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SEDIMENTARY AND TECTONIC HISTORY OF NORTH DAKOTA PART OF WILLISTON BASIN

by

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SEDIMENTARY AND TECTONIC HISTORY OF NORTH DAKOTA PART OF WILLISTON BASIN[1]

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Grand Forks, North Dakota

ABSTRACT

The Williston basin is a structural and sedimentary basin which includes 51,600 square miles in North Dakota. It contains sedimentary rocks of every geologic period from the Cambrian through the Tertiary and its history can be divided conveniently into the Sequence subdivision (Sauk Tippecanoe, Kaskaskia, Absaroka, Zuni, Tejas) based on the major unconformities within the preserved section. The maximum known sedimentary thickness is 15,128 feet in a well in McKenzie County in western North Dakota.

The Upper Cambrian to Lower Ordovician Epochs are represented by the Deadwood Formation, which is a stable shelf deposit extending eastward from the Cordilleran geosyncline. The Williston structural basin began to be filled in Middle Ordovician time with a relatively thin clastic sequence (Winnipeg Group) followed by predominantly carbonate deposition (Red River, Stony Mountain, and Stonewall Formations). Carbonate deposition continued through Early and Middle Silurian time (Interlake Formation) followed by a period of erosion marked by a major unconformity.

During the Middle and Upper Devonian Epochs the Williston basin was a part of the larger western Canada basin of deposition which was characterized by predominantly carbonate deposition with a thick evaporite in the lower part (Prairie Formation) and cyclical carbonate with some thin clastic and evaporite beds in the upper part (Duperow, Nisku, Three Forks). Deposition was continuous or nearly continuous into the Mississippian, but the center of the Madison depositional basin was nearly coincident with the present Williston basin. Mississippian deposition began with predominantly carbonate deposition, evaporites increasing in the upper part. The evaporites are mostly halite in the central basin area and anhydrite toward the flanks of the basin. Predominantly clastic deposition (Big Snowy Group) followed the evaporites; another unconformity is at the top of the Big Snowy.

The Pennsylvanian and Permian Periods are represented by clastics with minor carbonates (Minnekahta Formation) and some evaporites. This was a time of slight subsidence, with the Williston basin area a part of a larger depositional area extending south and west. Similar conditions continued through the Triassic with deposition of fine-grained clastics and some evaporites, which are overlain by some non-marine redbeds and another unconformity.

As the Williston structural basin had little effect on Jurassic or Cretaceous sedimentation, these periods are represented by eastward extensions of the predominantly fine-grained clastics from the Rocky Mountain area seas. The Tertiary Period is represented by a wedge of predominantly non-marine beds which thicken westward toward the Rocky Mountain area.

INTRODUCTION

The geologic history of the Williston basin is recorded by a sedimentary section ranging up to 15,000 feet in thickness in the central basin area, with every period from the Cambrian through the Tertiary represented. Major structural features within the basin are the Nesson anticline, a north-south-trending structure in northwestern North Dakota, and the Cedar Creek anticline, in southeastern Montana extending into southwestern North Dakota and northwestern South Dakota (Fig. 1). The Williston basin is an intracratonic basin. As its geologic history is closely related to other areas of the craton, it can be discussed conveniently by dividing the stratigraphic record into the Sequence subdivision (Figs. 2, 3) of Sloss and others (1949) and Sloss (1963).

[1] Read before the Rocky Mountain Section of the Association at Durango, Colorado, October 1, 1964. Manuscript received, May 7, 1965.

[2] North Dakota Geological Survey.

The writers have drawn freely from the literature and they gratefully acknowledge such use. As a complete bibliography would be too extended, they selected only some of the more recent and pertinent references. The interested reader can refer to this list for other references concerning parts of the stratigraphic column for which more detailed information is desired. The writers are grateful to J. A. Peterson, R. J. Ross, Jr., W. J. McMannis, and F. E. Kottlowski for criticism and revisions of the manuscript.

SAUK SEQUENCE

The initial sedimentary deposit is the Sauk Sequence, which is represented in the Williston basin by the Deadwood Formation of Late Cambrian to Early Ordovician age. The Deadwood is an onlap depositional sequence with a basal sandstone overlain by shale and carbonate and

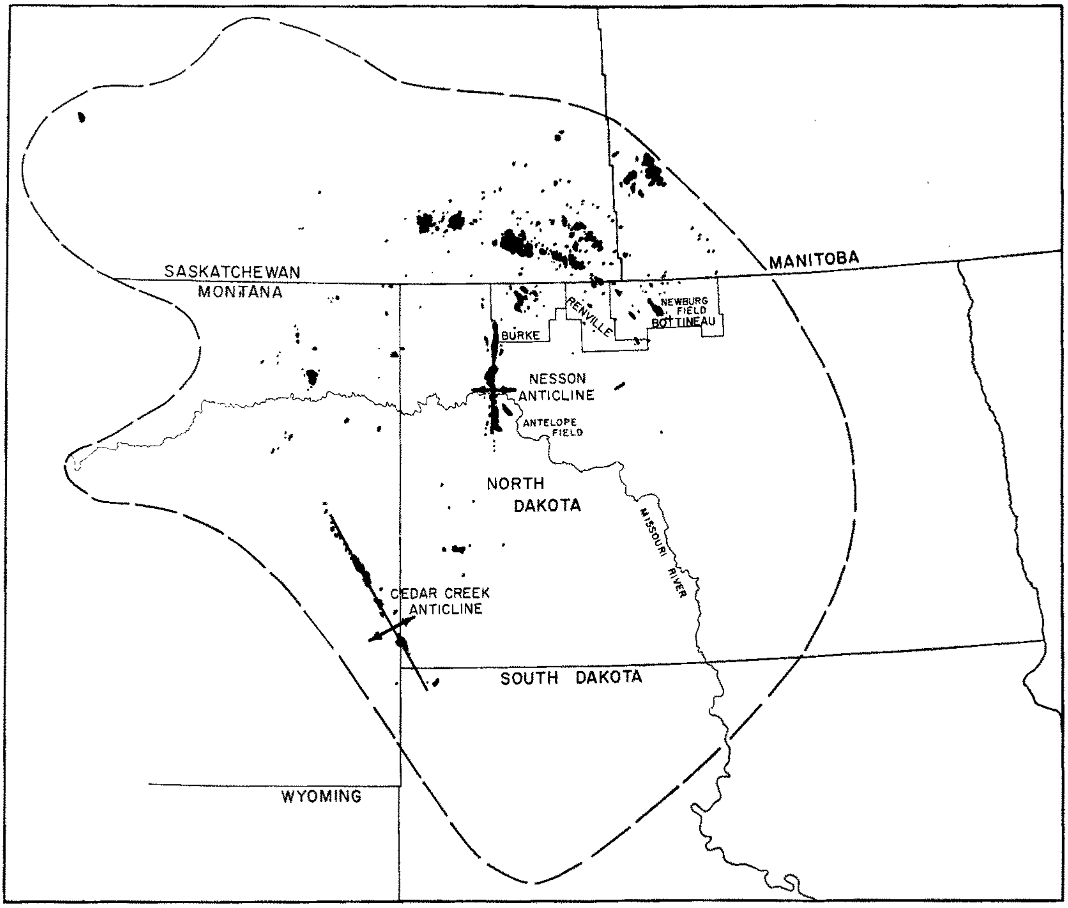

FIG. 1.—Location map showing Williston basin, two of its major structural features, oil fields of North Dakota, and some oil fields of adjacent areas.

