CANADA
DEPARTMENT OF MINES AND RESOURCES

MINES AND GEOLOGY BRANCH

GEOLOGICAL SURVEY

ECONOMIC GEOLOGY SERIES No. 14

PETROLEUM GEOLOGY OF CANADA

BY

G. S. Hume
Geologist for Oil Controller for Canada

OTTAWA
EDMOND CLOUTIER
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
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INTRODUCTION

Canada can be divided into a number of physiographic provinces in which there is a wide diversity of rock types and structures (Figure 1). The Canadian Shield forms a central axis. It is composed of Precambrian rocks and is entirely devoid of petroleum prospects. It embraces a large area around Hudson Bay, including Labrador and northern Quebec on the east and its boundary on the west extends from the east side of Lake Winnipeg in Manitoba northwest through Great Slave and Great Bear Lakes to the Arctic Ocean. It thus occupies northern Ontario, the northeast parts of Manitoba, Saskatchewan, and Alberta, and a large part of the Northwest Territories east of the Mackenzie River basin. A narrow band known as the Frontenac axis crosses St. Lawrence River into United States east of the east end of Lake Ontario. Lying within the Canadian Shield is the relatively shallow sedimentary basin of Hudson Bay lowland, occupying an area on the west side of James and Hudson Bays as far north as the port of Churchill and extending into the Arctic Archipelago. To the east of the Frontenac axis and south of the eastern part of the Canadian Shield is the St. Lawrence lowland of eastern Ontario and Quebec, underlain by relatively flat-lying strata of Palæozoic age. Farther to the east, in Gaspe Peninsula of Quebec and the Maritime Provinces, more complex structural conditions occur, with extrusions and intrusions of igneous rocks in the extension of the Appalachian system into eastern Canada. West of the Frontenac axis is the sedimentary basin of southwestern Ontario, bounded on the west and south by Lakes Huron, Erie, and Ontario, and on the north by the Canadian Shield.

In western Canada west of the Canadian Shield are the Interior Plains of Manitoba, Saskatchewan, and Alberta (Figure 2) occupying 375,000 square miles of comparatively flat-lying sediments bounded on the west by the narrow but more highly disturbed foothills belt, which forms a border for the mountains for 900 miles from the southern boundary of Canada to Liard River at the 60th parallel of latitude. The mountains are a part of the Cordillera of western Canada that are progressively younger from west to east. The eastern range of the Rocky Mountains is composed mainly of late Palæozoic limestones and dolomites with older sandstones and quartzites. These rocks are more resistant to erosion than the Mesozoic rocks that compose the southern foothills of Alberta, and in consequence the topographic division between the foothills and the mountains is fairly abrupt in most places despite similarity of structural conditions. To the north in northeastern British Columbia there are Triassic beds composed of limestones, calcareous siltstones, and sandstones, with some shales. The resistance of these to erosion is only slightly less than that of the younger Palæozoic beds, so that both give topography of high relief. In northeastern British Columbia also there is a structural gradation from the gentle folds of the Plains to the complicated and faulted folds of more westerly areas. This results in the foothills being less clearly defined by a sharp structural break, as is the case in southwestern Alberta, and thus they become much more of a transition belt between the plains and the mountains.

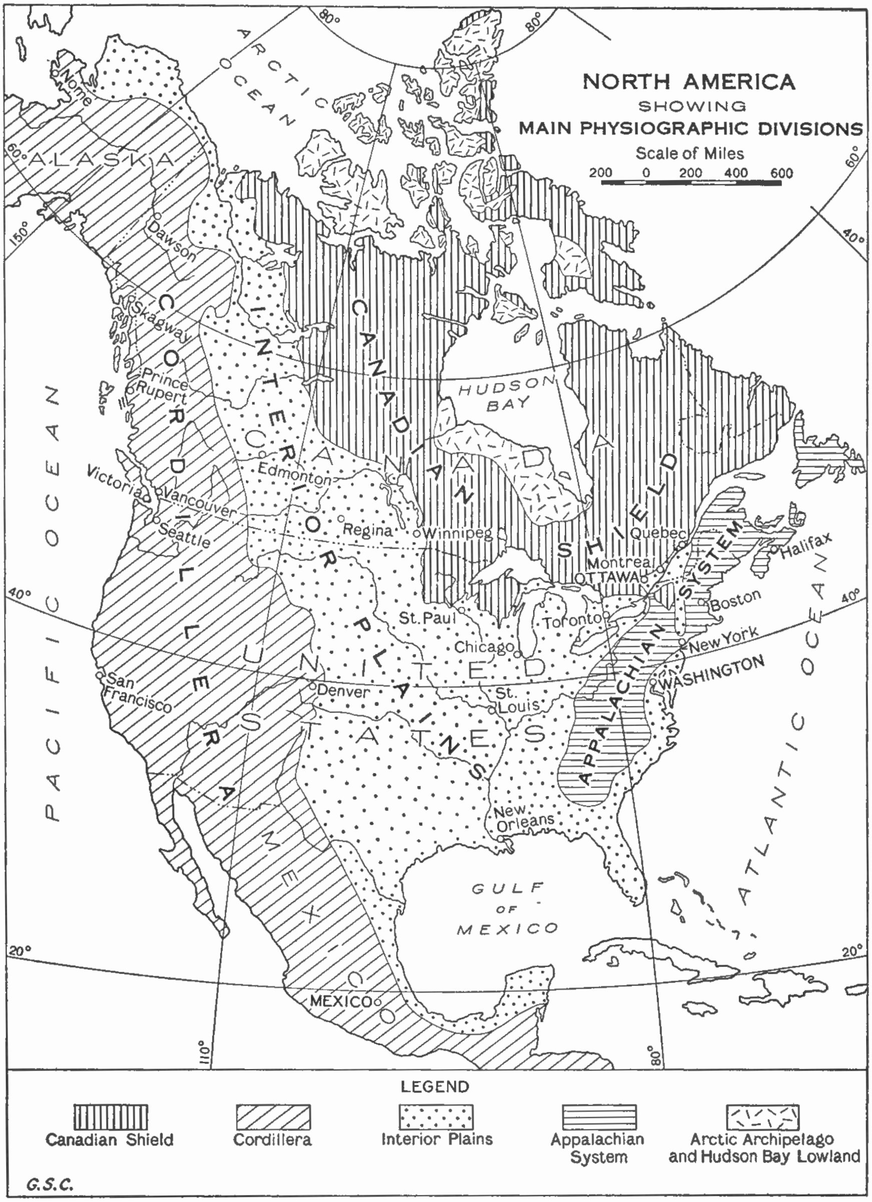

Figure 1. North America, showing main physiographic divisions.

To the north of Liard River at the 60th parallel of latitude the eastern range of mountains is offset to the east and continues northward on the west side of the Mackenzie basin, which occupies 150,000 square miles extending from Great Slave Lake to the Arctic Ocean. Within this area there are no foothills comparable with southwestern Alberta, but there are isolated mountains of folded sediments of Palæozoic and younger ages east of Mackenzie River and west of the margin of the Canadian Shield.

There are a few basins within the Cordillera that may have oil prospects. In the Flathead Valley of British Columbia, close to the International Boundary between Canada and the United States, and west of Waterton Lakes in Alberta there are Palæozoic, Mesozoic, and Tertiary sediments. Also Tertiary sediments occur in the Fraser River Valley of British Columbia near Vancouver. All the Tertiary, however, is believed to be non-marine.

In all these sedimentary areas of Canada only a few oil and gas fields have so far been developed, but these are widely scattered and evidences of oil are still more dispersed. In eastern Canada there is the Stony Creek gas and oil field of New Brunswick where the production of natural gas for domestic and commercial uses rather than the production of oil has been the main incentive for development. Then, too, there are the numerous oil seepages of Gaspe, Quebec, where drilling so far has not yielded producing wells but where the search for oil is still continuing. In Nova Scotia there are seepages of oil in the Lake Ainslie district of Cape Breton and favourable sedimentary and structural conditions are believed to occur on Prince Edward Island, where a well is now drilling.

The Ontario fields in the southwestern peninsula north of Lake Erie are among the oldest of the North American continent and have been producing for more than 80 years. The production has now declined to less than 150,000 barrels a year, and recently the search has been directed toward the discovery of new gas supplies rather than for oil.

In western Canada, in Alberta and Saskatchewan, the search for new petroleum supplies has been more intensive during recent years than in any previous period. Various conditions have contributed to this situation. Among these may be cited the development of the large Turner Valley field near Calgary, Alberta, which attracted attention to the petroleum prospects of western Canada; the wartime demand for large amounts of petroleum products that could not be supplied from the established production; the favourable prospecting regulations put in operation by the Provincial Governments and corporations, who are the main owners of the mineral rights; and, lastly, the important tax and other concessions made by the Dominion Government to encourage prospecting.

In the Mackenzie River basin of the Northwest Territories the oil field at Norman Wells, 75 miles south of the Arctic circle, was discovered in 1920 and a production sufficient to meet local requirements has been maintained since that time. Owing to war demands this producing area has now been developed to the rank of "a major oil field comparable to the average major field in the United States".[1] The search has now been extended over a much wider area, but so far no new fields have been discovered. The prospects are considered to be the best in Canada.

The Alaska Highway, beginning at Dawson Creek and extending north to Fort Nelson and from there northwest to Watson Lake, is almost wholly for the distance of 660 miles within the northeast part of British Columbia. This is probably the most promising oil prospecting territory in British Columbia

[1]Hopkins, O. B.: The Canol Project; Can. Geog. Jour., vol. XXVII, No. 5, Nov. 1943, p. 246.

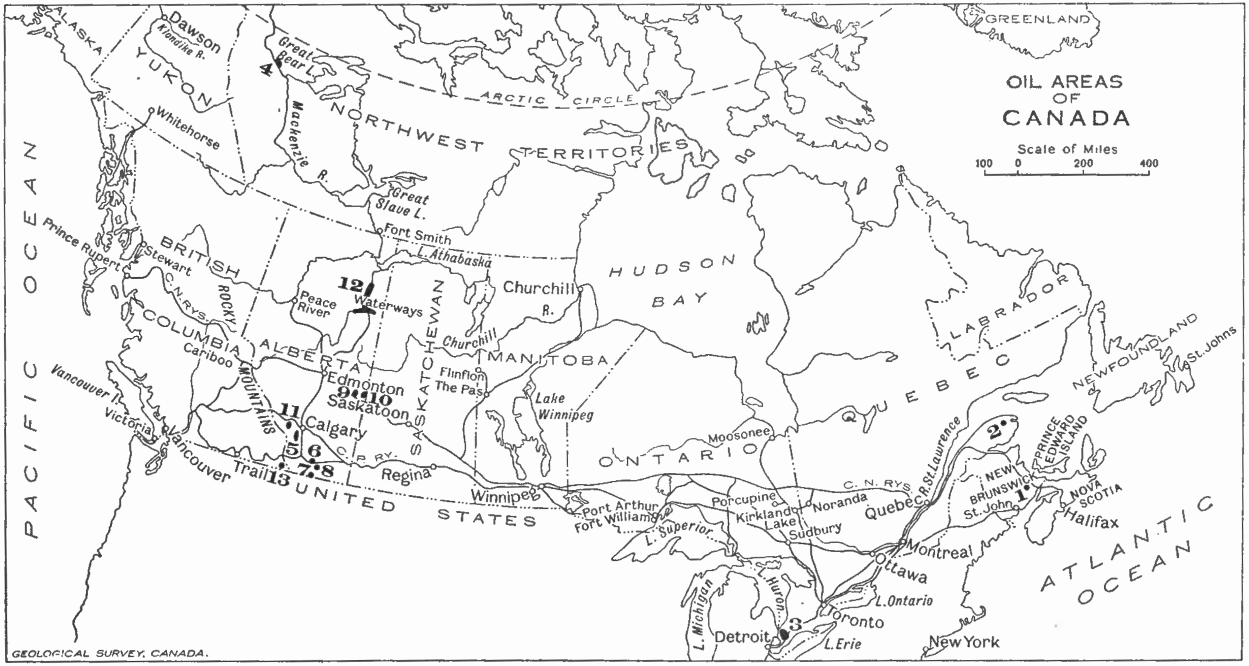

Figure 2. Oil areas of Canada. 1, Stony Creek gas and oil field; 2, Gaspe oil seepages; 3, Oil fields of Ontario; 4, Fort Norman oil area; 5, Turner Valley oil and gas field; 6, Taber oil field; 7, Red Coulée oil field; 8, Skiff oil area; 9, Wainwright oil field; 10, Ribstone oil area; 11, Moose Mountain area; 12, Athabaska bituminous sands; 13, Sage Creek-Flathead area.

and in it are 25,000,000 acres, comprising the northwest extension of the Alberta plains and foothills (Figure 16) and including an area south as well as north of Peace River. In it no deep drilling for oil has been done other than one well undertaken by the Provincial Government of British Columbia on Pine River south of the Peace River block. This well proved unproductive, but cannot be said to even condemn the structure on which it was drilled. During the past two summers considerable topographical and geological work has been done by the Dominion Government Topographical and Geological Surveys both to the south and north of Peace River in British Columbia, but a large part of the area is yet unmapped. It is a British Columbia Government reservation.

In the southeastern part of British Columbia, in the Flathead Valley, there are seepages of light oil issuing from Precambrian rocks. This area has had some prospecting, but so far has been inadequately tested. The oil accumulations, if present, are probably the result of a segregation in an anticlinal structure below a folded fault.

HUDSON BAY LOWLAND[1]

South and west of James Bay and extending northwest along Hudson Bay to the mouth of Churchill River is a low coastal plain with a maximum width of 150 miles (Figure 3). It contains Ordovician, Silurian, and Devonian strata, each known to rest directly on the Precambrian in various localities. In the south are local areas of Lower Cretaceous beds with thick seams of lignite.

In Moose River area south of James Bay a bore-hole has been drilled through the Lower Cretaceous to the Precambrian at a depth of 1,027 feet. It penetrated the following section[2]: 6 feet of muskeg; 74 feet of marine Pleistocene clay; 170 feet of Lower Cretaceous, of which the upper 114 feet is coal-bearing; 405 feet of Upper Devonian, consisting of 285 feet of grey shale, in part bituminous, underlain by 120 feet of porous cavernous limestone; 372 feet of Middle and Lower Devonian, consisting of 32 feet of red gypsiferous shale and gypsum; 149 feet of grey shale; 100 feet of limestone, of which the lower 63 feet is porous and cavernous; 59 feet of shale and limestone interbedded with gypsum; and 32 feet of arenaceous limestone and calcareous sandstone, in part red and carrying veins of gypsum and selenite. The Upper Devonian has been correlated on fossil content with the Portage and Hamilton of New York, and the upper 37 feet of the Middle Devonian with the Onondaga. The age of the remainder is more uncertain, but in part it contains a Lower Devonian flora.

The Silurian is exposed on several rivers flowing into the west side of Hudson Bay and consists of limestones and dolomites 295 feet thick. About 185 feet of this is Niagaran in age and the remainder has been correlated with the Alexandrean of the Michigan-Ohio basin, but is more closely related to the northern Silurian rocks of the Arctic Archipelago.

The Ordovician is only about 150 feet thick, consisting almost wholly of limestones where exposed. It is now regarded as Richmond in age.

In the area west of Hudson Bay the thickness of Silurian and Ordovician is so small that the prospects for oil are not attractive. The regional dip of the strata is to the east at a rate only slightly greater than the gradient of the rivers flowing to Hudson Bay. At various localities there are low undulations

[1]Wilson, A. E., Stewart, J. S., and Caley, J. F.: Sedimentary Basins of Ontario, Possible Sources of Oil and Gas; Roy. Soc., Canada, vol. XXXV, sec. IV, pp. 167-171 (1941). *Also see* Possible Future Oil Provinces of Eastern Canada; Bull. Am. Assoc. of Pet. Geol., vol. 25, No. 8, 1941.

[2]Dyer, W. S.: Oil and Gas in Eastern Canada, by G. S. Hume; Geol. Surv., Canada, Ec. Geol. Ser. No. 9, p. 90 (1932).

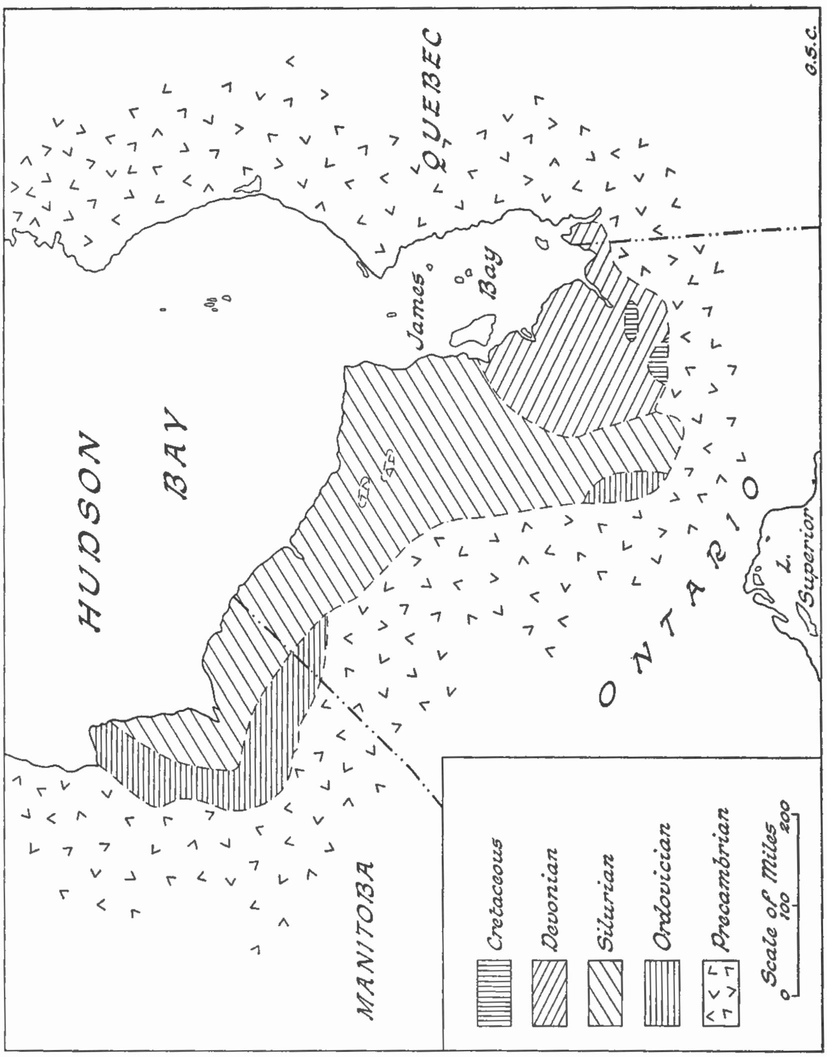

Figure 3. Hudson Bay Lowland.

10 to 50 feet high, and on one of these on Winisk River about 5 miles above the mouth of its tributary, the Shummatra, the base of the Silurian is exposed resting unconformably on Precambrian quartzites.[1] It would appear, therefore, that this "fold" may be due to deposition on a ridge of Precambrian rocks.

In Moose River area to the south and west of James Bay the oil prospects, if any, will be related to the Devonian because as shown by the bore-hole that was located in the centre of the basin, there are no older rocks above the Precambrian. In this area the oil prospects are considered[2] more favourable than on Albany River to the west, where erosion has exposed the Middle Devonian beds. Some bituminous beds have been noted, particularly in the Long Rapids formation of Portage age, the highest Upper Devonian present in the area. Analyses of these bituminous beds, some of which are shales and one, at least, bituminous limestone, showed an oil content of 1·6 to 5½ Imperial gallons a ton. Also porous beds are present that could act as reservoir rocks. On the lower part of Long Rapids of Abitibi River, about 75 miles from James Bay, a prominent anticlinal fold is present in Upper Devonian strata. According to Williams[3] this fold trends north about 65 degrees east and dips of 6 to 13 degrees have been recorded on the flanks. Smaller subsidiary folds are superimposed on the larger fold, which is well defined by limestone outcrops near the head and foot of Long Rapids. Precambrian rocks have been reported 4 miles to the northeast and hence it has been suggested that the "folding" is due to the uneven surface of the underlying crystalline rocks. The gypsum beds are also folded quite sharply in some places, but there has been no suggestion that this has been caused by tectonic forces rather than by internal changes induced by weathering agencies. Other folds are also present, so that so far as structure is concerned the necessary conditions for the accumulation of oil are present. In all the area, however, no seepages of oil are known to have been reported and there were no evidences of oil in the deep hole drilled in the centre of the Moose River basin. No dykes have been found cutting Cretaceous beds, but dykes have been noted cutting the Devonian in a few places and it has been suggested these may have accompanied some local pre-Cretaceous folding. The contact, however, between the Cretaceous and underlying Devonian, where observed, is not unconformable, and the weathered material of the Devonian has been incorporated into the basal Cretaceous beds to such an extent that the contact is not easily discernible. The contact is not easily recognized in drill holes except where cores are taken. The material at the contact is shale and the Cretaceous is greenish in contrast with the darker Devonian.

GASPE, QUEBEC

Gaspe Peninsula is a part of the Appalachian system of mountains, which in the United States trend in a northeast direction but in Gaspe turn to the east and then to the southeast where the mountain folds are truncated by a very rugged coastline.[4] The north coastline follows the structural trend and is a smooth curve without harbours. The interior of Gaspe is a plateau rising to an elevation of 4,200 feet above the sea and extending for 50 miles along the middle of the peninsula. The oil-bearing region is east and southeast of this plateau, principally in the drainage basins of York and St. John Rivers and

[1]Geol. Surv., Canada, Ann. Rept. 1902-3, vol. XV, Map No. 846.
[2]Dyer, W. S.: Palæozoic Geology of the Albany River and Certain of Its Tributaries; Ont. Dept. of Mines, vol. XXXVIII, pt. IV, pp. 47-60 (1929).
[3]Williams, M. Y.: Palæozoic Rocks of Mattagami and Abitibi Rivers, Ontario; Geol. Surv., Canada, Sum. Rept. 1919, pt. G, p. 11.
[4]Alcock, J. F.: Mount Albert Map-area, Quebec; Geol. Surv., Canada, Mem. 144 (1926).

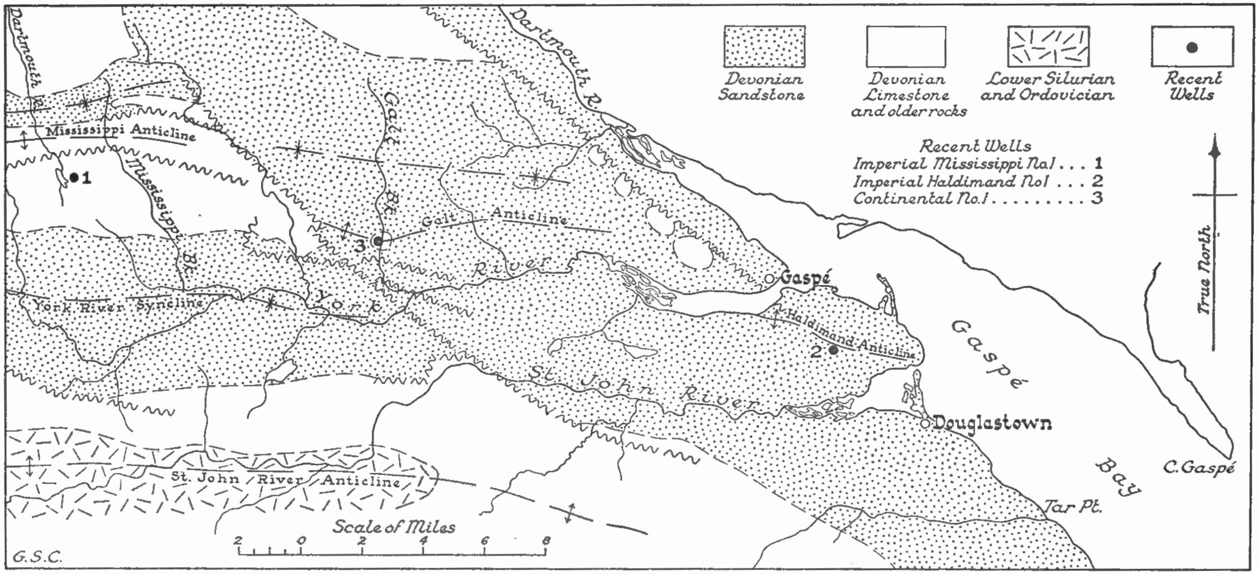

Figure 4. Gaspe, Quebec (mainly from Quebec Bureau of Mines).

embracing an area 40 or more miles east and west by 10 miles north and south (Figure 4). The oil prospects are related mostly to Devonian rocks, but Silurian strata underlying these may be of some importance. The geological history of Gaspe Peninsula is rather complex, but the main features are known. The rocks of early Palæozoic age were laid down in successive seas that at one time or another covered the whole area. Both the northern and southern margins of the area were uplifted, so that the central part became a basin that in Devonian time was occupied at different stages by fresh and marine waters in which a great thickness of sediments were deposited. Subsequent movements raised the whole peninsula and folded it into a series of synclines and anticlines. Igneous activity occurred both during the deposition of the Devonian rocks and later during the period of folding. The lowest beds of the Lower Devonian are generally known as the Gaspe Limestone series. These consist of limestones and shales, and in the upper York River area it is thought[1] they may be well over 4,000 feet thick, although at the coast, 30 miles to the east, the thickness is considered to be only half that amount. In the upper York River area the Gaspe limestones are overlain by the York Lake series, possibly also of Lower Devonian age, consisting of sandstones with associated limestones and in a few places some thin conglomerate beds. The York Lake series varies in thickness from 2,000 feet in the southeast to possibly 4,000 feet in more westerly areas. Toward the east the upper members appear to have been eroded prior to the deposition of the Middle Devonian Gaspe sandstones. At the head of York River, near York Lake, a 20-foot sill of porphyry occurs in the York Lake formation. The Gaspe sandstones are best known from the coastal region, where exposures occur on Dartmouth, York, St. John, and Malbaie Rivers. They consist of a series of crossbedded sandstones and conglomerates, mostly of freshwater deposition but partly marine, and are believed to be of Middle Devonian age. Logan assigned a thickness of more than 7,000 feet to them. In the basins of York and St. John Rivers the sandstones are commonly bituminous.

