Oil and Gas Potential of the Icebox Formation (Ordovician)

Aaron J. Ulishney[1], Richard D. LeFever[1], and Julie A. LeFever[2]

[1]Department of Geology and Geological Engineering
University of North Dakota
Grand Forks ND 58202

[2]North Dakota Geological Survey
University Station
Grand Forks ND 58202

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NORTH DAKOTA GEOLOGICAL SURVEY
Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources

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ACKNOWLEDGMENTS

We thank Ed Murphy and Lynn Helms for their comments on an earlier version of this paper, and Lynn Helms for providing us with test data on some of the Montana wells. This paper is based upon an M.S. thesis recently completed by the senior author at the University of North Dakota.

ABSTRACT

The Icebox Fm (Ordovician) is a regionally extensive shale, the middle of three formations within the Winnipeg Group. Wireline gamma-ray logs were used to recognize and trace coarser lithofacies within the Icebox Formation in North Dakota and eastern Montana.

Forty distinct sandy lithofacies were identified in the study area. Five have regional extent, and cover most of the study area. Five additional sand bodies each extend across several 10s of miles. The remaining 30 identifiable bodies are of only local extent, and typically are evident in only a few wells. Based on the existing cores, it appears that the sandy lithofacies probably represent intervals of bioturbated sandstone and siltstone within the shalier Icebox Formation.

The bioturbated sandy intervals were probably deposited in a lower shoreface or shallow offshore environment. Areas of greater sand body thickness to the west probably represent deposition in shoreline settings. There were several shallowing episodes in the region during Icebox time.

The Winnipeg Group has produced from 14 wells in seven fields in North Dakota. All of the production is from the Black Island Formation, below the Icebox. The wells are primarily gas producers. No wells have produced from the Winnipeg in Montana.

Formation tests on the Winnipeg have been reported on 85 wells in North Dakota and eastern Montana. Nine tests were done on the Icebox Formation. Of the nine, four reported gas and three reported oil. Five of the nine, all in eastern Montana, appear to have tested the sand bodies in the Icebox.

On balance, it seems likely that the Icebox Formation, particularly the sand bodies, has some oil and gas potential. The sand bodies have only been tested in five locations in eastern Montana. Large areas of sand body occurrence are entirely untested. The sand bodies have the potential to be good reservoir rock, and their proximity to an extensive source rock would have facilitated the accumulation of hydrocarbons. Any production from the Icebox will probably be predominantly gas.

Introduction

The Icebox Formation (Ordovician) is the middle of three formations within the Winnipeg Group, underlain by the sandstones and siltstones of the Black Island Formation, and grading up into the argillaceous carbonates of the Roughlock Formation. (Fig. 1). It is a regionally extensive shale, typically dark green to black, and reaches a maximum thickness of about 190 ft (58 m) in the center of the basin. (Fig. 2).

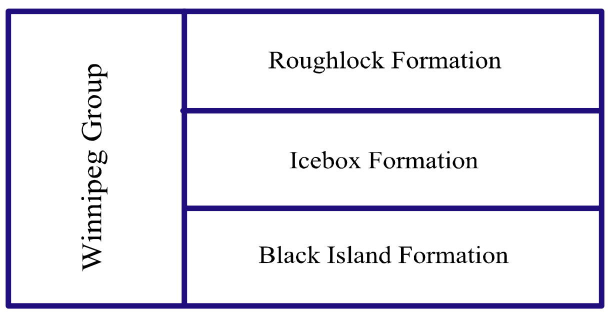

Figure 1. Stratigraphic nomenclature of the Winnipeg Group

Previous Works

The Icebox Formation and the Winnipeg Group have been the subject of numerous studies over the past several decades (*e.g.*, Andrichuk, 1959; Porter and Fuller, 1959; Carlson, 1960; 1964; Fuller, 1961; Paterson, 1971; Vigrass, 1971; McCabe, 1978; Carlson and Thompson, 1987; LeFever *et al.*, 1987; Kessler, 1991; Ellingson and LeFever, 1995).

Descriptions of sandy intervals within the Icebox Fm have appeared in the literature for more than 30 years. Most notable is the “Carman sand” in Manitoba (Vigrass, 1971), but other localized accumulations in the Dakotas, Montana, Manitoba, and Saskatchewan have been described by various workers (*e.g.*, Carlson, 1960; Carlson and Thompson, 1987; Kessler, 1991).

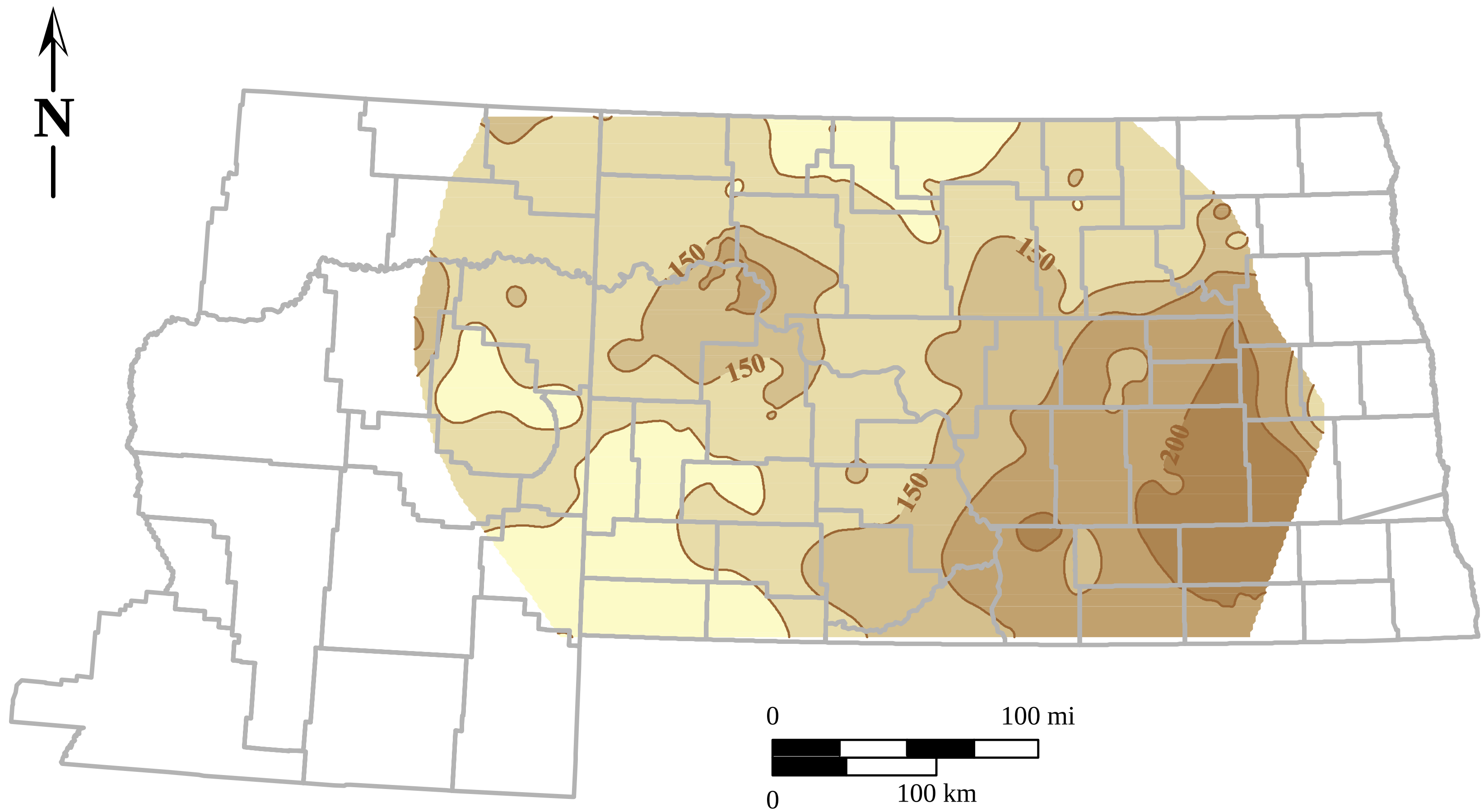

Figure 2. Isopach map of the Icebox Formation.

Methods

Wireline gamma-ray logs of the Icebox Formation from North Dakota and eastern Montana were examined. The area of study included all of North Dakota, and Montana from the eastern boundary west to about longitude 106W (Fig.3). One of the difficulties in working with gamma-ray traces of the Icebox Formation is that part of the trace is commonly off-scale; this characteristic makes it difficult to recognize units within the formation. To eliminate this “off-scale effect”, the traces were digitally reproduced and spliced into one continuous track (Fig. 4). The complete traces were then digitized and converted to LAS format. Some wells which penetrated the Icebox had no gamma-ray, and others had gamma-ray traces which were incomplete and could not be converted to digital form. Altogether, 365 well logs were converted (Fig. 5).

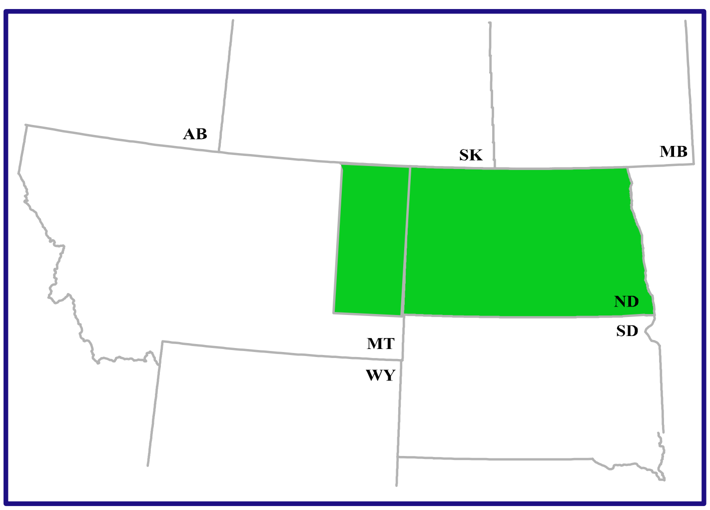

Figure 3. Study Area

Results

A total of 40 sandy lithofacies were identified in the study area; they were arbitrarily designated S1 - S40. Five have regional extent, and cover most of the study area (Figs. 6-10).

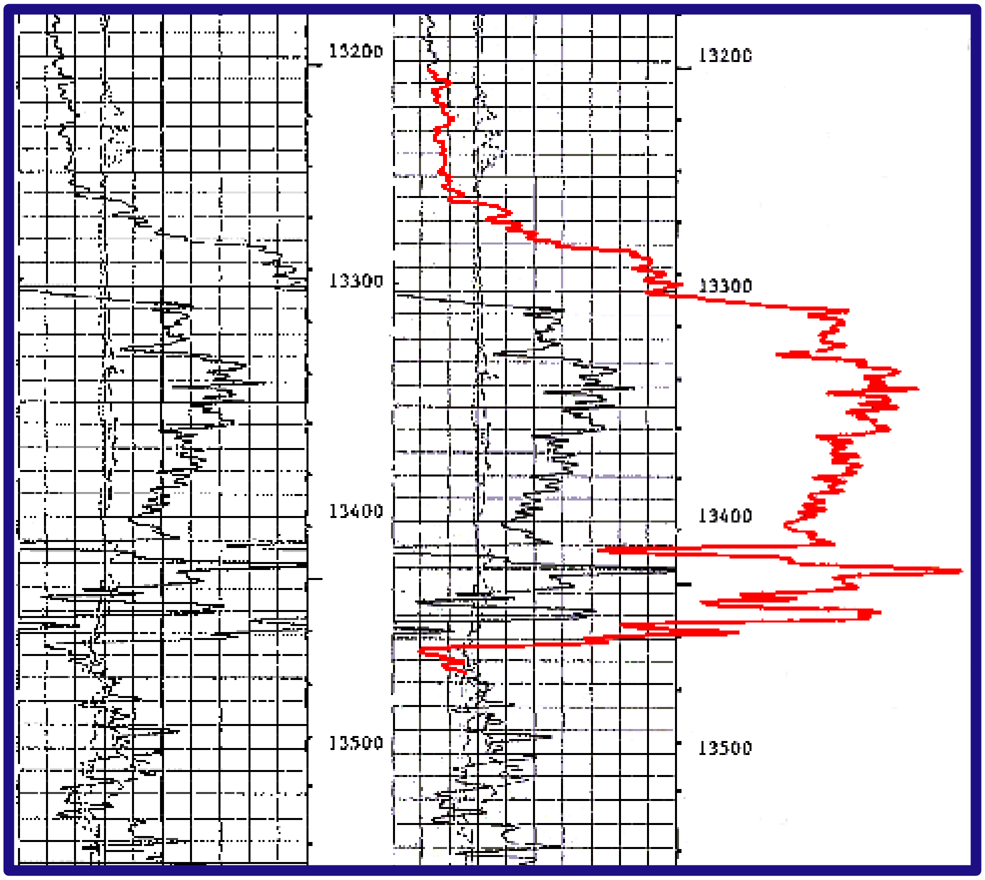

Figure 4. Example of elimination of "off-scale effect" and digital conversion of trace. Left - original gamma-ray log trace; right - gamma-ray log trace overlain by spliced trace.

