Distribution and Thickness of Devonian Rocks in Williston Basin and in Central Montana and North-Central Wyoming

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GEOLOGICAL SURVEY BULLETIN 1112-D

Prepared as part of the Department of the Interior program for the development of the Missouri River basin

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By CHARLES A. SANDBERG

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1961

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

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CONTRIBUTIONS TO ECONOMIC GEOLOGY

DISTRIBUTION AND THICKNESS OF DEVONIAN ROCKS IN WILLISTON BASIN AND IN CENTRAL MONTANA AND NORTH-CENTRAL WYOMING

By CHARLES A. SANDBERG

ABSTRACT

The report area includes approximately 200,000 square miles in the southern part of the Williston basin of North Dakota, South Dakota, and eastern Montana and in central Montana and north-central Wyoming. Devonian rocks underlie all but the south-central part of this large area, and they crop out on the flanks of the Bighorn, Pryor, Beartooth, Big Snowy, and Little Rocky Mountains and the Absaroka Range.

The Devonian rocks consist predominantly of marine carbonate, evaporite, and shale beds, which have a maximum thickness of 2,000 feet in northwestern North Dakota. Lower Devonian rocks assigned to the Beartooth Butte formation, an estuarine channel-fill deposit as thick as 150 feet, crop out at many isolated localities, generally less than half a mile in length, in the Bighorn, Pryor, and Beartooth Mountains and in the Absaroka Range. Middle Devonian rocks underlie the central Williston basin but do not crop out in Montana or Wyoming. They reach a maximum thickness of about 870 feet in north-central North Dakota. The Middle Devonian series is divided into the Elk Point group and the overlying Dawson Bay formation. The Elk Point group consists of the Winnipegosis and Prairie formations. The Winnipegosis and Dawson Bay formations are composed mainly of limestone and dolomite, but the Prairie is largely halite and anhydrite with a little sylvite. Upper Devonian rocks underlie most of the area studied and attain a maximum thickness of about 1,250 feet in northern Montana. The Upper Devonian series is divided in ascending order into the Souris River formation, the Jefferson group, consisting of the Duperow and Birdbear formations, and the Three Forks formation, overlain by the Bakken formation of Late Devonian(?) and Early Mississippian age. The Souris River, Duperow, and Birdbear formations were deposited in similar sedimentary cycles and their lithologies consist of various quantities of limestone, dolomite, dolomitic limestone, silty and argillaceous dolomite and limestone, and anhydrite with thin interbeds of shale, siltstone, and sandy argillaceous dolomite. The Three Forks formation contains calcareous and dolomitic shale with interbeds of limestone, dolomite, anhydrite, and siltstone. The lower half of the formation is commonly anhydritic, and sandstone is present locally at the top. The Bakken formation consists of two black carbonaceous shale beds separated by gray sandstone, siltstone, and dolomite.

Tectonic activity occurred along several major anticlines and one large reverse fault during Middle and Late Devonian and earliest Mississippian time. These structural features were eroded in Early Mississippian time and buried beneath thick Mississippian deposits; they are ancestral to but have slightly divergent trends from similar Laramide features. The ancestral structural features greatly influenced Devonian sedimentation and may have trapped large amounts of oil and gas in Devonian and older strata. Minor oil production has already been established from the Winnipegosis, Dawson Bay, Souris River, Duperow, and Three Forks formations, and many near-commercial oil shows have been found in the Birdbear formation.

INTRODUCTION

Rocks of Devonian age underlie the Williston basin, a large structural basin in North Dakota, northern and central South Dakota, eastern Montana, southwestern Manitoba, and southern and central Saskatchewan. They also underlie central and western Montana and northern Wyoming. This report considers the Devonian rocks in an approximately 200,000-square-mile area that includes only the United States part of the Williston basin and adjacent parts of central Montana and north-central Wyoming (fig. 17).

The isopach maps of the report (pls. 6, 8–11) are based on data from 530 wells and 21 measured surface sections. The total thickness of Devonian rocks at each control point is shown on plate 6. Only wells for which radioactivity or electrical logs were released prior to February 1, 1959, are shown. The author also studied the logs of about two hundred closely spaced field wells on the Cedar Creek and Nesson anticlines and in the Southwest Richey and Outlook oilfields, and about fifty wildcat wells in adjoining areas of Saskatchewan, Manitoba, and western Montana. The thickness data are based mainly on radioactivity-log correlations. The correlations are supported by the author's measured sections and descriptions of cored wells, and by more than 175 lithologic well logs, of which about a hundred were loaned by oil companies.

C. R. Hammond offered constructive criticism during the early part of this study and collaborated on an earlier paper on the stratigraphy and nomenclature of Devonian rocks in the area (Sandberg and Hammond, 1958).

REGIONAL SETTING

Several major Laramide structural features within the Devonian sedimentary basin were also active during Middle and Late Devonian time; these are the Central Montana uplift, Cedar Creek anticline, Nesson anticline, and Poplar dome (pls. 6, 8–11). The Central Montana uplift is a broad regional feature composed of many eastward-trending anticlines and synclines; it is elongated eastward

