NORTH DAKOTA GEOLOGICAL SURVEY

WILSON M. LAIRD
State Geologist

BULLETIN 40

STRUCTURAL AND STRATIGRAPHIC RELATIONSHIPS IN THE PALEOZOIC ROCKS OF EASTERN NORTH DAKOTA

by
Frederick V. Ballard

Grand Forks, North Dakota
1963

CONTENTS

LIST OF ILLUSTRATIONS

Figures

Plates (in pocket)

ABSTRACT

The thickness and areal extent of the commonly defined Paleozoic rock units in eastern North Dakota has been determined by a study of mechanical well logs. Isopachous maps of these units reveal several positive areas which persisted and influenced sedimentation and unit thickness throughout most of the Paleozoic Era. Precambrian topographic highs of either erosional or structural origin produced these influences in early Paleozoic time, whereas later effects resulted from perodic structural rejuvenation of the original highs. The activity of these highs appears to be related to the location of the basin depocenter. The most prominent highs were in Cavalier, Foster, and Stutsman Counties. A less persistent, but more important high from the standpoint of exploration, was at times present in Burleigh, Sheridan, and Wells Counties.

Except for thickness variations, the effects of these highs on sedimentation were generally relatively minor. However, in the basal part of the Bottineau interval of Mississippian age a distinct change in facies from carbonate to shale is affected over the high in Burleigh and Sheridan Counties. This shale facies is herein named the Carrington Shale facies after the town of Carrington, North Dakota, which is near the type section in the Pure Oil Company's J. M. Carr No. 1 well (Sec. 15, T. 146 N., R. 66 W., Foster County). This shale presents two types of potential stratigraphic traps. The first type is the updip facies change from carbonate to shale in the basal part of the Bottineau interval. The second is the seal effected where the shale overlies the truncated Birdbear and Duperow Formations of Devonian age.

THE STRUCTURAL AND STRATIGRAPHIC RELATIONSHIPS IN THE PALEOZOIC ROCKS OF EASTERN NORTH DAKOTA

INTRODUCTION

General Introduction

Geologists of the North Dakota Geological Survey have been aware for some time of several stratigraphic and structural anomalies in the Paleozoic rocks of eastern North Dakota. The purpose of this study is to define and determine the history of some of these anomalies which may be potential structural and stratigraphic traps for petroleum in an area which has not yet been productive.

It was the original purpose of this investigation to study a previously undefined stratigraphic unit between rocks of known Devonian and Mississippian age in eastern North Dakota. It was soon apparent that a complete study of the thickness and distribution of the Paleozoic rocks in eastern North Dakota would be necessary to discover possible causes for the occurrence of this unit. Subsequently, several features of interest were found in other Paleozoic rocks.

The area of study is in North Dakota, east of 101 degrees west longitude and includes slightly more than the eastern half of the state. The study was conducted during the spring and summer of 1962. The Paleozoic rock units commonly defined in this area were studied from available mechanical logs of exploratory wells and isopachous maps and electric log cross sections provide the basis for this report.

For purposes of discussion it was convenient to name those areas which were found to be persistently positive during the Paleozoic Era. The location of these positive elements or highs is shown on the index map (Figure 1). The highs were named after the counties in which they occur and were defined by isopachous maps and cross sections. The probable basement causes for these highs will be discussed later. The Foster and Stutsman highs were the most structurally active, although areally small. The Cavalier high was persistently active, but vascillated laterally. The Burleigh high, though, the least positive of the highs, had the greatest effect on sedimentation.

Although the emphasis of this report is on the stratigraphic and structural anomalies in the Paleozoic rocks of eastern North Dakota, a discussion of the lithology of each unit is included. It is hoped that the availability of this information and the potential hydro-carbon traps defined in this report will encourage future exploration for petroleum in eastern North Dakota.

Methods of Study

Mechanical logs allowed the writer to study a large area and stratigraphic interval with relative rapidity. When possible, to provide uniform correlation, only self-potential and resistivity curves were used. However, the electric logs of a few wells were unsatisfactory for correlation purposes and in such cases either sample logs, in the form of North Dakota Geological Survey Circulars, or gamma ray - neutron logs were used. With the exception of the boundaries of some Devonian and Pennsylvanian units, formation tops can be determined with reason-

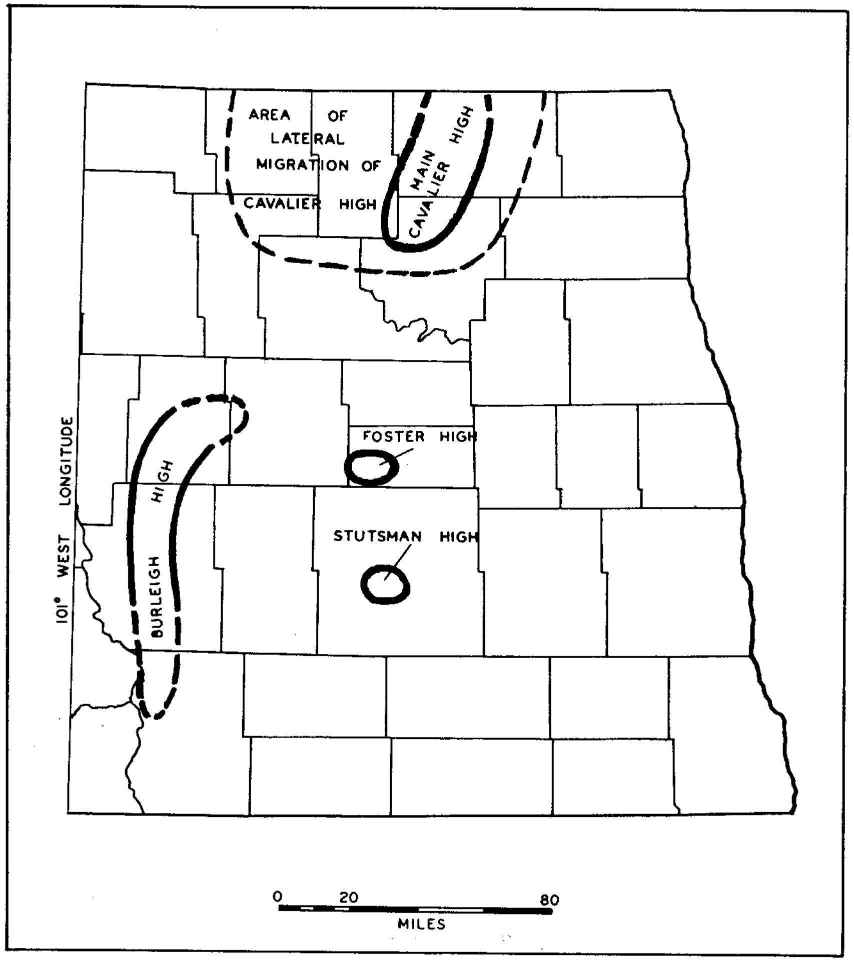


Figure 1. -- Index map of eastern North Dakota showing area of study and location of Paleozoic positive structural elements.

able accuracy from the logs. Exploratory wells drilled in eastern North Dakota are shown on the location map (Plate 1).

Included in this report are isopachous maps of each of the commonly defined Paleozoic rock units and electric log cross sections. The isopachous maps are actually isochore maps; that is, the interval thicknesses have not been corrected for dip or well deviation. The dip of most rock units does not exceed one-half degree in eastern North Dakota and the amount of error introduced by not correcting thicknesses for dip is less than that introduced by well deviation and picking formation tops from the logs. Thus, for all practical purposes the maps are isopachous maps.

Acknowledgements

The writer wishes to express his gratitude to Dr. Walter L. Moore, Associate Professor of Geology at the University of North Dakota, for suggesting the problem and for his constant interest and advice during the course of the study.

The invaluable assistance of Dr. Wilson M. Laird, State Geologist of North Dakota, for summer employment and allowing the writer use of the facilities of the North Dakota Geological Survey is sincerely appreciated. Thanks are also extended to Sidney B. Anderson, Clarence G. Carlson, William P. Eastwood, and other geologists of the North Dakota Geological Survey.

The suggestions and criticisms of Dr. Mark Rich, Assistant Professor of Geology at the University of North Dakota, are also acknowledged.

Previous Work

Few publications on the stratigraphic and structural anomalies of the area are available. McCabe (1959, p. 46 and 51) discussed the occurence and origin of the Routledge Shale Member of the Lower Lodgepole Formation in southern Manitoba. Carlson (1960, p. 32) showed an area in Foster County to be devoid of Deadwood sediments and suggests the area may represent a high on the Precambrian surface. Sidney B. Anderson (1962, oral communication) informed the writer of several unusual relationships which were discovered during various research studies conducted by the North Dakota Geological Survey. Previous stratigraphic reports mentioned local variations from typical relationships only in passing and made little attempt to trace their history through a particular geologic period.

STRATIGRAPHY

Cambrian - Ordovician System

Deadwood Formation

The Deadwood Formation was named by Darton (1901, p. 505) for exposures at Deadwood, South Dakota. According to Carlson (1960, p. 23), the formation at the type section is composed of limestone, sandstone, and shale, overlain by the Winnipeg Formation and lying unconformably on Precambrian rocks.

Carlson (1960, p. 33) gave the following description of the Deadwood Formation in eastern and central North Dakota:

A quartzose sandstone of variable thickness is present at the base of the Deadwood Formation in every well in east-central North Dakota. The sandstone is usually composed of well rounded, often frosted, medium- to coarse-grained, poorly cemented, quartzose sandstone. This basal sandstone unit is overlain by a shale and carbonate unit consisting of light gray, fine- to medium-crystalline, sandy, glauconitic limestone, dolomite and greenish gray shale with minor amounts of sandstone. The sand content increases toward the southeast, grading into a glauconitic, dolomitic sandstone near the erosional edge in southeastern North Dakota. The shale and carbonate unit is overlain by a sandstone unit composed of fine- to medium-grained, glauconitic, slightly calcareous sandstone. In central North Dakota, where the Deadwood Formation is thicker, the upper sandstone unit is overlain by limestone or dolomite, light gray, fine- to medium-crystalline, with scattered traces of glauconite and greenish gray shale.

The Deadwood Formation at the type section was generally considered to be of late Cambrian age. Lochman and Duncan (1950, p. 551) reported an early Ordovician fauna from the upper beds at the type section and Ross (1957, p. 450) reported a fauna of similar age in the upper beds in the subsurface in northeastern Montana. The lower Deadwood strata may be late Cambrian, but the upper beds are evidently of early Ordovician age. The Deadwood Formation unconformably overlies the Precambrian basement. The Winnipeg Formation overlies the Deadwood in eastern North Dakota with angular discordance. Near commercial shows of oil have been reported from the Deadwood Formation in the Amerada Petroleum Corporation's Scoria Unit No. 8 well (NE ¼ SW ¼ Sec. 10, T. 139 N., R. 101 W., Billings County, North Dakota). The maximum thickness of the Deadwood in eastern North Dakota is about 425 feet.

The thickness and areal distribution of the Deadwood Formation is shown on the isopachous map (Plate 2). The formation is absent in extreme eastern North Dakota except for occasional outliers such as the one in Grand Forks County. The map shows two small areas, one in Stutsman County and one in Foster County which are devoid of Deadwood sediments. These two areas, the Stutsman and Foster highs, were evidently topographic highs on the pre-Deadwood basement surface. Another thin area may occur in Sheridan and Burleigh Counties, over the Burleigh high, as shown by the dashed contours. Deadwood control in this area is poor and the thinning shown is inferred from the thinning in the overlying Winnipeg Formation (Plate 3). The erosional limit of the Deadwood in the northeast part of the map exhibits some irregularities which may reflect positive features immediately to the north and east.

Ordovician System

Winnipeg Formation

The term Winnipeg Sandstone was first applied by Dowling (1895, p. 66) to a sandstone section in the Lake Winnipeg area, Manitoba. This sandstone lies with angular discordance on Precambrian rocks and is conformably overlain by a limestone unit, the Red River Formation of later writers. In eastern North Dakota the Winnipeg Formation is composed mainly of greenish gray shale which generally has a thin basal sandstone. Carlson (1960, p. 54) recognized three conformable members of the Winnipeg Formation: the Black Island, Icebox, and Roughlock Members. The basal or Black Island Member is composed of well rounded, often frosted, fine- to medium-grained, friable, quartzose sandstone. This member thickens in the north and northwest North Dakota. The Icebox Member consists of greenish gray to dark greenish gray, splintery to fissile, waxy, non-calcareous shale (Carlson, 1960, p. 59). The Roughlock or upper Member consists of light gray, fine-grained calcareous sandstone and siltstone and grades into calcareous shale to the north. On the cross sections and isopachous map the members of the Winnipeg Formation are not differentiated.

The Winnipeg Formation unconformably overlies either the Deadwood Formation or Precambrian rocks in eastern North Dakota. The Winnipeg Formation goes through a detailed progressive lithologic transition into the overlying Red River Formation (Porter and Fuller, 1959, p. 141). The average thickness of the Winnipeg Formation is about 200 feet. Carlson (1960, p. 73) on the basis of the conodont fauna believed the Winnipeg to be Middle Ordovician in age.

The isopachous map of the Winnipeg Formation (Plate 3) shows thinning, similar to that of the Deadwood Formation, over the Foster and Stutsman highs. Another thin area occurs in Burleigh, Sheridan, and Wells Counties over the Burleigh high. An unusual thickening occurs in Stutsman and Logan Counties west and north of the Stutsman high. The east-west trending thin nose in Benson, Ramsey and Walsh Counties oscillates laterally in various overlying formations. The marked thinning in the Winnipeg near Grand Forks occurs over a Deadwood outlier (Plate 2).

Red River Formation

Conformably overlying the Winnipeg Formation is several hundred feet of limestone, dolomite, and dolomitic limestone called the Red River Formation. The Red River Formation was named by Foerste (1929) and applied to the carbonates overlying the Winnipeg Formation and underlying the Stony Mountain Formation in Manitoba. Several earlier writers (Dowling, 1895, and Foerste, 1929) have recognized three members in the Red River Formation, but in this report these members were not separately mapped.

For purposes of brief lithologic decription it is convenient to discuss two distinct lithologic parts of the formation; the lower fragmental, dolomitic limestone unit, and the upper cyclical, evaporite-bearing unit. The lower unit is generally a mottled, fossiliferous-fragmental limestone which is partially dolomitized. In the central part of the Williston Basin the lower unit is often porous and medium-grained, but becomes a dense microgranular and lithographic dolomite toward the margins of the basin. The upper unit is comprised of a cyclical repetition of fragmental limestone, argillaceous dolomite, and anhydrite. This unit is not extensive in the area of this report.

The Red River Formation conformably overlies the Winnipeg Formation and is conformably overlain by the Stony Mountain Formation. The Red River Formation is late Ordovician in age (Porter and Fuller, 1959). Oil is produced from the Red River Formation in the Cedar Creek, Little Missouri, and Beaver Lodge fields. Recent discoveries in the Scoria field indicate future Red River production in that area.

The isopachous map of the Red River Formation (Plate 4) shows thin areas in Foster and Stutsman Counties similar to those on previous maps. The thin nose in Cavalier and Towner Counties with an adjacent thick trough to the east suggests a northwestward migration of the Cavalier high from its position in Winnipeg time. The Red River Formation also thins over the Burleigh high in Sheridan County.

Stony Mountain Formation

The Stony Mountain Formation, an Upper Ordovician sequence of red shales and overlying carbonates, was named by Dowling (1900, p. 46F) for exposures at Stony Mountain, near Winnipeg, Manitoba. The Saskatchewan Geological Society (1958) recognized two members of this formation; the lower or Stoughton Member and the upper or Gunton Member. Carlson and Eastwood (1962, p. 6) applied this nomenclature to the Stony Mountain Formation in North Dakota. These two members have not been separated in this report, but are easily recognized on electric logs.

The Stoughton Member consists of a series of interbedded argillaceous limestones and calcareous shales. The limestones vary from dark to light gray and the shales vary from gray to greenish gray and grayish red purple. The Stoughton limestones are generally fossiliferous and fragmental in the central basin, but grade into pale, nodular dolomites near the basin margin (Porter and Fuller, 1959, p. 155).

The Gunton Member typically consists of yellowish gray, fine-grained dolomite in southeastern North Dakota. In the central basin area the Gunton is brownish gray to yellowish brown, limy dolomite and fossiliferous, dolomitic limestone with a thin bed of anhydrite near the top (Carlson and Eastwood, 1962, p. 6). The anhydrite pinches out toward the eastern basin margin and is not present in the area of this report.

The Stony Mountain Formation conformably overlies the Red River Formation and its conformably overlain by the Stonewall Formation. The Stony Mountain is late Ordovician in age. The formation averages about 135 feet in thickness in eastern North Dakota. There is no commercial production from the Stony Mountain at present, but gas and oil shows have been found in northwestern North Dakota.

The isopachous map of the Stony Mountain Formation (Plate 5) shows thinning over the Foster and Stutsman highs. The slightly thin noses in Burleigh and Sheridan Counties are weak reflections of the Burleigh high. The Cavalier high is vaguely evidenced by the thin nose in Towner County. The relatively low and uniform thickness of this formation partially obscures evidence of the previously persistent highs.

Ordovician - Silurian System

Stonewall Formation

The term Stonewall Formation was ascribed to all the Silurian strata of southern Manitoba by Kindle (1914, p. 249). The type section was designated as an exposure of Lower Silurian beds in a quarry near Stonewall, Manitoba. Baillie (1951, p. 90) proposed the term Interlake Group to include all the Silurian strata of Manitoba and restricted the term Stonewall to the lowermost Silurian beds. Subsequently, the term Stonewall Formation has had a varied application. The evolution of the Ordovician nomenclature of the Williston Basin is shown in Figure 2. The term Stonewall Formation is used in this report as defined by Porter and Fuller (1959, p. 157, Fig. 13). They designated the interval from 9540 to 9710 feet in the Imperial Hummingbird No. 6 well (Lsd. 6, sec. 13, T. 2, R. 19, W. 2, Saskatchewan) as a characteristic section of the Stonewall Formation. The Stonewall can be readily separated from the overlying Interlake Formation in the subsurface.

The Stonewall Formation in eastern North Dakota is predominantly yellowish gray to orange pink dolomite with pink and reddish alterations near the erosional limit (Carlson and Eastwood, 1962, p. 9). In the central part of the basin the formation consists of limestones, dolomitic limestones, and thin anhydrites. Thinly interbedded red and gray, calcareous shales and argillaceous dolomites are common near the top of the Stonewall Formation.

The Stonewall Formation conformably overlies the Stony Mountain Formation and is conformably overlain by the Interlake Formation. The Ordovician - Silurian systemic boundary was tentatively placed within the Stonewall Formation by Carlson and Eastwood (1962, p. 9). They considered the lower part of the Stonewall to be late Ordovician in age and the upper part to be of early Silurian age. The maximum thickness of the Stonewall Formation in eastern North Dakota is about 70 feet.

The isopachous map of the Stonewall Formation (Plate 6) is not particularly informative because the formation is relatively thin. However, there are vague reflections of the Foster and Stutsman highs by indentations in the erosional limit and thinning in the eroded portion of the formation. The thin nose and adjacent thick trough in Cavalier County reflects the Cavalier high. The Burleigh high is not apparent on the map.

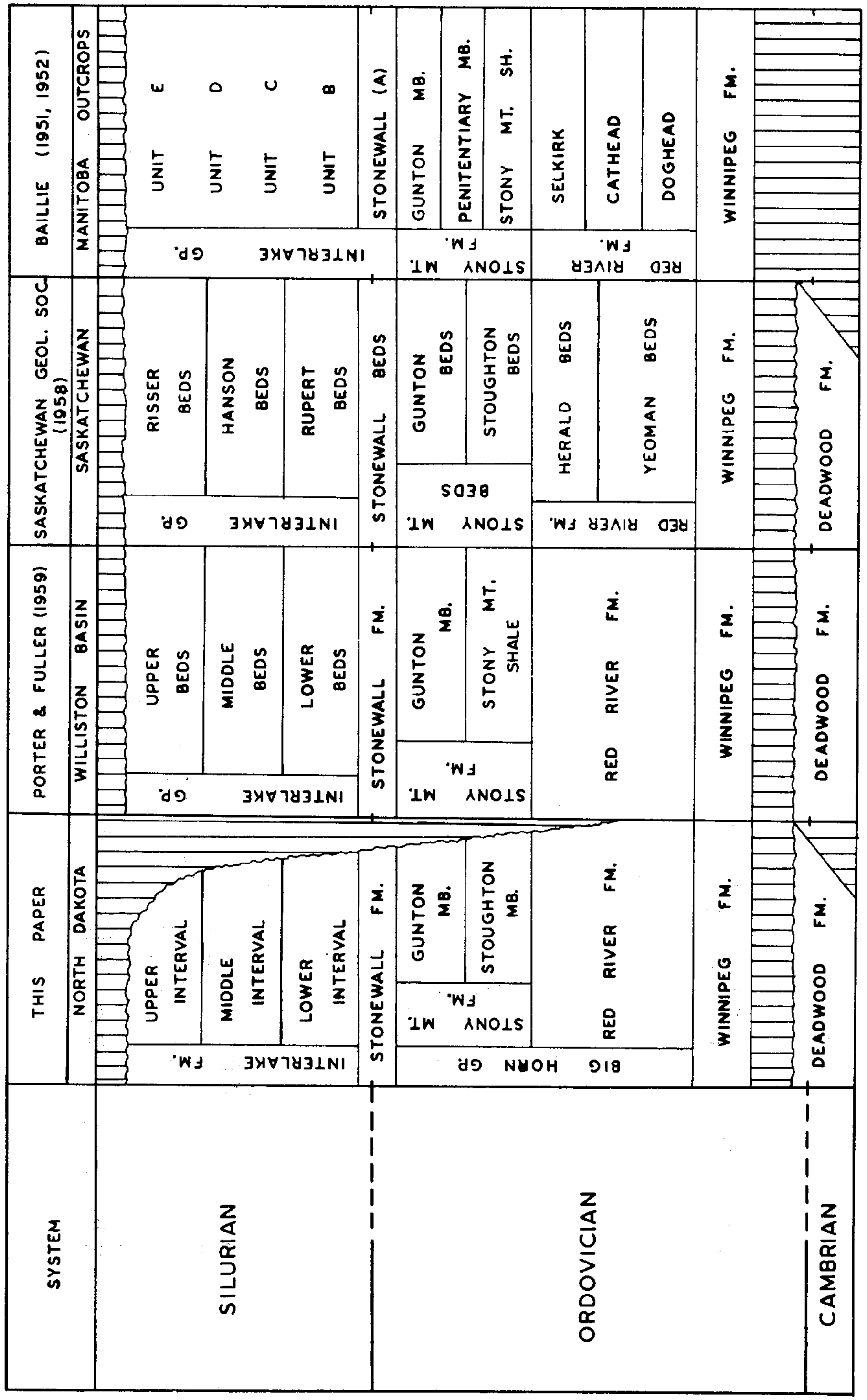


Figure 2. -- Previous and present stratigraphic nomenclature of the Lower Paleozoic rocks of the Williston Basin.

Silurian System

Interlake Formation

Baillie (1951, p. 6) proposed the term Interlake Group to include the strata overlying the Stony Mountain Formation and underlying the Ashern Formation. The Stonewall Formation has been both included and excluded from the group by subsequent writers. The term Interlake Formation, as used by the North Dakota Geological Survey, is synonymous with the Interlake Group of Porter and Fuller (1959, p. 161). The Formation includes the strata from the top of the Stonewall Formation to the unconformity at the base of the Devonian System. Carlson and Eastwood (1962, p. 11) accepted the marker horizons of Porter and Fuller as the basis for subdividing the Interlake Formation in North Dakota. They preferred to call the three subdivisions intervals rather than the paratime rock term "beds" as used by Porter and Fuller. The three intervals are not differentiated on the cross sections and maps in this report.

The lower interval of the Interlake Formation is composed of brownish, finely-crystalline dolomite with thin beds of anhydrite and anhydritic dolomite in the central basin area. In eastern North Dakota the anhydritic basin section gives way to pale orange to light yellowish gray and white, finely-crystalline dolomite (Carlson and Eastwood, 1962, p. 12).

The middle interval is predominantly pale-colored microgranular and lithographic dolomites and interbedded dolomitic, fragmental limestones with some chert. This interval also becomes pale orange, finely-crystalline dolomite in eastern North Dakota. Because of the absence of the anhydrite units in the lower interval near the basin margin, the middle and lower intervals cannot be separated in the eastern part of the state.

The upper interval has been removed by erosion in eastern North Dakota. In the central basin area this interval consists of argillaceous, purplish dolomites interbedded with thin shales and sandstone lenses. The upper part of the upper interval consists of a succession of white and gray, microgranular, dolomitized, vuggy, clastic limestones and dense porcellaneous anhydritic dolomites (Porter and Fuller, 1959, p. 165).

The Interlake Formation conformably overlies the Stonewall Formation. Devonian, Mississippian, and Mesozoic rocks overlie the Interlake with angular discordance. The Interlake Formation is of early and middle Silurian age (Carlson and Eastwood, 1962, p. 15). In the central basin area the Interlake Formation may not have been subjected to much erosion, but in eastern North Dakota the post-Interlake pre-Devonian unconformity truncates the Interlake, Stonewall, Stony Mountain, and upper beds of the Red River Formation. The maximum thickness of the Interlake Formation is about 575 feet, but in eastern North Dakota the thickness ranges from zero to 400 feet. The upper interval of the Interlake is capable of oil production in the Antelope and Beaver Lodge fields.

The Interlake isopachous map (Plate 7) shows the persistent thinning over the Burleigh high in Sheridan and Burleigh Counties present on isopachous maps of other units. Indentations of the erosional limit of the formation give a weak reflection of the Foster and Stutsman highs. The Cavalier high is evidenced by a northeast trending thin nose in Ramsey and Cavalier Counties.

Devonian System

Winnipegosis Formation

The nomenclature and correlation of the formations in the Devonian System is shown in Figure 3. The Winnipegosan Formation was named by Tyrrell (1892) from exposures along the shores of Lake Winnipegosis in Manitoba. The formation name was changed to Winnipegosis by Baillie (1953, p. 20) in accord with correct practices of stratigraphic nomenclature. The Winnipegosis Formation was redefined by Sandberg and Hammond (1958) to include the Ashern Formation of Baillie (1951a) because the Ashern Formation cannot everywhere be differentiated and numerous miscorrelations have resulted. The term Winnipegosis Formation is used in this report as defined by the North Dakota Geological Society (1961, p. 10 & 12) as the interval from 11,343 to 11,690 feet depth in the Mobil Producing Company's Birdbear No. 1 well (Sec. 22, T. 149 N., R. 91 W., Dunn County, North Dakota). The top of the Winnipegosis Formation of Sandberg (1961, Plate 7, Column 8) is stratigraphically lower than that of the North Dakota Geological Society. Sandberg and Hammond felt that all the evaporites in this section should be included in the overlying Prairie Formation. The Society decided that the interbedded evaporites and carbonates should be included in the Winnipegosis and more recent work (Anderson, 1962, oral communication) indicates this to be the better interpretation. Sandberg (1961, p. 113) stated that the Winnipegosis Formation is more extensive than the overlying Prairie Formation. The isopachous maps of the two formations (Plates 8 & 9) in this paper show the reverse situation to be the case in eastern North Dakota. It should be noted that separation of the Prairie Formation from the underlying Winnipegosis Formation and the overlying Dawson Bay formation becomes difficult on mechanical logs near the eastern limits of these formations and may account for the discrepancy.

The Winnipegosis Formation in the central Basin area consists of a lower grayish dolomitic sandstone, siltstone, or shale which grades upward into reddish or brown argillaceous dolomite containing numerous anhydrite inclusions. The upper part of the formation is composed of gray calcareous shale and siltstone overlain by fossiliferous, argillaceous, clastic limestone. The uppermost beds consist of interbedded anhydrite and dolomite. As a result of a change of facies, the Winnipegosis Formation in eastern North Dakota consists of red dolomitic shale or siltstone, argillaceous dolomite, and light brownish gray, finely-crystalline dolomite (Sandberg and Hammond, 1958, p. 2305).