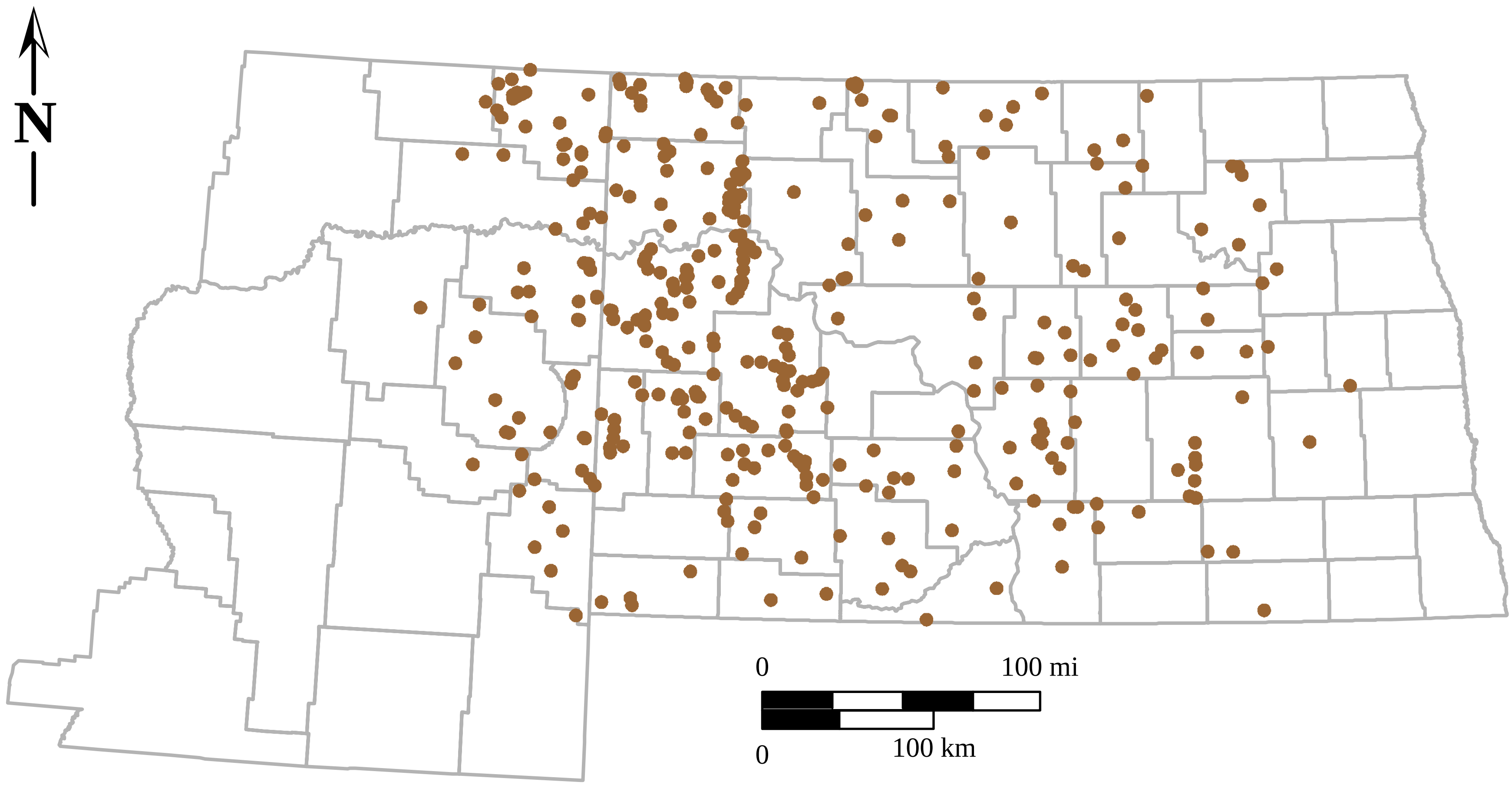

Figure 5. Locations of the wells used in this study.

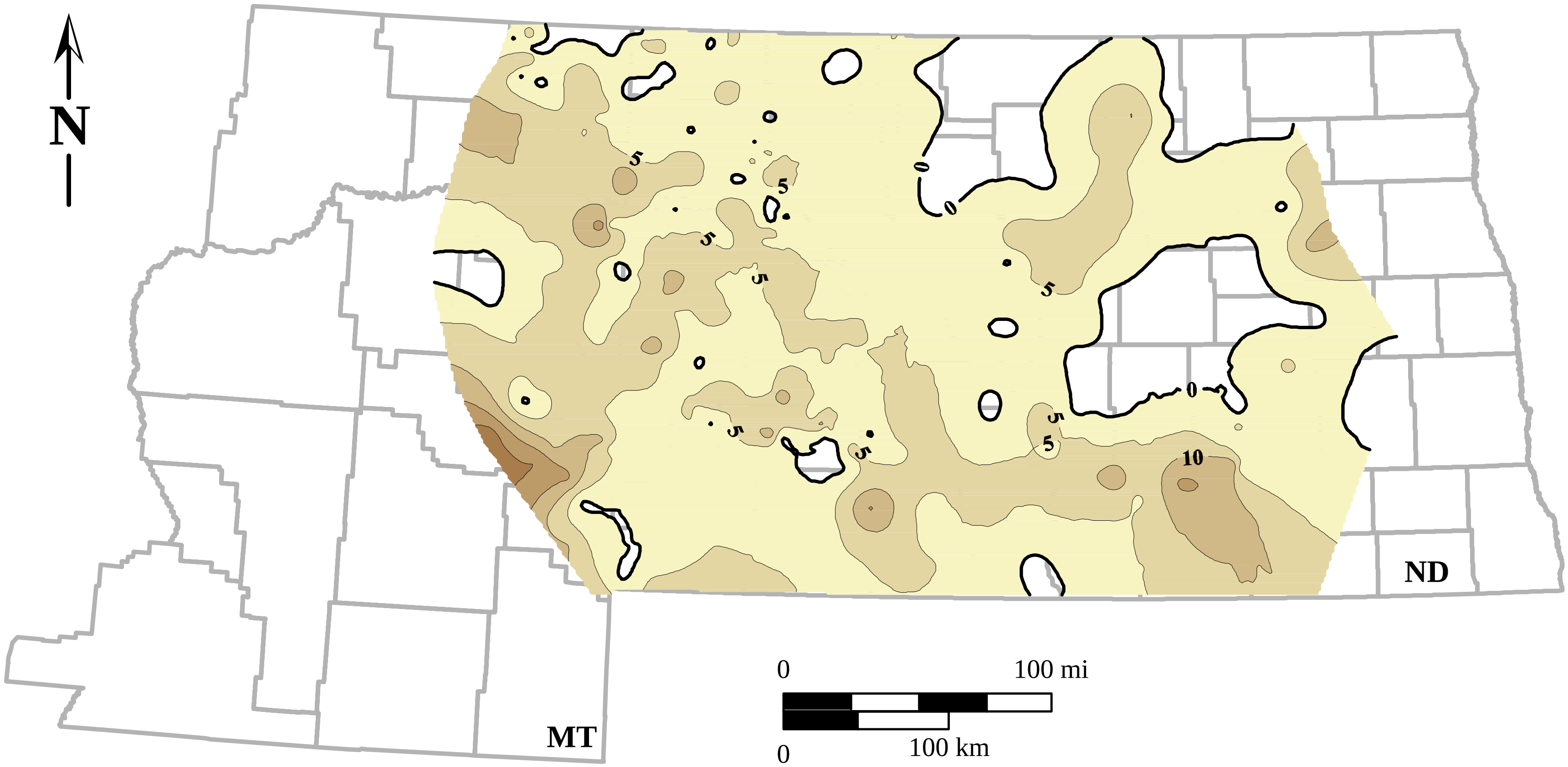

Figure 6. Distribution and thickness of sandy unit S1.

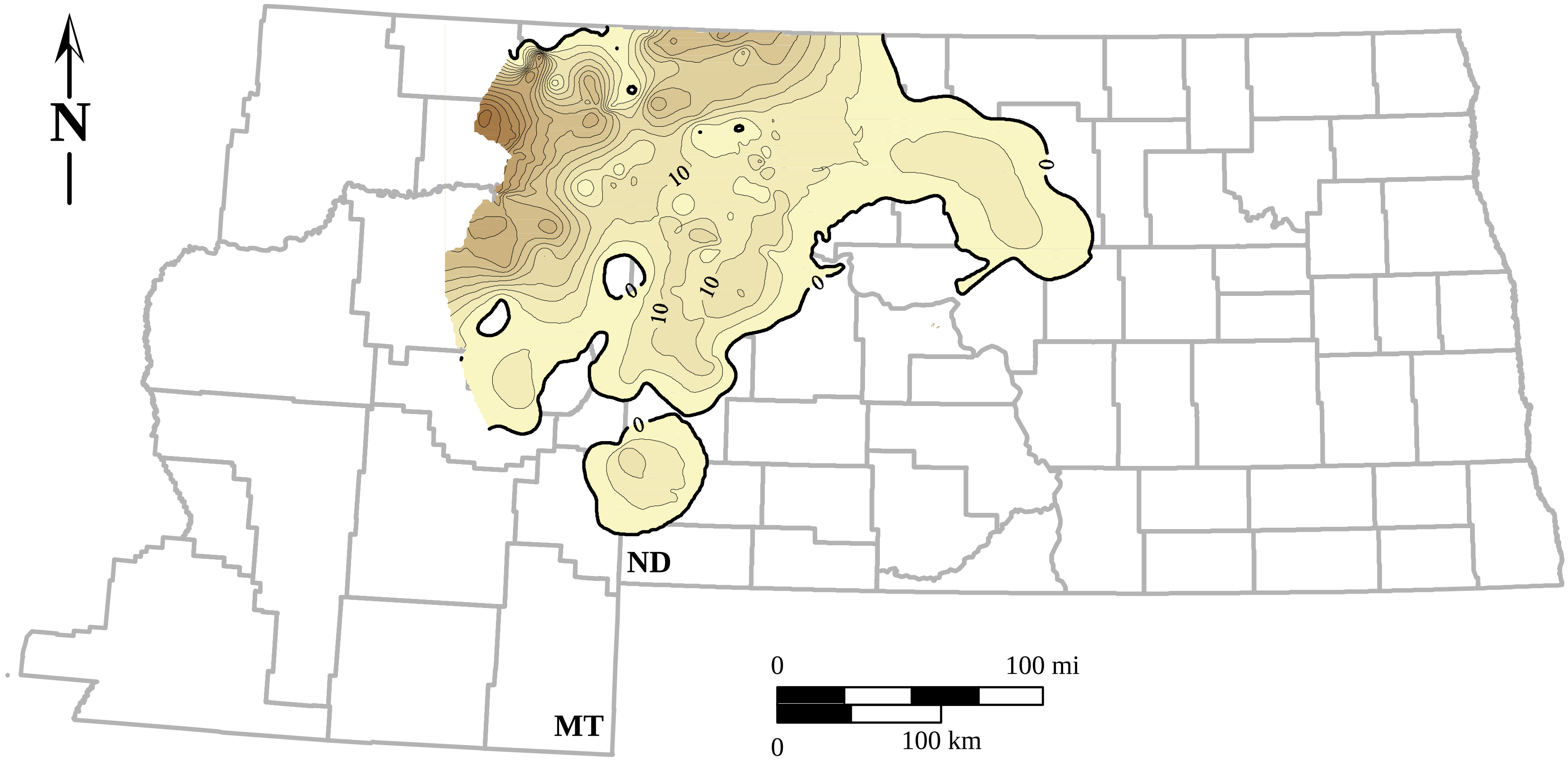

Figure 7. Distribution and thickness of sandy unit S2.

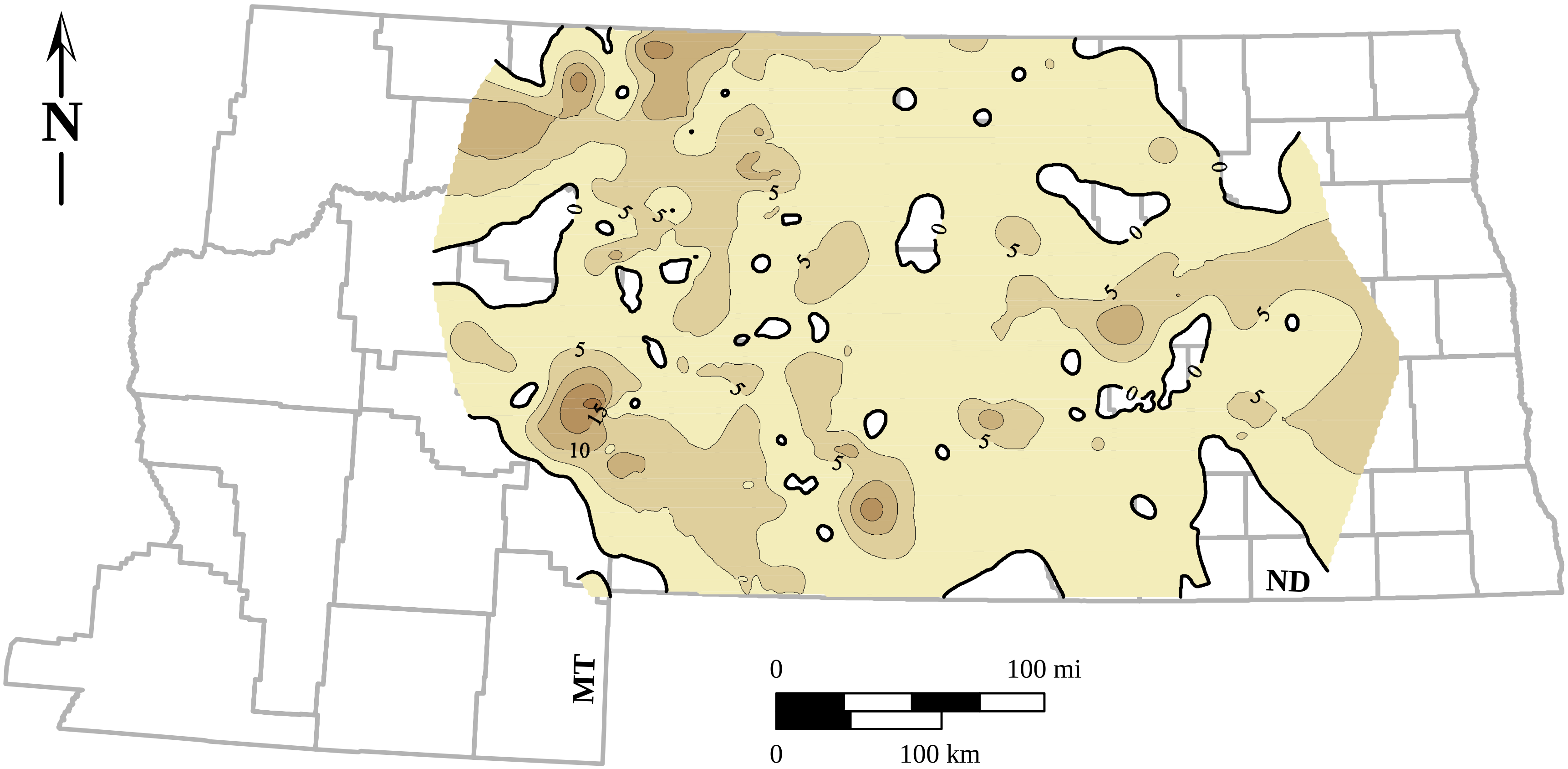

Figure 8. Distribution and thickness of sandy unit S3.