Seepages were first described from Gaspe Peninsula in 1846, following a visit there by Sir William Logan of the Geological Survey of Canada in 1844. This was the first statement in regard to the occurrence of petroleum in anticlines, but a clear statement of the anticlinal theory was not made until 1861 when T. Sterry Hunt set forth his ideas in an address in Montreal on March 1 of that year. In Gaspe, seepages occur in many localities, in some places issuing from the limestones but more generally from the overlying sandstones. Sir William Logan in the "Geology of Canada, 1863", described a number of these seepages, particularly on Dartmouth, York, and Malbaie Rivers.

The main period of folding affecting the possible oil-bearing Devonian strata occurred toward the close of the Middle Devonian. The period of Appalachian folding that affected eastern United States in the Permian did not extend on any large scale at least into Gaspe, as rocks of late Devonian or Carboniferous ages in the vicinity of Chaleur Bay to the south of Gaspe are little disturbed. During the Middle Devonian deformation, however, the older Devonian beds were strongly folded and many anticlines and synclines have been outlined; dips of 20 to 25 degrees are common, although much steeper dips are known and overturned beds may be present.

The first drilling was undertaken in Gaspe in 1860, but a much more persistent effort was made in 1889 when the Petroleum Oil Trust organized in England began operations. In the next few years more than fifty wells were drilled, some of which were more than 3,000 feet deep, and many of them were

[1]Jones, I. W., and McGerrigle, H. W.; Bur. of Mines, Quebec, 1937, P.R. No. 130.

2,000 or more feet in depth. Some of these wells penetrated the Gaspe sandstones into the underlying limestones. Many of the holes were dry or yielded only salt water and small volumes of gas. A few, however, yielded oil in sufficient quantity to encourage the building of a short pipeline and the erection of two refining stills, each of 150 barrels capacity. This optimism was not justified by the amount of oil obtained and operations ceased in 1902.

In 1937 the Quebec Bureau of Mines mapped[1] parts of the drainage areas of St. John and York Rivers in which thirty-five of the fifty-eight original wells were located, and as a result of this study concluded "that a very few of these wells were suitably located with respect to structures considered to be most favourable for oil accumulation. They are, for the most part, at or near synclinal axes. There are extensive areas with more favourable conditions farther up the flanks of the folds toward the anticlinal crests."

In 1939 Imperial Oil Company, Limited, located Mississippi No. 1 well east of Dartmouth Lake (Figure 4). This well was carried to a depth of 5,995 feet when it was abandoned. In the well the following section was drilled: 0 to 2,500 feet, grey, siliceous limestone with a minor amount of shale; 2,500 to 3,210 feet, grey, greenish, and brownish shales, in part calcareous; 3,210 to 5,995 feet, dark grey limestone, in part argillaceous, with pale greenish arenaceous limestone below 5,350 feet and finely granular below 5,450 feet. The lower part of the well is believed to be still in Lower Devonian or Silurian beds. No significant oil shows occurred.

In 1941-42 Imperial Oil Company, Limited, drilled a second well in Gaspe on the Haldimand anticline, to a depth of 4,770 feet. This well was wholly in sandstones and did not reach the underlying limestones.

In 1943 Continental Petroleums, Limited, commenced drilling a well on the Galt anticline, where the Devonian sandstones are eroded through to the underlying limestones. At the end of 1943 this well had reached a depth of more than 2,000 feet and was still in limestones. It is hoped to continue this well through the Devonian to the Silurian unless production is found in the higher beds.

There is no doubt that petroliferous beds occur in the Gaspe area and that there are structures favourable for the accumlation of oil and gas. The absence of strata with sufficient porosity to provide reservoir beds has apparently been the cause of failure of recently drilled wells, although some of the earlier wells are reported to have yielded several barrels a day and one of these, Petroleum Oil Trust No. 20, about a mile north of York River at the mouth of Mississippi Brook, is reported to be still flowing 2 to 5 gallons a day of light amber-coloured oil (49 degrees) from the $6\frac{5}{8}$-inch casing. Much of the upper part of the limestones is siliceous, and although these give seepages in various localities some of the oil shows are thought to be associated with fracture zones resulting from faulting. In the early drilled wells some oil came from the sandstone beds, some from the underlying limestones, and some from the contact between them.

NEW BRUNSWICK

All gas and oil production in New Brunswick is confined to one area south of Moncton, the Stony Creek field, the geology of which is shown on Figure 5. The oldest rocks in the area, probably Precambrian in age, consist of a metamorphic and igneous group that underlies an upland, plateau-like area known as Caledonia Mountain, where the maximum elevation is about 1,300 feet above sea-level. Overlying these rocks is a group of Carboniferous

[1]Jones, I. W., and McGerrigle, H. W.: Bur. of Mines, Quebec, 1937, P.R. No. 130.

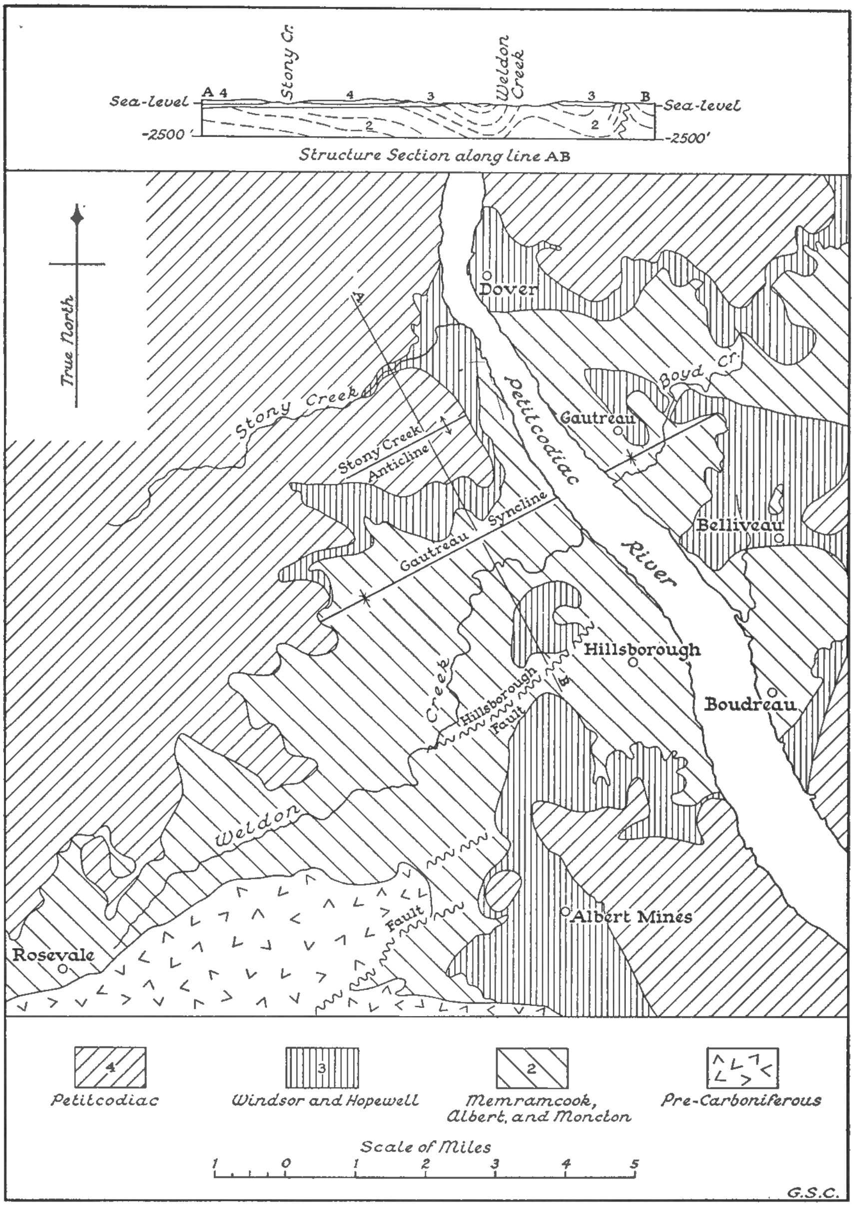

Figure 5. Geology of the Stony Creek gas and oil field, New Brunswick.

strata underlying the flanks of the upland and also the country to the east and north, which slopes away from the upland surface. These younger rocks were formerly mapped as the Horton, Windsor, Demoiselle, and Petitcodiac series, of which the Petitcodiac is Pennsylvanian and the others, with the exception of the Demoiselle, whose age is in doubt, are Mississippian. More recently the Horton has been subdivided into: (1) the Memramcook formation; (2) the Albert formation; and (3) the Hillsborough and Weldon formations; the latter two constituting the Moncton group. The Demoiselle has been renamed the Hopewell group.

The Memramcook consists of interbedded red shales and sandstones (1,500± feet thick) overlying or grading into red strata, with much interbedded arkose and conglomerate. It is succeeded conformably by the Albert (4,000± feet thick), which is the source of the gas and oil. The Albert beds consist chiefly of dark grey shale, but grey sandstone, conglomerate, and a few thin limestone beds also occur in the formation. Some of the shale beds are bituminous and a thick lens of salt in the upper part was encountered in wells near Gautreau. On the east side of Petitcodiac River wells have penetrated 500 to 900 feet of salt beds, and one well on the west side of the river cut 1,500 feet of salt-bearing strata. At Rosevale, on the north side of Caledonia Mountain, the Albert shales overlap onto pre-Carboniferous rocks. The formation is probably of lagunal or estuarine origin, deposited in a basin 50 miles long and 20 to 30 miles wide, but its full extent is not known, as part of it is buried under younger strata.

The Weldon formation (1,500 feet thick) consists of red shale and sandstone conformable with the Albert beds. Along the edge of Caledonia Mountain, from Albert Mines to Rosevale, a thick boulder conglomerate overlapping onto pre-Carboniferous rocks forms the base of the formation, and suggests that an upward movement of Caledonia Ridge took place at the close of Albert time. Mottled red and greyish white volcanic ash rock lies 300 feet above the base of the Weldon on Boyd Creek. On Peck Creek, typical Weldon red shales are separated from overlying Hillsborough conglomerate by a narrow zone of interbedded shales and conglomerate, but on Boyd Creek erosion of Weldon beds took place before the deposition of the Hillsborough strata, which there contain ash fragments. Where the Weldon and Hillsborough grade into each other, the combined beds are known as the Moncton group.

The Windsor series consists of fossiliferous marine limestone, local amounts of red shale, and gritty conglomerate, and deposits of gypsum and anhydrite. The beds rest conformably on Moncton strata, but overlap in places onto pre-Carboniferous rocks.

The Hopewell group is locally divided into three formations: (1) the Maringouin, consisting of red shales and sandstones; (2) the Shepody, made up of red shale and sandstone with interbeds of grey sandstone; and (3) the Enragé, composed of red shale with some sandstone and some conglomerate near the base. The age of the Maringouin beds is not known definitely. They succeed the Windsor strata conformably and may be a continental phase of the Upper Windsor. Plant remains in the Shepody and in the Enragé indicate a Pennsylvanian age for both. The Hopewell beds, in general at least, lie conformably on the Windsor strata, but an interval of erosion separates the beds of the two groups, as shown by the fact that basal Hopewell beds locally contain boulders of Windsor limestone.

The Petitcodiac group is locally divided into two formations, an older, the Boss Point, and a younger, the Grande Anse. The former is made up of grey sandstone and shales, red sandstone and shale, and some quartz-pebble

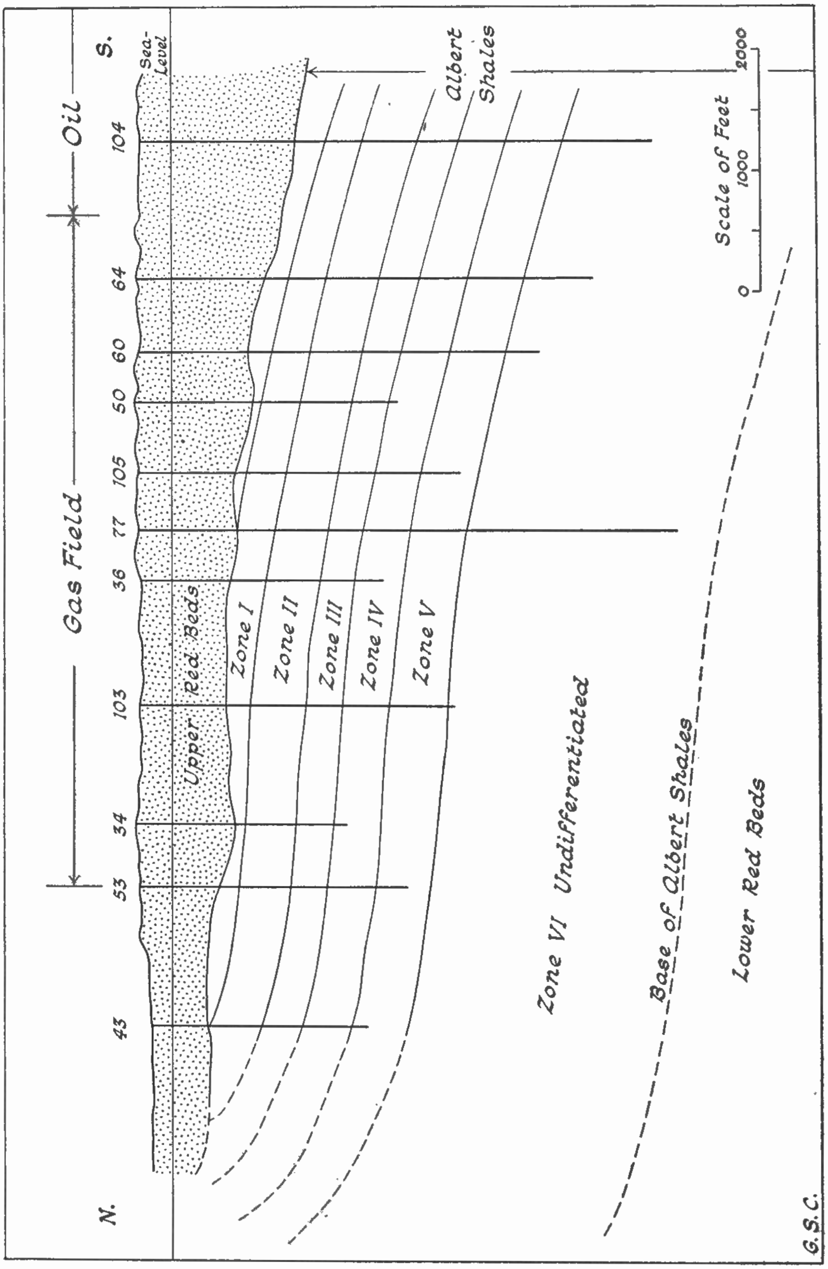

Figure 6. Section across Stony Creek field (after Henderson).

conglomerate; the latter consists of reddish brown sandstone and sandy shale, in part with lenticular beds of arkose and pebble conglomerate. In places sedimentation appears to have been continuous from Windsor to Boss Point time, but in others, as along Caledonia Mountain, it was interrupted in Windsor time and was resumed at different times in different localities. The Boss Point was locally deformed prior to the deposition of the Grande Anse beds, but in other localities the two formations appear to be conformable.

Owing to the fact that the Albert beds in the Stony Creek field are concealed by younger strata, their structure has largely to be determined from drilling. The main field has been developed on the south flank of an anticlinal fold (Figure 6).

The bituminous shales with their associated sandstones of the Albert formation have been divided[1] into six groups, the most productive of gas and oil being groups III, IV, and V, which have a total thickness of about 1,200 feet. Gas has been found in sandstone beds of groups I and II, but the producing sands appear to lens out laterally and production from them only occurs in some wells. The sands throughout all the zones have a low degree of porosity, but in certain instances are as much as 100 feet thick. Commonly, however, the upper part of the sands may be hard and tightly cemented, and this forms a cover for the productive lower part. It has been the practice in the field to deepen the wells periodically to lower sands as the upper ones become exhausted. In this way the individual wells have had a long life, in a number of wells exceeding 25 years. Initial yields of gas up to 18,000 M have been obtained, but mostly the flow has been much less. Maximum pressures of 1,250 pounds per square inch have been obtained, which is considerably higher than hydrostatic pressure. The total developed area of the gas field is about 1,200 acres and that of the oil field about 275 acres. Up to 1940 the production of gas had been 14,585,000 cubic feet per acre. The oil is highly viscous, with a gravity of 37 degrees A.P.I. and a wax content of 10 to 11 per cent. In the period between 1924 and 1942 twenty oil wells were drilled and the production has been 20,000 to 30,000 barrels a year, reaching a maximum of 31,359 barrels in 1941 but dropping to 27,760 barrels in 1942. The depth of the producing oil wells is 2,500 to 3,000 feet. Production of gas from the field is currently slightly more than 600,000 M cubic feet a year. The field has produced more than 19,000 million cubic feet of gas and 300,000 barrels of oil.

The prospects for the discovery of other fields in New Brunswick appear to be related to the distribution of the Albert shales[2]. These occur in a basin that stretches 50 miles from beyond Elgin in the west to beyond the valley of the Memramcook on the east and 20 to 30 miles wide from Caledonia Mountain northward. A search has been made outside the Stony Creek field by drilling twenty-five wells since 1909, but a number of these were not favourably located with reference to known structures. Also, in many places the possible gas and oil structures are concealed by younger strata deposited on the bevelled edges of the Albert formation. The wells, therefore, have by no means exhausted the prospects of the basin. A buried ridge of pre-Carboniferous rocks crosses the basin north of the Stony Creek field and determines its northward extension, but still farther north Albert shales occur over a considerable area. Sandstones from outcrops 6 miles northwest of Salisbury, 12 miles west of Moncton, contain oil residues.

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[1]Henderson, J. A. L.: The Development of Oil and Gas in N.B.; Trans. Can. Inst. Min. and Met., vol. XLIII pp. 159 178 (1940).

[2]*See* Norman, G. W. H.: Geol. Surv., Canada, Hillsborough Map No. 647A (1941).

PRINCE EDWARD ISLAND

For many years it has been assumed that the Mississippian rocks productive of gas and oil in New Brunswick might extend into the Gulf of St. Lawrence and be present under non-marine Pennsylvanian beds that completely cover Prince Edward Island. In 1908 and 1909 five wells were sunk on a gentle anticline. Two of these wells were carried to a depth of over 2,000 feet, one to a depth of 1,900 feet, and two to a depth of nearly 1,700 feet. These wells were undertaken[1] more in the interest of finding the possible underlying coal measures than in finding oil. None of them got through the red sandstones and shales of the Pennsylvanian. In 1925-7 another well was drilled by H. L. Doherty and Company of New York on Governor Island, on the south coast of Northumberland Strait. This well reached a depth of 5,970 feet, but also failed to reach the bottom of the Pennsylvanian red beds.

Following seismic surveys, another well location has recently been made on piers built in Hillsborough Bay. The well will be carried to much greater depths than previous drill holes in the hope of reaching the Mississippian beds under the Pennsylvanian.

NOVA SCOTIA

Lake Ainslie[2] district, Cape Breton Island, Nova Scotia, attracted attention many years ago on account of reported seepages of oil on the west shore. Several anticlines and synclines are known to occur in Mississippian and Pennsylvanian rocks in a structural basin that extends across Cape Breton from the west coast through Lake Ainslie to the northwest coast.

The oil occurrences appear to be related to the Mississippian beds, which have been divided into the Horton and the overlying Windsor series.[3] The Horton strata are freshwater terrestrial deposits, for the most part fluvial, and consist of conglomerates, crossbedded sandstones interbedded with grey and greenish shales, and two or three thin bands of chocolate shale. Certain bands of sandstone are brownish, and when struck yield a petroleum odour. The thickness of the Horton series is approximately 5,700 feet. The basal part of the Windsor series is exposed on the shores of Lake Ainslie, and this consists of bituminous and thinly bedded limestones resting disconformably on Horton rocks, but in certain places having a basal conglomerate. Elsewhere exposures of upper Windsor beds occur, and in one place there is 16 feet of oolitic limestone of which the upper 10 feet is cavernous. This limestone is underlain by red shale, and argillaceous sandstones and gypsum beds are present. The thickness of the Windsor is considered to be approximately 2,000 feet.

The Pennsylvanian beds overlying the Mississippian are very thick, but only one outcrop of Pennsylvanian occurs on Lake Ainslie, at Doherty Cove at the north end of the lake. The strata are grey and chocolate-red shales and sandstones of non-marine origin.

A number of faults have been mapped in the Lake Ainslie area and these are considered by Bell[3] to be normal faults in which the displacement "unless undue allowance is made for non-sequence of sedimentation must be hundreds, if not thousands, of feet."

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[1]Geol. Surv., Canada, Sum. Rept. 1908, pp. 23–25 (1909).
Geol. Surv., Canada, Sum. Rept. 1909, pp. 30–37, with logs of wells (1910).

[2]Hume, G. S.: Oil and Gas in Eastern Canada; Ec. Geol. Ser. No. 9, pp. 182–187 (1932).

[3]Bell, W. A: Prospects for Petroleum in Lake Ainslie District, Cape Breton Island, with notes on the Occurrence of Barite and Granite; Geol. Surv., Canada, Sum. Rept. 1926, pt. C, pp. 100–109.

Evidences of petroleum occur in the brown colouring of brown sandstones of the upper Horton beds where they outcrop at McIsaacs Point on the west side of Lake Ainslie. In the vicinity of the point globules of petroleum have been observed rising to the surface of the lake. Bell[1] also found inspissated petroleum in a barite vein on the east side of Lake Ainslie.

Details of the drilling have been given by Norman[2]—"shortly after 1864, two holes were put down to depths of respectively, 650 and 900 feet on McIsaac farm on the west side of lake Ainslie 1½ miles south of Hay river. The second hole gave the best results, yielding it is said nearly 100 gallons of oil after boring activities had ceased for a few days." Some other wells were drilled in 1879-80 and one well at 1,100 feet yielded some oil said to have had a gravity of 22·5 degrees. In 1898 a bore-hole 2,240 feet deep encountered salt water at 1,600 feet. Two other holes, one to a depth of 3,200 feet, were put down in 1902, and others between 1912 and 1914. In 1924 the Gulf Oil Corporation did some exploratory work on the Mabou anticline and test drilling was done. The holes were mostly in steeply dipping, gypsiferous strata of Mississippian age. These wells showed that Windsor strata are present along the crest of the Mabou anticline and to a depth of 900 feet, but on account of the complicated structural conditions encountered in the gypsum beds they gave no information on the nature of the anticlinal structure. In no hole was the bottom of the gypsum and anhydrite beds reached.

In 1942, a seismic survey of the Mabou area was undertaken by a Boston syndicate, but the results have not been made public. Drilling is proposed but has not yet been started.

In other parts of Nova Scotia some drilling has been done and certain areas are now being investigated with a view to further drilling. In 1930 Imperial Oil Company, Limited,[3] drilled a well on the Scotsburn anticline near Scotsburn, Pictou county. The strata occurring in this area all belong to the Upper Mississippian and Lower Pennsylvanian and are non-marine. Albertite, similar to that in the Albert shales, Albert county, New Brunswick, occurs in joint cracks in the sediments. Also, a small oil occurrence has been noted from Lower Pennsylvanian rocks in joint cracks in a calcareous concretionary sandstone. The occurrence is more like a pocket than a seepage. The object of the well was to reach the Horton series, to which the Albert shales, the productive oil formation in New Brunswick, belongs. The well was drilled to a depth of 1,980 feet. The upper 900 feet was mainly shales with some sandstones and interbedded volcanic flows. Three bands of black oil-shale were penetrated, at 415, 640, and 845 feet. The lower 1,000 feet was mainly igneous rocks, probably lava flows. The whole section penetrated is believed to have been upper Horton rocks.

In 1931 Imperial Oil Company, Limited, drilled another well on the Minudie anticline near Amhert, N.S. The structure exposes Windsor strata, so that the object in drilling, as on the Scotsburn anticline, was to reach the equivalents of the Albert shales of the Horton series of New Brunswick. When the well was started it was estimated that the Windsor series of limestone, gypsum, and salt beds would not be more than 1,000 feet thick. Below this 2,000 to 4,000 feet of red and chocolate shales were expected above the Albert shale equivalents, into which it was hoped to drill 1,000 feet. The well was drilled to 4,132 feet without penetrating the Windsor series and, consequently, was abandoned. The depth to the Albert shale equivalents would have been 6,000 to 8,000 feet.