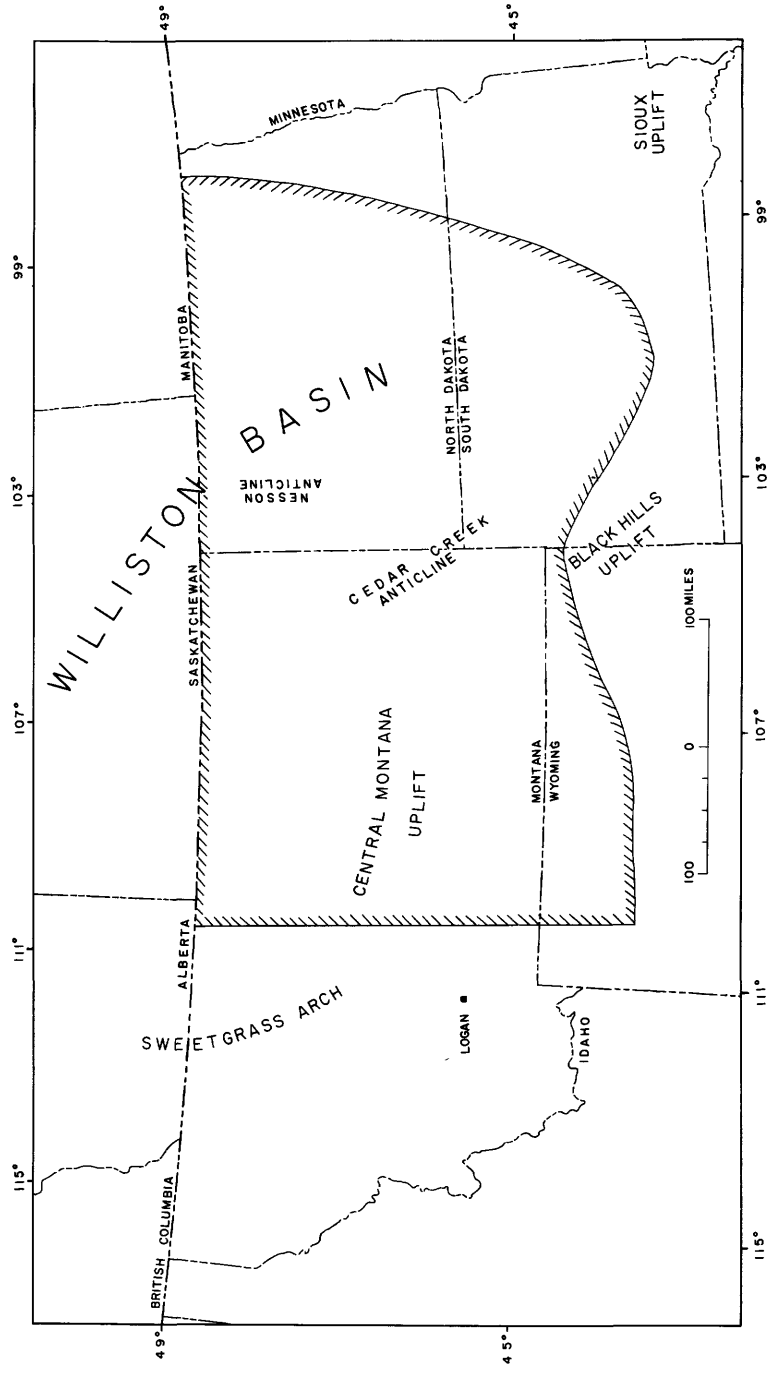

FIGURE 17.—Index map showing area of report.

between Rs. 16 and 40 E. and lies between Tps. 6 and 18 N. in Montana. The Cedar Creek anticline is a narrow, 125-mile-long, northwest-plunging asymmetrical anticline with a steep west limb; it extends from northwestern South Dakota through the southwestern corner of North Dakota to east-central Montana. The Nesson anticline is a southward-plunging, 75-mile-long, 15-mile-wide anticline near the center of the Williston basin in northwestern North Dakota. The Poplar dome is an elliptical fold, 25 miles long from east to west and 15 miles wide, in Tps. 28–29 N., Rs. 50–51 E., in northeastern Montana.

Devonian deposition and pre-Mississippian erosion were influenced by structural features whose locations were similar to the Laramide Central Montana uplift, Cedar Creek anticline, Nesson anticline, and Poplar dome but whose trends were slightly different. The locations of these ancestral features are illustrated by anomalously thin areas on the Devonian isopach maps (pls. 6, 8–11).

Rocks of Devonian age crop out along the west edge of the report area on the flanks of the Bighorn, Pryor, Beartooth, Big Snowy, and Little Rocky Mountains and the Absaroka Range. In the Big Snowy Mountains, Devonian rocks were thinned by latest Devonian and earliest Mississippian erosion of the ancestral Central Montana uplift. However, in the other mountain ranges, Devonian rocks were not appreciably thinned by erosion at any time in the Paleozoic. Therefore, in contrast to the smaller folds in the basin area, these mountains were not active during Devonian and Early Mississippian time.

STRATIGRAPHY

Lower, Middle, and Upper Devonian rocks are present in the Williston basin and adjacent areas. The Beartooth Butte formation of Early Devonian age (Dorf, 1934) is a discontinuous estuarine channel-fill deposit that crops out at many isolated localities in south-central Montana and northern Wyoming, but its outcrops are too small to be shown at the scale of plate 6. The Middle Devonian series is divided into the Elk Point group and the Dawson Bay formation. The Elk Point group consists of the Winnipegosis and Prairie formations (pl. 7). The Prairie consists of a lower member, which mostly overlies but in part grades laterally into the Winnipegosis formation, and an upper, salt member. The Upper Devonian series is divided into the Souris River formation, the Jefferson group, consisting of the Duperow and Birdbear formations, and the Three Forks formation, overlain by the Bakken formation of Late Devonian(?) and Early Mississippian age (pl. 7). In north-central Montana, the

Three Forks formation contains near its base an evaporitic unit designated the Potlatch member.

The thickness of the Elk Point group is shown on plate 8 and that of the Dawson Bay formation on plate 9. The Souris River and Duperow formations are combined on one isopach map (pl. 10) and the overlying Birdbear and Three Forks formations are combined on another (pl. 11).

UNDERLYING UNITS

In the central Williston basin, rocks of Middle Devonian age unconformably overlie the Silurian Interlake group of Baillie (1951b, p. 6). On the margins of the basin and beyond the limits of the Dawson Bay formation (Middle Devonian), Upper Devonian rocks truncate the Silurian rocks, the Stony Mountain formation of Late Ordovician age, and part of the Red River formation of Late Ordovician age (pl. 7). In parts of central Montana where the Red River formation or its equivalent surface formation, the Bighorn dolomite, was removed by pre-Devonian erosion, Upper Devonian rocks directly overlie beds of Late Cambrian and Early Ordovician age.

DEVONIAN SYSTEM

The rocks of the Devonian system consist predominantly of marine carbonate, evaporite, and shale beds, which have a maximum thickness of approximately 2,000 feet near the center of the Williston basin in northwestern North Dakota (pl. 6). The data used to compile the map of the Devonian system are based on the thickness of Middle and Upper Devonian rocks only. Although the Beartooth Butte formation of Early Devonian age is widely distributed, its isolated occurrences are too small to be regionally considered. The present limits of the Devonian approximate the depositional limits, whose position has, however, been contracted slightly by pre-Mississippian and pre-Jurassic erosion. The regularity of this erosional edge is interrupted only by a salient around the ancestral Black Hills uplift in southeastern Montana.

INTERPRETATION OF DISTRIBUTION AND THICKNESS

The most conspicuous feature shown on the isopach map is the area of thinning, which resulted from pre-Mississippian erosion of Devonian rocks on the ancestral central Montana uplift (pl. 6). Absence of the uppermost beds indicates that Devonian rocks have been eroded to a thickness of less than 100 feet in an area 140 miles long from east to west and 25 miles wide. At the center of the ancestral uplift the Devonian rocks have been completely removed.