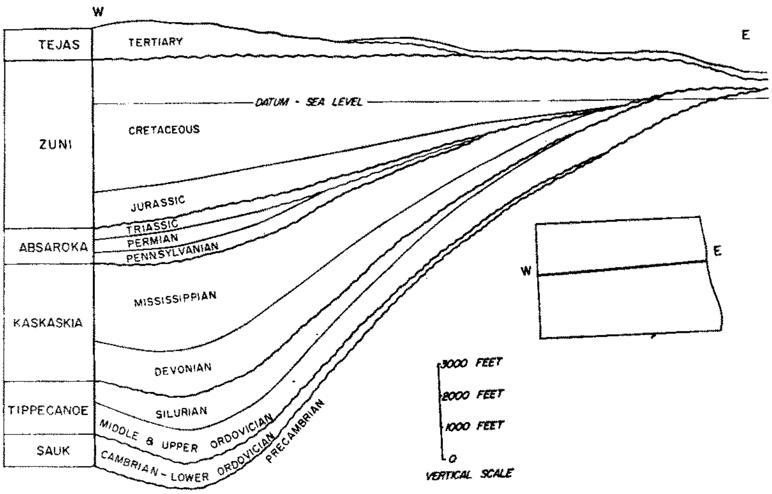

FIG. 2.—Cross section showing major unconformities in North Dakota stratigraphic column.

SEQUENCE	SYSTEM	GROUP OR FORMATION		DOMINANT LITHOLOGY
TEJAS	TERTIARY	GLACIAL DEPOSITS		Glacial Drift
		WHITE RIVER		Clay, Sand and Limestone
		GOLDEN VALLEY		Clay, Sand and Silt
		FORT UNION GROUP	TONGUE RIVER	Shale, Sandstone and Lignite
			CANNONBALL	Marine Sandstone and Shale
			LUDLOW	Sandstone, Shale and Lignite
ZUNI	CRETACEOUS	HELL CREEK		Sandstone, Shale and Lignite
		MONTANA GROUP	FOX HILLS	Marine Sandstone
			PIERRE	Shale
		COLORADO GROUP	NIOBRARA	Shale, Calcareous
			CARLILE	Shale
			GREENHORN	Shale, Calcareous
			BELLE FOURCHE	Shale
		DAKOTA GROUP	MOWRY	Shale
			NEWCASTLE	Sandstone
			SKULL CREEK	Shale
			FALL RIVER	Sandstone and Shale
			LAKOTA	Sandstone and Shale
	JURASSIC	MORRISON		Shale, Clay
		SUNDANCE		Shale, green and brown and Sandstone
		PIPER		Limestone, Anhydrite, Salt and red Shale
ABSAROKA	TRIASSIC	SPEARFISH		Siltstone, Salt and Sandstone
	PERMIAN	MINNEKAHTA		Limestone
		OPECHE		Shale, Siltstone and Salt
	PENNSYLVANIAN	MINNELUSA		Sandstone and Dolomite
		AMSDEN		Interbedded Dolomite Limestone, Shale and Sandstone
KASKASKIA	MISSISSIPPIAN	BIG SNOWY GROUP	HEATH	Shale
			OTTER	Sandstone and Limestone
			KIBBEY	
		MADISON		Interbedded Limestone and Evaporites
				Limestone
		BAKKEN		Siltstone and Shale
	DEVONIAN	THREE FORKS		Shale, Siltstone and Dolomite
		BIRDBEAR		Limestone
		DUPEROW		Interbedded Dolomite and Limestone
		SOURIS RIVER		Interbedded Dolomite and Limestone
		DAWSON BAY		Dolomite and Limestone
		PRAIRIE		Halite
		WINNIPEGOSIS		Limestone and Dolomite
TIPPECANOE	SILURIAN	INTERLAKE		Dolomite
		STONEWALL		Dolomite and Limestone
	ORDOVICIAN	STONY MOUNTAIN FM.	GUNTON MEMBER	Limestone and Dolomite
			STOUGHTON MEMBER	Argillaceous Limestone
		RED RIVER		Limestone and Dolomite
		WINNIPEG GROUP	ROUGHLOCK	Calcareous Shale & Siltstone
			ICEBOX	Shale
			BLACK ISLAND	Sandstone
SAUK	CAMBRIAN	DEADWOOD		Limestone, Shale and Sandstone

FIG. 3.—North Dakota stratigraphic column.

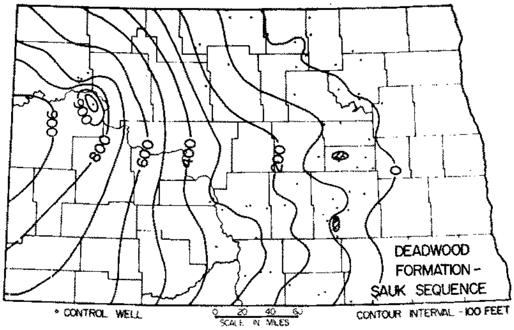

FIG. 4.—Isopachous map of Sauk Sequence.

then by another sandstone. Overlying the upper sandstone is a predominantly carbonate unit which accounts for most of the increased thickness of Deadwood in the western part of the State. Cross sections in eastern North Dakota and southward toward the Black Hills show a widespread truncation of beds of the Deadwood by the basal beds of the Winnipeg Group. Therefore, the original depositional limits of the Deadwood may have extended for a considerable distance beyond the present erosional limits shown on the isopachous map (Fig. 4). The only commercial hydrocarbon production from the Deadwood has been a small amount of condensate in one well on the Nesson anticline from the depth interval 14,000-14,040 feet.

TIPPECANOE SEQUENCE

The Williston basin began to be a slightly negative area during deposition of the Tippecanoe Sequence (Middle Ordovician-Early Devonian). This Sequence appears to be a transgressive event, the seas invading the area from the south and east, and the Williston basin area during most of that time being part of a much more extensive epicontinental sea. Deposition appears to have been essentially continuous from the Middle Ordovician through Early and Middle Silurian time and was characterized by widespread uniform conditions of sedimentation. Isopachous maps of the lithologic units of this Sequence (Figs. 5-14) are essentially depositional thicknesses, except for narrow eroded bands along the southeastern margin of each map (Black Island through Stonewall interval). However, the Interlake Formation reflects a considerable amount of pre-Devonian erosion. The Tippecanoe Sequence began with deposition of the Winnipeg Group clastics, which are divided into three formations in ascending order: Black Island, Icebox, and Roughlock Formations. The Black Island is clean quartzose sandstone; the Icebox is greenish gray, generally non-calcareous shale; and the Roughlock consists of fine-grained, calcareous clastics. Formational contacts within the Winnipeg Group and the contact with the overlying Red River Formation are generally gradational.