[1]Bell, W. A.: Geol. Surv., Canada, Sum. Rept. 1926, pt. C, p. 106.
[2]Hume, G. S.; Oil and Gas in Eastern Canada; Ec. Geol. Ser. No. 9, p. 183 (1932).
[3]Report on the Petroleum Possibilities of Cumberland and Pictou Counties, N.S., by Imperial Oil, Ltd.; Dept of Public Works and Mines, N.S., pt. 2 (1931).

ONTARIO[1]

The southwestern peninsula of Ontario, bounded by Lakes Huron, Erie, and Ontario, has a record of sustained petroleum production for 80 years. The area is underlain by Palæozoic strata ranging in age from Ordovician to late Devonian. In general the beds dip at low angles of about 20 to 30 feet to the mile to the south and southwest, and as this dip exceeds the slope of the surface in the same direction the beds become progressively deeper buried under younger strata to the south and southwest. The Niagara escarpment, beginning in Canada at Niagara River and responsible for Niagara Falls, extends northwest across Ontario to the north end of Bruce Peninsula between Lake Huron and Georgian Bay. It also occurs farther northwest on Manitoulin Island off the north shore of Lake Huron. West and south of the Niagara escarpment outcrops are relatively scarce and the bedrock is concealed by a thick deposit of unconsolidated clays, sands, and gravels. It is in this area, however, that all the oil and gas fields occur, and as shown by wells the thickness of Palæozoic nowhere exceeds 4,500 feet.

The Precambrian rocks under the Palæozoic of southwestern Ontario are mainly gneisses, schists, and granitic rocks, but in various places crystalline rocks, presumably similar to the Grenville series, occur. The strata overlying the Precambrian are mainly arkose or sandstone beds varying considerably in thickness and character, as would be expected from deposition on an uneven erosional surface. The age is believed to be Ordovician and there are no Cambrian beds west of the Frontenac axis (Figure 7). These basal arkose beds have yielded oil in one or two wells, but very little production is to be expected from them; in various places they contain a saline water with a high percentage of calcium and sodium chlorides. Above the basal arkose is the so-called Trenton group of the Lower Ordovician, which varies in thickness from 500 to nearly 1,000 feet, with the thicker sections in Lambton and Kent counties in the southwest part of the peninsula. Only one commercial oilfield has so far been found in the Trenton group. This is the Dover field near Lake St. Clair. It is probable that fracturing and faulting produced the necessary porosity in this field, and hence the lack of production elsewhere (except for small flows of gas) may be ascribed to lack of porous horizons. In Ohio and Indiana, where the Trenton group has given large production of oil, the porosity has been ascribed to an erosional interval between the Trenton and overlying shales. It may be that such an erosional break is largely absent in southwestern Ontario, although it has been recorded from exposures in Georgian Bay and Manitoulin Island.[2]

In the vicinity of Georgian Bay the Trenton group is overlain by 33 feet of bituminous shales, and in 1859 at Collingwood on Georgian Bay these shales were distilled for oil, but the project was later abandoned. These shales with other grey shales are what was formerly grouped under the name of Utica, and these in turn are overlain by greenish grey shales. The whole assembly is Cincinnatian in age. Only small amounts of gas have been found in these beds, but one occurrence at Caledon, north of Toronto, is interesting, because of a content of $\frac{8}{10}$ of 1 per cent helium. Unfortunately only small volumes of gas were available after the drilling of several wells. The Queenston red shales are the youngest Ordovician beds in the Niagara area, and to the northwest the red shale is replaced by grey shale and dolomite. These beds are barren of oil and gas. Thus it may be said that as far as production of oil is concerned

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[1]Information in part from unpublished manuscript: Evans, C. S., and Stewart, J. S., Geological Survey of Canada *See also* Caley, J. F.; Palæozoic Geology of Toronto-Hamilton Area, Ontario; Geol. Surv., Canada, Mem. 224 (1940): and Palæozoic Geology of the Brantford Area, Ontario; Geol. Surv., Canada, Mem. 226 (1941).

[2]Sproule, J. C.: Contributions to the Study of the Ordovician of Ontario and Quebec; Geol. Surv., Canada, Mem. 202, p. 98 (1936).

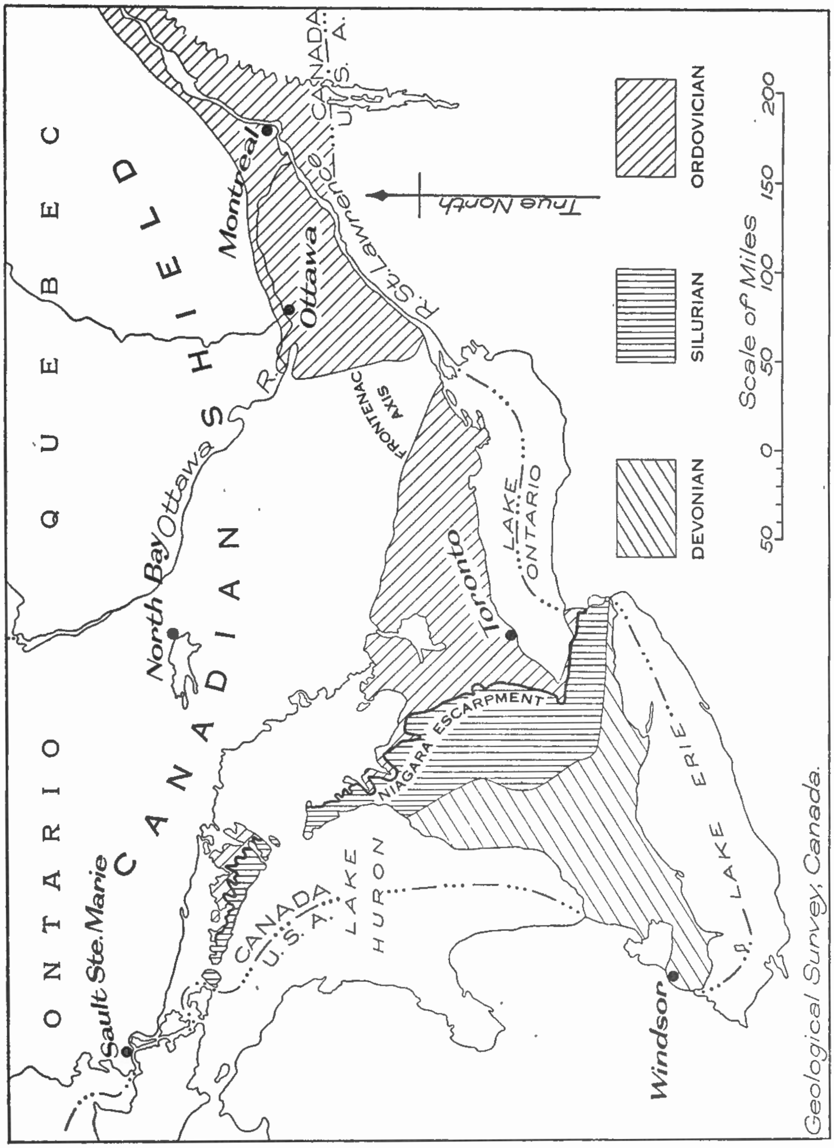

Figure 7. Geology of southern Ontario.

the Ordovician of southwestern Ontario has yielded very little other than from the Dover field, but in future prospecting the Trenton group would seem to offer the most favourable opportunities for possible commercial yields.

The Silurian overlying the Ordovician shows quite wide variations in the stratigraphy,[1] particularly in the lower part, and locally several members are productive of gas with some oil. For example, the basal member of the Silurian in the Niagara area is the Whirlpool sandstone 25 feet thick. This is a reservoir rock and has yielded gas in the Niagara area, with oil in one small field near Brantford (Figure 8). It does not extend far to the west of the Niagara area. In the overlying series of shales, sands, and dolomites there are some red and grey sandstones of the Cabot Head-Grimsby group that have yielded gas over extensive areas. The total thickness of the whole of the Lower Silurian is probably not more than 200 feet. The Middle Silurian beds consist of limestones and dolomites, and these form the crest of the Niagara escarpment. Their total thickness varies from 100 to 400 feet. The upper member—the Guelph dolomite—contains in its upper part the most important gas-producing horizon of southwestern Ontario, and has yielded large quantities of gas in fields in Kent, Lambton, Essex, and Oxford counties. It also has yielded oil in a number of fields, but the present yield is relatively small. The Upper Silurian beds in the southwestern peninsula of Ontario belonging to the Cayugan group consist of fine-grained dolomites, grey shales, beds of gypsum or anhydrite, and in many places beds of salt. The salt beds vary widely up to 350 feet, and in one well near Sarnia 640 feet of salt was reported. This variation in the thickness of salt accounts for a wide variation in the thickness of this group of beds, from 300 feet to more than 1,000 feet. The lower part of this formation yields gas and has also yielded some oil.

The Lower Devonian overlying the Silurian is known from wells to consist of limestones and dolomites with some thin sandstone members in certain localities. Outcrops, however, do occur in the vicinity of Detroit River and on islands in Lake Erie on the western edge of a broad syncline that contains younger strata. These Lower Devonian beds, so far as known, are unproductive of oil and gas. They are overlain by Middle Devonian limestones from 60 to 200 feet thick, which have been the most prolific source of oil in Ontario, and it is from these that the first wells in Ontario obtained oil at shallow depths up to 400 feet. The Middle Devonian limestones are overlain by further Middle Devonian shales and thin limestones, and in most areas these are the cover beds for the oilfields of Middle Devonian age. In the central part of the syncline, extending from Lake Erie through Kent and Lambton counties to Lake Huron, there are Upper Devonian shales that in part are black and bituminous and contain up to 10 gallons of oil a ton. These are the youngest strata of the southwestern peninsula of Ontario.

The structure of the southwestern peninsula of Ontario is relatively simple. There is a gentle southwest dip of 20 to 30 feet to the mile to the south and southwest, and in the vicinity of Kent and Lambton counties in the southwestern part of the peninsula there is a broad shallow syncline. Regionally, however, the southwest dip of the beds continues into the Michigan Basin to the west, where there are found strata younger than any that occur in Ontario. The Middle Devonian limestones of Ontario, which produce oil at a depth of less than 400 feet, are also productive of oil in the Michigan Basin at a depth of about 3,000 feet. The oilfields associated with Middle Devonian limestones in southwestern Ontario are all in anticlines of small closure in the synclinal structure extending through Lambton and Kent counties. In Enniskillen township, Lambton county,

[1] Williams, M. Y.: Silurian Geology and Faunas of Ontario Peninsula; Geol Surv., Canada, Mem. 111 (1919).

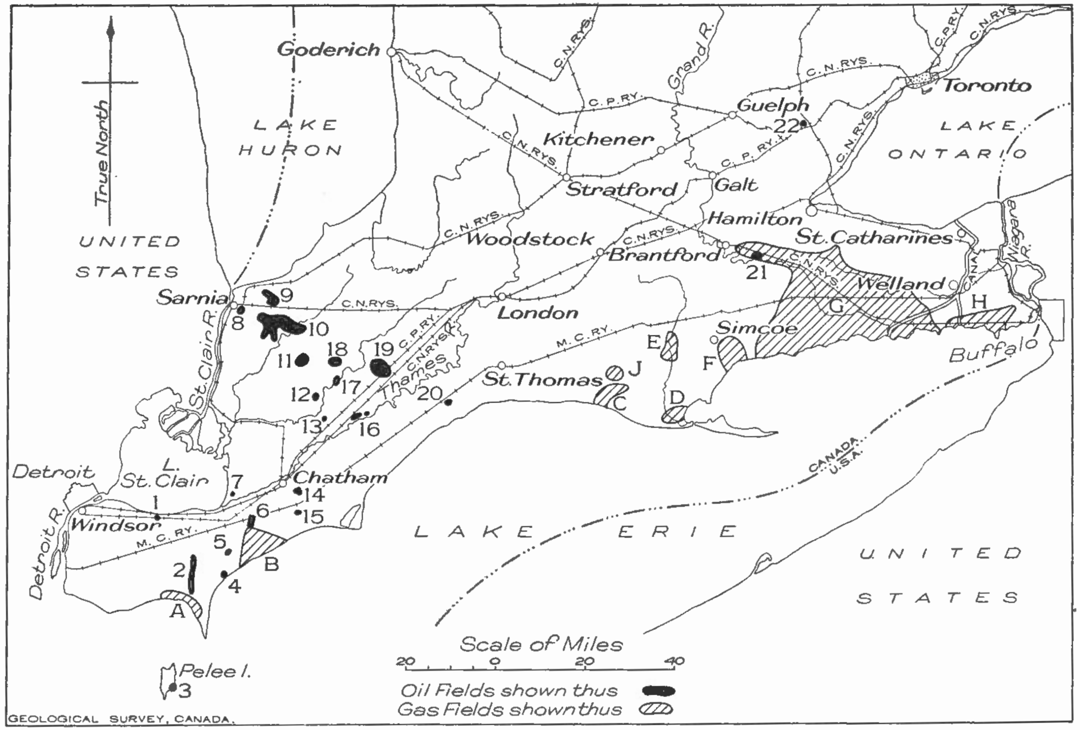

Figure 8. Oil and gas fields of southern Ontario. Oil fields: 1, Belle River; 2, Leamington; 3, Pelee Island; 4, Wheatley; 5, Romney; 6, Tilbury; 7, Dover West; 8, Sarnia; 9, Plympton; 10, Petrolia; 11, Oil Springs; 12, Dawn; 13, Thamesville; 14, Kipp; 15, Raleigh; 16, Bothwell; 17, Euphemia; 18, Brook; 19, Mosa; 20, Dutton; 21, Onondaga; 22, Milton. Gas fields; A, Leamington; B, Kent; C, Bayham and Malahide; D, Port Rowan; E, Middleton; F, Simcoe; G, Haldimand; H, Welland; J, Brownesville.

seepages of oil were known to the Indians and earliest settlers, and development only awaited the use of the oil. This began in 1857 when Mr. W. H. Williams, of Hamilton, undertook the distillation of the tarry bitumen from a seepage at the present site of Oil Springs in order to fill a demand for illuminating oil. It was soon discovered that by drilling below the asphaltic residue of the seepage, the material was more fluid, so that in 1858 a well was drilled to a gravel bed filled with oil overlying the bedrock. The first well into the bedrock was drilled at Oil Springs in 1861, following the success of the Drake well in Pennsylvania. It reached the oil-producing horizon at a depth of 160 feet. This led to great activity and many wells were drilled, reaching the oil horizon at less than 400 feet in depth. Many of these wells flowed several hundreds of barrels a day, and several flowed 1,000 to 6,000 barrels; the largest is said to have been the Black and Mathewson well, which flowed 7,500 barrels a day. As there was no means of controlling the flow of the wells much of this oil was wasted and flowed down Black Creek to Lake St. Clair. The success in the Oil Springs field led to the development of the Petrolia field, a few miles distant. These two fields still continue to yield oil, and of a total production for Ontario of 133,000 barrels for 1943, these fields yielded a large part after almost 80 years of continuous operations. Oil Springs, the earliest field to be discovered, has yielded approximately 7,946,500 barrels of oil from an area of about 1⅓ square miles, and still continues to yield at slightly less than 30,000 barrels a year.

THE INTERIOR PLAINS

GENERAL STATEMENT

The possible oil-bearing area of the Interior Plains includes the southwest quarter of Manitoba, the southwest two-thirds of Saskatchewan, and the greater part of Alberta, a total of 375,000 square miles (Figure 2).

The Palæozoic formations overlap the Precambrian of the Canadian Shield and underlie the younger strata of the Plains, but they may vary considerably in age and thickness from place to place.

In the Cordillera to the west of the Plains there are more than 11,000 feet of Cambrian strata, consisting of sands, siliceous silts, and limestones. Not much is known about the extent of the Cambrian under the Plains, but in wells in southern Alberta beds of this age have been identified from deep wells, in one of which a thickness of more than 500 feet is Cambro-Ordovician with the lower part definitely Cambrian. Cambrian strata do not occur along the edge of the Canadian Shield in Manitoba, nor are they present in the Fort McMurray area of Alberta, where wells have been drilled to the Precambrian.

In Manitoba, Ordovician beds occur resting on the west edge of the Precambrian of the Canadian Shield. The lowest beds are sandstones, which fill up the irregularities of the Precambrian erosion surface. These are overlain by shales and limestones with a total thickness of about 700 feet, the highest beds being Richmond in age. To the northwest, along the edge of the Canadian Shield in Manitoba, Cretaceous beds overlap onto the Precambrian, and hence conceal all Palæozoic rocks. The extent of the Ordovician under the Plains is problematical. There are Ozarkian beds in the eastern Rocky Mountains with a total thickness of 2,700 or more feet, including beds up to Chazy age. These are known to thin rapidly eastward, but Ordovician strata have tentatively been identified from wells in southern Alberta. The thickness is relatively small.

Silurian beds represented by dolomites, gypsum, limestones, and shales outcrop in Manitoba, particularly on the shores of Lake Winnipegosis. The thickness is variable according to whether gypsum is or is not present in the section measured. In a well drilled at Mafeking, Manitoba, 610 feet of beds occurred. Most of the beds are pre-Niagaran in age. In wells drilled at Fort McMurray, Alberta, 370 feet of dolomites and shales with gypsum, anhydrite, and salt occur, and Allan[1] has referred these beds to the Middle Silurian, although they contain no fossils. In various parts of Canada the Silurian has salt and anhydrite deposits, but the Devonian in southern Alberta also has similar beds. No strata of Silurian age have been identified from wells in southern Alberta, and probably none is present. Silurian does not occur along the front range of the Rocky Mountains.

The Devonian presumably underlies the whole of the plains of western Canada. Beds of this age outcrop in Manitoba, but no Lower Devonian is present. In the Mafeking well, the Devonian was 310 feet thick, consisting of 30 feet of red and greenish shaly dolomite overlain by 120 feet of grey and brown dolomite, in turn overlain by 150 feet of light grey to brown dolomite. Devonian rocks outcrop along the western edge of the Precambrian in Saskatchewan, and are exposed under the Cretaceous on Athabaska River at Fort McMurray, Alberta. The beds are entirely Upper Devonian[2] and are about 440 feet thick. The thickness of the Devonian in southern Alberta as determined from deep wells is more than 1,200 feet, and this includes an anhydrite zone. The Devonian outcrops very extensively along the edge and in the front range of the Rocky Mountains and in outliers in the foothills. In the Moose Mountain area[3] west of Calgary the thickness is approximately 2,000 feet. The age of the lower part has not been positively identified as Middle or Lower, but the upper part is definitely Upper Devonian.

The Mississippian beds overlying the Devonian are also about 2,000 feet thick in the Moose Mountain area west of Calgary. The upper part, the Rundle formation, 1,400 feet thick, contains the two porous zones in the upper 350 feet that are productive of gas and oil in Turner Valley. The Devonian is separated from the Mississippian by a black bituminous shale. This is thin, but is very widespread. In certain places along the mountains there are in reality two black shale beds separated by shaly limestones that resemble the overlying Mississippian Banff formation. The age has been assigned[4] to the Devonian, but doubt has been thrown on this age determination by the two shale beds with the gradation upwards and the identification of Mississippian fossils from the intermediate zone in a well in southern Alberta. The contact with the black shales and the underlying Devonian is sharp.

Mississippian beds occur under the plains of southern Alberta, and have been encountered in many wells. In the Commonwealth Milk River well they were about 1,100 feet thick, but 100 miles north in the Princess area, i.e., about 100 miles east of Calgary, the thickness is only about 400 feet. The black shale separating the Mississippian and Devonian occurs in both these areas. The position of the edge of the Mississippian beds to the north of Princess is not known, but in a well drilled at Castor, 100 miles north of Princess, only 175 feet of Mississippian occurred. Mississippian strata are believed to be entirely absent in the Wainwright area, 130 miles southeast of Edmonton, but probably occur in the Alberta syncline, as the black bituminous shales separating them from the Devonian are present under 155 feet of limestones in the Duvernay well on North Saskatchewan River, 70 miles northeast of Edmonton. In the Pouce-Coupé area of Peace River district, the Guardian well encountered a chert conglomerate believed to be the top of the Palæozoic at a depth of 6,774 feet. The chert conglomerate was underlain by limestones,

[1]Allan, J. A.: Salt Deposits at McMurray, Alberta; Trans. Can. Inst. Min. and Met., vol. XL. p. 627 (1937).
[2]Warren, P. S.: The Age of the Devonian Limestone at McMurray, Alberta; Can. Field Naturalist, vol. XLVII, No. 8, p. 148 (1933).
[3]Beach, H. H.: Moose Mountain and Morley Map-Areas, Alberta; Geol. Surv., Canada, Mem. 236 (1943).
[4]Warren, P. S.,: Age of the Exshaw Shale in the Canadian Rockies; Am. Jour. of Sci., vol. XXXIII, pp. 454-457 (1937).

the age of which is not definitely known, but at 6,815 feet some fossils were obtained that are considered to be Devonian. It is probable, therefore, that no Mississippian was encountered in this well as at Vermilion Chutes on the lower Peace River, 250 miles northeast, Cretaceous strata rest on Devonian limestones. Mississippian, and a small thickness of Pennsylvanian strata, occur in the eastern mountains of British Columbia on the western part of Peace River,[1] so that these must thin eastwards as in southern Alberta. Mississippian limestones occur in wells drilled in southwestern Saskatchewan, but do not occur above the outcrops of Devonian in Manitoba.

There is probably no Pennsylvanian anywhere under the plains of Western Canada. A small thickness of quartzites of this age occurs along the western edge of the foothills and in the mountains, but elsewhere beds of this age are unknown.

Triassic beds are unknown in the foothills and plains of southern Alberta, and there is none so far as known in either Saskatchewan or Manitoba. They do, however, occur in the foothills of central western Alberta, north of Red Deer River, and thicken northwestward. Presumably this thickening is also accompanied by an extension eastward under the plains, because 2,000 feet of beds of this age occur in the Guardian well of Peace River area. The strata are limestones and dolomites with red, gypsiferous shales. The upper part of these beds was porous and oil-bearing.

Jurassic strata, mostly shales with a few limestone bands, are present in the foothills and extend under the plains of southern Alberta and western Saskatchewan. The thickness is variable. Over the Sweet Grass Arch of southern Alberta the thickness may be less than 100 feet, whereas to the east and west 200 to 300 feet of beds may be present. In a well at Moose Jaw, Saskatchewan, the thickness is probably more than 250 feet,[2] but it is doubtful if beds of this age occur in eastern Saskatchewan where at the time of their deposition there seems to have been a Palæozoic ridge. Jurassic beds, however, occur in Manitoba to the east of this ridge, but their character is somewhat changed. They are largely shales.

Jurassic beds thin out to the north from southern Alberta and are not present in east-central Alberta. They do, however, occur in the Guardian well in Peace River area, where a thickness of 450 feet is assigned to them. They are everywhere present in the foothills areas of western Alberta and eastern British Columbia, and reach a thickness of 1,300 feet in the Mountain Park-Cadomin areas near Jasper, Alberta.

The Cretaceous of the Alberta plains is highly variable in lithology and in the thickness of various formations. Lower Cretaceous strata, entirely non-marine, occur in southern Alberta, where in the Crowsnest Pass area the lowest formation, the Kootenay, is coal-bearing. The Kootenay thins very rapidly eastward, so that most of the beds of Lower Cretaceous age under the plains are considered to be the equivalents of the overlying Blairmore group. In Turner Valley, on the eastern edge of the foothills, the Blairmore is 1,050 to 1,200 feet thick, but this also thins eastwards. Sands in the base of the Lower Cretaceous are productive of oil in the southern plains. In the Mountain Park-Cadomin area near Jasper, Alberta, the Blairmore equivalents contain the coal seams mined in that area. To the northwest in the foothills of British Columbia marine beds appear in the upper part of the Lower Cretaceous, but the non-marine lower part persists. This same condition is found to the east on the plains in the Fort McMurray-Athabaska area, where the Lower Cretaceous

[1]Williams, M. Y., and Bocock, J. B.: Stratigraphy and Palæontology of the Peace River Valley of British Columbia; Trans. Roy. Soc., Canada, vol. XXVI, sec. IV, pp. 201-204 (1932).

[2]Wickenden, R. T. D.: Notes on Some Deep Wells in Saskatchewan; Trans. Roy. Soc., Canada, vol. XXVI, sec. IV, pp. 177-196 (1932).

consists of an alternation of marine and non-marine beds, with the basal non-marine McMurray formation containing the bituminous sands. As all the Lower Cretaceous of southern Alberta is non-marine, the seas in which the marine sediments were deposited had their shorelines to the south of the Fort McMurray area and north of southern Alberta. It is considered that the oil fields at Wainwright, Vermilion, and Lloydminster, 250 to 300 miles south of Fort McMurray, are connected with this change in sedimentation.

In the Crowsnest Pass area of southern Alberta there are volcanics interbedded[1] with the upper Blairmore beds and lying above them. These beds are of local extent and are not definitely recognized in samples from wells on the plains.

The Upper Cretaceous of the southern plains began with the deposition of marine shales of Colorado age, 1,200 to 1,800 feet thick in southern Alberta,[2] but in Peace River area the Dunvegan sandstone 500 or more feet thick is the basal formation. The equivalent of the Dunvegan sandstone in the Fort McMurray-Athabaska area is the Pelican sandstone, 35 feet thick. It may be that this is the equivalent of the Viking sand,[3] from which gas is produced east of Edmonton. The Colorado marine shales are everywhere overlain by marine shales of Montana age. In southern Alberta these are relatively thin, but in east-central Alberta they are the Lea Park formation, which is 600 to 800 feet thick and the upper,[4] but not likely the uppermost, part of the LaBiche shale of the Athabaska section.

