NORTH DAKOTA GEOLOGICAL SURVEY
WILSON M. LAIRD, State Geologist
Bulletin 34

Subsurface Geology and Development of Petroleum in North Dakota

by
CLARENCE G. CARLSON,
WALLACE E. BAKKEN
& JACK KUME

Reprinted from
The Compass Vol. 37
No. 2, pp. 123-143, Jan., 1960

Grand Forks, North Dakota, 1960

Subsurface Geology and Development of Petroleum in North Dakota

CLARENCE G. CARLSON, WALLACE E. BAKKEN AND JACK KUME*

ABSTRACT

North Dakota became an oil state in 1951 with the discovery of oil in the Nesson Anticline in northwestern North Dakota from rocks of Silurian, Devonian and Mississippian age. The initial production was from rocks of Silurian age, but the Madison group reservoirs of Mississippian age have been more productive, accounting for 98 per cent of the oil production in North Dakota. Subsequent developments have also produced oil from rocks of Ordovician, Pennsylvanian (?) and Triassic age.

The Nesson Anticline is the most important producing area in North Dakota, accounting for 95 per cent of the production. The remainder of the production comes from north-central to northwestern North Dakota paralleling the Canadian border and from the southwestern part of the state. The accumulations in the Nesson Anticline area are primarily structural traps whereas the accumulations along the Canadian border are either stratigraphic or combination structural - stratigraphic traps.

The stratigraphic column of North Dakota includes about 15,000 feet of sedimentary rocks, with every system of the Phanerozoic being represented. There are a number of unconformities present but the major one is the pre-Mesozoic unconformity which truncates all Paleozoic formations.

The present rate of production is about one million barrels per month. Exploration and development has exceeded the rate of production so the proved reserves have been increased each year. The North Dakota success ratio for wildcat drilling has varied from a low of 3.6 per cent in 1954 to a high of 17.3 per cent in 1958. The development drilling success ratio has varied from a low of 75 per cent in 1958 to a high of 94 per cent in 1954. The total drilling in the state has reflected the wildcat success ratio rather closely thus far. Secondary recovery methods such as pressure maintenance programs are being started in some of the pools and these programs are also adding to the proved reserves of North Dakota.

ACKNOWLEDGMENTS

Much of the information in this paper has been obtained from the files, records and reports of the Conservation Division of the North Dakota Geological Survey. Special thanks are due Mr. C. B.

* Members, Beta Zeta Chapter.

Folsom, Petroleum Engineer, and Mr. Louis Larson, former Statistician of the Conservation Division, for information, access to the records and files, and helpful comments during the preparation of this paper. The writers are indebted to Dr. F. D. Holland, Jr., Associate Professor of Geology, University of North Dakota, for suggesting the topic, helpful suggestions during the preparation of the paper and for reading the manuscript. We also wish to thank Dr. W. M. Laird, State Geologist, for aiding the Writers in the preparation of the manuscript.

INTRODUCTION

North Dakota became an oil state in April, 1951, with the discovery of oil in the Amerada Petroleum Corporation—Clarence Iverson No. 1 well located in Sec. 6, T. 155 N., R. 95 W., Williams County. This well was the discovery well for the Beaver Lodge Silurian pool located on the Nesson Anticline in northwestern North Dakota. The initial production was from the Interlake formation of Silurian age. The Clarence Iverson No. 1 well produced 3,092 barrels of oil from the Interlake formation before the Silurian interval was plugged, and the well was recompleted in the Duperow formation of Devonian age in July, 1951. After 17,408 barrels of oil were produced, this interval was plugged, and the well was recompleted in November, 1952. in the Madison group of Mississippian age. Since then, this well has produced 178,935 barrels of oil from the Madison group as of January 1, 1959. It is interesting to note that the Madison interval was first missed in the drilling of the initial well because the producing interval is only about 250 feet below a thick salt section of the Charles formation. Since the drillers were not using a salt base mud, the wellbore washed out in the salt section causing much caving, so the samples were very poor through the Madison interval. When oil was later discovered in the Madison group limestone in nearby wells, the Clarence Iverson No. 1 well was plugged back to the Madison because of the more favorable reservoir characteristics.

As of January 1, 1959, 64 fields with 71 pools have been discovered. The location of these fields is shown on the location map (see Fig. 1).

STRUCTURE

The Williston Basin, named for the city of Williston in northwestern North Dakota, includes within its boundaries nearly all the state of North Dakota as well as part of Montana, Saskatchewan and Manitoba. The center of the structural basin has shifted somewhat during geologic time (Laird, 1953), but the center of the present-day basin is located about 40 miles southeast of the city of Williston, North Dakota. All the sedimentary rocks dip gently toward the

center of the basin with only a few interuptions by minor folding of the smaller structures superimposed on the major basinal structure.