The Black Island Formation lies unconformably on the Deadwood Formation, except in eastern North Dakota, where it onlaps the Deadwood and lies non-conformably on Precambrian rocks. The isopachous map of the Black Island (Fig. 7) shows that the thickening of the Winnipeg Group (Fig. 6) in the central basin area is mainly the result of an increased thickness of the basal sandstone in that area. Oil "shows" have been reported from the Black Island Formation of central North Dakota, but the only commercial production to date has been on the Nesson anticline, where one condensate well produces from a depth of 13,400-13,500 feet.

The isopachous map of the Icebox Formation (Fig. 8) shows a slight thickening in the central basin area, but the striking feature is the nearly

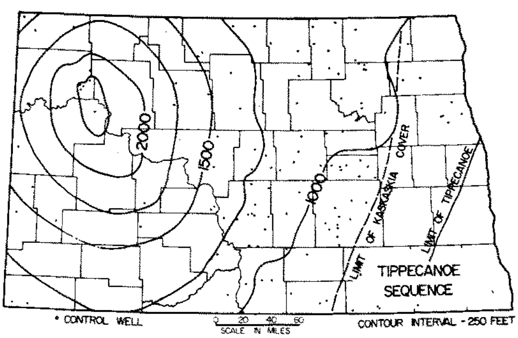

FIG. 5.—Isopachous map of Tippecanoe Sequence.

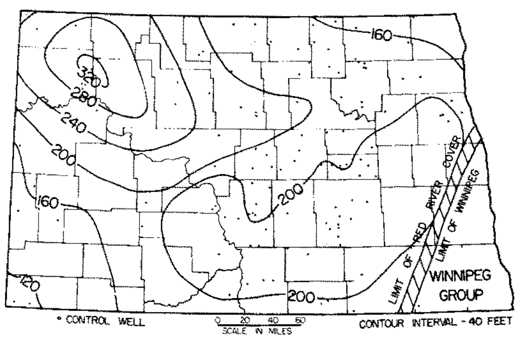

FIG. 6.—Isopachous map of Winnipeg Group.

uniform thickness of this unit through most of the State, as well as southeastward toward its erosional limit. Cross sections in southeastern North Dakota show some thin limestone tongues in the Icebox Formation near the erosional limits. These tongues are slightly thicker and are more numerous near the erosional limit, suggesting that this unit was once much more extensive toward the southeast, and may have extended originally across the Transcontinental arch to the upper Mississippi Valley. On the southwestern flank of the basin, the Icebox Formation onlaps the Black Island Formation and lies unconformably on the Deadwood Formation in northwestern South Dakota.

The isopachous map of the Roughlock Formation (Fig. 9) shows that the thickest sections are in southeastern North Dakota, near the erosional limits of this unit. The isopachous map of the Red River Formation (Fig. 10) shows that the thickest deposition took place farther west in west-central North Dakota. It also shows that the basin, as a negative element, was still relatively inactive, and that these beds were certainly much more extensive toward the east and south than their present limits indicate.

The Red River Formation is predominantly limestone or dolomitic limestone with some thin evaporite beds in the upper part. Along the Cedar Creek anticline, the Red River is the major producing formation, and most of the Red River production in North Dakota has come from that area. Some commercial production has also been found in extreme northwestern North Dakota, on the Nesson anticline, and between the Nesson and Cedar Creek anticlines.

The Stony Mountain Formation, which overlies the Red River, may be divided into a lower argillaceous limestone member termed the Stoughton Member, and an upper clean carbonate unit termed the Gunton Member. The isopachous map of the Stoughton (Fig. 11) shows that this argillaceous member thickens southeastward almost to its erosional limit, suggesting that it probably extended originally southeastward across the present arch.

Isopachous maps of the Gunton (Fig. 12) and the overlying Stonewall Formation (Fig. 13) show a changing tectonic pattern, as the central part of the basin became a slightly negative area during deposition of these predominantly carbonate units. This tectonic pattern continued, the central basin area becoming increasingly negative during Early and Middle Silurian time.

The lower and middle intervals of the Interlake Formation are predominantly finely crystalline dolomites with a few thin clastic and evaporite marker beds. The upper interval of the Interlake consists of pelletoidal and fragmental, dolomitic limestone. Cross sections show that pre-Devonian erosion removed considerable thicknesses of upper and middle Interlake; the areal extent

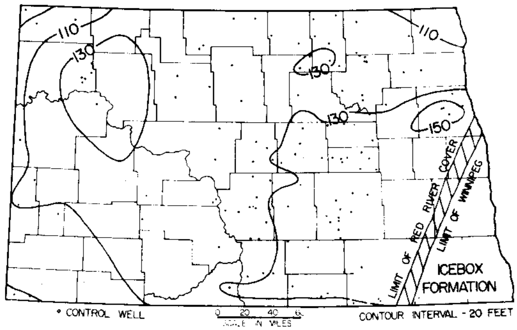

FIG. 8.—Isopachous map of Icebox Formation.

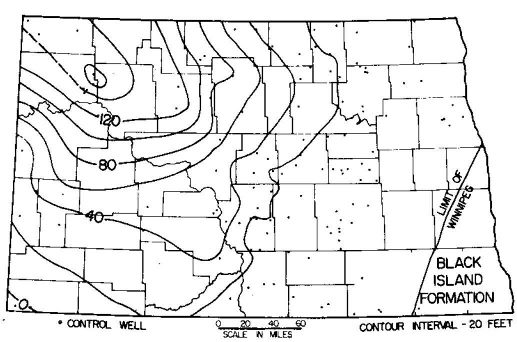

FIG. 7.— Isopachous map of Black Island Formation.

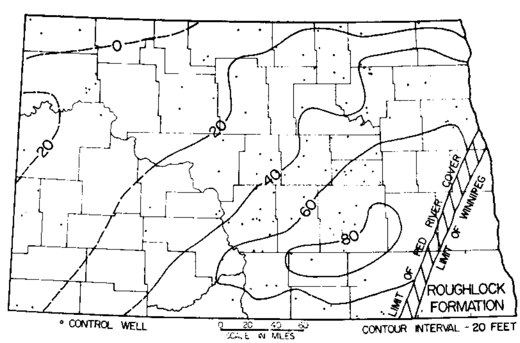

FIG. 9.—Isopachous map of Roughlock Formation.