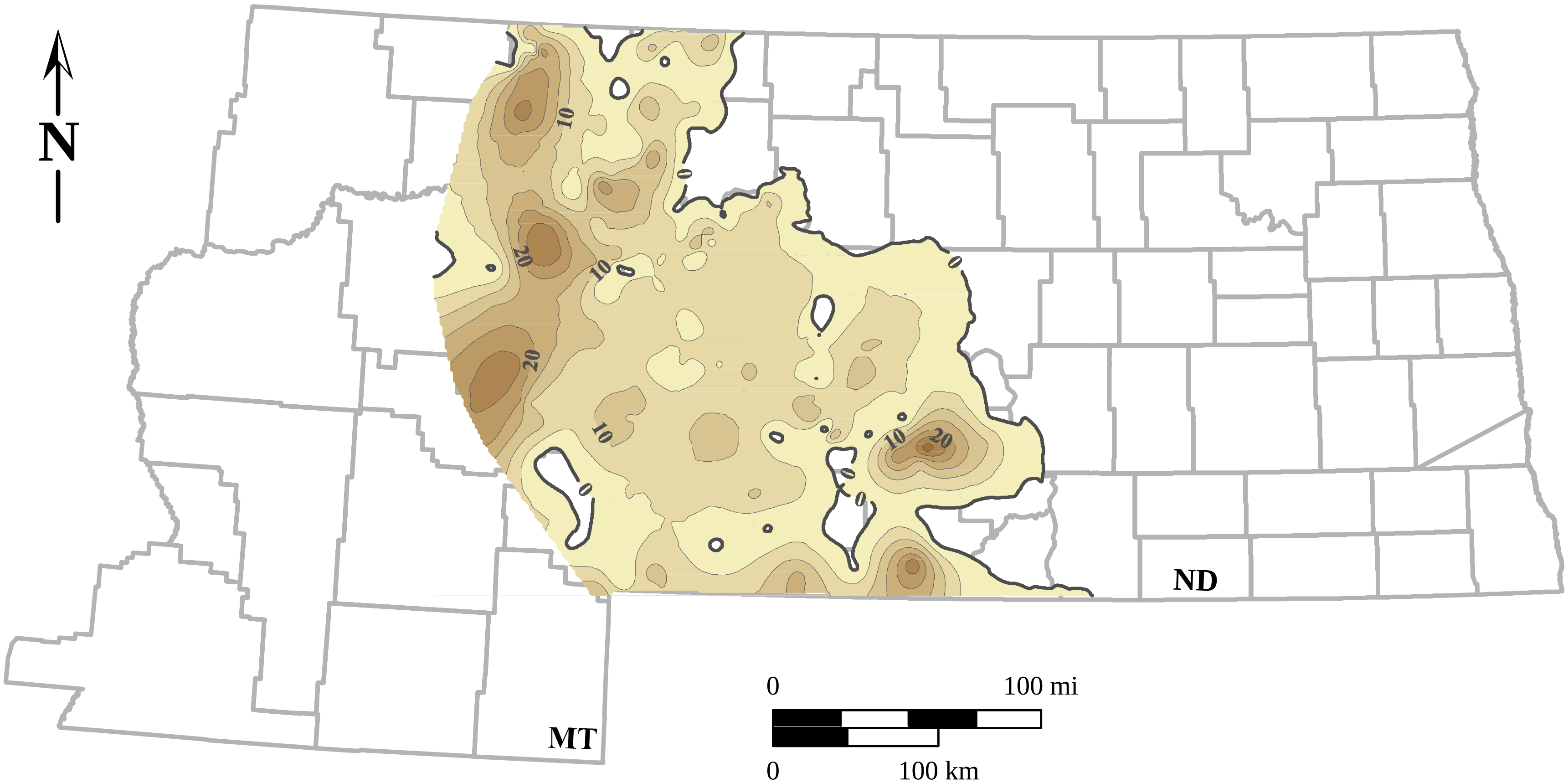

Figure 9. Distribution and thickness of sandy unit S5.

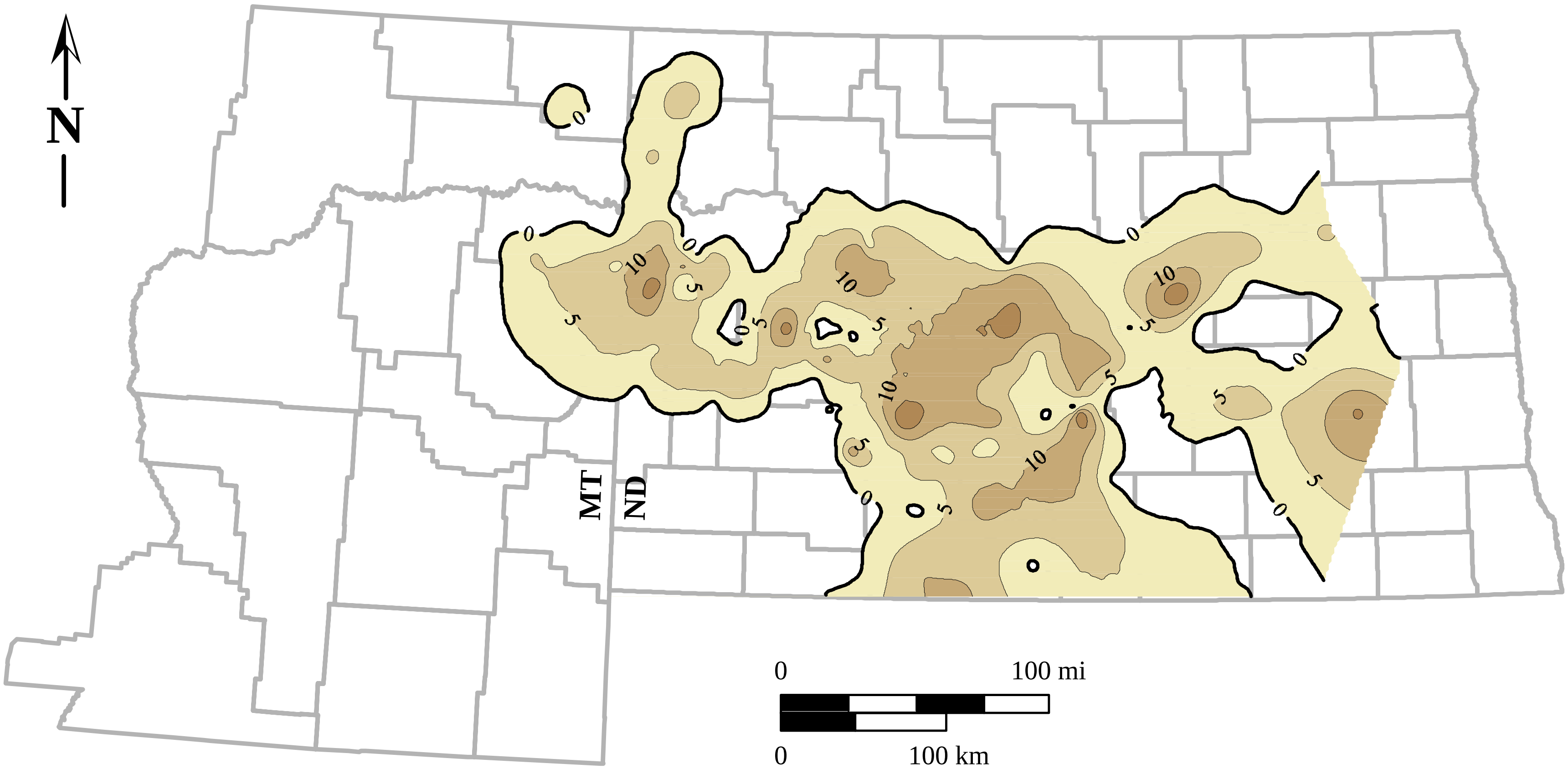

Figure 10. Distribution and thickness of sandy unit S6.

These major bodies have a maximum thickness of at least 20 ft (6 m), and one is 72 ft (22 m) at its thickest. Although typically 5-10 ft thick over much of North Dakota, the major bodies, with one exception, tend to thicken westward, and their greatest known thicknesses occur near their westward limits.

Five additional sand bodies each extend across several 10s of miles, and have maximum thicknesses ranging from 10 ft (3 m) to 23 ft (7 m) (Figs. 11-14). These extensive sand bodies average somewhat thinner than the major bodies, but show no obvious thickness trends.

The remaining 30 identifiable bodies are of only local extent, and typically are evident in only a few wells (Fig. 15-24). Table 1 summarizes the location data for the recognized sand bodies.

The sandy units appear to be distributed evenly throughout the Icebox Formation. The stratigraphic distribution of the major units is illustrated in Figure 25.

Cross-sections

Seven cross-sections were constructed, three east-west, and four north-south (Plates 1 & 2).

Cores

Only six cores have sampled the sandy bodies in the Icebox Formation in North Dakota (Fig. 26), all in the lower part of the formation. The core depicted in Figure 27, from the Icebox Fm in Divide County, includes sand body 3 (S3), and is typical of the cored bodies. Based on the existing cores, it appears that the sandy lithofacies probably represent intervals of bioturbated sandstone and siltstone within the shalier Icebox Formation.

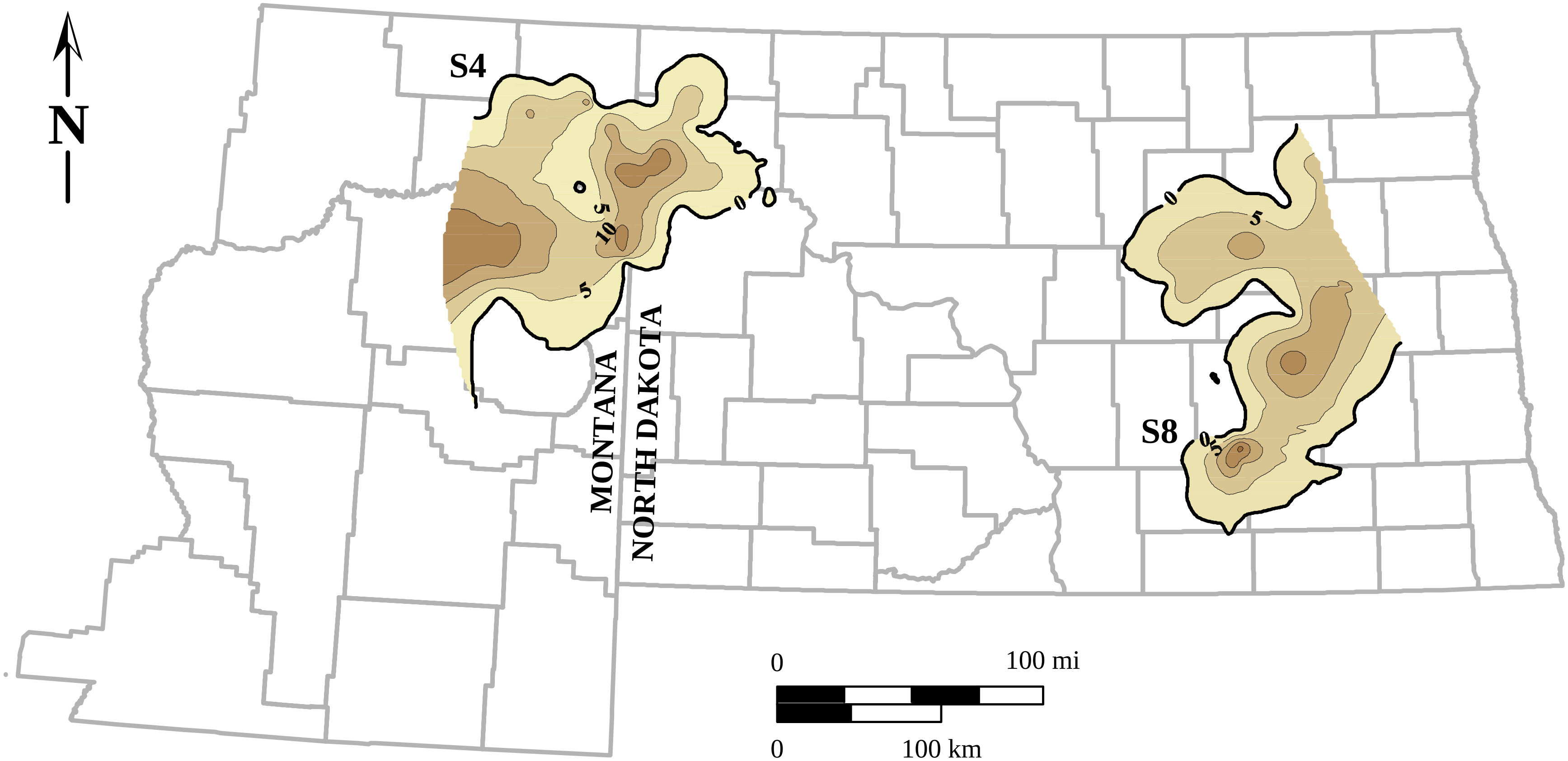

Figure 11. Distribution and thickness of sandy units S4 and S8.

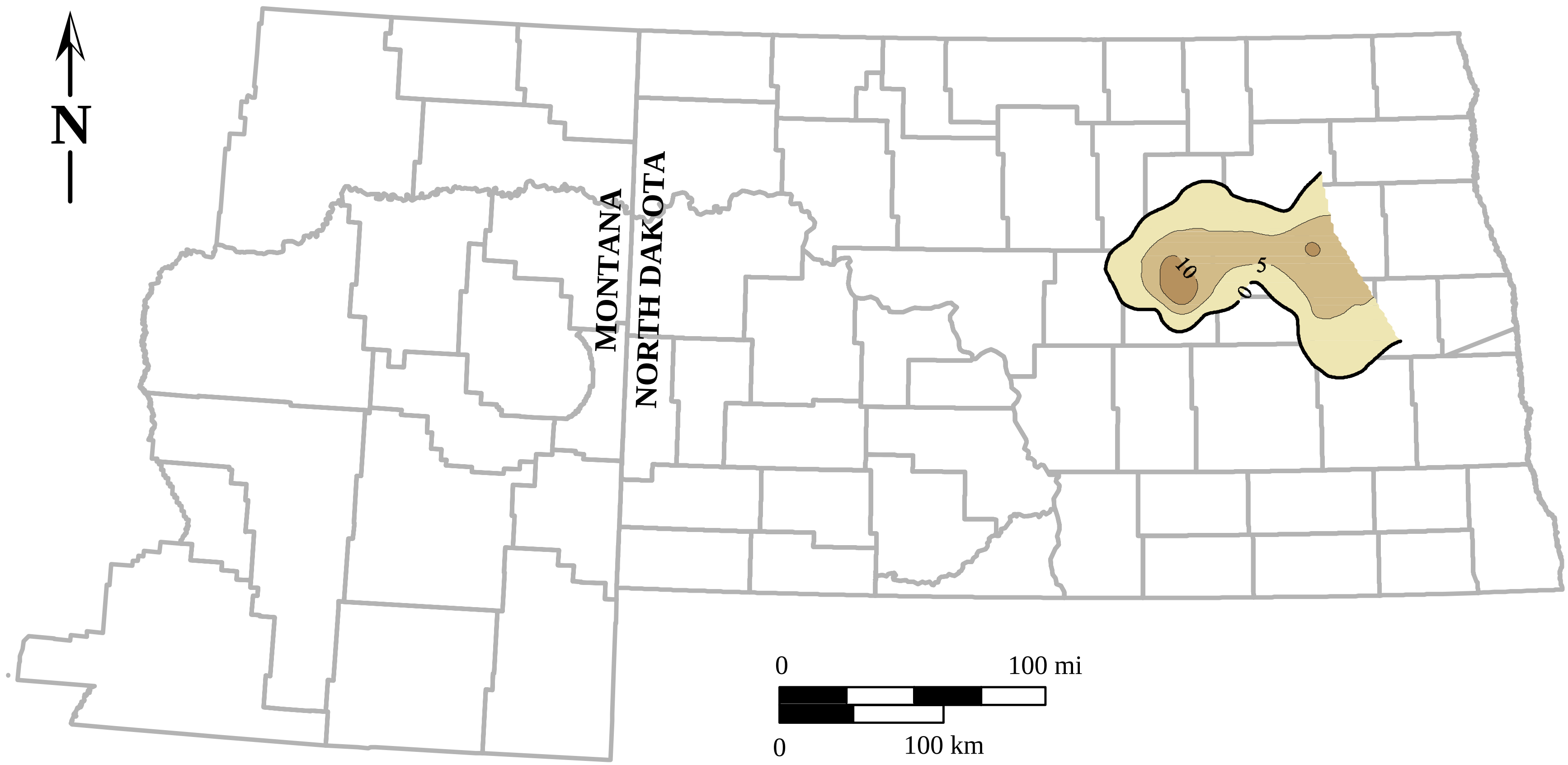

Figure 12. Distribution and thickness of sandy unit S10.