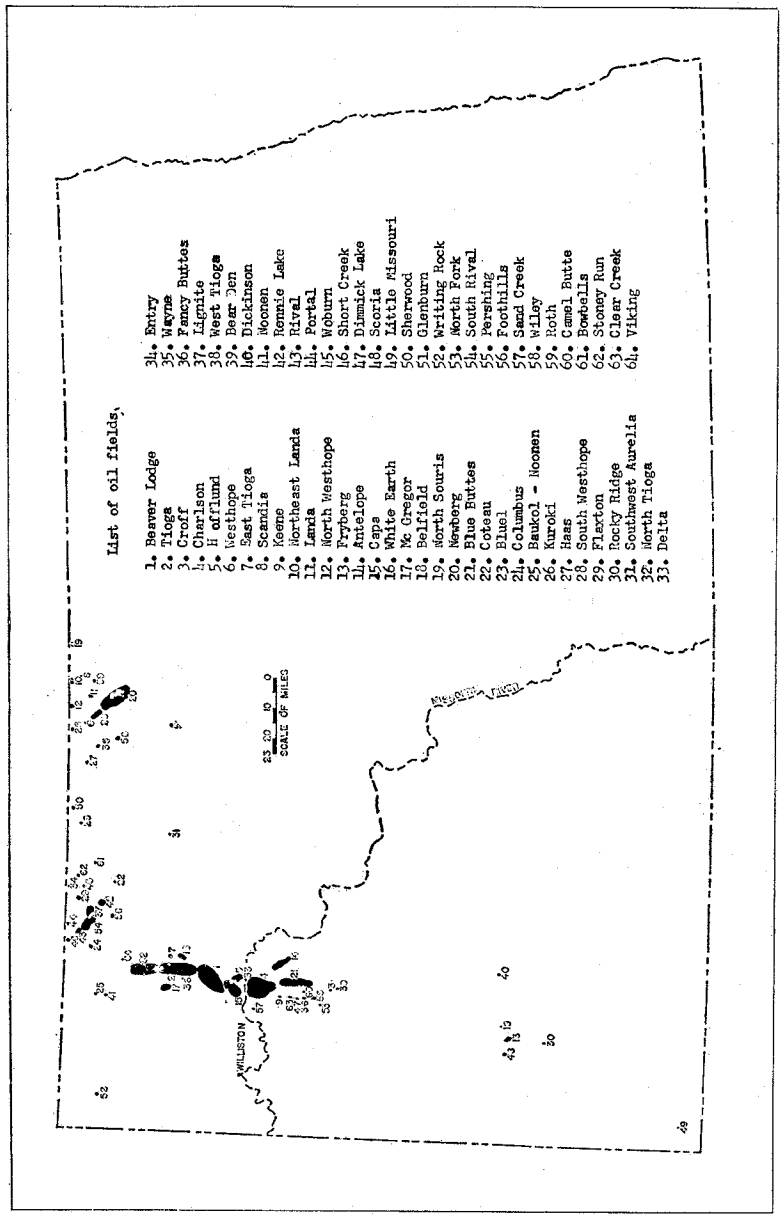

Fig. 1—Location map showing the oil fields of North Dakota. The fields are numbered in the order of their discovery.

TABLE I Stratigraphic Column for North Dakota

Era	System	Series	Grp.	Formation	Thickness (feet)	Lithology
Cenozoic	Tertiary	Pleistocene		Glacial drift	0-500	Till, outwash, lake deposits
		Oligocene		White River	50-200	Light colored clay, shale, sandstone and limestone
		Eocene		Golden Valley	5-175	Light colored, kaolinitic clays, micaceous silts and sands
		Paleocene	Fort Union	Tongue River	200-800	Light and dark colored shale and sandstone; lignite
				Cannonball	0-450	Light gray sandstone, siltstone and clay.
				Ludlow	0-250	Buff colored sandstone and shale; lignite
Mesozoic	Cretaceous	Upper		Hell Creek	100-575	Gray, bentonitic sandstone and shale and lignitic shale
			Montana	Fox Hills	180-320	Light colored, shaly, bentonitic sandstone and sandy shale
				Pierre	800-2200	Medium to light gray shale with minor bentonites
			Colorado	Niobrara Carlile (undifferentiated)	400-500	Medium to light gray, calcareous shale
		Lower		Greenhorn	120-150	Dark gray, calcareous shale and thin beds of shaly limestone
				Belle Fourche	100-350	Medium dark gray, micaceous shales with some bentonite
			Dakota	Mowry	60-170	Medium gray to dark gray, bentonitic shale, some bentonite
				Newcastle	0-200	Light gray, shaly and silty, fine grained sandstone
				Skull Creek	40-140	Medium to dark gray, soft shale
				Fall River	30-200	Light gray, fine to coarse grained sandstone and sandy, silty shale
				Fuson	30-100	Medium dark gray shale and some fine grained sandstone
				Lakota	20-110	White to light gray, fine to coarse grained sandstone
	Jurassic	Upper		Morrison	0-260	Gray and green non-marine shales and siltstones
			Sundance	Swift	0-320	Greenish gray shale and gray to greenish gray, calcareous silt and sandstone
				Rierdon	0-320	Greenish gray, calcareous shale
		Middle		Piper	0-420	Light gray shale and white danse limestone in upper part; white anhydrite and red shale in the lower part.

TABLE I Stratigraphic Column for North Dakota (continued)

Era	System	Series	Grp.	Formation	Thickness (feet)	Lithology
Mesozoic	Triassic			Spearfish	0-700	Orange-red siltstones & shales with some anhydrite and two beds of salt; thickness of salt up to 300 feet
Paleozoic	Permian			Minnekahta	0-40	Pink to purple limestone and anhydritic limestone
				Opeche	0-280	Orange-red shale and siltstone with some anhydrite and halite
	Pennsylvanian			Minnelusa	0-500	Pink to red, fine grained sandstone and some silty dolomite
				Amsden	0-200	Pink to white dolomite, sandy dolomite and dolomitic sandstone; red and green shales
	Mississippian	Upper	Big Snowy	Heath	0-150	Dark gray to black shales and locally sandstones
				Otter	0-170	Variegated shales with some thin limestones
				Kibbey	0-280	White to pink, fine grained sandstone and white limestone
			Madison	Charles Poplar Interval Ratcliffe Interval Midale Interval Frobisher	0-800	Massive salt beds, anhydrite and associated shales
				Mission Alida Canyon Interval	0-500	Light to dark brown, fossiliferous fragmental and oolitic limestone
		Lower		Tilston Interval Lodgepole Bottineau Interval	0-850	Light gray, fossiliferous limestone, shaly in part and cherty in part
				Bakken	0-120	Upper black shale, middle calcareous siltstone and silty limestone, lower black shale
	Devonian	Upper		Three Forks	0-220	Interbedded greenish gray shale and pale orange silty dolomite and dolomitic siltstone
				Birdbear	0-115	Light gray to medium brownish gray, finely crystalline limestone and dolomitic limestone with thin anhydrites in upper part
				Duperow	0-500	Medium gray to brownish gray, fine grained limestone and dolomitic limestone

TABLE I Stratigraphic Column for North Dakota (continued)

Era	System	Series	Grp.	Formation	Thickness (feet)	Lithology
Paleozoic	Devonian	Upper		Souris River	0-300	Interbedded brownish gray, argillaceous limestone and dolomitic limestone and shale
				Dawson Bay	0-140	Light brown, microcrystalline, anhydritic limestone and some silty argillaceous dolomite
		Middle		Prairie Evaporite	0-500	Halite and minor amounts of sylvite and anhydrite
				Winnipegosis	0-300	Medium gray, argillaceous, fragmental limestone and dark gray, calcareous shale
				Ashern	0-30	Moderate red to greenish gray, siltstone, shale and sandstone
	Silurian			Interlake	0-1100	Light gray to white, finely crystalline dolomite in the upper 400 feet; brown to dark brown finely crystalline dolomite
	Ordovician	Upper		Stonewall	0-100	Dolomitic limestone; argillaceous dolomite
				Stony Mountain	0-180	Interbedded argillaceous limestones and calcareous shale in lower part; fossiliferous fragmental limestone in upper part
		Middle		Red River	0-720	Brown, fragmental, fossiliferous limestone and dolomitic limestone
				Winnipeg	0-330	Greenish gray, waxy shale in upper part; fine to medium grained quartzose sandstone in lower part
	Cambrian	Upper		Deadwood	0-800	Light gray, fragmental, argillaceous limestone and medium gray shale in upper part; light gray, dolomitic, glauconitic sandstone and sandy, glauconitic dolomite in lower part
Precambrian						Granite, syenite, amphibolite and schist

The Nesson Anticline, named by Collier (1918), is one of these smaller structures within the Williston Basin. It is a north-south trending anticline located in northwestern North Dakota. Although this structure was mapped as early as 1918, it was not until 1951 that oil was discovered in this structure. Exploration has shown that this structure is not a simple anticline, but rather a series of smaller domes and anticlines along a structurally high trend. The closure of these smaller domes and anticlines is generally less than 80 feet in the Madison group reservoirs.