The Montana marine shales of southern Alberta are overlain by non-marine beds. On the eastern edge of the foothills these are 1,700 or more feet thick, but to the east and northeast marine shales interfinger with the non-marine beds and finally, still farther east, the succession of marine shales continues upwards. In southern Alberta and the southern foothills the non-marine Montana shales are overlain by marine Bearpaw beds. These have a wide distribution across the southern plains, but in the more northeasterly areas have been bevelled off by erosion. In the Lethbridge area[5] the thickness is 726 feet, and in the Cypress Hills area of western Saskatchewan it is about 700 feet.[6] To the north of Bow River in the foothills Bearpaw beds entirely disappear, and the equivalents of the non-marine beds which elsewhere overlie them occur in continuous succession with the underlying non-marine strata of Montana age. These higher non-marine beds in this area constitute the top of the Upper Cretaceous, but in southern Alberta beds belonging to the Willow Creek formation are partly, if not wholly,[7] Cretaceous in age.

In southern Saskatchewan the Eastend formation overlies the Bearpaw shales. This is overlain by the Whitemud formation correlated with the upper part of the St. Mary River formation of southern Alberta and its equivalent beds of the Edmonton of central Alberta. Both these formations directly overlie Bearpaw shales. Above the Whitemud there is an erosinal unconformity, above which is the Ravenscrag formation, the lower part of which is Cretaceous and the upper part Palæocene in age. The division between the Cretaceous and Tertiary is placed at the first coal seam in the Ravenscrag, but as both upper and lower parts are non-marine, the division is arbitrarily drawn.

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[1]Hage, C. O.: Geol. Surv., Canada, Beaver Mines; Map 739A, marginal notes (1943).

[2]Russell, L. S., and Landes, R. W.: Geology of the Southern Alberta Plains; Geol. Surv., Canada, Mem. 221, p. 22, (1940).

[3]Hume, G. S., and Hage, C. O.: The Geology of East-Central Alberta; Geol. Surv., Canada, Mem. 212, pp. 12, 13 (1941).

[4]McLearn, F. H.: The Fossil Zones of the Upper Cretaceous Alberta Shale; Trans. Roy. Soc., Canada, vol. XXXI, pp. 117–118 (1937).

[5]Link, T. A., and Childerhose, A. J.: Bearpaw Shale and Contiguous Formations in Lethbridge Area, Alberta, Donaldson Bogart Dowling Memorial Symposium; Am. Assoc. Pet. Geol., vol. 15, No. 10 (1931).

[6]Fraser, F. J., McLearn, F. H., Russell, L. S., Warren, P. S., and Wickenden, R. T. D.: Geology of Southern Saskatchewan; Geol. Surv., Canada, Mem. 176, p. 22 (1935).

[7]Hume, G. S.: Geol. Surv., Canada, Preliminary Map, Stimson Creek, Alberta, Paper 43-8 (1943).

The Tertiary of Alberta is entirely non-marine and occurs mainly in the Alberta syncline extending from the International Boundary in the south to north of Athabaska River in central Alberta. In the Swift Current area[1] of Saskatchewan conglomerates and sandstones of Tertiary age occur. These are possibly in part late Eocene and possibly in part Oligocene. Oligocene conglomerates, sandstones, silts, and marls occur[2] in Cypress Hills in Alberta and Saskatchewan, and Miocene gravels have been reported[3] from the Wood Mountain area of southern Saskatchewan.

SOUTHERN ALBERTA

Everywhere on the plains the structures are gentle. At the edge of the foothills in southwestern Alberta the beds dip a few degrees eastward, but in a relatively short distance readily discernible dips are replaced by gently tilted strata of less than 1 degree. One of the most pronounced folds[4] in the area south of Calgary is the Lloyd Lake-Twin Dome anticline. It trends east 20 degrees south oblique to the foothills, beginning on their eastern edge in the Sarcee Reserve and continuing for 75 miles. The structure can be best observed on secs. 27 and 28, tp. 21, rge. 29, W. 4th mer., east of the Calgary-McLeod road and at Twin dome on Highwood River near its junction with Bow River. At this latter place a well was drilled in 1938 to a depth of 7,152 feet. The top of the Palæozoic occurred at 6,651 feet, and in it some gas shows and water occurred. The top of the Palæozoic is about 450 feet higher than the predicted depth in the incompleted Ranchmen's well near Aldersyde, 6½ miles from the Twin Dome well, and in which exceptionally good shows of oil have occurred in Lower Cretaceous strata. The Ranchmen's well was suspended on account of mechanical difficulties when it was within a couple of hundred feet of the top of the Palæozoic. A second Ranchmen's well is drilling about 2 miles southwest of the first and has reported an oil show in Lower Cretaceous strata.

The large structural feature of southern Alberta is the Sweet Grass Arch. This plunges northward and on it to the south in Montana is the Kevin Sunburst field. In Alberta it has local folds superimposed on it, such as Twin River, Del Bonita and its continuation northwestward through Ross Lake, Spring Coulée, and Blood Indian Reserve southwest of Lethbridge (Figure 9). Wells have been drilled on all these structures, and in some of them oil shows have occurred in the top of the Palæozoic. Some production has come from the Del Bonita structure, and a recently completed well reaching the top of the Palæozoic at 5,035 feet has found oil saturation in the upper part of the limestone and is now on test.

Close to the International Boundary, the Red Coulée field[5] has been producing from seven wells for 10 years or more. The discovery well was drilled in 1930 and produced oil of 31 degrees A.P.I. from a sand in the Lower Cretaceous at a depth of 2,370-78 feet. The producing sand consists of from 45 to more than 59 feet of fine- to medium-grained, loosely cemented quartz and black chert sand. In some wells some sandy shale occurs within the sand, breaking it into separate parts. The sand is not considered to be at the base of the Lower Cretaceous, but 50 feet or so above it. The division between Lower Cretaceous and underlying Ellis formation (Jurassic) is not always easily recognized.

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[1]Russell, L. S., and Wiekenden, R. T. D.: An Upper Eocene Vertebrate Fauna from Saskatchewan; Trans. Roy. Soc., Canada, vol. XXVII, pp. 53–65 (1933).

[2]Williams, M. Y., and Dyer, W. S.: Geology of Southern Alberta and Southwestern Saskatchewan; Geol. Surv., Canada, Mem. 163, p. 69 (1930).

[3]Sternberg, C. M.: Miocene Gravels in Southern Saskatchewan; Trans. Roy. Soc., Canada, vol. XXIV, sec. IV, pp. 29–30 (1930).

[4]*See* Hume, G. S.: Geol. Surv., Canada, Midnapore Map, No. 606A (1940).

[5]Evans, C. S.: Milk River Area and the Red Coulée Oil Field, Alberta; Geol. Surv., Canada, Sum. Rept. 1930, pt. B, pp. 1–30 (1931).

The Red Coulée field is considered to be on a plunging northward nose on the Sweet Grass Arch. A flattening of dip in the vicinity of the International Boundary rather than a reversal to the south is responsible for the oil accumulation.

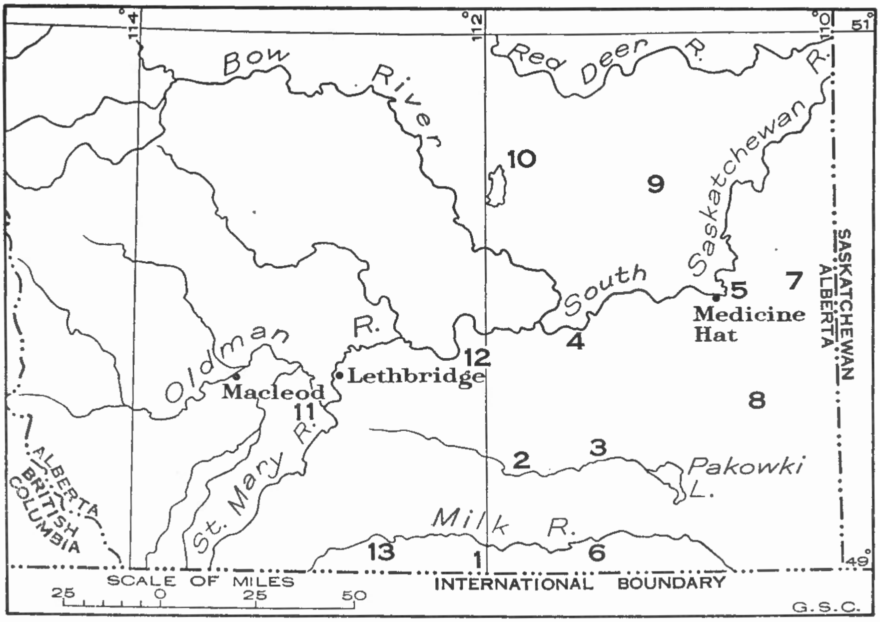

Figure 9. Oil and gas fields of southern Alberta. 1, Red Coulée area; 2, Skiff (Devenish) area; 3, Foremost gas field; 4, Bow Island gas field; 5, Medicine Hat gas field; 6, Milk River area; 7, Many Island Lake area; 8, Cypress Hills area; 9, Suffield area; 10, Brooks area; 11, Blood Indian Reserve-Lethbridge-Spring Coulée area; 12, Taber-Barnwell-Chin Coulée area; 13, Del Bonita-Twin River area.

In the last few years much geophysical work and core drilling has been done in southern Alberta, and quite a number of areas have been tested by deep wells. A stratigraphic trap has been found by Dominion Oil Company in the Taber area (Figure 9). It is a sand, apparently at the base of the Lower Cretaceous, and wells are now drilled to outline the productive part. The oil has a gravity of 18 to 20 degrees A.P.I. No. 1 well began producing in July 1942 and up to the end of October 1943 had yielded 73,648 barrels. In this area at the end of 1943 there were four producing wells, on separate legal subdivisions, i.e., 40 acres, and another well, Plains No. 2, about 2 miles to the northwest. Plains No. 2 well was completed in 1937, and the oil, which is produced with some water (sulphur), has a gravity of 27 degrees A.P.I. It may be on an entirely separate producing area from the other group of wells, as two wells drilled in the intervening area failed to find production. Several wells have been drilled in the vicinity of the four successful Dominion Oil Company's wells, and it appears that the trend of the sand may be northeast and southwest, as wells to the south and north, close to the producing area, have either failed to find the sand, or have found it too tight to yield oil. The oil has a sulphur content and is low in straight run gasoline.

Two other areas in southern Alberta, Princess and Tilley-Brooks, have received concentrated drilling in efforts to develop producing oil fields, and both have failed. Princess is about 100 miles east of Calgary and Tilley-Brooks is 15 miles to the southwest. In the Princess area Dominion Oil Company's (Standard of B. C.) No. 2 well gave some production, but drilling in the immediate vicinity failed to produce a field. In this area[1] the top of the Palæozoic occurs at a depth of about 3,200 feet. The oil is thought to come in the upper part of the Palæozoic limestone, but much trouble with water developed. Princess No. 1 well in this area was drilled to the Precambrian, and the following section was found:[2] Upper Cretaceous to a depth of 2,820 feet, with the Bow Island gas sand at 2,480 feet; Lower Cretaceous from 2,820 to the top of the Sunburst sand at 3,165 feet. The basal sand of the Lower Cretaceous is correlated with the Sunburst of Montana on the basis of position only. The Jurassic (Ellis) of this area is not definitely identified and may not be present. Lying on top of the Palæozoic limestone is a detrital zone as much as 30 feet thick with chert containing Mississippian fossils. The Mississippian occurred from 3,236 feet to 3,615, where black shale (Exshaw), which is known to separate the Devonian from the Mississippian over a wide area, was found. The Devonian is considered to be from 3,615 to 5,463 feet, and contains much anhydrite with dolomite. No Ordovician has been recorded, and the beds between 5,463 and 6,147 feet, the top of the Precambrian, are considered to be Cambrian in age.

In the Tilley-Brooks area Imperial Oil Company drilled a number of wells following the discovery of oil in Tilley No. 2 well, which was completed at a depth of 3,185 feet. The oil occurred in the top of the Palæozoic. Drilling in proximity to No. 2 well did not give any further production.

Various other tests in southern Alberta up to the end of 1943 have failed to establish new fields, although in a number of wells in widely separated areas encouraging shows of oil have been obtained.

EAST-CENTRAL ALBERTA

This includes the area from Red Deer east to the Saskatchewan boundary and north to Fort McMurray on Athabaska River. In this area, beginning with drilling in 1922 in the Wainwright area, a few producing wells were found, which have continued to yield oil to the present time. The oil has a gravity of 18 to 22 degrees A.P.I. The oil comes from a sand 120 to 140 feet below the top of the Lower Cretaceous, and in this area is encountered at a depth of 2,200 to 2,300 feet. The best producer in the field at present is Hargal No. 3B well, which, since its completion in 1925 to the end of October 1943, has yielded 39,700 barrels, and is currently giving the largest production. The Sasko-Wainwright well, completed in 1929, has given 48,700 barrels up to the end of October 1943, and several other wells have a small steady production.

In 1935 and 1936 a structure known as the Battleview anticline was located on Battle River, northeast of Wainwright, by the Geological Survey. Seismic work on this structure has outlined several producing gas and oil areas extending as far north as Vermilion (Figure 10). The first well drilled on this structure a short distance north of Battle River was a very large gas well. The second well, 10 miles north of the first, was also a gas well which has become the centre of the gas production for the town of Vermilion. The third well was drilled 10 miles north of the second and six miles east of Vermilion. It is close to the Canadian National Railway at Borradaile station. This was the discovery

[1]Stewart, J. S.: Steveville Oil and Gas Field, Alberta; Geol. Surv., Canada, Paper 41-10 (1941).
[2]Beach, F. K.: Schedule of Wells Drilled for Oil and Gas to 1941; Dept. Lands and Mines, Alberta.

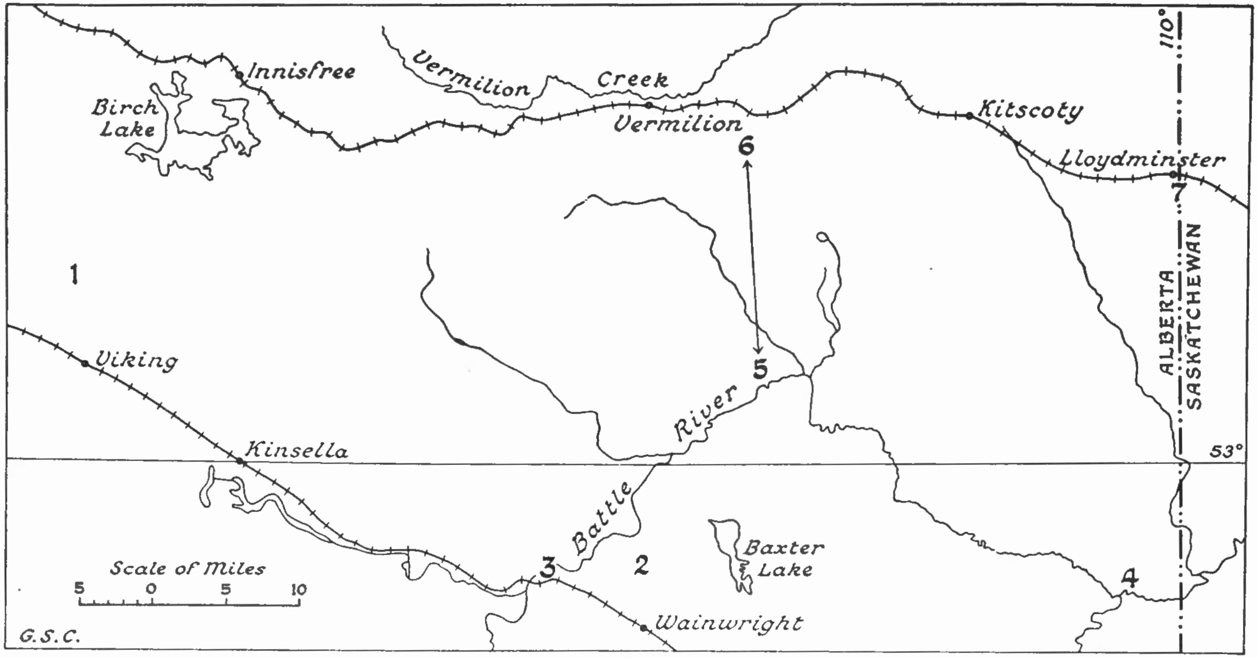

Figure 10. Oil and gas fields of east-central Alberta. 1, Viking field; 2, Wainwright field; 3, Fabyan field; 4, Ribstone field; 5-6, Battleview anticline; 7, Lloydminster field.

well of the Vermilion field. The production is heavy oil of 14 to 15 degrees A.P.I. from a sand about 130 feet below the top of the Lower Cretaceous at a depth of 1,800 to 1,900 feet, depending on surface elevation. A number of wells were drilled in this field prior to 1943 when the Canadian National Railways, through a subsidiary company, Cannar Oil, Limited, acquired acreage and began drilling to obtain oil for their locomotives on the mountain division from Jasper to Vancouver. To the end of 1943 Cannar Oils had drilled twenty-six wells, two of which have been abandoned and a few others of which are relatively poor. The results, as a whole, however, have been up to expectations. The production of this field for October 1943 was nearly 13,000 barrels, of which more than 7,000 barrels came from wells belonging to Cannar Oils. The production is filling a war need.

In 1943 some further drilling has been done at Lloydminster,[1] which is on the boundary between Alberta and Saskatchewan. The new wells are in Alberta. Some encouraging results have been obtained, and further wells will be drilled. The oil is of a similar type to that at Vermilion, and in one well comes from a sand at the top of the Lower Cretaceous, but mostly it is derived from lower sands, the best one of which is 165 feet in the Lower Cretaceous.

In the east-central part of Alberta a number of wells have been drilled to the Palæozoic, which occurs at a depth of 2,000 to 3,000 feet. Oil shows have been found, but no production has resulted. The age of the Palæozoic is believed to be Devonian, and a feature of it in some wells has been the high degree and thickness of the porosity found. The Devonian surface is known to be quite uneven as the result of erosion prior to the deposition of Lower Cretaceous beds. In some wells a considerable thickness of what is believed to be detrital sand occurs on top of the limestone surface. One or two areas, where buried limestone knobs have been located by seismic surveys, have been tested by drilling, and in one of these an oil show occurred in the upper Palæozoic beds. A seismic survey carried out by the Oil Controller for Canada and the Department of Mines and Resources, Ottawa, in 1943, has located a very pronounced buried knob of Palæozoic limestone in and adjoining the south part of the Buffalo National Park at Wainwright, and it is hoped this will be drilled. The area is interesting in that it is expected the detrital sand at the top of the Palæozoic will in this area lens out northward against the south side of the limestone mass, and thus form a favourable stratigraphic trap for oil.

Ninety miles east of Edmonton in the Viking and Kinsella areas north of the Canadian National Railway (Figure 10) there is a large gas field that supplies Edmonton and adjoining communities. The gas occurs in the Viking sand, below which there are 140 feet of marine shales, in turn overlying non-marine sandstones and shales of Lower Cretaceous age. The contact between the marine shales and the non-marine beds is sharp, and is usually considered the division between the Upper and Lower Cretaceous sediments. However, the foraminifera[2] found in the marine shales have been identified as occurring elsewhere in Lower Cretaceous beds, so that it is probable these are also Lower Cretaceous. There are small, smooth, black chert pebbles both in the Viking sand and in the shales above the non-marine Lower Cretaceous beds.

The amount of production in the Viking sand is much more directly related to the porosity of the sand than to the local structure. The regional dip is to the southwest, and up the dip the sand changes to sandy shale. Similar conditions may also occur down the dip. There have been oil shows in wells down

[1] Hume, G. S., and Hage, C. O.: The Lloydminster Gas and Oil Area, Alberta and Saskatchewan; Geol.. Surv., Canada, Paper 40-11 (1940).
[2] Hume, G. S., and Hage, C. O.: The Geology of East-Central Alberta; Geol. Surv., Canada, Mem. 232, p. 12 (1941).

the dip in the Viking sand, but in spite of the drilling of several wells, no production has been obtained. So far as is known, the Viking sand is free of water. Some further exploration will be done.

NORTHWEST ALBERTA—PEACE RIVER AREA

In northwest Alberta, in the Peace River area, some drilling has been done. At the town of Peace River the top of the Palæozoic occurs at a depth of less than 1,000 feet, and at Vermilion Chutes, 175 miles northeast of the town, Devonian limestones outcrop and are overlain by Cretaceous strata. The regional dip is thus to the southwest at less than 1 degree.

At the town of Peace River and north of it, several wells have been drilled that gave some gas and oil. Sands in the base of the Lower Cretaceous, not far above the Devonian, have been found to be oil saturated, but yield their oil at a low rate, and in the previously drilled wells much trouble has been encountered with water. At Vermilion Chutes a hole drilled into the Devonian is reported to have found porous beds impregnated with bitumen, and in the neighbourhood heavy black oil comes to the surface in springs. A seepage also occurs on Tar Island on the crest of a broad anticline. Tar Island is about 25 miles below the town of Peace River.

In the Pouce-Coupé area of Alberta, 100 miles west and slightly south of the town of Peace River, some wells have been drilled. Gas has been found in Lower Cretaceous beds, and in the Guardian well some oil was encountered in the top of the Triassic, which occurred at a dept of 4,774 feet.[1] The log of this well is interesting in that it revealed Triassic under the plains of northwest Alberta. The thickness of Triassic in the well is considered to be 2,000 feet. The beds are limestones and dolomites with red gypsum-bearing shales in two zones, between depths of 5,120 and 5,255 feet, and between 5,350 and 5,459 feet. Also in the Guardian well, beds thought to be Jurassic in age occurred between depths of 4,324 and 4,774 feet—that is, a thickness of 450 feet. Both Jurassic and Triassic strata are absent 100 miles distant at the town of Peace River, so that somewhere to the east of the well these beds lens out. In the well the Bullhead non-marine Lower Cretaceous beds are about 2,000 feet thick, whereas at Peace River the basal formation—the Loon River—is mainly marine shale with arenaceous beds near the base of the formation.

The Palæozoic limestone was encountered in the Guardian well at a depth of 6,774 feet, and fossils from 6,815 feet are believed to be Devonian. In the mountains to the west on Peace River, Mississippian and a small thickness of Pennsylvanian strata occur, so that these must wedge out eastward before reaching the Guardian location.

This lensing of the strata of various ages eastward presents interesting possibilities in regard to oil accumulations in stratigraphic traps, and it may be the shows of oil in the vicinity of the town of Peace River are related to the up-dip migration of oil along the erosional unconformity on top of the Devonian beds.

ATHABASKA BITUMINOUS SANDS

In northern Alberta, 300 miles north of Edmonton, there is an area of bituminous sands in the Lower Cretaceous McMurray formation, which rests directly on Devonian limestones. The centre of the bituminous sand area is at Fort McMurray on Athabaska River (Figure 11), but the bituminous sands outcrop along the river for 42 miles above Fort McMurray to 76 miles

[1] Allan, J. A., and Stelck, C. R.: Subsurface Formations of the Pouce-Coupé River District, Alberta; Trans. Roy Soc., Canada, vol. 34, sec. 4 (1940).

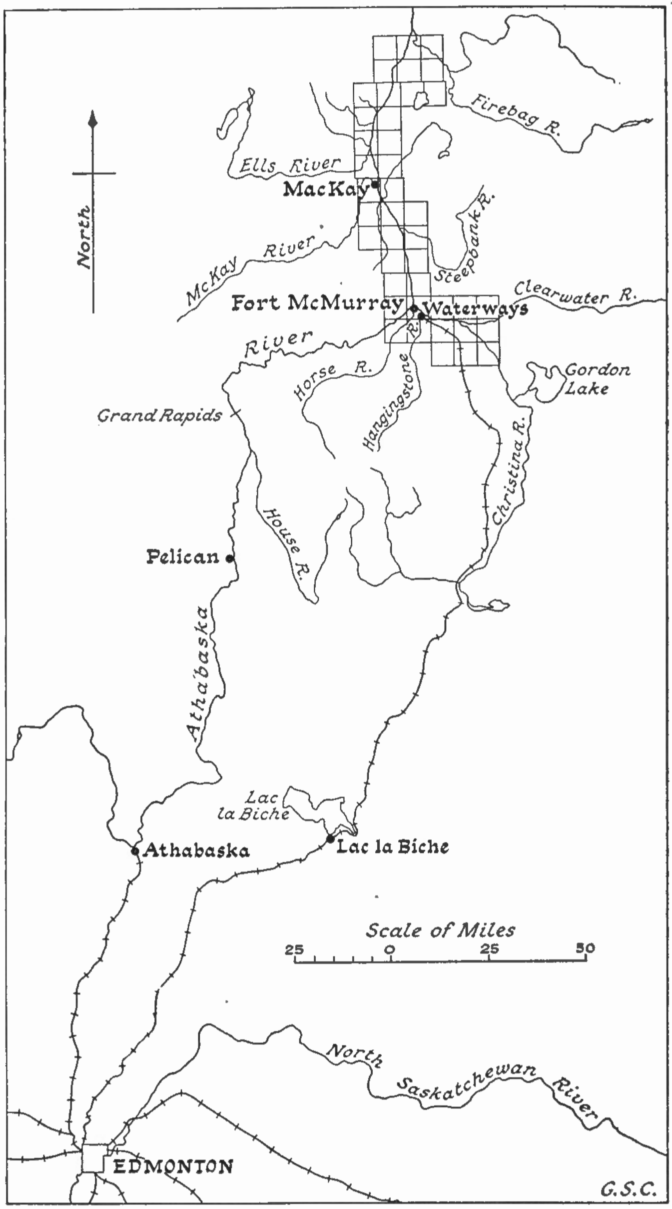

Figure 11. Athabaska bituminous sands.

below it and on tributary streams. The McMurray formation has a thickness of 110 to 180 feet and, as shown by large-scale crossbedding, is a deltaic formation. In the Fort McMurray area the valleys of the Athabaska and its tributary streams, Clearwater, Horse, and Hangingstone Rivers, are cut several hundred feet below the general plateau level, so that although the bituminous sands outcrop along the sides of all these valleys they are overlain at plateau level by the Clearwater shales, which have a total thickness of 275 feet. Also in the Fort McMurray area the regional dip is to the southwest, and in this direction the bituminous beds disappear below younger Cretaceous strata. Along Athabaska River north of Fort McMurray for many miles the contact of the bituminous sands and Devonian limestones shows at many places. The structure is gently undulating, and small folds of Devonian rising 20 feet above water-level alternate with long distances in which the contact is below water-level.