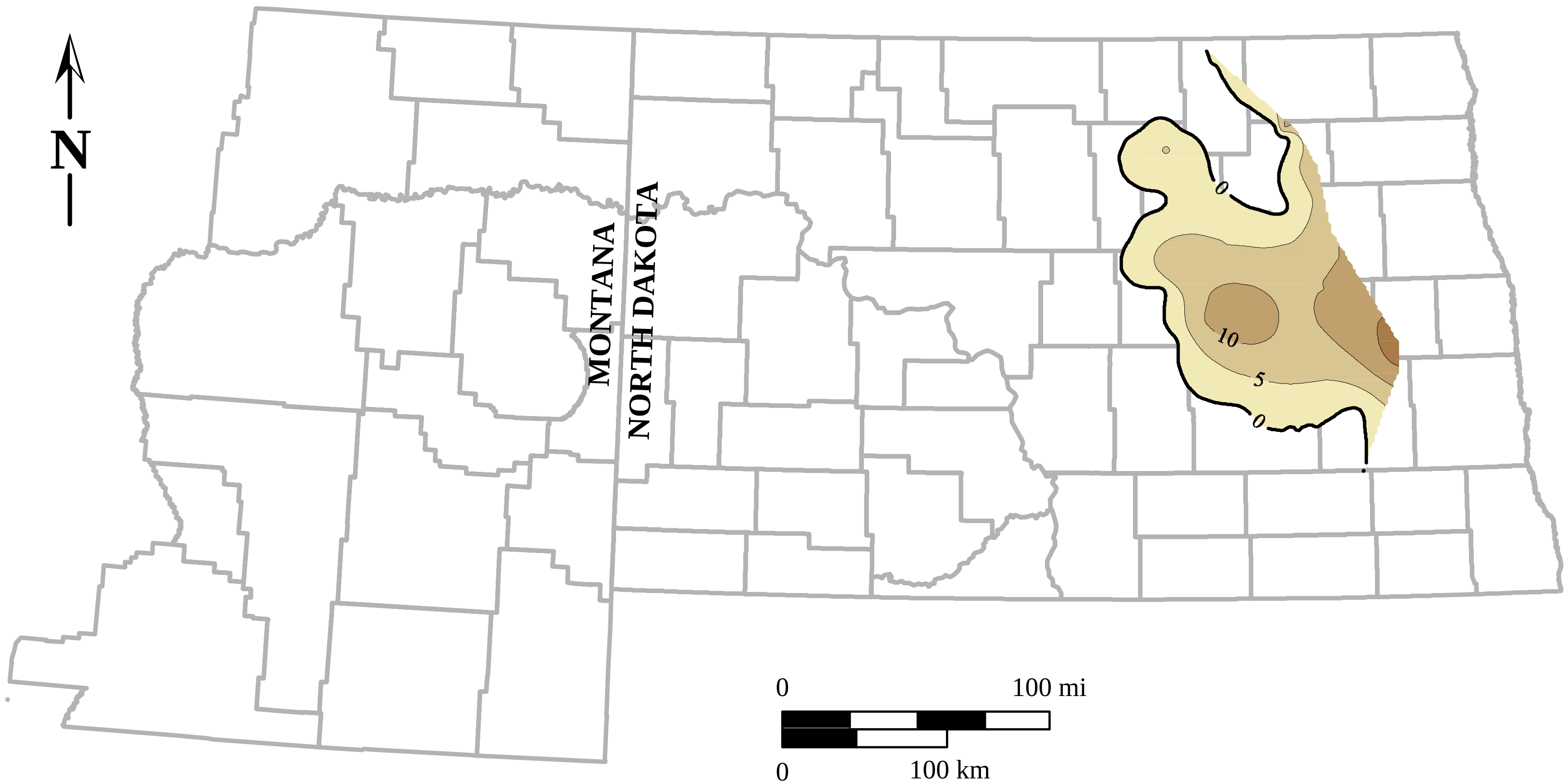

Figure 13. Distribution and thickness of sandy unit S19.

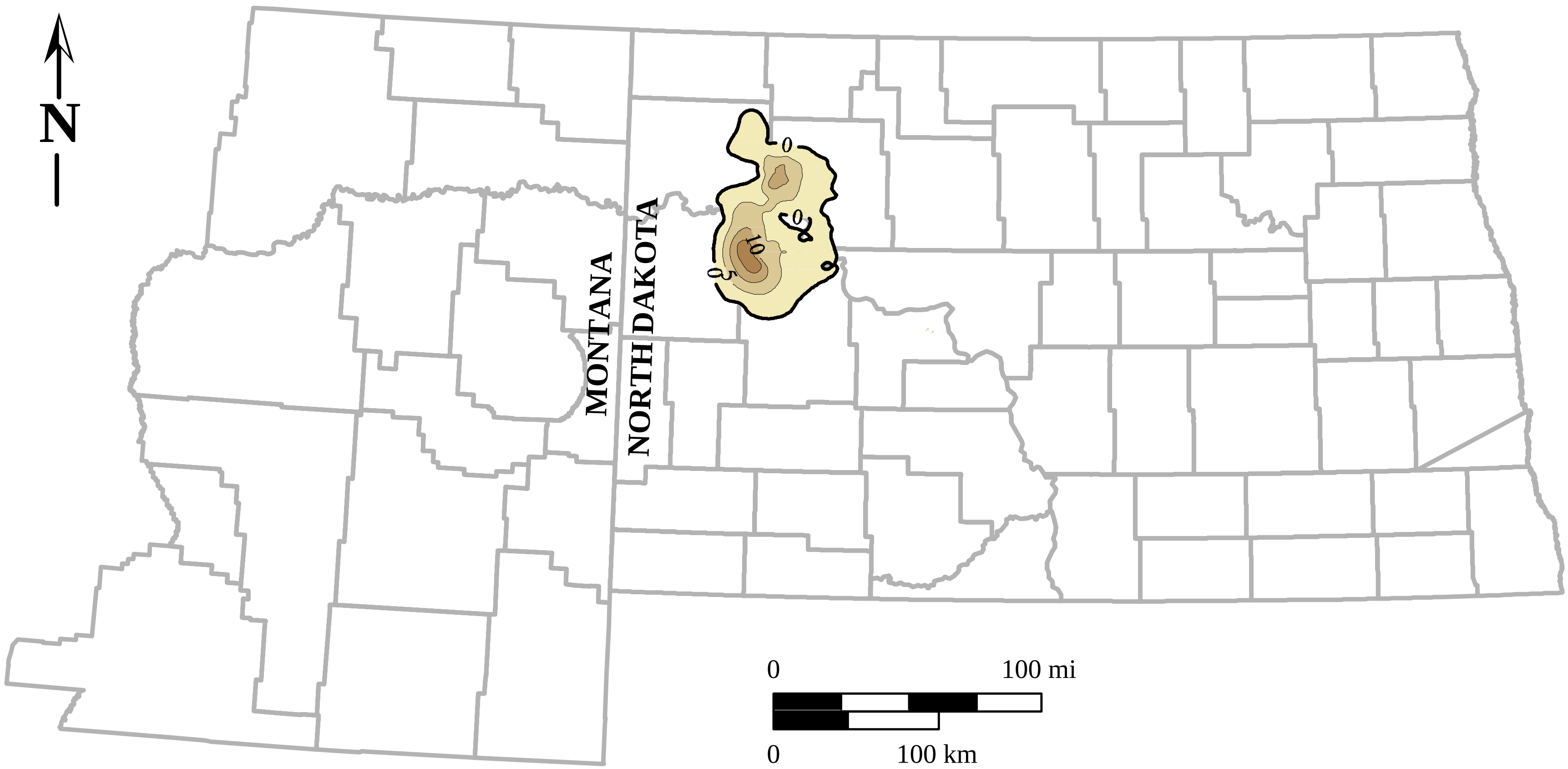

Figure 14. Distribution and thickness of sandy unit S32.

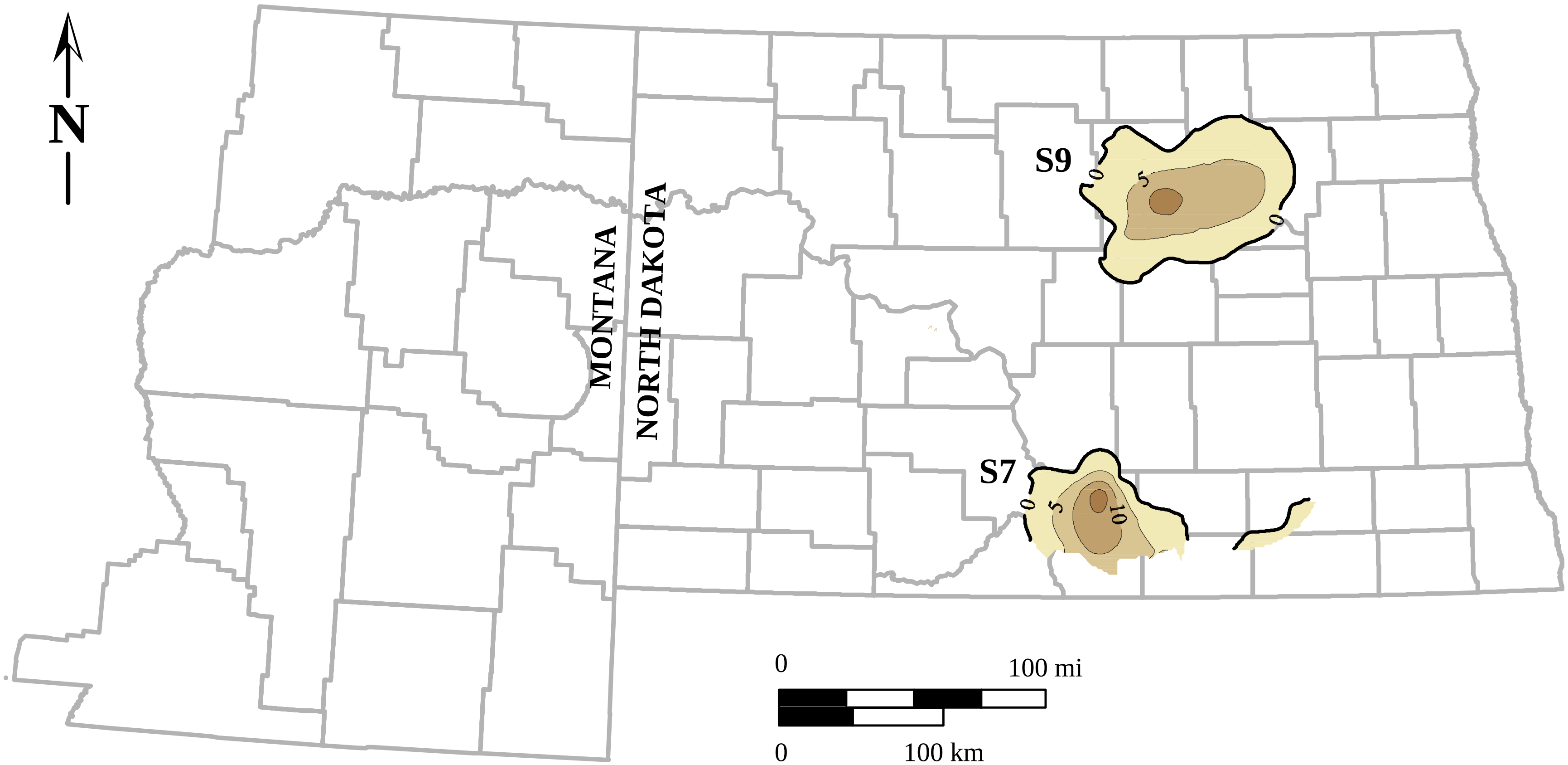

Figure 15. Distribution and thickness of sandy units S7 and S9.