The Nesson Anticline extends for about 66 miles. This trend, including 23 fields, has a width varying from one to four miles, usually less than 2.5 miles. These fields are shown on the location map (Fig. 1) as fields numbered 32 at the north to 39 at the south.

Another well-known structure of the Williston Basin is the Cedar Creek Anticline which extends into the southwestern part of North Dakota. It has been productive of gas from the Eagle sandstone of Cretaceous age in this area since 1929. Oil has also been produced from the lower Paleozoic rocks on this structure in the Montana part of the Williston Basin; but only one pool containing one well has been discovered on this structure in the North Dakota part of the Basin.

A number of smaller folds have been discovered by seismic methods and drilling, but they have had only minor importance in adding to the oil reserves of North Dakota. Several smaller structures have been found by these methods in Billings County, southwestern North Dakota, about 60 miles south of the southernmost production along the Nesson Anticline. Their geographic alignment suggests that they may have an origin similar to the structures on the Nesson Anticline.

The origin of the folding of the Nesson Anticline is not definitely known. Thus far, only four wells, all located in the Beaver Lodge field, have penetrated to Precambrian rocks. These wells show a marked relief of the Precambrian surface. A study of the formations immediately above the Precambrian shows wide variations in thickness of the Deadwood formation (Upper Cambrian) in this area, but the overlying Winnipeg formation (Middle ? Ordovician) is quite uniform in thickness. The variation in thickness of the Deadwood formation accounts for only part of the difference in elevation of the present Precambrian surface. Therefore, basement faulting, which has usually been suggested as the cause of the Nesson Anticline, is probably a valid explanation for at least a part of the structure. Compaction of sediments over Precambrian topographic highs has probably accounted for some of the closure of the smaller structures on the Nesson Anticline.

In northwestern North Dakota, some minor noses are noted on structure maps (unpublished maps, N. Dak. Geol. Survey) of the

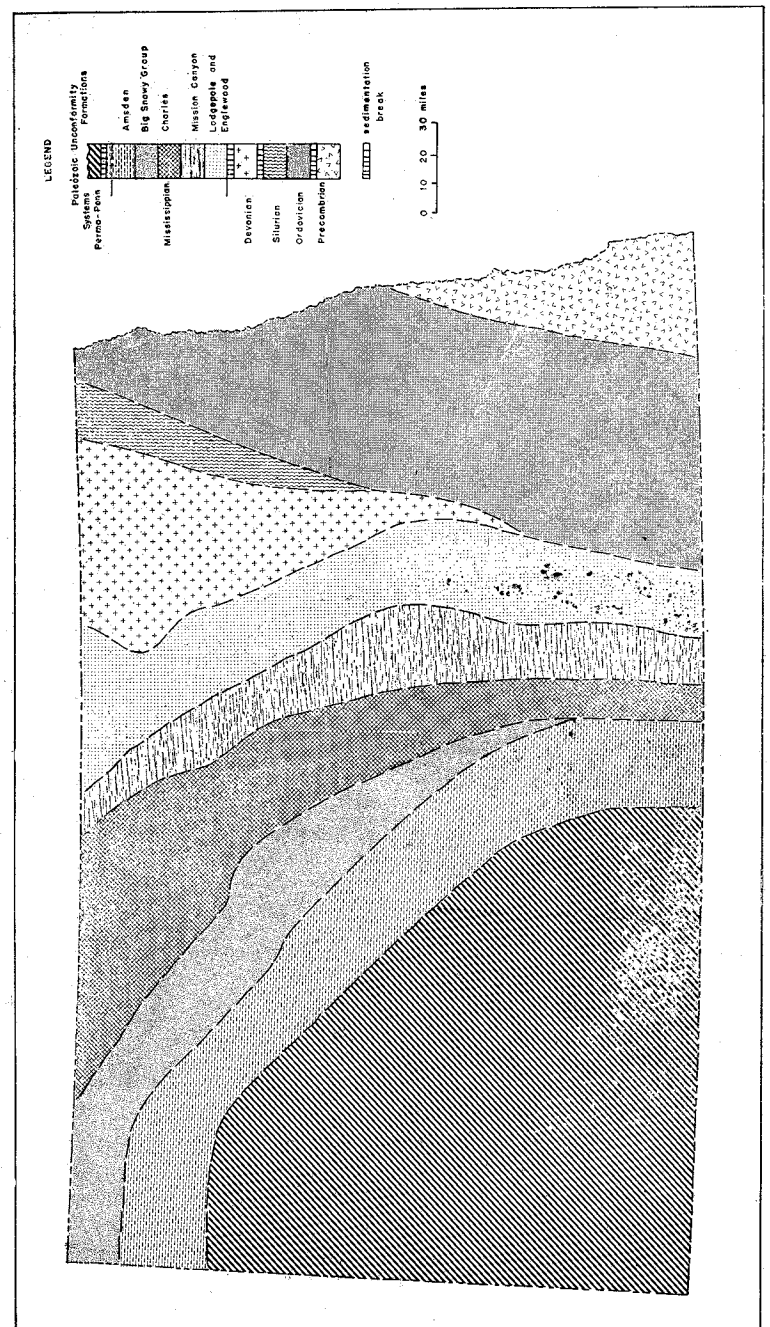

Fig. 2—Pre-Mesozoic paleogeologic map of North Dakota (after Maywald, 1957).

Madison reservoirs, but the oil accumulations seem to be mainly stratigraphically controlled. Minor structures are also present in the Madison group in Bottineau County in north-central North Dakota, but most of the traps are stratigraphic traps or combination structural-stratigraphic traps.

STRATIGRAPHY

Table 1 is a stratigraphic column of North Dakota showing the generalized lithologies and the maximum and minimum thicknesses of the formations. The maximum thickness is generally near the center of the basin; although, since the center of the basin has shifted somewhat during geologic time, the geographic position of the thickest section likewise varies somewhat with the different geologic periods.