The origin of the oil in the bituminous sands has been a matter of considerable importance in reference to possible oil fields in the adjoining areas to the south and west where the bituminous sands are completely covered. McConnell[1] suggested that the oil may have been derived from the underlying Devonian. Wells have been drilled to the Precambrian at Fort McMurray in the search for salt, and complete cores are available for study. There is nothing in these to suggest that the Devonian was the source of the oil. Ball[2] has argued for in situ origin of the oil in the bituminous sands. When the bitumen is extracted the sand is clean, fine, white quartz with little other foreign material except clay in certain layers. This would not appear like a source for oil, especially as it is known the sand grains have a thin film of water around them inside the bitumen. As already indicated, the McMurray formation in part at least is deltaic. It is overlain by marine Lower Cretaceous beds, which in turn are overlain by an alternation of other non-marine and marine Lower Cretaceous strata. This condition extends many miles southward to the Wainwright and Vermilion areas, where oil fields have now been developed in beds of this age. Oil saturated sands have also been found by drilling near the town of Athabaska. It is not inconceivable, therefore, that all this oil has a similar origin and is indigenous to the Lower Cretaceous strata. The oil in the Fort McMurray deposit could be derived from the edge of the delta, and if so the distance of migration would be small. Drilling to find the grade of the bituminous sands in several localities seems to show that the deposits are richer close to the outcrops than at some distance from them, suggesting a partial migration of the bitumen even in its present state with a concentration due to damming at the outcrop by the more oxidized viscous material. This, if true, will to a certain extent invalidate the estimates[3] of tremendous volumes of oil content in the bituminous sands, although admittedly the volume is still very large. There is a suggestion also that the richer areas of bituminous sands occur in the synclines of the undulating surface. Support is given to this as it is known that the Abasand location, 2 miles south of Fort McMurray, is in a syncline with the limestone outcropping on Horse River a short distance above the plant and again 20 feet above water-level at the junction of Horse and Athabaska Rivers, whereas at the Abasand plant there are 20 to 25 feet of beds below the level of Horse River. At the Abasand location the bitumen content is 15 per cent or 0·9 of a barrel a ton of bituminous sand. In some areas, but perhaps not all, it is also known that the lower beds of the bituminous sands are richer than the upper. All these facts suggest some migration, but it is not considered that the evidence is conclusive.

[1]McConnell, R. G.: Geol. Surv., Canada, Ann. Rept. 1890–91, vol. V, pt. D (1893).
[2]Ball, Max W.: Athabaska Oil Sands: Apparent Example of Local Origin of Oil; Bull. Am. Assoc. Pet. Geol., vol. 19, No. 2 pp. 153–171 (1935).
[3]*See* Ball, Max W.: Athabaska Oil Sands: Apparent Example of Local Origin of Oil; Bull. Am. Assoc. Pet. Geol. vol. 19, No. 2, pp. 153–171 (1935).

The bituminous sands have been the subject of considerable detailed study[1] and much research has been done in attempts to find a cheap method of mining and extracting the bitumen. At present there are two plants, one at Abasand and one, Oil Sands, Limited, at the former site of International Bitumen Company, at Bitumont, 50 miles down Athabaska River from Fort McMurray. In 1943 Oil Sands, Limited, operated for only a short time and produced some asphalt. The Abasand plant is being rebuilt.

Abasand Oils, Limited,[2] was organized in 1930. The first years were devoted to laboratory research, but in 1932 and 1933 a pilot plant was built. This was operated at Denver, Colorado, for a time and then moved to Toronto, Ontario, for experimental and demonstration purposes. In 1936 a 250-barrel a day separation plant was built at Abasand, on Horse River, 2 miles south of Fort McMurray, on a 581-acre Dominion Government reservation. Changes in the design of the plant were found necessary and these, together with the building of a refinery and the solution of the mining problem, took considerable time and it was not until May 1941 that the plant began actual operations. Between May and September, 1941, 19,000 tons of sand yielding 17,000 barrels of bitumen were mined and processed to yield gasoline, diesel oil, fuel oil, and coke. The plant was destroyed by fire in November 1941 and rebuilt in 1942. Originally a shale planer was used for mining, but this was found expensive and unsatisfactory and was discarded in favour of shooting the sands and mining with a steam shovel. The sands when shaken with a moderate blast have a tendency to disintegrate. Superficially it appears as if the blast breaks the thin film of oil around the sand grains. After shooting, the sand appears grey, that is the colour of the sand shows through the oil film, whereas on a fresh, undisturbed surface the sands are black, the colour of the bitumen. This discovery, that the sands can be mined by steam shovel after shooting, is of major importance. The sands are not sticky and do not cling to the surface of the shovel. The rebuilt plant operated from August to November in 1942 and produced 11,156 tons of sand, yielding 10,041 barrels of crude bitumen. For a number of reasons the operation was not satisfactory, and considering the money invested it never even approached being commercial. The design of the plant did not allow economical operation in that the heat loss was excessive and a high percentage of the total products were consumed in producing hot water, which is used in washing the bitumen from the pulverized sands in the extraction process. The refinery was also out of adjustment with the separation plant. All these difficulties led the financial sponsors of the project to hesitate about continuing with the operation, and hence in the spring of 1943 the Dominion Government, on the advice of the Oil Controller, entered into an arrangement with Abasand Company to rebuild the plant and to operate it as a pilot plant for the purpose of solving the many problems and determining the cost of producing the bitumen by the McClave process, the rights to which are owned by the Abasand Company. Samples of bitumen have also been submitted to Universal Oil Products, Chicago, for determination of the products that can be made from them and the type of refinery required for their manufacture. Accordingly, in 1943 the Abasand plant was being rebuilt as a 600-ton a day pilot plant, and it is expected to be in operation in 1944.

In conjunction with the Abasand plant, test drilling was also carried on in 1942 and 1943 to locate a favourable area for large-scale mining operations. In the selection of the site the amount of overburden is important, and this greatly restricts the choice of area. Two areas have so far been drilled to a

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[1]Ells, S. C.: Bituminous Sands of Northern Alberta; Mines Branch, Dept. of Mines, Canada, Report No. 632 (1926).

[2]Ball, Max W.: Development of the Athabaska Oil Sands; Trans. Can. Inst. Min. and Met., vol. XLIV, pp. 58-91 (1941).

limited extent, but sufficient to show that neither has the grade of the present Abasand deposit. The first of these areas is at Wheeler Island, 53 miles north of Fort McMurray, and the other is at Steepbank, on the angle between Athabaska and Steepbank Rivers (Figure 11). The bitumen content in both these deposits varies considerably, vertically through the deposit as well as laterally in approximately the same beds. Also, particularly in the Wheeler Island area, there are barren bands of clay. Clay may offer some difficulty in the separation process and, therefore, is undesirable in any commercial deposit. The drilling to date has not led to the discovery of a deposit such as it is hoped to find. The narrow Horse River Valley restricts operations at the present Abasand location and, therefore, is unsuitable for large-scale operations, although a moderately large daily capacity might be feasible. The former Abasand operations were under the direction of Max W. Ball, to whom tribute is due for persistence and courage in attempting to solve many difficult problems and obtain production of oil from the Athabaska bituminous sands on a commercial basis.

FOOTHILLS OF SOUTHWESTERN ALBERTA

The foothills occupy a belt 12 to 20 miles wide in front of the Rocky Mountains, extending from the International Boundary between the United States and Canada northwest for 900 miles to Liard River. North of this there is an offset eastward in the mountain ranges and, as already pointed out, the Mackenzie River area is a basin between mountain ranges on both sides of this river. The geology of the foothills is best known in southern Alberta and in other places where major rivers offer relatively easy means of access, but much of the northern area has not been studied. Major rivers like the Oldman, Bow, Peace, and Liard cut across the foothills from west to east regardless of the northwest and southeast structurally trending ridges, and hence they are part of an antecedent drainage system. The structure of the foothills is complex and the Mesozoic rocks of which they are mainly composed are highly faulted and folded, with great overthrust blocks in the Palæozoic resting on one another on their adjacent edges. Within the foothills there are also outlying masses of Palæozoic limestones in elongated ridges. Most of these are faulted along their eastern edges, but one exception is Moose Mountain (Figure 12), 30 miles west of Calgary, which is a fold. The type of structure in these Palæozoic outliers is similar to the type of structure along the main front of the Rocky Mountains. The Rocky Mountains are composed mostly of fairly massive Palæozoic rocks, and because of their much greater resistance to erosion they stand at considerably higher elevations than the softer Mesozoic rocks of the foothills.

The Palæozoic rocks in the foothills are known from a number of outliers and from drilling. The main source of information, however, is from the adjoining mountain front, where Palæozoic strata are overthrust onto Mesozoic rocks. In a number of places Devonian rocks are known to rest on Cambrian beds without any Ordovician or Silurian being present. Rocks of both these ages, however, do occur elsewhere in the Rocky Mountains. The Devonian consists almost wholly of limestones and dolomites, and in the southern foothills the thickness is 3,000 to 3,500 feet. Several wells have been drilled into the Devonian either in or on the flanks of Palæozoic outliers such as at Moose Mountain, west of Calgary, and at Clearwater, 80 miles northwest of the same place. At Moose Mountain, one well is producing a small volume of oil from a depth of less than 1,500 feet in the Devonian. The well commenced drilling close to the top of limestones of this age in a canyon where the overlying Mississippian

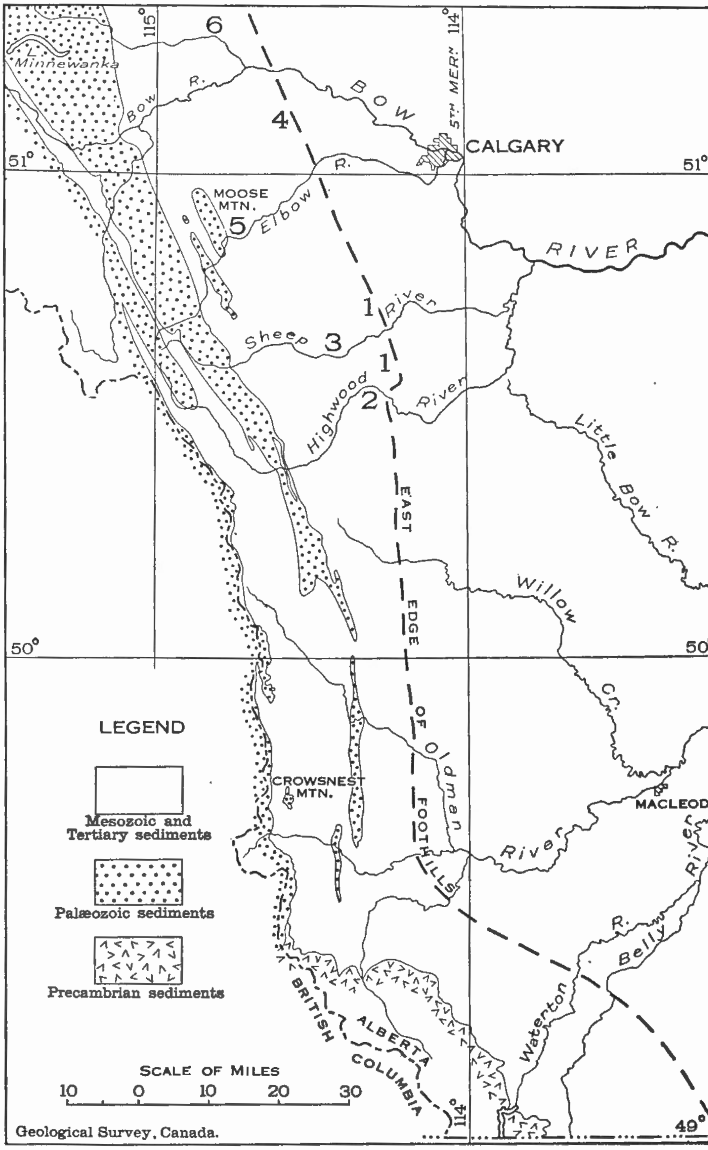

Figure 12. Foothills Area in southwestern Alberta. 1, Turner Valley oil and gas field; 2, Highwood uplift; 3, Waite Valley; 4, Jumping-pound structure; 5, Moose Mountain Palæozoic outlier; 6, Wildcat Hills.

limestones and shales were largely eroded. The top of the Devonian is marked by a very dark bituminous shale, in places 20 feet thick; it is known for 100 miles along the edge of the mountains, and is present under the plains of southern Alberta. It is an excellent horizon marker. In the Clearwater Palæozoic outlier, previously mentioned, a well also commencing near the top of the Devonian encountered strong oil shows at 1,100 to 1,300 feet in depth. Apparently, however, the beds had a low degree of permeability, and a considerable amount of anhydrite was noted from well cuttings. Anhydrite and gypsum are known in the Devonian from Moose Mountain, but only as thin layers in the limestones or dolomites. On the plains of southern Alberta a deep test drilled in the Bow Island gasfield encountered about 40 feet of anhydrite in the Devonian, and other wells have penetrated anhydrite-bearing beds.

The Mississippian, which overlies the Devonian, is represented in the southern foothills of Alberta by 700 feet of limestones and limy shales overlain by 1,400 feet of massive and crystalline limestones and dolomites of the Rundle formation. It is in the upper 350 to 400 feet of the Rundle limestones that the main oil and gas zones of Turner Valley occur. The top of the Rundle where exposed in Moose Mountain west of Calgary is a chert conglomerate overlain by dark Jurassic shales. Traissic beds are present in the Banff area only 75 miles away, and are present in the western foothills in areas north of Bow River, but so far as known do not occur in the eastern foothills in southern Alberta. In Turner Valley the Jurassic beds are only about 200 feet thick, and these are in turn overlain by Cretaceous beds. The Lower Cretaceous of the southern foothills is entirely non-marine. In the Crowsnest Pass area of southern Alberta the oldest Lower Cretaceous beds are sandstones and shales of the Kootenay formation. These strata contain the coal seams mined at Fernie, McGillivray Creek, Blairmore, and Bellevue. In Turner Valley the Kootenay is never over 100 feet thick, and in some wells it is not recognized at all. The formation thickens quite rapidly westward, and a few miles west of Turner Valley several hundred feet of beds are present. The Kootenay is overlain by further non-marine beds of the Blairmore group. In southern Alberta these beds do not contain any large coal seams, but in the Mountain Park and Cadomin areas west of Edmonton the main coal seams are in strata of this age. In Turner Valley one coal seam is present about 650 feet from the top of the formation that there is 1,050 to 1,200 feet thick. The base of the Blairmore in western foothills areas is marked by a massive conglomerate containing chert and quartzite pebbles. In Turner Valley this horizon is known as the Dalhousie conglomerate and sandstone and is relatively fine although easily recognized. The lower part of the Blairmore in Turner Valley contains about 150 feet of limy sandstones with shales immediately underlying a fairly coarse granular quartz sandstone known as the "Home sand," which yields oil and gas in some wells. The Home sand is probably quite local in its development. Above it the Blairmore consists of green shales, grey sandstones, and maroon shales at one or two horizons. Conglomerates occur locally, particularly in one horizon, which is called the McDougall-Segur sand and is 200 to 400 feet from the top of the formation. These conglomerates differ from the conglomerate at the base of the Blairmore in that they contain pebbles of prophyry. Presumably these are derived from uplifted masses of igneous rocks to the west and are an evidence of the orogeny then taking place in the western Cordilleran area. In the Crowsnest area of southern Alberta the Crowsnest volcanics intervene between the Lower Cretaceous non-marine beds and the overlying marine Upper Cretaceous shales of Colorado age. On Ghost River and elsewhere north of Bow River the contact is in places marked by as much as a foot of bentonite, and everywhere the basal Upper Cretaceous shales contain a grit or sandstone that in a few areas is a conglomerate with pebbles and cobbles up to a few inches in diameter. This bed in Turner Valley is known as the "Grit". It may be only a few inches to more than a foot thick, or it may be in two or more horizons separated by shales. On Highwood River west of the south end of Turner Valley beds belonging to this phase of sedimentation are as much as 20 feet thick and commonly are underlain by 10 to 20 feet of dark shales above typical Blairmore strata. The so-called "Grit", therefore, belongs in the Upper Cretaceous.

The Upper Cretaceous in the southern foothills consists of 2,500 to 3,000 feet of marine shales known as the Alberta formation, overlain by non-marine beds that greatly increase in thickness northward. In southern foothills areas it is commonly possible to separate the Alberta formation into upper and lower parts, as they are separated by a sandstone called the Cardium. In Turner Valley the Cardium sandstone is about 40 feet thick. About 150 feet above it is a pebble zone not more than 2 inches thick, consisting of fine black, green, and pink pebbles with polished surfaces usually about the size of rice grains, but occasionally somewhat larger. Another similar pebble zone occurs about 100 feet below the Cardium sandstone. To the west of Turner Valley these pebble zones become conglomerates on the top of sandstone horizons, so that the Cardium in these western areas really includes all beds between the upper and lower sandstone and conglomerate members. To the north of Bow River the amount of shale between the various sandstones decreases until the whole thickness becomes what is known in more northerly areas as the Bighorn formation. The persistence of the thin pebble beds without any sandstone is one of the remarkable features of the Alberta formation of Turner Valley, and where well samples are taken at regular intervals of 10 feet, as now required, the pebble zones are always observed. The Alberta formation is mostly Colorado in age, but the upper 300 feet or more of the upper part is Montana containing a large *Baculites* and other fossils. It is probable that the division between Alberta shales and the overlying non-marine beds of Belly River age is not always drawn at precisely the same horizon. On the west flank of Turner Valley there is a sandstone member 50 or more feet thick capped by a thin pebble bed and separated from non-marine beds by about 300 feet of marine shales. A few miles west this sandstone becomes very massive and in places quite conglomeratic, and where exposures are not good it is impossible to separate it from the Belly River beds above. However, in Turner Valley and for at least 100 miles north along the eastern foothills there is a thin coal seam about 20 to 30 feet above the top of the highest marine Alberta shales. This horizon, although consisting of not more than 6 inches to 1 or 2 feet of coal and coaly shales, is always present and is most remarkable for its extent and persistence. In Turner Valley the Belly River formation, consisting of alternating sandstones and shales, is 1,700 feet thick. It is marked by a fairly thick coal seam at the top—the coal that is mined on the plains of southern Alberta at Lethbridge. In the eastern foothills of southern Alberta the Belly River is overlain by marine Bearpaw shales. These thin and disappear westward and have not been recognized in the foothills north of Bow River. The overlying Edmonton formation is non-marine sandstones and shales about 1,100 feet thick east of Turner Valley, and these beds are in turn overlain by the Paskapoo formation of Tertiary age. Where the Bearpaw disappears north of Bow River it becomes increasingly difficult to separate the Belly River from the Edmonton because the coal horizon at the top of the Belly River cannot be identified. Also the Edmonton cannot be separated from the overlying Paskapoo even though in certain plains areas of southern Alberta the two are divided by an erosional disconformity with a conglomerate at the base of the Paskapoo formation. The

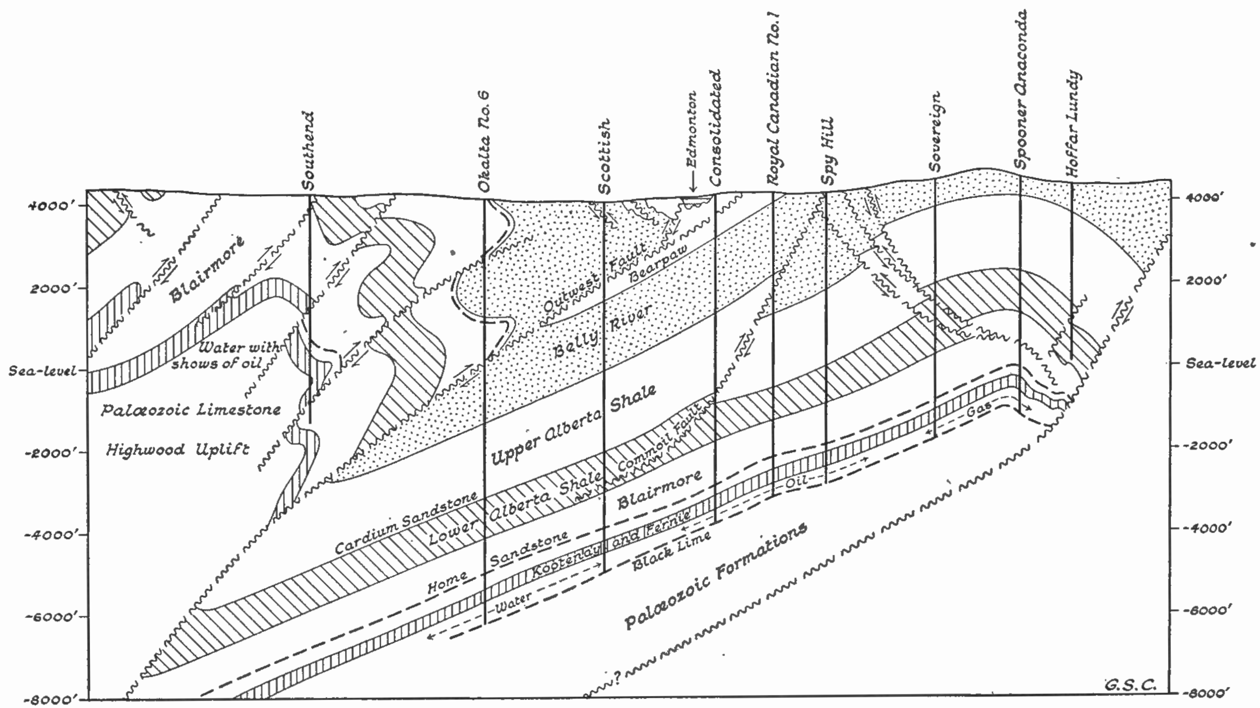

Figure 13. Cross-section of southern Turner Valley.

problem of a division in this non-marine series north of Bow River is made more difficult by a great increase in thickness. In the vicinity of Bow River certain hills are capped by conglomerates that unconformably overlie all older beds. These are believed to be later Tertiary, although no fossils are known from them. They are the youngest beds known in the southern foothills.

Great difficulty has been experienced in interpreting the structure of the foothills because of the fact that the softer Mesozoic beds and the underlying more resistant Palæozoic limestones yielded differently under severe mountain-building forces. It thus happens that complicated structures in the softer beds may not be reflected in the underlying limestones. As the location of the uplifted limestone masses is of prime importance in the search for oil fields these must be sought by an interpretation of the regional structure of the overlying Mesozoic beds. In the study of foothills structure the drilling in Turner Valley has supplied details that could not otherwise have been obtained. In this field more than 350 wells have now been drilled to the Palæozic limestone over a length of about 20 miles, so that the field is defined in an east, west, and south direction. It is probable that it may extend a short distance farther north. The Geological Survey has made extensive studies of Turner Valley and these are shown on two cross-sections herewith presented (Figures 13, 14).