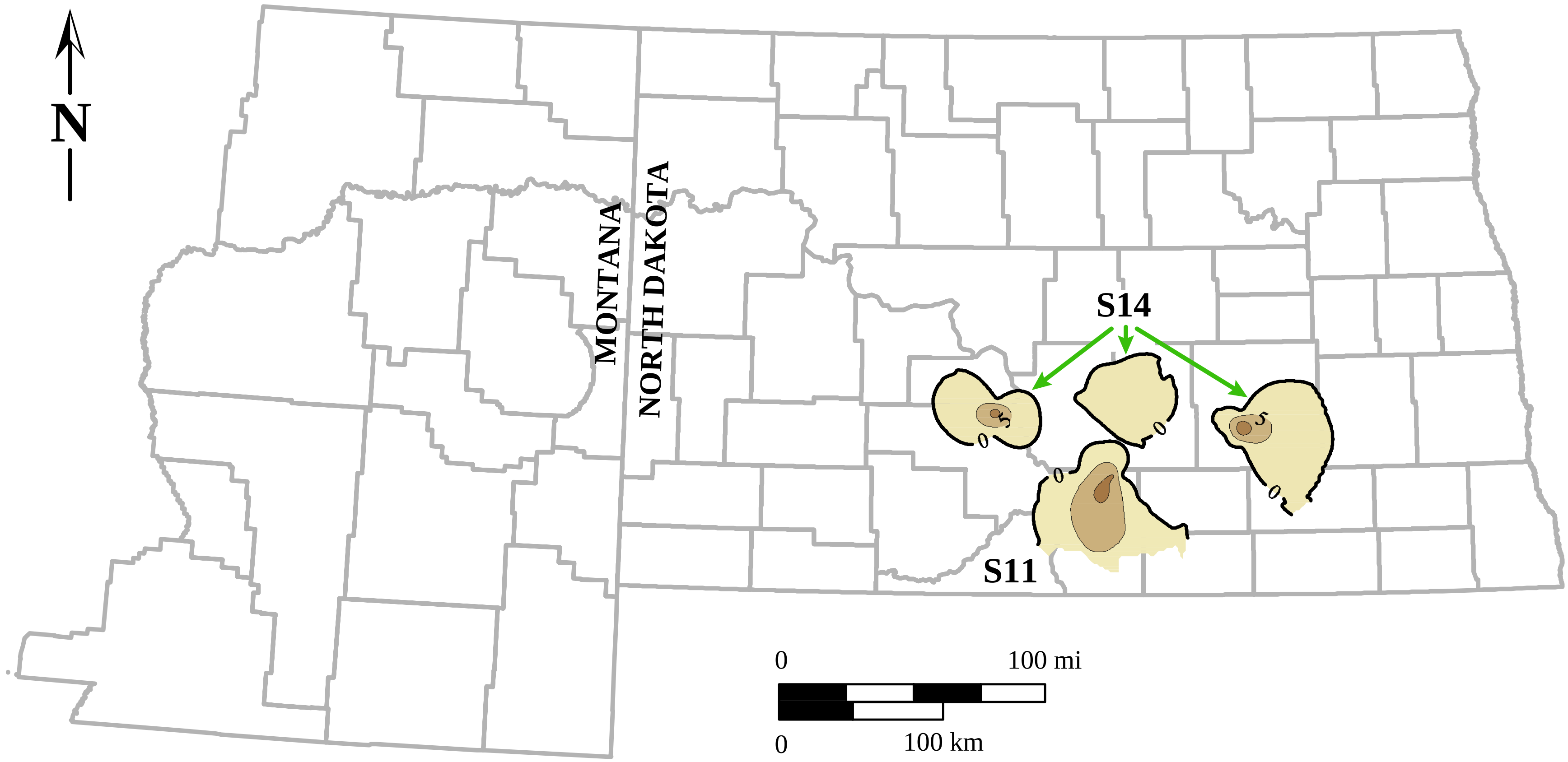

Figure 16. Distribution and thickness of sandy units S11 and S14.

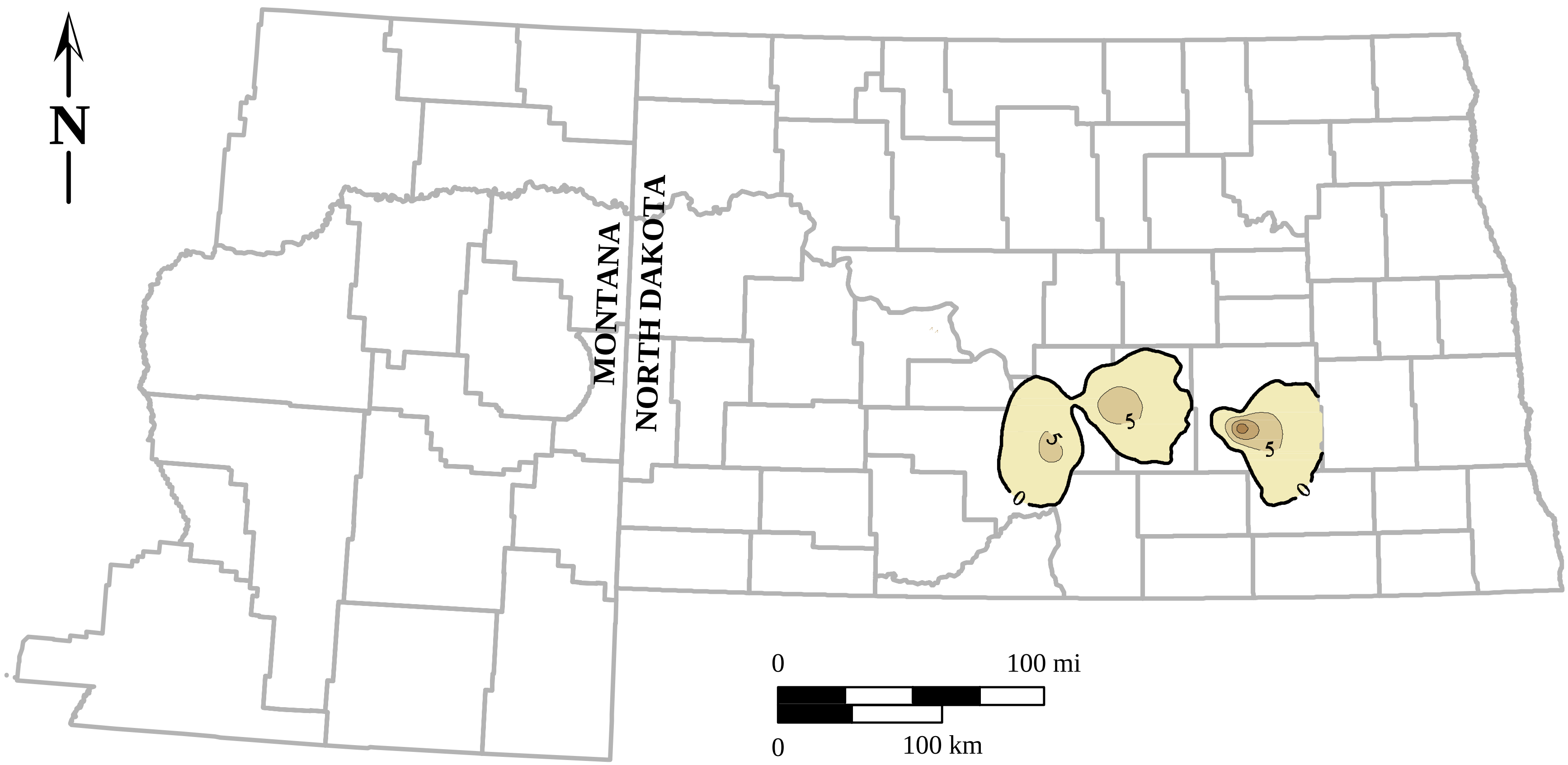

Figure 17. Distribution and thickness of sandy unit S15.

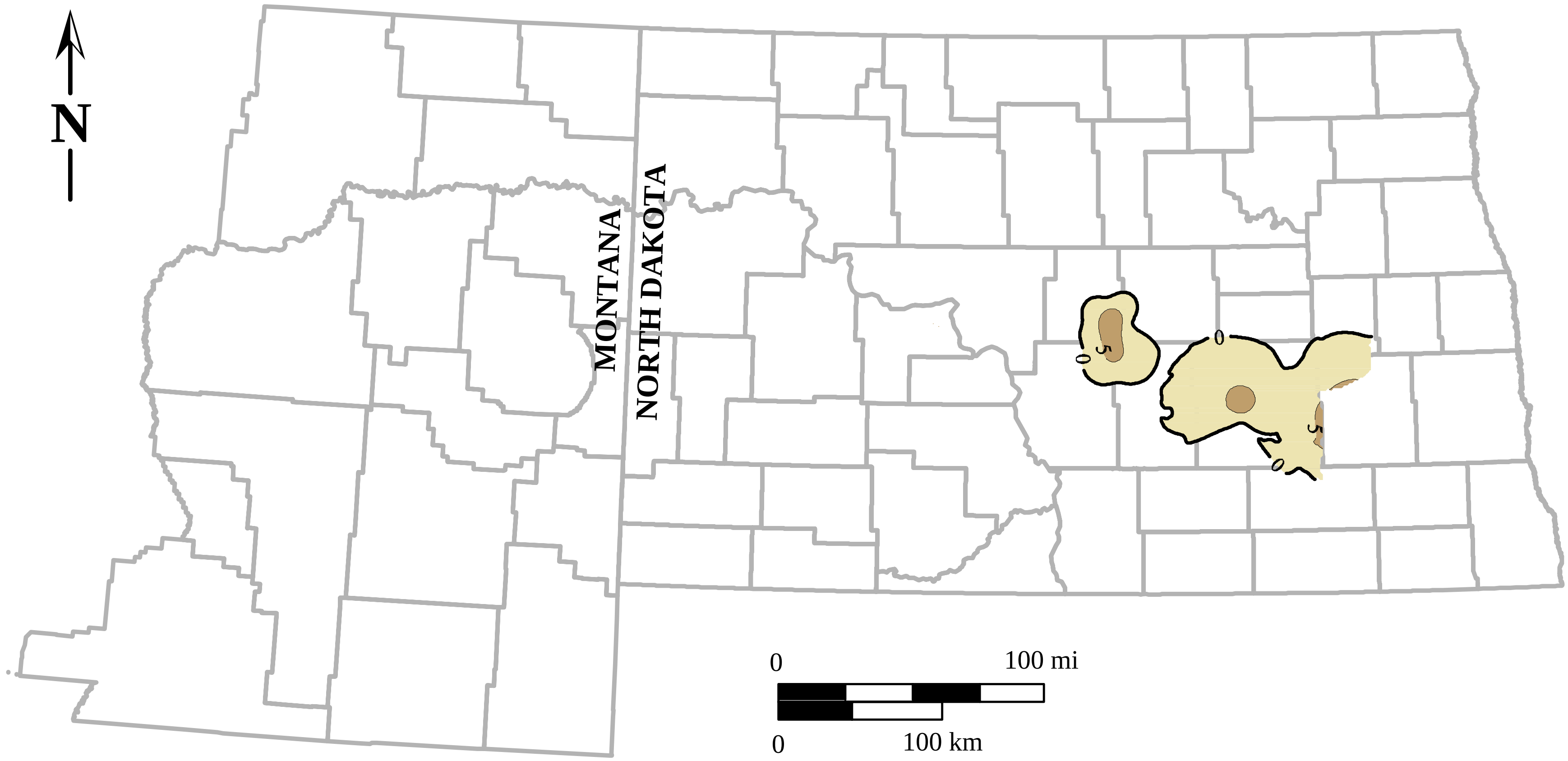

Figure 18. Distribution and thickness of sandy unit S16.

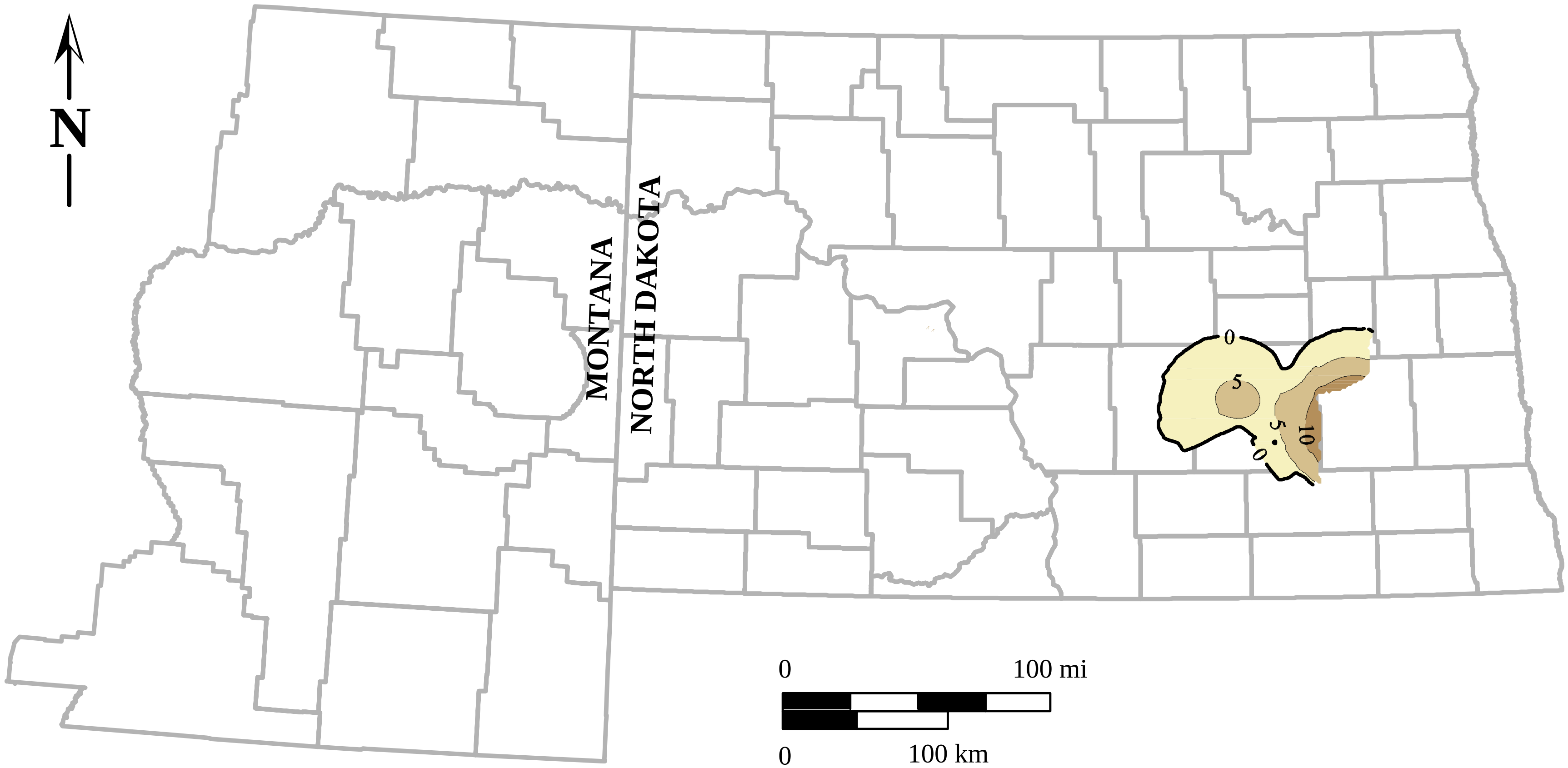

Figure 19. Distribution and thickness of sandy unit S17.