In east-central Montana, Devonian rocks on the ancestral Cedar Creek anticline were thinned by pre-Mississippian erosion from an original thickness of as much as 650 feet to less than 200 feet in an area 120 miles long and 10 miles wide. The erosional thinning in this area extends north of the end of the present anticline in T. 17 N., R. 53 E., to the Southwest Richey oilfield in T. 22 N., R. 48 E., McCone County, Mont. Devonian rocks were completely removed from many domes, some of them too small to be shown on the maps, along the crest of this ancestral anticline. An inferred high-angle pre-Mississippian reverse fault, about 1 to 3 miles west of the crest, offsets the steep west limb. A complete normal section of Devonian rocks is preserved in the northern part of the Sheep Mountain syncline on the downthrown west side of the fault.

The existence of this fault and its age have been inferred from: (a) the presence of repeated sequences of Ordovician and Silurian rocks in several wells drilled on the west limb of the anticline, (b) an abrupt change in thickness of Devonian rocks between the west limb and the crest (at one place from 650 to 0 feet in less than a mile), (c) the much lower elevation of pre-Mississippian rocks in a well assumed to be west of the fault, and (d) the fact that the Lodgepole limestone and other Mississippian formations are not thinned across the crest and are unaffected by reverse faulting parallel to the trend inferred for the reverse fault in pre-Mississippian formations.

In northeastern Montana, the Devonian is slightly thinner around the Poplar dome and the Outlook oilfield in Tps. 35–36 N., Rs. 52–53 E., than in surrounding areas. Continuity and consistent thinning of all stratigraphic units, as shown on the thickness maps (pls. 8–11), indicate retarded subsidence during deposition in this area.

The central part of the Williston basin is outlined roughly on the map by the 1,300-foot isopach in northeastern Montana and the 1,100-foot isopach in North Dakota (pl. 6). The delineation of the basin from adjacent shelf areas is particularly well marked in McHenry County, N. Dak., by the wide spacing of isopachs. Within the central basin, an area of thinning marks the northwest-trending ancestral Nesson anticline between T. 149 N., R. 93 W., and T. 155 N., R. 95 W., northwestern North Dakota.

At the east edge of the basin, in Towner and Cavalier Counties, northeastern North Dakota, Devonian rocks are preserved in a northeast-trending lobe that is flanked by areas of strata thinned by erosion.

In Stanley County, S. Dak., the Devonian is absent in a small area where Pennsylvanian rocks rest directly on basement rocks, probably the Sioux quartzite of Precambrian age. This area may represent an

island or monadnock on which Paleozoic rocks older than Pennsylvanian were not deposited.

Metamorphic and intrusive igneous rocks crop out in many areas from which Devonian rocks have been almost completely removed by Recent erosion in the mountains of central Montana and north-central Wyoming (pl. 6). Surrounding these areas are belts of uplifted sedimentary rocks in which the Devonian is generally present.

INTERPRETATION OF PRE-MISSISSIPPIAN OUTCROP PATTERN

The paleogeologic map (pl. 6) shows clearly the distribution of the younger Upper Devonian formations, the Duperow, Birdbear, and Three Forks, but masks the distribution of the Middle Devonian formations, which are almost everywhere overlain by Upper Devonian rocks.

The Elk Point group is restricted to the central Williston basin and nowhere lies in contact with Mississippian rocks. The overlying Dawson Bay formation, although slightly more extensive, caps the Devonian system only where Upper Devonian rocks have been removed by erosion from small domes at the north end of the ancestral Cedar Creek anticline and from a narrow belt on the east edge of the Williston basin.

The Souris River formation, although not restricted to the central Williston basin, is less extensive than the other Upper Devonian formations. It is the uppermost unit of the Devonian only along the crest of the ancestral Cedar Creek anticline where the Three Forks, Birdbear, and Duperow formations have been eroded and in a narrow belt on the east edge of the Williston basin. The Duperow is the most extensive Devonian formation. It extends beyond the limits of the Birdbear and Three Forks into south-central Montana, north-central Wyoming, and south-central South Dakota, but has been removed by pre-Mississippian erosion from parts of the ancestral Central Montana uplift and Cedar Creek anticline. The present limit of the Birdbear is governed largely by erosion. The pre-Mississippian outcrop of the Birdbear formation is a belt between the pre-Mississippian outcrops of the Duperow and Three Forks. The limit of the Three Forks is parallel to that of the Birdbear and is also largely controlled by erosion. Because of its stratigraphic position, the Three Forks occupies the largest area of pre-Mississippian outcrop but also is the most extensively eroded Devonian formation.

In parts of Ramsey, Towner, and Cavalier Counties in northern North Dakota, rocks of Mississippian age were completely removed by pre-Jurassic erosion. East of the erosional limit of Mississippian rocks (pl. 6), the Devonian is unconformably overlain by Jurassic rocks.

BEARTOOTH BUTTE FORMATION

A sequence of thinly bedded red and buff calcareous shale, limestone, and limestone conglomerate and massive gray limestone that crops out on the east and west sides of Beartooth Butte in north-central Wyoming was named the Beartooth Butte formation by Dorf (1934). This formation, which is 0 to 150 feet thick at that locality, was deposited in an estuarine channel cut into the Bighorn dolomite and is overlain by the marine Jefferson limestone. On the basis of a large and unique fauna of ostracoderms and arthrodires and a small flora of psilophytes, Dorf assigned an Early Devonian age to the formation.

The Beartooth Butte formation has also been identified at Cottonwood Canyon on the west side of the Bighorn Mountains in north-central Wyoming (Blackstone and McGrew, 1954). Many isolated outcrops of unfossiliferous rocks that are assignable to the Beartooth Butte on the basis of lithology and stratigraphic relations were found and measured in the Beartooth, Bighorn, and Pryor Mountains and in the Absaroka Range by Blackstone and McGrew (1954), W. G. Pierce (oral communication, 1959), and the writer. The thickness of the Beartooth Butte is generally less than 150 feet, and its length of outcrop does not exceed half a mile at any locality. The Beartooth Butte formation has not been differentiated from basal channel-fill deposits of the Winnipegosis formation in the subsurface.

ELK POINT GROUP

The Elk Point formation was the name originally given to a sequence of anhydritic dolomite, silty limestone, red and green dolomitic shale, and one to three salt beds in Alberta and western Saskatchewan (McGhee, 1949). The formation was raised to group status by Belyea (1952) and traced into the Canadian part of the Williston basin by Baillie (1953, 1955). Baillie divided the group in the subsurface into three formations, in ascending order, the Ashern, Winnipegosis, and Prairie. The Winnipegosis in the United States part of the basin has been redefined (Sandberg and Hammond, 1958) to include the thinner Ashern formation of Baillie (1951a), which cannot be everywhere differentiated.