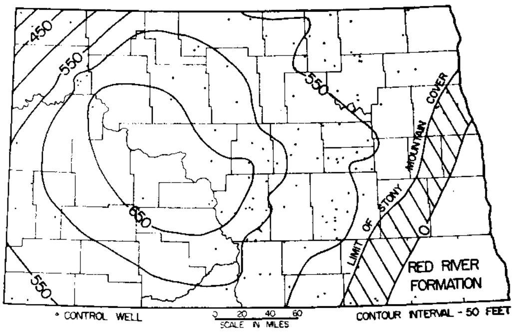

FIG. 10.—Isopachous map of Red River Formation.

of the upper Interlake is indicated approximately by the 500-foot contour line on the Interlake isopachous map (Fig. 14). Commercial oil production from the Interlake in North Dakota has been found only in structural traps along the Nesson anticline, where production is from the upper Interlake interval, but the lower Interlake is a major producing formation on the Cedar Creek anticline in Montana.

Kaskaskia Sequence

The Williston basin was a more tectonically negative area during deposition of the Kaskaskia Sequence (Early Devonian-Late Mississippian, Fig. 15) than during the previous two Sequences, with a preserved accumulation of more than 4,000 feet of sedimentary rocks in the central basin area. The initial deposits of the Kaskaskia Sequence appear to represent a transgressive sea spreading across the area from the north and west, with the Williston basin a part of a larger Devonian seaway whose thickest deposits are in western Canada.

The lowest Devonian beds are the Winnipegosis Formation, a predominantly carbonate unit, which generally has been divided into a lower member composed of fine-grained, silty and argillaceous carbonate, and an upper member composed of limestone and anhydrite. The reddish weathered zone on the pre-Devonian surface, commonly termed the Ashern, is herein included in the lower member of the Winnipegosis. Areas where the upper member contains anhydrite are shown on the isopachous map (Fig. 17). Present distribution of Winnipegosis is probably very nearly that of its original depositional extent.

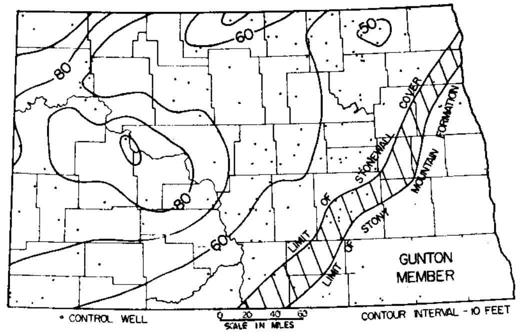

FIG. 12.—Isopachous map of Gunton Member of Stony Mountain Formation.

The Prairie Formation consists mainly of salt, with some limestone and anhydrite. Areas of salt are shown on the isopachous map (Fig. 18), and these areas may be of special interest in future oil exploration, because differential solution of salt beds, which is known to occur in north-central North Dakota, may provide structural traps in overlying reservoir rocks.

The Dawson Bay Formation consists of limestone and dolomitic limestone. The isopachous map (Fig. 19) shows that the Dawson Bay on-

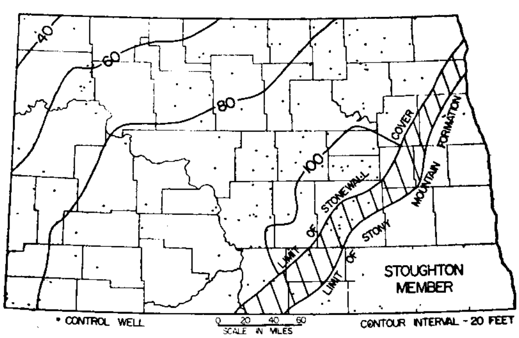

FIG. 11.—Isopachous map of Stoughton Member of Stony Mountain Formation.

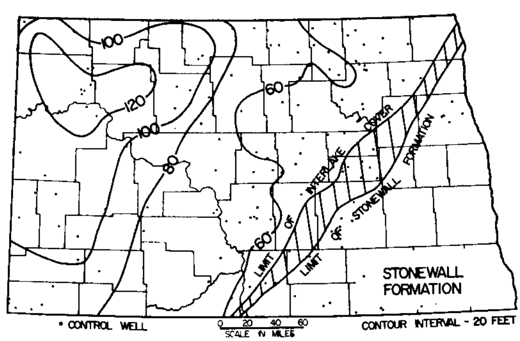

FIG. 13.—Isopachous map of Stonewall Formation.

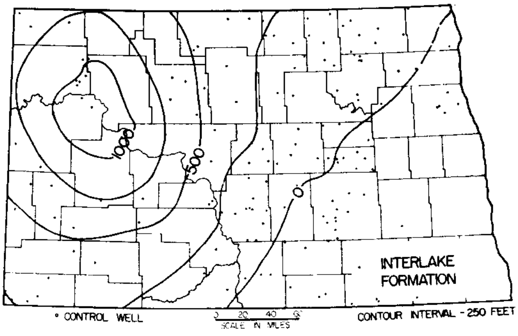

FIG. 14.—Isopachous map of Interlake Formation.

laps the Prairie on the southern and eastern flanks of the basin. Although the present easternmost limits are erosional limits, the original depositional extent was probably not much greater than its present extent.

The Souris River Formation (Fig. 20) indicates a changing pattern of deposition as alternating limestone and thin argillaceous beds were deposited. This cyclical deposition probably took place on a shallow shelf of the Late Devonian seas, these seas spreading farther south and east than the earlier Devonian seas.

The Duperow Formation also consists of cyclical carbonate and shale deposits but contains smaller quantities of shale than the Souris River. The isopachous map of the Duperow (Fig. 21) shows a further onlap by Late Devonian seas, but all present limits are erosional. Oil is produced from the Duperow in several structural traps along the Nesson anticline.

The Birdbear Formation consists mainly of limestone. Present limits of the Birdbear (Fig. 22)

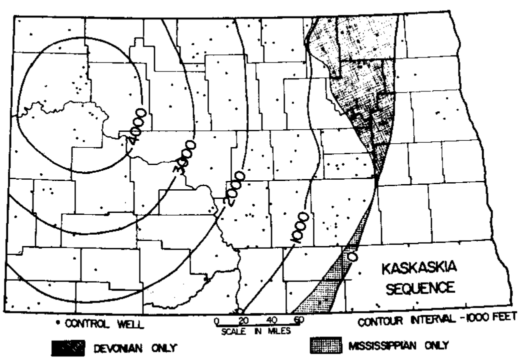

FIG. 15.—Isopachous map of Kaskaskia Sequence.

