous rocks occur with the lower formations on both flanks. To the northwest, a cross-fold trending almost east and west brings Middle Devonian rocks to the surface at Mackenzie river and forms a distinct ridge which crosses Carcajou river about 50 miles above its junction with the Mackenzie. The north slope of this ridge is very steep west of Carcajou river where the beds dip northward at 80 degrees and it is probable that to the west the fold passes into a fault. Farther down Mackenzie river, another cross-fold parallel to that just described forms Wolverine anticline or Carcajou ridge on the northeast side of the Mackenzie and may continue as far west as West mountain, although in the intervening area Cretaceous rocks showing only small dips are exposed near the mouth of Carcajou river. Eastward the Wolverine anticline abuts against a mountain of the Norman range. Between this mountain and the Mackenzie, in a southwest direction, the country is flat and dotted with small lakes and sloughs lying in a muskeg that conceals all underlying rock. Thus, in the northern part of the basin between Norman and Carcajou mountains there are cross-folds which modify the basin structure, but since these cross-folds are such that they bring the Middle Devonian rocks to the surface they do not appear to offer favourable structures for oil. The details of the structure in the southern part of this basin are unknown, but it may be that other minor folds occur either parallel to the main mountain ranges or parallel to the cross-folds already described. Such minor folds, if present, would be the most favourable locations for test wells, but since the country is almost completely covered by a thick deposit of muskeg the location of such folds would be extremely difficult.

Wells Drilled

Northwest Company (Imperial Oil Company) No. 1 well was drilled in 1920 on the east side of Mackenzie river at the mouth of Bosworth creek. This is the "discovery" well in which oil estimated at 100 barrels a day was obtained at a depth of 783 feet. The oil came from the Fort Creek shales and cavings caused the cessation of the flow. In 1922 the well was deepened to 951 feet and a flow of 60 to 70 barrels of oil was secured. In 1923 the well was further deepened to 1,025 feet and the flow of oil increased to about 100 barrels. It is understood the well has a potential capacity at the present time of about 100 barrels a day. The well is now capped.

Fort Norman Oil Company well was drilled in 1921 about 8 miles up Mackenzie river from the Northwest Company's No. 1 well, on the east bank of the river. The well was drilled to a depth of 1,512 feet. A flow of gas estimated at 300,000 cubic feet a day was obtained between depths of 385 and 500 feet. No commercial supply of oil was secured.

Northwest Oil Company. Bluefish Well. This well is located on the east bank of Mackenzie river at the mouth of Bluefish creek, a short distance down the Mackenzie from Bear rock at the mouth of Great Bear river. The well was abandoned because of drilling troubles.

Northwest Oil Company "C" location well was drilled in 1921-1922. It is located on the west side of Mackenzie river south and slightly east of the Northwest Oil Company's No. 1 well. It was drilled to a depth of 3,057 feet and finished in the Beavertail limestone. It is a dry hole.

Northwest Oil Company "D" location well is on Bear island, Mackenzie river, south and slightly west of the Northwest Oil Company's No. 1 well. The well was drilled in 1921 to a depth of 2,304 feet. A small show of oil was obtained at about 1,945 feet and a flow of salt water at 2,060 feet. The flow of oil occurred at the contact of the Fort Creek and Beavertail formations. The salt water flow occurred in the Beavertail-Ramparts limestone.

Northwest Oil Company No. 2 well was drilled in 1924-25, 150 feet from No. 1 well. A production of oil was obtained at 936 and 1,063 feet, amounting to about 110 barrels a day. Also "shows" of oil were found at other depths. The main flow is believed to be from the Fort Creek shales. The well was drilled to 1,602 feet, but without any further results.

Oil and Gas Horizons

The Northwest Oil Company's No. 1 well was drilled on a seepage of oil issuing from the Bosworth formation. A number of other seepages from this formation are known east of the Mackenzie, but so far as the writer is aware no seepages have been reported in this area west of the Mackenzie. The Bosworth formation consists of alternating beds of shale and sandstone and is considered the most favourable for oil accumulations of any of the Devonian formations, since the proportion of sand in it is much higher than in any other Devonian horizon.

As proved by the Northwest Company's Nos. 1 and 2 wells the Fort Creek formation contains oil. The shales of this formation in many exposures are highly bituminous.

The brecciated limestones that are tentatively placed in the Silurian Bear Mountain formation are in places so highly bituminous that a strong odour is emitted on breaking the rock. These brecciated limestones are, in places, quite dolomitic and are sufficiently porous to act as an oil reservoir. At other places, however, they contain much gypsum and it is possible the brecciation has resulted from the change of anhydrite to gypsum. It is possible in certain localities these rocks might be found to be oil-bearing, but in the mountains where they are exposed no seepages of oil from them were seen.

The basal Cretaceous beds are largely sandstones with some shale and as they lie in certain localities on the Bosworth formation which is undoubtedly oil-bearing, they might under favourable structural conditions act as oil reservoirs. The basal sandstones are overlain by fissile black shales, capable, on account of their fineness, of acting as a suitable cap rock to retain the oil. In certain localities, however, the black Cretaceous shales rest directly on the Devonian and as the Cretaceous is separated from the Devonian by an erosional unconformity, the Cretaceous rests on the Bosworth formation in some localities, whereas in other localities, as for example at the Ramparts of the Mackenzie, the Cretaceous shales rest on the Ramparts limestone. The most favourable localities, therefore, for oil in the Cretaceous, would be where the basal sandstones rest on the Bosworth formation under cover of the higher Cretaceous shales and where there is sufficient local structure to concentrate the oil. There are certain portions of country in the vicinity of Little Bear river where such conditions are fulfilled, but nothing is known regarding the details of local folding.

Future Oil Prospects

Nos. 1 and 2, Bear Island and "C" wells of the Northwest Oil Company, and the well of the Fort Norman Oil Company, were drilled on westward dipping beds on the west flank of the anticlinal fold which forms the Norman range. The Bear Island and "C" wells are down the dip from Nos. 1 and 2 wells and seem to indicate that no oil may be expected in that direction along the dip slope. It is very difficult to understand how the oil has been accumulated at Nos. 1 and 2 wells of the Northwest Oil Company in a shale formation (Fort Creek) which with the associated formations dips uniformly westward and comes to the surface only a few miles east of the wells. In the Fort Creek formation on Canyon and Vermilion creeks, a sandstone horizon 50 to 70 feet thick was found about 800 feet above the base of the formation. In a former report it was suggested that the accumulation of oil in the vicinity of the wells might be due to the presence of the sandstone horizon that occurs on Canyon creek, but this sandstone is not present in No. 2 well. No local folding with which the concentration of oil might be associated has been detected in the vicinity of the oil wells.

As already stated two large cross-folds are known at the north end of the basin structure, but since in each erosion has revealed the core of Middle Devonian rocks, their value as oil structures is very doubtful and depends only on the possibility that oil might be present in the brecciated limestones underlying the Devonian rocks. As already stated, these in places are sufficiently porous to act as oil reservoirs and are known to be somewhat bituminous.

It has been stated that some seepages on the east side of Mackenzie river come from the Bosworth formation which outcrops over large areas. As there is no cover to prevent the free escape of the oil at the outcrop no production could be hoped for from this formation over the area where it is exposed at the surface. If, however, local structures could be located in the areas to the west where the Bosworth is overlain by Cretaceous shales, the prospects for oil accumulations in the Bosworth would seem to be good. Since the Bosworth formation is thinner at "C" well than on Carcajou river to the west, the strata of the uppermost part of "C" well were at first considered to belong to the Bosworth formation, but are now confidently believed to be Cretaceous shales. Thus at "C" well there is a cover of Cretaceous shales which would prevent the escape of the oil upwards, but since "C" well is down the dip from Nos. 1 and 2 wells of the Northwest Oil Company and no local structure is known, there is no apparent reason why any oil originally present in the Bosworth formation should not have migrated up the dip and escaped at the outcrops on the eastern side of Mackenzie river. That such a process is taking place seems to be indicated by seepages at the outcrop. The structural conditions at Bear Island well are similar to those at "C" well and the conclusion to be drawn from these two wells seems to be that no accumulation of oil is likely to occur on the west side of Mackenzie river except where there is a local structure superimposed on the basin structure such as would prevent the migration of the oil to the outcrop.

The migration of the oil up the dip in an eastward direction assumes, on the basis of the hydraulic theory of oil migration, an underground flow of water in the basin structure from west to east, and this seems to be borne out by the springs and seepages on the east side of Mackenzie river. The relative elevations of the outcrops of the Devonian on the east and west sides of this basin are imperfectly known, but the country in the vicinity of Carcajou mountains where the Bosworth beds outcrop is somewhat higher than the territory occupied by the Bosworth formation on the east side of Mackenzie river. This difference in elevation may provide the hydrostatic head necessary to cause the eastward migration of the underground waters, as a result of which the oil would be flushed toward the eastern side of the basin and would appear at the outcrop in seepages such as do occur. By such a theory the most favourable prospects for oil would lie toward the eastern outcrop, where local folds on the main fold are of such a nature that the eastward flow is prevented and the oil caused to accumulate. If such local folds are not present the oil would be flushed to the outcrop, would be lost, and no commercial production could be expected. It is unfortunate that the conditions causing the accumulation of oil at Nos. 1 and 2 wells of the Northwest Oil Company are not understood, but since in those wells the oil occurs in shales that on account of their texture offer very little opportunity for the migration of liquids, the conditions are not comparable with those involving movement through sandstones, such as are present in the Bosworth formation. It seems almost necessary to assume a certain amount of fracturing of the shales to allow an accumulation of oil in them at any point on a scale sufficient to give an oil well, and, if such is the case, the wells when freely drawn upon would not be expected to yield oil for any great length of time.

From what is known of Norman oil-field, the prospects for a large production of oil do not seem very favourable, unless local structures superimposed on the basin structure can be located. If the hydraulic theory of accumulation of oil be accepted the best prospects should occur toward the eastern side of the basin in such local anticlines as exist. It would seem unreasonable to assume in the downwarping of a basin such as that between Norman and Carcajou mountains, that the movement was so regular as to cause only one, large, regular downfold without a certain amount of local crumplings. That such was not the case is shown at the northern end of the basin where cross-folds have been developed. Other small folds either parallel to the mountains or to the cross-folds, should occur elsewhere. The writer is of the opinion that the value of the Norman oil-field as a large producer of oil depends on the extent to which minor folds have been developed and can be located in areas favourably situated. It is well established that oil-bearing beds are present and that there are a number of horizons which, given proper conditions, are of sufficient porosity to act as oil reservoirs.

Character of Oil from Northwest Oil Company's No. 1 Well. An analysis of the oil from the Northwest Oil Company's No. 1 well, made by J. A. Kelso, University of Alberta, and published in Geological Survey, Summary Report 1920, pt. B, page 58, is as follows:

Specific gravity	0·845	(36° Baumé)
Distillation—		
70 to 150 degrees C.	22·5 per cent	(Gasoline)
150 " 300 "	38·5 "	(Illuminants)
300 " 350 "	33·9 "	(Light lubricants)
350 " 375 "	4·1 "	(Medium lubricants)
Loss	1·0 "	

Log of Northwest Oil Company's No. 2 Well, Norman

The following log, supplied and published with the permission of the Imperial Oil Company, illustrates the character of the sediments in Norman area.

Description	Depth in feet		
Surface materials	0	to	30
Light grey, slightly calcareous, clay shale with a little fine sand	30	"	120
Light grey, non-calcareous, clay shale. Showing of oil at 122 feet	120	"	130
Light-grey, non-calcareous clay shale with a little fine sand	130	"	200
Light grey, calcareous clay shale with a little fine sand	200	"	220
Light grey, non-calcareous, clay shale with a little fine sand	220	"	230
Bluish grey shale with grey sandstone	230	"	240
Harder, bluish grey shale, sandy	240	"	270
Bluish grey shale, sandy. Gas at 272 feet	270	"	280
Bluish grey shale	280	"	290
Bluish grey shale, sandy.	290	"	310
Bluish grey shale, calcareous	310	"	320
Bluish grey shale, sandy	320	"	390
Bluish grey shale, soft	390	"	400
Bluish grey shale	400	"	430
Bluish grey shale, sandy and hard	430	"	440
Bluish grey shale, sandy	440	"	450
Bluish grey shale, very little sand	450	"	460
Bluish grey shale	460	"	490
Bluish grey shale, fairly hard	490	"	500
Bluish grey shale	500	"	700
Dark grey, soft, calcareous shale with some bluish grey shale	700	"	710
Bluish grey shale, calcareous and harder than above	710	"	720
Bluish grey shale, fairly hard, non-calcareous	720	"	770
Bluish grey shale, fairly hard, calcareous	770	"	790
Bluish grey shale, non-calcareous. Showing of oil at 792 feet	790	"	810
Bluish grey shale	810	"	850
Bluish grey shale, fairly hard, calcareous	850	"	860
Bluish grey shale, slightly calcareous	860	"	880
Bluish grey shale, fairly hard, calcareous. At 895 feet 25 bbls. of oil, which decreased to 2 bbls. a day	880	"	900
Bluish grey shale, fairly hard, slightly calcareous	900	"	920

Log of Northwest Oil Company's No. 2 Well, Norman—Continued

Description	Depth in feet
Bluish grey shale, fairly hard, non-calcareous	920 to 950
Blue-black shale, hard, non-calcareous, some pyrite	950 " 960
Blue-black shale, with some pyrite and calcite in veins	960 " 970
Blue-black shale	970 " 980
Dark, greyish black shale, soft	980 " 1,030
Dark, greyish black shale with brownish tinge	1,030 " 1,040
Dark, greyish black shale, harder	1,040 " 1,050
Dark, greyish black shale, very hard, with much pyrite	1,050 " 1,060
Dark, greyish black shale	1,060 " 1,070
Dark, brownish black shale, hard, with pyrite. This is evidently the base of the Fort Creek shales	1,070 " 1,086
Hard, brown limestone with petroleum odour	1,086 " 1,095
Hard, brown limestone	1,095 " 1,130
Hard, brown limestone, petroleum odour	1,130 " 1,140
Hard, brown limestone	1,140 " 1,190
Hard, brown limestone, becoming darker with depth	1,190 " 1,200
Hard, brown limestone	1,200 " 1,240
Hard, dark brown limestone	1,240 " 1,250
Hard limestone, lighter colour than above	1,250 " 1,260
Hard, brown limestone	1,260 " 1,290
Hard, light brown limestone	1,290 " 1,450
Hard, light brown limestone, becoming more shaly	1,450 " 1,460
Hard, light brown limestone	1,460 " 1,470
Hard, light brown limestone with some dark shale	1,470 " 1,480
Dark grey, calcareous shale	1,480 " 1,600

It is not definitely known what horizon is represented by the shales in the bottom of this well. The Beavertail and Ramparts limestone from sections measured in other parts of Norman area are considered to have a thickness exceeding that of the limestones in this well, but it is possible that the thickness in outcrops was over-estimated.[1] Outside Norman area the Ramparts limestone overlies the Hare Indian River shales and, possibly, these may be partly represented by the shales in the bottom of the well. Kindle and Bosworth[2] state that the thickness of the Hare Indian River shales exceeds 300 feet, so that it is possible the well stopped in these shales. The objection to this interpretation of the lower shales of the well is that the Hare Indian River shales are not known to be present elsewhere in Norman area and since in the mountains both to the east and the west the Ramparts limestone rests directly on brecciated limestones and dolomites of the top of the Bear Mountain formation, the Hare Indian River shales have been presumed absent. It is possible, therefore, that the calcareous shales reported in the well, from 1,480 to 1,600 feet, are a shaly phase of the Ramparts limestone, or possibly are a phase of the Bear Mountain brecciated limestones. However, in view of what is known of the stratigraphy of Norman area, neither of these possibilities seems logical and it is much more reasonable to assume the shales belong to the Hare Indian River formation. This would mean a considerable erosional interval between the Silurian and the Devonian in order to account for the absence of these shales in Carcajou mountains where in the cliffs along the gorge of Carcajou river the contact between the Devonian and Silurian can be observed for long distances.