In general, Turner Valley is a fault block cut off by a major fault on both sides and with the Palæozoic limestone showing a westward dip of 20 to 25 degrees in the south end of the field. On the east edge the limestone is drag-folded above the fault and this is reflected by a well-marked anticlinal structure in the Belly River and Alberta formations on the surface. Drilling for gas with naphtha has been done throughout the whole length of the field to the more uplifted parts of the limestone, although some parts have been much more intensively drilled than others. On the west flank of the surface anticline, wells have reached the limestone at a sufficient distance down the dip to obtain oil, whereas still deeper wells have penetrated the water below the oil. The dip of the limestone fault block has been shown to be uniform, and in general faults present on the surface within the width of the main block do not cut the limestone. In the central part of Turner Valley the dip of the limestone may be as low as 15 degrees, but at the south end of what is known as the north proved area, the dip is much steeper for a limited area. It again flattens off northward. This relatively gentle dip on most of the Palæozoic limestone is in marked contrast with the surface dips of the Mesozoic beds. Belly River strata on the east and west flanks of Turner Valley rarely dip less than 50 degrees, and on Sheep River, which transversely intersects central Turner Valley, the dips are 65 to 70 degrees. On the surface the anticlinal structure is fairly symmetrical, and for this reason no major fault on the east side was suspected until it was encountered by wells. Undoubtedly at depth on the east side above the major fault there are overturned beds, although on the east flank of Turner Valley overturned beds are absent or only present to a very slight degree in one area where vertical beds occur. The occurrence of gentle dips on the limestone and steep dips on surface beds is at least partly explained by rotation on faults that may have considerable displacement on the surface but die out at depth above the limestone. A fault in southern Turner Valley, known as the Commoil fault, is a good illustration. In Commoil No. 1 well this fault gave a repetition of 1,290 feet of drilling, encountering the Belly River-Alberta shale contact first at a depth of 1,460 feet, reaching the fault at 1,970 feet, and encountering the same contact again at 2,750 feet. In wells to the west of this the fault was encountered at lower levels and showed less displacement, until finally in wells still farther

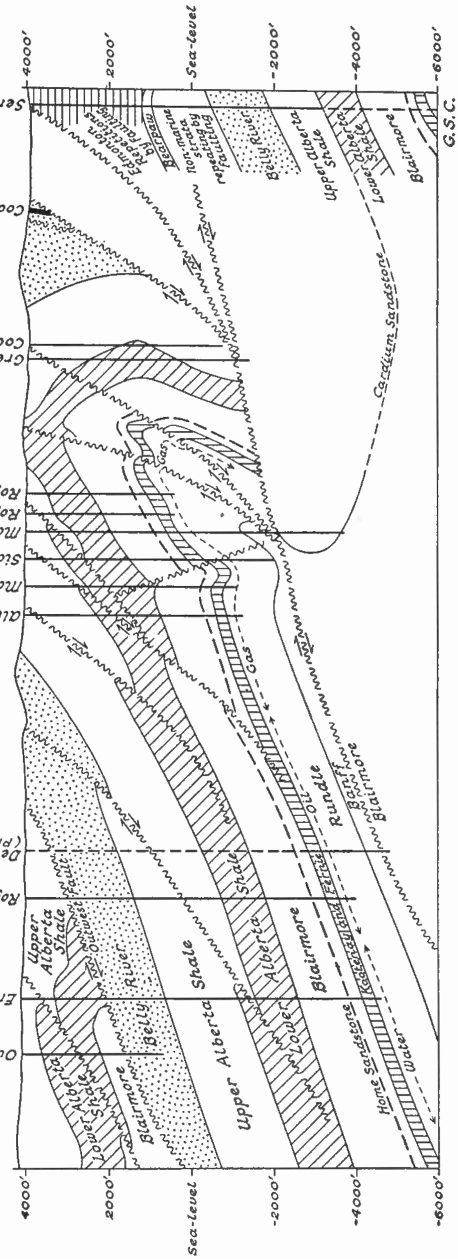

Figure 14. Cross-section of central Turner Valley.

west the fault had passed into a bedding-plane slip and could not be recognized. It can easily be seen how such a fault, which started as a bedding-plane slip as an adjustment in the softer beds above the limestone, would cause a large rotation where the magnitude of displacement was very considerable at the surface. This, then, is at least a partial explanation of the steep surface dips on the west flank where the structure is complicated by numerous surface faults. All faults are in general steeper than the beds cut by them, so it is to be expected that most of the faults at the surface will be steep as is known to be the case in many outcrops. The Commoil fault was the first indication in the foothills that the inclination of some faults changes at depth, because in a number of cases information derived from drilling indicated that the faults at the surface were fairly uniform with a dip of approximately 60 degrees. In southern Turner Valley certain sandstones in the Alberta shales have been repeated once or even twice in several wells. This has been interpreted by the writer as the result of a zone of east-dipping faults, a back thrust resulting from the drag on the major overthrust. This interpretation has not been wholly accepted and other geologists have preferred to think of these faults as a series of west-dipping faults. East-dipping faults have been proved to occur in a number of other structures in the foothills and always the displacement is moderate. It seems, therefore, logical to expect similar faults in Turner Valley. At least one fault that cuts the Palæozoic limestone of central Turner Valley is generally regarded as having an eastward inclination, and others may be present. This fault is, however, somewhat different from the east-dipping faults in southern Turner Valley concerning which differences of opinion exist.

The west side of the Turner Valley fault-block is cut off by the Outwest fault from the Highwood uplift. In the Highwood uplift the limestone is within very moderate depths of the suface and is known to rise to an elevation of more than 2,000 feet above sea-level, whereas the highest known elevation in Turner Valley is in Royalite No. 14 well at 786 feet above sea-level. In spite of this, only shows of oil with water were encountered in the Highwood uplift, whereas the water line in Turner Valley is at an elevation of more than 4,100 feet below sea-level. The difference in the water-level in the two blocks adjoining one another is, therefore, known to be more than 6,000 feet, and may be 6,500 feet or more. From available information it thus seems that the Highwood block is effectively sealed off from the Turner Valley fault-block by the Outwest fault, but that the water in the lower part of the Turner Valley fault-block may be in open connection around the plunging south end of Turner Valley with the water in the Alberta syncline to the east, as the east side major thrust fault dies out southwards. Within the productive zones of the Palæozoic limestone of Turner Valley the closure is more than 5,000 feet, which is phenomenal.

Turner Valley is now considered to be a structural ridge of limestone thrust-faulted on its eastern edge, and in no way is it different from some outliers of Palæozoic limestone of the foothills except that it is deeply covered by Mesozoic strata. In the northern end as now developed there is a shifting to the west due to the fact that the fault on the east side is believed to bifurcate and one part cuts across the east flank of Turner Valley thus throwing the edge of the limestone block farther west than was formerly expected. North of this, however, the normal northwest trend is resumed and the buried ridge of limestone plunges downwards across the valley of Fish Creek, where Edmonton strata occur on the surface.

The structure of the north end of the field is not as simple as the south end, as the Palæozoic limestone is broken by a number of faults into separate fault-blocks thrust onto one another. To the east of the main uplift is a fault-block the extent of which is unknown, but it is significant in that it appears to indicate that, in at least this case, the faulting occurred after the oil accumulation. Throughout most of its length Turner Valley has production in two porous zones in the upper 350 feet of Palæozoic beds. On the west flank of the north end of the field water has been encountered in the lower porous zone of the limestone in wells reaching the top of the limestone at about 4,250 feet below sea-level, whereas in the upper porous zone the oil-water line is somewhat deeper. In the downfaulted block east of the main uplift of Turner Valley oil occurs in the upper porous zone in a well reaching the top of the limestone 6,025 feet below sea-level, or at a depth of 10,048 feet. It is inferred that this block originally formed part of the fold at the time of accumulation of the oil, but that later faulting depressed it in relation to the main structure and that it carried its oil content down with it and is thus entirely cut off from communication in the reservoir rock with the main Turner Valley uplift. Some of the best wells in the Turner Valley field are in the north end of the main uplift. In some of these the high production is due to good porosity in the two porous zones, in others it is partly due to fracturing of the limestone beds as a result of faulting.

Production of gas with naphtha began with the completion of Royalite No. 4 well in 1924, with a flow of 17,000 to 20,000 M cubic feet a day. This well, in the 10 years of its life, produced 911,313 barrels of naphtha valued at $3,000,000, and in addition supplied large volumes of gas for commercial and domestic use in Calgary, which is connected by both gas and oil pipelines to the field. Some of the naphtha wells drilled down the flank began to change to crude oil after a few years' production, but it was not until 1936 when Turner Valley Royalties well was completed at a depth of 6,828 feet in the south end of the field that drilling for oil actually began. This well had an initial production of about 850 barrels a day, and still continues to produce by flowing. Up to the end of 1943 its yield has been approximately 660,000 barrels. The south end of the field for a distance of 5 miles and a width of 1 mile to 1¼ miles has now been almost completely drilled. With the exception of a few wells drilled in the early days, the spacing is restricted to not less than 40 acres.

The north end of the field was opened up by the completion of Home Millarville No. 2 well in 1939. This has been the largest producer in the field, and its yield of crude oil to the end of 1943 has been approximately 1,150,000 barrels. It has no offsets to the east and south and may be in a fractured limestone area. The north end of the field is not as completely drilled as the south end and although the limits are being approached they have not yet been reached.

Good productive wells occur for 5 miles in the south end of the field and for 5½ miles in the north end. Between these there is an area 9 miles long where production has been more uncertain, due to local lack of porosity in the reservoir rock. There are some wells in this area and the acreage is mostly owned by small independent operators who were unable to finance the drilling. In order to keep up the supply of light oil for Western Canada from Turner Valley, which reached a peak production of 29,770 barrels a day in February 1942, and subsequently began to decline, the Dominion Government under the Oil Controller for Canada formed Wartime Oils to finance this drilling. Money is being loaned to the operators for drilling on the basis of a small royalty and low interest and will be paid back out of production. Drilling contracts are approved but there is no drilling by the Government company. This drilling program started in the summer of 1943 and by the end of 1943 three wells were completed with eleven rigs working. It is planned to drill at least twenty-six wells if results continue to be favourable. It is hoped wells of initial yields of 150 to 300 barrels will be obtained, but some may be lower.

The record of drilling within Turner Valley has been good in spite of the complications of the structure. In the winter of 1941-42 there was an unjustified wildcat drilling campaign to extend the north end of the field by a great number of wells drilling simultaneously. This resulted in the loss of more wells than were justified to get the geological information that was obtained. Drilling is now proceeding outward from production and the north end of the field will be found without further economic waste.

At the end of 1942 in Turner Valley one well had produced nearly 1,000,000 barrels, eleven additional wells had produced more than 500,000 barrels each, twelve more than 400,000 barrels, twenty-eight more than 300,000 barrels, thirty-eight more than 200,000 barrels, and fifty-six more than 100,000 barrels each. At the end of 1943 there were two hundred and seventeen producing oil wells and the field has produced a total of approximately 51,500,000 barrels of crude oil and 1,245,000 million cubic feet of gas with naphtha from a proved area of 10,000 acres in the gas area and 8,900 acres drilled in the oil area. The crude oil has a gravity of 40 to 43 degrees A.P.I. and contains more than 40 per cent gasoline on straight run distillation. The record drilling time, according to Taylor,[1] is 110 days for 7,415 feet. Acidization is used to increase the flow of the oil from the limestone.

Turner Valley may be taken as the type of foothills structure in southern Alberta, but experience has shown that many folds that in general show similar surface structural features do not have the Palæozoic limestone within them above the thrust fault that in each case cuts them off at depth. The results of drilling have demonstrated that one of the great danger points in drilling is the Kootenay coal beds below the Lower Blairmore and a number of wells have encountered faults of large displacement when they were stratigraphically very close to the top of the Palæozoic limestone. Drilling on the west flank of Turner Valley showed that no Devonian was present under this structure, but that a fairly low-angled fault followed down the Banff shales (Figure 14) at only a slightly greater inclination than the dip of the strata. This, of course, cannot continue indefinitely, and at some place still farther west the fault presumably may cut lower stratigraphic horizons or die out as a bedding plane fault. Beach[2] has shown that the Banff shales are commonly the locus of faults in Moose Mountain. Next to Turner Valley the Jumpingpound structure 20 miles west of Calgary and 18 miles north of the north end of Turner Valley has received more drilling than any other foothills structure. Following a deep test drilled high on the structure, a well was drilled a mile west of the crest, but both wells encountered the underlying fault at almost exactly the same stratigraphic position, namely the top of the Jurassic (Fernie) shales under the Kootenay, about 150 to 200 feet stratigraphically above the Palæozoic. Subsequently, extensive seismic work was done by the Shell Oil Company and a well has been drilled still farther west, close to the strike of the northward continuation of the north end of Turner Valley. This well reached the top of the Palæozoic limestone at 11,588 feet and was completed at 12,056 feet. Good porosity was encountered in the limestone, but water was present. Another well of interest now being drilled is on the Wildcat Hills anticline (Figure 12) north of Bow River. The surface structure is anticlinal,

[1]Taylor, Vernon: Development of Turner Valley Crude Oil Field; *The Miner*, Vancouver, B.C., March 1940, p. 26.
[2]Beach, H. H.: Moose Mountain and Morley Map-Areas, Alberta; Geol. Surv., Canada, Mem. 236, p. 51 (194 .

but at a depth of 7,420 feet the well encountered a fault and passed from Blairmore beds into Upper Cretaceous shales. This is a stratigraphic displacement of approximately 2,500 feet. The well is being continued, but the depth to the Palæozoic, if it can be reached, will be very great and the character of the structure below the fault is somewhat uncertain. In this case the information from surface geological mapping was checked by gravimeter surveys. Another structure, the Sullivan Creek anticline[1] close to the mountains west of the south end of Turner Valley, has had one well drilled on it to a depth of 3,590 feet. In this case the Palæozoic limestone was not cut off by a fault but was encountered at a depth of 2,375 feet. Although it was penetrated for 1,200 feet, only small porosity yielding 625 M cubic feet of gas was found. The structure is large and deserves further testing in which Devonian prospects should be considered.

In the foothills of southwestern Alberta there are few oil seepages and those that do occur are not particularly significant. There are quite a number of gas seepages, however, that are directly related to structural conditions. Some of these, as those on Coal creek of the Highwood uplift (Figure 12), are substantial, and smaller ones are known from a great many areas. The oil seepages are small and, so far as the writer knows, are mainly connected with the lower shales of the Upper Cretaceous. In certain areas globules of oil are present in the bedding planes when the shales are broken, and in the early days of drilling in Turner Valley, when cable tools were used, shows of oil were commonly reported from these beds. In the gas area of the central part of Turner Valley a fault cutting the Upper Blairmore may have allowed oil to migrate downward into what became known as the McDougall-Segur sand, from the discovery well of this name, and wells of small production were drilled over a limited area. Gas and oil in other sands of the Blairmore, however, may have been derived from the Palæozoic limestone. There is no water below the surface beds in any strata in Turner Valley above the Palæozoic limestone. The original well drilled in Turner Valley in 1914 was located close to a gas seep and encountered gas and oil in sand of the Blairmore formation. This well was about three-quarters mile south of Royalite No. 4 well, which reached the Palæozoic limestone in 1924. The seepage is close to the centre of the anticline, which in this area in the upper strata has a sharp but small subsidiary syncline that may have caused sufficient fracturing to allow for the occurrence of the seepage. In this case, therefore, the seepage has particular significance in relation to the production that was later discovered.

FOOTHILLS OF CENTRAL WESTERN ALBERTA

The foothills area from Bow River northwest to Athabaska River has been partly mapped by the Geological Survey, but the area north of this to the British Columbia boundary is not so well known. There are some pronounced differences in the stratigraphy as the various formations are traced northwestward along the foothills, and in the area north of Red Deer River[2] Triassic beds occur. These continue to increase in thickness to the northwest.

The Palæozoic rocks known from the foothills of central western Alberta are much the same as in southwestern Alberta with about 1,500 feet of Mississippian beds, mostly limestones underlain by 3,300 feet of Devonian limestones. In places there is a small thickness of Pennsylvanian quartzite much the same as in the western foothills farther south. The Triassic beds, with

[1]Hage, C. O.: Dyson Creek Map-Area, Alberta; Geol. Surv., Canada, Paper 43-5 (1943).
[2]Beach, H. H.: Marble Mountain Map-Area, Alberta; Geol. Surv., Canada, Paper 42-3 (1942).

a thickness up to 700 feet, are fine-grained, arenaceous shales overlain by soft, alternating buff and red limestones and grey, fissile shales. The Jurassic is very much thicker than in southern Alberta, and in the Mountain Park and Cadomin[1] areas consists of 1,300 feet of dark marine shales with some sandstone beds. Above the Jurassic the lower Cretaceous is also much thicker than farther south. The Nikanassin formation, the equivalent of the Kootenay of the Crowsnest Pass area, is 1,900 feet thick. It does not have workable coal seams, but is non-marine. It is overlain by the basal Blairmore conglomerate, here called the Cadomin formation, and above it are 1,700 feet of beds consisting of sandstones, dark shales, and conglomerates, with coal seams that are mined at Luscar, Mountain Park, Cadomin, and Brazeau. Above these are about 400 feet of greenish shales and sandstones, the equivalents of the upper part of the Blairmore of the southern foothills. The upper Cretaceous section is also much thicker than farther south. The Blackstone formation, 1,700 feet thick, compares with strata of the same age 750 feet thick at Turner Valley and 1,100 feet thick in the foothills on Red Deer River. The Cardium sandstone of Turner Valley is replaced by the Bighorn formation 350 feet thick, consisting of sandstone beds in groups separated by some shales, and the overlying Wapiabi formation about 1,700 feet thick is only slightly greater than in the southern foothills. These beds are mostly Colorado in age, but at the top are several hundred feet of marine Montana beds the same as in the Turner Valley area. Above the Wapiabi the non-marine Montana beds of the Brazeau formation correspond to Belly River and perhaps higher beds of more southern areas. There are no Bearpaw beds in this part of the foothills and non-marine beds, the equivalents of the Belly River, are overlain by the equivalents of the Edmonton, in turn overlain by the equivalents of the Palæocene (Paskapoo). All these non-marine beds constitute the Saunders group,[2] which, however, has been divided into upper and lower by coal-bearing beds. The whole sequence of non-marine beds has a thickness up to 14,000 feet.

The foothills of central western Alberta have a number of Palæozoic outliers. These are Marble Mountain, north of Red Deer River, and its northwest continuation the Clearwater anticline to and beyond Ram River, Limestone Mountain to the west of Marble Mountain, the Brazeau and Bighorn Ranges in the area between North Saskatchewan and Athabaska Rivers, Folding Mountain south of Athabaska River, and others (Figure 15). The structure has been most intensively studied in the coal areas bordering Jasper Park and in the Brazeau area, where some drilling has been done. Particularly in the Brazeau area have folded faults been observed by MacKay[3]. Folded faults have been seen in the southern foothills[4], but are not so apparent as farther north. In the area of Brazeau and Cardinal Rivers, about half-way between North Saskatchewan and Athabaska Rivers, a very complicated fault system has been described[5], but the interpretation is regarded as extreme.

In this part of the foothills a number of wells have been drilled on various structures beginning in Mesozoic beds, and a few wells on the limestone outliers. Two wells on the Grease Creek structure, 45 miles northwest of Calgary and

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[1]MacKay, B. R.: Stratigraphy and Structure of the Bituminous Coalfields in the Vicinity of Jasper Park, Alberta; Trans. Can. Inst. Min. and Met., vol. XXXIII, pp. 473–509 (1930).

[2]Allan, J. A., and Rutherford, R. L.: Sci. and Ind. Research Council of Alberta, Rept. No. 6 (1923).

[3]MacKay, B. R.: Paper presented at the Edmonton meeting of Can. Inst. Min. and Met., Oct. 1941 (not published).

[4]Hume, G. S.: A Folded Fault in the Pekisko Area, Foothills of Alberta; Trans. Roy. Soc., Canada, vol. XXXV. sec. IV, pp. 87–92 (1941).

[5]Hake, B. F., Willis, Robin, and Addison, C. C.: Folded Thrust Faults in the Foothills of Alberta; Geol. Soc. Am., vol. 53, No. 2, pp. 291–334 (1942).

Hage, C. O.: Folded Thrust Faults in Alberta Foothills west of Turner Valley; Trans. Roy. Soc., Canada, vol. XXXVI, sec. IV, pp. 67–68 (1942).

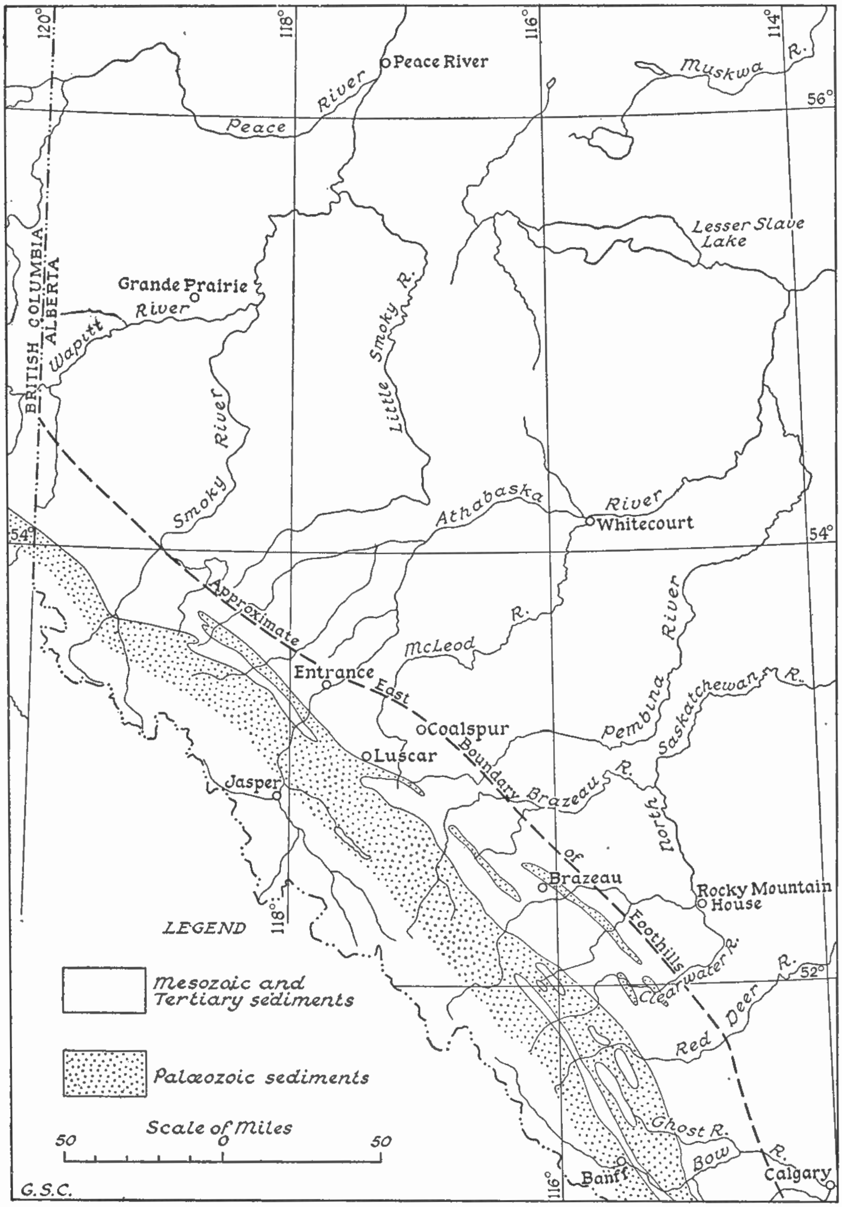

Figure 15. Foothills area of central western Alberta.

south of Red Deer River, both failed to reach their objective, the Palæozoic limestone. A fault of large displacement was encountered in the second well, which was abandoned at a depth of 7,401 feet. Farther north on the Walton Creek anticline just north of Red Deer River similar conditions were found and a fault with a stratigraphic displacement of 2,000 to 3,000 feet was penetrated at a depth of 4,290 feet.

On Red Deer River, 3 miles east of the mountain front, a well was drilled to a depth of 8,282 feet without encountering a fault, but the bottom of the hole was considerably off the vertical and steep-dipping Fernie was being drilled at the time the well was abandoned. The well began drilling at the Cardium sandstone, but is on the plunging end of a faulted anticline that to the south exposes almost the complete section of Blairmore. Water occurred in the Blairmore sands.

Two wells were drilled on a Palæozoic outlier on Clearwater River, and in both of these shows of oil occurred in Devonian strata. Another well 20 miles to the northwest on the Ram River anticline has some oil in what is presumed to be either Devonian or older beds, at a depth of 4,340 feet. This well was drilled on the east side of an asymmetric Palæozoic fold and for a considerable depth penetrated steeply inclined strata.

One of the most interesting tests drilled in this whole area was the Home Brazeau well on the Brazeau structure,[1] 40 miles northwest of the town of this name. To the east of the well location on this structure there is a strong seepage of wet gas. The well encountered many repetitions by faulting and was abandoned in the Blairmore at a depth of 8,728 feet. Several million feet of wet gas under high pressure were encountered. The prospects of this structure are still considered worthy of further tests, but there is no doubt the depth to the Palæozoic will be great.[2]

Another test still farther north was that of the Shell Oil Company north of Athabaska River at Entrance, 40 miles north of Jasper. This well was suspended at a depth of 4,774 feet when it was found the depth to the Palæozoic was much greater than had been anticipated.

In the foothills north of Bow River no well commencing in Mesozoic strata has reached the underlying Palæozoic beds. It would be thought that since outliers of Palæozoic rocks occur, these same beds would be found at moderate depths in structures of the same type. No such structure is at present known and where the geology has been mapped only deeply buried Palæozoic would be expected. The problem of finding favourable structures is no doubt complicated by folded faults and the difficulty of interpretation. If this folding after faulting is as extreme as some authors believe, the prospects of central western foothills would seem to be highly speculative, due to the difficulties likely to be encountered in making favourable locations. The problem would appear to be to decide which are primary folds, i.e., folds formed before the faulting and thus likely to receive the oil accumulations in contrast with secondary folds formed after the faulting and in which the occurrence of oil would be more a matter of chance resulting from redistribution due to the disturbance of the original accumulations.

There is one fold in the vicinity of Lovett and Coalspur[3] that has received some attention. It is believed to be in front of the main foothills disturbed belt, but has a northeast dipping fault along the crest resulting in a short and steeper west flank, in contrast with a long gentle east flank. This is the reverse of the usual foothills structures. Some drilling was done on this anticline many years

[1]Sanderson, J. O. G.: Geology of the Brazeau Area; Trans. Can. Inst. Min. and Met., vol. XLII, pp. 429–442 (1939).
[2]MacKay, B.R.: Wapiabi Creek; Preliminary map with cross-sections, Geol. Surv., Canada, Paper 40-13 (1940).
[3]MacKay, B. R.: Cadomin sheet; Geol. Surv., Canada, Map 209A (1929).

ago and it is known that the top of the Wapiabi shales occurs at a depth of less than 3,000 feet. The depth to the Palæozoic limestone in any well on this fold will thus be very great, as in the western part of the area there are more than 9,500 feet of strata between the top of these shales and the top of the Palæozoic limestones. No doubt there will be considerable thinning of these strata eastward, but the depth to the Palæozoic in any well would be expected to exceed 10,000 feet, even drilling a normal section on a comparatively low dip.