Our present knowledge of the stratigraphic column of the Williston Basin is based largely on information derived from oil exploration. The formation and group terminology has been somewhat confusing due to the problems caused by crossing the International boundary, the introduction of informal oil field terminology and local and regional facies changes. Recently the governmental agencies of several states and provinces have held joint conferences in an attempt to end the confusion by establishing a uniform terminology for the Paleozoic rocks of the Williston Basin. It is hoped that the geological societies will also agree to a uniform terminology. The formation and group terminology presented here is that currently being used by the North Dakota Geological Survey. It is similar to the terminology used by the North Dakota Geological Society, but contains minor modifications.

The age assignments are based on physical equivalence of the subsurface formations to the area of outcrop of these units; because very little detailed paleontological work has been done on the subsurface formations. The age of some of the subsurface formations is rather indefinite, because there is some question as to the age of some of the formations in the outcrop areas; and because the subsurface formations in some instances represent a more complete geologic record than do the areas of outcrop.

There are a number of unconformities in the stratigraphic column, but the major unconformity is the pre-Mesozoic unconformity truncating all the Paleozoic formations. The Paleozoic formations are all present in the southwestern part of the state but they generally thin to their erosional limits to the east and northeast. The pre-Mesozoic paleogeologic map (Fig. 2) shows the easternmost limits of the Paleozoic systems in North Dakota.

A detailed discussion of the stratigraphy is beyond the scope of this paper. This discussion will be primarily concerned with the stratigraphy of the oil producing horizons. The reader who is interested in a more detailed stratigraphic discussion is referred to the

list of references which includes most of the important papers pertaining to the stratigraphy of North Dakota. These papers have provided much of the data included in the stratigraphic column.

In southwestern North Dakota several small pools have been found in a sandstone which has been considered to be in the Heath formation of Mississippian (?) age. The Rocky Ridge field in Billings County, producing from a depth of about 8,050 feet, is an example of these accumulations. In the discovery well the critical interval includes a sandstone unit 40 feet thick overlain by 25 feet of shale and this is overlain by 25 feet of sandstone. The upper sandstone is productive in the discovery well and in two wells to the northwest of the discovery well. However, three offset wells to the southeast, southwest and northeast of the discovery well failed to encounter the upper sandstone and were unproductive. It has been suggested by Harris (1959, p. 44) that these are bar-type or channel sandstones, probably associated with an unconformity and may belong higher in the stratigraphic column than the Heath formation (possibly basal Pennsylvanian).

The Madison group of Mississippian age has accounted for 98 per cent of all the oil produced in North Dakota as of January 1, 1959. Consequently it has received more study than any other part of the stratigraphic column. However, the local and regional facies changes as well as the International boundary have caused much confusion in arriving at a satisfactory nomenclature for this group.

The Madison group has been divided into the Charles formation, the Mission Canyon formation and the Lodgepole formation. Formerly these formations were thought of as overlying each other, but the present usage recognizes that these formations have a facies relationship and are partially time equivalents. The Charles formation was mainly an evaporitic unit containing some interbedded anhydrite and limestone. The Mission Canyon formation was mainly a carbonate unit composed of bioclastic and oolitic limestone, but it included some interbedded anhydrite near the margin of the Basin. The Lodgepole formation was the argillaceous and siliceous limestone at the base of the Madison group. The main area of confusion was in defining the Charles-Mission Canyon formation contact.

The upper part of the Madison group is composed of repeated evaporitic cycles whose geologic record is one of interbedded anhydrite and limestone. It has been recognized for some time that the evaporitic and oolitic facies descend the stratigraphic column towards the margin of the Basin. Hence, if the base of the Charles formation is drawn on the base of the evaporites, the base of the Charles formation descends the column stratigraphically toward the margin of the Basin. Likewise, if the base of the Mission Canyon formation is drawn on the base of the bioclastic and oolitic facies, the base of the Mission Canyon formation descends the column stratigraphically toward the margin of the Basin.

The present usage recognizes the Charles formation or magnafacies as the evaporitic facies; the Mission Canyon formation or magnafacies as the bioclastic and oolitic facies and the Lodgepole formation or magnafacies as the argillaceous and siliceous limestone facies. It recognizes that these facies have an interfingering relationship and that the facies boundaries are not time parallel. This usage expresses the facies relationships well, but it is not very useful for structure mapping in petroleum exploration.

The anhydrite beds in the upper part of the Madison group are very widespread and are considered to be nearly time parallel by many geologists. These anhydrite beds form excellent "marker" beds and often the mechanical log characteristics of these "marker" beds can be traced for 40 to 50 miles beyond the extent of the anhydrite. The limestone beds between the anyhydrites form important reservoirs on the east flank of the Williston Basin. A terminology for these depositional cycles, using the anhydrites as "marker" beds, has been proposed by the Saskatchewan Geological Society. Their terminology has been adopted in North Dakota with one modification. They used the term "Beds" as a para time rock unit for these marker defined units. In North Dakota, however, the term "interval" has been substituted for "Beds." This terminology which was originally used for southeastern Saskatchewan is useful in the north-central to east-central part of North Dakota. In the deeper parts of the Basin these units cannot be separated and the Madison group is left undifferentiated except for some prominent gamma ray marker horizons which have received informal names.

The Nesson Anticline area has accounted for about 95 per cent of North Dakota production as of January 1, 1959; nearly all of this production has been from the Madison group. These accumulations are all associated with minor structures on the Nesson Anticline, producing from depths of 7,900 to 9,000+ feet. The closure of these structures is not large but there are several porous intervals in the Madison group so the gross pay section exceeds the closure in nearly every field. These pools are considered to be primarily structural traps although they may be partially stratigraphically controlled. The Madison group also produces from stratigraphic traps of both the primary and secondary types in the shallower parts of the Basin.

In Burke County and Divide County areas of northwestern North Dakota, a number of pools have been found in the Madison group limestones at depths of about 5,800 to 6,100 feet. The production is found in an area where a major facies change occurs in the Madison group. The evaporites change from the halites of the central part of the Basin to anhydrites toward the margin of the Basin. Thus the Madison group is composed of interbedded anhydrite and limestone in this area. Structural maps of the Madison group pools show a slight nosing but no closure is found in any of these pools when contoured on a 20 foot interval. This suggests that

the oil accumulations are closely related to local facies changes within the Madison group and especially within the Midale interval. The full details of these porosity and permeability changes are not yet known. An illustration of this type of stratigraphic accumulation is shown by the South Rival field in Burke County (see Fig. 3). The porous limestone in the lower Midale interval changes to anhydrite updip thereby trapping the oil. The anhydrite is believed to be partly primary anhydrite and partly a replacement of the limestone.

The secondary type of stratigraphic trap is illustrated by most of the fields in Bottineau County in north-central North Dakota where the post-Paleozoic unconformity truncates the Madison group.