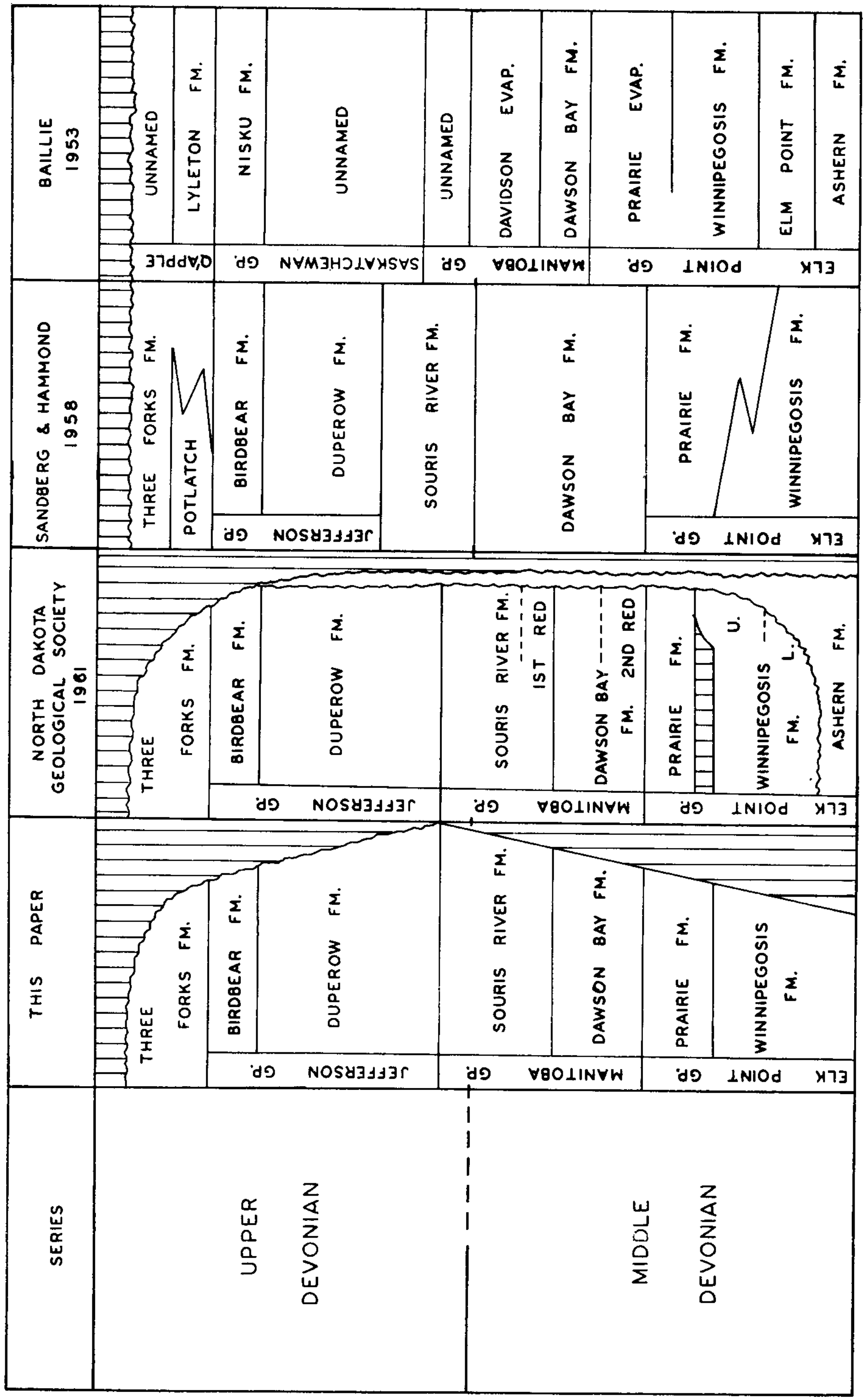


Figure 3. -- Previous and present stratigraphic nomenclature of the Devonian rocks of the Williston Basin.

The Winnipegosis Formation unconformably overlies the Interlake Formation and is conformably overlain by the Prairie Formation. In eastern North Dakota the maximum thickness is about 200 feet. Sandberg and Hammond (1958, p. 2306) stated that the age of the Winnipegosis is middle Devonian. The Winnipegosis Formation produces oil in the Outlook field in Sheridan County, Montana.

The Winnipegosis isopachous map (Plate 8) shows a thin nose trending north-south in Sheridan County which reflects the Burleigh high. The Foster and Stutsman highs are not evidenced as they lie east of the limit of the formation. The Cavalier high is evidenced by the east-west trending thin nose in Rolette and Bottineau Counties.

Prairie Formation

The Elk Point Formation of McGehee (1949 and 1952) was elevated to group status in the Williston Basin by Baillie (1953, p. 18). Baillie (1953, p. 24) applied the term Prairie Evaporite Formation to the salt and anhydrite beds in the upper part of the Elk Point Group. The name was subsequently shortened to the Prairie Formation by Sandberg and Hammond (1958, p. 2306) in accordance with the Code of Stratigraphic Nomenclature. The lower part of the Elk Point Group is included in the Winnipegosis Formation of this paper. The Prairie Formation is used in this report as defined by the North Dakota Geological Society (1961, p. 7). As stated in the discussion of the Winnipegosis Formation, the Prairie Formation of the Society differs from that of Sandberg and Hammond in the position of the Winnipegosis - Prairie boundary. The type section of Baillie (1953) is the Imperial Davidson No. 1, Lsd. 16, Sec. 8, T. 27 N., R. 1 W 3d Meridan, Saskatchewan. The interval from 11,173 to 11,343 feet depth in the Mobil Producing Company No. 1 Birdbear well was designated as a reference section by the North Dakota Geological Society (1961).

In the central basin area the Prairie Formation can be divided into two members. The lower member is predominantly anhydrite and dolomite interbedded with shale and thin halite beds. The upper member consists of halite and some sylvite and thin shales. Sandberg (1961, p. 114d) stated that the lower part of the salt member grades marginward into the upper part of the lower member. The salt or upper member constitutes the entire formation in some areas, but in the area of this report the salt member is present in only a small area in western Bottineau County.

As previously stated, separation of the Prairie Formation and overlying Dawson Bay Formation as shown by Sandberg (1961, Plate 7, Column 9) is somewhat tenuous in eastern North Dakota. This writer and Mr. Sidney B. Anderson of the North Dakota Geological Survey have considered placing the lower shale member of the Dawson Bay Formation in the Prairie Formation because more reliable correlation would be possible. This adjustment of the correlative top would further confuse the literature and we have decided to follow the formation boundaries as suggested by the North Dakota Geological Society.

The Prairie Formation conformably overlies the Winnipegosis Formation and is conformably overlain by the Dawson Bay Formation. The Prairie is of middle Devonian age. The formation attains a maximum thickness of 70 feet in eastern North Dakota. Solution of salt from the Prairie Formation and subsequent collapse of overlying strata is evidenced in Bottineau County in the vicinity of the California Company Blanche Thompson No. 1 well in Bottineau County, North Dakota, in Manitoba (McCabe, 1959), and in Saskatchewan.

The isopachous map of the Prairie Formation (Plate 9) reflects the persistent thinning over the Foster, Cavalier, and Burleigh highs. As this formation is relatively thin the margin of error which exists in determining the formation boundaries becomes of greater importance and this map may be somewhat misleading because of the small contour interval. Unless the anomalous areas have 20 feet or more relief, they may reflect the above uncertainties more than changes in thickness.

Dawson Bay Formation

The Dawson Bay Formation is the lower unit of the Manitoba Group of Baillie and was named from outcrops along the shores of Dawson Bay at the north end of Lake Winnipegosis in Manitoba by Baillie (1953, p. 26). The interval from 11,052 to 11,173 feet depth in the Mobil Producing Company Birdbear No. 1 well was designated as a reference section for North Dakota by the North Dakota Geological Society (1961). The Dawson Bay Formation is slightly more extensive in eastern North Dakota than the underlying Elk Point Group. Sandberg and Hammond (1958, p. 2307) recognized two members of the Dawson Bay Formation: a lower argillaceous member and an upper carbonate member.

The argillaceous member is about 20 feet thick in central North Dakota and thickens slightly in the northeastern part of the state. The member is composed of dolomitic siltstone or silty, argillaceous dolomite, with interbedded argillaceous limestone and dolomitic shale. The color varies from light brown to grayish red (Sandberg and Hammond, 1958, p. 2307).

The carbonate member consists of finely crystalline to microcrystalline porous dolomite or limestone. The uppermost beds are either anhydritic dolomite and limestone or bedded anhydrite. (Sandberg and Hammond, 1958, p. 2308). The color varies from brownish gray to medium dark gray. The member is usually lighter colored near the basin margins.

Baillie (1953, p. 42) stated that the Dawson Bay Formation is of middle Devonian age and conformably overlies the Prairie Formation to which it is faunally related. The Souris River Formation conformably overlies the Dawson Bay in most places, but the contact may be unconformable near the eastern limits of the two formations. The Dawson Bay attains a maximum thickness of 170 feet in eastern North Dakota. Petroleum is produced from the Dawson Bay Formation in some areas of the Williston Basin and the excellent porosity of the formation suggests it may have future potential in other areas.

The Dawson Bay isopachous map (Plate 10) reveals thinning over the Cavalier high and several isolated thick areas in the northern part of the map. The wider spacing of the contours in Burleigh and Sheridan Counties gives a weak reflection of the Burleigh high. The Foster high is completely devoid of Dawson Bay sediments. It should be noted that a definite southwest-northeast primary strike is evidenced by the isopachytes. This represents the first definite indication in this area of the movement of the Devonian depocenter to the north and west of the earlier Paleozoic basin center which was located in west central North Dakota.

Souris River Formation

In February, 1953, the Williston Basin Nomenclature Committee of the American Association of Petroleum Geologists proposed the term Souris River Formation. The interval between 5904 and 6162 feet in the California Company Blanche Thompson No. 1 well (Sec. 31, T. 160 N., R. 81 W., Bottineau County, North Dakota) was designated as the type section. The report of the Committee was never published and subsequently Sandberg and Hammond (1958, p. 2310) formally proposed the term Souris River Formation. However, they designated the interval from 10,743 to 11,052 feet depth in the Mobil Producing Company Birdbear No. 1 well (Sec. 22, T. 149 N., R. 91 W., Dunn County, North Dakota) as the type section. Both wells have been cored through the entire formation, but they believed the interval in the Birdbear well to be more representative. The North Dakota Geological Society (1961) designated the Birdbear well as a reference section in North Dakota for the entire Devonian System.

The Souris River Formation consists of gray, greenish gray, and brownish gray, thinly interbedded shaly dolomite, argillaceous limestone, shale, siltstone, and anhydrite (Sandberg, 1961, p. 115). The dolomite, limestone, and shale, are often silty or sandy. Sandberg also discussed evidences of vague cyclic sedimentation.

The Souris River Formation generally rests conformably on the Dawson Bay Formation, but near the eastern limits of the Dawson Bay the contact is unconformable. The Souris River is more extensive than the Dawson Bay in eastern North Dakota except for a small area in Ramsey, Cavalier, and Walsh Counties. Where the Souris River Formation overlaps the Dawson Bay, it rests unconformably on Silurian and Upper Ordovician rocks. The Duperow Formation conformably overlies the Souris River except near the eastern limit of the Souris River where the contact is unconformable. The maximum thickness of the Souris River Formation in eastern North Dakota is about 275 feet. The lower part of the formation is middle Devonian in age, but the upper part is of late Devonian age (North Dakota Geological Society, 1961, p. 22). Oil is currently produced from the Souris River Formation in the McGregor, Sand Creek, Croff, and Charlson fields.

The isopachous map of the Souris River Formation (Plate 11) also exhibits the northeast-southwest striking contours which reflect the north-

western shift of the Devonian depocenter into Saskatchewan. Thinning is apparent over the Foster high, but the Burleigh high is not evidenced. The Cavalier high is shown by the thin nose in Cavalier County.

Duperow Formation

The term Duperow Formation was originally proposed by Powley (1951, p. 35) in an unpublished thesis submitted to the University of Saskatchewan. The interval from 3,310 to 4,150 feet in the Tidewater Oil Company, Duperow Crown, well No. 1 in southwestern Saskatchewan constitutes the type section. Powley considered the Duperow Formation to be equivalent to all but the lower section of the Beaverhill Lake Formation of Late Devonian age in Alberta. Subsequently, the Williston Basin Nomenclature Committee of the American Association of Petroleum Geologists in 1953 abandoned Powley's definition of the Duperow Formation and applied the term to the overlying unit which is equivalent to the Woodbend Formation in Alberta. This usage, which was already in use was adopted officially by most basin area geological surveys and societies. However, the Committee failed to designate a type section for the Duperow Formation. In 1958 Sandberg and Hammond (1958, p. 2316) established the interval from 10,400 to 10,743 feet depth in the Mobil Producing Company, Birdbear No. 1 well as the type section.

The Duperow Formation is composed of medium-gray, brownish gray, and yellowish gray limestone, argillaceous limestone, dolomitic limestone, saccharoidal dolomite, and anhydrite, interbedded with thin beds of greenish gray and yellowish gray dolomitic shale, siltstone, and sandy dolomite. A 10 to 15 foot bed of greenish gray dolomitic shale or shaly dolomite comprises the uppermost part of the Duperow and is a conspicuous marker on mechanical logs (Plate 31). Cyclical sedimentation is not uncommon (Sandberg, 1961, p. 116).

The Duperow Formation conformably overlies the Souris River Formation except to the east where it rests unconformably on rocks of Silurian and Ordovician age. In normal sequence the Duperow is conformably overlain by the Birdbear Formation. East of the limit of the Birdbear Formation the Duperow is unconformably overlain by the Bottineau interval of Mississippian age or rocks of Mesozoic age. In eastern North Dakota the Duperow ranges from zero to 400 feet in thickness and is the most extensive Devonian formation. The Duperow Formation is late Devonian in age (North Dakota Geological Society, 1961, p. 25). Oil is presently produced from the Duperow in the McGregor, Northwest McGregor, Beaver Lodge, and Charlson fields in North Dakota.

The isopachous map of the Duperow Formation (Plate 12) is characterized by the northeast-southwest striking contours. Remnants of thinning over the Cavalier high can be seen in the northeast trending finger-shaped remnant of the formation in Cavalier County. The erosional indentation in the formational limit adjacent to this finger evidently reflects a later position of the Cavalier high. The change in contour spacing in Burleigh and Emmons Counties may reflect the Burleigh high. The Stutsman and Foster highs are slightly evidenced by thinning in the eroded portion of the formation.

Birdbear Formation

The term Birdbear Formation was proposed by Sandberg and Hammond (1958, p. 2316) and the type section was designated as the interval from depths 10,310 to 10,400 feet in the Mobil Producing Company's Birdbear No. 1 well (Sec. 22, T. 149 N., R. 91 W., Dunn County, North Dakota). The interval of the Birdbear Formation was previously called the "Nisku" Formation, a term used for a similar stratigraphic unit in Alberta. Work by Sandberg and Hammond and others demonstrates that this formation, although lithologically and stratigraphically similar, is separated from the type Nisku by the arch separating the Williston and Alberta Basins.

The Birdbear Formation consists of thick-bedded, light gray to medium brownish gray, finely-crystalline, porous limestone and dolomite (Sandberg and Hammond, 1958, p. 2320). Local zones of argillaceous, silty, anhydritic dolomite and limestone and some interbedded anhydrite are not uncommon. A massive bed of anhydrite comprises the upper 10 to 20 feet of the formation in some areas.

The Birdbear Formation conformably overlies the Duperow Formation and in the central basin area is generally overlain by the Three Forks Formation. In much of the area of this report the Birdbear is unconformably overlain by the Bottineau interval of Mississippian age or by Mesozoic rocks. When the Birdbear Formation is overlain by carbonates of the Bottineau interval the contact cannot be accurately determined from mechanical logs and sample logs must then be used. The Birdbear is dated as late Devonian by stratigraphic position. The maximum thickness of the formation in the map area is about 100 feet. The Birdbear produces oil in the Charlson field and porosity and near commercial shows suggest possible future discoveries.

The Birdbear isopachous map (Plate 13) exhibits an unusual erosional limit in Cavalier County which evidently reflects the position of the Cavalier high. Two conspicuous features are apparent on this map: 1.) a thin linear area occurs over the Burleigh high and 2.) the contours strike more nearly north-south indicating the depositional basin had moved southward into North Dakota.

Three Forks Formation

Peale (1893) proposed the term Three Forks Shales to describe the argillaceous section between the Jefferson Limestone and the Madison Limestone near what is now the town of Three Forks, Montana. Sloss and Laird (1947) proposed that exposures on the north side of the Gallatin River at Logan, Montana, be designated as the type section. However, the application of the term Three Forks Formation to surface exposures is still in a state of controversy. Sandberg and Hammond (1958, p. 2323) devoted several paragraphs to an attempt to resolve this controversy.

For purposes of subsurface correlation in the Williston Basin they designated the interval from depths 10,076 to 10,310 feet in the Mobil Producing Company, Birdbear No. 1 well as the standard subsurface section of the Three Forks Formation in the Williston Basin.

The term Lyleton Formation was proposed by Allan and Kerr (1950) to include the red dolomitic shales and siltstones in north central North Dakota near the basin's eastern margin which are laterally separated from, but in the same stratigraphic position as the Three Forks Formation. The Lyleton Formation was never formally defined or proposed and had a varied application in subsequent literature. Sandberg and Hammond proposed that the term Lyleton be dropped and that the section which it was proposed to designate be assigned as a facies of the Three Forks Formation. The writer will later propose that this isolated red shale and siltstone in eastern North Dakota, previously called the Lyleton or Three Forks Formation, be designated a facies of the lower part of the Bottineau interval of Mississippian age.

The Three Forks Formation is composed of interbedded and interlaminated greenish gray, grayish orange, and grayish red dolomitic siltstone and shale. Bedded anhydrite and round anhydrite inclusions are common in the lower half of the formation (Sandberg and Hammond, 1958, p. 2325). A thin bed of fine-grained sandstone and coarse-grained siltstone, informally called the Sanish Sand, occurs locally at the top of the Three Forks near the south end of the Nesson anticline. Oil is produced from the Sanish sand in several fields in North Dakota.

The Three Forks Formation conformably overlies the Birdbear Formation, but the contact is unconformable over areas of local uplift. McCabe (1954, p. 2003) states that a marked angular unconformity separates the Lyleton (Three Forks of this report) from the overlying Bakken or Lodgepole Formations. In eastern North Dakota the Three Forks is unconformably overlain by the Bakken except in a few small areas where the Three Forks extends farther eastward and is then overlain by the Bottineau interval. The Three Forks Formation is of late Devonian age (Sandberg and Hammond, 1958, p. 2326). The maximum thickness of the Three Forks in eastern North Dakota is about 100 feet.

The isopachous map of the Three Forks Formation (Plate 14) shows few unusual thickness variations. The contour pattern in Rolette and Bottineau Counties may result from errors in determining the formation top on the logs for in this area the Bakken and Three Forks Formation are difficult to differentiate without the aid of sample logs. A slightly thick trend is indicated in McHenry County. The strike of the contours is indicative of a depositional basin centered in North Dakota.

Mississippian System

Bakken Formation

The Bakken Formation was defined as the interval from 9,615 to 9,720 feet depth in the Amerada Petroleum Corporation, H. O. Bakken No. 1 well (Sec. 12, T. 157 N., R. 95 W., Williams County) by Nordquist

(1953, p. 72). The Bakken Formation has been referred to as the "Kinderhook", Englewood, and Exshaw Formations by various writers, until the Williston Basin Correlation Committee adopted the term Bakken Formation in 1953. The Bakken No. 1 well is located on the Nesson anticline where the Bakken Formation attains its maximum thickness and can be subdivided into three members. In eastern North Dakota the lower member is absent and the other two are not separated in this report.

Fissile, non-calcareous black shale containing finely divided pyrite comprises the lower member. A pebble conglomerate is present at the base of the member in the marginal areas of the basin.

The middle member consists of argillaceous dolomite, gray siltstone, and fine-grained sandstone, and thin seams of shale. The sandstone and siltstone are often slightly feldspathic. Pyritized brachiopods and finely disseminated pyrite are common.

Black non-calcareous shale similar to that of the lower member composes the upper member. The upper member is the thinnest, but most extensive of the three members. The color of the upper member becomes gray, reddish, or yellowish in several places in the marginal areas.

McCabe (1954, p. 2004) stated that the Bakken Formation rests with angular unconformity on pre-Mississippian formations. In the deeper parts of the Williston Basin the Bakken may be conformable with the underlying Three Forks Formation. The Bottineau Interval conformably overlies the Bakken Formation. The Bakken is considered to be Kinderhookian in age (Kume, 1960, p. 28). Kume (1960, p. 50) considers the lower shale unit of the Englewood Formation of the Black Hills to be equivalent or nearly equivalent to the lower shale of the Bakken Formation. The Bakken in eastern North Dakota varies from zero to 60 feet in thickness.

The isopachous map of the Bakken Formation (Plate 15) is of questionable accuracy near the northeast limit of the formation because differentiation of the Bakken and Three Forks is difficult without the aid of sample logs. A small area of unusual thickness occurs in Rolette County. The two thick trends near the west edge of the map may be a result of differential compaction of the shale over thick areas of the medial arenaceous member.

Madison Group

The nomenclature of the Madison Group is in a state of flux. Figure 4 shows the more recent changes of the Madison nomenclature. The left column lists the subdivisions (intervals) in use by the North Dakota Geological Survey and used in this report. Although these intervals provide a workable system of subdivision of the Madison Group and are presently in use, they have not to date been formally proposed and defined. These five intervals were briefly mentioned in an abstract by Smith (1960, p. 19), but were not defined. He proposed that the Lodgepole, Mission Canyon, and Charles Formations be considered as

magnafacies and the five intervals be adopted as mappable para-time units based on log deflections or markers, and not on lithology. (Fig. 5). Figure 6 is an electric log showing the tops of the various intervals as presently in use by the North Dakota Geological Survey. It is not the purpose of this discussion to propose formally or defend these intervals, but rather to familiarize the reader with current usage.

It is hoped that the North Dakota Geological Society will soon supplement Mr. Smith's abstract with a formal definition of the terms. It should be noted that although many of the interval names are the same as those formally proposed by the Saskatchewan Geological Society (1956), the boundaries used in North Dakota are not in all cases the same. Although most of the geological organizations of the Williston Basin have agreed to the present usage, legal complications hinder redefinition in Saskatchewan.

The Bottineau, Tilston, and Frobisher - Alida intervals cannot be separated in the deeper parts of the basin. Any one Madison interval may display both lateral and vertical facies changes.

Bottineau Interval

The Bottineau interval in eastern North Dakota is essentially equivalent to the Lodgepole Formation of other writers. The lower two-thirds of the interval is characterized by exceedingly variable lithology and numerous rapid facies variations. The most prominent lithologic variable in the Bottineau is the argillaceous content. The lithology varies from black shale, red and gray calcareous shale, argillaceous limestone, cherty limestone, glauconitic limestone, dolomitic limestone, to dolomite (McCabe, 1959, p. 24). The limestones are generally clastic and vary from finely-crystalline to granular. The porosity ranges from vuggy to fine intergranular. The Bottineau interval, from east to west, changes facies from cherty carbonates to argillaceous carbonates, and again to cherty carbonates.

Carrington Shale Facies

In eastern North Dakota an isolated body of mottled red and green, non-calcareous shale occurs between beds of known Devonian age and the Bottineau interval (Plate 16). Previous writers have considered this shale to be equivalent to the Three Forks Formation of Devonian age. As a result of this study, the writer proposes that this shale is an eastern facies of the lower part of the Bottineau interval (Plate 32) and the term Carrington Shale facies is proposed for this shale. The type section is designated as the interval from 2, 362 to 2,425 feet mechanical log depth in the Pure Oil Company, J. M. Carr No. 1 well, Sec. 15, T. 146 N., R. 66 W., Foster County, North Dakota. The name is derived from the nearby town of Carrington, North Dakota.

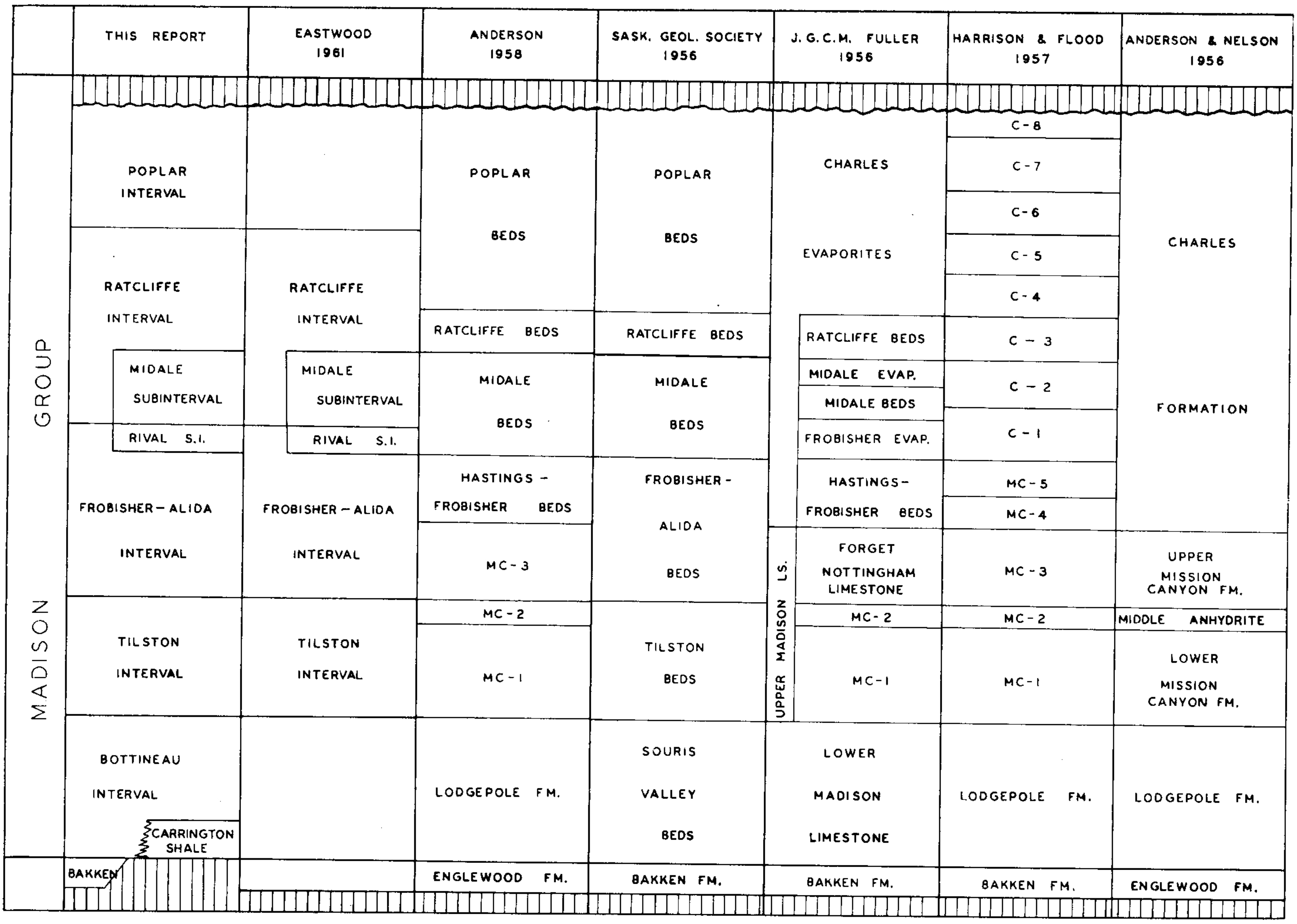


Figure 4. -- Previous and present stratigraphic nomenclature of the Madison Group and Bakken Formation in the Williston Basin.