[1] Hume, G. S.: Geol. Surv., Canada, Sum. Rept. 1922, pt. B, p. 55.
[2] Kindle, E. M., and Bosworth, T. O.: "Oil-bearing Rocks of Lower Mackenzie River Valley"; Geol. Surv., Canada, Sum. Rept. 1920, pt. B, p. 44.

Introduction

Great Slave lake is the fourth largest lake on the North American continent, being exceeded only by Superior, Huron, and Michigan lakes. At no place, however, is it more than 70 miles wide and it is divided into three major divisions, a northern, eastern, and western. The longer axis of the lake passes through the eastern and western arms in a northeast-southwest direction. The main part of the lake is between latitudes 61 and 62, but a large part of the north and east arms lies to the north. The lake reaches from longitude 117° 30′ to 109°.

The eastern part of the lake, the east arm, is within the area of Precambrian rocks of the Canadian Shield; the rest of the lake lies within an area of Palæozoic sediments. The boundary between the Precambrian and Palæozoic follows the north arm in a northwesterly direction, with Palæozoic strata forming the west shore and with patches of Palæozoic lying on Precambrian along the east shore.

The shore of the western arm of Great Slave lake is for the most part low and is described by Cameron[1] as follows:

"The south shore from Stoney island west to Little Buffalo river is formed of delta deposits from Slave river . . . . . . At Resolution a low range of hills rises above the silts and extends west into the lake, forming Mission and Moose islands and, still farther west, Burnt islands.

From the mouth of Little Buffalo river, which marks the western limit of the delta deposits, the shoreline is characterized by wide, shallow bays separated by low, gravelly, or rocky points. Usually each bay has a gravelly or sandy beach behind which lies a narrow stretch of low, swampy muskeg or shallow, open lagoon. South of Pine point the ground rises gently inland until at a distance of some 10 miles it reaches an elevation of 300 feet above the present lake-level . . . . . . West of the mouth of Buffalo river the shoreline is generally low-lying and swampy with few pronounced points.

West of a line drawn from Hay river to Slave point on the north shore, the shores of the lake are formed presumably of soft shales, and the adjacent land is low-lying and swampy. Long stretches of spruce and tamarack muskegs reach inland from the lake. These are bounded on the south by Eagle mountains . . . . . .

From Slave point the [north] shore runs north for about 40 miles and then east for 25 miles and then swings in a wide circle to the north arm . . . . . . Many deep, narrow bays stretch inland approximately parallel to one another . . . . . . The heads of the bays are in most cases low and swampy, like those on the south shore . . . . . . Wide marshes, in many cases containing large, open sloughs, stretch inland from the bays. On the broader points low, wave-cut cliffs in the limestone occur, though frequently the cliffs are situated some distance inland from the present lake shore . . . . . . The inland country north of the lake is a low spruce and tamarack muskeg slightly higher than the lake, with numerous, long, narrow hills rising 100 to 150 feet above lake-level . . . . . . One of the pronounced features in this region is the absence of drainage towards the lake. Throughout the entire 136 miles of shoreline between Mackenzie river and the North arm only one small stream was found entering the lake."

South of Great Slave lake lies the Alberta plateau, marked by north-facing escarpments extending from near Fort Smith on Slave river north-westerly and giving rise to falls on Hay and Kakisa rivers. The falls on Hay river are 40 miles south of the lake. On the north side of Great Slave lake, as pointed out by Cameron, no large streams enter. To the north-west lies Horn mountain rising, according to Whittaker,[2] to a height of

[1] Cameron, A. E.: "Hay and Buffalo Rivers, Great Slave Lake and Adjacent Country"; Geol. Surv., Canada, Sum. Rept. 1921, pt. B, p. 10.

[2] Whittaker, E. J.: "Mackenzie River District Between Great Slave Lake and Simpson"; Geol. Surv., Canada, Sum. Rept. 1921, pt. B, p. 47.

2,000 feet above the monotonous plain of muskeg and lake to the south-east. On the North arm, Ordovician and Silurian rocks form an eastward-facing cuesta rising in the north directly from the plateau surface of the Canadian Shield, whereas in the south the escarpment is close to or at the lake shore.

Stratigraphy

The following table of formations is taken from reports by Cameron[1] and Whittaker.[2]

Table of Formations

	Formation	Description	Thickness in feet
Cretaceous	....	Soft, greenish shales with sandstone beds and concretions, on Hay river. Thin, fissile, brown-black shales, which weather yellow, on Horn mountain	
Upper Devonian	Hay River limestones	Hard, dolomitic limestones, shaly limestones, limy shales	300
	Hay River shales	Shaly limestones, soft clay shales with limestone, sandstone, and ironstone bands	400
	Simpson shales	Greenish grey clay shales weathering to fissile shale	150 to 250
Middle Devonian	Slave Point limestone	Grey, shaly limestone	200
	Presqu'île dolomites	Hard, crystalline dolomites, dolomitic limestones, thin-bedded, grey, shaly limestone	375
	Pine Point limestone	Soft, grey, shaly limestones, blue to black, thin-bedded, hard limestones, grey to brown, shaly limestones	100 to 595
	Horn River shales	Brown-black, fissile shales	100
Silurian	Fitzgerald dolomites	Grey, dolomitic limestones with gypsum and anhydrite	275
Ordovician (at least in part)		Red, calcareous shale, red gypsum, salt, and red arenaceous shale	595
Precambrian		Hard, red sandstones, granite	

[1] Cameron, A. E.: "Hay and Buffalo Rivers, Great Slave Lake and Adjacent Country"; Geol. Surv., Canada, Sum. Rept. 1921, pt. B, p. 13.

[2] Whittaker, E. J.: "Mackenzie River District Between Great Slave Lake and Simpson"; Geol. Surv., Canada, Sum. Rept. 1921, p. 51.

Structure

Over the whole of Great Slave Lake area the strata depart only slightly from the horizontal, though there is a regional southwesterly dip. The lower Palæozoic beds outcrop along the North arm and in the vicinity of Resolution and southward on the south side of the lake. The higher Devonian strata lie to the west and Cretaceous beds occur in Horn mountain at a considerable elevation above the lake-level. On the south shore, "at Pine point and in Resolution bay," according to Cameron,[1] "the exposures indicate a gentle anticlinal tendency, the apex of the anticline being in the vicinity of the point itself." This anticline is shown by the presence of Pine Point limestones for some distance on both sides of Pine point, but flanked both to west and east by the higher Presqu'île dolomites. It is probable that the anticline trends in a northwest direction to the north shore, where, in the vicinity of Sulphur bay, the Presqu'île formation is exposed with the higher Slave Point limestones to the east and west. This anticline is of the nature of a broad warp with gentle dips and is made apparent only by the distribution of the several formations and not by observed dips. It seems probable that even this broad anticline has had an appreciable influence tending to cause the migration of oil toward the axis, for on Pine point, which is presumably on the axis on the south shore, the Pine Point limestones have a high bituminous content; and on the north shore, seepages of oil occur in the Presqu'île dolomites in the vicinity of Windy (Nintsi) point, again presumably on the crest of the anticline.

From geological work done by J. J. O'Neill,[2] geologist for the White Beaver Oil Company, it appears there is local folding in the vicinity of Hay river some distance south of Great Slave lake. The fold on which the White Beaver Oil Company's well was located strikes, according to O'Neill, about northeast and southwest, or at about right angles to the large fold crossing Great Slave lake from Pine to Windy points. The closure from crest to trough on this fold is approximately 300 feet, but there may be a southwest plunge since the regional dip of the strata at this locality is in this direction. The position of the apex of the anticline is unknown and it is possible the well was at a considerable distance away from it, in which case the anticline has oil possibilities toward the apex if there is closure to the northeast. Cameron[3] also reports gentle anticlinal folding in the Devonian above Alexandra falls on Hay river, but the extent and magnitude of these folds are unknown.

Oil and Gas Horizons

Seepages of oil are known in only two formations in Great Slave Lake area, namely the Pine Point and the Presqu'île formations. The Fort Creek shales in Norman area have proved to be oil-bearing in the North-

[1] Cameron, A. E.: "Hay and Buffalo Rivers, Great Slave Lake and Adjacent Country"; Geol. Surv., Canada, Sum. Rept. 1921, pt. B, p. 34.

[2] Personal communication.

[3] Cameron, A. E.: "Exploration in the Vicinity of Great Slave Lake"; Geol. Surv., Canada, Sum. Rept. 1917, pt. C, p. 27.

west Oil Company's Nos. 1 and 2 wells and it is believed the Fort Creek shales are equivalent in age to the Simpson shales of Great Slave Lake area. The Simpson shales are not exposed, so far as known, anywhere on Great Slave lake, but are presumed to underlie the country at the western end of the lake in the vicinity of the Mackenzie, and according to Whittaker[1] are exposed on Mackenzie river 5 miles above Rabbitskin river and at intervals to Simpson. No seepages of oil are known from these shales, but as they weather easily and rarely outcrop, knowledge regarding them is very limited. At Pine point, on Great Slave lake, the Pine Point formation is, in part, highly bituminous, but the sediments exposed there lack the appearance of being such as would act as reservoirs for large quantities of oil and they were barren in the Windy Point well.

The seepages at Windy point and on Sulphur bay on the north shore of the lake are from the Presqu'île formation. According to Cameron,[2] the rocks of this formation where exposed are "massive, bedded, generally coarsely crystalline, porous, and cavernous dolomites. Large caverns and pores are numerous and are frequently lined with dolomite crystals and filled with semi-liquid bituminous matter." This formation, both on account of its oil content and its porosity, is considered to be the best prospective oil horizon in Great Slave Lake area. The Slave Point limestones are also slightly bituminous in certain areas, but lack the porosity that characterizes the Presqu'île dolomite and no seepages of oil are known from them.

Wells Drilled

The Northwest Oil Company (Imperial Oil Company) in 1921-22 drilled a well at Windy (Nintsi) point on the north shore of Great Slave lake. The well began in the Presqu'île dolomites and penetrated the total thickness of the Palæozoic below. No oil was found. The well is abandoned.

The White Beaver Oil Company in 1922 drilled a well 15 miles south of Great Slave lake in the vicinity of Hay river. The depth of the well is 712 feet. A strong flow of salt water was struck in the Presqu'île formation. The well is abandoned.

Future Oil Prospects

The well of the Northwest Oil Company was drilled on the crest of the broad anticline in the vicinity of Windy point and as already stated the well began in the Presqu'île dolomite from which oil seeps at that place. Since at this locality the Presqu'île formation has no cover there hardly could be sufficient pressure, within a formation of such high porosity, to cause oil to flow in commercial quantities into a well. No oil was found in the underlying Palæozoic formations. The broad, anticlinal structure that occurs at this locality apparently has influenced the oil to flow

[1] Whittaker, E. J.: "Mackenzie River District Between Great Slave Lake and Simpson"; Geol. Surv., Canada, Sum. Rept. 1921, pt. B, p. 52.

[2] Cameron, A. E.: "Hay and Buffalo Rivers, Great Slave Lake and Adjacent Country"; Geol. Surv., Canada, Sum. Rept. 1921, pt. B, p. 23.

toward the crest of the anticline, since that is where the seepages occur. Any oil that might otherwise have been concentrated at the crest of the anticline is escaping by seepage and no commercial production is to be expected at this locality. The conditions under which the oil occurs lead to the hope that if, at the western end of Great Slave lake where the Presqu'île formation is presumably overlain by the Simpson shales, other anticlines, preferably not so broad, exist, the prospects for oil wells on such anticlines would be very good. On such structures the Simpson shales would form an effective cover to retain the oil in the Presqu'île formation which, as it is sufficiently porous over a wide area where exposed, would probably be porous in the west also. The only exploration so far attempted on the north side of Mackenzie river at the western end of Great Slave lake, was the survey of Horn river and mountain by E. J. Whittaker. Mr. Whittaker found no exposed Devonian rocks younger than the Pine Point limestones and no evidence of structure suitable for oil accumulations. Cretaceous strata form Horn mountain, but since the Devonian is separated from the Cretaceous by an erosional unconformity it is not known if the whole Devonian succession is present; however, as the Simpson shales outcrop on Mackenzie river it is inferred that they are present and hence there would be a suitable cover for an oil-field. Since east of Horn river there are no large streams, the possibility of finding suitable outcrops by which to determine local structure is rather remote and search for structures within this promising area would have to be undertaken by shallow drillings.

There appears to be little prospect of finding oil in the broad anticline at Pine point. No great thickness of Palæozoic sediments is present and as the Pine Point formation outcrops it scarcely could act as a reservoir rock.