NORTHEASTERN BRITISH COLUMBIA

The foothills of central western Alberta continue northwestward into British Columbia for 450 miles to and beyond Liard River (Figure 16), but are not such a clearly defined belt as in southwestern Alberta. This change is partly the result of a change in the type of structure, which in turn may be related to the stratigraphy.

Between Athabaska River at Jasper, Alberta, and the British Columbia boundary there are some marked changes in the stratigraphy, but this is in an area that has received comparatively little study by the Geological Survey. The stratigraphy south of Peace River in British Columbia has, however, been studied, particularly in connection with a well drilled by the British Columbia Government at the mouth of Commotion Creek on Pine River, a tributary of Peace River from the south. The main changes in the stratigraphy compared with more southerly areas are in the Mesozoic rather than in the Palæozoic, although the Palæozoic has received relatively little attention.[1] Devonian, Mississippian, and Pennsylvanian strata are present. The Triassic resting on the Palæozoic is greatly increased in thickness from all southern areas and on Peace River is considered[2] to be approximately 3,000 feet thick. It is composed of grey and purple arenaceous limestones with calcareous sandstones and shales. Above these are a few hundred feet of dark Jurassic shales and these are overlain by non-marine Lower Cretaceous sandstones and shales with some conglomerate beds and coal. This assemblage of beds is known as the Bullhead group and in the vicinity of Peace River west of Hudson Hope may be 4,000 or more feet thick. It thins very markedly northward. The lower part is very hard and quartzitic and is composed of massive, crossbedded sandstones with fine conglomerates. The upper part contains coal seams in what has been called the Gething member. McLearn[3] has suggested that the Bullhead "includes three distinct members—a lower sandstone, a middle conglomerate-bearing member, and an upper or Gething coal-bearing member—comparable respectively with the Nikanassin, Cadomin conglomerate, and Luscar formations of the Mountain Park area", but this is only a tentative correlation. The Bullhead group, in the Peace-Pine Rivers area, is overlain by the Fort St. John group,[4] a series of interbedded shale and sandstone formations, chiefly of marine origin. The oldest strata in the group constitute the Moosebar shales, which have a thickness of almost 800 feet in Peace River area and are at least that thick on Pine River. The Moosebar is overlain, in the Pine River section, by the Commotion formation, 1,300 to 1,500 feet of interbedded shales and sandstones with some conglomerate and coal near the top. In the Peace River region this thickness is not apparent, the only sandstone being the Gates, which consists of three sandstone members separated by shales, the whole being only 80 feet thick. According to

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[1]Williams, M. Y., and Bocock, J. B.: Stratigraphy and Palæontology of the Peace River Valley of British Columbia; Trans. Roy. Soc., Canada, vol. XXVI, sec. IV, pp. 201–4 (1932).
[2]McLearn, F. H.: Mesozoic of Upper Peace River; Geol. Surv., Canada, Sum. Rept. 1920, pt. B, p. 3.
[3]McLearn, F. H.: Notes on the Geography and Geology of the Peace River Foothills; Trans. Roy. Soc., Canada, vol. XXXIV, sec. IV, p. 72 (1940).
[4]Wickenden, R. T. D., and Shaw ,G.: Geol. Surv., Canada, Paper 43–13 (1943).

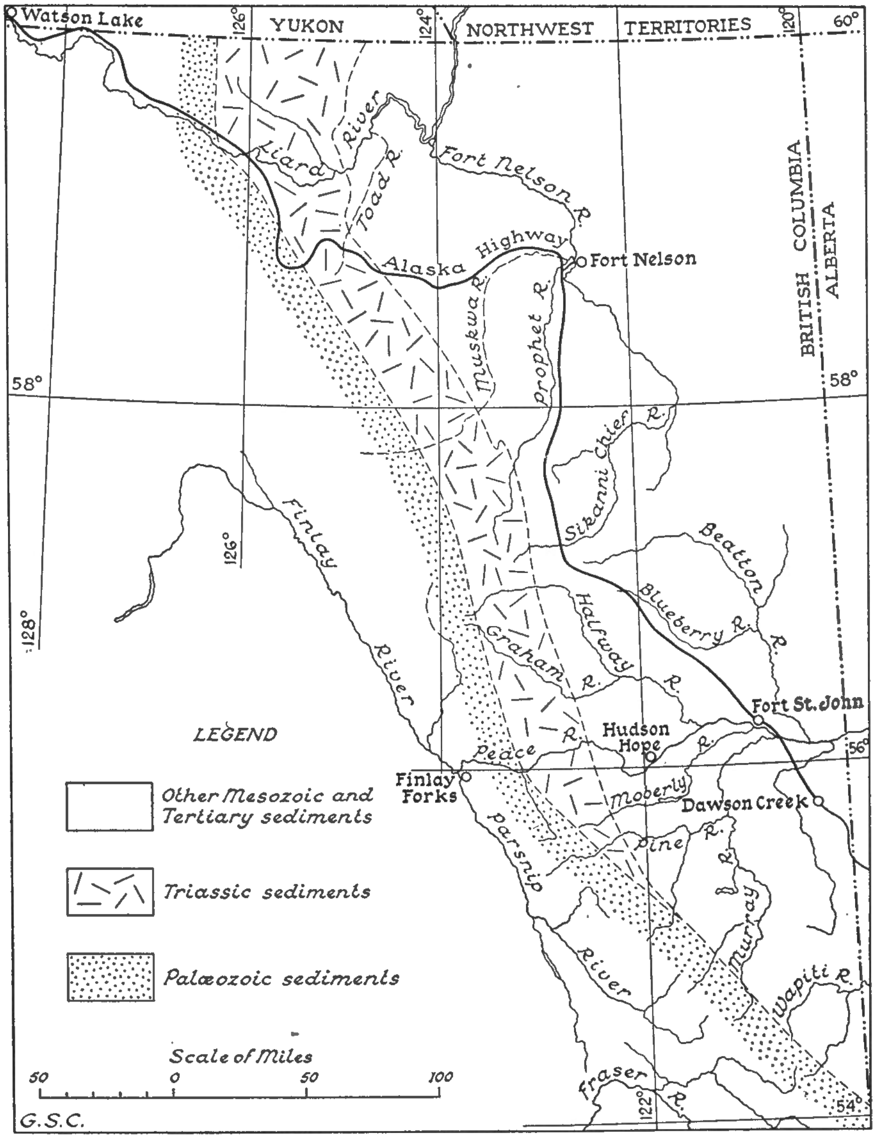

Figure 16. Northeastern British Columbia.

McLearn, the Gates is probably the stratigraphic equivalent of the lower part of the Commotion formation. Above the Gates and Commotion beds lie the Hasler shales, between 1,100 and 1,200 feet thick on Pine and somewhat thicker (1,300 feet) on Peace River. They are wholly marine. The Hasler, in turn, is overlain in both sections by the Goodrich formation, consisting of 550 to 600 feet of marine sandstone and some interbedded shale. These are succeeded by about 800 feet of marine shales of the Cruiser formation, constituting the uppermost strata of the Fort St. John group. This group is of Lower Cretaceous age and forms a marine section over 4,500 feet thick, in striking contrast with the southern foothills where marine strata of this age are absent. The base of the Upper Cretaceous is placed at the base of the Dunvegan formation, a freshwater sandstone at least 1,200 feet thick in the Pine River region. These beds form the tops of plateau areas to the north of Peace River and commonly occur as cliffs along the deep valley sides. To the east in Alberta the Dunvegan is overlain by the Smoky River marine shales of Colorado age.

A feature of the Peace River area northwest to Liard River is the extent of the Triassic outcrops. These beds are arenaceous limestones, calcareous sandstones, and shales, and on account of their hardness form hills of high relief only slightly less than the mountains formed by the Palæozoic rocks. A feature of the Lower Cretaceous also is the hardness of the lower member of the Bullhead group. This is a quartzitic sandstone that is well exposed along the upper part of Peace River Canyon and forms high ridges just west of Hudson Hope and north of Peace River. The coal[1] from the Gething member of the Bullhead group is also high grade, with the coal from Gething Creek having an analysis showing 1 to 1·6 per cent moisture, 8·4 to 8·6 per cent ash, 24·5 to 26 per cent volatile matter, and 64 to 65·9 per cent fixed carbon. Analysis of coal taken from the Commotion Creek well to depths of 4,370 feet showed fixed carbon 75·6 to as high as 83 per cent, volatile matter 10 to 20 per cent, ash 2·6 to 6·4 per cent, and moisture 0·4 to 0·6 per cent. This high carbon content cannot be accounted for by metamorphism due to deformation as the beds in which the coal occurs are not excessively folded, nor can it be accounted for by heat due to proximity of any igneous rocks because these are unknown in this area. The high grade of coal and the extreme hardness of the lower Bullhead Mountain formation in Peace River Canyon and in the Commotion Creek well are, therefore, not readily accounted for.

The structures in the northeastern part of British Columbia are very different from those of the southern foothills in that there are very gentle folds in front of the more westerly faulted anticlines. On Peace River the folds in the Triassic have wide, very gently arched tops with steeply tilted beds on both flanks, and this type of structure is common. Thrust faulting is present, but not to the extent that it occurs in the southern foothills. This different type of structure is probably due to the much greater resistance to deformation offered by the harder beds of the Triassic and lower part of the Bullhead group. The Butler ridge anticline west of Hudson Hope is double crested, with a sharp syncline in the central part and a fault on the eastern side. This fault in this area could be considered the east edge of the foothills. It sharply divides a prominent anticlinal structure to the west from very gentle folds to the east, which might readily be ascribed to the Plains. There is no such sharp division, however, that can be traced northwest and southeast along the edge of a foothills belt.

The Commotion Creek structure on Pine River, where the British Columbia Government drilled a well in 1940-2, has gentle dips up to 11 degrees on the west

[1]McLearn, F. H.: Peace River Canyon Coal Area, British Columbia; Geol. Surv., Canada, Sum. Rept. 1922, pt. B, pp. 1-46.

flank and steep to vertical dips on the east flank, which is faulted. Originally this fault was considered to dip east, but later work on the stratigraphy has shown that it is a thrust fault from the west. Steeply dipping beds were encountered in a number of places in the well.

The Commotion Creek well was drilled in the valley of Pine River, which has outcrops along the valley sides. In the well, however, the surface deposits were 1,081 feet thick. It is thought that the base of the Moosebar occurred in the well at a depth of 2,408 feet and that the base of the Gething was at 3,990 feet. The well was drilled to a depth of 6,940 feet without reaching the base of the Bullhead group. No oil or gas was encountered.

A number of structures in British Columbia both south and north of Peace River have been studied by the Geological Survey, but no recent drilling has been done aside from the Commotion Creek well. In one structure 50 miles southwest of Beaverlodge, Alberta, on the Monkman trail, there is a very large gas seepage issuing through a small pool of water on the side of a hill on the crest of an anticline. This seepage is interesting in that the gas from it contains more than 12 per cent ethane and heavier hydrocarbons. The structure on which it occurs would probably be considered the most easterly in the foothills of this area. It has relatively gentle west dips, but a shortened east limb resulting from thrust faulting. The beds occurring on the crest of the anticline are higher stratigraphically than the Dunvegan formation, which in this area might have favourable reservoir beds. Other sandstones are present above the top of the Bullhead, but on account of its hardness and thickness, drilling these beds in this area may be inadvisable.

An intersting feature of the Peace River area has been referred to in connection with the depth of surface deposits in the Commotion Creek well. The base of these deposits, at a depth of 1,081 feet, is 920 feet above sea-level. Pine River joins Peace River near Fort St. John, and from there via Lakes Athabaska and Great Slave to the Arctic Ocean, the outlet for this drainage, the distance is close to 2,000 miles. There is little doubt that Pine River is a rock-cut gorge in the deeper part and the same is true of Peace River above Hudson Hope where the valley sides are now largely covered by fine grey silts. The canyon of Peace River is post-glacial in age, but the old river valley can be traced along the route of the road west from Hudson Hope. The deep fill of the river valleys has also been noted in drilling for water at Fort Nelson.

NORTHWEST TERRITORIES

Mackenzie River Basin from Great Slave Lake 750 miles north to the Arctic Ocean occupies an area of approximately 150,000 square miles. It is bounded on the east by the Canadian Shield of Precambrian rocks and on the west by Mackenzie Mountains. Exploratory surveys were carried out in this area by the Geological Survey and others in the latter part of the nineteenth century, but it was not until 1920, when drilling for oil actually began, that any serious attention was paid to the oil prospects. This is readily accounted for by the remoteness of the region, about 1,200 miles by water to Fort Norman from the end of the railroad at Waterways, Alberta, on Clearwater River, a tributary of the Athabaska; the lack of fast transportation facilities of former years; and the short summer season. Numerous and copious oil seepages had been reported, however, from widely separated localities, but mainly if not entirely from Devonian rocks. During the 4 years 1920 to 1923 inclusive, several parties sent out by the Geological Survey made as thorough investigation of various parts of the area as seemed warranted at that time, and this together with the geological work done by Imperial Oil Company in the same period was mainly the basis of our information up to the beginning of the Canol development in 1942.

In such a large area it can be readily understood that there are wide variations in the lithology and thickness of rocks of the same age, and also a wide diversity of structural conditions. It should be recognized, therefore, that the oil prospects in the vicinity of Great Slave Lake are quite distinct from those at Fort Norman, 400 miles northwest, and these again are quite different from the less well known Arctic Red River area, 250 to 300 miles still farther north, and the Wind River basin of the Yukon, north of latitude 65 degrees and 250 miles west of Fort Norman. All these areas have good oil prospects, and seepages are known from all with the possible exception of the Arctic Red River area where the Devonian is mainly concealed by younger rocks.

GREAT SLAVE LAKE AREA

The eastern end of Great Slave Lake is underlain by Precambrian rocks (Figure 17), but west of Slave River and the north arm of the lake Palæozoic rocks occur and in a general way these dip to the west so that in Horn Mountains to the north of Fort Providence Cretaceous strata overlie the Palæozoic. Horn Mountains are a high plateau of relatively flat-lying sediments, and flat-lying beds with gentle folds occur throughout the whole Great Slave Lake area. The best sections of Upper Devonian are found along Hay River, which enters Great Slave Lake near the southwest end. These consist of 300 feet of dolomitic and shaly limestones—the Hay River limestones—underlain by 400 feet of shaly limestones and limy shales—the Hay River shales—in turn underlain by 250 feet of greenish shales, of the Simpson formation. The Middle Devonian consists of 200 feet of Slave Point limestones resting on 375 feet of Presqu'ile dolomites. These beds are very porous and give large seepages of oil at their outcrops along the northwest shore of Great Slave Lake where the regional dip is to the southwest. The Presq'ile dolomites overlie the Slave Point limestones, which outcrop on the south shore of the lake not far west of Fort Resolution as well as at other places. Below the Slave Point limestones, but known only from Horn River area north of Fort Providence, are 100 feet of Horn River shales. On the west side of the north arm of Great Slave Lake about 275 feet of Silurian dolomites of Niagaran age overlie 595 feet of gypsiferous red beds of the Ordovician. No Cambrian is known.

This succession of strata is much different from that occurring to the northwest in the Fort Wrigley area, where the southern end of Franklin Mountains shows some sharp folds. In Great Slave Lake area the highest known Silurian is Guelph in age, but in the Wrigley area there are 1,600 feet of Upper Silurian strata[1] underlain by 1,000 feet of older Silurian beds. As has been previously pointed out,[2] this may indicate a regional uplift that was progressively greater southward in early Devonian time and consequently resulted in erosion being deeper to the south than to the north, thus removing the Upper Silurian from the Great Slave Lake area. This inference is given some support by the fact that in the McMurray area of Alberta, where salt wells have penetrated to the Precambrian, the basal Palæozoic sediments, which are gypsum- and salt-bearing, may be Devonian rather than Silurian,

[1]Williams, M. Y.: Geol. Surv., Canada, Sum. Rept. 1922, pt. B, p. 73.
[2]Hume, G. S.: Oil Prospects of Great Slave Lake and Mackenzie River Areas; Trans. Can. Inst. Min. and Met., vol. XXXV, pp. 92-103 (1932).

with a very small thickness of Silurian and no older Palæozoic rocks in this area, either indicating much greater erosion than farther north or non-deposition. The sedimentation of the Middle Devonian is also instructive in regard to possible regional uplift prior to its deposition. In Great Slave Lake area, as already shown, the Middle Devonian consists of 1,170 feet of limestones and dolomites, and these are very shaly in certain parts. To the northwest,

Figure 17. Western portion of Northwest Territories, showing Mackenzie River basin.

in the Fort Wrigley area, strata of the same age are dominantly massive and dense limestones and are at least 2,000 feet thick. This change in sedimentation and increase in thickness of the Middle Devonian northward from Great Slave Lake area may be due, therefore, to deeper water deposition, a condition that would result from relatively greater uplift southward prior to their deposition. The Middle Devonian contains the most promising potential oil productive strata in Great Slave Lake area, and, therefore, the change northward may be significant in relation to oil prospects.

Only two wells[1] have been drilled in Great Slave Lake area and both of these failed to find commercial production. One of these was on the north shore of Great Slave Lake at Windy Point and the other 15 miles south of Great Slave Lake on Hay River. The latter well is interesting in that it obtained a strong artesian flow of water from the Middle Devonian Presqu'ile formation. There is no obvious head for this water and the suggestion has been made that it owes its pressure to gas in the crest of the structure on which it was drilled. The formation is very porous.

FORT NORMAN AREA

In the Mackenzie Basin and mountains of the Fort Norman area, strata consisting of Cambrian, Ordovician, Silurian, Middle and Upper Devonian, Cretaceous, and Eocene are known to be present. Seepages of oil are very common in Devonian beds and all production so far obtained comes from strata of this age. Cambrian and Ordovician beds are known to occur in Carcajou Mountains on the west side of the Mackenzie Basin, but their character and extent have not been studied in any detail. They consist mostly of red and green shales and sandstones; the lower part is definitely known to be Cambrian, but the age of the upper or assumed Ordovician part is much more doubtful. However, Ordovician red beds with gypsum are present on Great Slave Lake and elsewhere in the Mackenzie Basin. The Silurian is somewhat better known. In the Mount Charles area on Great Bear River the lowest beds are gypsiferous shales, but the extent of these beds has not been determined. To the south in Franklin Mountains the lowest Silurian beds consist of 500 feet of calcareous shales with red interbeds grading upward into buff limestones. These strata are Lower Silurian in age. [2] In Franklin Mountains south of Great Bear River and west of Mackenzie River the Lower Silurian beds are overlain by 560 feet of Middle Silurian limestones, and these in turn by 1,500 feet of Upper Silurian limestones. In the area north of Great Bear River the combined thickness of beds believed to be Middle and Upper Silurian in age is 1,400 to 1,500 feet. These consist of Middle Silurian well-bedded limestones overlain by about 400 to 500 feet of beds that so far as is known are devoid of fossils and in places contain thick gypsum beds. In other places these same beds are highly porous, with vugs of considerable size. Where such conditions are present there is little or no stratification. These highly porous rocks under proper structural conditions are capable of acting as excellent reservoir beds for oil and gas, and they are somewhat bituminous in certain localities.

North of the oil wells, which are 50 miles north of Fort Norman, the Silurian limestones are overlain by about 300 feet of dark shales, and these in turn by 650 to 700 feet of massive Middle Devonian limestones. Devonian strata are widely known in Western Canada across the whole of the Prairie Provinces into the mountains and northward from the International Boundary between the United States and Canada to the Arctic islands. The character and thickness of the beds change considerably in such a large area, but over most of it the Devonian consists of limestones and dolomites.

The Upper Devonian in the Fort Norman area consists of about 1,500 feet of dark shales of the Fort Creek formation overlain by 1,600 to 2,000 feet of the Bosworth formation of sandstones and shales. The Fort Creek shales are so

[1] Hume, G. S.: Oil and Gas in Western Canada; Geol. Surv., Canada, Ec. Geol. Ser. No. 5, pp. 294–295 (1933).
[2] Williams, M. Y.: Geol. Surv., Canada, Sum. Rept. 1922, pt. B, p. 78.

highly bituminous in some places that they have been burnt to clinkers, presumably by spontaneous ignition. Where such action has occurred the shales have been turned to a red colour and the shales in part have been melted into slag-like material. Vermilion Creek, near Norman Wells, gets its name from the colour of the burnt shale. In certain areas large lenses of sand occur in the Fort Creek shales. The Bosworth formation overlying the Fort Creek shales contains a great many sand beds favourable for oil reservoirs. These alternate with greenish grey shales. The whole assemblage is marine and contains abundant fossils.

The Cretaceous is unconformable on the eroded top of the Devonian. There apparently was some regional movement in the time interval separating strata of these two ages and it is suggested the period of uplift could have been at the end of the Carboniferous or in early Mesozoic, when deformation took place in other parts of the Cordillera system. The Cretaceous consists of marine beds underlain by non-marine strata with coal. The marine shales offer excellent cover for the retention of oil in the Bosworth sands under favourable structural conditions. They are found in the vicinity of Fort Norman on the west side of Mackenzie River. The thickness of Cretaceous is unknown.

Eocene beds[1] unconformably overlie all older strata in the Mackenzie area and are only slightly disturbed by the folding that occurs in these older beds. The Eocene contains the burning coal seams on Mackenzie River near Great Bear River. These were noted by Mackenzie in 1789, and still continue to burn.

In 1914, at the time of the first oil boom in Turner Valley, Alberta, a Calgary syndicate engaged Dr. T. O. Bosworth to investigate the Mackenzie River area, where seepages were known to occur. Bosworth staked three claims 50 miles north of Fort Norman. These claims were later acquired by the Northwest Company, a subsidiary of Imperial Oil Company, Limited, and the first wells were drilled on them near the mouth of what is now known as Bosworth Creek. The first well, Discovery No. 1, was drilled in 1920 and obtained oil of 38 degrees A.P.I. at 783 feet. In 1922 the well was deepened to 991 feet and in 1924 to 1,025 feet. The production from it at this depth was 125 barrels a day. The bottom of the well was still in Fort Creek shales, with the underlying limestone not reached. Between 1921 and 1924 three wildcat wells were drilled by the Northwest Company (Figure 18). These were Bluefish No. 1, north of Bear Rock at Fort Norman, Bear Island No. 1, on Bear Island on Mackenzie River 1¼ miles south of the mouth of Bosworth Creek, and "C" location, on the south bank of Mackenzie River. Only the Bear Island well gave some oil shows. This well now contains some oil and is apparently on the edge of the producing area. In 1924 a second well, Discovery No. 2, was drilled 150 feet from No. 1. This well was completed in 1925 at a depth of 1,602 feet with a production capacity about the same as No. 1 well. In 1932 the mining developments of Great Bear Lake, following the discovery of pitchblende and the discovery of gold at Yellowknife on the north arm of Great Slave Lake, led to the demand for oil products and a small still was erected to make gasoline and diesel fuel. In 1939 another well, No. 3, was drilled on the north side of the river about 2,750 feet up river from Nos. 1 and 2. This well showed little oil at first, but subsequently was made into a small producer. In 1940 No. 4 well, about 1,200 feet down river from Nos. 1 and 2, was drilled and had a capacity of about 150 barrels a day. Also in 1940 a new refinery was put in operation with a capacity of 840 barrels of crude oil a day and alkalate was taken to the refinery for blending in making 87 octane aviation gasoline. In 1941 Imperial Oil distributed from the Fort

[1]Hume, G. S.: Geol. Surv., Canada, Sum. Rept. 1921, pt. B, p. 76 (Flora identification by W. A. Bell).