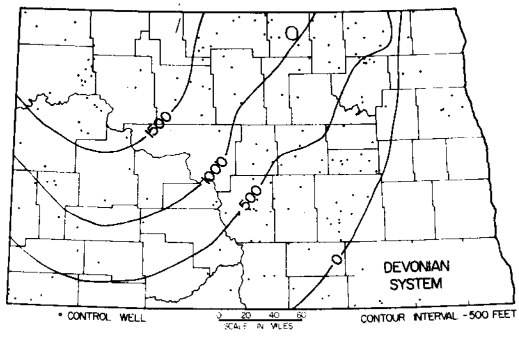

FIG. 16.—Isopachous map of Devonian System.

were determined by pre-Mississippian erosion. The Birdbear generally has very good porosity, but oil production in North Dakota is only in one pool along the Nesson anticline.

The Three Forks Formation consists of shale, anhydrite, siltstone, and dolomite. A thin sandstone, locally present at the top of the Three Forks, is productive in the Antelope field on the Nesson anticline. The Three Forks isopachous map (Fig. 23) reflects some pre-Mississippian erosion on the flanks of the basin, but in the central basin area, within the limits of the lower Bakken, there was little, if any, erosion. Thus, the unconformity between the Devonian and Mississippian Systems does not assume the significance of an inter-Sequence unconformity in the Williston basin.

Configuration of the Mississippian sedimentary basin closely resembles that of the present Williston basin (Fig. 24) with an accumulation of sediments in excess of 2,500 feet in the central basin area. The fine-grained clastics of the Bakken Formation were deposited in restricted basin condi-

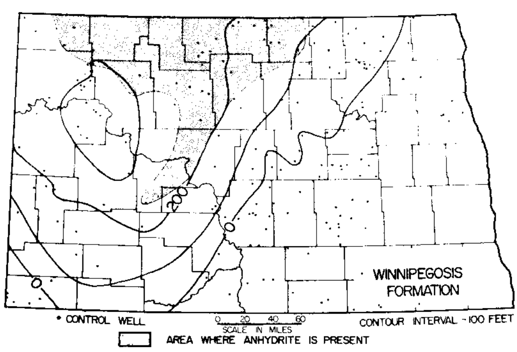

FIG. 17.—Isopachous map of Winnipegosis Formation.

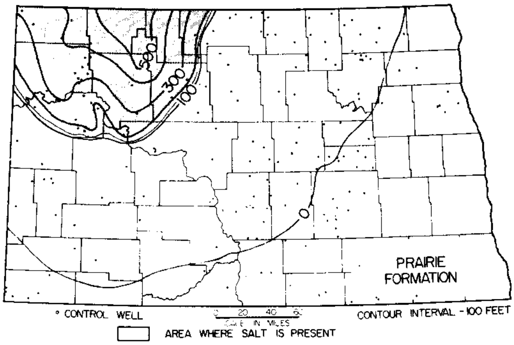

FIG. 18.—Isopachous map of Prairie Formation.

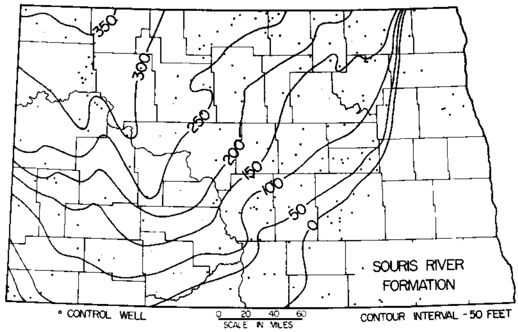

FIG. 20.—Isopachous map of Souris River Formation.

tions. The Bakken is divided into three units: lower black shale, middle calcareous siltstone, and upper black shale unit. The limit of the lower Bakken is shown on the isopachous map (Fig. 25), and each succeeding unit bears an onlap relation to the underlying unit.

After deposition of the Bakken, Mississippian seas spread farther over the craton during deposition of the Madison (Fig. 26). It was a time of predominantly normal marine carbonate deposition, followed by a gradual restriction of circulation, resulting in cyclical carbonate and evaporite deposition. Evaporite deposition began earliest on the northeastern flank of the basin and gradually extended basinward. Three gross lithologic types recognized within the Madison are conveniently referred to as the Lodgepole, Mission Canyon, and Charles facies.

The Lodgepole facies is a thin-bedded, argillaceous or cherty, generally dense, light gray to dark gray limestone facies.

The Mission Canyon facies is a massive-bedded, generally pure limestone, composed largely of fragmental and oölitic material, ranging in color from brownish gray to light yellowish gray. In the central basin area, the Mission Canyon is mainly fragmental limestone, whereas on the margins oölitic limestone is more common. In some areas, the limestone has been partly to completely dolomitized.

The Charles facies consists mainly of halite and anhydrite. Thin shale and minor sandstone tongues are also associated with some anhydrite beds, and together these beds serve as markers within the Madison Formation. Some primary dolomite also may be included in this facies.

The terms Charles, Mission Canyon, and Lodgepole originally were proposed as formations, and they are within the limits of such a definition. However, the facies changes have such an intertonguing relation to one another that, in the stratigraphic work of petroleum geologists in the Williston basin, it has been found more convenient to divide the Madison strata into paratime rock units or intervals. The basis for such subdivision is the widespread evaporite beds with associated fine-grained clastics. These beds are

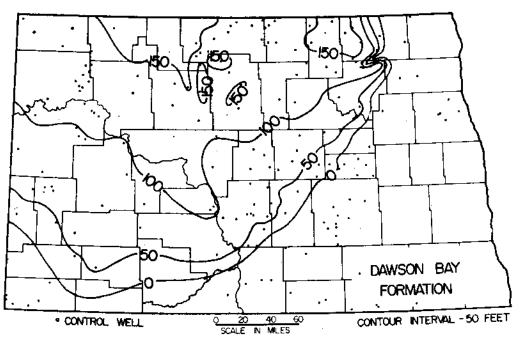

FIG. 19.—Isopachous map of Dawson Bay Formation.

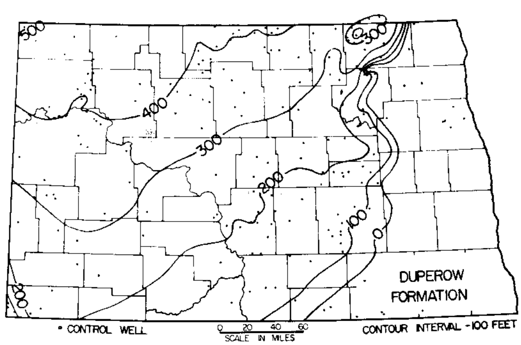

FIG. 21.—Isopachous map of Duperow Formation.