At the location of the White Beaver Oil Company's well on Hay river, 15 miles south of Great Slave lake, there is some local folding. Drilling, however, as already stated, yielded a strong flow of salt water from the Presqu'île formation. If there is any movement of underground water through the Presqu'île formation, the presence of sulphur springs and oil seepages on the north shore of Great Slave lake would point to a northward flow, but the regional dip of the rocks is apparently southwestward and there is no known place where the Presqu'île outcrops at an elevation sufficient to give a hydrostatic head great enough to cause the strong flow of salt water at the White Beaver Oil Company's well. Thus, the only probable explanation for this strong flow is that the well was drilled on the flank of an anticline, or dome, in the central part of which gas exists under pressure sufficient to cause the water to flow when the proper horizon was reached by the drill. If such is the case some oil may be present below the gas and above the salt water, but the amount of gas and oil in this structure, if such are present, depends on the size of the structure, i.e. the closure above the salt water. If the well location is high up on the flank of the fold the amount of structure that can possibly be occupied by oil and gas will be relatively small, whereas if the well is at a considerable distance down the flank there is a possibility that commercial supplies of gas and oil may be found. Since the details of the structure and the relation of the well to it are not known no predictions can be made.

Log of the Windy Point Well

The following log of the Windy Point well, as given by Cameron,[1] illustrates the thickness and character of the various formations at this place. The top of the well is 15 feet above Great Slave lake.

Age	Formation	Description	Thickness in feet	Depth in feet
		Sand and broken rock	6	0 to 6
Middle Devonian	Presqu'île dolomites	Light grey dolomite	15	6 to 21
		Dark brown dolomitic limestone	15	21 " 36
		Light brown dolomitic limestone	50	36 " 86
		Soft, grey, shaly limestone	15	86 " 101
		Mottled, partly recrystallized, dolomitic limestone	25	101 " 126
		Soft, grey, shaly limestone	5	126 " 131
		Mottled, partly recrystallized, dolomitic limestone	25	131 " 156
		Soft, grey, shaly limestone	5	156 " 161
		Mottled, partly recrystallized, dolomitic limestone	14	161 " 175
	Pine Point limestones	Grey, shaly limestone	165	175 " 340
		Hard, grey limestone	157	340 " 497
		Brown, shaly limestone	33	497 " 530
		Hard, black limestone	20	530 " 550
		Brown, shaly limestone	30	550 " 580
		Hard, grey limestone	20	580 " 600
		Dark grey limestone	30	600 " 630
		Grey, shaly limestone	50	630 " 680
		Dark grey limestone	50	680 " 730
		Light grey, shaly limestone	40	730 " 770
Silurian	Fitzgerald dolomites	Light brown, dolomitic limestone	20	770 " 790
		Grey, dolomitic limestone with gypsum	110	790 " 900
		Gypsum	10	900 " 910
		Grey dolomitic limestone with gypsum	70	910 " 980
		Gypsum and anhydrite	65	980 " 1,045
[2]Ordovician (at least in part)	Red beds	Red shale with gypsum and salt	25	1,045 " 1,070
		Reddish stained salt	20	1,070 " 1,090
		Salt	30	1,090 " 1,120
		Red shale with salt and gypsum	20	1,120 " 1,140
		Gypsum	40	1,140 " 1,180
		Dark shale with gypsum and salt	20	1,180 " 1,200
		Salt	20	1,200 " 1,220
		Red shale with gypsum	40	1,220 " 1,260
		Red shale with gypsum and salt	120	1,260 " 1,380
		Reddish stained salt	10	1,380 " 1,390
		Gypsum and anhydrite	10	1,390 " 1,400
		Red shale with gypsum and salt	240	1,400 " 1,640
Precambrian		Red sandstone	20	1,640 " 1,660
		Brownish red sandstone	90	1,660 " 1,750
		Granite	56	1,750 " 1,806

[1] Cameron, A. E.: "Hay and Buffalo Rivers, Great Slave Lake, and Adjacent Country"; Geol. Surv., Canada, Sum. Rept. 1921, pt. B, p. 16.

[2] An Ordovician fauna was found in these red beds on the southern part of the North arm. (*See* report "Ordovician and Silurian Fossils from Great Slave Lake"; Geol. Surv., Canada, Mus. Bull. No. 44, pp. 59-64.)

OTHER PROSPECTIVE AREAS WITHIN MACKENZIE RIVER BASIN

The area west and south of Great Slave lake has already been referred to. In this area folding is known to be present in the vicinity of Hay river, though little information is available regarding the extent and magnitude of the folds.

The Mackenzie lowlands to the northwest become much narrower between North Nahanni and Root mountains on the west and Franklin mountains on the east, but farther northward in the vicinity of Redstone and Gravel rivers there is an extensive area overlain by Cretaceous and Tertiary strata in which folds of sufficient magnitude should offer favourable oil prospects in the underlying Devonian. This area extends into Norman field in the vicinity of Little Bear river, although a small mountain outlier south of Norman shows much more intensive folding than is known elsewhere, except in the mountains to the east and west. This small mountain outlier[1] is a sharp fold, but it may be inferred that in an area where such sharp folding occurs there may be as yet undetected folds of a much less pronounced character in which oil may have accumulated.

No attempt has yet been made to study the oil prospects of the Mackenzie lowlands and Peel plateau north and west of Norman field, but it is known that large areas in this part of Mackenzie district are underlain by rocks of the same age as the petroliferous Devonian strata of Norman area.

FRASER RIVER AREA, BRITISH COLUMBIA[2]

By W. A. Johnston

Drilling Operations and Their Results

The first deep drilling in Fraser River Delta area was done about 1875 in search of workable seams of coal. The first bore-hole was located on the south shore of Burrard inlet. About 1887 the Canadian Pacific Railway Company drilled a number of holes at Kitsilano and Port Haney in search of coal, but no logs of these holes are available. A great number of shallow borings in the drift deposits, especially in the Nicomekl-Serpentine valley, and one deep boring by the P. Burns Company, have been made in search of Artesian water. The first well drilled for oil and gas was located at Steveston and was put down about 1906. The recent drilling operations began in 1913 and have continued to the present.

The Steveston well was drilled by Mr. H. C. Fritts, to whom the writer is indebted for the following information regarding the well. A rotary drilling rig was used and a 13-inch hole was carried through sand to a depth of 700 feet, at which point a large boulder was encountered. The boulder was drilled for 6 feet and the 10-inch casing set. A 10-inch hole was carried to a depth of 860 feet, where the first shale bed was encountered and a flow of gas obtained. A gas pressure of 88 pounds to the square inch was obtained by bushing the 10-inch pipe to $\frac{1}{4}$-inch and using a steam gauge. From 800 feet to 1,000 feet, where the first hard shale was encountered, the formation varied from fine sand to shale. The 8-inch casing was set at a depth of 1,000 feet. Drilling was continued with a 6-inch stem to a depth of 1,200 feet, when operations ceased because of lack of capital. A part of the casing still remains in the hole.

The Pitt Meadows well, the location of which is shown on Map 1965, was begun by the Pitt Meadows Oil Wells, Limited, in December, 1913. The well is located on the tidal floats about one mile northeast of Sheridan hill. The first well was put down at this point by the Cosset Development Company, of which Mr. W. T. Patterson was manager, and

[1] Geol. Surv., Canada, Sum. Rept. 1923, pt. B.

[2] Extracted from "Geology of Fraser River Delta Map-area," by W. A. Johnston, Geol. Surv., Canada, Mem. 135, pp. 60-72, (1923).

reached a depth of about 1,200 feet, but owing to difficulties it was then abandoned. The drilling was done with a standard drilling rig. A second hole reached a depth of 1,990 feet on January 1, 1919, only about 100 feet in depth having been made in three years owing to the loss of tools in the hole. A depth of 2,026 feet was reached in 1921, when it was decided to put down a diamond-drill hole in the bottom of the hole already drilled. The diamond-drill hole was carried to a depth of 2,724½ feet, the first 100 feet being two and three-eighths core and the remainder two and a quarter core.

The unconsolidated surface deposits in the Pitt Meadows well apparently extended to at least 1,047 feet. The upper part consisted of recent alluvium and the lower part of glacial deposits. Glaciated pebbles are stated to have been brought up from a depth of over 1,000 feet. The character of the upper part of the bedrock is not definitely known as the plant was burnt in January, 1914, and the samples were lost. . . . . . . It is stated by Mr. C. A. McRae, manager for the company, that salt water containing oil with a paraffin base was struck at 1,148 feet and that a small quantity of oily material was obtained from between 1,855 and 1,875 feet. Some gas was also struck. Salt water (density 1·016 and temperature 59° F.) was flowing from the top of the casing in September, 1921, and bubbles of gas were rising through the water. The temperature of the water indicates that it comes from a depth of several hundred feet, for it is 10 degrees warmer than the spring waters in the area, which are very nearly the same as the mean annual air temperature.

The Port Haney Oilfields Company drilled a well in the bed of Kanaka creek about 3 miles east of Port Haney and 1 mile east of the eastern boundary of Map 1965. The hope of finding natural gas or oil at this locality was based on a reported occurrence of gas in a diamond-drill hole put down about 1890 by the Canadian Pacific railway. The present drill hole is located near the southeast corner of sec. 15, tp. 12, W. 7th mer., and is about 10 feet from where the old hole is supposed to have been. The well was drilled 1,254 feet with a small keystone drilling rig. Small flows of gas are said to have been struck at 193 feet and at 262 feet. No oil was found. Fresh water issues in a small stream from the top of the casing, a part of which remains in the hole, and bubbles of gas rise through the water.

The Spartan Oil Company, of which Mr. S. W. Miller is manager, was organized in 1918 with a capitalization of $500,000 and took up oil rights over 260 acres comprised in lots 120 and 131 in the municipality of Vancouver, 3 miles east of the boundary of the city. Hopes of obtaining oil were based largely on a supposed oil spring or seepage near the company's holdings. The occurrence is described elsewhere. On the advice of Mr. Wm. Jewell, a geologist who examined the area in 1918, a test hole was put down 2,000 feet. It is stated that oil and gas were encountered at different levels and at 1,669 feet a sand was encountered that the company's geologist believed would prove commercially productive. He recommended that a well be drilled to 3,000 feet, or lesser depth if oil were met in satisfactory quantity. Well No. 2 was put down and reached a depth of 2,875 feet early in 1922. Drilling operations were then discontinued. The caving of soft clay shales, especially in the lower part of the well, caused considerable difficulty. The elevation of well No. 1 is 131 feet and of well No. 2, 216 feet above sea-level. . . . . .

The Boundary Oil Company, Limited, of which Mr. S. A. Thompson is managing director, was organized in 1918 with a capitalization of $500,000, increased to $1,000,000 in 1920. The company holds leases on the tidal flats at Boundary bay, 16 miles south by east of Vancouver. Drilling began in 1919, four test holes being put down to about 350 feet. A new drilling plant was purchased and well No. 2 was drilled to 2,473 feet when the tools were lost and all efforts to recover them failed. No. 3 well (*See* Map 1965) was started on April 6, 1921, and on June 3 was down 2,300 feet. . . . . . . Below 2,300 feet considerable difficulty was caused by sand partly filling the casing. The sand apparently came from some point above the end of the 10-inch casing, but may have come, in part, from beds lower down. . . . . . . The boring reached a depth of 4,112 feet in March 1922 . . . . . . the bottom 350 feet of which contains perforated button screen casing set opposite six sand horizons. An attempt to test the well by bailing was then made. Considerable difficulty was experienced in lowering the water in the well, but it was finally bailed to a depth of 3,600 feet when the casing collapsed. The casing was reinforced with cement, the bridged-over part was drilled through, and bailing resumed. The test showed no commercial quantities of gas or oil. It is proposed by the company to put down a diamond-drill hole in the bottom of the boring to determine definitely the character of the lower strata. The well was drilled by Mr. C. E. Milburn. It is stated that during the drilling thousands of barrels of water were absorbed by the sands, some of which were dry and contained gas, whereas others were water saturated. It was impossible to tell because of the effect of the heavy mud fluid used in drilling, just what sands were dry and what were water bearing. Water which was somewhat saline was struck at about 2,200 feet and possibly again at a lower level, but most of the water was fresh or nearly so. Small flows of gas were also struck at several horizons. Colours of oil are said to have been observed in the bailings and in the waste water from various depths, and samples of sandstone and shale from near the bottom of the well showed, when treated with chloroform, some light-coloured, oily material. This may be petroleum or an oil derived from fossil resin, the quantity obtained being not sufficient for determination. Samples of material from the well cuttings, which were reported to be gilsonite or solidified petroleum, were found on examination to be lignite.

The Empire Oil and Natural Gas Company, of which Mr. R. H. Wright is manager and Mr. Roy Widney, driller, has been engaged since 1918 in sinking a well in sec. 27, tp. 10, range 4, W. 7th mer. The well is about one-quarter mile south of the Yale road and about one mile east of the eastern border of Map 1965. The elevation is about 325 feet above the sea. A standard drilling rig is used. The first hole was put down 350 feet without reaching bedrock, and was then abandoned owing to boulders in the drift. A second hole reached 140 feet and was also abandoned. A third hole was begun November 27, 1918, and in December, 1922, had reached a depth of 3,980 feet. . . . . . . A test of the hole by bailing, at about 3,600 feet, showed small quantities of highly saline water, but no commercial quantities of oil or gas. The bailings from the well in many cases showed a brownish scum of froth, apparently an emulsion formed by the water, and finely divided carbonaceous and resinous material derived from the cuttings. Several small seams or lenses of lignite were passed through, and some of the lignite contains considerable quantities of fossil resin. The resinous material when treated with chloroform gives a colour somewhat resembling that of petroleum. A sample of material brought up by the bailer from about 3,600 feet was obtained by skimming the surface of the sludge. The sample was examined by R. T. Elworthy, chemist of the Mines Branch, Department of Mines, who reports that:

"The material was treated with the following solvents, with the results noted: (1) chloroform. The substance was thoroughly shaken with chloroform in a separatory funnel. After standing, the chloroform was run off and carefully evaporated on the water bath. A dark brown, sticky residue remained, which had the distinctive smell of a bitumen. It was readily soluble in ether and carbon bisulphide. Petroleum would be very different from the sticky residue obtained. (2) Ether. Ether had little solvent action on the material. (3) Carbon bisulphide, shaken with the material, extracted a dark brown substance similar to that obtained with chloroform. The material when heated at first darkened and fumed slightly, but with no noticeable smell of mineral oil. On further heating to dull redness it became greyish. Chloroform extracted nothing from the heated material. Under the microscope the clay suspension was seen to be impregnated with small, yellow particles which closely resemble ground-up fossil resin. The clay residue, after extraction with chloroform, still contained similar yellowish material, but to a smaller degree. These experiments confirm Mr. Johnston's belief that the soluble material is most probably derived from bituminous shale. The sample was too small for many observations to be made."