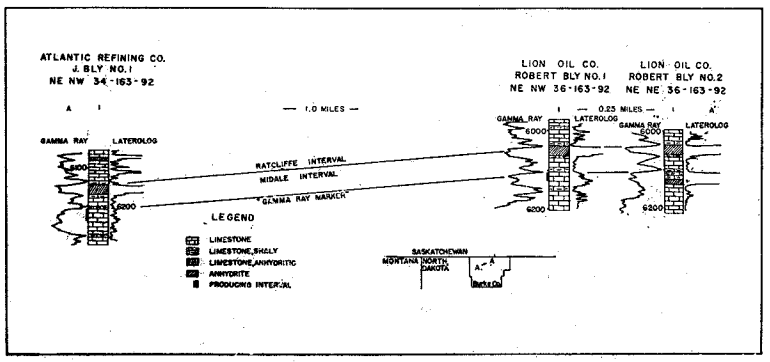

Fig. 3—Cross-section showing a stratigraphic trap in Burke County.

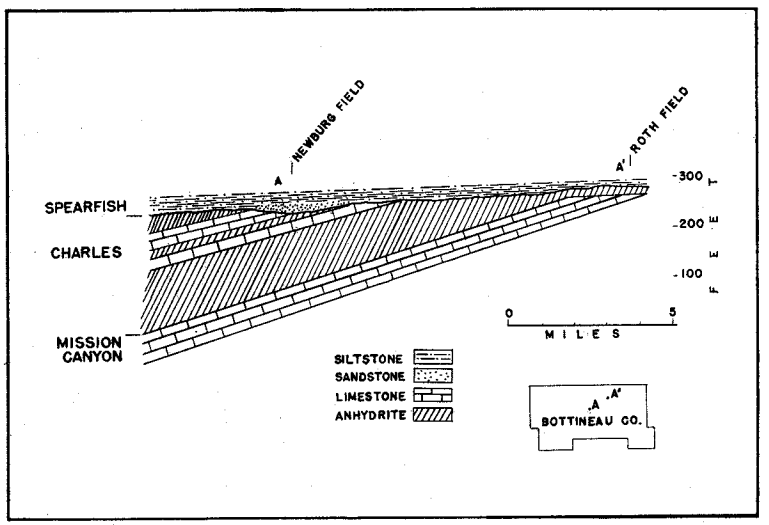

Fig. 4—Cross-section in Bottineau County showing secondary types of stratigraphic traps.

In this area the Madison group consists of interbedded anhydrite and limestone. These porous limestone beds, where they are truncated by the unconformity, often have a secondary anhydrite developed which together with the siltstone of the overlying Spearfish formation of Triassic age forms the caprock of these reservoirs. Most of these accumulations are small.

A notable exception to the above generalization is the Newburg field whose special conditions have resulted in a larger accumulation (Folsom, *et al.*, 1958). The unconformity is at a depth of about 3,400 feet in the Newburg area. A sandstone of limited lateral extent at the base of the Spearfish formation and overlying a porous limestone bed of the Ratcliffe interval forms an excellent reservoir rock in this field (see Fig. 4). Many of the wells produce from both the Ratcliffe interval and the Spearfish formation, so it is clear that the oil has migrated to its present position through the Madison group.

Some of the small fields in the western part of Bottineau County produce from the Frobisher-Alida interval in what are apparently rather small, structural accumulations not associated with the unconformity.

The first oil production in North Dakota was from the Silurian and Devonian rocks, but these reservoirs were not being developed until very recently, because the lesser depth and the reservoir characteristics of the Madison reservoirs were more favorable. One exception was the Sanish pool in the Antelope field on the east side of the Nesson Anticline. This pool produces a good quality crude oil (43° API gravity) from a rather local sandstone development at the top of the Three Forks formation of Devonian age on the Antelope anticlinal structure from a depth of about 10,150 feet. The discovery well for this pool was the Pan American Petroleum Co.—W. Starr No. 1 well located in SW, SE, Sec. 21, T. 152 N., R. 94 W., McKenzie County. It was completed in December of 1953 with an initial potential of 1,420 barrels per day. The W. Starr No. 1 well was the best well in the state, having produced 279,254 barrels of oil before being plugged in July, 1958, due to casing difficulties. Subsequently another well has been drilled on the same tract and is now in production.

The Duperow formation of Devonian age is productive in the Beaver Lodge field near the north end of the Nesson Anticline from a depth of about 10,150 feet. The completion practice has been to perforate about 300 feet of brownish gray, fine grained limestone and dolomitic limestone. Core analysis data is not available on the Duperow reservoir, but it is probably a fractured carbonate reservoir. The crude oil is 42° API gravity, but it requires special handling because of its high pour point (70° F).

The Interlake formation of Silurian age is also capable of production in the Beaver Lodge field from a depth of about 11,440

feet. The gravity of the crude oil is 53° API, but the gas-oil ratio is 7,000 or 8,000 to 1. The pool is not now being produced until its full extent is determined. Then, if it is economically favorable, the gas will be recycled to produce more of the condensate while conserving the reservoir energy.

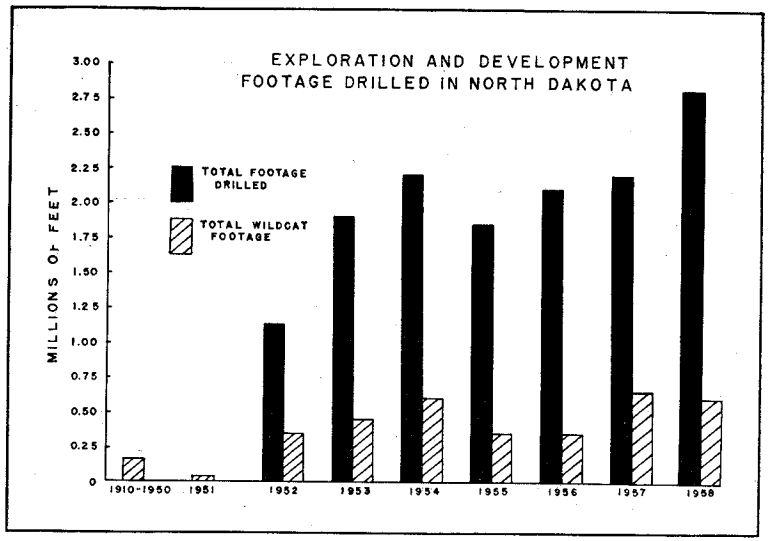

Fig 5—A comparison of exploration footage drilled with development footage drilled.