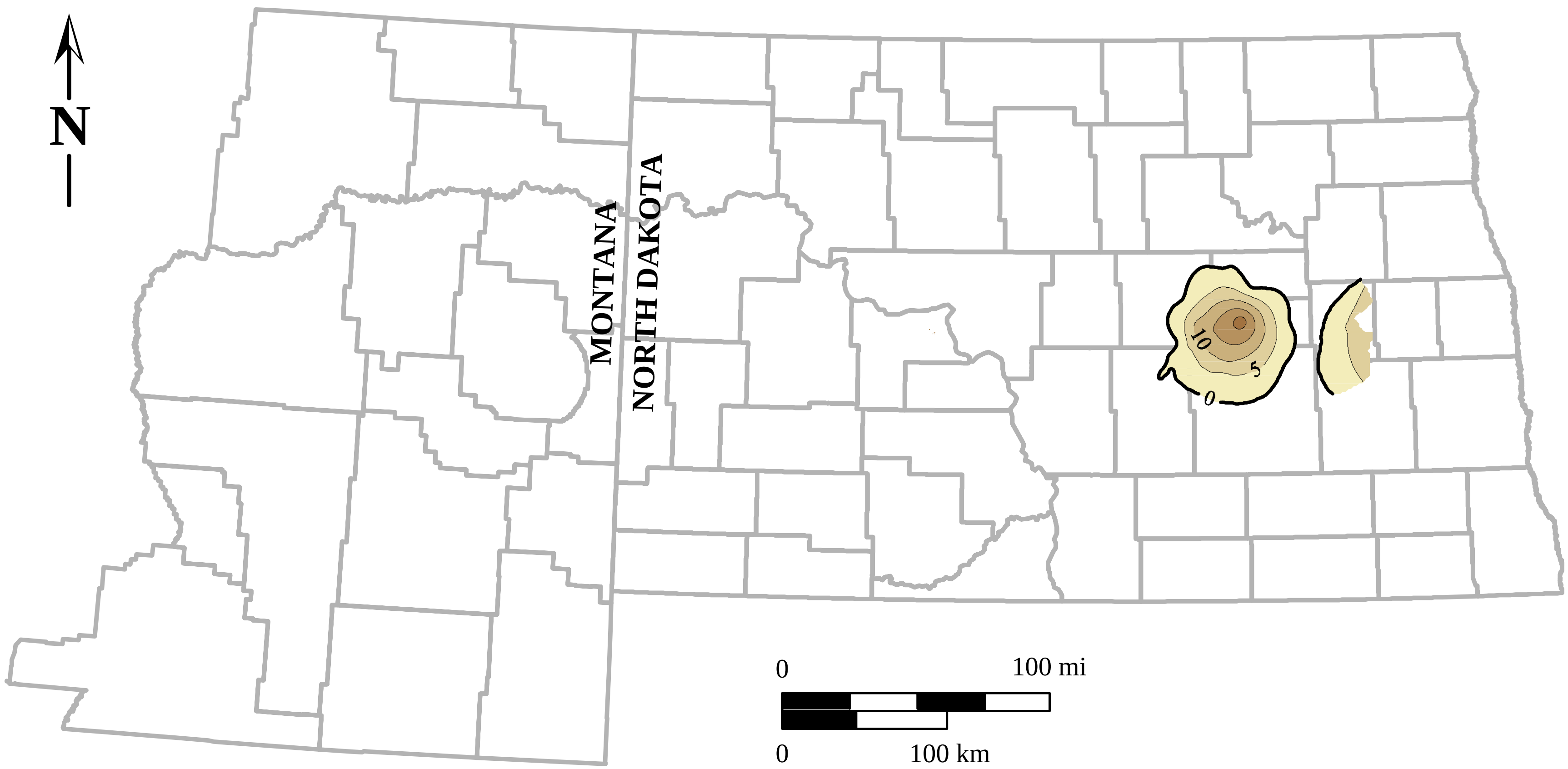

Figure 20. Distribution and thickness of sandy unit S18.

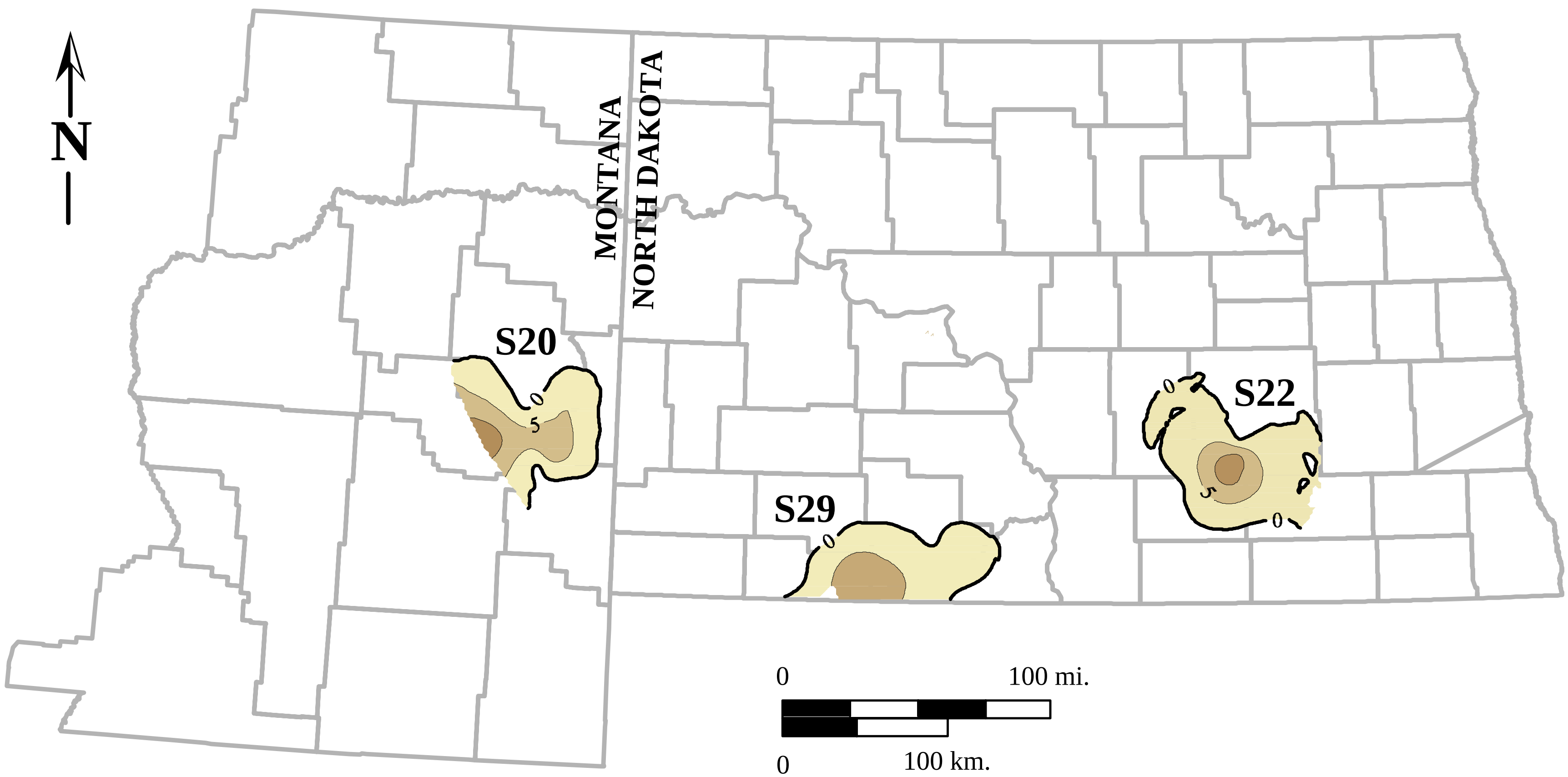

Figure 21. Distribution and thickness of sandy units S20, S22, and S29.

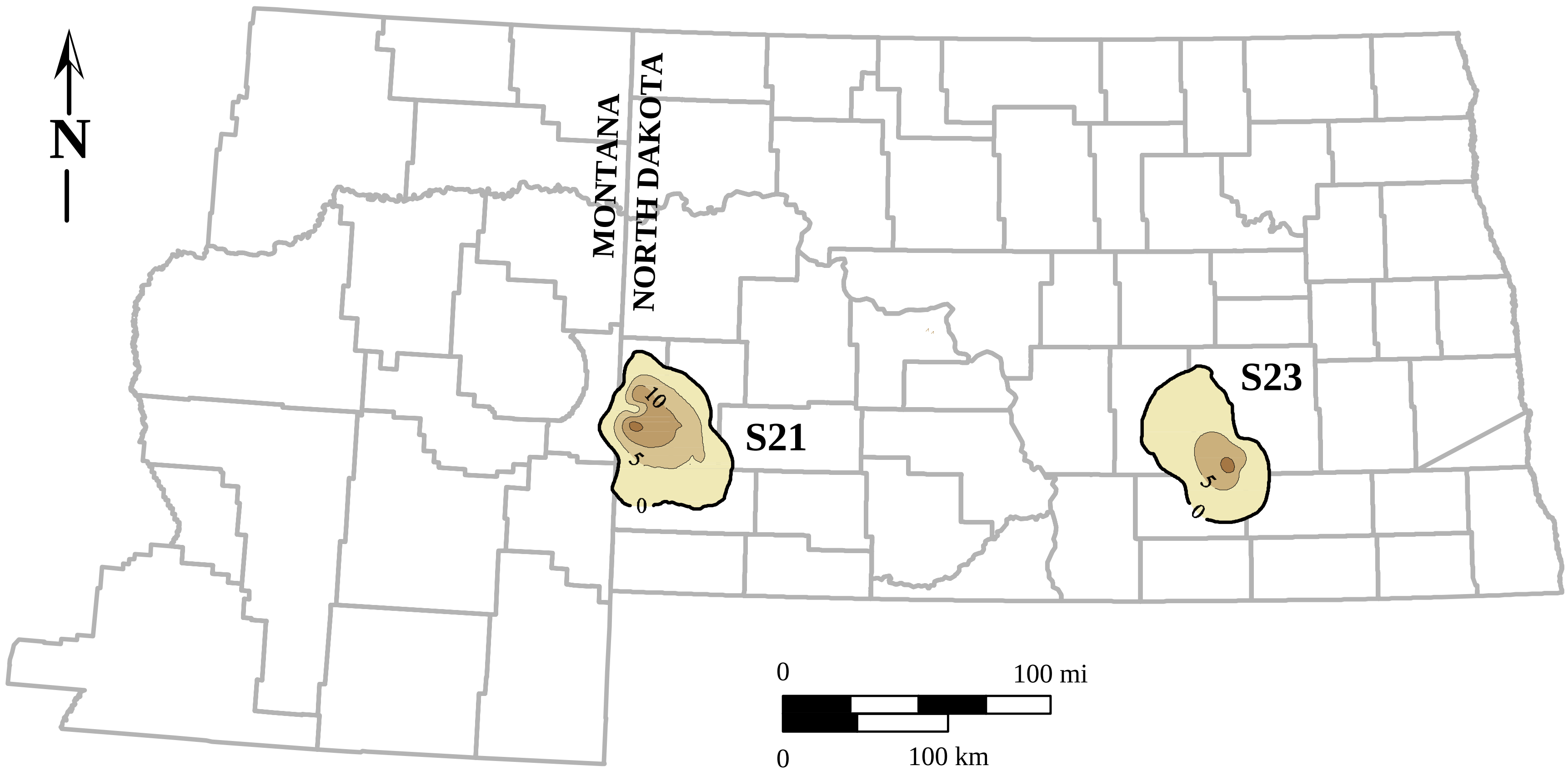

Figure 22. Distribution and thickness of sandy units S21 and S23.

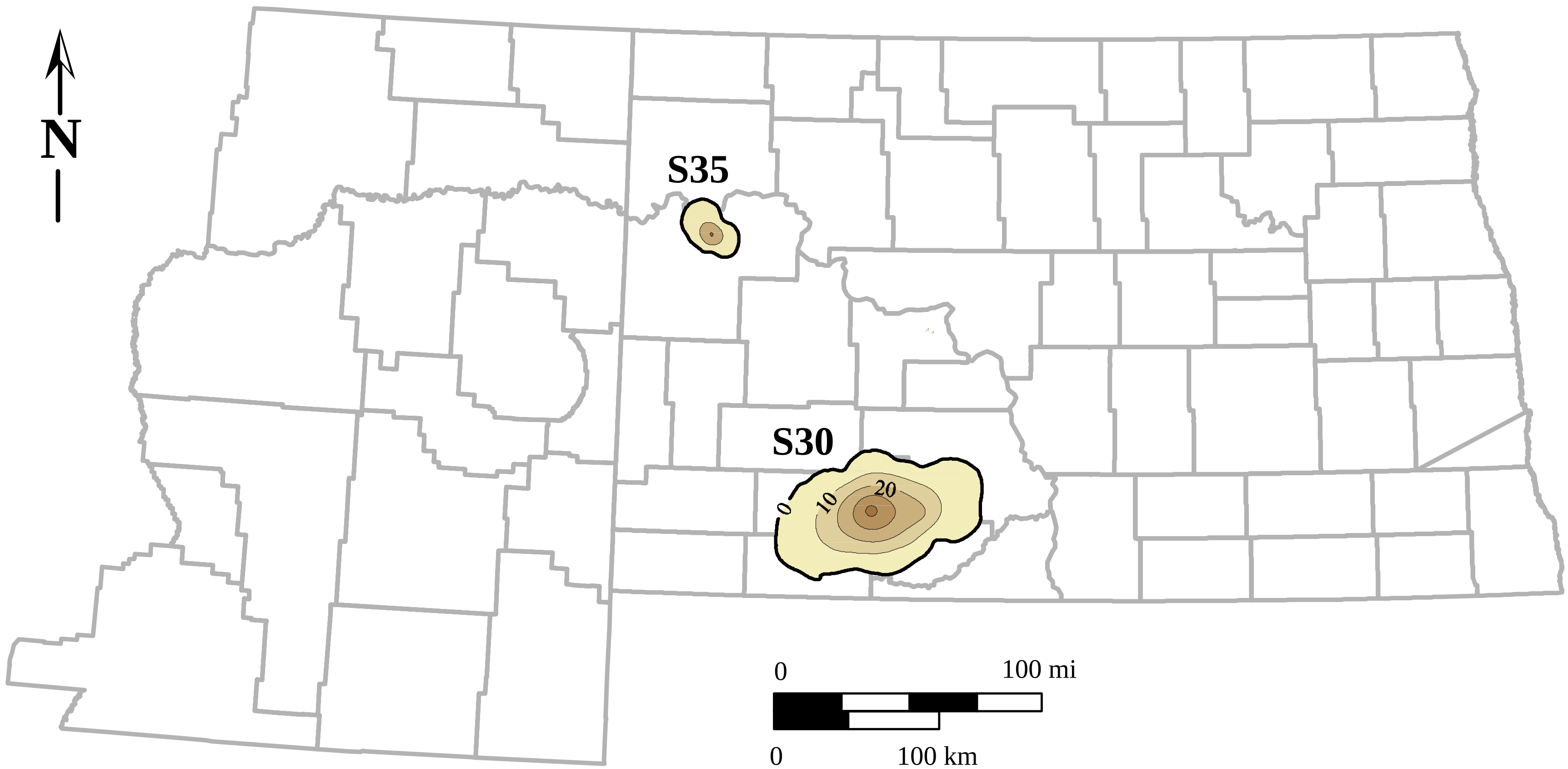

Figure 23. Distribution and thickness of sandy units S30 and S35.