A depth of 4,200 feet was reached in June, 1923 . . . . . . Colours of oil showed in the bailings from 4,200 feet and are said to have been obtained at several horizons in the marine series of rocks below 3,540 feet, but no commercial quantities of oil have been obtained. Drilling is being continued in an attempt to thoroughly test the rocks at a greater depth.

Oil and Gas Possibilities

Gas springs occur in the Recent delta of the Fraser at Steveston, at Boundary bay, on the north arm of the Fraser near the entrance, and at other places. They also occur along Still creek near the head of Burnaby lake, at Pitt meadows near Pitt lake, and at various places in the low swamp ground along the Fraser and tributary streams. They are probably all or nearly all springs of swamp gas. The abundance and volume of the springs at Steveston—on account of which the first boring in search of oil or gas was made at this locality—may possibly indicate that the gas comes in part from the bedrock, but the great thickness of the Recent deposits—in which it is hopeless to look for commercial supplies of gas because they have no favourable structure—seems to show that this is not the case. A sample of the gas from Steveston was analysed by Mr. F. C. Phillips[1] in 1894, who found it consisted of: nitrogen, 6·30 per cent; carbon dioxide, 0·14 per cent; and

[1] Am. Chem. Jour., vol. 16, p. 406 (1894).

paraffins (chiefly methane, with traces of the higher hydrocarbons of the series), 93·56 per cent. The gas, whatever its source, is a dry gas and, therefore, is probably not a petroleum gas. A gas spring in Still creek near the Douglas Road bridge is said to bring up, at times, small globules of oil along with the gas bubbles. It is doubtful, however, whether the oil comes from the bedrock, as there is probably a considerable thickness of surface deposits at this point. It is possible, also, that the oil may have been lost during lumbering, or other operations, and become included in the mud in the bottom of the creek. Wet mud or clay has a remarkable affinity for oil and will retain oil for long periods unless it is disturbed, or water is made to circulate through it freely. No gas springs coming from the solid rock are known to occur in the area, though such springs would be difficult to detect and may occur.

Gas flows have been struck in several of the wells drilled in the area. The gas is derived partly from the unconsolidated surface deposits and partly from the bedrock. Probably all or nearly all from the surface deposits is swamp gas. A sample from a considerable depth in the Boundary Bay well was analysed by G. S. Eldridge and Company of Vancouver and was found to consist mainly of methane with only a trace of ethane. The gas, therefore, is probably not associated with petroleum. Gas that is high in nitrogen was struck in the Pitt Meadows well and in the Port Haney well. The gas from the Pitt Meadows well yielded about 99 per cent of nitrogen with 0·5 per cent of oxygen and 0·5 per cent of carbon dioxide. The helium content was found to be 0·003 per cent.[1] An analysis of the gas from the Port Haney well, by G. S. Eldridge and Company, showed: oxygen, 7·5 per cent; carbon dioxide, 1·2 per cent; olefines, 0·15 per cent; paraffins, 22·5 per cent; nitrogen, 68·3 per cent. The helium content was only 0·013 per cent.[2] Water flows from both wells and the gas bubbles up through the water. The samples of gas were obtained by immersing a funnel in the water and filling a bottle by displacement of the water from it. The gas from the Pitt Meadows well—which is almost entirely nitrogen—is probably derived from the dissolved air of the rain and snow water which supplies the flow of water from the well. "The oxygen of this dissolved air, during the underground passage of the water, is used up in chemical processes such as the oxidation of iron pyrites and of organic matter with which it comes in contact. Nitrogen being chemically inactive passes on unaffected, and thus becomes relatively more concentrated in the gases which finally emerge." This theory of the source of the nitrogen springs in Banff area, British Columbia, has been put forward by R. T. Elworthy,[3] and is applicable in the present case. The head which causes the flow water from the wells is evidently derived from the high mountainous area in the wells, and the rocks are well jointed, so that the surface waters containing dissolved air are probably carried down to considerable depths. The gas from the Port Haney well is apparently a mixture of dry natural gas and nitrogen. The natural gas is probably derived from thin coal seams in the rock, and the nitrogen in the manner already described. The gas does not indicate the presence of oil in the rocks, for it is dry gas. The nitrogen is of no value for the manufacture of nitrates, for the flows are small, and it is improbable that reservoirs could be formed in the rocks. At depth the gas is dissolved in the water and it appears at the surface as gas bubbles when the pressure is removed. Nitrogen is detrimental to natural gas as an illuminant or as fuel, for it dilutes the hydrocarbon content and lowers the calorific value. The general question of the occurrence in commercial quantities of natural gas—which depends on the structure of the rocks of the area—is described under "structure".

Oil seepages are reported to occur at several points in the area. The first definitely reported and the only one said to come from bedrock is that already referred to, in the woods of north Vancouver. The correct location is probably in the bed of a small creek on district lot 815, in west Vancouver. A search for the seepage, in 1920, however, failed. There are several places in this general neighbourhood where oil occurs on the surface waters, but it evidently comes from the greasing of skids in lumbering operations. The basal sandstone and conglomerate of the Tertiary series outcrop in places near the supposed location of the seepage and if a seepage occurs it probably comes from these rocks. In 1914 the west Vancouver Hollyburn Oil Company was organized to drill at this locality, but no drilling was done.

The best known and most important of the supposed seepages is known as the Burnaby, and is located in a peat bog just south of the Great Northern railway about 2,000 feet west of Sperling avenue (Pole-line road), near the west end of Burnaby lake. It is said to have

[1] McLennan, J. C.: "Report on Some Sources of Helium in the British Empire"; Mines Branch, Dept. of Mines, Canada, Bull. No. 31, p. 15 (1920).

[2] Ibid., p. 15.

[3] "Mineral Springs of Canada," Mines Branch, Dept. of Mines, Canada, Bull. No. 20, pt. II, p. 143 (1918).

been discovered in 1917 by Thomas Hannah, who fell through a hole in the peat and found that his legs were covered with crude oil. It is also stated that the occurrence was known for several years previous to 1917, but this seems to be in doubt. Large quantities of oil have been obtained from the locality and oil could still be seen on the surface of the water in 1922. A small stream of water flows into the bog near where the oil occurs, but the water in the bog is nearly stagnant except after heavy rain. Several square yards of the surface peat are saturated with the oil, which oozes from the peat in periods of high water and appears on the surface of the water in pools beneath and between the stumps of large trees that have been killed by fires or removed in lumbering operations. It is again absorbed by the peat when the water falls. The peat has a maximum depth of 27 feet and is underlain by silty clay interbedded with thin, peaty layers. The depth of the peat decreases rapidly towards the north, the bog extending only about 100 feet in this direction. The peat—which is in reality only slightly altered vegetable material—showed no signs of oil except in the upper part, nor did the underlying silty beds. No appreciable quantities of gas occur. In the spring of 1922 borings were made, pits were sunk, and a pump was installed, under the direction of Mr. C. Estlin, to obtain the oil and determine whether a true seepage existed. Mr. Estlin states that 10 barrels of oil were recovered. The oil came with the water and ceased when the water was pumped out. Channels in the peat, one foot or even more in diameter, were found. The oil occurred chiefly in the channels and on the under side of logs in the peat. No oil was found in the clay under the peat.

A sample of the oil from the Burnaby peat bog, collected by the writer in 1920, was analysed by Mr. P. V. Rosewarne, chemist of the Mines Branch, Department of Mines, who reports on it as follows:

Specific gravity at 15·6° C. (60° F.) = 0·974

Distillation test—

Water distillate, 6 per cent at 100° C.
Oil distillate (straight run)

1st drop	at 275° C.	40 per cent	at 370° C.
5 per cent	at 305° C.	50 "	" 380° C.
10 "	" 322° C.	60 "	" 386° C.
20 "	" 341° C.	62 "	" 388° C.
30 "	" 355° C.		

Cracking began at 388° C.

Water distillate obtained	6·0	per cent
Oil, straight run distillate	62·0	"
Oil, after cracking had begun	19·0	"
Residue	10·5	"
Loss	2·5	"
	100·0	
Total bitumen in residue, soluble in carbon bisulphide	11·9	"
Paraffin base in residue	4·5	"
Asphalt base in residue	7·4	"

Unsaturated hydrocarbons

16 cc. sample of crude oil was shaken up with sulphuric acid (sp. gr. 1·84) and repeatedly cooled in ice water.

The whole mass became thick, black, and viscid. No line of separation could be detected, even after the sample had stood for several days

Saponification of crude oil

Duplicate tests showed no saponifiable matter present

Summary

(a) Results which suggest that oil is a crude oil
- (1) Comparatively wide distillation range
- (2) Ease of cracking
- (3) Relatively large residue on distillation
- (4) Both paraffin and asphalt bases present
- (5) No saponifiable matter
- (6) A similar oil to above was sent to this laboratory for analysis from the same locality in 1917

(b) Results which suggest that oil has been previously refined
- (1) No low boiling fraction
- (2) High specific gravity

Conclusion

(a) If sample is an oil not native to the locality it seems likely that it is either crude oil from some other oil-field or an unfiltered stock oil from a refinery.

(b) The weight of evidence seems in favour of declaring sample to be a crude oil, since it must be remembered that crude oils have been obtained which contain no fraction boiling at a low temperature and which have a high specific gravity, but whether the sample is native or not to the locality in which it was collected, it is impossible to state from results of laboratory tests.

The source of the oil is not definitely known. Granting that it is a crude oil, as seems probable, it is difficult to understand how it can be derived from the bedrock. At the diamond-drill hole of the Spartan Oil Company, about 1,000 feet north of the occurrence and about 75 feet higher, the surface deposits are 110 feet thick and they are probably as thick or thicker beneath the bog. The surface deposits consist in part of silt and clay and if the oil has passed through this material, as it must have done if it comes from the bedrock, it would probably be filtered and appear at the surface as a light-coloured oil, or would form an emulsion with the water and clay and appear at the surface as impure asphalt, and not as a heavy, dark oil. It has been suggested that a fault occurs along Burnaby valley and that the oil comes from it, but there is no direct evidence of a fault. Even if a fault does occur it would not affect the surface deposits. It has been suggested that a tank car of oil was at one time lost in a sink-hole in the bog along the Great Northern railway a short distance west of this locality, but this has been denied by railway officials. It is at least not evident that the oil comes from the bedrock and, therefore, the occurrence cannot be considered as proof that the rocks are oil bearing.

An oil seepage was reported to occur on the property of Mr. P. W. Thomas, on Imperial street, in Point Grey municipality. A strong odour of gasoline, and some oil, were noted by Mr. Thomas in digging a drain there. A small, undrained depression occurs in the surface deposits and the oil may at one time have been lost and remained on the surface of the groundwater until brought to the surface by the rise of the groundwater during an exceptionally wet season. Oil, if spilled, will sink into the ground and remain on the surface of the groundwater for long periods unless the ground has sufficient slope to cause the groundwater to flow. The surface deposits are of considerable thickness at the locality, so that it is not evident that the oil comes from the bedrock. The reported occurrences of oil in water wells in the surface deposits at several places in the area are probably due to oil that has been lost and is slowly moving down slopes on the surface of the groundwater.

Sand or sandstone impregnated with fir pitch has been noted at several places in the region, but is not an indication of the presence of petroleum. The material is partly soluble in chloroform, to which it gives a colour somewhat resembling that of petroleum, and, therefore, may readily be mistaken for it. It, however, has not the odour or general appearance of petroleum.

Salt water is generally met with in oil wells, but its occurrence in the rocks does not necessarily indicate the presence of petroleum. Fresh water is in many cases encountered at shallow depths in oil wells and deep-seated salt water below the oil, but in some cases the waters met with above the oil horizons are even more salty than the under waters.[1] The under water is usually a brine and may be considered as the sea water that remained in the sediments after they were formed.[2] In many places, however, salt water unaccompanied by oil has been struck in deep wells. Salt or brackish water occurs in many of the wells in Fraser Delta area. The water met with in many of the wells in the surface deposits, particularly in the Nicomekl-Serpentine valley, is brackish. The salt is evidently derived from the surface deposits, which are in part marine. The salt water that flows from the Pitt Meadows well may be derived from these deposits at a considerable depth. A qualitative analysis of a sample of water from the Empire well at a depth of about 3,600 feet was made by Mr. R. T. Elworthy of the Mines Branch, who states:

"The water had a strong saline, bitter taste. It was faintly alkaline in its reaction with methyl orange. The specific gravity at 70 degrees F. was 1·032. The total dissolved saline matter, dried at 110 degrees C., amounted to 43,590 parts in 1,000,000 parts by weight of water, which is equivalent to 3,148·94 grains per imperial gallon. This mineral matter consisted, principally, of sodium chloride, together with smaller quantities of chlorides and traces of sulphates of calcium and magnesium."

The density of the water is greater than that of normal sea water, which at 60 degrees F. is 1·027. It is apparently a brine. Its chief significance is that it indicates that strata of marine origin occur at about this depth, most of the strata passed through above 3,540

[1] Neal, R. O.: "Petroleum Hydrology Applied to Mid-Continental Field"; Trans. Inst. Min. Eng., vol. 61, p. 565 (1920).

[2] Rogers, G. S.: "The Sunset-Midway Oil Field, California"; U.S. Geol. Surv., Prof. Paper 117, p. 66 (1919).

feet being freshwater in origin. It does not indicate the presence of petroleum, but on the other hand does not preclude the possibility of petroleum at greater depths. No salt water was struck in drilling the Spartan wells, the strata passed through being all freshwater in origin. The water flowing from the diamond-drill hole was analysed by G. S. Eldridge and Company and found to contain only 132 parts a million of total solids, which consist mainly of calcium carbonate, with small amounts of silica, alumina, chlorine, sulphates, and alkalis. Water that was brackish, if not salty, was obtained in the Boundary Bay well at a depth of about 2,200 feet and possibly again near the bottom of the well. A sample of water from about 3,600 feet contained only 226 parts per million of solids, consisting mainly of sodium chloride. The sample, however, may have been diluted with fresh water coming in from a higher level. The salt or brackish water indicates the presence of marine horizons, but signifies little regarding the presence of petroleum.