The Elk Point group ranges in thickness from 0 to more than 700 feet east of the Nesson anticline (pl. 8). It is restricted to the central Williston basin and has not been penetrated in any wells in South Dakota. On the map the basin facies of the group is separated from the surrounding shelf facies approximately by the 150-foot isopach in Montana and the 250-foot isopach in North Dakota (pl. 8). Slight depositional thinning took place along the northwest-trending ancestral Nesson anticline. An area of thinning extends from the north

end of the present Cedar Creek anticline to the vicinity of Glasgow, Mont. Along this trend slight regional uplift and erosion probably preceded deposition of the overlying Dawson Bay formation. Small elongate areas of thickening in McCone and Valley Counties, Mont., probably show the location of basal Winnipegosis channel-fill deposits. The area of extreme thinning within the Outlook field in T. 36 N., R. 53 E., Mont., resulted from solution of salt in the Prairie formation during Late Devonian time.

The assignment of a Middle Devonian age to the Elk Point group is based on the occurrence of the brachiopod *Stringocephalus burtini* Defrance, an index fossil of late Middle Devonian (Givetian) age in Europe (Baillie, 1953, p. 41).

WINNIPEGOSIS FORMATION

Rocks exposed along the shores of Lake Winnipegosis in Manitoba were named the Winnipegosan formation by Tyrrell (1892). The name Winnipegosis was formally established by Baillie (1953, p. 20). The Winnipegosis formation is more extensive than the overlying Prairie formation and consequently its limit is the limit of the Elk Point group (pl. 8). In the area of this report the Winnipegosis ranges in thickness from 0 to 300 feet and rests unconformably on Silurian rocks.

In the central Williston basin the Winnipegosis may be divided into three units. The lower unit is greenish-gray dolomitic siltstone, sandstone, or shale, stained red and light brown. It ranges in thickness from less than a foot to about 50 feet. The middle unit is dark-gray calcareous shale and siltstone and ranges in thickness from 60 to 130 feet. The upper, carbonate unit is brownish-gray to medium dark-gray fossiliferous fragmental limestone about 120 feet thick.

Near the margins of the basin the Winnipegosis formation changes facies. The lower and middle units merge to form a single unit that ranges in thickness from less than a foot to about 50 feet and is composed of red dolomitic shale and siltstone or argillaceous dolomite. Channel filling by this unit results in anomalous thicknesses in Valley County, Mont. (pl. 8). The upper, carbonate unit is generally less than 100 feet thick and is light-gray or light brownish-gray finely crystalline to microcrystalline dolomite.

PRAIRIE FORMATION

The name Prairie evaporite formation was applied to salt and anhydrite beds in the upper part of the Elk Point group by Baillie (1953, p. 24). The type section is the interval between depths of 4,350 and 4,990 feet in the Imperial Oil 1 Davidson well in Lsd. 16, sec. 8, T. 27,

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R. 1 W., 3d Meridian, Saskatchewan, Canada. The name was shortened to Prairie formation by Sandberg and Hammond (1958).

The Prairie formation is present only in the deepest part of the Williston basin. It ranges in thickness from 0 to more than 525 feet and is divided into a lower member and a salt member. The lower member is mostly anhydrite and dolomite interbedded at the center of the basin with thin beds of shale and halite, but it grades laterally in all directions to argillaceous limestone and dolomite that are only slightly more anhydritic than the underlying Winnipegosis. The salt member is predominantly halite; it contains some sylvite and a few thin beds and stringers of shale. The lower part of the salt member grades marginward into the upper part of the lower member. The salt member constitutes the entire formation on some parts of the Nesson anticline (pl. 7, col. 7) but constitutes only about three-quarters of the formation in the area of maximum thickness east of the anticline. The salt member represents the final phase of evaporite precipitation and is less widespread than the lower member.

The Prairie formation has been partly or completely dissolved in some areas, and where halite was dominant, as it was in parts of the Outlook oil field, only a residual mudstone derived from shale interbedded with the halite remains. Where the Prairie was largely interbedded anhydrite and dolomite, evaporite-solution breccias have resulted.

Near the center of the basin, the contact between the evaporite facies of the lower member of the Prairie and the underlying Winnipegosis formation is sharp. However, in a belt extending 40 miles beyond the eastern and southern limits of the salt member, the carbonate facies of the lower member interfingers with and is difficult to differentiate from the Winnipegosis. Therefore, the well-defined limit of the salt member is shown (pl. 8) rather than the limit of the more extensive lower member.

DAWSON BAY FORMATION

The Dawson Bay formation was named by Baillie (1953, p. 26) from exposures along the shores of Dawson Bay at the north end of Lake Winnipegosis in Manitoba. The Dawson Bay ranges in thickness from 0 to 185 feet and is thickest in north-central North Dakota along the international boundary. It is divided into an argillaceous member overlain by a carbonate member in Montana and North Dakota (Sandberg and Hammond, 1958). In central North Dakota, the argillaceous member is a 10- to 35-foot bed of grayish-red dolomitic siltstone or shale and argillaceous dolomite, and the carbonate member is a 100- to 150-foot bed of brownish-gray finely crystalline to microcrystalline porous dolomite or limestone, anhydritic in the

upper part. On the margins of the Williston basin the carbonate member is generally light gray or light brownish gray. In eastern Montana and southwestern North Dakota, the thickness of the carbonate member decreases and the thickness of the argillaceous member increases, whereas the formation thins slightly toward the western limit.

The Dawson Bay formation is slightly more extensive than the Elk Point group but is also restricted to the Williston basin. The thickness of the Dawson Bay is remarkably uniform, as illustrated by the widely spaced isopachs (pl. 9), except close to the limits where it was affected by pre-Late Devonian erosion. Erosion has produced several areas of noticeable thinning in eastern Montana. These are along the trend of the ancestral Cedar Creek anticline as far north as the Southwest Richey field in McCone County, and around the Poplar dome and the Outlook field. The area of thinning in southern Bottineau County, N. Dak., may have resulted from retarded deposition caused by local uplift.

The Dawson Bay formation conformably overlies the Elk Point group, which has a related fauna, and is Middle Devonian in age (Baillie, 1953, p. 42). The contact between the Dawson Bay and the overlying Souris River formation is conformable in North Dakota where deposition was probably continuous, but the apparent absence of the upper half of the Dawson Bay, revealed by radioactivity logs (pl. 7) and lithologic evidence, indicates that the contact is disconformable in parts of eastern Montana.