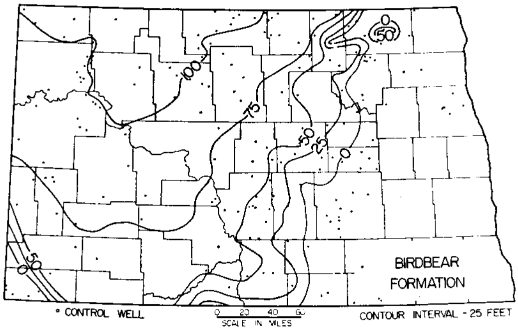

FIG. 22.—Isopachous map of Birdbear Formation.

marked by well-defined, easily recognizable electric-log and gamma-ray characteristics that can be traced for long distances. Their widespread occurrence as thin units is believed to be evidence that they are probably time-parallel units. This basis of subdivision was first introduced by Fuller (1956) working in southeastern Saskatchewan, and such a subdivision is now used on both sides of the International border. Lacking a formal terminology for these units within the stratigraphic code, the writers refer to these para-time rock units as intervals within the Madison Formation.

In ascending order, the intervals of the Madison are the Bottineau, Tilston, Frobisher-Alida, Ratcliffe, and Poplar. Near the margins of the basin where this subdivision was devised, all of the intervals can be recognized; however, in the central basin area, there are only two markers which can be recognized. The North Dakota Geological Society (Smith, 1960) used these two markers for redefinition of the Poplar and Ratcliffe intervals, because these were the most satisfactory in North Dakota. The writers accept these redefinitions.

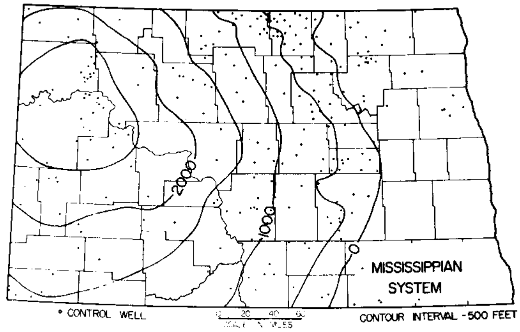

FIG. 24.—Isopachous map of Mississippian System.

Charles and Mission Canyon general facies patterns cross time planes (Fig. 27), appearing at gradually lower stratigraphic levels toward the basin flank. In detail, the Mission Canyon and Charles facies have a complex intertonguing relation in each of the Poplar through Frobisher-Alida intervals, and these relations are important for oil exploration. Oil accumulations in the Madison, which on January 1, 1964, accounted for 78 per cent of North Dakota's crude oil reserves, are of three general trap types. The majority of the reserves are in structural traps along the Nesson anticline, where most of the Madison production is from the Frobisher-Alida interval. Stratigraphic traps are of two general types: (1) porosity pinch-outs, caused by updip facies changes, which are an important trapping mechanism in the Burke-Renville area; and (2) porosity pinchouts at the pre-Mesozoic unconformity, which are an important trapping mechanism in the Bottineau area, as well as in southeastern Saskatchewan and Manitoba.

The Big Snowy Group (Fig. 28), which con-

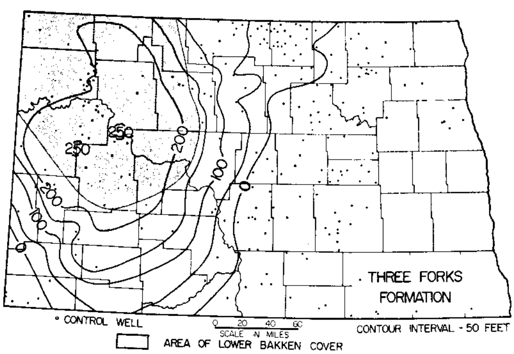

FIG. 23.—Isopachous map of Three Forks Formation.

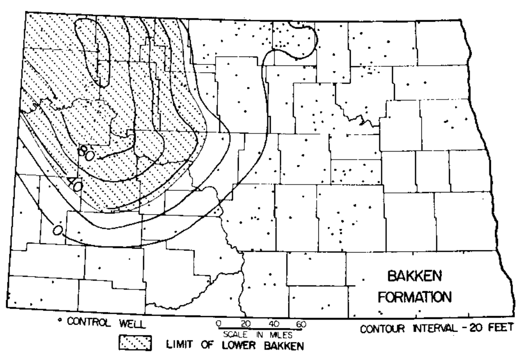

FIG. 25.—Isopachous map of Bakken Formation.

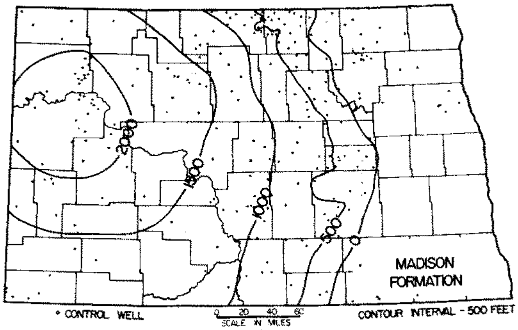

FIG. 26.—Isopachous map of Madison Formation.

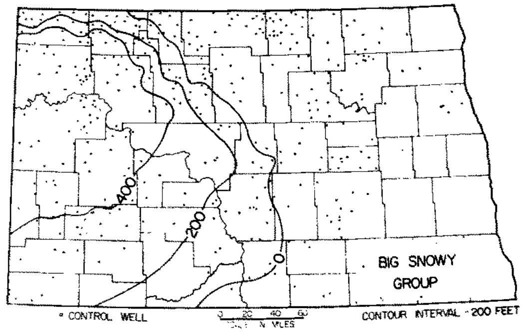

FIG. 28.—Isopachous map of Big Snowy Group.

formably overlies the Madison Formation, has been divided into three formations which, in ascending order, are: Kibbey, Otter, and Heath. The Kibbey may be divided into three lithologic units: a lower siltstone and shale, a middle limestone, and an upper sandstone. There is no production from the Big Snowy in North Dakota at present, but the Kibbey sandstone has excellent reservoir characteristics and should be considered prospective, especially because it recently has proved to be productive in eastern Montana. The Otter Formation is composed predominantly of greenish gray to gray, variegated shale and thin-bedded, light gray limestone. The Heath Formation is composed of gray to black shale.

ABSAROKA SEQUENCE

The Absaroka Sequence (Late Mississippian-Early Jurassic, Fig. 29) is a predominantly clastic sequence, beginning with Late Mississippian or Early Pennsylvanian deposits, which lie unconformably on sediments of Mississippian age.

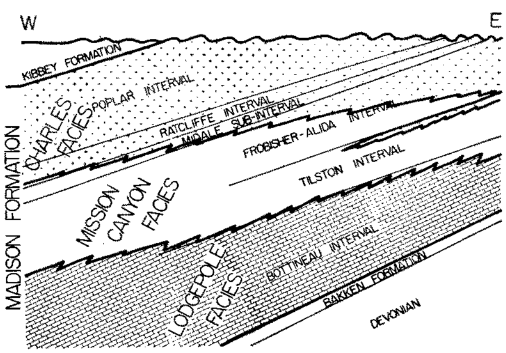

FIG. 27.—Generalized facies diagram of Madison Formation.