The temperature gradient,[1] which is believed by some investigators to be abnormally high in oil-fields, and, therefore, to be of some significance, is not definitely known. The water bailed from the Empire well at a depth of 2,670 feet had a temperature of 81 degrees F. Taking the ground temperature at the surface as 49 degrees (the mean annual temperature), the temperature gradient to a depth of 2,670 feet is one degree increase for each 84 feet in depth. A Negretti and Zambra thermometer was let down in the bailer to a depth of 4,200 feet and showed a maximum temperature of only 88 degrees F. The temperature gradient is not abnormally high and is apparently less in the lower part of the well than in the upper, but sufficient data are not available accurately to determine the gradient.

The rock outcrops, the cores of the Spartan diamond-drill hole, and rock samples from other wells, indicate that the Tertiary sedimentary rocks of the map-area are mostly of freshwater origin. They contain in places thin seams and lenses of lignite. Geologists are generally agreed that petroleum and natural gas must originate from organic life, either directly or indirectly. "The fact that no commercial accumulations of either are found outside of marine beds, except where these accumulations have clearly come up from marine beds below, would point to the sea as the ultimate source of the organisms or raw material from which these hydrocarbons were derived."[2] The fact that the strata underlying the Fraser Delta map-area are mostly freshwater in origin, therefore, indicates that they are not likely to be oil or gas-bearing unless they are underlain by marine beds from which the oil or gas may have migrated. The numerous thin lenses and seams of coal also show that the vegetable material which the beds originally contained was altered to form coal and not petroleum. Petroleum as a rule does not occur in coal-bearing beds, but in many cases occurs in marine strata beneath the coal-bearing beds and occasionally in lignite-bearing beds; probably in such latter cases because of migration of the oil.[3] Because of lateral variation, also, such as might be expected in alluvial and deltaic beds like those of Fraser Delta region, the same geological horizons may be coal-bearing in the landward part and petroleum-bearing in the seaward part. There is little definite evidence, however, regarding the character of the marine phase of the Tertiary deposits in Fraser Delta region. The salt water struck in the Empire well at a depth of about 3,600 feet indicates that the beds penetrated below that depth are probably marine. The beds are mostly shale, which are probably Tertiary in age. Cretaceous beds may occur in places beneath the Tertiary beds, but there is no evidence that they do. The Tertiary rocks are seen in places to rest on the granitic rocks of the Coast Range batholith. They probably have a maximum thickness of at least 5,000 feet, so that even if Cretaceous rocks do occur they can hardly be regarded as an available source of oil. Moreover, the Cretaceous rocks as exposed on the east side of Vancouver island are in part coal-bearing and are not known to be oil-bearing.[4]

Oil-shales or rocks of somewhat similar character, from which material resembling petroleum can be obtained by distillation or by the use of solvents such as chloroform or ether, have been obtained in small quantities from two of the wells. But oil-shales do not indicate the presence of petroleum. They contain a series of substances, generally classified as "kerogen," from which oil can be distilled. Occasionally they contain some free oil or material resembling petroleum which is soluble in chloroform, but the soluble material is usually small. "Oil and gas in small quantities may be disseminated through all marine shales, and may be localized occasionally in small, porous streaks under conditions where no commercial quantities could be expected. A showing of small quantities of either oil

[1] Ibid., p. 36.
[2] White, I. C.: Bull. Geol. Soc. Am., vol. 32, No. 1, p. 183 (1921).
[3] Emmons, W. H.: "Geology of Petroleum"; 1921, p. 88.
[4] Clapp, C. H.: "Geology of the Nanaimo Map-area"; Geol. Surv., Canada, Mem. 51 (1914).

or gas in a well is, therefore, not a necessary proof of the existence of, or of approach to, an oil pool."[1] The small showings of oil found in marine shales in the lower part of the Empire well, for example, are, therefore, only what might be expected.

The answer to the first question, whether or not the rocks of the area are gas- or oil-bearing, is that they are gas-bearing to some extent, but there is little or no definite evidence that they are oil-bearing, except possibly to some slight extent in the lower marine parts of the rock series. The freshwater origin of most of the sediments shows that oil is not likely to have formed in the rocks. The reasons why oil had not been formed in the fresh-water deposits may be, as suggested by Johnson and Huntley,[2] that bacterial decay of organic material in fresh water differs from that which takes place in salt water. A considerable part of the Tertiary deposits also consists of continental, subaerial deposits, and Schuchert has pointed out that during the formation of such deposits oxidation is so active that commercial supplies of petroleum cannot be formed.[3] The marine phases of the rock series are deeply buried and it is not clear from the results of drilling that they are oil-bearing, at least to any great extent.

The structure of the Tertiary rocks of the northern part of the area—the only part in which bedrock outcrops—is a gentle monocline. The strata have a fairly uniform dip of 10 to 15 degrees towards the south, with only slight variations from this general direction. The dip becomes less towards the south and in the most southerly outcrop at South Westminster is only 4 or 5 degrees. The structure of the rocks in the central and southern parts of the area is not known, but it is unlikely that the southward dip continues as far as the International Boundary, and rocks of similar age are known to be folded in the adjacent state of Washington.[4] The strata penetrated in the Boundary Bay well are, for the most part, younger than the Tertiary beds exposed in the northern part of the area. It is probable, therefore, that a deep downwarping of the basin has taken place and that a great thickness of Tertiary rocks exists in the central and southern parts of the area. The existence of folds which might bring the lower Tertiary beds or older formations within reach of the drill is problematical. The Tertiary rocks are probably down-faulted against the Coast Range batholithic rocks in the eastern part of Burrard inlet and small faults occur at other places. They may be extensively faulted in the central part of the area. Dykes of igneous rocks cut the Tertiary sediments in the vicinity of Vancouver, but are not known to occur in other parts of the area.

The monoclinal structure of the rocks is not necessarily unfavourable, for in such a structure terraces (places where the general dip is flattened or reversed) may occur, and lensing of the strata or sealing of the outcrops by faulting or cementation may produce reservoirs for accumulation of oil or gas. But such structures are usually considered as less favourable than dome or anticlinal structures. There is no evidence of dome or anticlinal structure in the map-area, but such structures may be concealed beneath the drift and alluvial deposits The dykes of igneous rocks in part of the area are not necessarily an unfavourable feature, for oil-fields are known in which dykes of igneous rock occur. The rocks contain many porous sandstone and sand lenses which would form good reservoir rocks and many shale beds which might form impervious covers to prevent the escape of the oil or gas. But the rock exposures and the well logs show clearly that both the sandstone and the shale occur in lenses. This is exactly what is to be expected from the fact they they are mostly freshwater in origin and are mainly alluvial plain deposits. A part is apparently marine and there the individual beds should be thicker and of greater lateral extent. But the marine beds are mostly shale which do not form good reservoir rocks, that is rocks suitable for containing oil-pools. The lens-like character of the freshwater strata and the small extent of the lenses are unfavourable features; for the size of the possible reservoirs is thus restricted and because of the disconnected character of the sand lenses and the presence of numerous shale lenses, opportunity for migration of the oil or accumulation of gas in reservoirs would not be possible to any great extent, even if considerable quantities of oil or gas were present in the rocks. The presence of natural gas in the rocks at considerable depths, and under considerable pressure, as was found in the Boundary Bay well, might be taken as evidence that a favourable structure for gas accumulation exists. But the gas pressure which caused blow-outs at the well was probably due to the fact that the gas was under the pressure of the column of water and mud in the hole, and that the blow-out was caused by the sudden relief of pressure on removal of the tools

[1] Zeigler: "Popular Oil Geology," pp. 114, 115.
[2] "Principles of Oil and Gas Production"; 1916, p. 21.
[3] "Petroliferous Provinces," Discussion of E. G. Woodruff's Paper; Trans. Am. Inst. Min. Eng., Chicago Meeting, 1919.
[4] Wash., Geol. Surv., Bull. No. 13 (1916).

or by the action of the bailer. Flows of gas which continued violently for short periods have been struck in several of the wells. But the lens-like character of the freshwater strata and the fine-grained character of the marine strata seem to show that there is little chance of accumulations of natural gas in reservoirs of sufficient size to be of commercial importance.

The answer to the second question, therefore, whether or not the structure of the rocks is favourable for the accumulation of oil or gas into pools of sufficient size to be of commercial importance, is that the general structure of the Tertiary rocks may not be unfavourable, but their internal structure is such that important reservoirs of oil or gas are not likely to occur. It is hopeless to drill for oil in the igneous rocks of the Coast Range batholith; they are not a possible source of oil and are not sufficiently porous to act as reservoir rocks. It is not definitely known whether older sedimentary rocks underlie the Tertiary rocks in places in the area, but even if they do they are probably beyond the reach of the drill. It must be concluded, therefore, that the prospects of obtaining commercial supplies of oil or gas in Fraser Delta area are not very bright.

APPENDIX

List of Wells Drilled in Manitoba, Saskatchewan, Alberta, North West Territories, and British Columbia

This list, except the part relating to British Columbia, has been prepared from information supplied by the North West Territories and Yukon Branch, Department of the Interior.

Wells Drilled for Oil and Gas, in Manitoba

—	Well No.	L.S.	Sec.	Tp.	Range	Mer.	Elev.	Depth	Remarks
							Feet	Feet	
Stony Mountain Oil and Gas Co.		7	29	12	2	E 1		1,009	Drilling commenced 1922
At Rosenfield			9	1	3	1	770	1,037	Abandoned
George Mann (Lundar)		NW.	6	20	4	1		Shallow	Drilling commenced 1921. Abandoned
At Morden			5	3	5	1	978	601	Abandoned
Martin and Rathwell	1	NW.	35	19	6	1		28	Drilling commenced 1921. Abandoned
" "	2	9	34	19	6	1		267	Drilling commenced 1921
At Rathwell			7	8	8	1	1,071	1,885	Abandoned
At Manitou			23	2	9	1	1,290	925	Abandoned
At Nepawa			33	14	15	1		1,798	Abandoned
Lindsay and Thompson		NW.	30	22	17	1		380	Drilling commenced 1921. No results
H.E. Gurton and province of Manitoba	1	9	29	30	17	1		113	Drilling commenced in 1920. Abandoned owing to drilling trouble. No oil nor gas
" " "	2	9	29	30	17	1		40	Same
" " "	3	9	29	30	17	1		57	"
" " "	4	NE.	29	30	17	1		1,473	Drilling commenced 1921. Abandoned 1922. No oil nor gas
Agassiz Oil Development Co. (Riding mts.)			26	23	20	1		320	Drilled in 1921. No results
At Vermilion river				23	20	1		743	Abandoned
Riding Mountain Oil Development Co		S	26	23	20	1		320	Drilling commenced 1921
At Deloraine			3	3	23	1	1,644	1,800	Abandoned
Northern Manitoba Oil Co.	1	SE.	33	42	26	1			Drilled in 1921. Abandoned
" "	2	SE.	33	42	26	1		996	Drilling commenced 1921. A little gas at 345 feet. Abandoned
" "	3		33	42	26	1		1,360	Drilling commenced 1923. Gas showings at 230 and 410 feet
Porcupine Mountain Oil and Gas Co.	1	2	3	42	26	1	1,063	350	Drilling commenced 1923. Small pockets of gas. Abandoned
	2	2	3	42	26	1	1,063	977	Drilling commenced 1923. Small showings of oil and gas at 70, 95, 104, 898 feet. Gas in small pockets only. Abandoned 1924

Wells Drilled for Oil and Gas in Saskatchewan (Data to 1924)

—	Well No.	L.S.	Sec.	Tp.	Range	Mer.	Elev.	Depth	Remarks
							Feet	Feet	
At Fort Pelly	....	....	....	32	32	1	....	501	Drilled 1874-5. Abandoned
At Kamsack	....	....	....	29	32	1	....	773	Abandoned
Saskatchewan Exploration and Development Co.	....	....	22	7	3	2	....	1,513	Drilled 1918. Abandoned
North Battleford Oil and Gas Co.... Rambler Exploration Co.	....	1	1	50	5	2	....	30	Abandoned
North Battleford Oil and Gas Co. Man River Oil and Gas Co.	....	2	....	50	5	2	....	300	No information
North Battleford Oil and Gas Co.	....	3	....	50	5	2	....	264	Drilling commenced 1924. Suspended
Souris Valley Oil Fields Co.	....	SW.	24	1	7	2	....	266	Drilling commenced 1914. Abandoned. No oil nor gas
At McLean Station	....	....	13	18	16	2	....	188	Abandoned
Abray and Patterson	....	....	13	15	19	2	1,926	2,410	Drilled 1909–10. Abandoned
At Wilcox	....	NE.	24	13	20	2	1,896	1,450	Abandoned
At Belle Plains	....	....	31	16	23	2	1,877	1,551	"
Moose Jaw	....	....	32	16	26	2	1,778	3,302	"
Hanley Development Co.	....	NE.	6	31	4	3	....	2,069	"
Mackenzie and Mann	....	....	24	39	7	3	1,400	1,358	" Salt water at 1,340 feet
Great West Natural Gas Corp., Rush lake	....	2	30	19	11	3	....	2,325	"
B. F. Emerick (near Keithville)	....	NW.	35	18	16	3	....	414	Drilled in 1910. Abandoned
Battleford Oil and Gas Co.	....	....	....	44	18	3	....	....	No record
Eastend Gas Co.	....	....	31	6	21	3	....	1,245	Drilling commenced 1924. Gas showings at 350, 878, 1,075 feet. Well abandoned. No appreciable results
Northwest Co. (N. Muddy lake)	....	11	7	39	22	3	....	2,233	Drilling commenced 1920. Abandoned. No gas nor oil
Unity Valley Oil Co.	....	....	22	41	24	3	....	....	Drilling
Maple Creek Gas, Oil, and Coal Co.	....	....	15	11	26	3	....	1,860	Gas at 1,120 and 1,500 feet. Abandoned
Northwest Co. (Boundary group)	....	4	9	1	27	3	....	3,963	Drilling commenced 1920. Abandoned 1923. No gas nor oil
H. L. Williams	....	....	23	34	28	3	2,534	2,824	Abandoned

Wells Drilled for Oil and Gas in Alberta

(Data complete to 1926 unless otherwise stated.)
List of wells arranged from east to west and from south to north, except where a few modifications have been made to group wells in the same field.)