SOURIS RIVER FORMATION

The Souris River formation was named in 1953 by the Williston Basin Nomenclature Committee of the American Association of Petroleum Geologists, but the committee report was not published. The formation was formally proposed by Sandberg and Hammond (1958, p. 2310) who described it and designated the standard subsurface section as the interval between depths of 10,743 and 11,052 feet in the Mobil Producing 1 Birdbear well (pl. 7, col. 8). (A standard section replaces an inadequately defined or unpublished type section or supplements a distant type section that is unrepresentative of the formation in an area under investigation.)

The Souris River formation contains gray, greenish-gray, and brownish-gray thinly interbedded shaly dolomite, argillaceous limestone, shale, siltstone, and anhydrite. The dolomite, limestone, and shale are commonly silty, but locally they may be sandy. Deposition occurred in sedimentary cycles that were generally incomplete and are poorly defined in the resulting rock sequence. A reconstructed sequence representing a complete cycle would consist, from base to

top, of (a) siltstone or shale, (b) argillaceous and (or) silty limestone or dolomite, (c) slightly argillaceous dolomite or limestone, and (d) anhydrite or anhydritic dolomite and limestone. The formation ranges in thickness from 0 to 340 feet and is thickest in west-central North Dakota. It underlies most of the report area but is absent because of nondeposition or erosion in southeastern, south-central, and central Montana (pl. 10). The Souris River is more extensive than the Middle Devonian formations and represents the first southward and westward transgression of Devonian seas from the central Williston basin.

The Souris River formation conformably overlies the Dawson Bay formation in the central Williston basin but truncates progressively older beds westward in Montana. Beyond the western limit of the Dawson Bay, the Souris River rests unconformably on beds ranging in age from Silurian to Late Cambrian. The Souris River conformably underlies the lithogenetically related Duperow formation, which was deposited during similar but more complete sedimentary cycles. The Souris River is assigned a Late Devonian age on the basis of physical characteristics and conformity with Upper Devonian beds, but its lowermost beds in the central Williston basin may be Middle Devonian (Sandberg and Hammond, 1958).

DUPEROW FORMATION

The Duperow formation was named by D. Powley in 1951 in an unpublished thesis, "Devonian stratigraphy of central Saskatchewan," submitted to the University of Saskatchewan. Because of a misunderstanding in usage, the Williston Basin Nomenclature Committee decided in 1953 to abandon Duperow in the sense that Powley had originally intended, and applied the name to the overlying lithologic unit. The Duperow formation, as revised, of Late Devonian age, has been frequently referred to in geologic literature. It was formally proposed by Sandberg and Hammond (1958, p. 2316), who described the formation and designated the standard subsurface section as the interval between depths of 10,400 and 10,743 feet in the Mobil Producing 1 Birdbear (pl. 7, col. 8). The Duperow is the lower formation of the subsurface Jefferson group and is equivalent to all but the upper 70 feet of the type Jefferson formation that crops out near Logan, Gallatin County, Mont.

The Duperow formation is composed of medium-gray, brownish-gray, and yellowish-gray limestone, argillaceous limestone, dolomitic limestone, rhombic dolomite, and anhydrite interbedded with thinner beds of greenish-gray and yellowish-gray dolomitic shale, siltstone, and sandy argillaceous dolomite. The uppermost part of the Duperow is generally a 10- to 15-foot bed of greenish-gray dolomitic shale or

shaly dolomite. Sand grains may be scattered throughout the formation but are most common in the upper third. Near the depositional limit of the formation in north-central Wyoming the number of shaly and sandy beds increases. These beds contain abundant grains of glauconite and probably represent a near-shore facies. Deposition was generally cyclical, but complete depositional cycles are exceptional in the report area.

The Duperow formation ranges in thickness from 0 to approximately 600 feet. It attains its maximum thickness in north-central and northeastern Montana along the international boundary. It is the most widespread Devonian formation and is the only one except for the discontinuous Beartooth Butte formation that underlies south-central Montana and north-central Wyoming. The Duperow underlies most of the report area but was removed by pre-Mississippian erosion from part of the ancestral Central Montana uplift and parts of the Cedar Creek anticline. The Duperow conformably overlies the thinner bedded and more argillaceous Souris River formation, but beyond the limit of the Souris River, it rests unconformably on beds ranging in age from Silurian to Late Cambrian. The Duperow conformably underlies the Birdbear formation.

INTERPRETATION OF DISTRIBUTION AND THICKNESS OF SOURIS RIVER AND DUPEROW FORMATIONS

During the early part of Late Devonian time the Williston basin was a less conspicuous sedimentary basin than during Middle Devonian time. Thickening of the Souris River and Duperow formations into the basin is indicated on the map only by the slight southward swing of the isopachs in central and western North Dakota (pl. 10). The area of maximum thickness of these formations is in north-central Montana, along the international boundary, where they are about 935 feet thick. The limit of the combined Souris River and Duperow formations is regular and interrupted only by a major salient resulting from a combination of nondeposition and erosion in the area of the ancestral Black Hills uplift in southeastern Montana. The increasing abundance of sand, silt, and glauconite as the present edge is approached suggests the proximity of the depositional limit to the present edge (pl. 10) except in southeastern Montana and northeastern North Dakota; the closely spaced isopachs on the map suggest that pre-Mississippian and pre-Jurassic erosion, respectively, have truncated the formations in those areas.

The limit of the combined formations generally coincides with the limit of the more extensive Duperow, except along the ancestral Cedar Creek anticline and along a narrow belt in northeastern North Dakota where pre-Mississippian and pre-Jurassic erosion, respec-

tively, have removed the stratigraphically higher Duperow. The zero isopachs near the ancestral Cedar Creek anticline represent the edges of the Souris River. Areas from which both the Duperow and Souris River have been eroded (pl. 10) probably were domes along the crest of the ancestral anticline.

The area of conspicuous thinning in central Montana resulted partly from the absence of the Souris River formation (pl. 10) and of the lowermost beds of the Duperow formation, presumably because of nondeposition, and partly from pre-Mississippian erosion of the upper part of the Duperow. Thinning, in an area trending southeast from the Bearpaw Mountains through the Judith Mountains in central Montana, resulted from nondeposition of the lower part of the Souris River formation, reflected on the map by the embayment in the limit of the Souris River (pl. 10). This area of nondeposition probably coincides with an arch formed early in Late Devonian time.