Rocks of this Sequence need further study, and some revision of the terminology herein used should be made but the writers are not yet ready to make such revisions. One unconformity has been recognized within the Spearfish Formation, and other minor ones may be present within this Sequence. On the northeastern flank of the basin, where the zero contour diverges from the 500-foot contour, it is possible that some redbeds of the overlying Zuni Sequence may have been included in the isopachous map of the Absaroka Sequence.

The term Amsden Formation has been applied to an interval of interbedded sandstone, shale, and carbonate unconformably overlying Mississippian rocks in southwestern North Dakota. Some of this interbedded sandstone and shale previously has been referred to the Heath, but the strata are lithologically similar to the Tyler Formation of Montana and are probably an equivalent of that formation. Oil is produced from some of these "Tyler" sandstone beds in several wells, probably from stratigraphic traps associated with channel deposits of early Absaro-

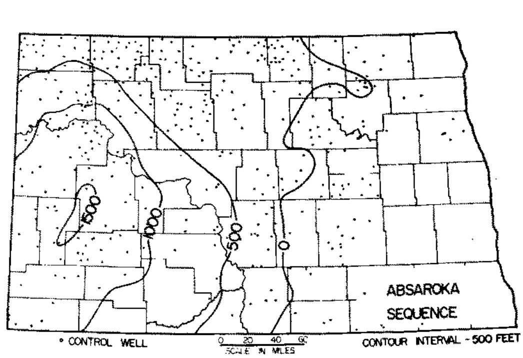

FIG. 29.—Isopachous map of Absaroka Sequence.

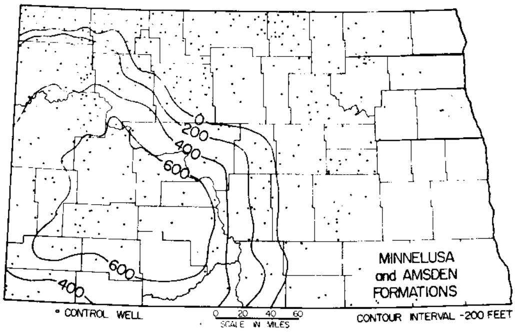

FIG. 30.—Isopachous map of Amsden and Minnelusa Formations.

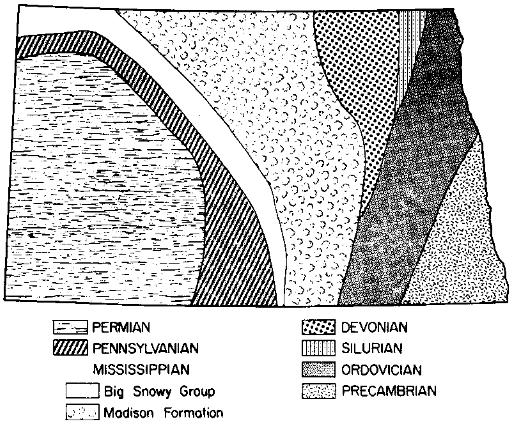

FIG. 32.—Pre-Spearfish paleogeologic map.

ka origin. One of these wells has produced more than 600,000 barrels since its discovery in January, 1957, the greatest cumulative production of any well in North Dakota.

The Minnelusa Formation is predominantly sandstone, but it contains some carbonate and shale. The Minnelusa generally has excellent reservoir characteristics, but there has been no oil production from it in North Dakota. However, the Minnelusa and Amsden Formations both contain large volumes of nitrogen gas in some of the Madison pools in structural traps along the Nesson anticline. Intra-Spearfish erosion has thinned these units along their northern and eastern margins (Fig. 30).

The Opeche Formation consists of red shale, siltstone, and evaporites, principally halite. As the Minnekahta uniformly consists of 30-40 feet of limestone and anhydrite, thickness variations on the isopachous map (Fig. 31) are almost entirely caused by variations of the Opeche. Intra-Spearfish erosion also accounts for the present limits of these formations on their northern and eastern margins.

The pre-Mesozoic paleogeologic map (Fig. 32) shows the changing tectonic patterns through the Paleozoic and indicates areas where unconformity traps might be expected. The Spearfish Formation generally provides the seal above the unconformity for the Madison traps in Bottineau County, but a localized sandstone development at the base of the Spearfish provides a good reservoir rock in the Newburg field.

The Spearfish Formation (Fig. 33) recently has been divided into three units in North Dakota: (1) lower gray shale and red siltstone unit, (2) middle salt unit, and (3) upper red siltstone, sandstone, and shale unit. The lower two units are considered to be marine deposits of Permian age, the Permian-Triassic boundary lying somewhere within the upper unit. The lower unit is conformable with the underlying Minnekahta. The upper unit onlaps the lower and middle

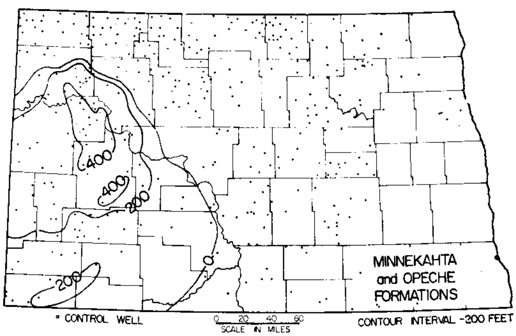

FIG. 31.—Isopachous map of Opeche and Minnekahta Formations.

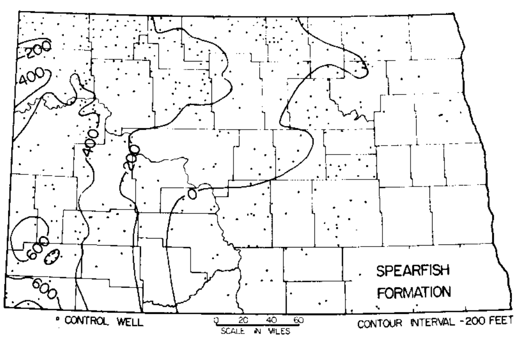

FIG. 33.—Isopachous map of Spearfish Formation.

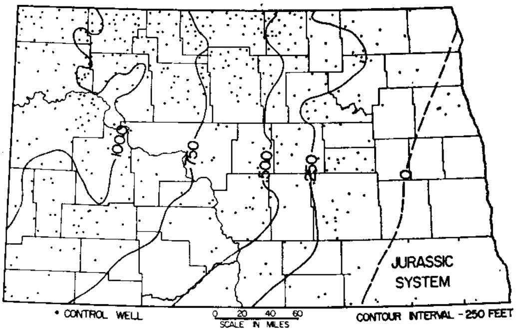

FIG. 34.—Isopachous map of Jurassic System.

units, where the unconformably overlies rocks of Permian to Devonian age.