—	Well No.	L.S.	Sec.	Tp.	Range	Mer.	Elev.	Depth	Remarks
							Feet	Feet	
Medicine Hat Development Co. (Snake River Oil Co.)	1	4	19	14	1	4	....	1,550	Drilling commenced 1921. Well completed 1922. Three million cub. feet of gas at 1,535 feet
Medicine Hat Development Co......	2	SW.	20	14	1	4	....	....	Drilling suspended
Community Oil Wells, Ltd...........	1	7	19	14	1	4	2,490	2,078	Drilling commenced 1922. Gas at 1,498 and 1,630 feet
Canadian American Oil Co. (leased by Many Islands Oil and Gas Co.)	....	12	31	13	1	4	....	1,315	Drilling commenced 1923. 750,000 cub. ft. of gas
Imperial Oil Co. (Ribstone).........	....	....	5	45	1	4	1,851	....	Gas at 1,392 feet. Oil show at 1,870 to 1,900 feet. Drilling
Ribstone Oils, Ltd..................	1	1	1	46	1	4	1,921	....	Drilling
Advance Oil Co......................	....	1	16	45	1	4	1,933	....	"
Many Islands Oil and Gas Co........	1	13	34	13	2	4	2,368	....	Gas at 795, 1,220, 1,275, 1,427 feet. Oil shows at 3,005 and 3,110 feet
W. B. Nicholson.....................	....	14	12	15	4	4	....	1,306	Operated 1917. Gas 40,000 cub. ft., 120 lbs. pressure Gas used to light and heat two farm houses
Fuego Oil Co........................	....	16	34	25	4	4	2,800	2,270	Drilling commenced 1924. Gas at 887 and 947 feet
Northwest Co. (Misty hills).........	....	NE.	29	32	4	4	2,451	3,304	Drilling commenced 1920. No oil nor gas
William Maybin......................	....	....	19	33	4	4	....	403	Drilling commenced 1922. Abandoned
West Regent Oil and Gas Co.........	....	16	19	34	4	4	2,200	3,540	Drilling commenced 1922. Small amount of gas
Northern Exploration Co. (J. R. Talpey, Monitor)	....	NW.	5	35	4	4	2,219	600	Drilled 1920
Medicine Hat Petroleum Co.........	1	4	14	11	6	4	....	355	Drilling commenced 1922. Hole became crooked
" "	2	5	14	11	6	4	....	800	Drilling commenced 1922. Abandoned
" "	3	5	14	11	6	4	....	550	Drilling commenced 1924

MEDICINE HAT AREA

—	Well No.	L.S.	Sec.	Tp.	Range	Mer.	Elev.	Depth	Remarks
							Feet	Feet	
Medicine Hat, city, Main street	1	SW.	31	12	5	4	2,203	1,042	Initial gas flow 2,500 M. cub. ft.
" " Armoury	2	NE.	31	12	5	4	2,145	1,200	" " 3,000 M. "
" " Rosary	3	NW.	32	12	5	4	2,133	1,000	" " 2,000 M. "
" " Balmoral	4	SW.	32	12	5	4	2,129	1,000	" " 2,500 M. "
" " Elec. plant	5	NW.	35	12	6	4	2,168	1,134	" " 4,500 M. "
" " Craft	6	SW.	36	12	6	4	2,148	1,075	" " 3,500 M. "
" " S. Indust	7	NW.	18	12	5	4	2,347	1,200	" " 2,500 M. "
" " W. Indust	8	NE.	22	12	6	4	2,313	1,202	" " 2,250 M. "
" " Stella	9	SW.	28	12	5	4	2,148	1,002	" " 2,250 M. "
" " Hargrave	10	NW.	31	12	5	4	2,166	1,000	" " 2,500 M. "
" " Cousins-Sissons	11	NE.	25	12	6	4	2,269	1,075	" " 2,750 M. "
" " Central park	12	NW.	30	12	5	4	2,263	1,050	" " 3,000 M. "
" " Maple street	13	NW.	29	12	5	4	2,131	900	" " 2,500 M. "
Iron Rolling Mills, Powell	14	SE.	30	12	5	4	2,140	1,100	" " 2,500 M. "
Alberta Clay Products, B. Chief	15	NE.	29	12	5	4	2,134	1,100	" " 2,750 M. "
Ogilvie Milling Co., Ogilvie	16	NE.	30	12	5	4	2,137	1,050	" " 3,000 M. "
Maple Leaf Milling Co., Marlborough	17	SW.	30	12	5	4	2,152	1,000	" " 1,750 M. "
Purmal Brick Co., Purmal	19	NW.	28	12	5	4	....	1,000	" " 2,250 M. "
South Side Redcliff Gas Co	25	NE.	5	13	6	4	2,451	....	" " 4,000 M. "
Redcliff Brick and Coal Co	26	NW.	5	13	6	4	2,421	....	" " 4,600 M. "
West Side Redcliff Rolling Mills	27	NE.	7	13	6	4	....	....	No record
Broadway Redcliff Gas Co	28	SW.	17	13	6	4	....	1,187	Initial gas flow 5,000 M. "
Dominion Glass Co	29	SE.	17	13	6	4	....	....	No record
East Side Redcliff Gas Co	30	NE.	9	13	6	4	2,413	....	Initial gas flow 4,000 M. "
Dunmore Junction, C.P.R.	31	SW.	15	12	5	4	....	1,325	
Dunmore Townsite well	32	N.	2	12	5	4	....	....	No record
Wellington	34	4	27	12	5	4	....	996	
Canadian Pacific railway, Medicine Hat	1	SE.	31	12	5	4	2,179	900	Abandoned
" " "	2	SE.	31	12	5	4	2,180	960	Initial gas flow 2,250 M. cub. ft.
" " "	3	NE.	36	13	6	4	2,367	....	" " 2,995 M. "
Canada Cement Co	1	16	28	12	6	4	2,360	1,165	" " 2,250 M. "
" "	2	NW.	36	11	6	4	2,331	1,187	" " 1,800 M. "
" "	3	15	14	12	6	4	2,306	1,071	" " 2,500 M. "
" "	4	1	22	12	6	4	2,223	1,075	" " 1,500 M. "
" "	5	1	28	12	6	4	2,292	1,150	" " 1,500 M. "
Roth and Faurot	1	4	6	13	5	4	....	....	Gas at 1,080 feet. Drilled to 3,080 feet
" "	2	....	17	13	6	4	....	....	Drilling

James Mitchell	....	3	3	14	5	4	....	684	Farmer's well. Gas 34,500 cub. feet. Pressure 250 lbs.
Drowning Ford ranch	....	NE.	21	15	5	4	....	....	Farmer's well, producing
North Western Oil Holdings, Ltd	....	9	1	34	5	4	....	400	No record
British Petroleums, Ltd	1	1	36	45	7	4	2,187	2,017	Drilling commenced 1922. Traces of oil at 2,010 feet. Gas at 1,683, 1,796, and 2,010 feet. Hole full of water
" "	2	13	30	45	6	4	2,251	2,038	Drilling commenced 1923. Oil at 2,035 feet estimated initial flow at 100 bbls. a day. Heavy gas flow. Gas used as fuel in drilling other wells. No present oil production
Emerald Oil, Ltd	....	8	30	45	6	4	2,327	....	Drilling
Edmonton Wainwright Oils, Ltd	....	4	29	45	6	4	2,317	....	Oil
Wainwright Dome Oil Co	....	7	31	45	6	4	2,355	....	Oil
British Petroleums, Ltd	3	4	29	45	6	4	2,304	2,296	Drilling commenced 1924. Gas at 1,239, 1,307, 1,435, 1,714, 1,939 feet. Oil showing at 1,939 to 1,966 feet. Also oil showing 2,098 to 2,016 feet. Well abandoned
" "	4	13	30	45	6	4	2,252	2,036	Drilling commenced 1924. Oil from the same sand as in No. 2 well. Gravity of oil, 13·9 Bé.
" "	3B	4	29	45	6	4	....	2.259	Drilled in 1925. Oil sands with some thin shales 2,239 to 2,259 feet. Estimated oil production 50 to 75 bbls. Gravity of oil 18·9 Bé.
" "	5	....	31	45	6	4	2,320	....	Location only
British Wainwright Oil and Development Co	....	4	22	45	6	4	....	....	Drilling
Western Consolidated Oils, Ltd	1	8	20	45	6	4	2,270	....	Drilling commenced 1924. Well not yet completed
" " "	2	....	30	45	6	4	2,301	....	Oil. Well abandoned
Raymond C. Porter	....	3	24	12	7	4	....	1,155	Good flow of gas
George S. Worthy	1	15	12	13	7	4	....	785	Drilling commenced 1924, 150,000 cub. ft. of gas. Pressure 225 lbs.
Northwest Co., Tit hills (Czar)	....	10	17	39	7	4	....	3,500	Abandoned
Interior Oil Co. (Wainwright Oil Producers Syn.) (Wainwright Oil Development Co.)	....	9	36	44	7	4	....	....	Well not complete. Drilling
Imperial Oil Co. (Fabyan)	1	16	18	45	7	4	2,040	2,730	Drilling commenced 1921. 10,000,000 cub. ft. of gas at 1,870 feet. Small amount of heavy oil
Northwest Co., McMurray	1	....	16	88	7	4	1,320	504	Drilling commenced 1917. No results
" " "	2	....	27	85	7	4	1,320	820	Drilled 1918. Abandoned

MEDICINE HAT AREA—*Continued*

—	Well No.	L.S.	Sec.	Tp.	Range	Mer.	Elev.	Depth	Remarks
							Feet	Feet	
Viking Battle Creek Oil Co., Gratton No. 1	1	SE.	4	45	8	4	1,942	1,900	Gas flow 5,000,000 cub. ft.
Northwest Co., Gratton No. 2	2	2	14	45	8	4	1,969	2,015	Drilling commenced 1923. Showings of gas at 1,565 and 1,585 feet. Well abandoned
Sanctuary Oil Co.	1	10	10	5	8	4	....	2,845	Drilling commenced 1922. Gas at 960, 1,150, 2,110, 2,157, 2,190, and 2,566 feet, in all about 50,000 cub. ft. Showing of oil at 2,725 feet
Maple Leaf Oil Co.	1	1	24	45	8	4	1,992	1,775	Drilling commenced 1924. Finished as a good gas well. Showing of oil reported at 1,750 feet
" "	1	....	24	45	8	4	1,937	....	Not drilled at end of 1925
Fabyan Petroleums	....	....	24	45	8	4	1,928	....	Drilling
Trusts and Guarantee Co. (McDougall and Segur Exploration Co.)	....	16	24	2	9	4	....	185	Abandoned
Canadian Pacific railway at Suffield	....	....	4	13	9	4	2,200	1,200	Small show of gas
Village of Suffield	....	....	34	13	9	4	....	715	Drilling commenced 1922. Abandoned
Alberta Pacific Consolidated Oils	....	1	12	45	9	4	....	65	Abandoned
Irma Oil Holdings, Ltd.	....	16	28	45	9	4	2,252	1,014	Drilling commenced 1923. This hole abandoned. Drilling new hole
Charles W. Hague	....	4	11	51	9	4	....	300	Final record not complete
Southern Alberta Land Co.	....	....	34	14	9	4	....	1,900	Small gas well
" "	....	9	24	11	12	4	....	....	Drilled 1912. Record not complete

ATHABASKA AREA

—	Well No.	L.S.	Sec.	Tp.	Range	Mer.	Elev.	Depth	Remarks
Northern Alberta Exploration Co.	....	NE.	17	89	9	4	....	1,475	Several wells sunk and abandoned
Athabaska Oil and Asphalt Co.	1	S. ½	20	91	9	4	....	....	Abandoned
" " "	2	S. ½	8	90	9	4	....	....	"
" " "	3	N. ½	4	89	9	4	....	....	"
Fort McKay Oil and Asphalt Co.	1	NW.	18	94	10	4	....	....	"
" " "	2	SE.	2	93	10	4	....	....	"
A. Von Hammerstein	....	NW.	24	94	11	4	....	....	"
" "	....	....	19	92	9	4	....	....	"
" "	....	....	18	92	9	4	....	....	"
" "	....	....	13	92	10	4	....	....	"

Athabaska Oils, Ltd.				96	11	4			Oil at 100 feet. 250,000 cub. ft. gas
" "				96	10	4			Abandoned
" "				96	10	4			"
" "				96	10	4			"
" "				96	10	4			"
" "				96	11	4			"
" "				96	10	4			"
" "		NW.	36	95	11	4			"
Spokane Athabaska Oil Co.		3	1	97	11	4		143	"
Northern Production Co. (Edmonton Athabaska Oil Co.)	1		30	83	16	4		200	Drilling commenced 1914. Abandoned
" " "	2		30	83	16	4		665	3,000,000 cub. ft. of gas. Abandoned
Alcan Oil Co.	1	NW.	28	96	10	4		262	Abandoned
" "	2	14	24	96	10	4		560	Shows of oil and gas. Abandoned
Pelican Oil and Gas Co.		6	31	78	17	4			Three wells sunk. Heavy gas encountered at 830 feet
" "		NE.	32	77	17	4			
United Oils of Alberta, Ltd.	3	SW.	31	5	10	4		3,716	Three gas horizons penetrated at 1,660, 2,020, and 3,040 feet
Canadian Pacific railway, Alderson			29	15	10	4		1,426	Gas at 1,155 feet
Foremost, C.W.N.G.L.H.P. Co.	1	8	1	6	11	4	3,013	2,191	Well completed 1923. Three gas sands penetrated, giving 26,000,000 cub. ft.
" " "	2	13	29	5	10	4	3,002	2,215	Drilled in 1923. 7,538,800 cub. ft. of gas. Original pressure 600 lbs.
" " "	3	2	36	5	11	4	2,876	2,070	Drilled in 1923. 1,741,824 cub. ft. at 2,015 and 2,019 feet
" " "	4	8	12	6	11	4	3,071	2,252	Drilled in 1924. At 2,235 and 2,250 feet gas amounting to 14,410,000 cub. ft. Well at completion 20,000,000 cub. ft.
" " "	5	1	14	6	11	4			Drilling, 1926
Canadian Oil and Gas Co., Rogers well	1	16	29	1	11	4	3,270	2,797	Drilling commenced 1922; completed, 1925. 20,000,000 cub. ft. of gas encountered. Gas pressure 1,080 lbs. Gas at 870, 1,445, 2,526, 2,650, 2,653, and 2,620 feet
Northwest Co., Dead Horse coulée	2	5	32	1	11	4		2,578	Drilling commenced 1924; completed 1925. Gas at 500, 600, 1,005, 2,355 feet. Well abandoned
Beaver Oils, Ltd.			24	2	11	4		3,055	Abandoned