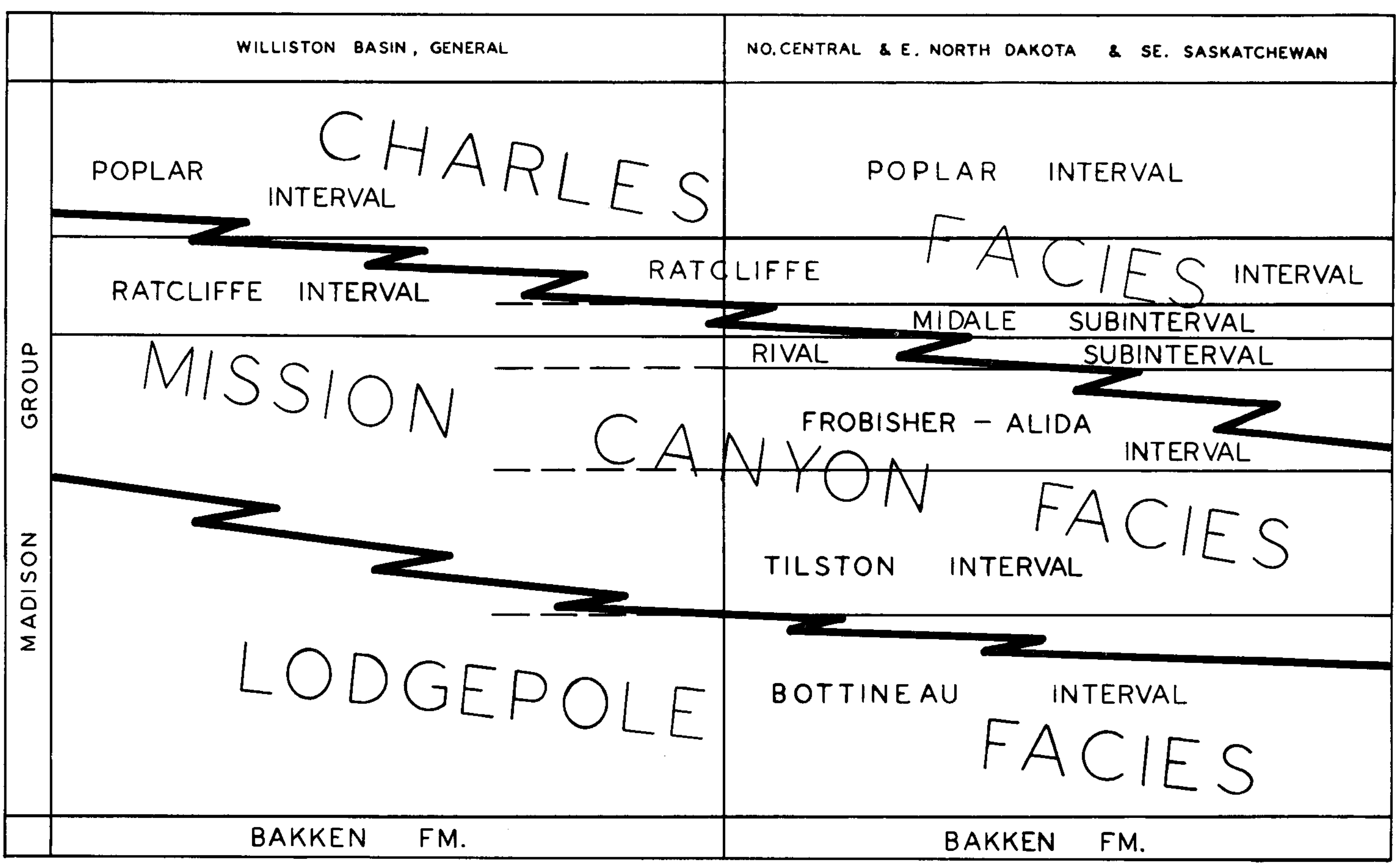


Figure 5 -- Diagram showing relationship of "marker" defined intervals to magnafacies of the Madison Group.

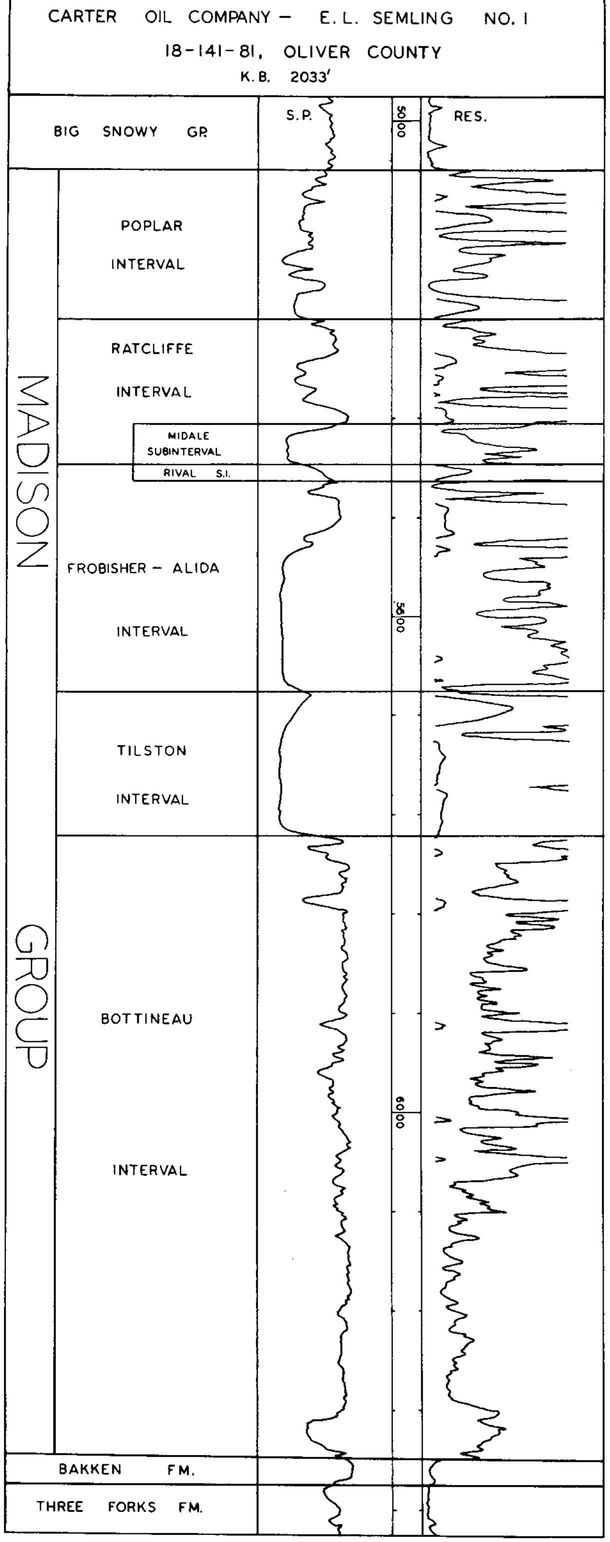


Figure 6.-- Typical electric log showing the markers which separate the intervals of the Madison Group.

The following lithologic description of the type section is based on samples and core on file with the North Dakota Geological Survey.

Lithologic description of type section of Carrington Shale Facies, sample and core depths are adjusted to electric log depths.

Samples:

2364 - 69 Shale, pale reddish brown, bentonitic, and medium gray, calcareous; small amounts of white chalky limestone.

2369 - 74 Shale, pale reddish brown, bentonitic, and light gray calcareous; small amounts of white chalky limestone.

2374 - 79 Shale, pale reddish brown, bentonitic, and medium gray, calcareous.

2379 - 84 Shale, pale reddish brown, bentonitic, and medium gray, calcareous; small amounts of white chalky limestone.

2384 - 89 Shale, pale reddish brown, bentonitic, and medium gray, calcareous; small amounts of white chalky limestone and dolomite.

2389 - 94 Shale, pale reddish brown, bentonitic, and light gray, calcareous.

2394 - 99 Shale, reddish brown, bentonitic, and medium gray calcareous; small amounts of white chalky limestone and dolomite.

Core:

2399 - 02 Shale, mottled pale reddish brown and pale green, bentonitic; few red calcite inclusions.

2402 - 05 Shale, mottled pale reddish brown and pale green, bentonitic; few brown calcite inclusions.

2405 - 08 Shale, pale reddish brown, bentonitic; occasional seams of pale green and white calcite.

2408 - 11 Shale, mottled pale reddish brown and pale green, bentonitic; few calcite inclusions.

2411 - 14 Shale, pale reddish brown, some pale green mottling, bentonitic.

2414 - 17 Shale, pale reddish brown and pale brown, bentonitic; few seams of red and pale green crystalline calcite.

2417 - 24 Shale, mottled pale reddish brown, pale brown, and pale green, bentonitic.

2424 - 27 Shale, pale reddish brown and interlaminated pale green and pale brown, bentonitic.

2427 - 28 Shale, pale reddish brown and pale green with some red mottling, bentonitic.

The type section is composed predominantly of non-calcareous shale with a high bentonite and/or montmorillonite content as evidenced by immediate swelling and breakdown of samples placed in water. Near the western margin, the Carrington Shale facies consists of black, slightly calcareous shale or argillaceous limestone.

The thickness and areal distribution of the Carrington Shale facies is shown on the isopachous map (Plate 16). Plate 17 is an isopachous map of the carbonate facies of the Bottineau interval and Plate 18 is an isopachous map of the Bottineau including the Carrington Shale Facies. It is apparent that the thickness and distribution of the shale complements that of the carbonate facies.

The Carrington Shale facies is identified as a facies of the Bottineau interval for the following reasons: 1.) stratigraphic position, 2.) angular discordance between shale facies and underlying Devonian formation, 3.) complementary relationships of carbonate and shale isopachous maps, and 4.) lithologic dissimilarity to the Three Forks Formation.

McCabe (1959, p. 50) has explained the occurrence of the Routledge Shale, in a similar stratigraphic position in Manitoba, by solution of Devonian salt in the interval of time between Bakken and Lodgepole deposition. The shale subsequently accumulated in the collapsed area. The Bakken Formation underlies the Routledge Shale and definitely dates the unit as Mississippian in this area. There is no apparent evidence that the Carrington Shale is a result of similar salt collapse tectonics and the origin of the unit will be discussed in a later chapter.

McCabe (1959, p. 45) considered the marker-bed equivalent of the Bottineau interval in Manitoba to be of Kinderhookian age and the Bottineau is assumed to be of similar age. The Bottineau conformably overlies the Bakken Formation, but overlies the Devonian units in eastern North Dakota with angular discordance. The Tilston interval conformably overlies the Bottineau. The Bottineau interval is the thickest interval of the Madison Group and varies from zero to 670 feet in thickness.

The isopachous map of the Bottineau interval (Plate 18) shows thinning near the erosional limit of the Tilston over the Foster high. Thinning over the Burleigh and Stutsman highs is vaguely evidenced, but the Cavalier high is apparent. Isopachous maps of the overlying units give no evidence of the Stutsman and Foster highs and little evidence of the Cavalier high as these highs lie to the east of the limit of the interval.

Tilston Interval

The Tilston interval was named by the Saskatchewan Geological Society (1956, p. 2) for the Tilston oilfield in southern Manitoba. The interval consists of oolitic and crinoidal coarsely-crystalline limestone and cherty fine-grained dolomitic limestone. The unit changes facies toward the basin center into dense, fine-grained limestone and there

cannot be separated from the Bottineau interval (Eastwood, 1961).

The top of the Tilston interval is marked by a unit of bedded anhydrite and shaly limestone about 10 feet thick (MC - 2 beds of earlier writers). In the central basin area this unit cannot be recognized.

The Tilston interval conformably overlies the Bottineau interval and is conformably overlain by the Frobisher - Alida interval. The thickness ranges from zero to 210 feet in the area of this report. The Tilston is assumed to be late Kinderhookian to early Osagean in age based on mechanical log correlation with the equivalent interval in Manitoba which was dated by McCabe (1959, p. 55 and Figure 3). Oil is produced from the Tilston in the North Souris and Roth fields in Bottineau County.

The isopachous map of the Tilston interval (Plate 20) shows thinning over the Burleigh high. A series of northwest to southeast trending noses occur in the northern part of the map area and are persistent in the overlying intervals of the Madison Group.

Frobisher - Alida Interval

The Frobisher - Alida interval was named by the Saskatchewan Geological Society (1956, p. 3) after the Frobisher and Alida oilfields in Saskatchewan. The lower part of the interval is a thick sequence of limestone with oolitic and psuedo-oolitic limestone containing lenses and tongues of anhydrite and shaly dolomitic limestone near the top (Eastwood, 1961). The upper part of the interval is mostly anhydrite with some dolomitic limestone, salt, and quartzose sandstone. The Rival subinterval forms the top of the Frobisher-Alida and is composed of 25 to 30 feet of anhydrite and dolomitic limestone.

The Frobisher-Alida attains a maximum thickness of 300 feet in eastern North Dakota and conformably overlies the Tilston interval. The Ratcliffe interval conformably overlies the Frobisher-Alida interval. Oil is produced from the Frobisher-Alida in several fields of the Wiley trend in Bottineau County. McCabe (1959, Figure 3) assigned the equivalent interval in Manitoba as Osagean to early Meramecean age.

The Frobisher-Alida isopachous map (Plate 21) shows a series of northeast to southwest and east to west trending noses. These noses may be a result of carbonate bank development or flowage of anhydrite. A thick trend is developed in central Burleigh County. Stratigraphic traps in several related oilfields in north central North Dakota (Wiley trend) are developed on the downdip side of an area of thick anhydrite and thin limestone associated with the noses.

Ratcliffe Interval

The Ratcliffe interval was named by Fuller (1956) for the Socony, Central Leduc Del Rio Ratcliffe No. 1 well in Saskatchewan. The basal unit of the interval is termed the Midale subinterval after the Midale Oilfield in Sasketchewan. The Midale subinterval is comprised of about 30 feet of dolomitic limestone. The upper beds of the Ratcliffe interval consist of alternating dolomitic limestones, anhydrites, and shales (Eastwood, 1961).

The Ratcliffe interval conformably overlies the Frobisher-Alida interval and is conformably overlain by the Poplar interval. In eastern North Dakota the maximum thickness of the Ratcliffe interval is about 170 feet. Oil is produced from the Ratcliffe in several fields on the Nesson anticline and in the Starbuck and Newburg-South Westhope fields. Mechanical log correlation of the Ratcliffe with the equivalent interval in Saskatchewan suggests a Meramecean age for this interval (Fuller, 1956).

The Ratcliffe isopachous map (Plate 22) again shows the numerous east to west and southwest to northeast trending noses which were similar on the maps of underlying intervals. The interval is not of sufficient extent in the map area to reveal any evidence of the eastern flank highs.

Poplar Interval

The Poplar interval was named by the Saskatchewan Geological Society (1956, p. 4) for the Poplar oilfield in Montana. The lithology of the Poplar includes interbedded anhydrite, halite, dolomite, mudstone, and shale. Commonly the sediments are iron-stained.

The Poplar interval conformably overlies the Ratcliffe interval and is unconformably overlain by the Kibbey or Otter Formations of the Big Snowy Group or by rocks of Mesozoic age. McCabe (1959, Figure 3) indicated the equivalent section in Saskatchewan to be of Meramecean age. The thickness of the Poplar in the area of this study varies from zero to 200 feet. To date, no petroleum is produced from this interval in North Dakota.

The Poplar isopachous map (Plate 23) shows several thin noses, but the thickness is affected in part by the unconformity at the top of the interval. The interval is not sufficiently extensive in the map area to reveal any definite trends.

Post-Poplar — Pre-Piper Solution Breccia

Collapse breccia which resulted from evaporite and carbonate solution occurs in Emmons, Logan, McIntosh, and Kidder Counties (Plate 24). This breccia is developed on the truncated Madison Group and consists of irregular fragments of limestone and dolomite in a matrix of calcareous silt and sand. The limestone fragments show evidence of solution. Part of this breccia is of Late Mississippian age as it is overlain by the Big Snowy Group in at least one well. However, much of the breccia may be post-Mississippian to pre-Piper (Jurassic) in age. The preservation of this breccia in this one area may be explained by its position, in a slightly negative area, between the Burleigh, Foster, and Stutsman highs.

Big Snowy Group

The Big Snowy Group was named by Scott (1935) and applied to the strata between the Madison Limestone and the Amsden Formation of central Montana. The Big Snowy Group is not extensive in the area covered in this report, but is included for completeness. As the stratigraphy of the group is complex in North Dakota, the formations were not separated by the writer and the unit was mapped as a group. Three formations are generally recognized in the Big Snowy Group. In ascending order they are: the Kibbey, Otter, and Heath formations. The Kibbey and Otter Formations were named by Weed (1899). Scott (1935) proposed the term Heath Formation.

The Kibbey Formation unconformably overlies the Madison Group The Kibbey in North Dakota consists of reddish to light gray, medium- to fine-grained sandstone underlain by a limestone or dolomite. Variegated shale comprises the basal part of the formation (Anderson, 1954).

The Otter Formation is composed of variegated green and red shales and small amounts of limestone. The limestone is commonly oolitic and ostra codal. Anhydrite is locally present.

The "Heath" Formation in North Dakota consists primarily of black to gray to red or green shales interbedded with mudstones and hematitic quartzose sandstones (Ziebarth, 1962).

The Big Snowy Group lies with angular discordance on the Madison Group and is unconformably overlain by the "Amsden" Formation. Ziebarth (1962, p. 44) states that the Mississippian-Pennsylvanian boundary is within the "Heath" Formation as shown in Figure 7. The Kibbey Formation is of Meramecean age and the Otter and "Heath" Formations are Chesterian in age. The maximum thickness of the Big Snowy in the area of this report is about 380 feet. Oil is produced from the Fryburg Sand of the "Heath" Formation in North Dakota. The isopachous map of the Big Snowy Group (Plate 25) includes such a small area that it is of little value.

Pennsylvanian System

"Amsden" Formation

The term Amsden Formation was proposed by Darton (1904) for exposures along the Amsden Branch of the Tongue River, near Dayton, Wyoming. The "Amsden" Formation in North Dakota is virtually unstudied, but is believed to be equivalent to the Amsden of central Montana as defined by Mundt (1959). The formation in North Dakota consists of pale orange to pink gray, dense dolomite with local sand units near the top. Dark colored shale and anhydrite are not uncommon.

The "Amsden" Formation unconformably overlies the Big Snowy Group and is conformably overlain by the Minnelusa Formation. If the Mississippian-Pennsylvanian boundary of Ziebarth (1962) is correct, the "Amsden" is of early Pennsylvanian age. The isopachous map of the "Amsden" (Plate 26) shows the formation to be up to 100 feet thick in eastern North Dakota.

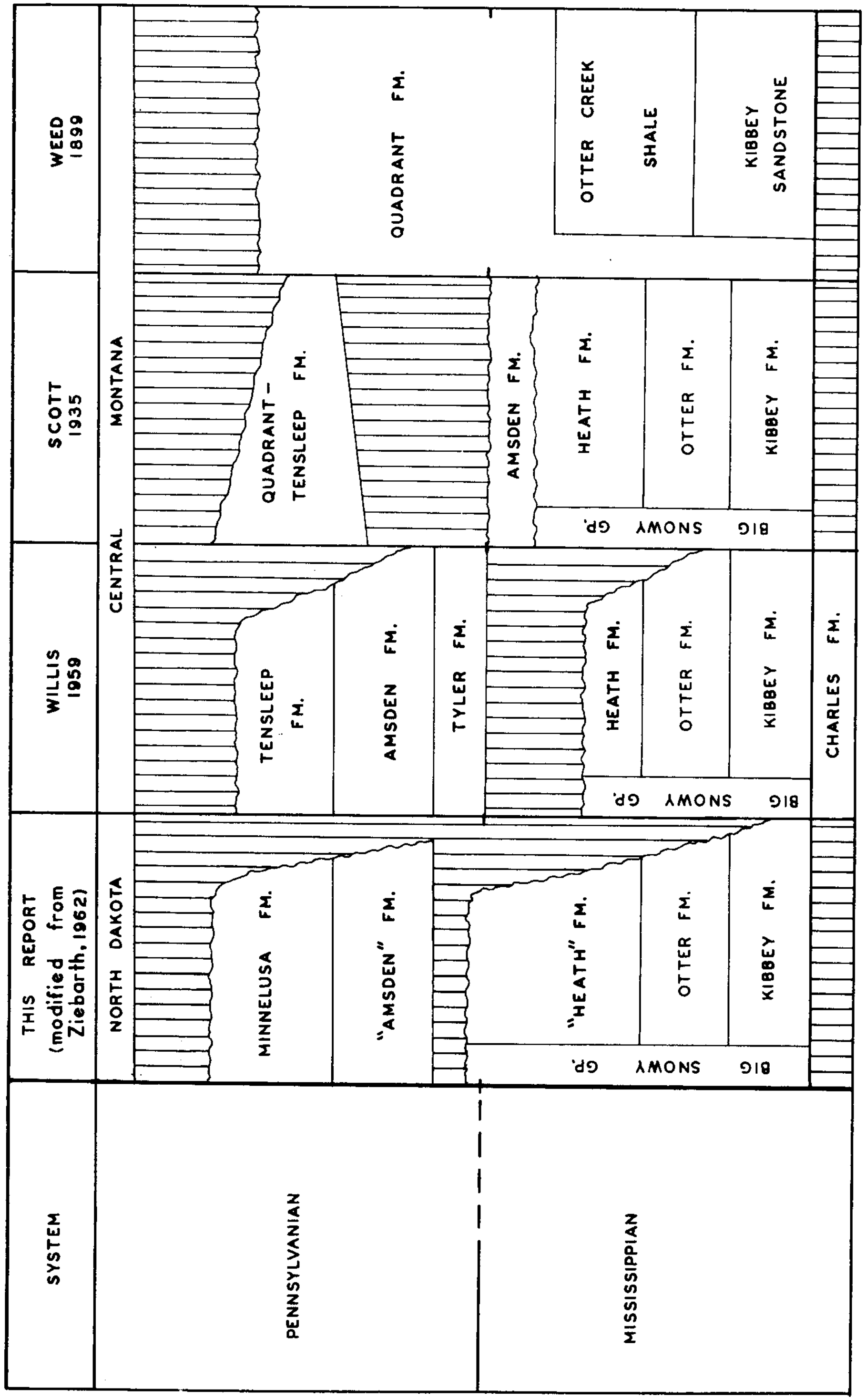


Figure 7 -- Previous and present stratigraphic nomenclature of the Upper Mississippian and Pennsylvanian rocks of the Williston Basin.

Minnelusa Formation

The term Minnelusa Formation was proposed by Darton (1901) to include the strata lying between the Pahasapa Limestone and the Opeche Formation. Several recent writers have subdivided the Minnelusa into six units. The formation is of such slight extent in eastern North Dakota that these subdivisions are not discussed.

The Minnelusa Formation consists of a basal sandstone or sand and red shale unit overlain by an argillaceous limestone with interbedded thin red and green shales. This unit is overlain by red, green, and brown shales and thin dolomites (McCauley, 1956, p. 152). The upper part of the Minnelusa is comprised of red to brown shales, siltstones, sandstones, and dolomites.

In most areas the Minnelusa Formation conformably overlies the "Amsden" Formation. The contact between the Minnelusa and the overlying Opeche Formation has been described as both conformable and unconformable. The true nature of the relationship is not yet resolved. Slight oil shows and local production suggest that the Pennsylvanian rocks of the Williston Basin may yield commercial possibilities. The maximum thickness of the Minnelusa in eastern North Dakota is about 300 feet (Plate 27).

Post-Permian — Pre-Jurassic Erosion

The Paleozoic rocks of North Dakota are truncated by two progressively overlapping unconformities and lie with angular discordance below the "Spearfish" Formation of Triassic age or the Piper Formation of Jurassic age. The pre-Mesozoic paleogeologic map (Plate 29) shows the subcrop pattern of the truncated Paleozoic rock units. In the western half of the map area the subcrop pattern probably results from post-Paleozoic to pre-"Spearfish" erosion. In the eastern part of the map area, much of the subcrop pattern is a result of post-"Spearfish" - pre-Piper erosion. Oil is produced in Bottineau County from traps formed where the "Spearfish" Formation seals the truncated Paleozoic rocks or where oil has seeped into the porous sands of the basal "Spearfish".

STRUCTURAL RELATIONSHIPS

Description of Structural Elements

In North Dakota the Williston Basin is the major structural element. This feature is defined on the east and south sides by the zero elevation structure contour line on the Dakota Sandstone as shown in Figure 8. Also shown on Figure 8 is the approximate position of the hinge line which separates the lower dips of the basin flank from the basin proper A change in spacing of the contours on several isopachous maps approximately defines the hinge line. Change in contour spacing on the map of the Pre-Mesozoic surface (Plate 28) also defines this hinge line. The area of the Williston Basin west of the hinge line is referred to as the central basin area. The area to the east of the hinge line is referred to as the eastern flank of the basin.

The positive elements discussed in this report are located on either the eastern flank of the basin or on the hinge line. The eastern flank, as evidenced by areal distribution, thickness variations, and facies changes of rock units, was subjected to much less subsidence than the central basin area.

The major positive areas in North Dakota are the Nesson and Cedar Creek anticlines in the central basin. The minor positive areas defined by this study are the Cavalier, Burleigh, Foster, and Stutsman highs (Figure 1). Although less prominent than the Nesson or Cedar Creek structures, these features had considerable effect on sedimentation in eastern North Dakota. These positive areas or highs on the eastern basin flank are defined by persistent thin areas observed on the isopachous maps.

Burleigh High

The Burleigh High is located in central Burleigh County, but at various times extended into Emmons, Sheridan, and Wells Counties. This feature is elongated in a north-south direction and approximately coincides with the basin hinge line in this area. The Burleigh high is best defined on the Winnipeg, Interlake, and Birdbear isopachous maps. However, most of the other isopachous maps show some reflection of this high as wider spacing of contours over the area. The structural relief of this high rarely exceeded 20 to 30 feet. The Burleigh high, though generally the largest areally, was the least structurally pronounced of the four positive areas on the eastern flank. However, this feature had the most effect on sedimentation.

Stutsman High

The Stutsman high is in central Stutsman County about 6 miles west of Jamestown, North Dakota and did not greatly exceed two townships in area through most of the Paleozoic. The Stutsman high did not migrate laterally as did the Cavalier and Burleigh highs. This high cannot be traced through much of the Paleozoic section as the erosional

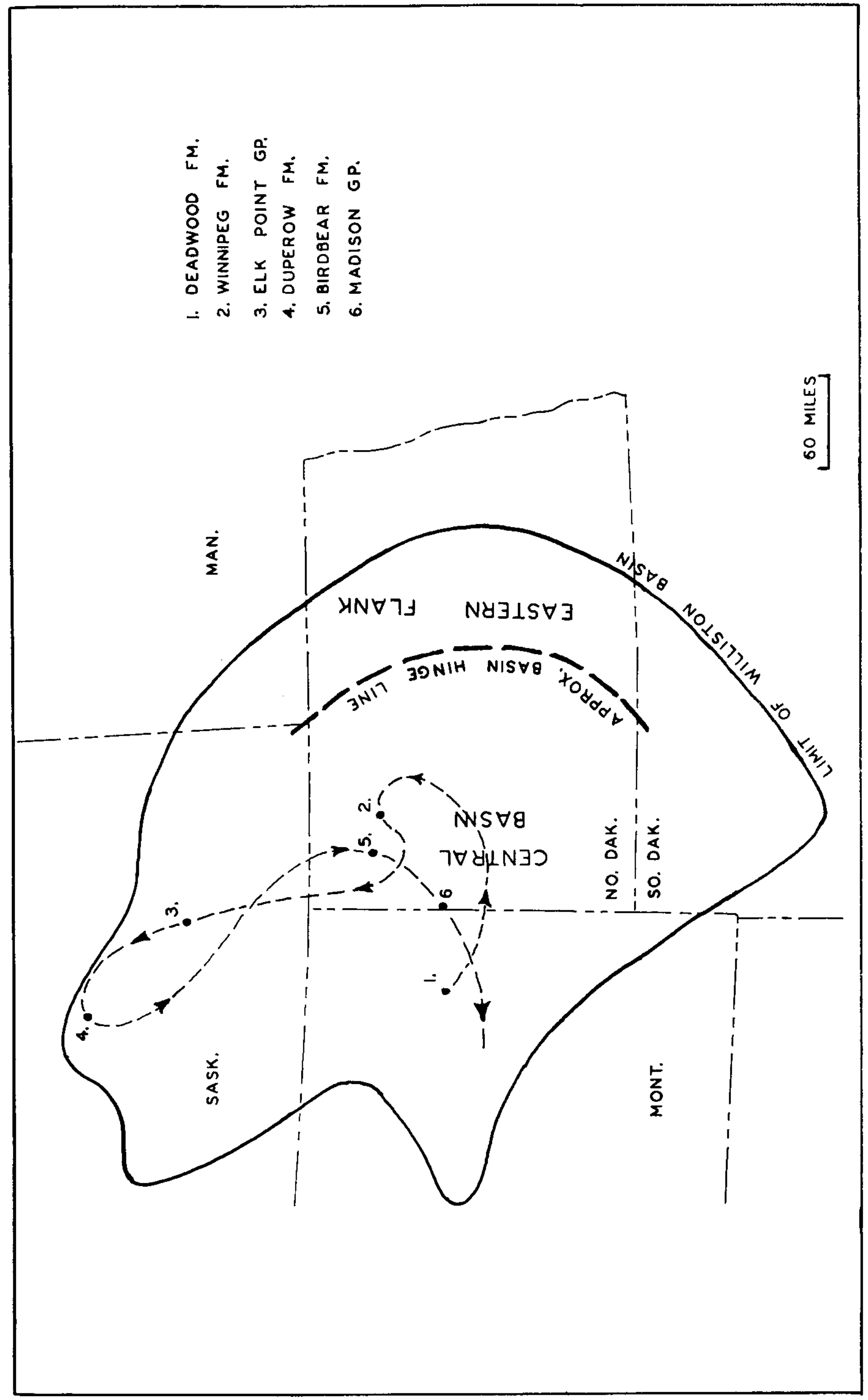


Figure 8 — Outline map of present Williston Basin showing Paleozoic migration of the depocenter.

limits of many of the formations lie to the west of the feature. The Stutsman high is best defined on the Deadwood isopachous map as it is devoid of Deadwood sediments. The Winnipeg and Red River isopachous maps also show good evidence of this high. The maximum structural relief of this high was about 110 feet and occurred in Deadwood time. As the Deadwood Formation is truncated by an unconformity, it is possible that the Stutsman high was at one time covered by Deadwood sediments. The Bottineau interval shows the last Paleozoic evidence of the Stutsman high.