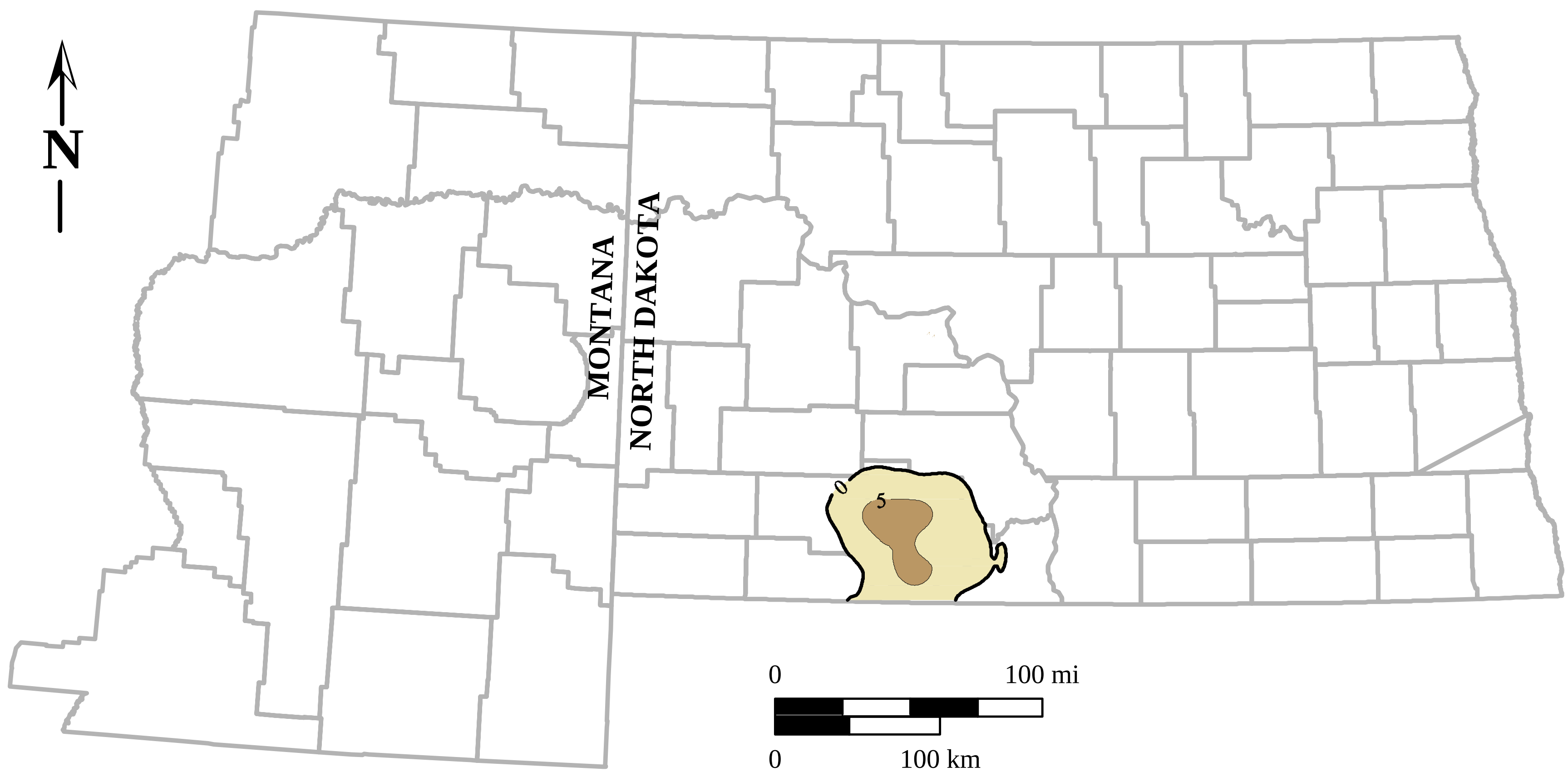

Figure 24. Distribution and thickness of sandy unit S36.

TABLE 1. CHARACTERISTICS OF THE SAND BODIES IN THE ICEBOX FORMATION.

Sandy Unit	No. Wells	Max.	Location
Major Units			
S1	249	23 ft	Entire study area
S2	128	72 ft	Western part of the study area
S3	247	23 ft	Entire study area
S5	160	34 ft	Western half of study area
S6	108	21 ft	Middle of study area
Extensive Units			
S4	31	20 ft	Northwestern part of study area
S8	12	23 ft	East-central North Dakota
S10	8	12 ft	East-central North Dakota
S19	17	18 ft	East-central North Dakota
S32	25	20 ft	Nesson Anticline in North Dakota
Minor Units			
S7	4	19 ft	Southeastern North Dakota
S9	3	13 ft	Northeastern North Dakota
S11	3	12 ft	Emmons County, North Dakota
S14	6	13 ft	East-central North Dakota
S15	7	21 ft	East-central North Dakota
S16	4	10 ft	East-central North Dakota
S18	4	23 ft	East-central North Dakota
S20	4	14 ft	Eastern Montana
S21	6	18 ft	Golden Valley County, North Dakota
S22	4	16 ft	Stutsman County, North Dakota
S23	4	12 ft	Stutsman County, North Dakota
S29	3	10 ft	South-central North Dakota
S30	3	45 ft	South-central North Dakota
S35	3	12 ft	McKenzie County, North Dakota
S36	4	8 ft	Grant County, North Dakota
Isolated Units			
S12	1	9 ft	Emmons County, North Dakota
S13	1	11 ft	Emmons County, North Dakota
S17	2	23 ft	Eastern North Dakota
S24	1	10 ft	Stutsman County, North Dakota
S25	1	5 ft	Benson County, North Dakota
S26	1	11 ft	Morton County, North Dakota
S27	2	12 ft	Central North Dakota
S28	2	13 ft	Central North Dakota
S31	2	16 ft	Stark County, North Dakota
S33	1	3 ft	McKenzie County, North Dakota
S34	1	6 ft	Sheridan County, Montana
S37	1	6 ft	Eastern Montana
S38	1	22 ft	Dawson County, Montana
S39	1	25 ft	McCone County, Montana
S40	1	10 ft	Fallon County, Montana

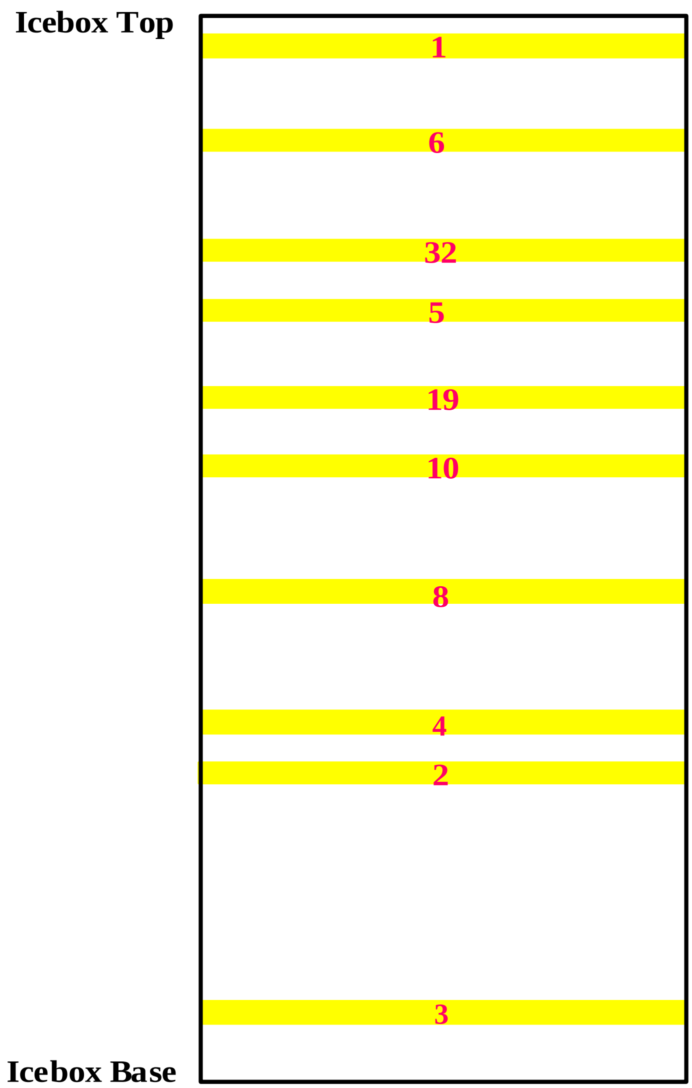

Figure 25. Approximate stratigraphic positions of the major and extensive sand bodies within the Icebox Formation.

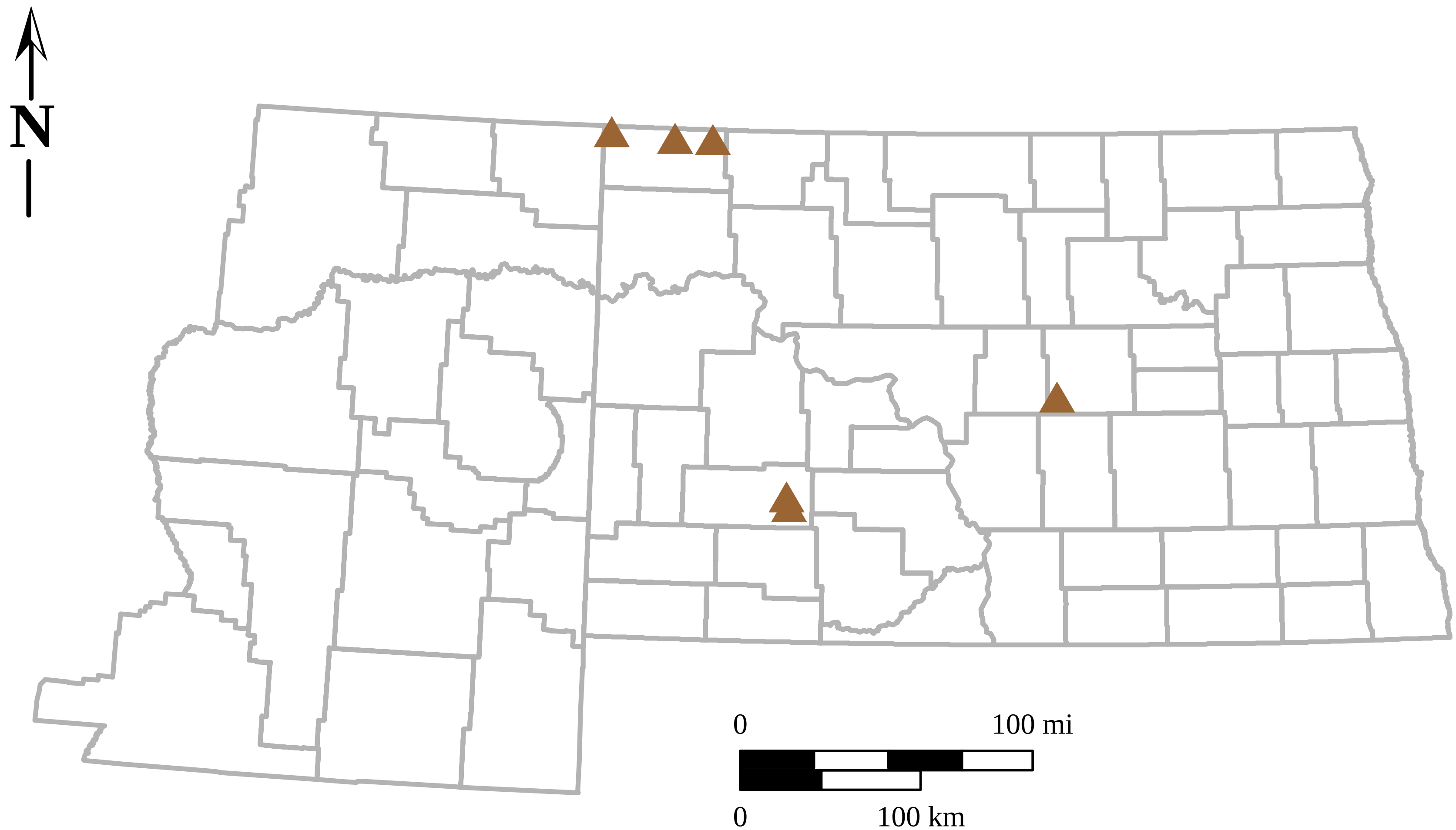

Figure 26. Locations of cores which penetrated sandy bodies within the Icebox Formation.