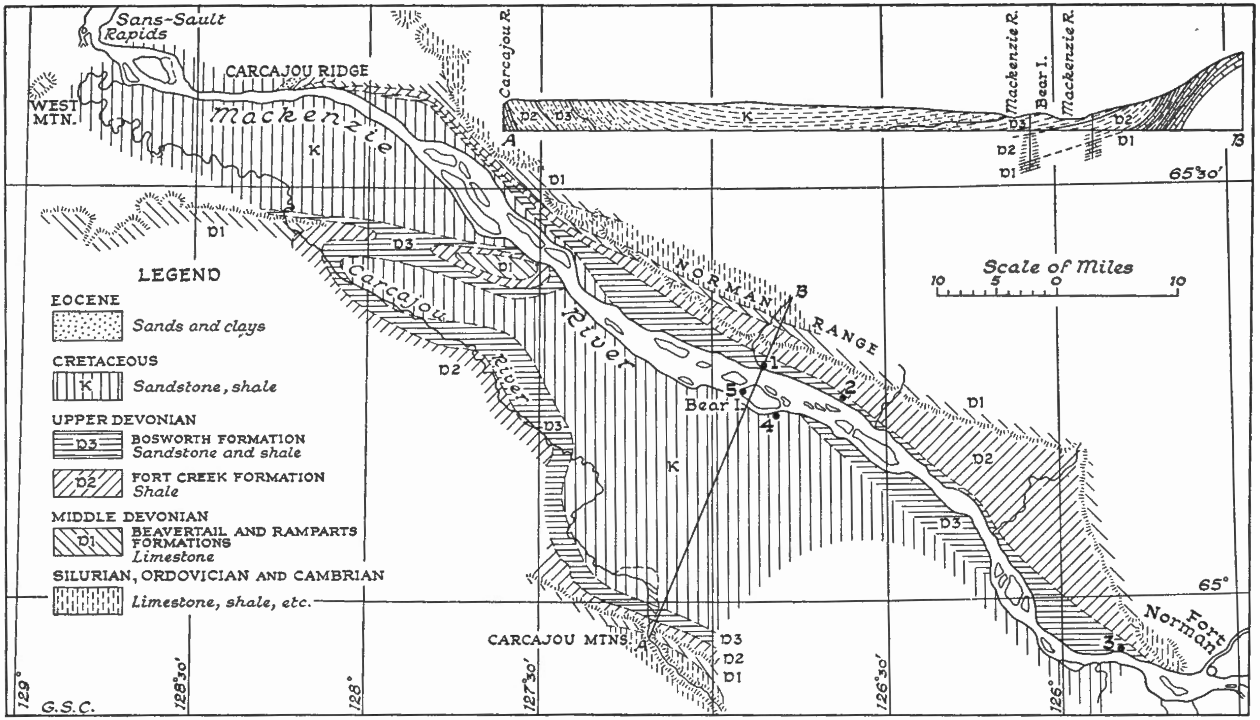

Figure 18. Geology of Fort Norman area, District of Mackenzie, Northwest Territories. 1, Producing oil wells; 2-5, Non-producing oil wells. 1, Northwest Oil Co., No. 1 and No. 2; 2, Fort Norman Oil Co.; 3, Northwest Oil Co., Bluefish well; 4, Northwest Oil Co., "C" location; 5, Northwest Oil Co., "D" location (on Bear Island). Wells shown are those drilled previous to the Canol development.

Norman field about 80,000 gallons of aviation gasoline, 112,000 gallons of motor fuel, and 230,000 gallons of fuel oil. This then was the situation when the Canol project was started in 1942.

The Canol project came about through military necessity. The object was threefold, namely, to drill wells for oil in the Fort Norman and adjoining areas, to transport the oil by pipeline 600 miles from Norman Wells to Whitehorse, and to build a refinery at Whitehorse to make petroleum products. Imperial Oil Company, Limited, was concerned only with the first of these objectives, namely oil production, and, accordingly, an arrangement was entered into between the United States Government and the Imperial Oil Company for the drilling of the wells, and between Imperial Oil Company and the Dominion Government for the securing of mineral rights and other necessary concessions. The pipeline and the Whitehorse refinery is a United States army project.

Work on the Canol project was started in the early summer of 1942, and in that year sixteen wells were drilled, of which two were dry. Up to November 1, 1943, fourteen more wells were drilled, bringing the total to thirty. Of these twenty-three found oil in commercial quantity and seven either were dry or obtained only a very small yield. These are in addition to the four producing wells of the Imperial Oil Company drilled prior to 1942. According to Hopkins,[1] "the area of the Norman discovery has proved much larger and more productive than was anticipated. Instead of being limited to a few million barrels it is on the order of a major oil field—no East Texas to be sure, but comparable to the average major field in the United States".

The area of the oil field at Norman Wells has been fairly well outlined and a very considerable part of the field is under Mackenzie River between the north bank and Bear Island. There are producing wells on Bear Island and a sand bar called Goose Island on its down stream end. The distance from the mouth of Bosworth Creek, the centre of the oil field on the north bank, and Bear Island is 1¼ to 1½ miles. At Norman Wells, Mackenzie River including the islands is 3 miles wide.

The structure of the field is simple. On top of the Middle Devonian limestone is a coral reef and this is the main reservoir rock. The reef has an irregular, oval-shaped surface and is up to 425 feet thick. Where it is thick the overlying Fort Creek shales are correspondingly thin. The seal for the oil in the reef is the shales surrounding and overlying the reef. The dip of the strata in the area of the field is in one direction, to the southwest at about 5 degrees as shown in Figure 18. The wells on Bear Island are about 2,000 feet deep, whereas in Discovery No. 2 well on the north bank of the river the base of the Fort Creek shales occurred at a depth of 1,086 feet.

The valley of Mackenzie River in the Fort Norman area is a large syncline about 20 miles wide between the Norman Range on the east side of the river and Carcajou Mountains on the west. The Norman Range is anticlinal and is a large fold that is eroded to expose Silurian strata on the crest of the fold near the top of the mountain range. Successively higher formations occur to the west on the flanks of the fold. On the east side of Mackenzie River the eroded edges of the Bosworth formation provide the abundant oil seepages common in the area, whereas to the west of the river the Bosworth formation is covered by a fairly thick succession of Cretaceous sandstones and shales. The edges of all the formations again appear on the west side of the basin, and in Carcajou Mountains, close to the edge of the basin, Cambrian rocks occur. The extent of

[1]Hopkins, O. B.: The Canol Project; Can. Geog. Jour., vol. XXVII, No. 5, p. 241 (Nov. 1943).

the Norman Basin parallel to the river is not known exactly, but may be considered to extend from 100 miles south of Fort Norman to the Ramparts of the Mackenzie, a total distance of not less than 250 miles.

Within the Fort Norman part of the Mackenzie Basin there are many pronounced folds. Some of these cross the basin obliquely as if formed by differential movements parallel to the basin trend, but owing to the fact that the soft beds are largely concealed by muskeg in the inter-stream areas and the massive Middle Devonian limestone more effectively resists erosion only such folds as expose a core of Middle Devonian or older strata are known. The Cretaceous beds, however, overlying the Upper Devonian are folded and there is good reason to expect suitable oil structures will be found where the Upper Devonian is protected by a Cretaceous cover.

In regard to reservoir rocks, the conditions in the Fort Norman area may not be unique. Coral reefs have been seen elsewhere,[1] but not at the stratigraphic horizon of the Norman Wells oil field. An interesting feature of the observed coral reefs is the abundance and fine preservation of crinoid heads. The Bosworth formation overlying the Fort Creek shales contains many sandstone beds that could under favourable structural conditions act as reservoir beds for oil and gas. Also in the Silurian[2] there are very massive cavernous beds up to 450 feet thick that are highly porous. These beds in places are somewhat bituminous. Exposures of them occur in the canyon sides of Carcajou River where it issues from the mountains as well as on Bear Mountain at Fort Norman and elsewhere. The Cretaceous also has a considerable thickness of sandstones in its lower part. There is no doubt, therefore, that reservoir rocks are present in all stratigraphic groups from the Silurian to the Cretaceous. This, together with favourable structures observed in an area where seepages give abundant evidence of oil, points to the Mackenzie Basin as the most favourable prospecting territory in Canada.

ARCTIC RED RIVER AND PEEL RIVER AREAS

The area through which Arctic Red River and the lower part of Peel River flows (Figure 17) is mainly underlain by Cretaceous strata, but concerning which the Geological Survey has little information. The rocks where exposed along Mackenzie River show gentle dips, quite in contrast with the sharp folds[3] of the Sans Sault Rapids 65 miles north of Norman Wells and 40 miles south of the Ramparts of the Mackenzie where Cretaceous beds rest unconformably on Middle Devonian limestones. There is no doubt, however, that to the north Upper Devonian rocks are present and these would be expected to occur under the Cretaceous of the Arctic Red and Peel Rivers area.

In the upper part of Peel River in the Yukon there is a plateau[4] with an elevation of 1,500 feet and a northward-facing escarpment overlooking the Mackenzie lowland. Peel River has cut a valley in the plateau 700 to 1,000 feet deep. In the upper part of Peel River the plateau is broken by several short ranges of mountains that expose Palæozoic rocks, but on the lower parts of Wind and Bonnet Plume Rivers, tributaries of the Peel, and along Peel River for 13 miles there is a Tertiary basin overlying Cretaceous rocks. Seepages of oil have been reported from this area, one from the mouth of Hungry Creek, 25 miles up Wind River from its junction with Peel River. This is less than 100 miles north of Beaver River,[5] to which there is a tractor road from Keno Hill, which in turn is connected with a 40-mile all weather road to Mayo Landing. Mayo Landing is on Stewart River, 170 miles above its junction with the Yukon. Both

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[1]Hume, G. S.: Geol. Surv., Canada, Sum. Rept. 1921, pt. B, p. 71. Whittaker, E. J.: Geol. Surv., Canada, Sum. Rept. 1922, pt. B, p. 97.
[2]These beds were inferred to be Silurian by Kindle.
[3]Kindle, E. M., and Bosworth, T. O.: Geol. Surv., Canada, Sum. Rept. 1920, pt. B, pp. 37-58.
[4]Camsell, C., and Malcolm, W.: The Mackenzie River Basin; Geol. Surv., Canada, Mem. 108, p. 19 (1921).
[5]Information from Bostock, H. S: Geological Survey, Canada.

of these rivers are navigable and in summer a boat service is maintained from Whitehorse, 600 miles by river from Mayo Landing. A road used only under favourable weather conditions also connects Whitehorse and Mayo Landing. Oil structures in the Wind River Basin, therefore, are within reasonable distance of transportation facilities in the Yukon. The elevation of the upper part of the Wind River Basin is about 2,000 feet and the pass to Beaver River is 3,500 feet.

FLATHEAD AREA, SOUTHEASTERN BRITISH COLUMBIA[1]

In southwestern Alberta and southeastern British Columbia is an area mainly of Precambrian strata (Figure 19) extending from east of Waterton Lakes to Flathead Valley and from the International Boundary northward for 25 miles. The area has long been of interest to the geologist because of the structure and the unusual association of oil seepages with rocks of Precambrian age. Seepages of oil and gas are known from several localities, and were first described by Selwyn[2] in 1891 following some prospecting activity that resulted from their discovery. At that time Selwyn, following Dawson's[3] reports of 1875 and 1885, regarded the oil seepages as occurring in Cambrian rocks. In 1902 Willis,[4] studying Lewis and Livingstone Ranges in Montana, discovered the great Lewis overthrust fault where strata of Late Precambrian age are overthrust onto Cretaceous rocks. The Late Precambrian of Lewis and Livingstone Ranges was correlated by Willis with Dawson's section, and this correlation was definitely established by Daly[5] in 1912, who ascribed all the Precambrian rocks to the Lewis series.

The Precambrian strata consist mainly of metamorphosed sediments of limestones, in part siliceous, argillites, and quartzites, with some thin lava flows. These beds are hard and comprise the Clark Range of mountains, which rise abruptly several thousand feet above the comparatively low relief of the foothills east of the Waterton Lakes area. On the east side of Flathead Valley the descent is equally abrupt from high mountains of Precambrian to a broad flat covered by boulder, gravel, and sand deposits, underlying which are gently tilted non-marine Tertiary deposits that were laid down in a lake in the valley and hence are much younger than the structural features to which the valley owes its origin. The Tertiary beds unconformably overlie Mesozoic and Palæozoic beds.

The structure of the Clark Range is a broad synclinal basin in the central part of which are Cambrian, Silurian, and Devonian strata. To the east the Precambrian strata are thrust over the Mesozoic of the foothills and to the west the Precambrian is faulted along the east side of Flathead Valley, but the nature of the fault is somewhat controversial. It was regarded by Daly and Mackenzie[6] as being a normal fault with downthrow to the west, but most geologists who have studied it in recent years regard it as a thrust with the fault plane dipping east. This has given rise to the suggestion that it is the Lewis fault that underlies the whole Precambrian mass, emerging again along the east side of Flathead Valley and thus allowing younger rocks underlying the thrust to be exposed as a "window" in Flathead Valley. Others,[7] however, regard the fault as separate from the main Lewis thrust, but dipping east toward it. The angle of dip is unknown, but could readily be determined by diamond drilling along the east edge of Flathead Valley.

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[1]Hume, G. S.: Waterton Lakes-Flathead Area, Alberta and British Columbia; Geol. Surv., Canada, Sum. Rept. 1932, pt. B, pp. 1-20.
[2]Selwyn, A. R. C.: Geol. Surv., Canada, Ann. Rept. 1890–91, vol. V, pt. I, pt. A, p. 9 (1893).
[3]Dawson, G. M.: British Boundary Comm. Rept., pp. 67, 68 (1875). Geol. Surv., Canada, Ann. Rept. 1885, vol. I, pt. B, p. 39 (1896).
[4]Willis, Bailey: Geol. Soc., Am. Bull., vol. 13, pp. 305–352 (1902).
[5]Daly, R. A.: Geol. Surv., Canada, Mem. 38 (1912).
[6]Mackenzie, J. D.: Geol. Surv., Canada, Mem. 87, p. 1 (1916).
[7]Link, T. A.: Am. Assoc. Pet. Geol., vol. 16, No. 8, p. 786 (1932).

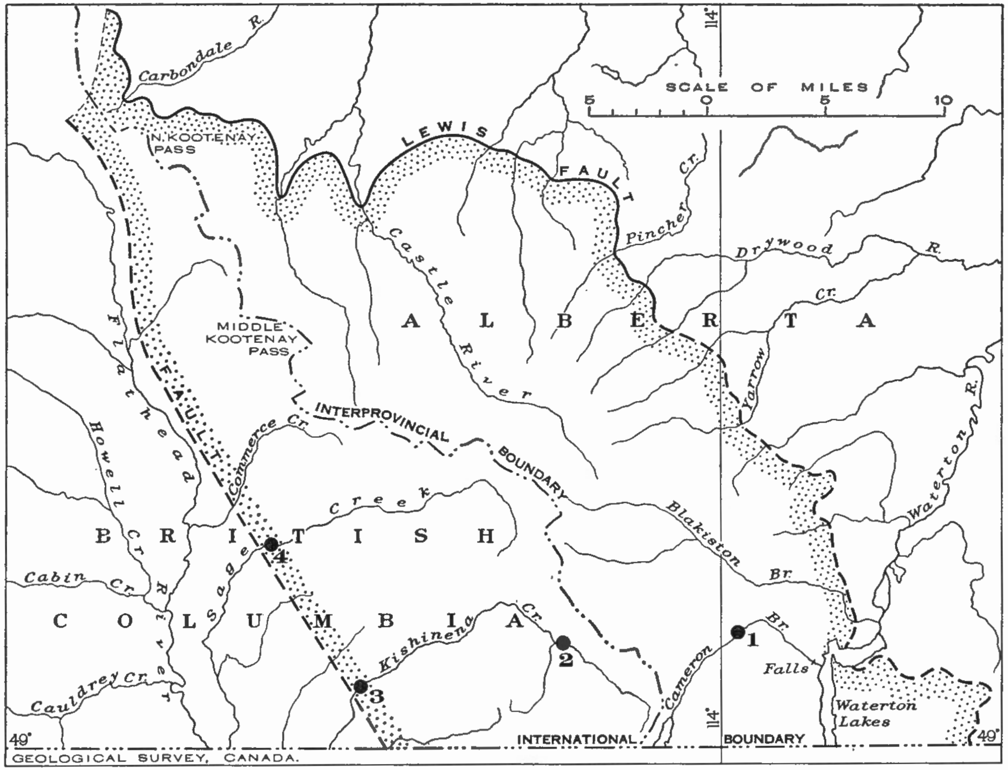

Figure 19. Waterton Lakes-Flathead Valley area, showing outline of area of Precambrian strata. 1, Cameron Brook petroleum seepages at "Oil City"; 2, Akamina Valley Oil Co.; 3, Kishinena dome; 4, Sage Creek dome.

In both the Waterton Lakes and Flathead Valley areas where the structure has been studied, folded faults have been located in the Precambrian rocks. On the west limb of the synclinal basin of Precambrian rocks close to Flathead Valley there is a regional dip of 25 to 30 degrees northeast, but close to the the west margin there is a reversal of dip, giving anticlinal conditions within the Precambrian rocks. This anticlinal arrangement is, however, quite strongly modified by east-west cross folds, which throw the strata into a series of domes. These cross folds presumably have also folded the fault underlying the Precambrian mass and thus have provided favourable structures for oil accumulation in the younger strata below the fault plane. Three domes have been observed along the mountain front, and one on Sage Creek about 10 miles up the Flathead Valley from the International Boundary has been studied in some detail (Figure 20). Others are reported to occur. On two of the observed domes on Kishinena and Sage Creeks seepages of oil have been seen, and those on Sage Creek are remarkable for their number and size. One seepage was bailed for several days in 1932 and gave a settled yield of 1¼ gallons to 1½ gallons of light straw-coloured oil. Strong gas flows are evident in several places. Similar seepages, but under somewhat different structural conditions, occur in Precambrian rocks on Cameron Brook not far west of Waterton Lakes. It is obvious, therefore, that petroliferous strata underlie the Precambrian, and it is inferred from the structure on Sage Creek that the accumulation that is giving rise to the seepages through the fractured Precambrian rocks occurs under the folded fault in rocks of either Mesozoic or Palæozoic age.

Several wells have been drilled on the Sage Creek dome in the Flathead Valley area. All wells encountered shows of oil and gas in fractured zones, and the oil varies from a white distillate to darker coloured crude. One of the deepest wells drilled was that of Columbia Oils, in 1937 and 1938. This well commenced drilling with cable tools and at a depth of 1,942 feet a diamond drill was installed and the well continued to 8,000 feet. The well was wholly in Precambrian rocks, mostly limestones, argillites, or shales. There were some very sharp changes in the attitude of the strata penetrated, and this, together with the fact that the fault was predicted at 4,000 to 5,000 feet and had not been encountered, led to a survey of the hole in the autumn of 1938. The record of the survey is as follows: 1,105 feet—3° 35′; 1,375 feet —10° 30′; 1,466 feet—16°; 1,646 feet—26° 45′; 1,922 feet—28°. This is the last recorded depth for cable tools and the deviation is believed to have all been in the same direction, namely south 16° 15′ east, which is the record at a depth of 2,818 feet. The instruments used would not record a deviation beyond 30 degrees, so that no measurements beyond this amount were possible. Apparently most of the diamond drill hole was greater than 30 degrees, and it is assumed the hole went horizontal; Lane Wells engineers, who made the measurements, estimate that at 8,000 feet it may have been 4,000 to 5,000 feet from the vertical. The well, therefore, proved nothing in regard to the structure. Sulphur water was present and rose to within 373 feet of the surface, with a packer set at 3,673 feet and the drill pipe open for 1½ hours. At shallow depths, 75, 95, and 134 feet, there were shows of oil and 3 barrels collected in the hole at 138 feet when the well was left standing overnight. At 1,130 to 1,140 there was a small amount of oil and a trace at 1,470 feet. At 2,370 feet enough gas was present to blow water 40 feet up in the derrick. Some oil was present. Following this blow the well made water. More oil was encountered at 3,119 feet, and in fractured rocks from 4,967 to 5,532 feet there was marked evidence of gas with some oil, particularly at 5,528 feet.

Above this the strata penetrated had been mainly limestones, but below 6,336 they were mainly grey, greenish, and purplish shales with very little gas or oil shows. The shales were regarded as belonging to the Waterton formation, which is the lowest exposed beds in Waterton Lakes area, and much lower than any strata known to outcrop in the Flathead area. The record of the dip of the

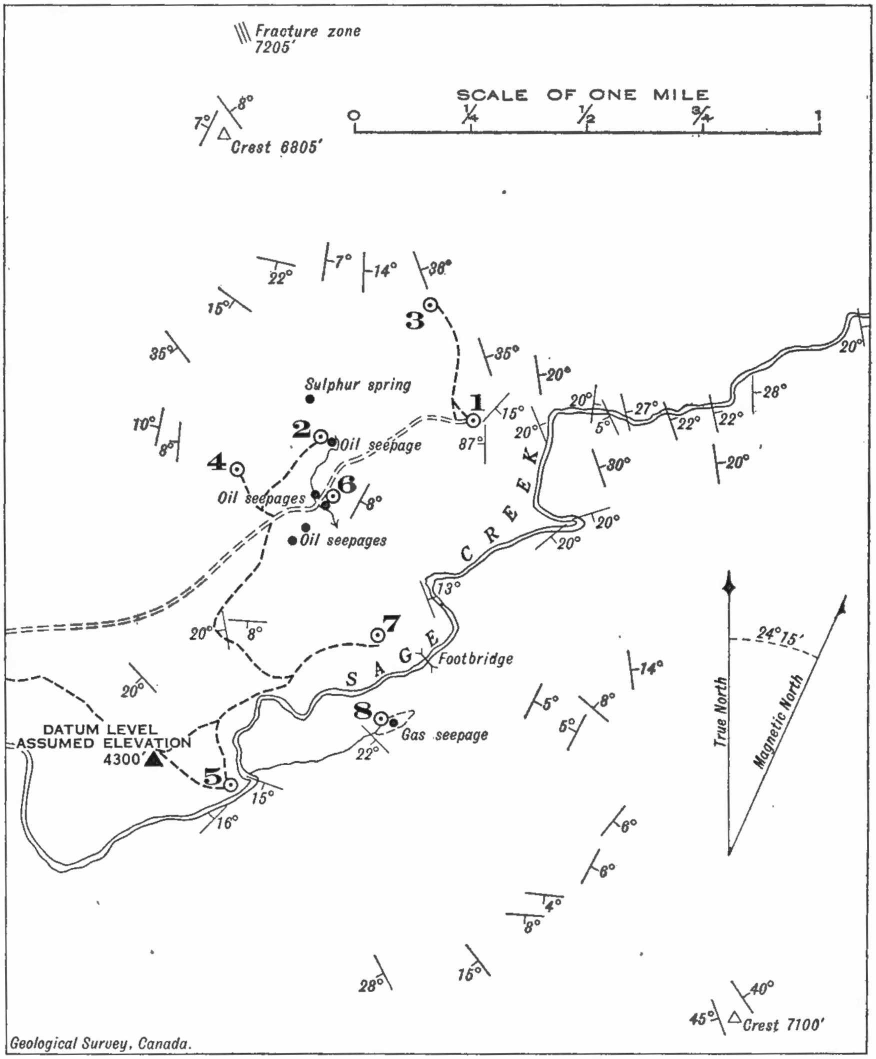

Figure 20. Sage Creek dome. 1, Crowsnest Glacier No. 1; 2, Crowsnest Glacier No. 2; 3, Crowsnest Glacier No. 3; 4, Crowsnest Glacier No. 4; 5, Flathead No. 1; 6, Flathead No. 2; 7 and 8, British Columbia Oil and Coal Development Co.

strata from the well is as follows: surface to 1,942 cable tools—no record; 1,942 to 3,670—6-inch hole drilled with diamond bit. Dips from 2,000 to 3,000 feet approximately 45 degrees, and steeper between 3,000 and 4,800 feet. From 4,800 to 5,800 dips very steep—i.e., 70 to 80 degrees. At 6,200 feet about 70 degrees and at 6,800 feet 57 to 58 degrees. From 7,000 to 7,500 feet dips somewhat variable, from 30 to 50 degrees; from 7,500 to 7,800 feet, 20 to 30 degrees, and from 7,800 to 8,000 feet formation is broken and dips generally steep.

The direction of deviation was apparently along the southeast axis of the fold (Figure 20), but it is impossible to correct accurately these core measurements. It is taken for granted, however, that the actual dip of the strata is probably not much different from the observed surface dips, and hence in a vertical hole it seems quite probable that no such great depth would have been necessary to reach the fault between the Precambrian and the underlying younger strata in which the oil is assumed to have originated.

Before any further drilling is done in the Sage Creek area the angle of the fault between the Precambrian and the underlying younger beds should be determined. This can be done by diamond drill holes suitably located. The fault contact is nowhere exposed, due to stream gravels and mountain talus in the valley bottom, but the approximate position is known, and diamond drilling could start close to it with other holes farther east. The angle of the fault at depth may not be exactly the same as that at the surface, but an approximate depth calculation could be made for any well if the surface inclination of the fault was known. From this information deductions could be made as to the feasibility of further drilling.

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Assiniboine Sheet (Man. and Sask.), Map 713A (1 inch=8 miles).

Fort Pitt (Sask), East half, Map 489A (1 inch=4 miles).

" " " West half, Map 490A (1 inch=4 miles).

Battleford (Sask.), East half Map 491A (1 inch=4 miles).

" " West half, Map 492A (1 inch=4 miles).

Ribstone Creek	(Alberta),	Map	501A	(1 inch=4 miles).
Hardisty	"	"	502A	"
Stettler	"	"	503A	"
Red Deer	"	"	504A	"
Tofield	"	"	505A	"
Edmonton	"	"	506A	"
Fallentimber (E.½)	"	"	548A	(1 inch=1 mile).
" (W.½)	"	"	549A	"
Taber	"	"	565A	(1 inch=4 miles).
Foremost	"	"	566A	"
Dunmore	"	"	567A	"
Midnapore	"	"	606A	(1 inch=1 mile).
Mafeking (Man. and Sask.)		"	637A	"
Etomami (Sask.)		"	638A	"
Wildcat Hills	(Alberta	"	652A	"
Jumpingpound	"	"	653A	"
Bragg Creek	"	"	654A	"
Fish Creek	"	"	667A	"
Bearberry	"	"	670A	"
Kitscoty	"	"	673A	(1 inch=4 miles).
Innisfree	"	"	674A	"
Moose Mountain	"	"	688A	(1 inch=1 mile).
Brooks	"	"	695A	(1 inch=4 miles).
Redcliff	"	"	696A	"
Pekisko Creek	"	"	698A	(1 inch=1 mile).
Beaver Mines	"	"	739A	"
Bassano	"	"	741A	(1 inch=4 miles).