Foster High

The Foster high is located in western Foster County near Carrington, North Dakota. This feature was generally confined to less than 50 square miles. The Foster high is best defined on the Deadwood and Dawson Bay isopachous maps as it is devoid of these two units. However, it is also well defined by thinning on the Winnipeg, Red River, and Souris River isopachous maps. This feature did not migrate laterally and attained a maximum structural relief of about 80 feet during Deadwood time. The Foster high was the most persistent positive element on the eastern flank of the Williston Basin. The electric log cross sections (Plates 30, 31, and 32) show the abrupt thinning which occurs in the J. M. Carr well (N.D.G.S. File No. 403) on the Foster high. Vague reflections of this high are shown by the eroded portions and indented erosional limits of several formations.

Cavalier High

The Cavalier high was extremely mobile in expression and at various times included parts of Cavalier, Walsh, Ramsey, Pierce, Benson, and Towner Counties. This feature is most prominent on the isopachous maps of the Winnipeg, Interlake, and Dawson Bay Formations. This high does not, with the contour intervals used exhibit closure in most formations, but rather occurs as a thin nose variably trending from north-south to east-west. The average structural relief was about 30 feet. Periodic migration and rejuvenation of this high is apparently the cause of the irregular erosional limits of several formations in Towner, Cavalier, and Ramsey Counties. The topographic high in this area on the pre-Mesozoic surface (Plate 28) is evidently a result of erosion which was influenced by the Cavalier high.

Effects of Hinge Line and Highs on Sedimentation

A decrease in the eastward rate of thinning of most units occurs over the basin hinge line. Changes of facies commonly occur over the hinge line in several of the pre-Mississippian formations. Commonly, the central basin evaporites change facies to fine, dense carbonates on the eastern basin flank.

The Carrington Shale Facies of the lower part of the Bottineau interval represents the most conspicuous change of facies caused by the

hinge line and an eastern flank high. The facies change occurs over and east of the Burleigh high which was active during and after deposition of the underlying Birdbear Formation. Although the Burleigh high had only about 20 to 30 feet of structural relief, it was apparently sufficient to provide environmental isolation which led to shale deposition. The eastern margin of the Carrington Shale basin was probably a combination of the Stutsman high and any topographic highs on the gentle eastward rising slope of the pre-Bottineau erosion surface. It is possible that the basin may have been a structural graben associated with high angle basement faulting, but there is little evidence for such an explanation. Although the mechanism of isolation and sedimentation of the Carrington Shale Facies is uncertain, its areal distribution and thickness evidence a definite association with the hinge line and Burleigh high.

The erosional limits of several of the formations reflect effects of the eastern flank highs, particularly the Stutsman and Cavalier highs. The erosional limits of the Interlake and Prairie Formations show effect of the Foster high.

Cause of Eastern Flank Highs

The eastern flank Paleozoic highs were evidently topographic highs of structural and erosional origin on the Precambrian rocks of the pre-Deadwood surface as evidenced by thinning of the Deadwood Formation. The carbonate units as well as the argillaceous units thin over the highs and reduce the possibility that the apparent positive areas were caused by differential compaction of shales over pre-Deadwood highs. The persistent positive nature of the eastern flank highs suggests renewed movement along old structural zones in the Precambrian basement.

Gravity, magnetic, and lithologic control on the Precambrian basement is not adequate at this time to formulate a specific structural explanation of the eastern flank highs. However, some conclusions can be drawn from the regional data available (Eardley, 1962; Gulbrandson et al., 1963; King, 1959). Figure 9 shows the Precambrian orogenic belts which underly the Williston Basin area (Eardley, 1962). The approximate boundary between the Algoman and the Algoman-Penokean belts coincides with the basin hinge line near the international boundary. It is inferred from the isopach data that the boundary may actually be a north-south concave westward facing arc which essentially corresponds with the basin hinge line in North Dakota. However, the dashed boundary of Eardley may be correct and the basin hinge line may reflect an infolded trend of Algoman or older rocks in the Penokean belt. In any case, the hinge line is in some way related to the aforementioned orogenic boundary or an associated infolded trend.

An interesting relationship between uplift of the eastern flank highs and the location of the basin depocenter can be established (Fig. 10). Laird (1953, p. 33) noted the migration of the basin center during Paleozoic and Mesozoic time. Figure 8 shows the migration of the depocenter as determined from available regional isopachous maps. The isopachous maps of this report show the eastern flank highs to have been most

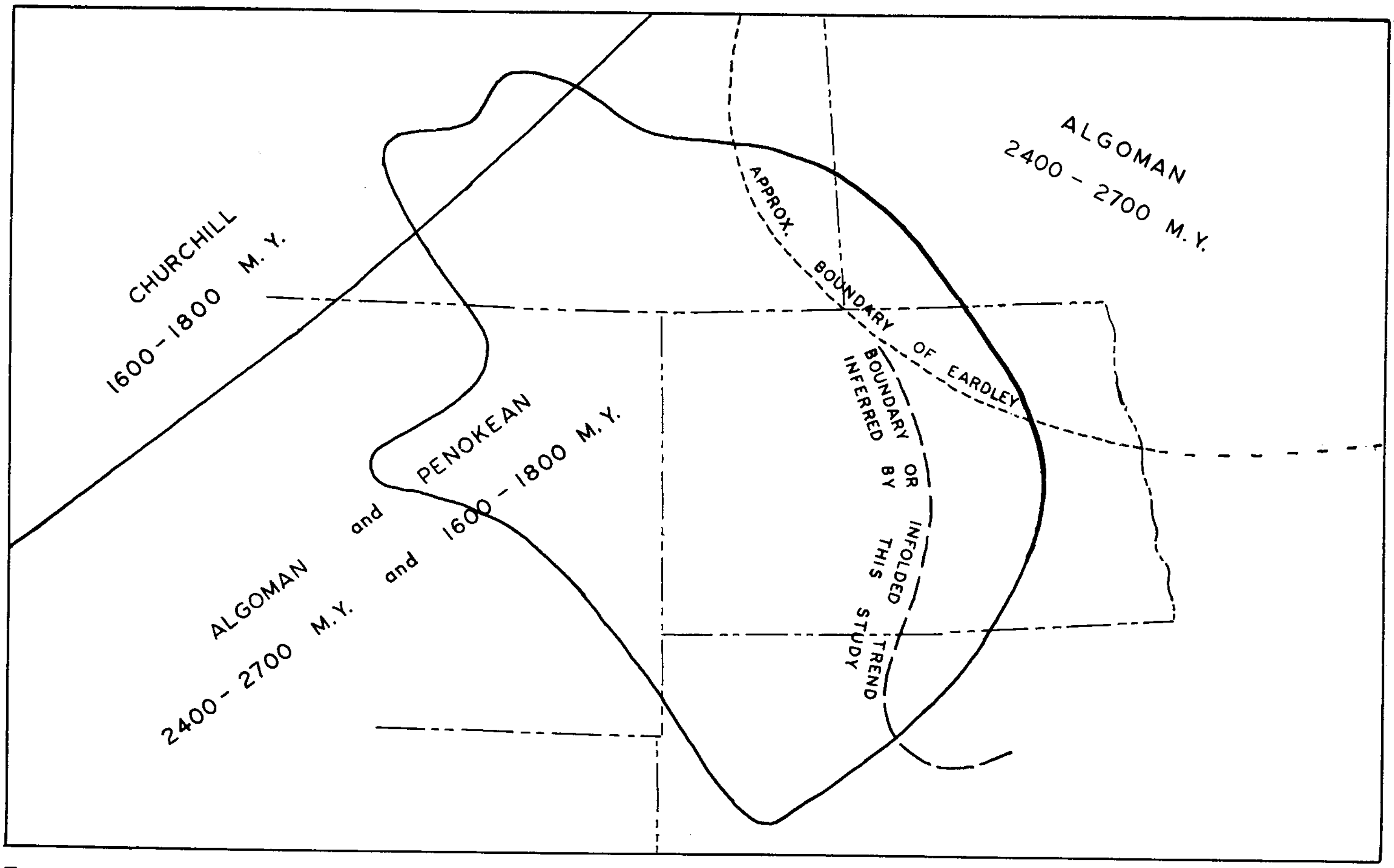


Figure 9 -- Map showing the Precambrian orogenic belts of the Williston Basin area. Modified from Eardley (1962).

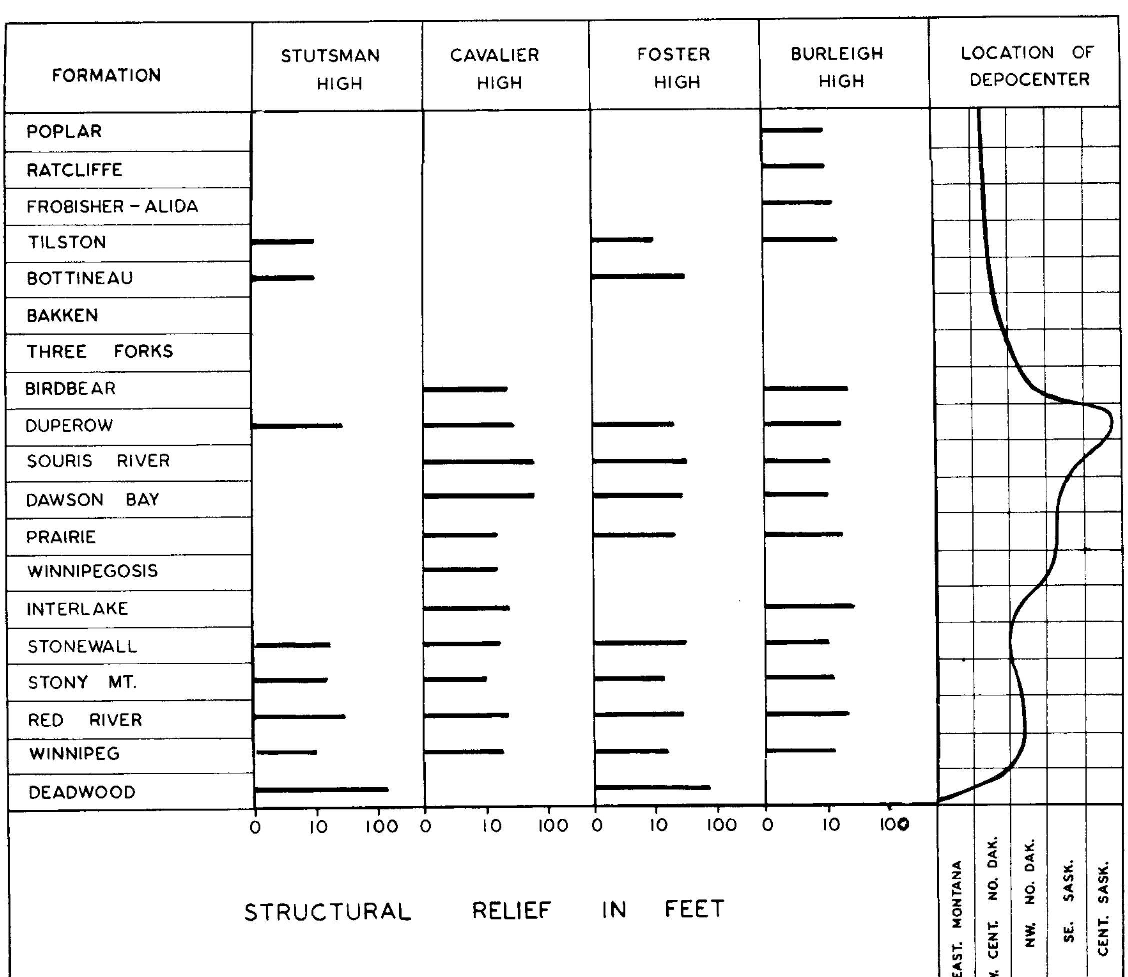


Figure 10. -- Diagram showing relative positive activity of eastern flank highs compared to location of the basin depocenter.

active when the basin depocenter (site of maximum deposition) was located in North Dakota or extreme southern Saskatchewan. The depocenter reached its northward limit during Duperow deposition and was located in central Saskatchewan. The basin tectonics at this time were probably related to the Churchill - Algoman and Penokean orogenic boundary. Only the Foster high was intermittently active at this time. The isopachous map of the Birdbear Formation shows the Burleigh high to have again become active as the depocenter returned to North Dakota. Figure 10 shows the Burleigh high was most active just prior to and after the depocenter was in Saskatchewan. The other eastern highs were less related to the hinge line, but Figure 10 shows them to be in some way related to the location of the depocenter. Future radio-dating of Precambrian cores will help determine if any structural trend or Precambrian orogenic boundary exists in the area of the approximate hinge line.

PETROLEUM POSSIBILITIES

Many of the Paleozoic formations are productive in the basin. However, the only production on the eastern flank to date is in western Bottineau County and northwestern McHenry County. Outside of these counties, exploratory wells have been drilled in all eastern North Dakota counties except Ransom, Cass, Griggs, Steele, and Traill Counties, but were dry and abandoned. Oil stains and other slight shows were found in a few of these wells.

Several prospective stratigraphic traps have been defined by this study. The rocks of the eastern flank of the Williston Basin which show the most attractive traps for oil and gas are of Devonian and Mississippian age. Recent discoveries in southwestern North Dakota indicate that possible traps in the Lower Paleozoic rocks of the eastern flank should not be neglected.

One type of stratigraphic trap in eastern North Dakota occurs where formations or beds pinch out against the Stutsman or Foster highs. The pinch out of the Dawson Bay Formation around the Foster high is the best example of this type of trap.

The updip change of facies from Bottineau carbonate to Carrington Shale in the lower part of the Bottineau interval provides a possible facies trap (Plate 32). If the carbonate porosity is well developed west of the shale facies and the overlying carbonates are of low permeability, this trap is an excellent prospect. Future drilling is necessary to verify the specific western limit of the shale facies.

Another stratigraphic trap exists where the truncated Duperow and Birdbear Formations are sealed by the Carrington Shale Facies (Plate 16). The Birdbear Formation has excellent porosity and near commercial shows have been found at several localities in the central basin. The Duperow Formation is presently productive in several fields.

The topographic high on the pre-Mesozoic surface in Cavalier County is a possible trap. The finger of Birdbear and Bottineau sediments is overlain and surrounded on the up dip side by Mesozoic rocks. However, several wells have been drilled in this area without production.

The Frobisher-Alida and Ratcliffe intervals may include undiscovered stratigraphic traps caused by porosity wedgeouts and porous limestone pinching out updip against the overlying anhydrite.

Local accumulations of oil may exist along the pre-Mesozoic unconformity. Traps of this type are presently productive in Bottineau County.

Several of the major producing basins of the world have excellent production along the basin flanks and a similar occurrence on the eastern flank of the Williston Basin would not be unusual. The drilling of future exploratory wells should be accompanied by careful drill stem testing in the horizons discussed in the preceeding pages. The potential traps outlined in this report indicate that eastern North Dakota should not be ignored as a potential petroleum producer.

SUMMARY

This study deals with the thickness and distribution of the Paleozoic rock units in eastern North Dakota.

The Carrington Shale Facies, previously considered as an eastern facies of the Three Forks Formation, is proposed to be an eastern facies of the lower part of the Bottineau interval. The Carrington Shale is considered a facies of the Bottineau interval for the following reasons: 1. stratigraphic position, 2. angular discordance between shale and underlying Devonian formations, 3. complementary relationships of shale and Bottineau carbonate isopachous maps, 4. lithologic dissimilarity to Three Forks Formation.

Four positive areas, the Cavalier, Burleigh, Foster, and Stutsman highs, are identified on the eastern basin flank from isopach data. These highs are believed to be a result of minor renewed movements along basement structural trends. The Burleigh high affected the environmental isolation which led to deposition of the Carrington Shale Facies. The activity of the four eastern flank highs is evidently related to the location of the basin depocenter which migrated from North Dakota to Saskatchewan in Devonian time and back to North Dakota in Mississippian time. The basin tectonics appear to be associated with Precambrian orogenic belts or infolded trends.

The Carrington Shale Facies provides two types of stratigraphic traps for oil and gas. The Bottineau carbonates change facies updip into Carrington Shale. This change of facies occurs along a north-south line from western Wells County to central Emmons County. The truncated Birdbear and Duperow Formations are sealed by the Carrington Shale Facies in Wells, Foster, Kidder, Stutsman, Logan and Emmons Counties. The Birdbear has excellent porosity and the Duperow is a commercial producer in other parts of the basin. Other local traps occur in eastern North Dakota.

Although there is no present petroleum production east of Bottineau County, the stratigraphic traps outlined in this report indicate that eastern North Dakota should not be ignored as a possible producer of petroleum.

REFERENCES

Allan, J. D., and Kerr, L. B., 1950, Oil and gas exploration in Manitoba: The Precambrian, v. 23, no. 10, p. 8 - 10.

American Commission on Stratigraphic Nomenclature, 1961, Code of stratigraphic nomenclature: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 5, p. 646-65.

Anderson, S. B., 1954, Stratigraphic sections of the Mississippian System in North Dakota: North Dakota Geol. Survey Rept. Invest. 16.

.............., 1958, Mississippian possibilities: North Dakota Geol. Survey Rept. Invest. 31, 9 p.

Anderson, S. B., and Nelson, L. B., 1956, Mississippian stratigraphic studies, Bottineau County, North Dakota: North Dakota Geol. Survey Rept. Invest. 24.

Andrichuk, J. M., 1959, Ordovician and Silurian stratigraphy and sedimentation in southern Manitoba, Canada: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 10, p. 2333-99.

Badgley, P. C., 1959, Structural methods for the exploration geologist: Harper and Brothers, New York, 280 p.

Baillie, A. D., 1951a, Devonian geology of the Lake Manitoba - Lake Winnipegosis area: Manitoba Dept. Mines Nat. Res. Pub. 49-2, 72 p.

.............., 1951b, Silurian geology of the Interlake area, Manitoba: Manitoba Dept. Mines Nat. Res. Pub. 50-1, 82 p.

.............., 1953, Devonian System of the Williston Basin area: Manitoba Dept. Mines Nat. Res. Pub. 52-5, 105 p.

Carlson, C. G., 1960, Stratigraphy of the Winnipeg and Deadwood Formations in North Dakota: North Dakota Geol. Survey Bull. 35, 149 p.

Carlson, C. G., and Eastwood, W. P., 1962, Upper Ordovician and Silurian rocks of North Dakota: North Dakota Geol. Survey Bull. 38, 52 p.

Darton, N. H. 1901, Preliminary description of the geology and water resources of the southern half of the Black Hills: U. S. Geol. Survey 21st. Ann. Rept., pt. IV, p. 489-589.

.............., 1904, Comparison of the stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain Front Range: Geol. Soc. America Bull., v. 15, p. 379-448.

Dowling, D. B., 1895, Notes on the stratigraphy of the Cambro-Silurian rocks of eastern Manitoba: The Ottawa Naturalist, v. 9, no. 3, p. 65-74.

.............., 1900, Report on the geology of the west shore and islands of Lake Winnipeg: Geol. Survey Canada Ann. Rept. 1898, pt. F.

Eardley, E. J., 1962, Structural Geology of North America: 2nd ed., Harper and Brothers, New York.

Eastwood, W. P., 1961, Maps of the Frobisher-Alida interval, North Dakota: North Dakota Geol. Survey Rept. Invest. 37, 3 pl. 6 text.

Foerste, A. F., 1929, Upper Ordovician and Silurian of American Arctic and sub-arctic regions: Denison Univ. Sci. Lab. Jour., v. 24, p. 27-79.

Fuller, J. G. C. M., 1956, Mississipian rocks and oilfields in southeastern Saskatchewan: Saskatchewan Dept. Min. Res. Rept. 19, 72 p.

Gardner, L. S., 1959, Revision of Big Snowy Group in central Montana: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 2, p. 329-50.

Gulbrandson, R. A., et al., 1963, Glauconite from the Precambrian Belt Series, Montana: Science v. 140, no. 3565, p. 390.

Harrison, R. L., and Flood, A. L., 1957, Mississippian correlations in the international boundary area: 1st Int. Williston Basin Symp., 1956, Conrad Pub. Co., Bismarck, No. Dak., p. 36-51.

Kindle, E. M., 1914, The Silurian and Devonian section of western Manitoba: Geol. Survey Canada Sum. Rept., 1912, p. 247-61.

King P. B., 1959, The Evolution of North America: Princeton University Press, Princeton, New Jersey, 189 p.

Kume, Jack, 1960, An investigation of the Bakken and Englewood Formations (Kinderhookian) of North Dakota and northwestern South Dakota: Unpublished Master's Thesis, University of North Dakota, Grand Forks, North Dakota.

Laird, W. M., The geology of the Williston Basin: Williston Basin Oil Review, v. 2, no. 8, p. 26-35.

Lochman, C., and Duncan, D., 1950, The Lower Ordovician Bellefontia fauna in central Montana: Jour. Paleontology, v. 24, no. 3, p. 350-53.

MacDonald, G. H., 1956, Subsurface stratigraphy of the Mississippian rocks of Saskatchewan: Geol. Survey Canada Mem. 282, 46 p.

McCabe, H. R., 1959, Mississippian stratigraphy of Manitoba: Manitoba Dept. Mines Nat. Res. Pub. 58-1, 99 p.

McCabe, Wm. S., 1954, Williston Basin Paleozoic unconformities: Am. Assoc. Petroleum Geologists Bull., v. 38, no. 9, p. 1997-2011.

McCauley, V. T., 1956, Pennsylvanian and Lower Permian of the Williston Basin: 1st Int. Williston Basin Symp., Conrad Pub. Co., Bismarck, No. Dak., p. 150-64.

McGehee, J. B., 1949, Pre-Waterways Paleozoic stratigraphy of Alberta Plains: Am. Assoc. Petroleum Geologists Bull., v. 33, no. 4, p. 603-13.

..............., 1952, A resume of the Elk Point Formation in view of recent drilling in the Williston Basin: Billings Geol. Society, Third Ann. Field Conf., Guidebook, p. 64.

Moore, P. F., 1958, Nature, usage, and definition of marker-defined vertically segregated rock units: Am. Assoc. Petroleum Geologist Bull., v. 42, no. 2, p. 447-51.

Mundt, P. A., 1950, Heath-Amsden strata, central Montana: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 6, p. 1915-35.

North Dakota Geological Society, 1961, Stratigraphy of the Williston Basin, Devonian System: Devonian System Committee, Bismarck, North Dakota, 47 p.

North Dakota Geological Survey, 1962, Official Oil production statistics in North Dakota, first half 1962: Grand Forks, North Dakota, 124 p.

Peale, A. C., 1895, Paleozoic section in the vicinity of Three Forks, Montana: U. S. Geol. Survey Bull. 110, 56 p.

Perry, E. S., and Sloss, L. L., 1943, Big Snowy Group, lithology and correlation in northern Great Plains: Am. Assoc. Petroleum Geologists Bull., v. 27, no. 10, p. 1287-1305.

Porter, J. W., and Fuller, J. G. C. M., 1959, Lower Paleozoic rocks of northern Williston Basin and adjacent areas: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 1, p. 124-90.

Powley, D., 1951, Devonian stratigraphy of central Saskatchewan: Unpublished Master's Thesis, University of Saskatchewan, Saskatoon, Saskatchewan, 98 p.

Ross, R. J., Jr., 1957, Ordovician fossils from wells in the Williston Basin, eastern Montana: U.S. Geol. Survey Bull., 1021, pt. M, p. 439-510.

Sandberg, C. A., 1961, Distribution and thickness of Devonian rocks in Williston Basin and in central Montana and North-central Wyoming: U. S. Geol. Survey Bull., 1112-D, 22 p.

Sandberg, C. A., and Hammond, C. R., 1958, Devonian System in Williston Basin and central Montana: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 10, p.2293-2335.

Saskatchewan Geological Society, 1956, Report of the Mississippian names and correlations committee: Regina, Saskatchewan, 4 p. and cross sections.

..............., 1958, Report of the Lower Paleozoic names and correlations committee: Regina, Saskatchewan.

Scott, H. W., 1935, Some Carboniferous stratigraphy in Montana and northwestern Wyoming: Jour. Geology, v. 43, p. 1011-32.

Shaw, A. B., and Bell, W. G., 1955, Age of Amsden Formation, Cherry Creek, Wind River Mountains, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 39, no. 3, p. 333-37.

Sloss, L. L., and Laird, W. M., 1947, Devonian System in central and northwestern Montana: Am. Assoc. Petroleum Geologists Bull., v. 31, p. 1404-30.

Smith, M. H., 1960, Revised nomenclature for the Williston Basin (abst.): Program Tenth Annual Meeting, Rocky Mountain Sec., Am. Assoc. Petroleum Geologists, Billings, Montana.

Strassberg, M., 1954, Summary of the Pure Oil Company J. M. Carr No. 1 well: North Dakota Geol. Survey Circ. 43, 9 p.