In areas in eastern Montana closer to the central Williston basin, depositional thinning that can be detected in individual beds of formations outlines the Southwest Richey oil field and Poplar dome. A small area of thick accumulation in T. 36 N., R. 53 E., Mont., in the Outlook oil field coincides with areas of thinning in the Elk Point group and Dawson Bay formation; it resulted from subsidence accompanying solution of the salt member of the Prairie formation. The northwest trend of the ancestral Nesson anticline in northwestern North Dakota is marked by thinning of individual units. Thinning in Towner County, N. Dak., resulted from erosion of the upper part of the Duperow formation where the overlying Upper Devonian beds had been removed by pre-Mississippian and pre-Jurassic erosion.

BIRDBEAR FORMATION

The Birdbear formation of Late Devonian age was proposed by Sandberg and Hammond (1958, p. 2318) to replace the "Nisku" formation which had been introduced into the Williston basin by Baillie (1953, p. 33), because of similar lithology and stratigraphic position to the type Nisku formation of the Alberta basin. The work of Belyea (1955) and others showed, however, that the type Nisku is truncated by erosion on the Alberta side of an arch separating the Alberta and Williston basins. Consequently, the continued use of "Nisku" for beds in the Williston basin seemed inappropriate. The type subsurface section of the Birdbear is the interval between depths of 10,310 and 10,400 feet in the Mobil Producing 1 Birdbear well (pl. 7, col. 8). The Birdbear is the upper formation of the subsurface Jefferson group and is equivalent to the upper 70 feet of the Jefferson formation at its type locality near Logan, Mont.

The lower part of the Birdbear is uniformly thick-bedded light-gray to medium brownish-gray porous finely crystalline saccharoidal dolomite and limestone. The upper quarter is anhydritic dolomite, alternating thin beds of anhydrite and dolomite, or massive anhydrite.

The formation ranges from 0 to 125 feet in thickness and is almost everywhere 75 to 115 feet thick except near its depositional limit and in eroded areas. In a few widely scattered wells in northern Montana and northwestern North Dakota along the international boundary, it exceeds 115 feet in thickness. The Birdbear underlies the Williston basin and north- and south-central Montana. Progressive truncation marginward of the upper units indicates that its present limit is largely the result of post-Devonian erosion. Absence of evidence indicating proximity to a depositional limit suggests that the area of deposition probably included parts of eastern North Dakota and all but the southeastern corner of Montana.

The Birdbear formation was deposited during the later part of a single sedimentary cycle; the earlier part of this cycle is represented by the widespread shale at the top of the underlying Duperow formation. Therefore, the contact between the Birdbear and Duperow is almost everywhere conformable. Shale beds at the base of the Three Forks formation commonly overlie the Birdbear conformably, but the contact is disconformable in a few areas of local uplift and erosion. The Birdbear is an excellent datum for regional correlation of lower Paleozoic rocks owing to its wide distribution, uniform lithology, almost constant thickness, and ease of distinction on lithologic and mechanical well logs (pl. 7) due to sharp contacts with shale beds above and below.

THREE FORKS FORMATION

The term Three Forks shales was proposed by Peale (1893) to describe beds resting on the Jefferson limestone and underlying the Madison limestone of Mississippian age at the junction of the three forks of the Missouri River near the present town of Three Forks, Mont. The type section, following the proposal of Sloss and Laird (1947), is considered to be on the north side of the Gallatin River at Logan, Mont. Peale (1893) described five lithologic units from the top to base of the Three Forks. Sloss and Laird (1947, p. 1410) redefined the lower contact to exclude Peale's bottom two units. They described the beds in these two units as "breccias and associated shales" and included them in the Jefferson. However, these beds cannot be separated from the Three Forks in geologic mapping, and they are lithogenetically related to the Three Forks and not to the Jefferson as suggested by Sloss and Laird. Therefore, Three Forks is em-

ployed here as originally defined by Peale. The standard subsurface section, which supplements the distant type section for the area of this report, is the interval between depths of 10,076 and 10,310 feet in the Mobil Producing 1 Birdbear well (pl. 7, col. 8).

In central and western North Dakota and northeastern Montana, the Three Forks formation is composed of greenish-gray, grayish-orange, and grayish-red dolomitic siltstone and shale. The lower half is commonly more anhydritic and contains bedded anhydrite in addition to round inclusions of anhydrite in the shale and siltstone. A fine-grained sandstone 5 to 15 feet thick at the top of the formation near the south end of the Nesson anticline is informally known as the Sanish sand. Along the eastern margin of the Williston basin, the Three Forks is predominantly red dolomitic siltstone and shale and has been called Lyleton shale by Allan and Kerr (1950, p. 10). In and west of the Little Rocky Mountains, the upper part of the formation is green calcareous shale interbedded with thin beds of limestone and siltstone and the lower part is anhydrite, dolomite, and dolomitic siltstone interbedded with shale.

The Three Forks formation ranges in thickness from 0 to approximately 240 feet and is thickest in the central Williston basin, east and south of the Nesson anticline. The formation underlies the Williston basin, south-central and northern Montana, and the Sheep Mountain syncline (pl. 11), but is less extensive than the Birdbear. The Three Forks has been more intensely eroded owing to its higher stratigraphic position. Absence of depositional features indicative of nearshore sedimentation suggests that the area of deposition of the Three Forks probably included part of southeastern and all of central Montana. Between the Central Montana uplift and the Canadian border, an eroded area (pl. 11) from which more than a hundred feet of beds was removed separates thicker sequences in the Williston basin and western Montana.

The Three Forks formation generally overlies the Birdbear conformably. The Three Forks is of Late Devonian age in the report area.

POTLATCH MEMBER

The "breccias and associated shales" unit of Sloss and Laird (1947) has been correlated between outcrops and wells, and the anhydrite beds (represented by evaporite-solution breccias in outcrop) in it seem to be interbedded with shale typical of the Three Forks. In the Sweetgrass arch area of northwestern Montana, the "breccias and associated shales" unit is equivalent to the upper part of the Potlatch anhydrite formation (Perry, 1928). Because it represents a tongue of the Potlatch, the unit was named the Potlatch member of the Three

Forks formation (Sandberg and Hammond, 1958, p. 2323). The eastern limit of the Potlatch member lies along a line extending northeastward from a few miles east of the Bridger Range through the Little Rocky Mountains (pl. 7, cols. 1 and 2).