Bow Island Field

—	Well No.	L.S.	Sec.	Tp.	Range	Mer.	Elev.	Depth	Remarks
							Feet	Feet	
Bow Island, C.W.N.G.L.H.P. Co....	1	6	15	11	11	4	2,300	1,916	Initial gas flow 8,500 M. cub. ft.
" " " ...	2	15	15	11	11	4	2,274	1,907	Abandoned on account of water
" " " ...	3	14	9	11	11	4	2,273	1,887	Initial gas flow 13,100 M. cub. ft.
" " " ...	4	3	17	11	11	4	2,273	1,879	" " 29,000 M. "
" " " ...	5	9	22	11	11	4	2,270	1,986	Abandoned on account of water
" " " ...	6	1	16	11	11	4	2,286	1,918	Initial gas flow 4,190 M. cub. ft.
" " " ...	7	8	18	11	11	4	2,283	1,900	" " 7,000 M. "
" " " ...	8	13	18	11	11	4	2,314	1,930	" " 12,160 M. "
" " " ...	9	2	24	11	12	4	....	1,911	Some gas, water, abandoned
" " " ...	10	8	23	11	12	4	2,281	1,904	" "
" " " ...	11	1	7	11	11	4	2,534	2,159	Initial gas flow 7,300 M. cub. ft.
" " " ...	12	13	7	11	11	4	2,467	2,159	" " 16,000 M. "
" " " ...	13	3	9	11	11	4	2,521	2,085	" " 18,540 M. "
" " " ...	14	1	1	11	12	4	2,548	2,148	No record
" " " ...	15	13	12	11	12	4	2,581	2,148	Initial gas flow 4,000 M. cub. ft.
" " " ...	16	4	4	11	11	4	2,554	2,218	Abandoned on account of water
" " " ...	17	1	25	11	12	4	2,594	2,166	" " "
" " " ...	18	4	1	11	12	4	2,663	2,563	Abandoned
" " " ...	19	16	25	10	12	4	2,531	2,146	Initial gas flow 3,000 M. cub. ft.
" " " ...	20	16	30	10	11	4	2,550	2,167	Abandoned
" " " ...	21	1	30	10	11	4	2,564	2,415	"
" " " ...	22	14	31	10	11	4	2,544	2,151	Initial gas flow 1,300 M cub. ft.
" " " ...	23	16	17	11	11	4	2,396	2,028	" " 2,300 M. "
" " " ...	26	15	33	10	11	4	2,559	2,220	Abandoned
" " " ...	27	4	20	11	11	4	2,496	2,130	Initial gas flow 1,300 M. cub. ft.
Bow Island town....................	....	12	4	11	11	4	2,275	....	" " 7,000 M. "
Fortymile coulée....................	....	4	23	8	11	4	2,621	2,079	Abandoned. Artesian water 500 bbls.
Dreamfield Oil Co...................	1	13	28	3	11	4	....	675	No results
" "	2	12	28	3	11	4	3,342	1,000	Drilling commenced 1921. Shows of oil at 350, 725, and 900 feet. Show of gas at 700 feet. Abandoned
Grand Trunk Pacific Development Co.	....	....	1	1	12	4	....	2,820	Abandoned
Imperial Oil Co., Burdett No. 1.....	....	....	8	11	11	4	....	4,060	"
" " Erickson No. 1.....	....	....	8	1	12	4	....	3,650	"
Urban Oil Co.........................	....	....	4	1	15	4	....	....	"

VIKING FIELD

—	Well No.	L.S.	Sec.	Tp.	Range	Mer.	Elev.	Depth	Remarks
							Feet	Feet	
Northwestern Utilities, Ltd.	1	13	24	48	13	4	2,285	2,435	Initial gas flow 9,000 M. cub. ft.
" " "	2	5	19	48	12	4	2,289	2,373	" " 2,700 M. "
" " "	3	10	25	48	13	4	2,290	2,365	" " 5,000 M. "
" " "	4	3	30	48	12	4	2,306	2,343	" " 1,350 M. "
" " "	5	8	36	48	13	4	2,290	2,220	" " 6,286 M. "
" " "	6	5	6	49	12	4	2,287	2,203	" " 7,617 M. "
" " "	7	1	6	49	12	4	2,303	2,215	" " 7,000 M. "
" " "	8	2	18	48	12	4	2,275	2,430	" " 2,000 M. "
" " "	9	8	24	49	13	4	2,262	2,340	" " 3,250 M. "
" " "	10	16	29	48	12	4	2,316	2,220	" " 3,000 M. "
" " "	11	16	32	48	12	4	2,279	2,152	" " 7,000 M. "
" " "	12	9	12	49	13	4	2,254	2,125	" " 9,000 M. "
United Dominion Petroleum Co. J. R. Talpey, Birch Lake well	....	2	14	50	12	4	2,120	2,411	Drilling commenced 1921. 1,500 M. cub. ft. of gas. Oil showing at 2,030 and 2,140 feet. Operations ceased 1923
Stokes Stephens Oil Co.	....	....	22	2	14	4	....	2,000	Abandoned
" "	....	....	25	2	11	4	....	798	Abandoned. No oil nor gas
Border Oil Co.	....	1	6	1	14	4	....	2,001	Drilling commenced 1922. Showing of oil and gas reported
Devenish Pet.	....	5	27	5	14	4	....	....	Oil
Canadian Pacific railway, Brooks.	....	SE.	32	18	14	4	....	....	Small production of gas
" " "	....	....	31	18	14	4	....	....	No record
Town of Castor	....	NE.	26	37	14	4	....	1,455	Gas at 1,430 feet
Town of Vegreville	....	NE.	19	52	14	4	....	2,000	225,000 cub. ft. of gas at 1,360 feet
Coutts-Sweetgrass Oils, Ltd., McLean well.	....	1	1	1	15	4	....	2,851	(Depth at end of 1923). Oil in small quantity at 350, 725, 900 feet. A little gas at 700 feet. Well abandoned 1925
Oil Lands Exploration Co., Somerville Co.	1	1	2	1	15	4	....	210	Drilling commenced 1922
" " "	2	8	2	1	15	4	....	200	" " 1923
Boundary Oil Co., McCulloch well	....	1	3	1	15	4	....	670	" " 1922. Abandoned
J. F. Moodie Co., Dundas well	1	2	4	1	15	4	....	1,360	" " 1923. Small show of gas
Canadian Pacific railway, Cassils	....	....	5	19	15	4	....	1,000	Small gas production

VIKING FIELD—*Continued*

—	Well No.	L.S.	Sec.	Tp.	Range	Mer.	Elev.	Depth	Remarks
							Feet	Feet	
T. M. Huff (Livingstone Maughan)...	....	1	11	1	15	4	....	310	No record
Lethbridge Oils, Ltd.	....	1	12	1	15	4	3,475	2,030	Drilling commenced 1922. Not operating during 1923-4
Frank Rose (Anglo-Indian Oils), J. F. Moodie..................	....	1	14	1	15	4	....	225	Drilling commenced 1923. Abandoned
Foster Oil and Gas Syndicate........	....	1	15	1	15	4	....	....	Drilling suspended
Northwest Co. (Red coulée).........	....	6	5	1	16	4	3,545	2,700	Drilling commenced 1922. A little gas at 1,525 feet. Oil at 2,505 feet. Well plugged and abandoned
Taber..............................	....	....	32	9	16	4	....	2,350	Abandoned
Chin coulée, C.W.N.G.L.H.P. Co....	1	14	31	9	17	4	2,708	2,166	Initial gas flow 4,000 M. cub. ft. Pressure 630 lbs. Main pipe-line to Calgary
" " "	2	3	1	10	18	4	2,700	2,622	Abandoned
" " "	3	14	6	10	17	4	2,709	2,254	Abandoned. No oil nor gas
" " "	6	5	32	9	17	4	2,223	2,508	Drilling commenced 1922. Show of gas at 925 feet
" " "	7	15	32	9	17	4	2,693	2,183	Drilled 1923. 750,000 cub. ft. of gas
" " "	8	16	29	9	17	4	2,721	2,470	" No oil nor gas
Prairie Natural Gas Co.............	1	4	36	32	17	4	....	400	Drilled 1920. 45,000 cub. ft. of gas at 400 feet. Pressure 45 lbs.
" "	2	4	36	32	17	4	2,750	477	Showings of gas at 302, 311 feet, 90,000 cub. ft. of gas at 371 to 381 feet. Show of gas at 435 feet
" "	3	5	36	32	17	4	2,800	480	Drilling commenced 1924. 100,000 cub. ft. of gas
Victoria............................	....	....	12	58	17	4	1,850	1,870	Abandoned
Santa Barbara Oils, Ltd............	....	....	31	78	17	4	....	2,120	"
Bassano............................	....	12	8	21	18	4	....	1,500	Initial gas flow 80,000 cub. ft.
Tofield.............................	....	....	1	51	19	4	....	1,203	Some gas. Abandoned
Camrose............................	....	....	2	47	20	4	2,427	1,235	149,200 cub. ft. of gas
Lethbridge.........................	....	....	31	8	21	4	2,983	2,220	Abandoned
MacDonald Syndicate...............	....	12	26	3	22	4	....	....	Drilling commenced 1924
Gleichen............................	....	....	13	23	22	4	....	502	Abandoned
"	....	....	13	22	23	4	2,926	502	"
West Canadian Coal Mining Co......	....	....	35	9	23	4	....	658	"
Fairholm Oil and Gas Co...........	....	SW.	30	52	23	4	....	2,065	Drilling commenced 1913. Flow of gas at 882 feet

In Edmonton			30	52	23	4		940	Abandoned
North Western Oil and Gas Co		South end of 1st ave., Edmonton						1,050	"
" " "		Jasper ave., Edmonton						1,800	"
Monarch, C.W.N.G.L.H.P. Co	1	10	1	10	24	4	2,950	1,775	Drilling completed 1920
" " "	2		12	10	24	4	3,093	2,813	Drilling commenced 1920. Suspended
Wetaskiwin	1	NE.	14	46	24	4	2,482	1,401	90,000 cub. ft. of gas daily
"	2	NW.	13	46	24	4	2,485	1,210	116,000 cub. ft. of gas initial flow
"	3	NE.	14	46	24	4		3,185	Abandoned 1919. No oil nor gas
Lethberta Oil Co		15	5	1	25	4		1,900	Abandoned
" " (Weeks well)		1	1	2	26	4		1,250	"
Dominion Oil Co		14	4	1	25	4		540	"
Weeks Alberta Oil Associates	1	16	5	1	25	4		1,900	"
" " "	2		5	1	25	4		2,780	"
Ponoka asylum	1	NW.	29	42	25	4		2,500	Operated 1916. 100,000 cub. ft. of gas. Abandoned
" "	2	4	32	42	25	4		2,650	302,040 cub. ft. of gas at 2,604 feet
American Canadian Oil Co., Morinville		SE.	13	56	25	4			Abandoned
California Alberta Oil Co		W.½	6	57	25	4		490	"
Lethbridge Oil Co		9	36	1	26	4		1,900	"
McFarlane Oil Co		NE.	14	2	26	4		2,900	"
Mutual Oil and Gas Development Co., Globe Drilling Co		13	14	47	27	4	2,450	1,180	Drilling commenced 1921. 250,000 cub. ft. of gas at 370 to 381 feet
T. E. Forester		11	6	19	28	4		220	Suspended
William Murray			6	19	28	4		770	No oil, a little gas
Federal Oil and Gas Co		NE.	22	20	28	4			Abandoned
Sam Drumheller Oil Co			13	20	29	4		300	Suspended
Ranchmen Oil Co		16	13	20	29	4			Drilling
Original Discovery Oil Co			30	1	30	4		1,020	Abandoned. No oil nor gas
" " "			30	1	30	4		1,294	Small seepage oil at 910 to 930 feet. Abandoned. Diamond-drill hole
Lineham Oil Co		16	30	1	30	4		1,900	Oil obtained. Abandoned
Western Coal and Coke Co	1		26	1	30	4			Abandoned
" " "	2		23	1	30	4			"
" " "	3		32	1	30	4			"
Pincher Creek Oil and Refining Co			29	1	30	4			"
" " "			4	2	30	4			Two holes 300 to 1,500 feet. Abandoned 1905
Northwest Co. (Twin butte)	1	15	14	4	30	4		2,780	Abandoned. No oil nor gas
" " "	2	1	20	3	29	4		4,392	Abandoned
Western Oil and Coal Co		SE.	27	6	30	4		1,510	Drilled in 1907. Abandoned
Pincher Creek Oil and Refining Co		8	24	1	1	5			Four holes from 300 to 800 feet; abandoned
" " "		9	25	1	1	5			Abandoned
Calgary Natural Gas Co			11	24	1	5		2,454	Some gas