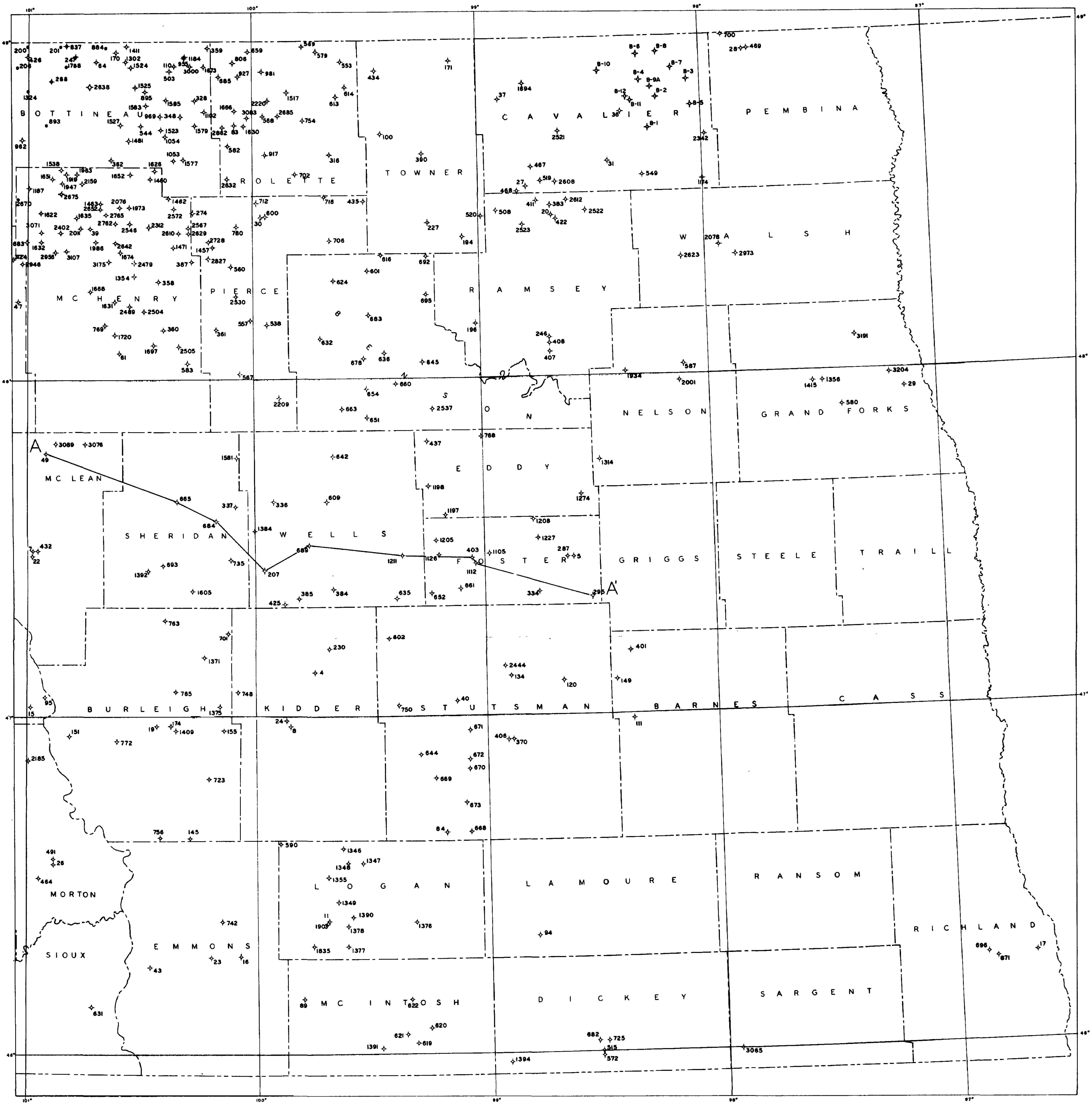
Tyrell, J. B., 1892, Report on northwestern Manitoba with portions of adjacent districts of Assinibia and Saskatchewan: Geol. Survey Canada Ann. Rept. 1890-91, pt. E.

Weed, W. H., 1899, Geology of the Little Belt Mountains: U. S. Geol. Survey 20th Ann. Rept., p. 295.

Weller, J. M., et al., 1948, Correlation of the Mississippian formations of North American: Geol. Soc. American Bull., v. 59, p. 91-196.

Willis, H. P., 1959, Upper Mississippian - Lower Pennsylvanian stratigraphy of central Montana and Williston Basin: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 8, p. 1940-67.

Ziebarth, H. C., 1962, The micropaleontology and stratigraphy of the subsurface "Heath" Formation (Mississippian-Pennsylvanian) of western North Dakota: Unpublished Master's Thesis, University of North Dakota, Grand Forks, North Dakota, 146 p.



LEGEND

• DISCOVERY WELL

✧ DRY HOLE

403 NORTH DAKOTA GEOLOGICAL SURVEY WELL NUMBER

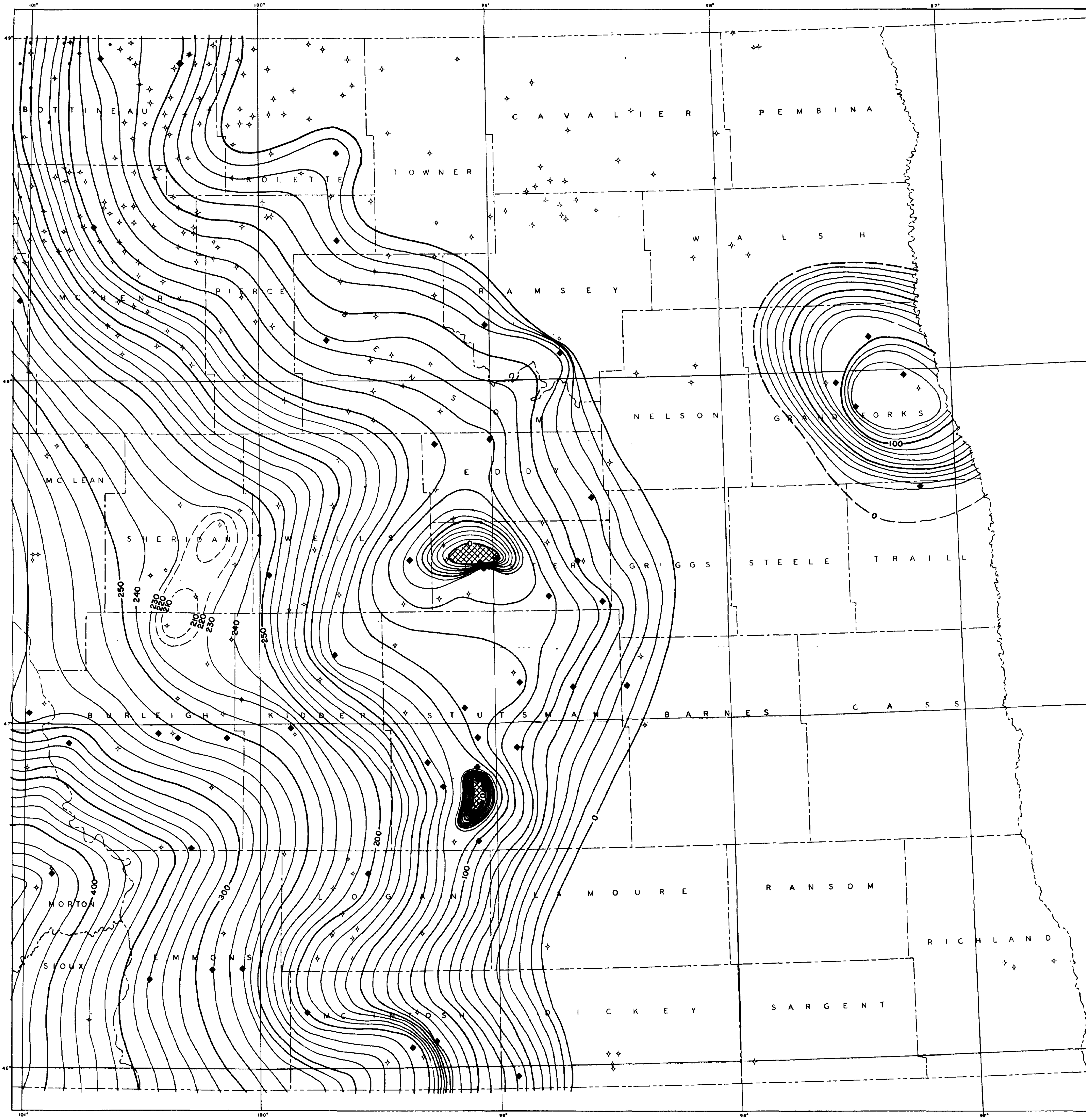
A——A' LOCATION OF PLATES 30, 31, & 32.

B-5 CARTER OIL COMPANY STRATIGRAPHIC TEST, CAVALIER COUNTY.