INTERPRETATION OF DISTRIBUTION AND THICKNESS OF BIRDBEAR AND THREE FORKS FORMATIONS

The Williston basin was again the center of sedimentary accumulation during latest Devonian time, although the deposition was in shallow water. The area of maximum thickness is an arcuate belt around the south end and east side of the Nesson anticline, where the Birdbear and Three Forks formations are about 340 feet thick (pl. 11). Thickening, noted along the west edge of the report area, increases westward to the vicinity of Three Forks, about 75 miles west of Big Timber, Mont., where the formations are also about 340 feet thick. The wider extent of the Birdbear beyond the overlying Three Forks and the configuration of their combined isopachs (pl. 11) clearly demonstrate the effects of intense pre-Mississippian erosion. Thickness anomalies show many trends and possibly indicate some buried anticlines that were masked beneath thick Mississippian deposits. Some of these anomalies lie close to and others seem to be unrelated to trends of known Laramide structural features.

Pre-Mississippian erosion removed the Birdbear and Three Forks formations from the ancestral Cedar Creek anticline and the Central Montana uplift, but a remnant is preserved in the Sheep Mountain syncline. The area of deposition of the Birdbear and Three Forks probably extended at least as far south as an arcuate line extending from the vicinity of Cody, Wyo., through the south side of the preserved lobe north of Billings, Mont., to the south end of the Sheep Mountain syncline.

An eroded area extends northwest from the present Cedar Creek anticline to the Southwest Rickey field and terminates abruptly against a belt of rapid thickening. Faulting or monoclinal folding followed by erosion may have caused the abrupt change in thickness in this area. An area of thinning, with at least one branch, extends northeast from the Central Montana uplift through the Poplar dome to the Outlook field in northeastern Montana. Although most of the apparent thinning is due to pre-Mississippian erosion, part is due to less sedimentary accumulation and part to post-Birdbear erosion in the area. This indicates that the northeast-trending belt was an area of continuing uplift during lastest Devonian time.

In the central Williston basin, the ancestral Nesson anticline is delineated by an area of thinning. Thinning of individual stratigraphic units and absence of beds at the top of the Three Forks formation indicate that the regional thinning was both erosional and

depositional. Uplift of the ancestral Nesson anticline probably continued therefore, to the end of Devonian time. Farther east, in Bottineau County, N. Dak., a northwest-trending thin area, whose shape suggests an erosional valley, extends into southwestern Manitoba and is unrelated to Laramide structure.

In northeastern and east-central North Dakota, a long arcuate area of thinning extends from Cavalier County southwest to Burleigh County and possibly represents a buried anticline or Late Devonian hinge line. The west side of this feature is delineated by the erosional limit of the Three Forks formation (pl. 11), and the east side is less distinctly bordered by slightly thicker areas of the Birdbear formation preserved in what is inferred to be a syncline paralleling the anticlinal feature. The synclinal nature of the eastern feature is well demonstrated at its north end by the preserved tongue of Birdbear that projects northeastward in Cavalier County. On either side of this tongue erosion has completely removed the Birdbear and cut into the underlying Duperow formation (pl. 10).

In southern North Dakota and northern South Dakota, an area of thinning separates the Williston basin into eastern and western lobes. This thinning is unrelated to pre-Mississippian erosion and presumably resulted from deposition over an area that was high in latest Devonian time. The western lobe terminates against the area of pre-Mississippian erosion at the south end of the Cedar Creek anticline.

OVERLYING UNITS

Upper Devonian rocks are disconformably overlain by the Bakken formation of Late Devonian(?) and Early Mississippian age in the central Williston basin and in northeastern and north-central Montana. The Bakken formation consists of two radioactive black shale beds (pl. 7, col. 8) separated by light-gray sandstone, siltstone, or dolomite. The lowermost Mississippian beds beyond the limit of the Bakken on the southern and eastern margins of the basin are correlated with the Englewood limestone (Lower Mississippian) of the Black Hills. Elsewhere, Devonian rocks are overlain unconformably by the Lodgepole limestone of the Madison group of Mississippian age (pl. 7, col. 10). In parts of Ramsey, Towner, and Cavalier Counties in northeastern North Dakota, Mississippian beds were completely removed by pre-Jurassic erosion. In this area (pl. 6) basal Jurassic beds unconformably overlie the Devonian.

GEOLOGIC HISTORY

In early Paleozoic time the Williston basin was an intracratonic basin bounded on the northeast and southeast by stable positive areas,

the Canadian Shield and Siouxia, respectively, and limited on the west and southwest by unstable positive areas, the ancestral Sweetgrass arch, the Central Montana platform, and the Black Hills uplift. The North Battleford arch marked the northwest limit of the basin. Sedimentation was controlled by two basic factors, the persistent downwarping of the basin proper and the intermittent uplift of the western structural features that caused continued shifting of the center of deposition. The stable areas on the east limited the basin throughout early Paleozoic time, but they contributed little sediment.

Following the retreat of Silurian seas, erosion removed more than 1,000 feet of Silurian and Ordovician carbonates from the basin margins. The erosion surface is generally one of moderate, but locally intense, relief. Isolated outcrops of Lower Devonian rocks that were deposited in estuarine channels cut as much as 150 feet below the top of Ordovician rocks have been found in the mountain ranges of south-central Montana and northern Wyoming.

MIDDLE DEVONIAN

The Williston basin, which had been above sea level through most or all of Early Devonian time, was covered by Middle Devonian seas that transgressed southeastward from northern Alberta over an unevenly eroded surface, reworked the post-Silurian regolith, and deposited clastic sediments. The seas continued to expand during the deposition of carbonates of the Winnipegosis formation. Slight regional uplift, accompanied by accelerated downwarping of the basin, contracted the depositional area and resulted in precipitation of the Prairie formation. During the transition from a normal to a restricted marine environment, anhydrite and halite were precipitated at the center of the basin while carbonate deposition continued along the margins. As the seas continued to shrink and salinity increased, halite was precipitated at the center, and anhydrite precipitation spread to the basin margins. Rapid expansion of the Dawson Bay seas caused a strong influx of red mud that capped the Prairie formation and prevented its dissolution when normal salinity was reestablished during deposition of the carbonate member of the Dawson Bay formation.

LATE DEVONIAN

There was probably little or no break between Middle and Late Devonian deposition at the center of the Williston basin, although slight erosion of Middle Devonian rocks took place on the margins. In the Outlook and Southwest Richey oilfields of eastern Montana,

slight uplift and erosion followed deposition of the Dawson Bay formation. The Souris River, Duperow, and Birdbear formations were widespread shallow-water deposits associated with the newly formed Alberta basin but separated from it by a submarine platform.