—	Well No.	L.S.	Sec.	Tp.	Range	Mer.	Elev.	Depth	Remarks
							Feet	Feet	
Willow Creek Oils, Ltd.		1	4	8	2	5		1,686	Abandoned
" "		12	21	9	2	5		1,385	"
Imperial Oil Co. (Rice creek)			4	14	2	5		5,747	Abandoned
Northwest Co., Willow creek	1	14	29	14	2	5		3,602	Some gas. No oil. Abandoned
" " (Alberta Assoc. Oil-fields)		5	7	16	2	5		2,800	Abandoned
Regina Progress		7	32	19	2	5	4,010	2,000	"
Dutch America (Record well)		13	4	19	2	5			Drilling. Some oil and gas
Dallas Oil Co.	1	11	20	19	2	5	4,204	3,100	Abandoned
Home Oil Co.	1	10	20	19	2	5	4,199	4,560	Drilling
" " (Advance No. 1)	1A	14	20	19	2	5	4,203		Temporarily closed down
" " (Advance No. 2)	2	14	20	19	2	5	4,205		" "
Midwest Oil Co.	1	8	31	19	2	5	4,028	3,750	" "
" "	2	3	24	20	3	5	4,024	3,740	" "
Royalite Oil Co.	1	14	6	20	2	5	3,959	3,924	Producing from Blairmore-Kootenay
" "	2	11	6	20	2	5	3,965	3,170	" " "
" "	3	14	6	20	2	5	3,914	2,830	Shut down
" "	4	12	7	20	2	5	3,978	3,740	Producing 500 bbls. per day from Palæozoic dolomite
" "	5	13	7	20	2	5	3,984		Abandoned
" "	6	16	31	19	2	5	4,000		Drilling
" "	7	3	13	20	3	5			"
Union Pacific Consolidated Oils, Ltd.		NW.	2	20	2	5		1,500	Abandoned
" " "		SE.	1	21	4	5			"
" " "		SW.	1	21	4	5			"
Fidelity Oil and Gas Co.		SW.	9	20	2	5			"
Sentinel Oil Co.			8	20	2	5	3,858		Drilling
New Valley Oil, Ltd.		4	6	21	2	5	3,873		"
Mount Stephen Oil and Gas Co.		13	7	20	2	5		2,150	Abandoned
" " "			7	20	2	5		1,400	No oil nor gas
Dalhousie Oil Co. (south'n Alberta)	1	4	18	20	2	5	4,002	3,546	Drilling. Oil in Blairmore-Kootenay
" " "	2	5	18	20	2	5	4,015	3,600	Abandoned at present
" " (Alberta, south'n)	3	10	13	20	3	5	4,046	3,200	Some oil
" " " "	4	8	13	20	3	5	4,012	3,600	"
" "	5	16	30	19	2	5	4,036		Drilling
" "	6	10	13	20	3	5			"
Big Chief Oil Co.			5	20	2	5	3,993		"
British Dominion Oil and Development Corp.	1	4	5	20	2	5	3,986		"
Highland Oil Co.		5	5	20	2	5	3,986		Suspended temporarily
Cooper-Nanton Oil Co.	1	1	7	20	2	5	3,901		Drilling

Great West Oils, Ltd.	1	SE.	7	20	2	5	3,903	....	Drilling
The Gap Oil Concessions, Ltd.	....	....	33	10	3	5	....	750	Abandoned
Sterling Oil and Refining Co.	....	4	15	17	3	5	....	226	"
Imperial Oil Co. (Highwood)	1	3	36	18	3	5	....	....	Drilling
Calgary Alberta Oil Co.	....	NE.	34	17	3	5	....	232	Abandoned
Black Diamond Oil Co.	1	SE.	3	20	3	5	....	....	"
" "	2	NE.	34	19	3	5	....	....	"
New Black Diamond Oil Co.	1	1	3	20	3	5	....	....	Drilling
McLeod Oil Co.	1	16	1	20	3	5	4,012	2,397	Drilling commenced 1923. 200,000 cub. ft. of gas at 1,000 feet. 20 bbls. of oil at 2,397 feet
" "	2	16	1	20	3	5	4,005	4,363	Producing from Palæozoic dolomite
" "	3	16	1	20	3	5	4,029	....	Drilling
Canadian Southern Oil and Refining Co.	....	9	1	20	3	5	3,996	2,200	Drilling commenced 1914-5. Oil encountered at 1,837, 2,230, and 2,430 feet; also some gas
Illinois-Alberta Oil Co.	1	14	12	20	3	5	4,008	3,858	Drilling commenced 1914. 3,500 M. cub. ft. of gas at 3,038 feet. Well produced 500 gals. per day for a time. Production now secured in Palæozoic dolomite
United Oils of Alberta	1	NE.	3	20	3	5	....	3,150	Abandoned
" "	2	....	23	20	4	5	....	1,500	"
Indiana-Alberta Oil Co.	1	8	1	20	3	5	3,979	2,774	Operated 17 to 20 bbls. of oil per day for a time
" "	2	9	1	20	3	5	3,955	2,555	Abandoned
Calmont Oils, Ltd.	1	2	1	20	3	5	4,016	....	Drilling
Dolomite Oils, Ltd.	1	8	1	20	3	5	3,972	....	"
New McDougall-Segur Oils Co.	1	14	12	20	3	5	4,014	....	Oil at 2,595 feet
Okalta Oils, Ltd.	1	1	1	20	3	5	3,959	....	Drilling
Seneca Oils, Ltd.	....	1	34	20	3	5	3,987 [ground]	....	"
Spooner Oils, Ltd.	1	12	13	20	3	5	4,060	....	"
Stockmen Oils, Ltd.	1	....	27	20	3	5	4,042	....	"
" " (Henderson No. 1)	2	7	27	20	3	5	4,036 [ground]	....	"
Vulcan Oil Co.	1	11	13	20	3	5	4,012	....	Producing from Palæozoic dolomite
Stokes Stephens Oil Co.	....	....	20	21	3	5	....	2,000	Abandoned
" "	....	....	32	21	3	5	....	....	Drilling
McDougall-Segur Oil Co.	....	SE.	16	21	3	5	3,995	3,620	Abandoned
Calgary Natural Gas Co.	....	....	5	24	3	5	....	3,400	"
Mrs. C. B. Walker	....	....	36	53	4	5	....	700	Drilling commenced 1920. No oil nor gas
Carrie Bell Walker Hill	....	....	36	53	4	5	....	110	Drilling commenced 1923
" "	....	....	36	53	4	5	....	....	To be used as a water well
Bragg Creek Oil Co., Ltd.	....	SW.	31	23	5	5	....	950	Abandoned
British Alberta Oil Co.	....	....	11	23	5	5	....	3,148	"

VIKING FIELD—*Continued*

—	Well No.	L.S.	Sec.	Tp.	Range	Mer.	Elev.	Depth	Remarks
							Feet	Feet	
Moose Mt. Oil Co.	1	....	34	23	5	5	....	2,410	Drilling commenced 1914. Produced some oil at 1,624 feet. Abandoned; casing pulled
Signal Hill Oil Co.	1	9	34	23	5	5	....	2,010	Showing of oil at 1,845 feet. Abandoned
" " "	2	9	34	23	5	5	....	1,450	Drilling
Gold Corn Oils, Ltd.	....		Morley Reserve				....	....	"
Reserve Oils, Ltd.	....			"			....	....	"
Wabash Oil Co.	....			"			....	....	"
Janse Bros. Ltd. (Dome well)	....	13	12	25	5	5	....	2,600	Good gas flow at 1,500 feet
Purity Oils, Ltd.	....	9	34	25	5	5	....	1,255	A little oil and gas. Abandoned
Ottawa Petroleum Products, Ltd.	....	7	7	32	5	5	....	....	Abandoned
London Union Oils, Ltd.	....	....	36	30	6	5	....	....	"
Monarch Oil Co.	....	NW.	5	32	6	5	....	3,608	100,000 cub. ft. gas. Abandoned
Mount Stephen Oil and Gas Co.	....	....	25	32	7	5	....	4,500	"
Alberta Associated Oilfields	....	SW.	34	39	10	5	....	....	"
Canadian Northern Oils Co. Prairie Oils, Ltd.	....	15	23	74	17	5	1,900	2,205	5,000 M. cub. ft. of gas
Peace River Oil Co.	1	4	31	85	20	5	....	1,136	Drilled 1917. Abandoned
" "	2	16	24	85	21	5	....	1,125	Drilled 1918. "
" "	3	6	4	85	21	5	....	1,282	" 1919. "
" "	4	9	24	85	21	5	....	....	" 1923, 500,000 cub. ft. of gas at 2,150 to 2,168 feet
Peace River Western Oil Co.	....	....	32	83	21	5	....	....	Abandoned
Victory Oil Co.	....	11	31	83	21	5	....	1,807	
North Pacific Oil Co.	....	10	11	85	21	5	....	850	Abandoned
Tar Island Oil and Gas Co.	....	14	24	85	21	5	....	1,087	Drilling commenced 1918. Oil shows at 982, 992, 1,022, and 1,072 feet. Gas at 855 and 980 feet
Community Oils, Ltd.	....	1	23	85	21	5	....	150	Abandoned
Canadian Petroleums, Ltd.	1	SE.	11	85	21	5	....	1,275	Drilling commenced 1918. Gas at 1,135 and 1,400 feet. Oil showing at 1,050 feet
" "	2	SE.	11	85	21	5	....	3,008	Drilling commenced 1920. Gas at 25, 622, 1,135, 1,272, and 1,516 feet. Showing of oil at 1,050 feet
Peace River Petroleums, Ltd.	1	R. lot 9	31	83	21	5	....	1,162	Drilling commenced 1918. Oil showings at 647, 830, 1,065, 1,124, and 1,151 feet. Gas at 696, 700, 794, 830, and 857 feet
" " "	2	9	28	87	20	5	....	897	Drilling commenced 1920. Oil showings at 205, 276, 410, 522, 805, 822, 844, 864, and 897 feet. Gas at 205 and 864 feet

" " "	3	9	28	87	20	5		890	Drilling commenced 1920. Gas at 860 feet. Abandoned
H. L. Williams		SE. 23		85	21	5			No record
P. M. Oil Co.		7	36	83	22	5		100	Drilling commenced 1924. Suspended
Northwest Co. (Coalspur)	1	11	3	49	21	5		1,490	Drilling commenced 1921. Abandoned
" "	2	3	3	49	21	5	3,777	3,985	Depth in 1925. Drilling. Gas at 880, 925, 930, 1,105, 2,000 feet. 426,000 cub. ft. of gas in all
Pouce-Coupé Oils, Ltd.		14	19	79	13	6		1,482	Drilling commenced 1922. Gas at 750 feet
Great Slave Oil and Refining Co.		SW. 19		80	13	6		110	Drilling ceased 1922
Northwest Co. (Pouce-Coupé)		7	26	80	13	6		3,057	10,100 M. cub. ft. of gas at 1,675 feet. No oil
International Oils			14	74	4	5			Drilling

Since 1926 a number of wells have been located in various parts of the foothills, and particularly in Turner Valley field. These wells are not included in this list.

Wells Drilled for Oil and Gas in North West Territories

Operator	Well No.	Location	Depth	Remarks
			Feet	
Northwest Co. (Windy point)	1	Windy point, north side of Great Slave lake	1,806	Drilling commenced 1920. No oil nor gas. Well abandoned
White Beaver Oil Co.		Hay river, 15 miles south of Great Slave lake	712	Drilling commenced 1922. Heavy flow of salt water. Abandoned
Northwest Co. (Norman) Discovery well	1	50 miles below Norman on east bank of Mackenzie river	1,025	Drilling commenced 1920. Oil at 787 and 993 feet. Production probably 100 bbls. per day
Northwest Co. (Bluefish location)		8 miles below Norman on east bank of Mackenzie river	430	Drilling commenced 1921. Abandoned
Northwest Co. "C" location		West bank of Mackenzie river opposite Bear island	1,704	Drilling commenced 1921. Gas at 145, 300, 385 feet. Small show of oil at 145 feet. Abandoned
" " "C" location		" " "	3,057	Drilling commenced 1922. No oil nor gas, Abandoned
" " "D" location		Bear island, Mackenzie river	2,304	Drilling commenced 1921. Small show of oil at 1,945 feet. Heavy flow of salt water at 2,060 feet. Abandoned
" " Discovery	2	Close to Discovery No. 1 well	1,600	Oil at 895 feet amounting to 25 bbls. per day, but settled to 2 bbls. per day. Production of well as completed about 110 bbls. per day
Fort Norman Oil Co.		6 miles up river from Discovery well. On east bank of Mackenzie river	1,512	Drilling commenced 1921. Between 385 and 500 feet, about 300,000 cub. ft. of gas. No work done on this well after 1921.

Wells Drilled for Oil and Gas in British Columbia

Operator	Well No.	L.S.	Sec.	Tp.	Range	Mer.	Elev.	Depth	Remarks
							Feet	Feet	
Kamloops Natural Gas, Oil, and Coal Co.	1	5	36	19	18	6	1,500	662	Drilling commenced 1920. Suspended
" " " ..	2	5	36	19	18	6	2,250	717	Drilling commenced 1924. Suspended
Surrey Oil Co.	....	9	3	7	....	E.C.M.	....	198	Drilling commenced 1919. Abandoned
Empire Oil and Natural Gas Co...	1	8	27	10	....	E.C.M.	....	361	Drilling commenced 1918. No oil nor gas
" " " ..	2	8	27	10	....	E.C.M.	....	140	Drilling commenced 1918. Suspended
" " " ..	3	8	27	10	....	E.C.M.	....	5,700	Drilling commenced 1918. Showing of oil, some gas
Province Oil and Gas Co.	....	....	30	10	....	E.C.M.	....	....	Drilling commenced 1920. Abandoned
Utility Oil and Gas Co.	1	16	24	10	....	E.C.M.	....	300	Drilling commenced 1920. Abandoned
" "	2	16	24	10	....	E.C.M.	....	336	Drilling commenced 1922. Abandoned
" "	3	16	24	10	....	E.C.M.	....	827	Drilling commenced 1923. Suspended
Lincoln Oil Co.	....	....	32	10	....	E.C.M.	....	....	No information concerning drilling
Monarch Oil and Gas Co.	....	NE.	29	10	....	E.C.M.	....	37	Drilling commenced 1920. Suspended
British Columbia United Oil Co...	....	SW.	22	16	....	E.C.M.	....	230	Drilling commenced 1923. Suspended
Pitt Meadows Oil Co.									
Vancouver Oil and Natural Gas Co.	1	6	18	40	5	E.C.M.	....	1,209	Drilling commenced 1914. A few small showings of oil reported. Nitrogen gas. Abandoned
" " " ..	2	....	13	40	5	E.C.M.	....	2,725	Showing of nitrogen gas and oil reported. Salt water
Fleming Oil Co.	1	lot 2	B. Lulu islands			....	....	230	Abandoned
" "	2	....	"			....	....	....	"
" "	3	....	"			....	....	....	"
" "	4	....	"			....	....	....	"
Spartan Oil Co.	1	lot 130	Burnaby lake			....	....	2,000	Gas and oil showings
" "	2	lot 131	"			....	....	1,800	Oil showings