SCALE 10 0 10 20 30 40 MILES

LOCATION MAP SHOWING EXLORATORY WELLS

PLATE I



LEGEND

◆ CONTROL WELL

•✦✧◆ EXPLORATORY WELL

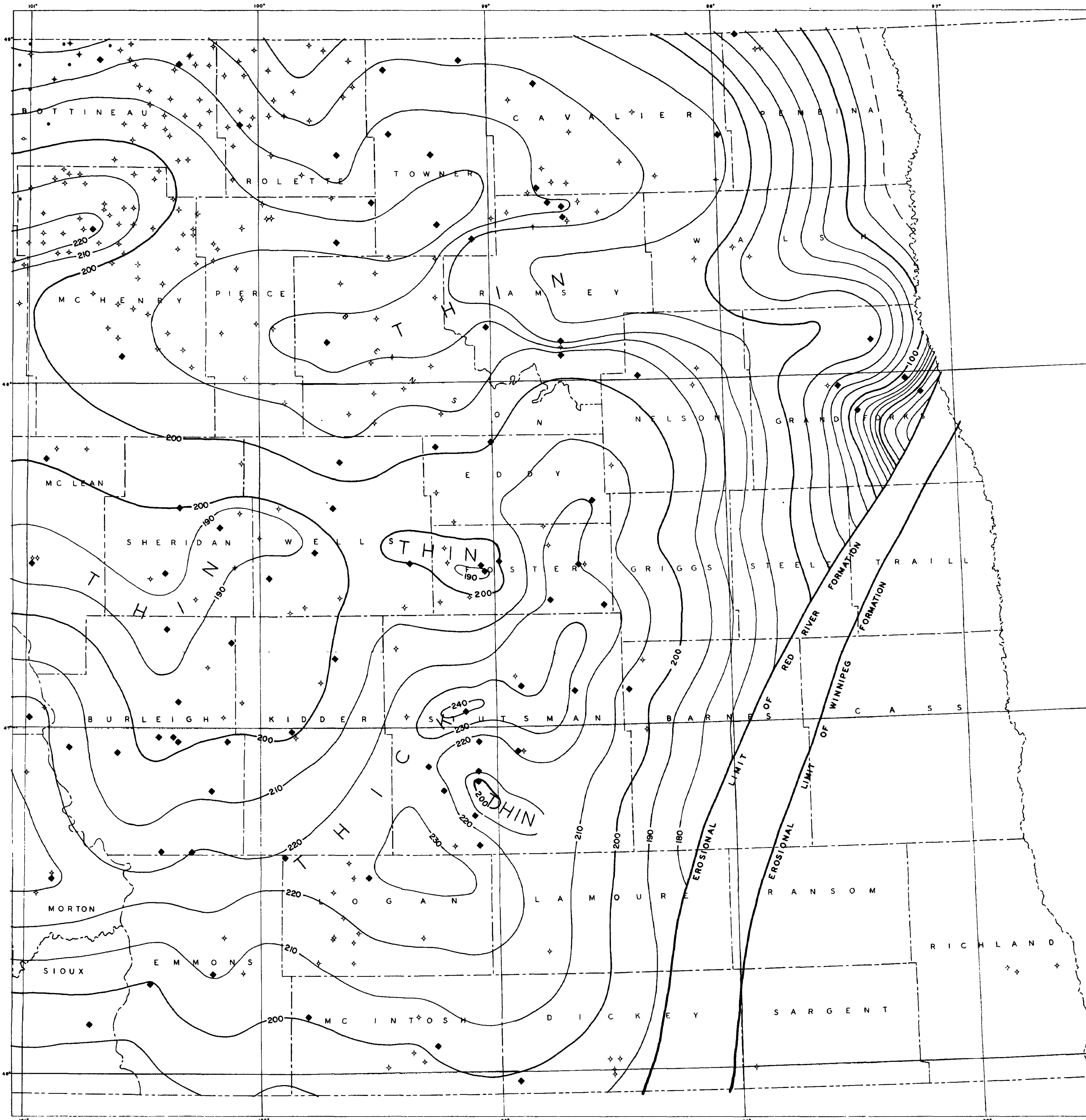
DEADWOOD FORMATION ABSENT

SCALE
10 0 10 20 30 40 MILES

ISOPACHOUS MAP OF DEADWOOD FORMATION

CONTOUR INTERVAL — 10 FEET

PLATE 2



LEGEND

◆ CONTROL WELL

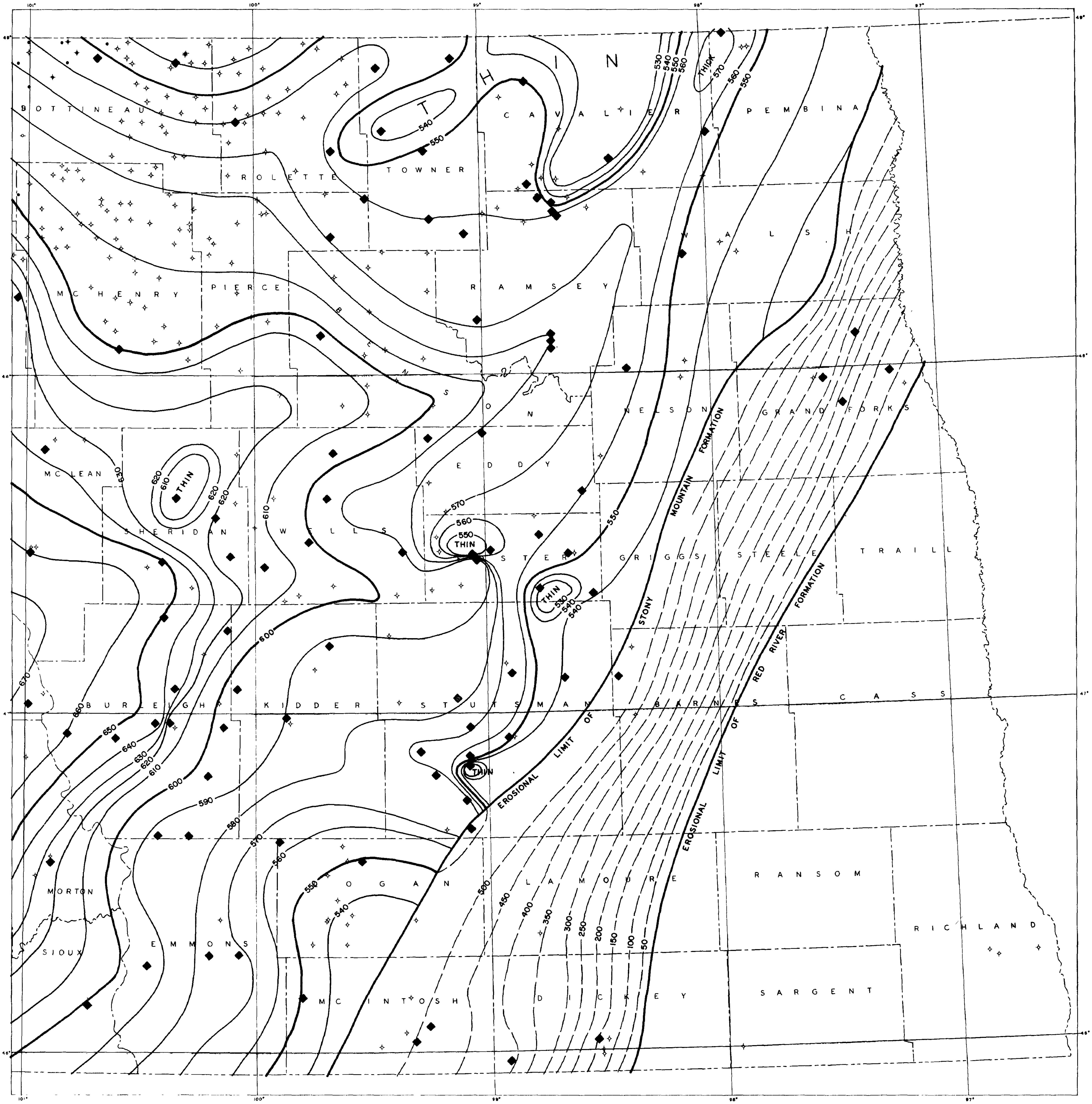
• ✦ ✧ ◆ EXPLORATORY WELL

SCALE 10 0 10 20 30 40 MILES

ISOPACHOUS MAP OF WINNIPEG FORMATION

CONTOUR INTERVAL — 10 FEET

PLATE 3



LEGEND

◆ CONTROL WELL

•✧✦◆ EXPLORATORY WELL

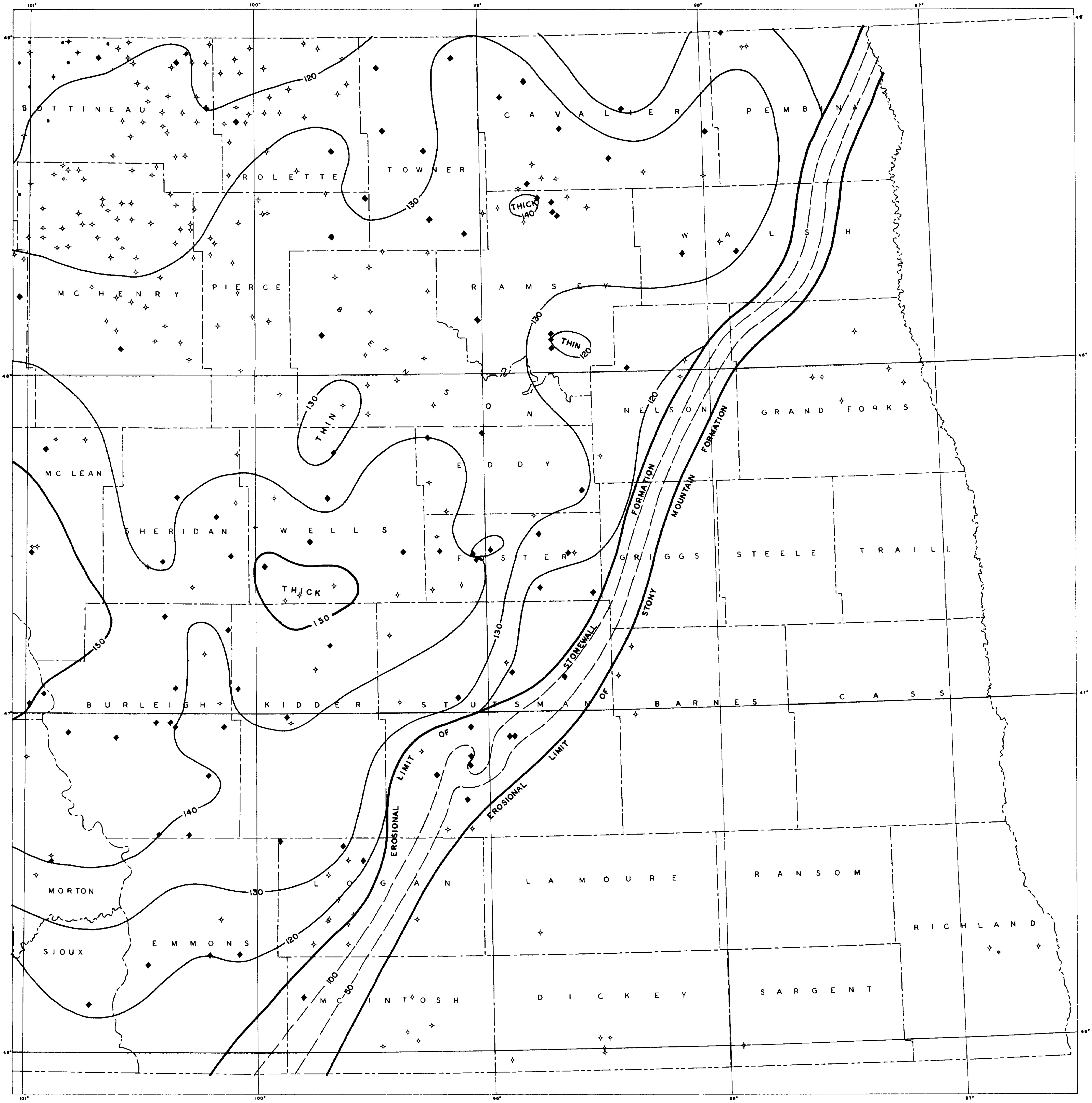
DASHED ISOPACHYTES HAVE 50' INTERVAL

SCALE 10 0 10 20 30 40 MILES

ISOPACHOUS MAP OF RED RIVER FORMATION

CONTOUR INTERVAL — 10 FEET

PLATE 4



LEGEND

◆ CONTROL WELL

•✦✧◆ EXPLORATORY WELL

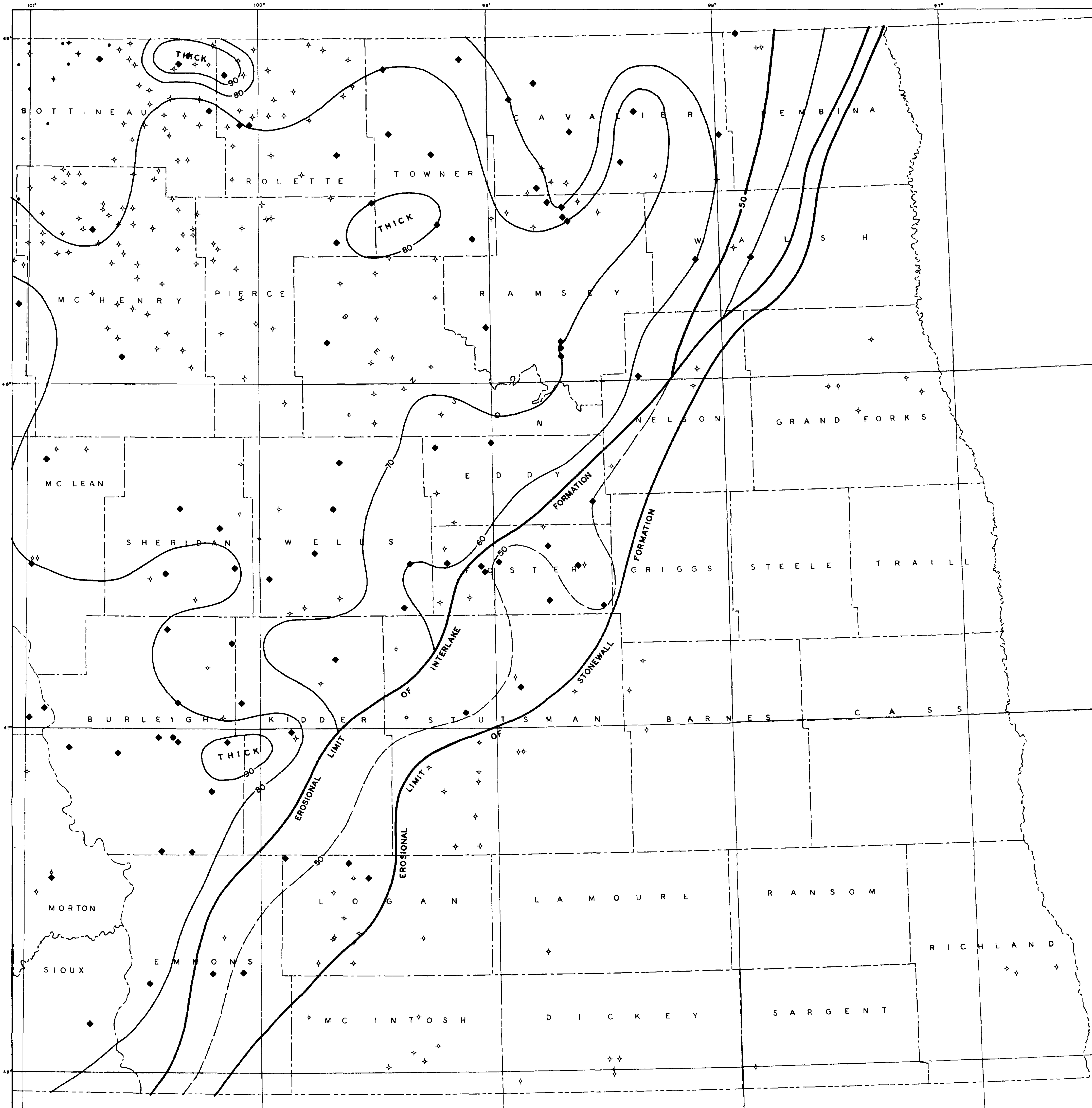
DASHED ISOPACHYTES HAVE 50' INTERVAL

SCALE
10 0 10 20 30 40 MILES

ISOPACHOUS MAP OF STONY MOUNTAIN FORMATION

CONTOUR INTERVAL — 10 FEET

PLATE 5



LEGEND

◆ CONTROL WELL

●-○-✦-◆ EXPLORATORY WELL

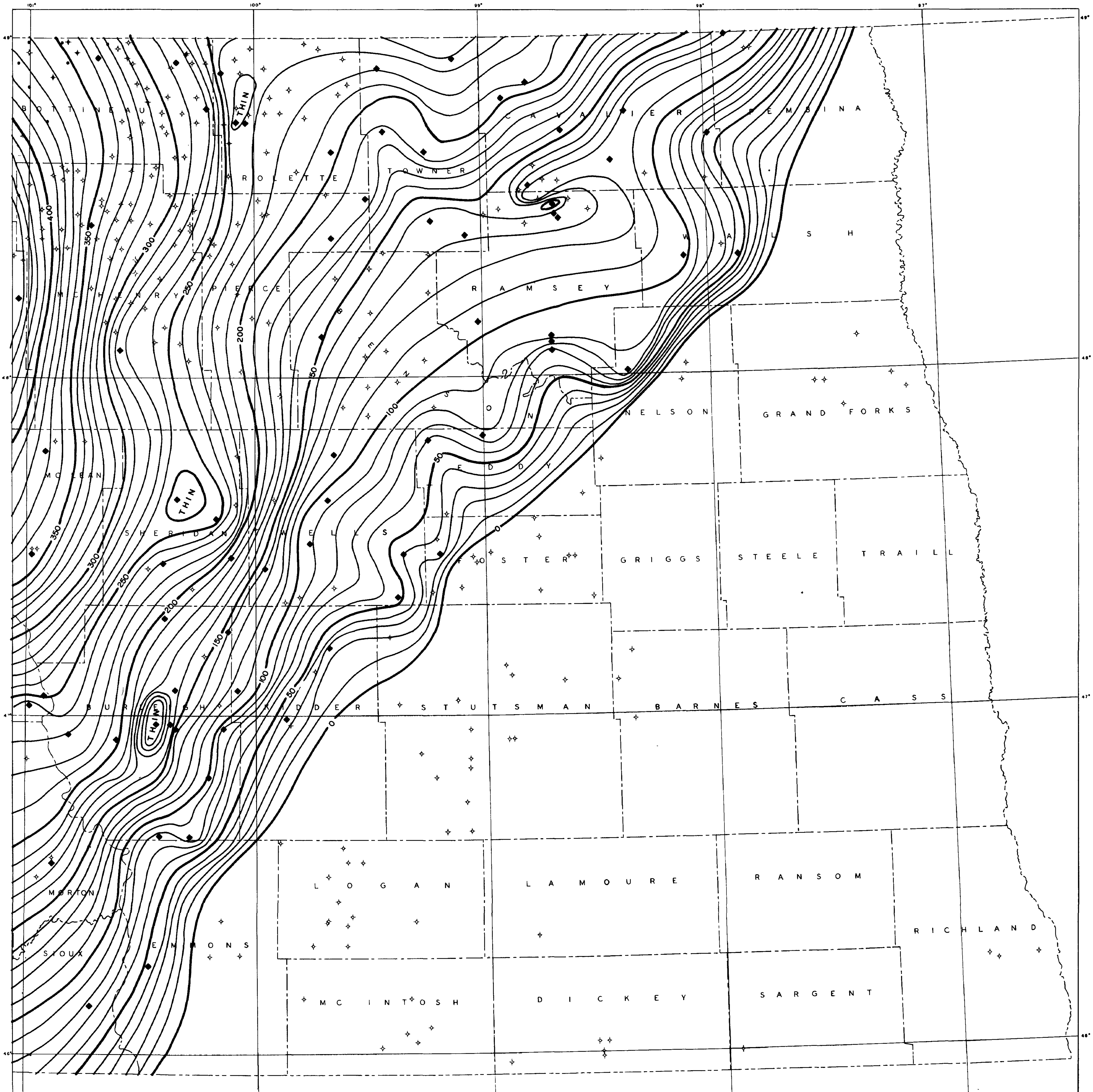
DASHED ISOPACHYTES HAVE 50' INTERVAL

SCALE 10 0 10 20 30 40 MILES

ISOPACHOUS MAP OF STONEWALL FORMATION

CONTOUR INTERVAL — 10 FEET

PLATE 6



LEGEND

◆ CONTROL WELL

•✧✦◆ EXPLORATORY WELL

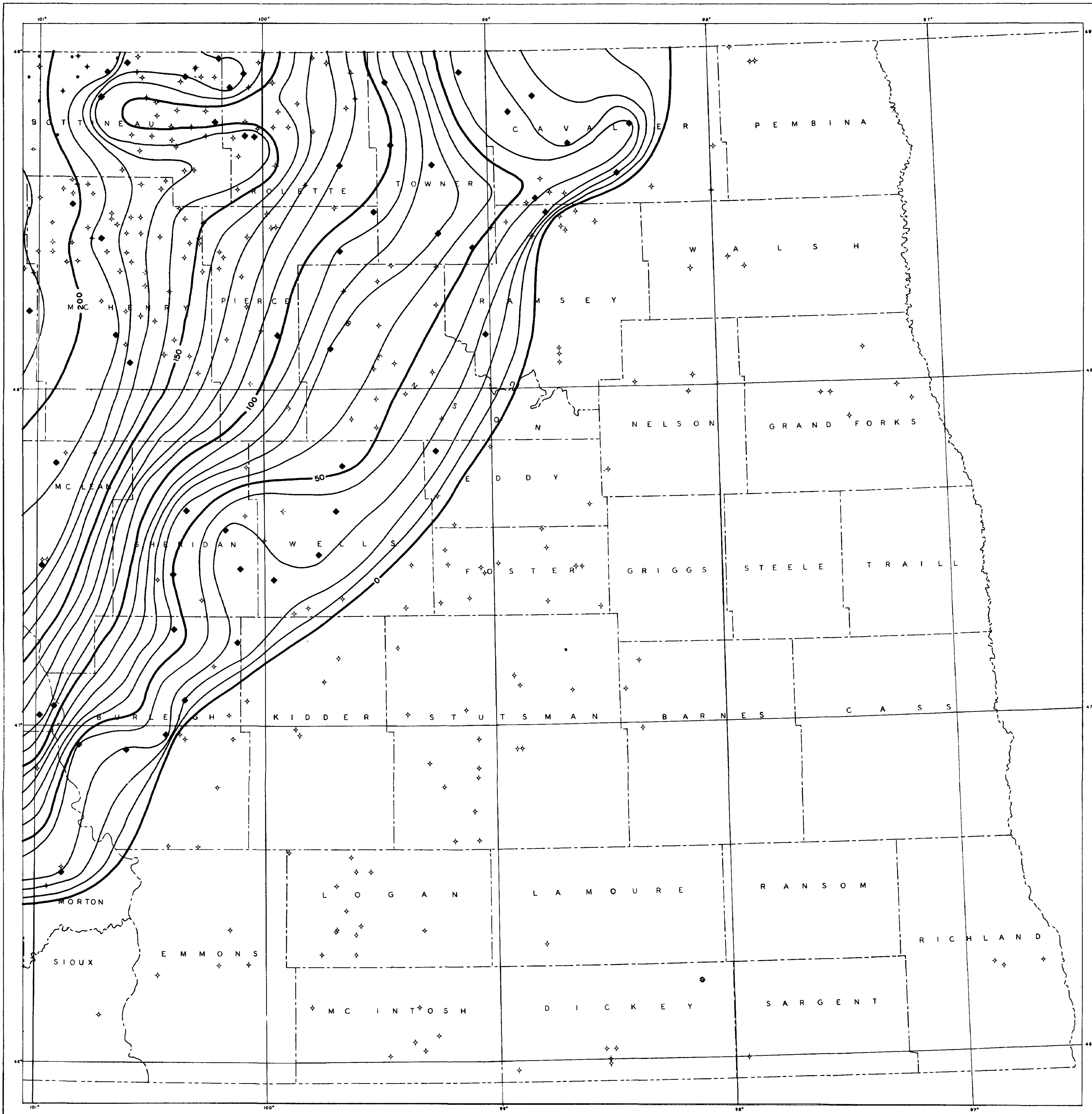
SCALE

10 0 10 20 30 40 MILES

ISOPACHOUS MAP OF INTERLAKE FORMATION

CONTOUR INTERVAL — 10 FEET

PLATE 7



LEGEND

◆ CONTROL WELL

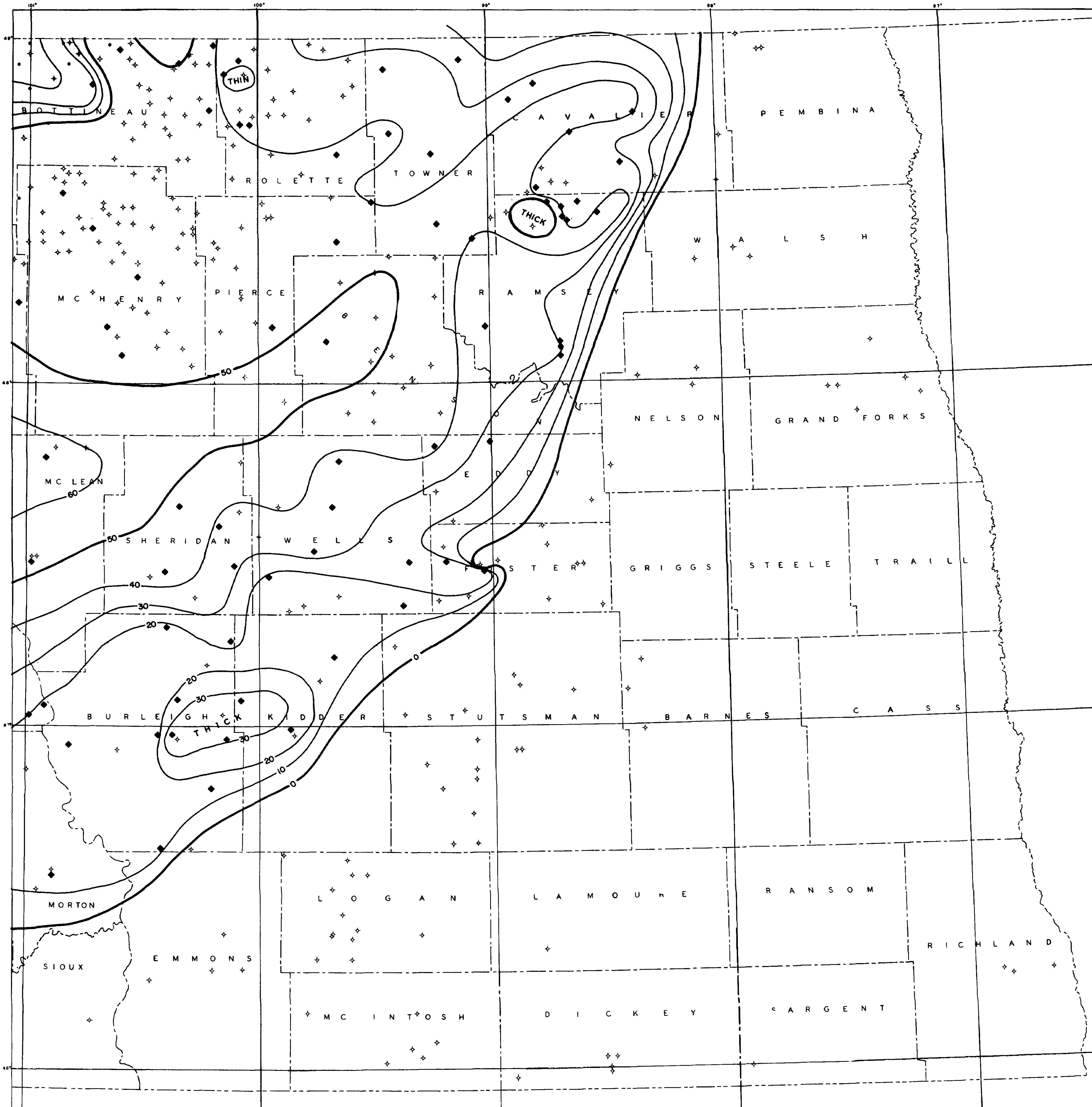
•✦✧◆ EXPLORATORY WELL

SCALE
10 0 10 20 30 40 MILES

ISOPACHOUS MAP OF WINNIPEGOSIS FORMATION

CONTOUR INTERVAL — 10 FEET

PLATE 8



LEGEND

◆ CONTROL WELL

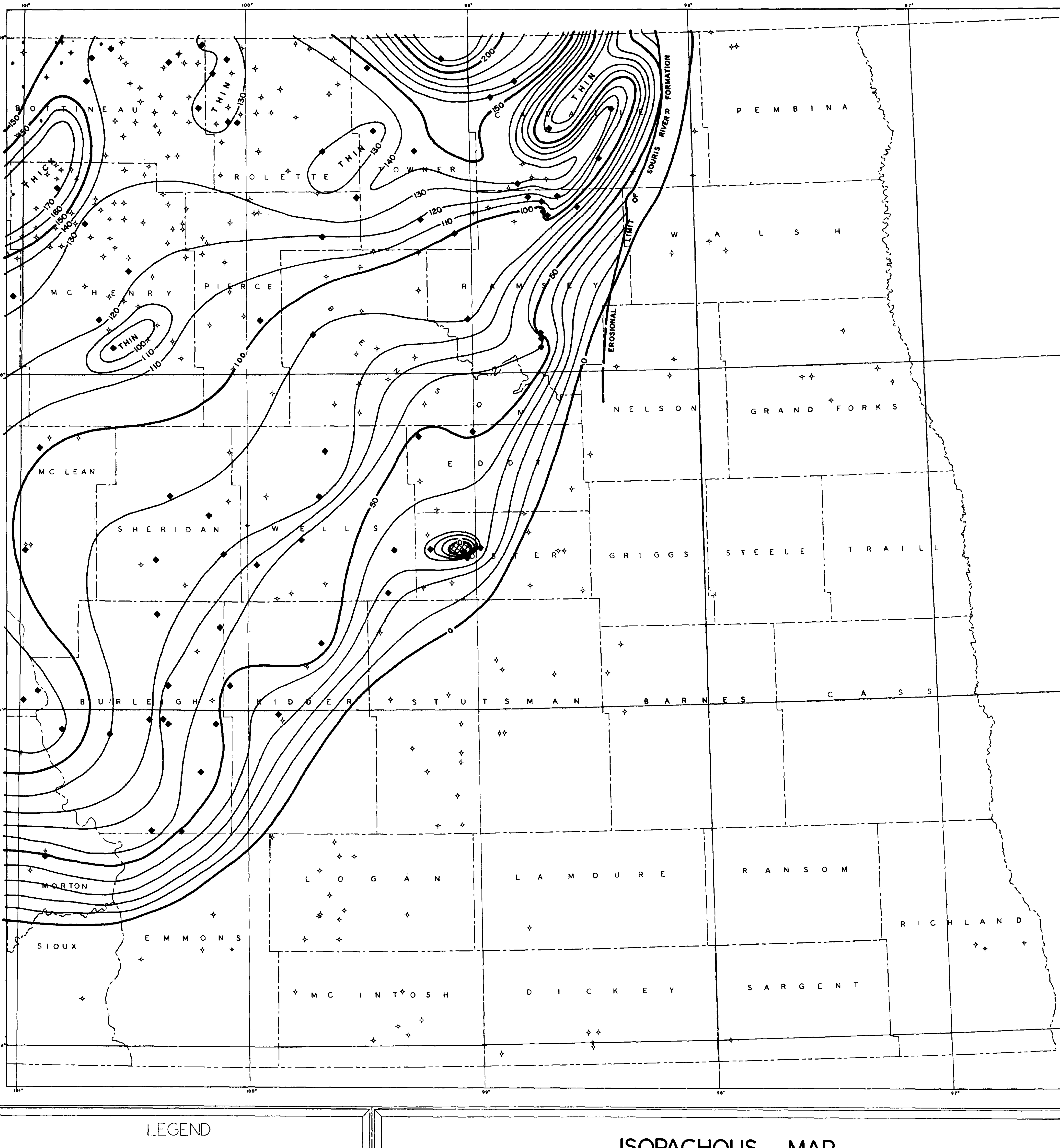
EXPLORATORY WELL

SCALE 10 0 10 20 30 40 MILES

ISOPACHOUS MAP OF PRAIRIE FORMATION

CONTOUR INTERVAL — 10 FEET

PLATE 9



LEGEND

◆ CONTROL WELL

•✦✧◆ EXPLORATORY WELL

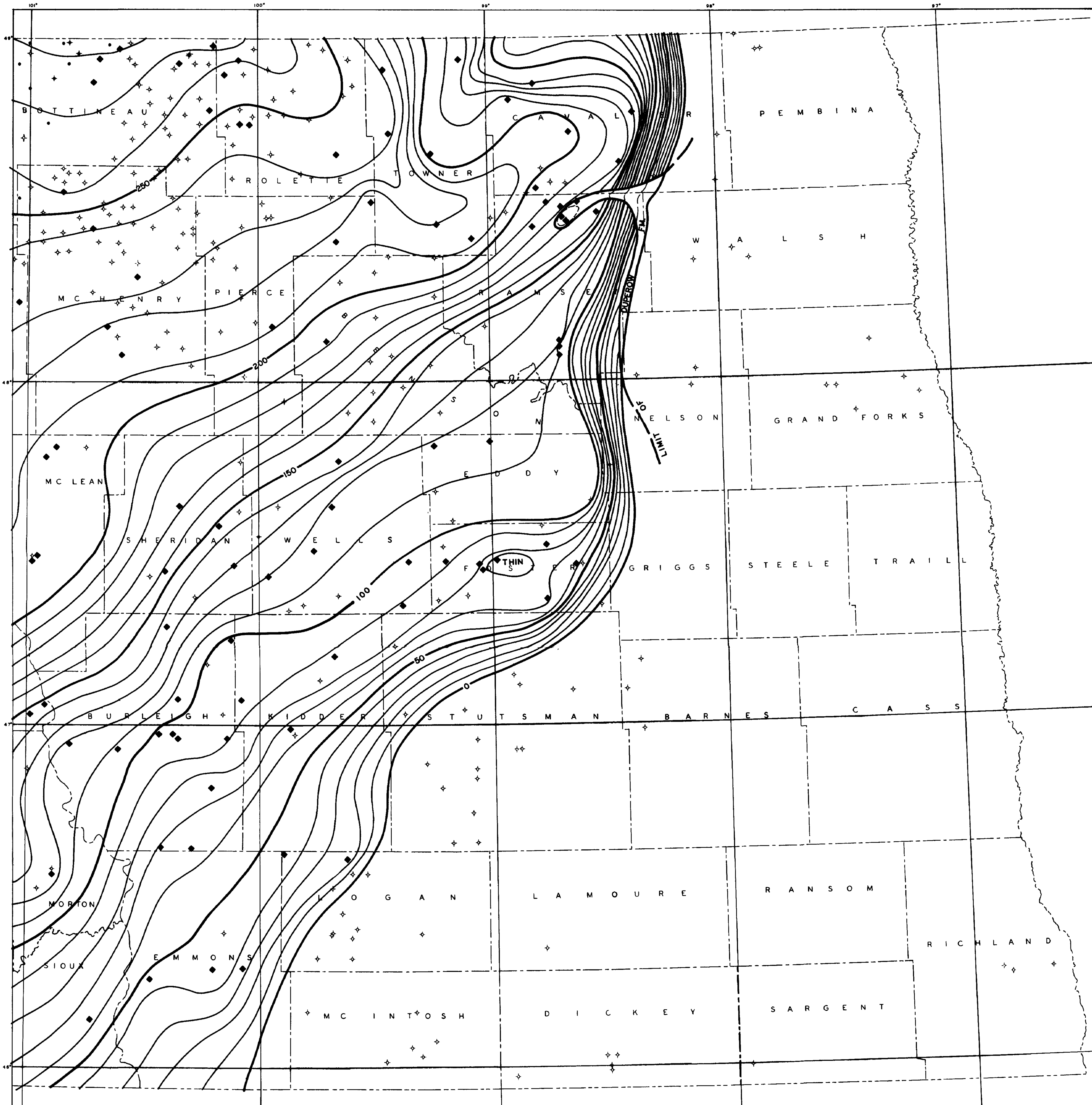
DAWSON BAY ABSENT

SCALE 10 0 10 20 30 40 MILES

ISOPACHOUS MAP OF DAWSON BAY FORMATION

CONTOUR INTERVAL — 10 FEET

PLATE 10



LEGEND

◆ CONTROL WELL

EXPLORATORY WELL

DASHED ISOPACHYTES HAVE 50' INTERVAL

SCALE

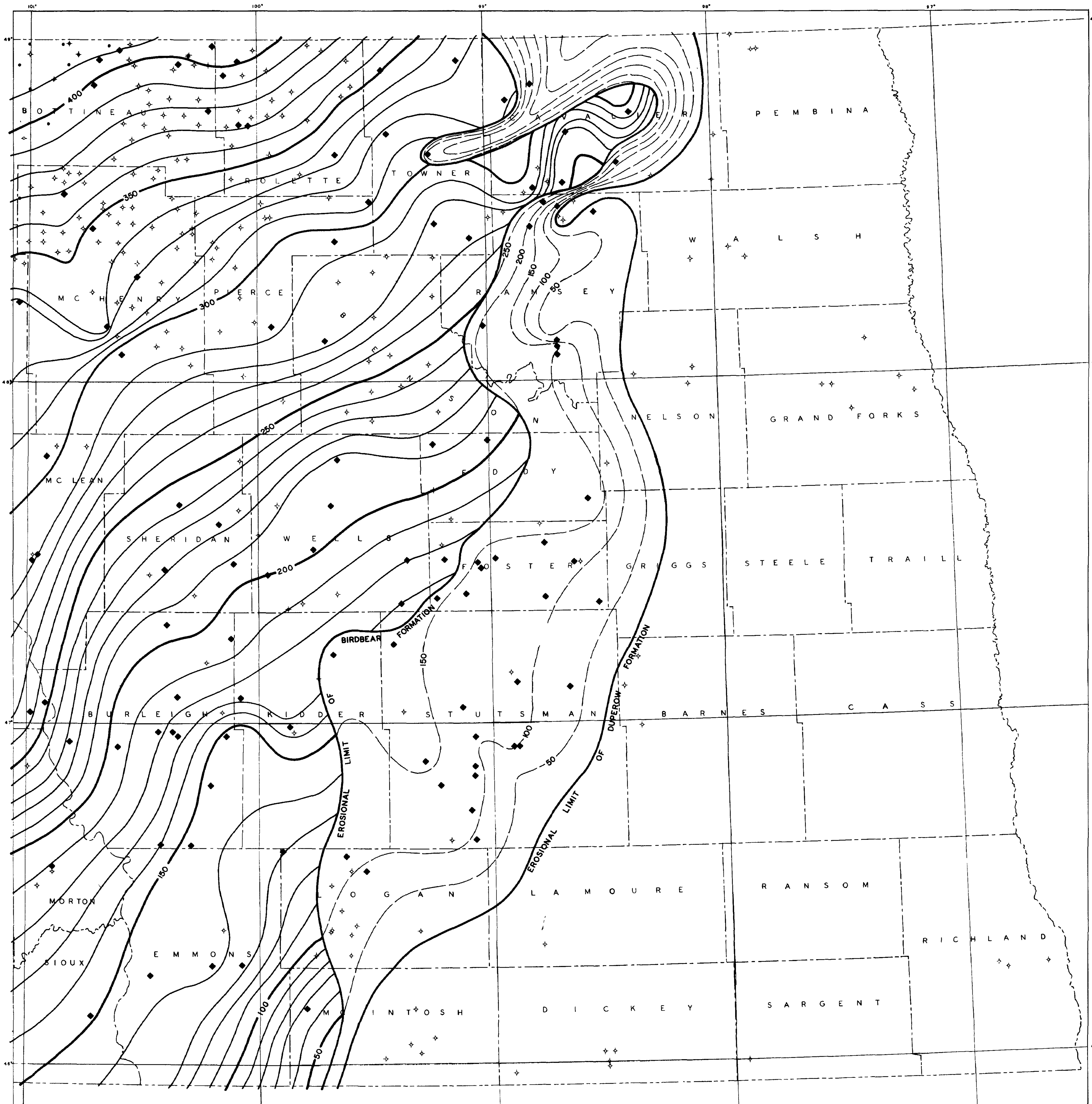