At the beginning of Late Devonian time the Sweetgrass arch area was largely a shelf. A part of this shelf and most of central Montana were probably above sea level. Souris River seas spread westward from the restricted Middle Devonian basin, and in northeastern and north-central Montana the Souris River formation was deposited on rocks ranging in age from Silurian to Cambrian. Minor pulsations of the seas resulted in cyclical deposition. Subsidence of the central Montana platform permitted early Duperow seas to transgress southward, and the Duperow formation was deposited as far south as northern Wyoming and around the north end of the Black Hills uplift. Cyclical deposition of the Duperow formation took place during major pulsations of the seas. In the Outlook oilfield, removal of the salt in the Prairie formation and collapse of the uplifted area took place during deposition of the Souris River and Duperow formations, and resulted in their great thickness there. Devonian seas reached their maximum extent during deposition of the upper part of the Duperow and the Birdbear. By this time the Williston basin had lost its identity as a depositional center, and an anhydrite basin had formed in the Sweetgrass arch area, although anhydrite precipitation there was interrupted temporarily by the transgression of the Birdbear seas.

Anhydrite beds at the top of the Birdbear formation in the Williston basin indicate a restriction of seas that continued into the early stage of Three Forks deposition. During early Three Forks time the anhydrite basin was being extended from the Sweetgrass arch area into north-central and southwestern Montana. Contemporaneously, slightly evaporitic conditions in central North Dakota caused deposition of anhydritic shales at the base of the Three Forks. Meanwhile, along the eastern margin of the Williston basin red siltstones and shales were being deposited in a near-shore environment.

Minor regional subsidence permitted the advance of seas from the northwest and closed the initial stage of Three Forks deposition. The precipitation of anhydrite in the Sweetgrass arch area and north-central Montana was followed by deposition of normal-marine green shale. Fluctuating normal- and restricted-marine conditions in the shallow seas of central North Dakota resulted in deposition of interbedded green and red shales and siltstones while deposition of red beds continued along the eastern basin margin. As the late Three Forks seas withdrew intermittently lenses of regressive sand interfingered with the shale in several areas.

EARLY MISSISSIPPIAN

There was little break in deposition between the Three Forks and the overlying Bakken formation. Black shales and siltstones were deposited in the restricted-marine environment of generally retreating but sometimes slightly advancing seas. Renewed uplift of the central Montana and Cedar Creek areas marked the close of black shale deposition. Compressive forces resulted in high-angle reverse faulting on the steep west flank of the ancestral Cedar Creek anticline. Accompanying and following these movements, a short period of intense erosion completely stripped Upper Devonian and some Lower Mississippian rocks from part of the ancestral Central Montana uplift and small domes along the crest of the ancestral Cedar Creek anticline.

Readvancing Early Mississippian seas covered the Williston basin and spread across the ancestral Cedar Creek anticline and Central Montana uplift which had by then been completely leveled by erosion. The Lodgepole limestone and other formations of the widespread Madison group, in places more than 2,300 feet thick, were deposited on Upper Devonian rocks and protected them from further erosion until pre-Jurassic time.

PETROLEUM POSSIBILITIES

The Williston basin and adjacent areas constitute a favorable province for the structural and stratigraphic entrapment of oil and gas in rocks of Devonian age. The area contains many anticlines and domes formed in Laramide time. In addition, some structural features, such as the ancestral Cedar Creek and Nesson anticlines, began to form in Middle Devonian time and continued to grow during Late Devonian time but were covered by Mississippian seas and remained inactive until Laramide time. These buried anticlines, some of which lie close to the trends of present anticlines, could contain oil and gas in Devonian and older strata. Devonian and older rocks on the Central Montana uplift probably do not have as much productive potential as in less disturbed areas in the Williston basin, because central Montana was subjected to many complex post-Devonian structural movements and several periods of erosion that have probably caused the dissipation and remigration of earlier petroleum accumulations.

The marginal facies of carbonate members of the Winnipegosis and Dawson Bay formations have excellent reservoir characteristics. The basin facies of these members are considered excellent source beds but commonly have poor porosity. Oil has been produced from

the Winnipegosis in the Amerada Patchin, J. A. Thorson, and State "F" wells of the Outlook field in Tps. 35 and 36 N., R. 52 E., and in the reworked Hunt 1 Hagan discovery well in T. 34 N., R. 52 E., Sheridan County, Mont. Oil has been produced from the Dawson Bay formation in several wells in secs. 25 and 33, T. 22 N., R. 48 E., of the Southwest Rickey field, McCone County, Mont.

The Souris River and Duperow formations contain carbonate reservoirs from which commercial oil production can be expected at least locally in areas of favorable porosity. The potential reservoirs in the Duperow, however, are generally thicker, less argillaceous, and more porous. The Souris River and Duperow were deposited in pulsating seas that provided a favorable environment for the growth and burial of organisms suitable for hydrocarbon generation, and hence they are also considered excellent source beds. The Duperow formation produced 290 barrels of oil per day beginning in July 1951 in the first oil well completed in the United States part of the Williston basin, the Amerada 1 Clarence Iverson discovery well in sec. 6, T. 155 N., R. 95 W., Williams County, N. Dak., in the Devonian pool of the Beaver Lodge field. This well was plugged back in December 1951 to the shallower Madison pool, and intensive exploration of the Devonian pool was delayed until the Amerada 1 Iverson-Nelson discovery well, near the old Clarence Iverson well, was completed in December 1957. Petroleum reservoirs in the Duperow and upper part of the Souris River in the Beaver Lodge field were developed rapidly, and exploration spread to several nearby areas during 1958. The first successful completion in the Duperow outside the Beaver Lodge field in June 1958 was the Amerada 1 Mogen discovery well of the Sand Creek field in T. 153 N., R. 96 W., McKenzie County, N. Dak.

The Birdbear formation has an excellent petroleum potential because of widespread distribution, persistent thickness, and favorable porosity. Although production from the Birdbear has not to date (1959) been established, many near-commercial oil shows have been found in it in widely separated test wells.

Sand lenses at the top of the Three Forks formation generally have low porosity and permeability except where fractured, and are of small geographic extent. Nevertheless, oil has been produced since December 1953 from the Sanish sand (local usage) at the top of the Three Forks in the Sanish field in T. 152 N., 94 W., McKenzie County, N. Dak. During 1957, production from the Sanish sand was extended to the Antelope field, with which the Sanish field was later combined, in the same township.

Petroleum production has been established to date (1959) in the Winnipegosis, Dawson Bay, Souris River, Duperow, and Three Forks formations. The porous Dawson Bay and Birdbear formations contain the best single reservoirs whereas the Duperow formation offers mulitiple reservoirs of greater aggregate thickness.

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