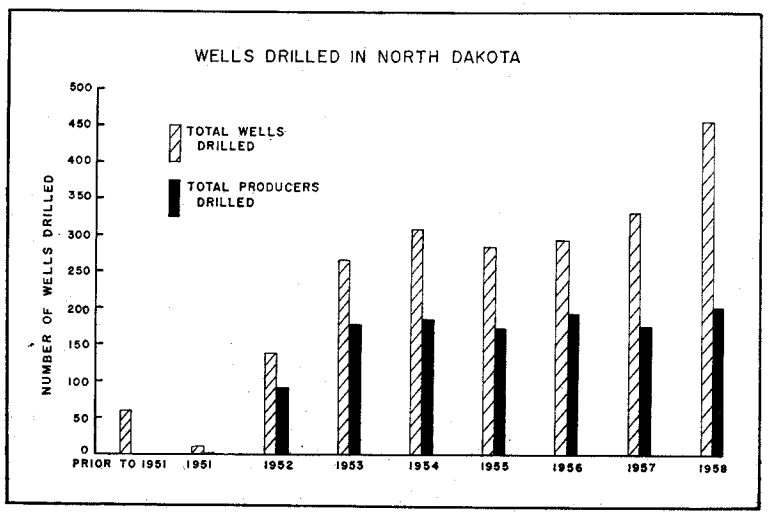

Fig. 6—A comparison of total wells drilled to total producers drilled.

The Red River formation of Ordovician age has good porosity and is a good producing horizon in the Montana portion of the Williston Basin. However, in North Dakota, production in this formation is limited to two fields, each containing only one well; one in Bowman County in southwestern North Dakota and one in Divide County in northwestern North Dakota. The well in Divide County has since been abandoned. The Red River formation has also produced some oil in tests in the Beaver Lodge field at a depth of 12,800 feet but not in commercial quantities. The potential of the Red River formation in the deeper parts of the Basin has not been thoroughly tested because of the depth.

TABLE 2

Success ratios for the various categories of wells

	Prior 1951	1951	1952	1953	1954	1955	1956	1957	1958
State		0.100	0.645	0.668	0.599	0.609	0.659	0.530	0.440
Wildcat		0.100	0.152	0.158	0.036	0.103	0.101	0.135	0.173
Development			0.901	0.916	0.937	0.892	0.870	0.882	0.754
Extension						0.826	0.824	0.632	0.833
Outpost						0.091	0.533	0.367	0.258

WILDCAT—A well located more than one and a half miles from a producing well or a field boundary at the time the well is spudded.

DEVELOPMENT—An offset well to a producer, or a well located within the boundary of a field at the time when the well is spudded.

EXTENSION—A well which is one location outside the boundary of a field at the time when the well is spudded.

OUTPOST—A well which is more than one location from the field boundary but less than one and a half miles from the field boundary at the time the well is spudded.

SUCCESS RATIO—The ratio of producing wells to total wells drilled.

EXPLORATION AND DEVELOPMENT

The history of oil exploration and development is shown by the graphs (Figs. 5 & 6) and the success ratio chart (Table 2). These graphs and the table show that the success ratios have had an important influence on the amount of drilling. The wildcat and development drilling both increased steadily from the initial discovery in 1951 through 1954 based on good success ratios for both wildcat (15%) and development (90%) drilling during 1952 and 1953. The very poor success ratio for wildcat drilling during 1954 (3.5%) resulted in a decline in drilling during 1955 and an apparent overall re-evaluation of the oil prospects in North Dakota.

A significant factor in this re-evaluation was that of the 22 pools discovered in North Dakota as of January 1, 1955, the Nesson Anticline had accounted for 13 pools and 10 of them were from the

Madison group limestones. Success in areas off the Nesson Anticline was confined to three small pools in southwestern North Dakota and six small pools in Bottineau County in north-central North Dakota, seven of which were also from the Madison group. Areas off the Nesson Anticline had accounted for 35 per cent of the wells drilled, most of which was wildcat drilling. The wildcat success ratio for these areas was about 4 per cent.

Beginning in 1955, the drilling began to be concentrated in two general areas of the state with the Madison group as the primary objective in both areas. The most important area continued to be the Nesson Anticline, but the area along the Canadian border with its shallower depths and production adjusted to the maximum efficient rate of recovery (abbreviated M.E.R.), became increasingly important as new discoveries were made. Since the accumulations along the Canadian border are generally smaller and of the stratigraphic type, more dry holes were drilled in determining the limits of these pools than in the structural traps on the Nesson Anticline. This factor accounts for the decline in the development ratios. It is noteworthy that the success ratio for wildcat drilling gradually increased from 1955 through 1958, and again, total drilling increased each year. The increased success reflects a better understanding of the facies relationships in the Madison group which is essential to the finding of stratigraphic accumulations toward the flanks of the Basin

SECONDARY RECOVERY

Early in 1957, operators in the Beaver Lodge and Tioga fields, headed by the major leaseholder, Amerada Petroleum Corporation, began studying the possibility of unitizing the two fields for the purpose of pressure maintenance projects. These two fields cover 36,346 acres and during the first six months of 1959 accounted for about 33 per cent of the North Dakota production.

The aim of these unitization projects, which are soon to be in full operation, will be to inject water into the Madison producing zone through wells situated around the periphery of the structure. This water will tend to arrest the decline of the reservoir pressure as each barrel of oil is produced. Amerada officials estimated the pressure maintenance program will cost between seven and eight million dollars.

As shown by the graphs (Fig. 7 & 8), the increase in production from the two fields is expected to exceed 126 million barrels. This additional recovery will amount to approximately one billion dollars worth of oil and gas products. If the Beaver Lodge and Tioga projects are successful, pressure maintenance programs will undoubtedly be attempted in other Madison pools on the Nesson Anticline.

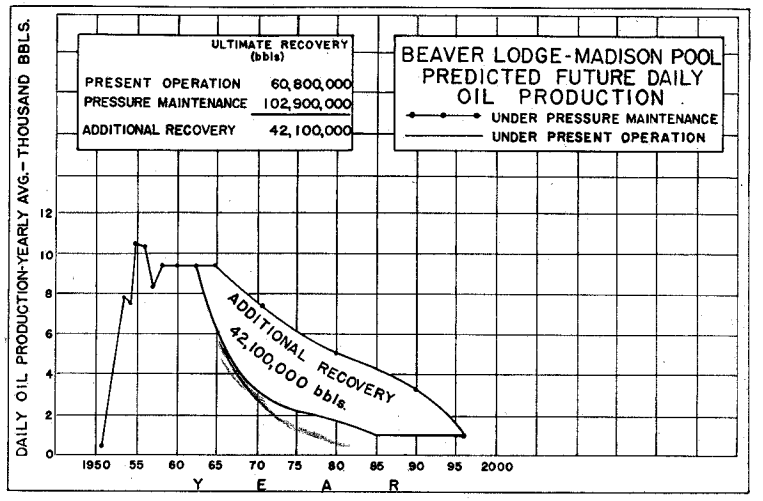

Fig. 7—Beaver Lodge Madison pool predicted future daily oil production (after: Williston Basin Oil Review, March, 1958, p. 25).