10 0 10 20 30 40 MILES

30
130
35
196

ISOPACHOUS MAP OF SOURIS RIVER FORMATION

CONTOUR INTERVAL — 10 FEET

PLATE II



LEGEND

◆ CONTROL WELL

◆✦✧◆ EXPLORATORY WELL

DASHED ISOPACHYTES HAVE 50' INTERVAL

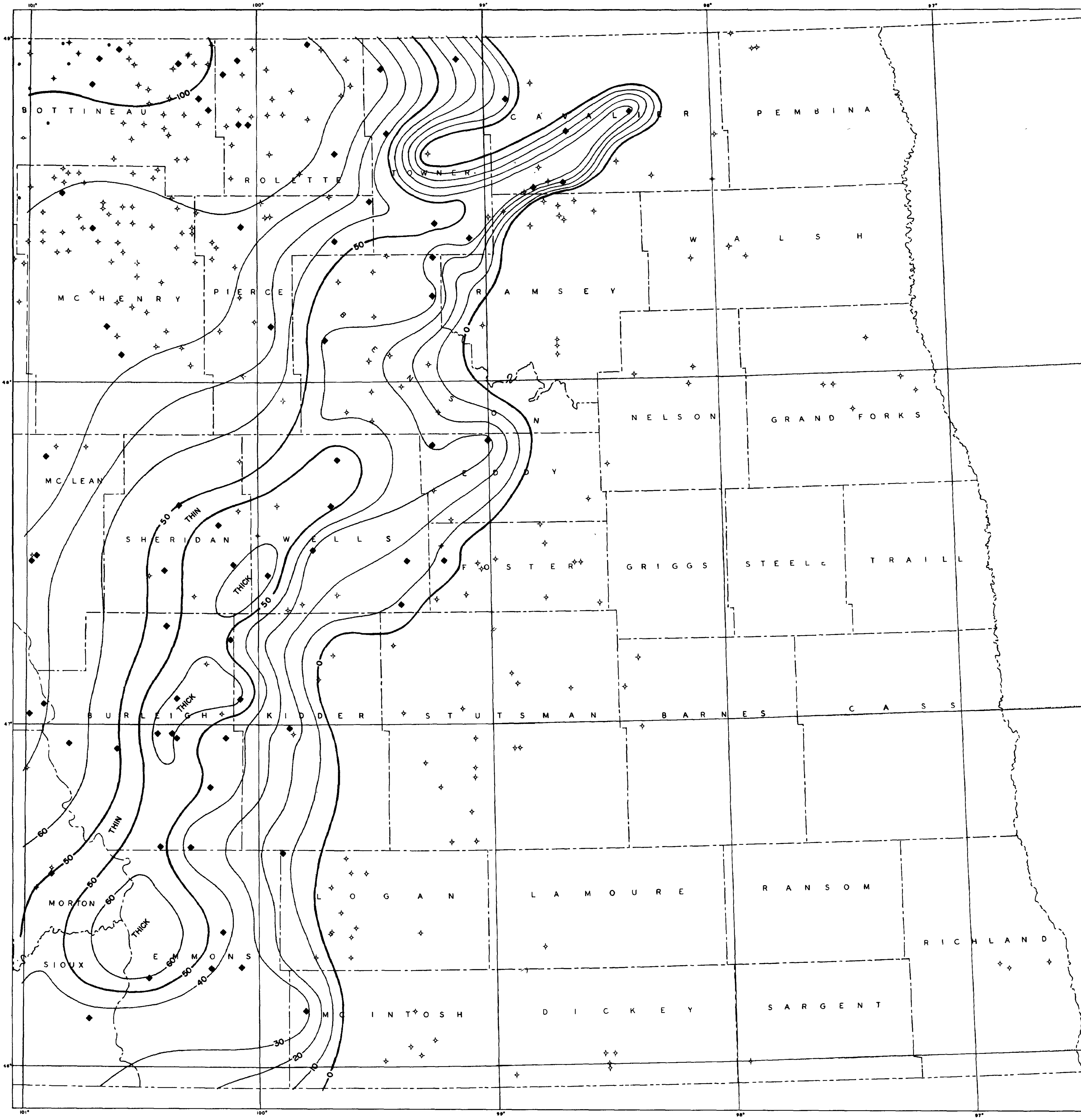
SCALE

10 0 10 20 30 40 MILES

ISOPACHOUS MAP OF DUPEROW FORMATION

CONTOUR INTERVAL — 10 FEET

PLATE 12



LEGEND

◆ CONTROL WELL

•✧✦◆ EXPLORATORY WELL

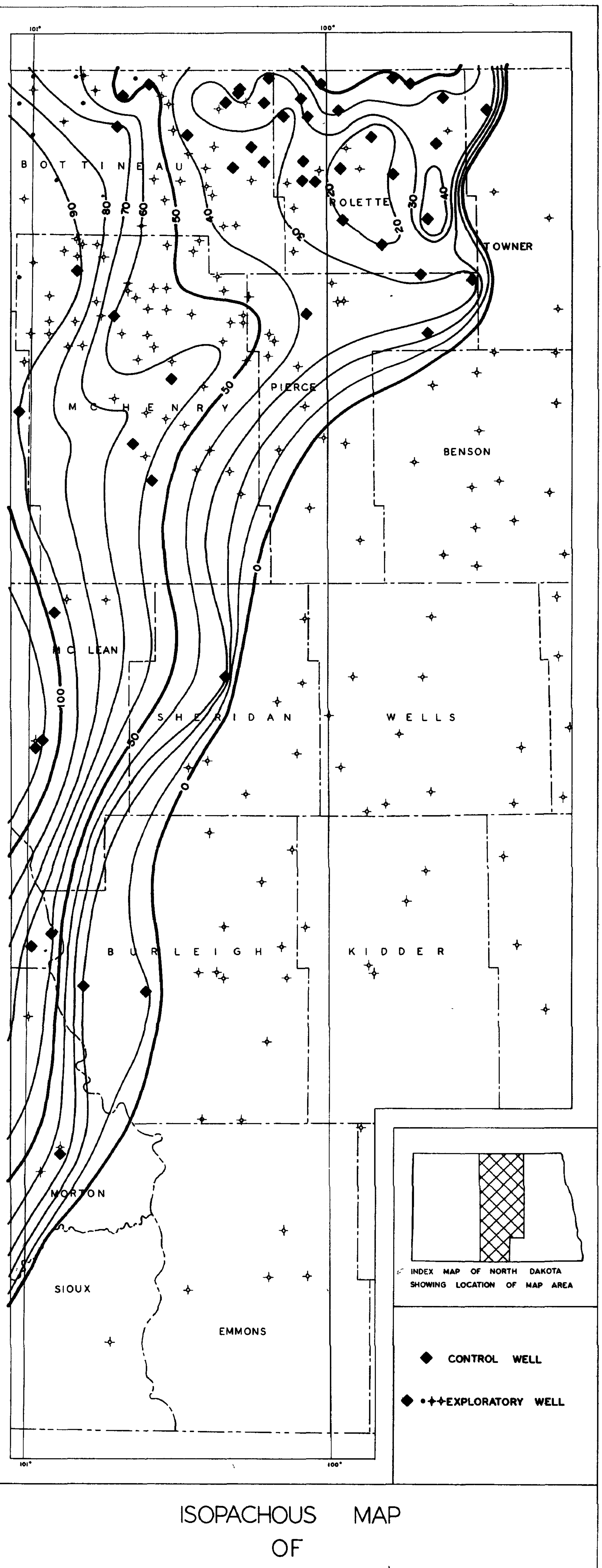
SCALE

10 0 10 20 30 40 MILES

ISOPACHOUS MAP OF BIRDBEAR FORMATION

CONTOUR INTERVAL — 10 FEET

PLATE 13

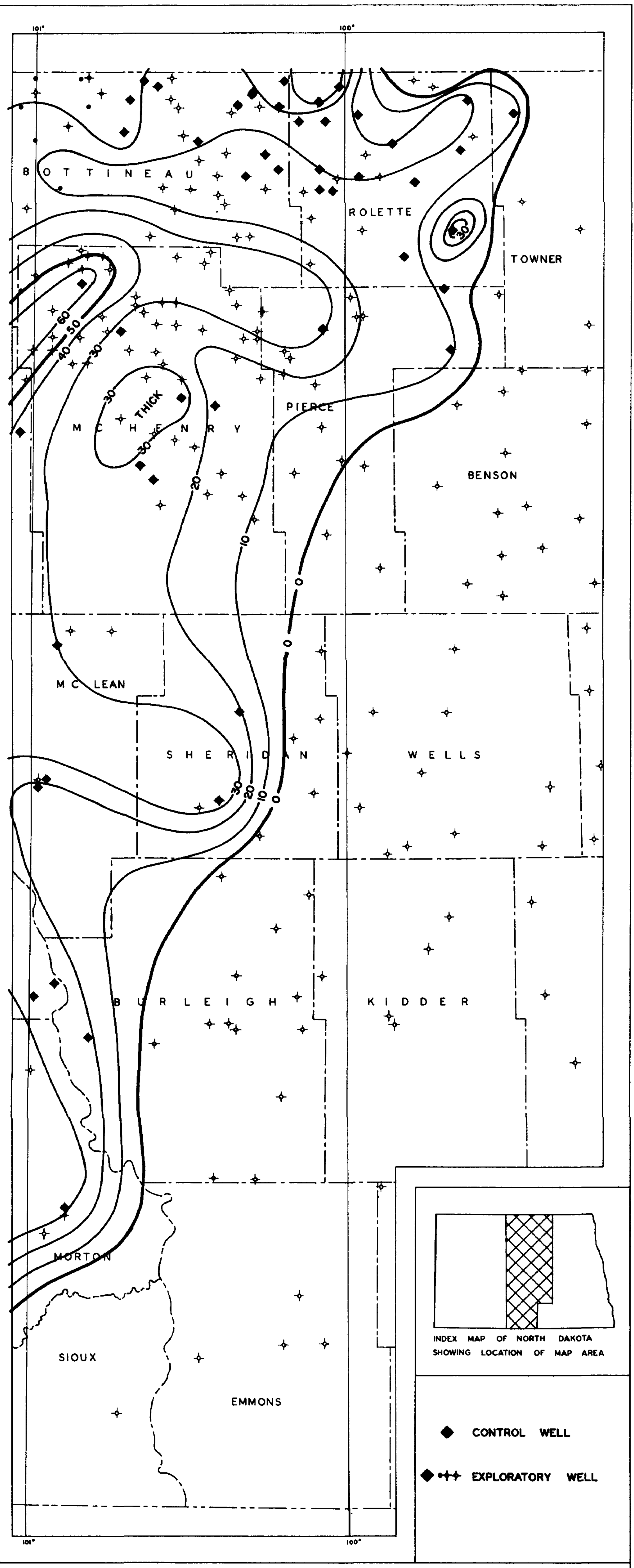


ISOPACHOUS MAP OF THREE FORKS FORMATION

CONTOUR INTERVAL — 10 FEET

SCALE

PLATE 14



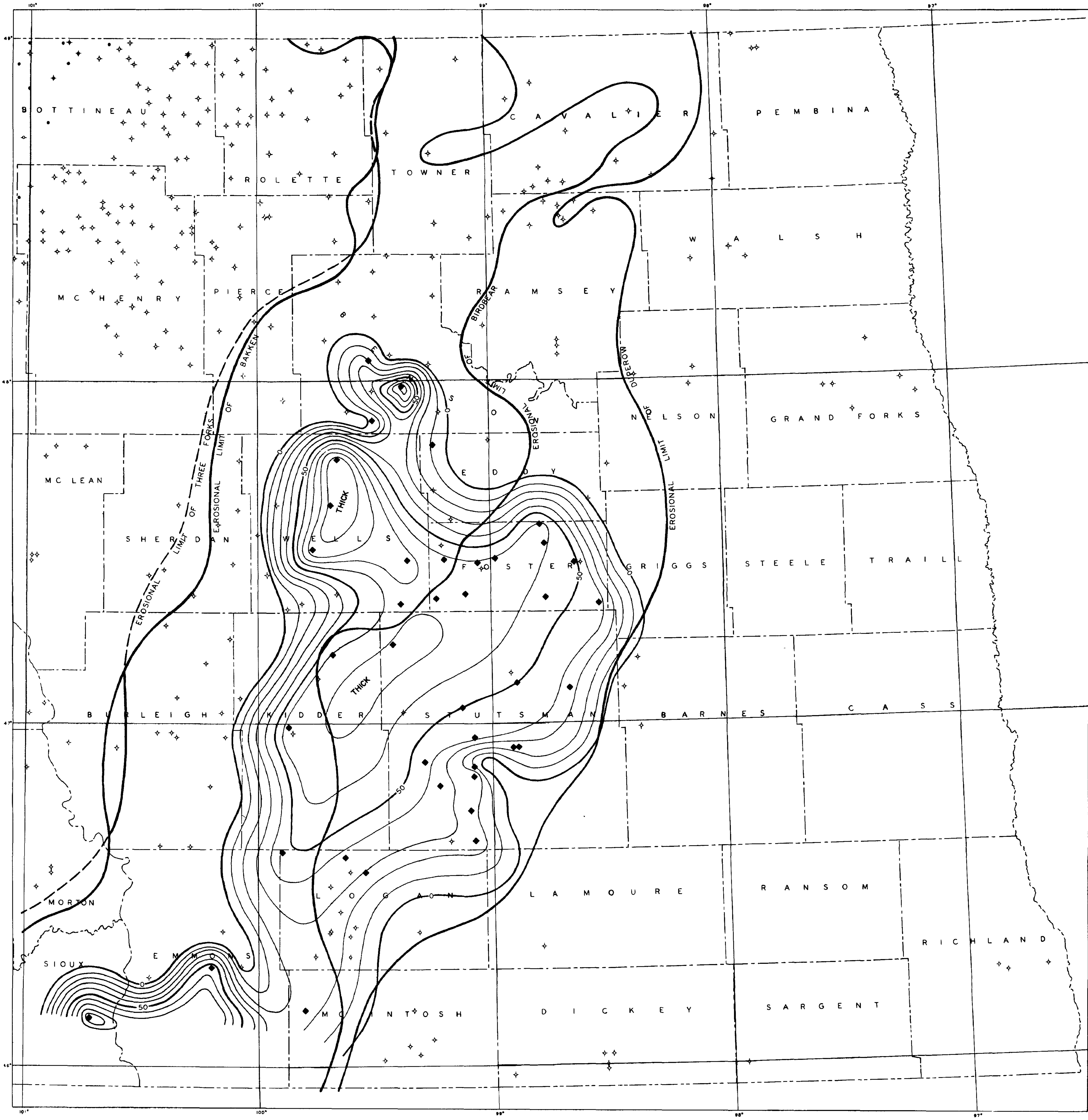
ISOPACHOUS MAP OF BAKKEN FORMATION

CONTOUR INTERVAL — 10 FEET

SCALE

10 0 10 20 30 40 MILES

PLATE 15



LEGEND

◆ CONTROL WELL

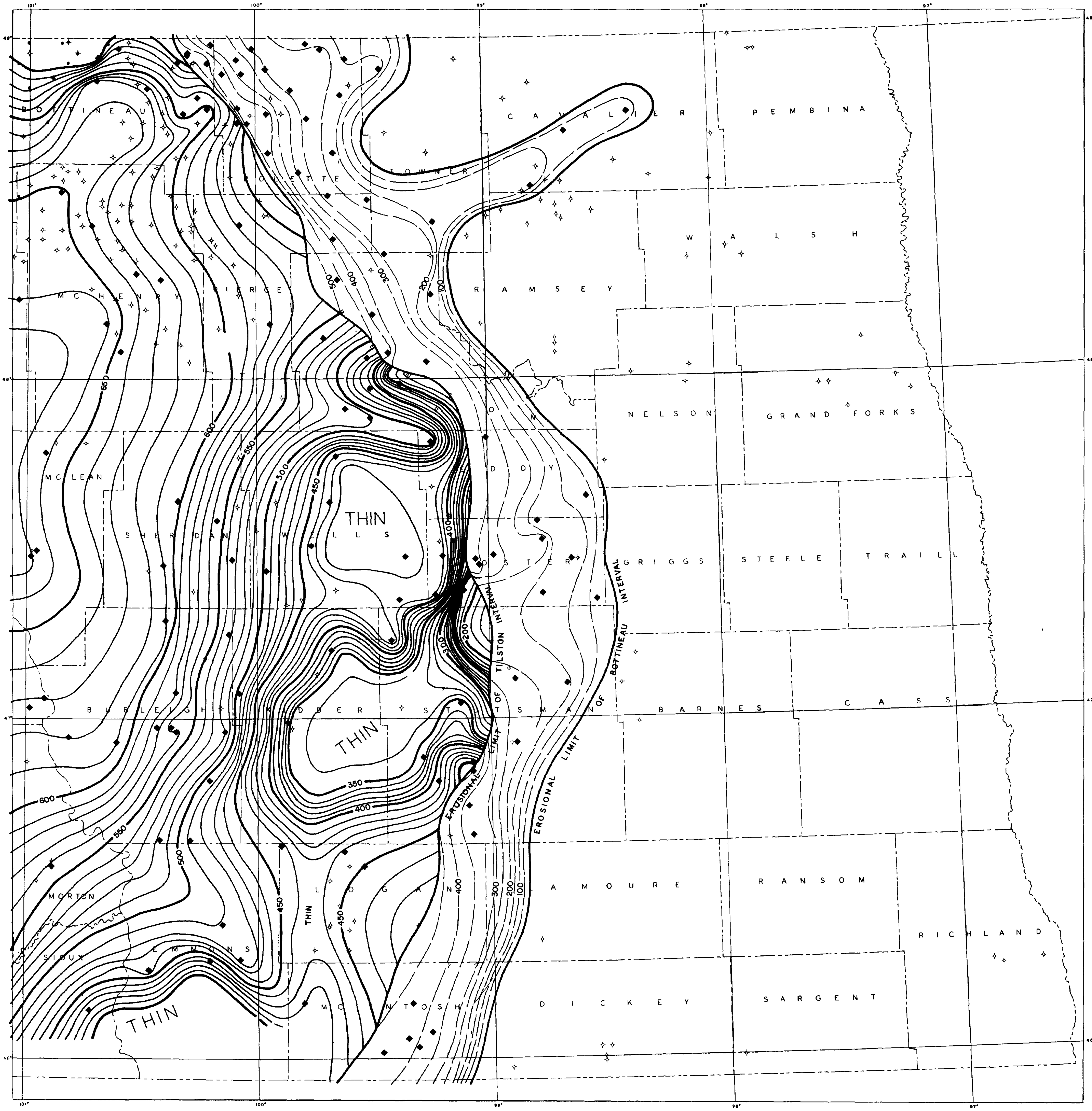
•✦✧◆ EXPLORATORY WELL

SCALE 10 0 10 20 30 40 MILES

ISOPACHOUS MAP OF CARRINGTON SHALE FACIES

CONTOUR INTERVAL — 10 FEET

PLATE 16



LEGEND

◆ CONTROL WELL

•✦✧◆ EXPLORATORY WELL

DASHED ISOPACHYTES HAVE 50' INTERVAL

SCALE

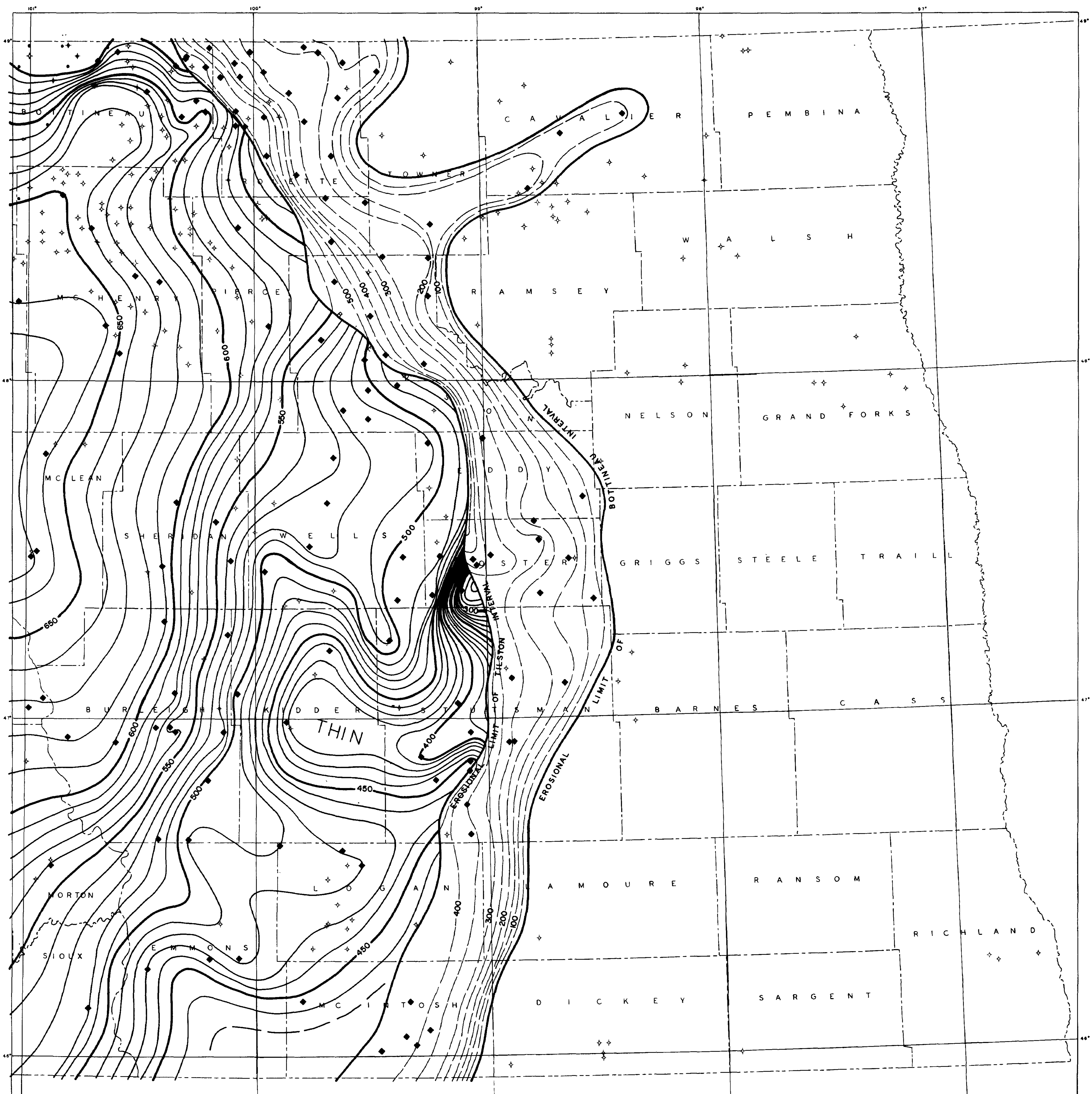
10 0 10 20 30 40 MILES

ISOPACHOUS MAP OF BOTTINEAU INTERVAL

CARRINGTON SHALE EXCLUDED

CONTOUR INTERVAL — 10 FEET

PLATE 17



LEGEND

◆ CONTROL WELL

•✧✦◆ EXPLORATORY WELL

DASHED ISOPACHYTES HAVE 50' INTERVAL

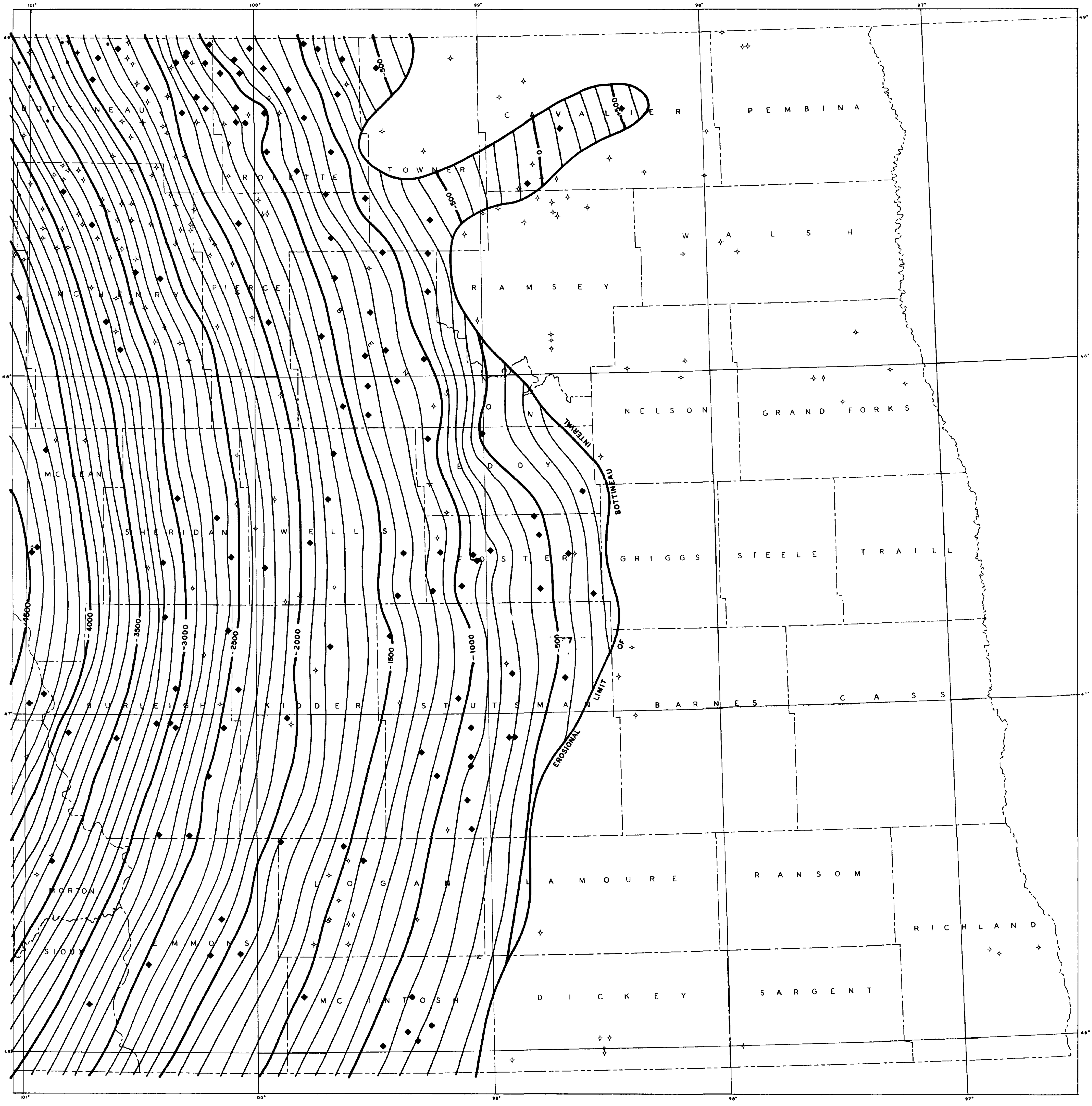
SCALE
10 0 10 20 30 40 MILES

ISOPACHOUS MAP OF BOTTINEAU INTERVAL

CARRINGTON SHALE INCLUDED

CONTOUR INTERVAL — 10 FEET

PLATE 18



LEGEND

◆ CONTROL WELL

• ✧ ✦ ◆ EXPLORATORY WELL

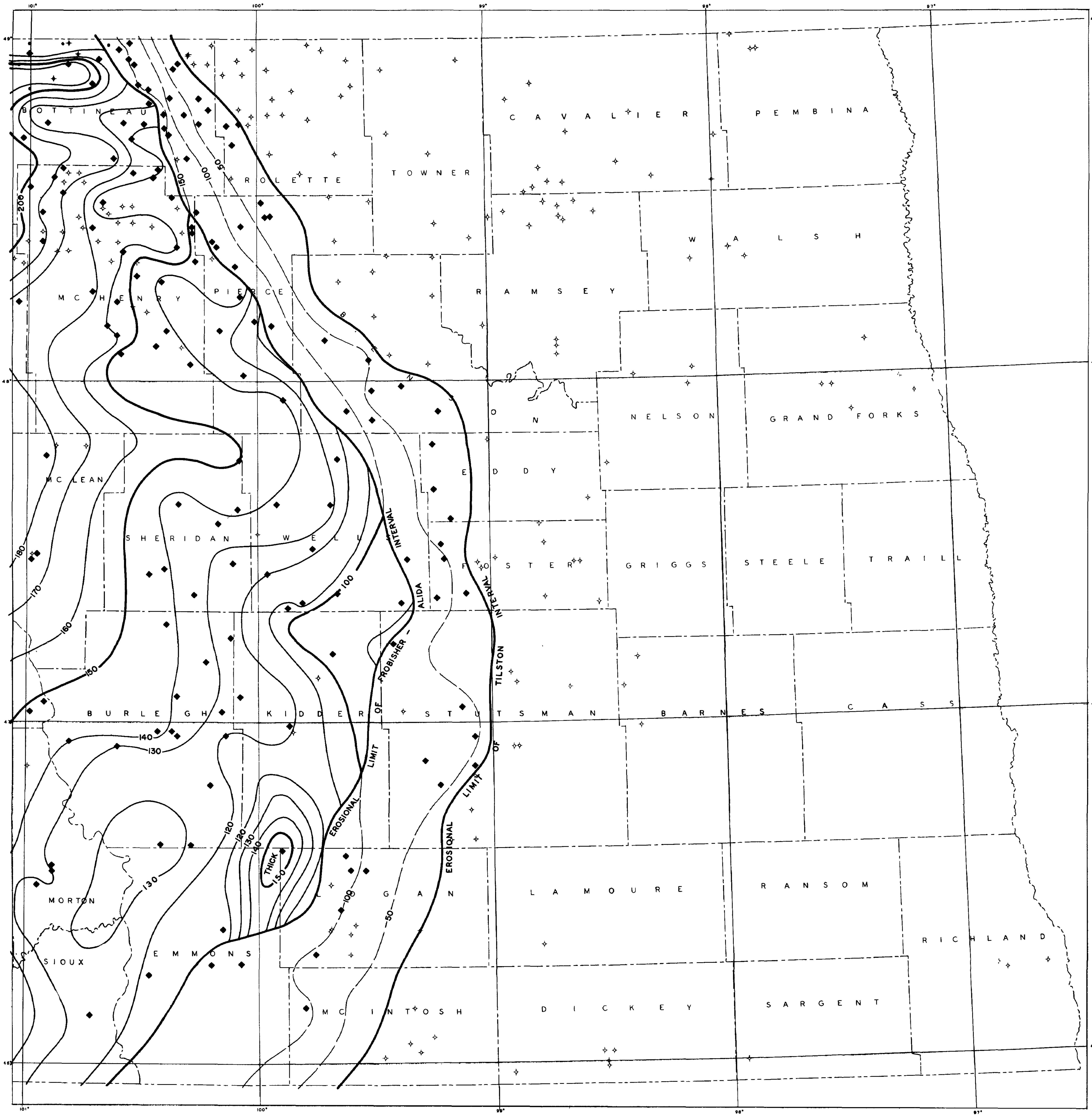
SCALE

10 0 10 20 30 40 MILES

STRUCTURE MAP ON BASE OF BOTTINEAU INTERVAL

CONTOUR INTERVAL — 100 FEET

PLATE 19



LEGEND

◆ CONTROL WELL

•✧✦◆ EXPLORATORY WELL

DASHED ISOPACHYTES HAVE 50' INTERVAL

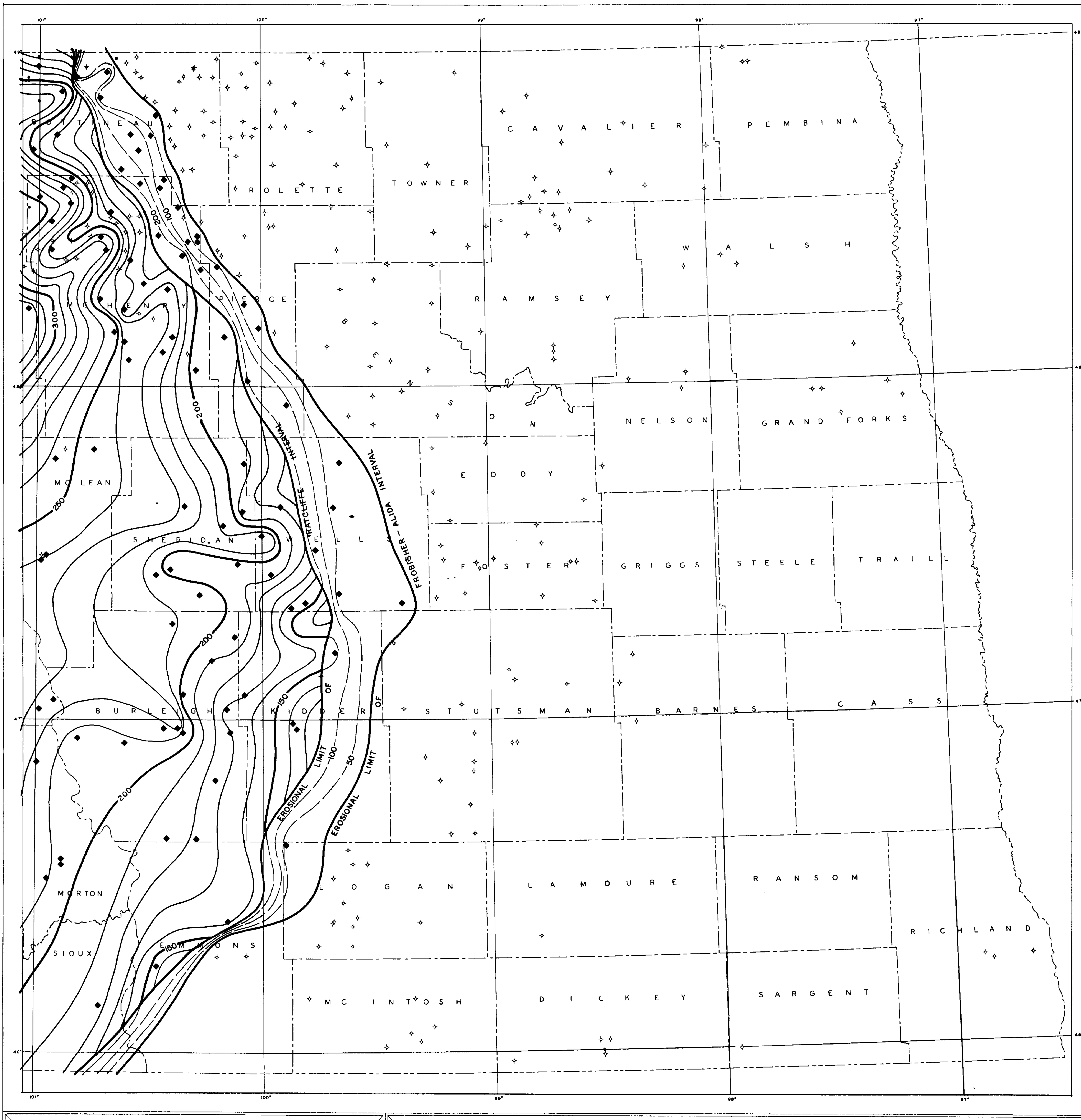
SCALE

10 0 10 20 30 40 MILES

ISOPACHOUS MAP OF TILSTON INTERVAL

CONTOUR INTERVAL — 10 FEET

PLATE 20



LEGEND

◆ CONTROL WELL

•✧✦◆ EXPLORATORY WELL

DASHED ISOPACHYTES HAVE 50' INTERVAL

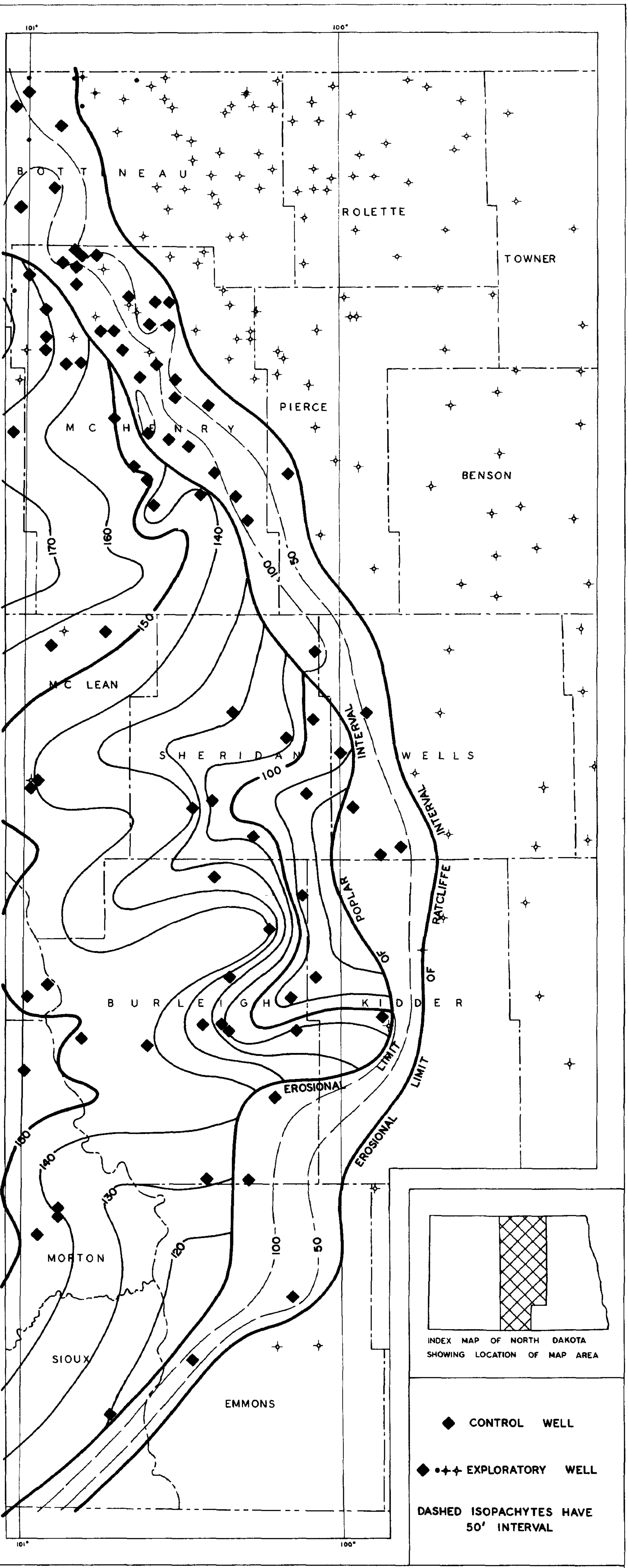