ZUNI SEQUENCE

The Zuni Sequence (Middle Jurassic-middle Paleocene) is a predominantly clastic sequence deposited in the Williston basin part of the widespread Jurassic and Cretaceous seas of the Western Interior. Jurassic (Fig. 34) strata are as much as 1,200 feet thick in extreme northwestern North Dakota, and extend over all but the extreme eastern part of the State. Jurassic deposition began with restricted environmental conditions, in which the evaporites and red shale of the Poe Member of the Piper were deposited. These conditions were followed by normal marine conditions, in which carbonates of the Piper Formation were deposited, followed by fine-grained clastics of the Sundance Group.

Late Jurassic and Early Cretaceous deposits include light-colored, non-marine siltstone and shale of the Morrison Formation and sandstone, siltstone, and shale of the Lakota Formation. There was little, if any, erosion in the basin area

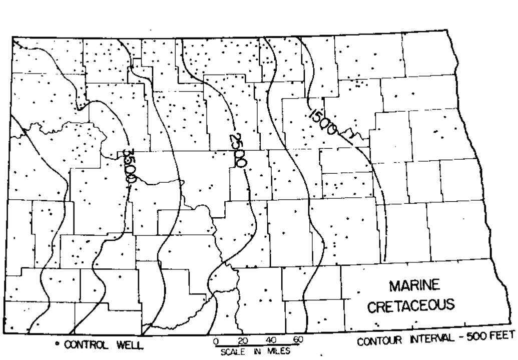

FIG. 35.—Isopachous map of marine Cretaceous.

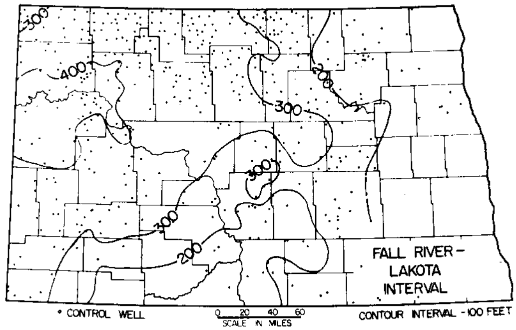

FIG. 36.—Isopachous map of Fall River-Lakota interval.

before Cretaceous seas again extended over this area. Marine Cretaceous (Fig. 35) deposits occur in all but the extreme southeastern part of North Dakota and have a thickness in excess of 4,000 feet in the western part of the State. Pre-glacial erosion accounts for much of the thinning in the eastern part of the State.

The Dakota Group is an interbedded sandstone and shale interval which, in ascending order, generally has been divided into at least five formations: Lakota, Fall River, Skull Creek, Newcastle, and Mowry Formations. In practice, the upper three formations are easily separable, but the Lakota-Fall River interval (Fig. 36) consists of interbedded sandstone and shale which thicken and thin abruptly, making correlation of separate beds for any distance and subdivision of this unit difficult. The term Lakota generally is applied to the lower part of this interval, which consists of as much as 200 feet of lenticular sandstone, siltstone, and shale of non-marine to marine origin. The term Fall River is applied to the upper part of this interval, which consists of

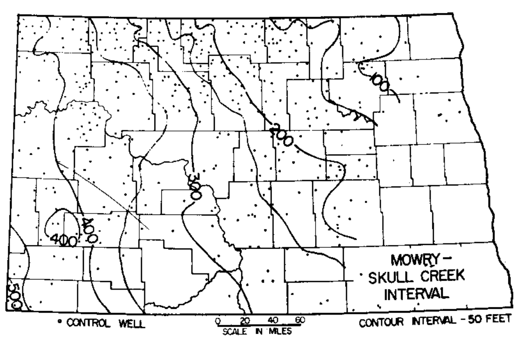

FIG. 37.—Isopachous map of Skull Creek-Mowry interval.

sandstone and gray shale of predominantly marine origin. Sandstone of the Fall River grades upward into siltstone and then into shale of the overlying Skull Creek-Mowry interval (Fig. 37). The isopachous map of the Newcastle Sandstone (Fig. 38) shows rapid changes in thickness which might provide traps for hydrocarbons. However, most of these sandstone tongues or wedges thicken updip toward the basin margins, with the result that, even with these variations, it may be necessary to locate structural traps for oil accumulations. Another possibility might be pinchouts along the western flank of the Nesson anticline.

The Upper Cretaceous is a thick gray marine shale which includes all of the formations from the Belle Fourche through Pierre. This section has been of little interest to oil explorationists, except for the Eagle Sandstone Member of the Pierre Formation, which is present in the southwestern part of the State, and which produces gas on the Cedar Creek anticline. The Fox Hills Sandstone is the regressive phase of the Upper Cretaceous seas and was succeeded by deposition of the predominantly non-marine Hell Creek Formation.

Tejas Sequence

The Tejas Sequence (late Paleocene-present) is represented by predominantly non-marine deposits derived from a western source area. These deposits have been divided into the Fort Union Group, Golden Valley, and White River Formations, and glacial drift. Exceptions to the non-marine conditions of the latest Cretaceous-Tertiary episode were the shallow marine seas in which the Brien Sandstone Member of the Hell Creek Formation and the Cannonball Formation of the Fort Union Group were deposited.

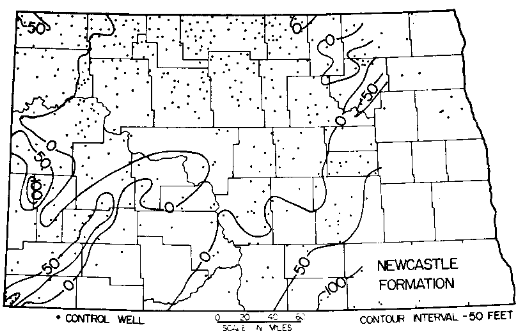

Fig. 38.—Isopachous map of Newcastle Formation.

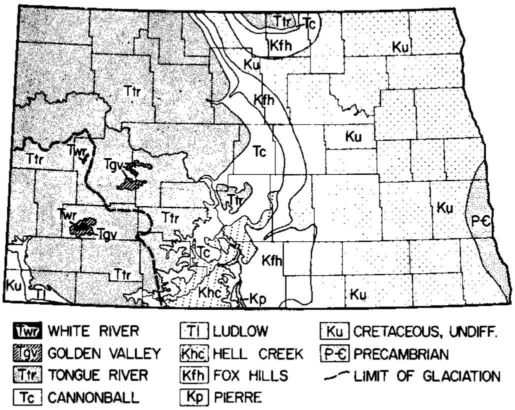

Fig. 39.—Generalized bedrock map of North Dakota.

After deposition of the Tertiary formations there was a period of erosion before the glaciers advanced over all but the southwestern corner of the State. The glacial drift is thin and patchy south and west of the Missouri River, whereas the area north and east of the Missouri River generally is covered by variable thicknesses of glacial drift. Bedrock exposures are few in this latter area, except in some places near the Missouri River. The generalized map (Fig. 39) shows the present distribution of Tertiary and Upper Cretaceous bedrock, if the glacial drift were removed.

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