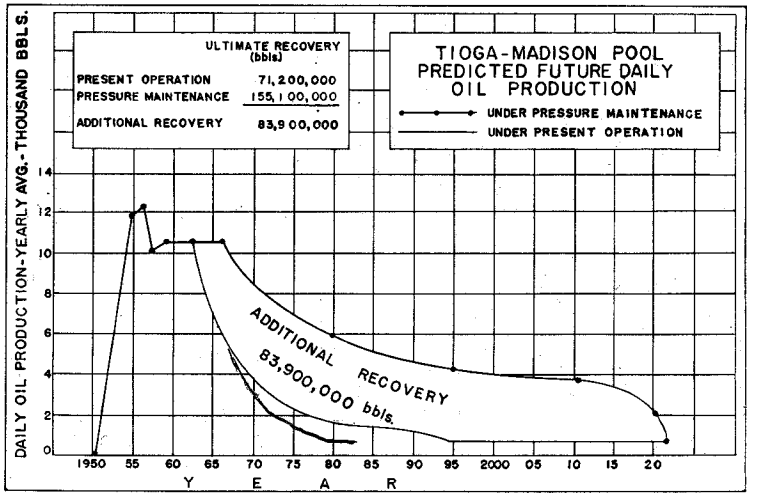

Fig. 8—Tioga-Madison pool predicted future daily oil production (after: Williston Basin Oil Review, March 1958, p. 25).

RESERVES

Table 3 shows the estimated reserves of crude oil and natural gas liquids in North Dakota and its per cent of the proved reserves of the United States on January 1st of the years 1952 through 1958. This table was compiled from statistics published in the annual forecast issues of World Oil (1953-1959).

TABLE 3

Estimated Proved Reserves — Liquid Hydrocarbons in North Dakota 1952-1958

Year	Crude Oil (bbls.)	Natural Gas Liquids (bbls.)	Total Liquid Hydrocarbons	Per Cent of U.S.
1952	4,983,000		4,983,000	0 015
1953	76,203,000		76,203,000	0.234
1954	128,271,000		128,271,000	0.372
1955	181,213,000		181.213,000	0.520
1956	185,532,000		185,532,000	0.530
1957	195,834,000		195,834.000	0.530
1958	258.221 000	22,700,000	280,921,000	0.780

Since the North Dakota reserves of natural gas liquids from 1952 to 1957 were negligible, World Oil does not list this separately but includes it under Miscellaneous Natural Gas Liquid Reserves along with that of Florida and Alabama.

The latest estimated proved reserves of liquid hydrocarbons (280,921,000 bbls.) would last for about 23 years at the present rate of production of about one million barrels per month. However, the proved reserves have been increased each year through new discoveries and development drilling. The reserves of the state are also being increased through secondary recovery programs such as the Beaver Lodge and Tioga pressure maintenance projects.

MARKETING

Most of the oil produced in North Dakota is sent to four areas for refining; these areas are: 1) Mandan, North Dakota (Standard Oil of Indiana), 2) Wrenshall, Minnesota and Superior, Wisconsin area (International Refineries and Murphy Corporation), 3) St. Paul, Minnesota (Northwestern Refining Co.) and, 4) Williston, North Dakota (Westland Oil Co.).

The total amount of oil produced per month in North Dakota is based on the market demand and is regulated by the State Industrial Commission. This Commission is composed of the governor, attorney general and secretary of agriculture and labor with the state geologist acting as advisor. At monthly meetings, nominations from purchasers are received and considered. The market demand is then prorated among the producing wells on the basis of their ability to produce, the depth to the producing horizon and the acreage in the drilling unit.

The state is divided into two marketing districts for purposes of proration (see Fig. 9). District 1 includes all of the fields on the Nesson Anticline and the fields in the southwestern part of the state. Nearly all of this oil is refined at Mandan, North Dakota. The wells in this district are prorated because their productive capacity exceeds the available market. As of July 1, 1959, the oil from this district was selling at the wellhead for $2.95 per barrel. District

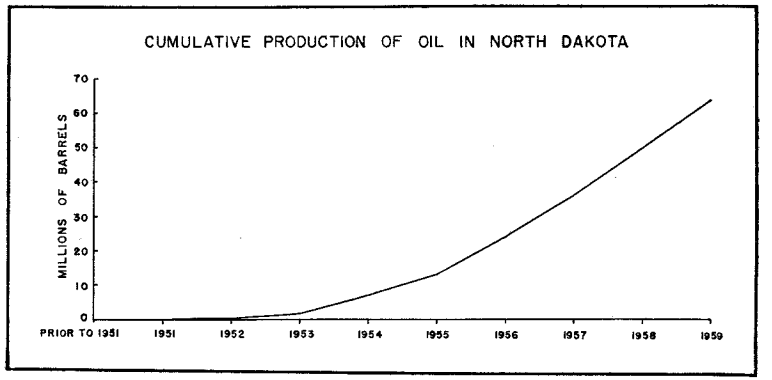

Fig. 9—Cumulative production for North Dakota by years.

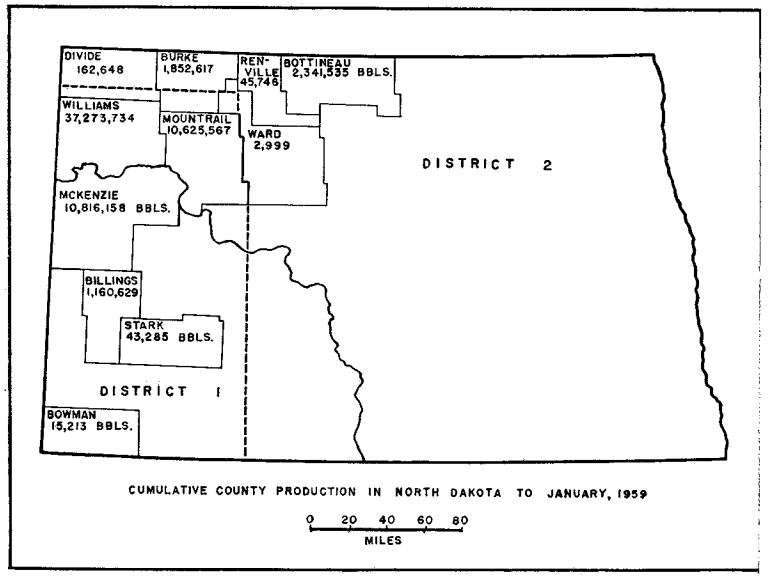

Fig. 10—Cumulative production by counties in North Dakota to January, 1959.