SCALE

10 0 10 20 30 40 MILES

ISOPACHOUS MAP OF FROBISHER-ALIDA INTERVAL

CONTOUR INTERVAL — 10 FEET

PLATE 21



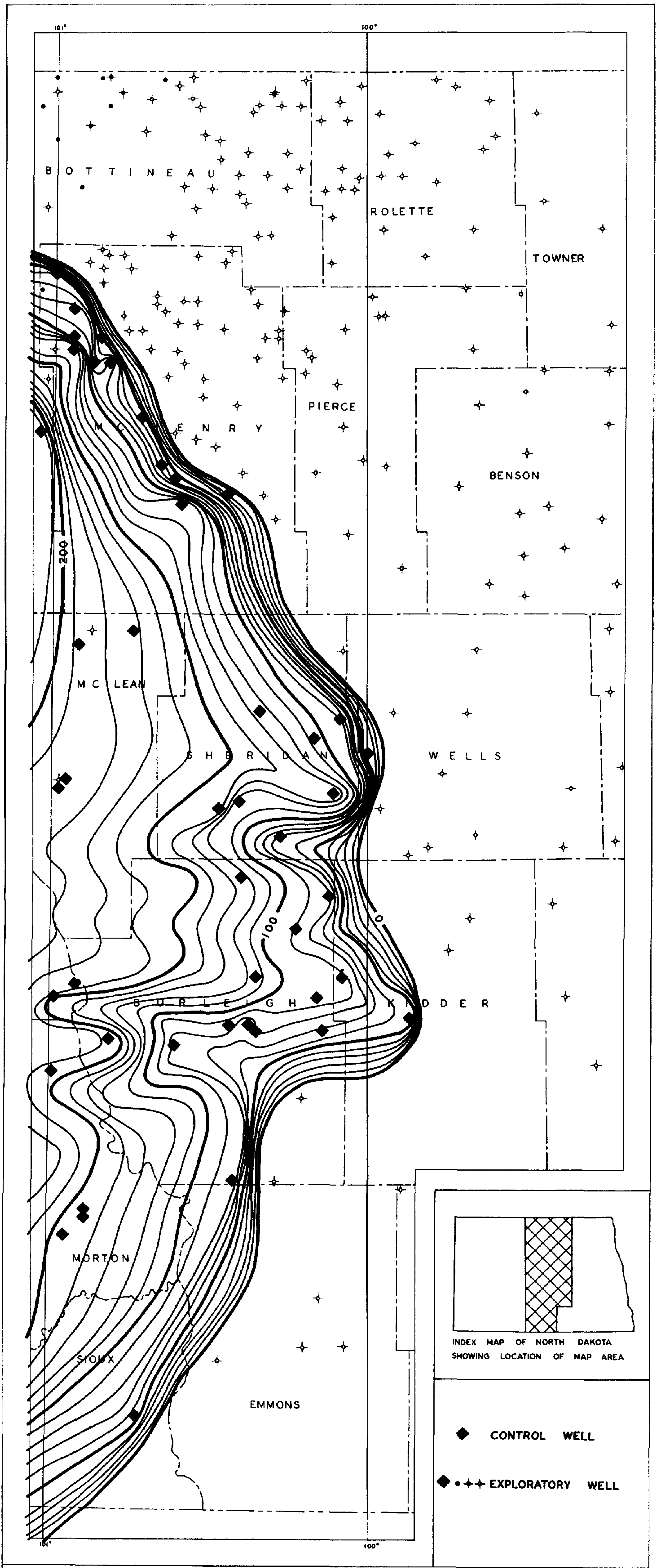
ISOPACHOUS MAP OF RATCLIFFE INTERVAL

CONTOUR INTERVAL — 10 FEET

SCALE

10 0 10 20 30 40 MILES

PLATE 22



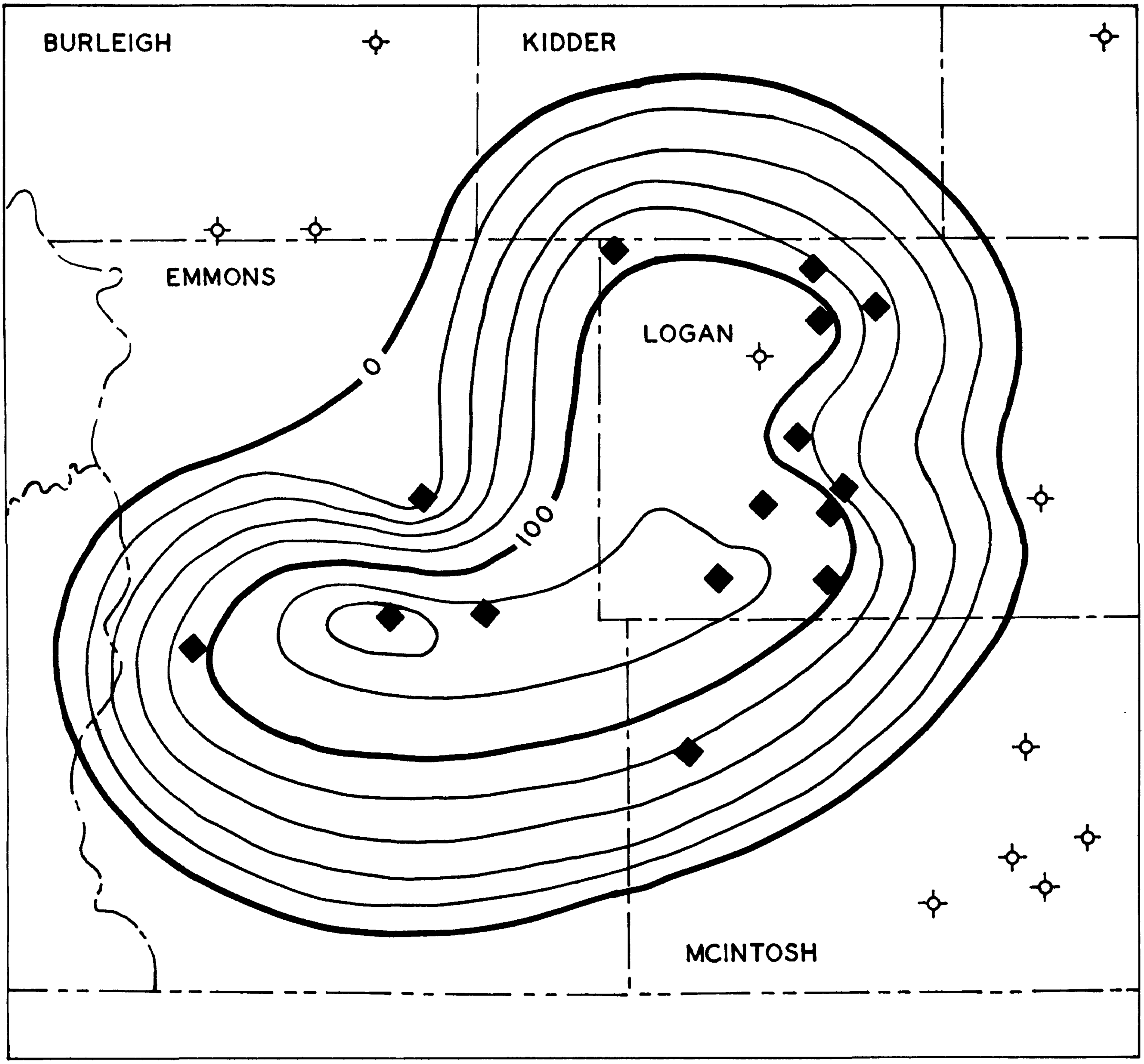
ISOPACHOUS MAP OF POPLAR INTERVAL

CONTOUR INTERVAL — 10 FEET

SCALE

10 0 10 20 30 40 MILES

PLATE 23

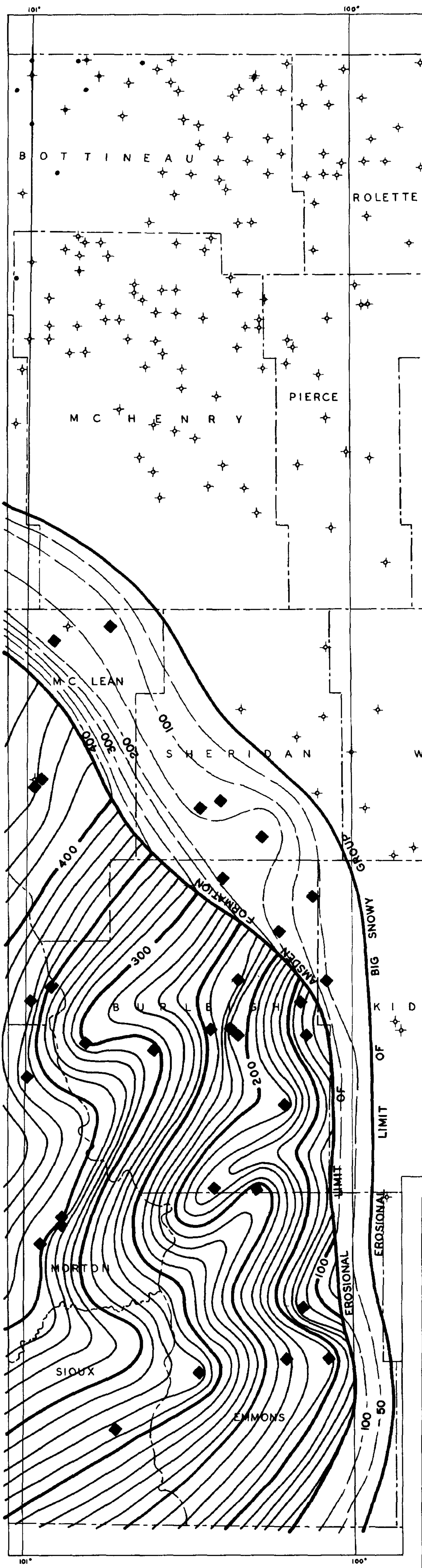


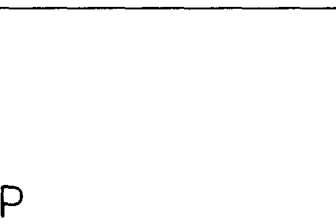
ISOPACHOUS MAP OF POST-POPLAR --- PRE-PIPER SOLUTION BRECCIA

◆ CONTROL WELL

⌖ ◆ EXPLORATORY WELL

CONTOUR INTERVAL — 20 FEET





INDEX MAP OF NORTH DAKOTA SHOWING LOCATION OF MAP AREA

◆ CONTROL WELL

◆ • ✦ ✧ EXPLORATORY WELL

DASHED ISOPACHYTES HAVE 50' INTERVAL

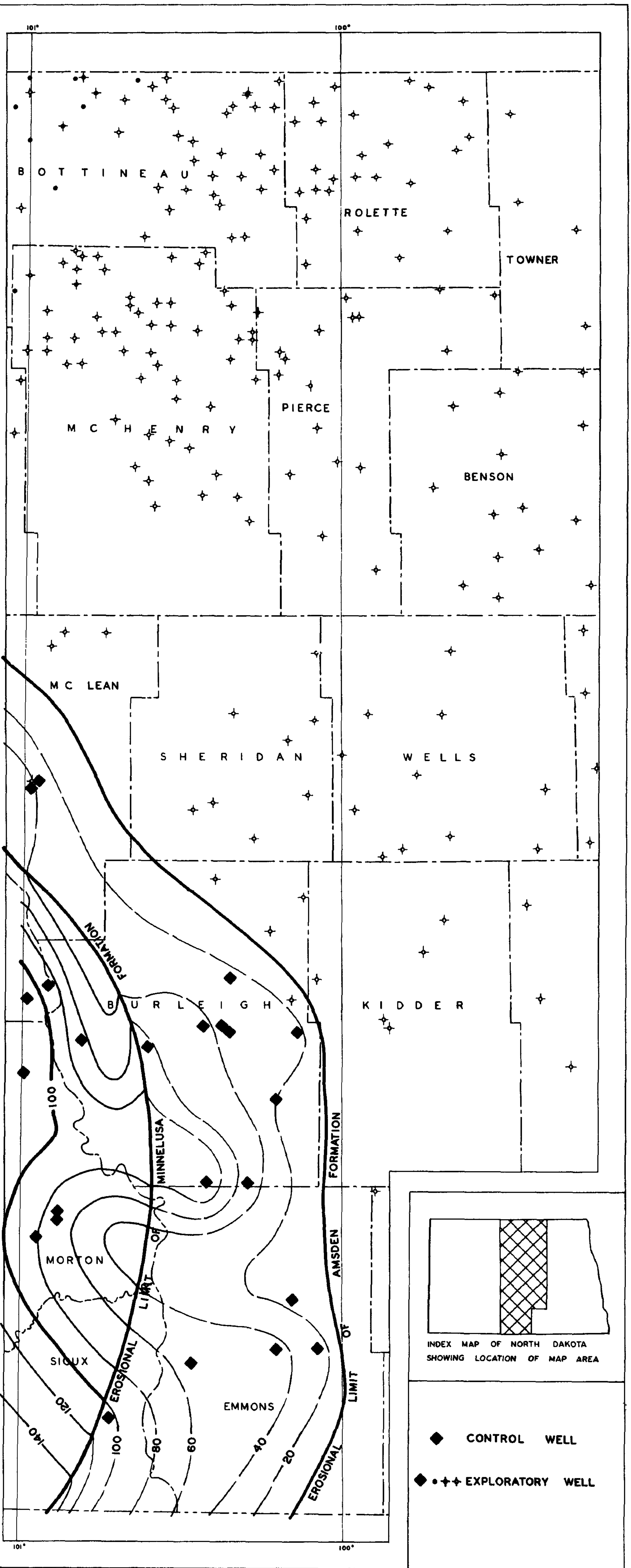
ISOPACHOUS MAP OF BIG SNOWY GROUP

CONTOUR INTERVAL — 10 FEET

SCALE

10 0 10 20 30 40 MILES

PLATE 25



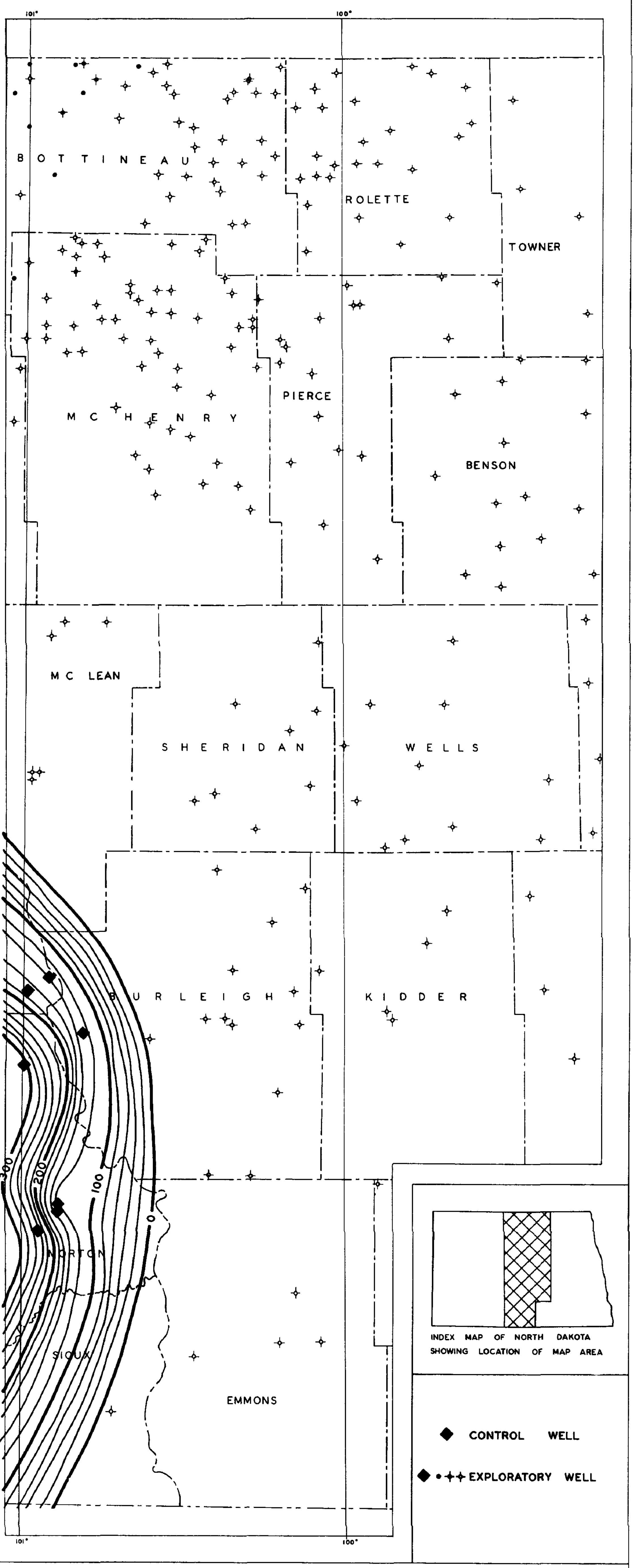
ISOPACHOUS MAP OF "AMSDEN" FORMATION

CONTOUR INTERVAL — 20 FEET

SCALE

10 0 10 20 30 40 MILES

PLATE 26



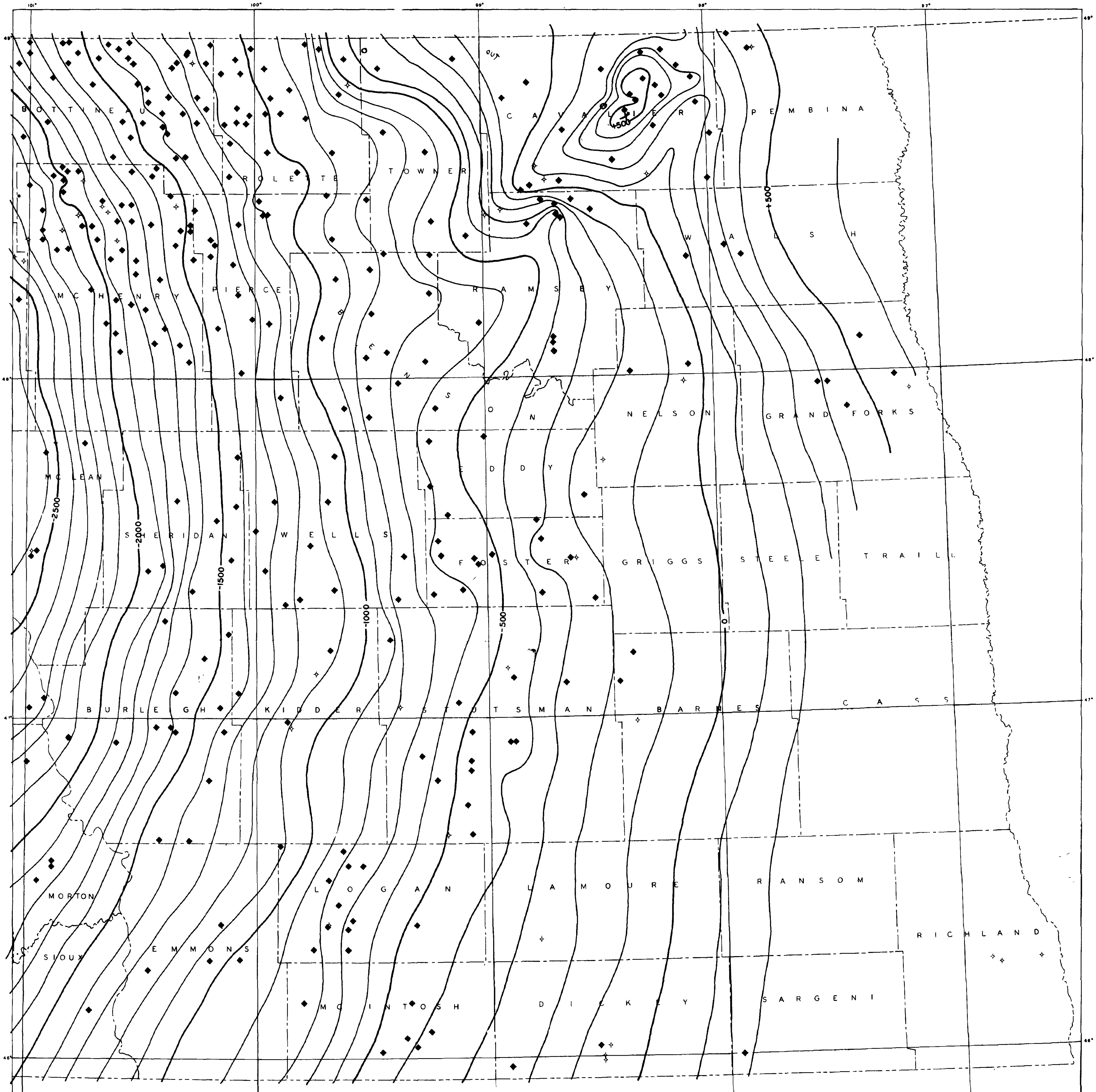
ISOPACHOUS MAP OF MINNELUSA FORMATION

CONTOUR INTERVAL — 20 FEET

SCALE

10 0 10 20 30 40 MILES

PLATE 27



LEGEND

◆ CONTROL WELL

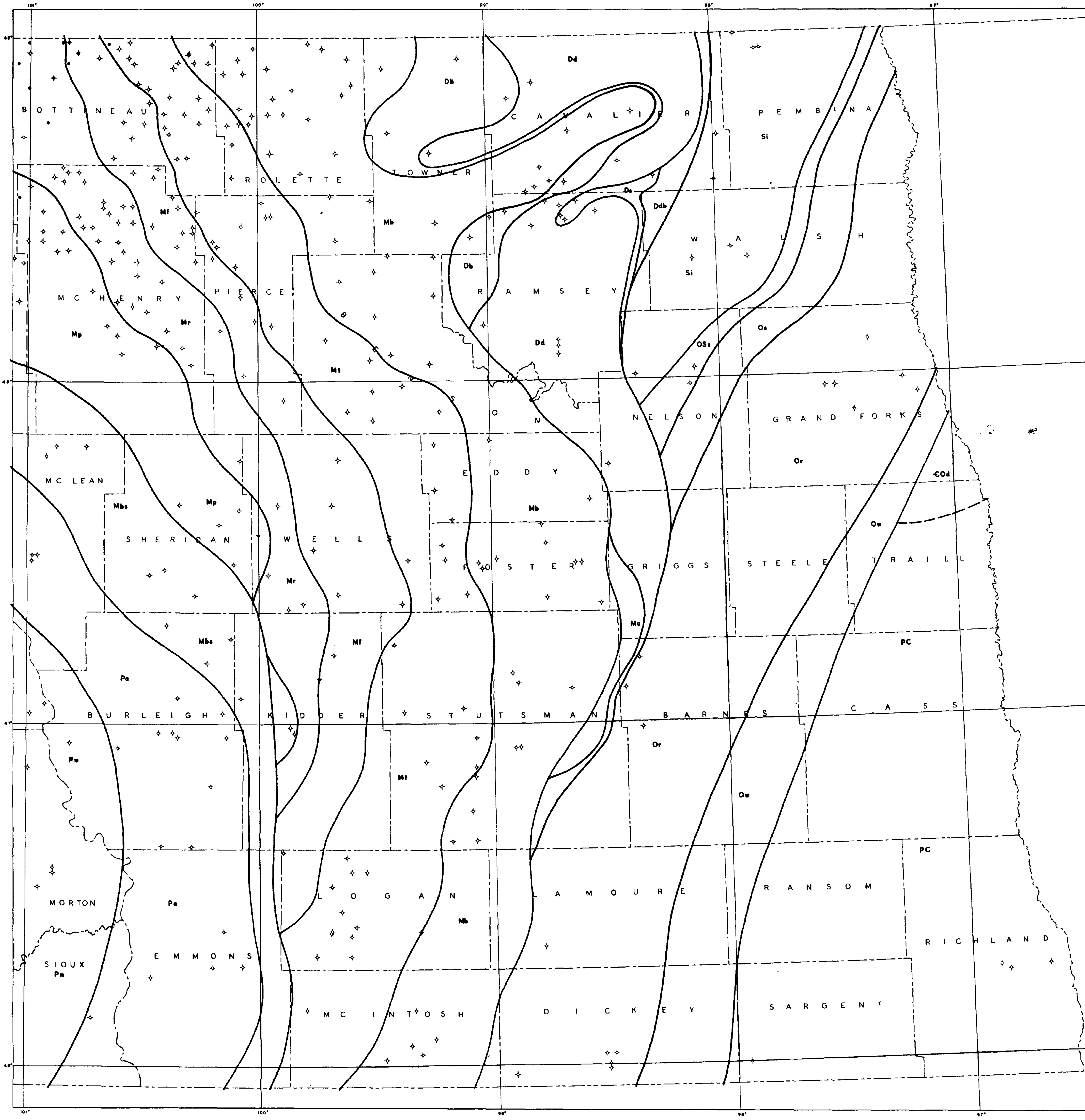
•✦✧◆ EXPLORATORY WELL

SCALE
10 0 10 20 30 40 MILES

CONTOUR MAP OF PRE-MESOZOIC SURFACE

CONTOUR INTERVAL — 100 FEET

PLATE 28



LEGEND

Pm	Minnelusa Fm.	Mf	Frobisher–Alida Int.
Pa	Amsden Fm.	Mt	Tilston Int.
Mbs	Big Snowy Gp.	Mb / Mc	Bottineau Int. / Carrington Sh.
Mp	Poplar Int.	Db	Birdbear Fm.
Mr	Ratcliffe Int.	Dd	Duperow Fm.
Ds	Souris River Fm.	Os	Stony Mountain Fm.
Ddb	Dawson Bay Fm.	Or	Red River Fm.
Si	Interlake Fm.	Ow	Winnipeg Fm.
OSs	Stonewall Fm.	€Od	Deadwood Fm.
		PC	Precambrian

SCALE
10 0 10 20 30 40 MILES

PRE-MESOZOIC

PALEOGEOLOGIC MAP

PLATE 29

PLATE 30

CROSS SECTION OF THE CAMBRIAN, ORDOVICIAN, AND SILURIAN SYSTEMS IN EASTERN NORTH DAKOTA

PLATE 31

CROSS SECTION OF THE DEVONIAN SYSTEM IN EASTERN NORTH DAKOTA

PLATE 32

CROSS SECTION OF THE MISSISSIPPIAN AND PENNSYLVANIAN SYSTEMS IN EASTERN NORTH DAKOTA