2 includes the fields along the Canadian border. Their marketing area is chiefly to the east in Minnesota and Wisconsin, however, some is marketed at the refinery at Williston, North Dakota. The wells in this district are prorated only on M.E.R. at the present time since their available market exceeds their productive capacity. The oil produced from this district sells for about $1.95 to $2.32 per barrel at the wellhead (price as of July 1, 1959). The oil from this district receives a lower price because it must compete with crude oil from Canada as well as other domestic sources. The crude oil from Canada is shipped into the Minnesota and Wisconsin mar-

keting areas by pipeline whereas the crude oil from North Dakota is transported by rail which is relatively more expensive.

As of January 1, 1959, over 60 million barrels of oil have been produced from 11 counties (Fig. 9). The cumulative production by county is shown in Fig. 10.

ADDENDUM

A total of 420 wells were drilled in North Dakota during 1959, of which 264 were producing wells. The total footage drilled was 2,341,138 feet with wildcat drilling accounting for 301,380 feet. This represents the lowest total for wildcat drilling since 1951. One explanation for this decrease in exploration is the problem of markets, and also decreased success ratio was probably a significant factor. The success ratios for the various categories of wells were as follows: wildcat 0.097, development 0.760, extension 0.719, and outpost 0.521. Only six wildcats were successful; three of these were located in Bottineau County and one each located in Burke, Dunn and McKenzie Counties. All of these discoveries were from the Madison group.

The most significant discovery was the Rough Rider field. located about 35 miles southwest of the southernmost production along the Nesson Anticline and about 35 miles northwest of the Fryburg field. Another significant test was the deepest well in the state (bottoming in Precambrian at 15,135 feet) drilled in the Antelope field which, although not yet completed, will probably establish two new producing intervals (Interlake, Duperow and possibly Birdbear formations) in that field.

The secondary recovery projects in the Beaver Lodge and Tioga fields are now in full operation and are already proving quite successful. The first pressure survey since the start of the program was made in June, 1959. It showed that the pressure decline had not only been arrested, but that the reservoir pressure had increased slightly from the previous survey in December, 1958.

During the latter part of 1959, a new market for oil from southwestern North Dakota was found at Glendive, Montana. Hence, the fields in southwestern North Dakota have been placed in a new marketing district; and as of January 1, 1960, this district was not being prorated.

SELECTED AND CITED REFERENCES

Anderson, S. B., 1954, Stratigraphic section of the Mississippian system in North Dakota: **N. Dak. Geol. Survey Rept. Inv. 16.**

———— and Nelson, L. B., 1956, Mississippian stratigraphic studies, Bottineau County, N. Dak.: **N. Dak. Geol. Survey Rept. Inv. 24.**

Barnes, T. R., 1955, Williston Basin—new province for oil exploration: **Am. Assoc. Petroleum Geologists Bull.**, v. 37, p. 340-354.

Bateman, A. F., Jr., 1957, Structure contour map of Nesson Anticline: **U. S. Geol. Survey Open File Map.**

Collier, A. J., 1918, The Nesson Anticline, Williams County, North Dakota: **U. S. Geol. Survey Bull. 691-G**, p. 211-217.

Edie, R. W., 1958, Mississippian sedimentation and oil fields in southeastern Saskatchewan: **Am. Assoc. Petroleum Geologists Bull.**, v. 42, p. 94-126.

Folsom, C. B., Jr., and Anderson, S. B., 1955, What are the prospects in Williston Basins east side?: **Oil and Gas Jour.**, v. 54, no. 32, p. 92-96.

————, **et al.**, 1958, Preliminary study of the Newburg and South Westhope fields: **N. Dak. Geol. Survey Rept. Inv. 28.**

Francis, D. R., 1957, Jurassic stratigraphy of Williston Basin area: **Am. Assoc. Petroleum Geologists Bull.**, v. 41, p. 367-398.

Hainer, J. L., 1956, The geology of North Dakota: **N. Dak. Geol. Survey Bull. 31**, 46 p.

Hansen, D. E., 1955, Subsurface correlations of the Cretaceous Greenhorn-Lakota interval in North Dakota: **N. Dak. Geol. Survey Bull. 29**, 46 p.

Hansen, Miller, 1956, Geologic map of North Dakota: **N. Dak. Geol. Survey.**

Harris, S. H., 1959, Rocky Ridge pool, Billings County, North Dakota: **Second International Williston Basin Symposium,** Bismarck, North Dakota, p. 40-46.

Laird, W. M., 1944, The stratigraphy and structure of North Dakota: **N. Dak. Geol. Survey Bull. 18.**

————, 1953, The geology of the Williston Basin: Williston Basin Oil Review, v. 2, no. 8, p. 26-35; **Interstate Oil Compact Quart. Bull.**, v. 12, no. 2, p. 71-79.

———— and Towse, D. F., 1953, Stratigraphy of North Dakota with reference to oil possibilities: **N. Dak. Geol. Survey Rept. Inv. 2.**

Maywald, R. H., 1957, North Dakota pre-Mesozoic paleogeologic map: **N. Dak. Geol. Survey.**

McCabe, W. S., 1954, Williston Basin Paleozoic unconformities: **Am. Assoc. Petroleum Geologists Bull.**, v. 38, p. 1998-2010.

North Dakota Geological Society and Saskatchewan Geological Society, 1956 (1957), **First International Williston Basin Symposium:** Bismark, Conrad Publishing Co.

————, 1958 (1959), **Second International Williston Basin Symposium:** Bismarck, Conrad Publishing Co.

North Dakota Geological Survey, 1959, **Official oil in North Dakota** (Production statistics, second half of 1958).

Peterson, J. A., 1957, Marine Jurassic of northern Rocky Mountains and Williston Basin: **Am. Assoc. Petroleum Geologists Bull.**, v. 41, p. 399-440.

Porter, J. W., and Fuller, J. G. C. M., 1958, Lower Paleozoic rocks of northern Williston Basin and adjacent areas: **Am. Assoc. Petroleum Geologists Bull.**, v. 43, p. 124-189.

Sandberg, C. A., and Hammond, C. R., 1958, Devonian system in Williston Basin and central Montana: **Am. Assoc. Petroleum Geologists Bull.**, v. 42, p. 2293-2334.

Towse, D. F., 1957, Petrology of Beaver Lodge Madison limestone reservoir, North Dakota: **Am. Assoc. Petroleum Geologists Bull.**, v. 41, p. 2493-2507.

Waldren, C. H., Meldahl, E. G., and McGowan, L. L., 1955, North Dakota—oil state: **The Compass,** v. 32, no. 2, p. 98-108.