Carter Oil - #1 Dallas D. Moore
NWNE Sec. 7, T163N, R102W
Divide County, North Dakota

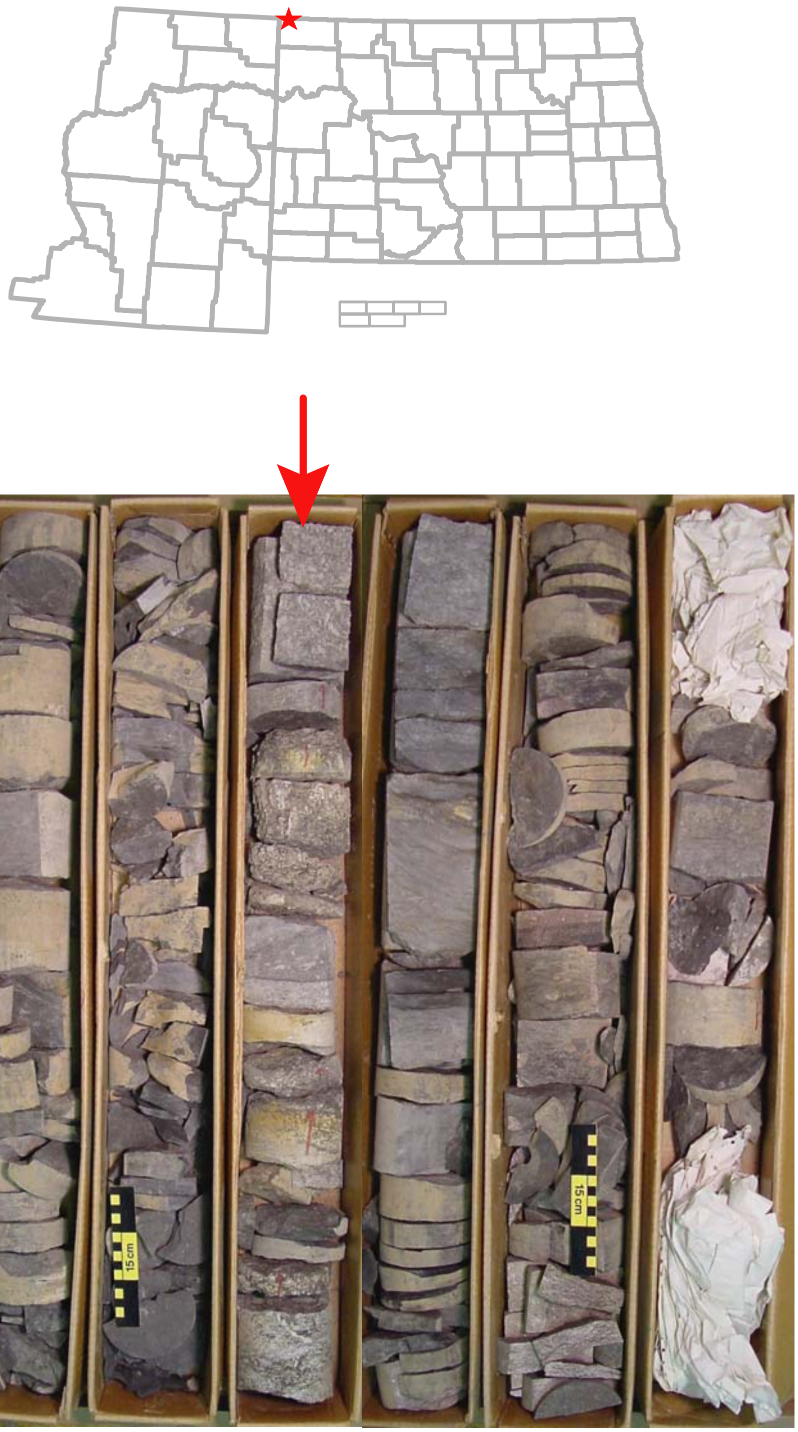

Figure 27. Core of a sandy interval from the Icebox Formation, Divide County, North Dakota.

Discussion

Depositional Environments and History

The Icebox Formation consists predominantly of greenish-gray to dark greenish-gray shale. Bioturbation is common throughout the Icebox Formation; prominent burrows occur locally. Local zones within the Icebox shales are fossiliferous, and contain brachiopods, trilobite fragments, and numerous other unidentifiable fossil fragments.

The Icebox Formation was deposited in a marine environment, seaward of the nearshore environments (Thompson, 1984; Carlson and Thompson, 1984; LeFever et al., 1987; Ellingson and LeFever, 1995). Normal marine conditions are indicated by the invertebrates present; the high degree of bioturbation indicates that oxidizing conditions existed for at least the upper part of the substrate. The depth of water is uncertain, but the presence of several sandy lithosomes may indicate that depths were not great. The lack of coarse material may reflect distance from shore rather than water depth.

The Winnipeg Group represents the initial deposits of the mid-Ordovician transgression (basal Tippecanoe sequence). The Black Island Formation was deposited under fluvial/deltaic, and, later, shallow marine and shoreline conditions. Sea level continued to rise throughout Black Island time. By the end of Black Island time, the sea covered all of the basin, and shales of the Icebox Formation were being deposited throughout most of the central basin.

Further sea level rise and migration of the shoreline gradually covered the sources of the fine-grained sediment of the Icebox Formation. The reduction in argillaceous input allowed carbonate sediment production to begin farther offshore, and the argillaceous carbonates of the Roughlock Formation were deposited. Over time, the sources of clastic sediment were completely covered, and the Roughlock Formation was succeeded by the cleaner carbonates of the Red River Formation.

Major Sand Bodies

The bioturbated sandy intervals which have been cored in the Icebox Formation strongly resemble the bioturbated portions of the upper part of the Black Island Formation, and were probably deposited under similar conditions, in a lower shoreface or shallow offshore environment (Thompson, 1984; LeFever et al., 1987; Ellingson and LeFever, 1995). The thinner portions of the major sand bodies over most of the study area exhibit log characteristics similar to the cored intervals, and probably represent similar environments.

Areas of greater sand body thickness to the west probably represent deposition in shoreline settings. That interpretation is based on two lines of reasoning: 1) thickening to the west is consistent with deposition closer to the source (shallower water); and 2) some (although not all) of the gamma ray log traces of the thicker sand bodies show a coarsening-upward log character, which is consistent with shoreline deposition. It should be noted that no core data exist to support this interpretation. The interpretation of the paleoenvironments in the area over Icebox time is depicted in Figure 28.

The occurrence of regionally extensive sand bodies within the shales of the Icebox Formation indicates that there were several shallowing episodes in the region during Icebox time. Although the Icebox was deposited during a long-term sea level rise, over the short term sea levels in the region must have fluctuated. Something similar was described for the Ordovician of Iowa, where several short-term fluctuations were superimposed on the overall sea level rise (Fig. 29; Witzke and Bunker, 1996). Whether the fluctuations in sea level recorded in North Dakota and Montana were eustatic or the result of local conditions has yet to be determined.

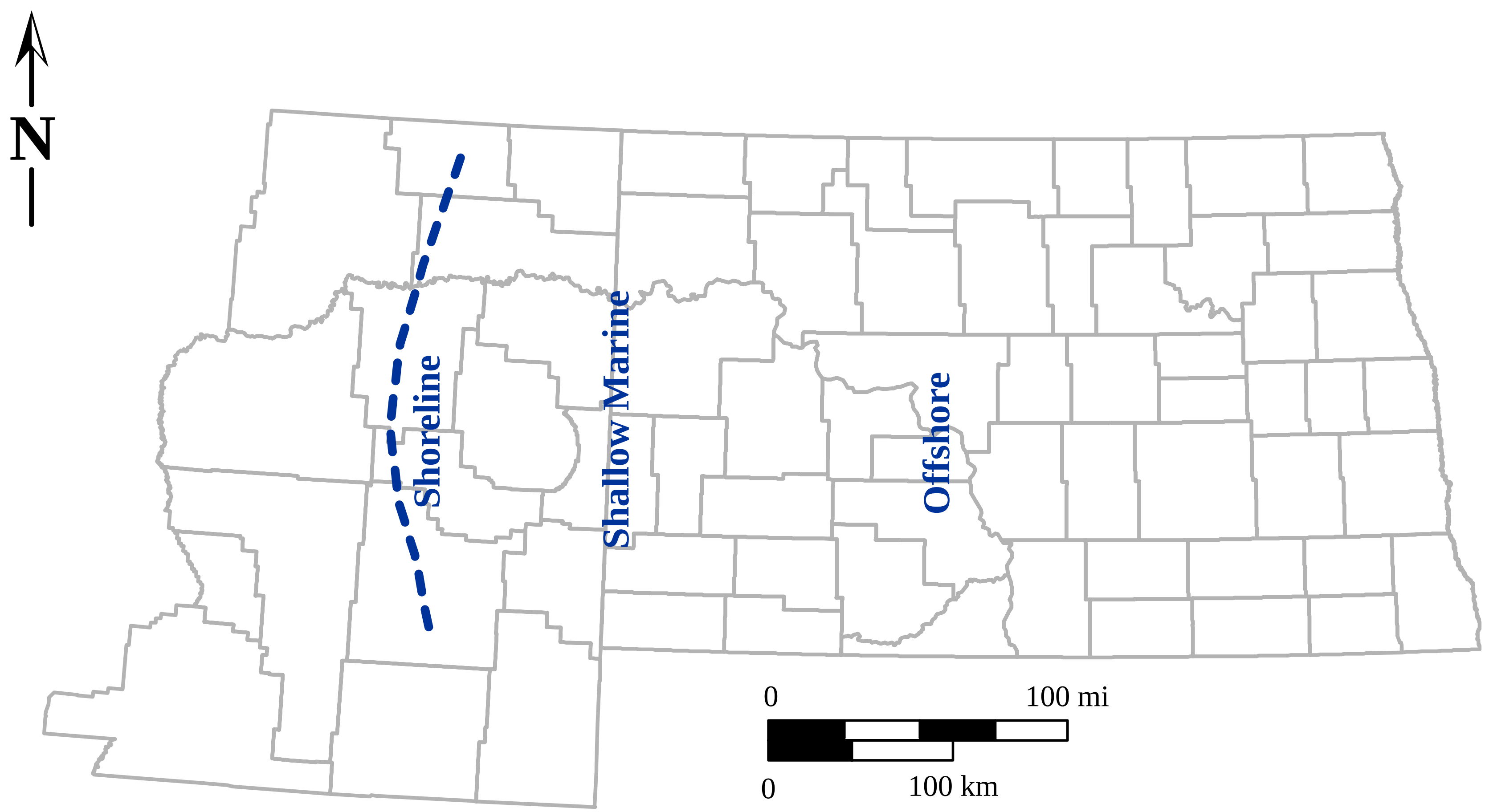

Figure 28. Generalized paleoenvironmental interpretation for the major sand bodies in the Icebox Formation.

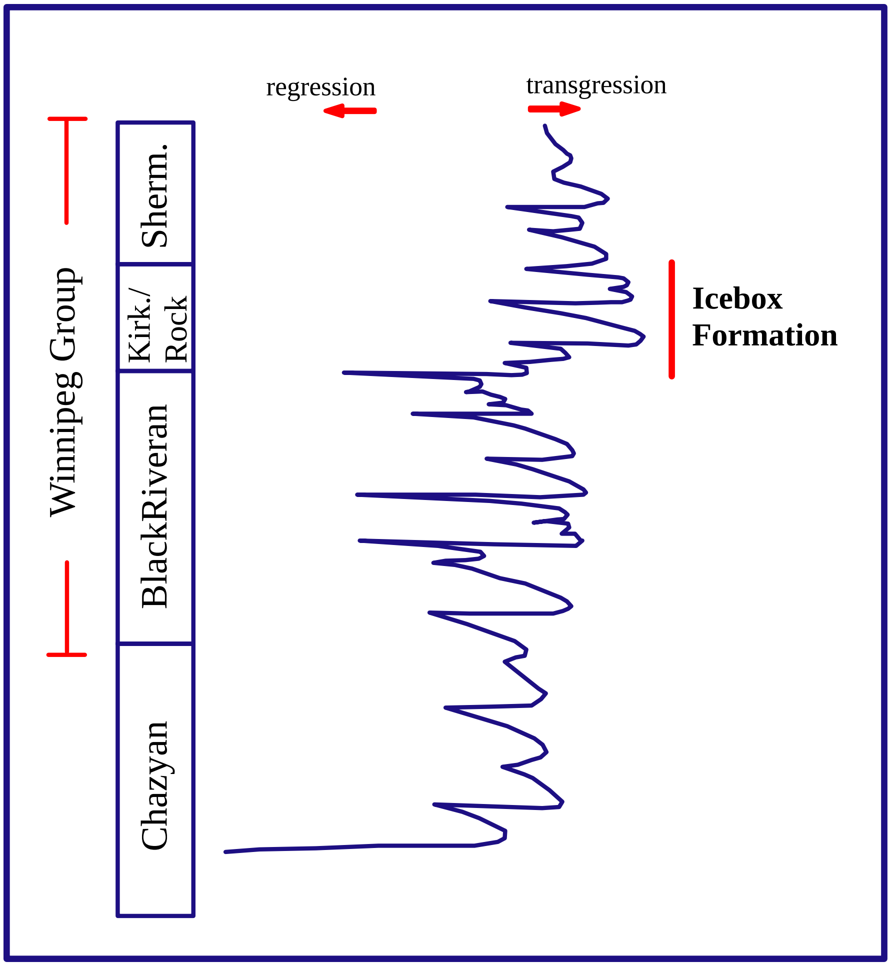

Figure 29. Sea level changes for part of the Ordovician in Iowa (after Witzke and Bunker, 1996). Age assignments for the Winnipeg Group after Thompson (1984).

Other Sand Bodies

The other sand bodies, whether classified as extensive, minor or isolated, do not appear to have resulted from significant basinwide sea level fluctuations. Because of their limited geographic extent, it seems likely that many were deposited on top of smaller topographic highs, perhaps associated with local structural features. In such cases, a small sea level drop might have been enough to allow some sediment to accumulate on top of such features, without producing regionally extensive coarser lithofacies. Examples of sandy bodies associated with known local features include: S32 (Nesson Anticline), S11 (Burleigh-Emmons County high), S15, S16, S17 and S18 (Stutsman County high).

Oil and Gas Potential

Production History

The Winnipeg Group has produced from 14 wells in seven fields in North Dakota (Fig. 30; Table 2). Not all of the wells are still active producers. All of the production is from the Black Island Formation, below the Icebox. Although there is minor oil production, the wells are primarily gas producers. There appears to have been no Winnipeg production in Montana.

Tests

Formation tests on the Winnipeg Group, including both drill stem tests and production tests, have been reported on 85 wells in North Dakota and eastern Montana (Fig. 31). Of the 85 tests, 43 reported gas from the Winnipeg (Fig. 32), and 9 reported oil (Fig. 33).

Most of the reported tests were done on the Black Island Formation, or on an interval which included the Black Island and some of the overlying Icebox, or some of the underlying Deadwood Formation. Nine tests were done on the Icebox Formation (Fig. 34). Of the nine, four reported gas and three reported oil. Five of the nine, all in eastern Montana, appear to have tested the sand bodies in the Icebox; one test reported oil, one gas, and one both.

Production tests were run on the Icebox in two wells in Sheridan County, Montana (Fig. 35; Table 3). In both cases, the tested interval was in a thick section of one of the sandy units.

We have obtained one analysis from core of the Icebox Formation, which was taken in eastern Montana, at the Amerada-Hess Federal #36-44 (SESE Sec. 36, T32N R54E, Sheridan County; Fig. 36). The core was taken in the lower Icebox and includes all of sand body S2 and a small part of sand S3. The analysis describes the S2 sand as fine to very fine-grained, locally

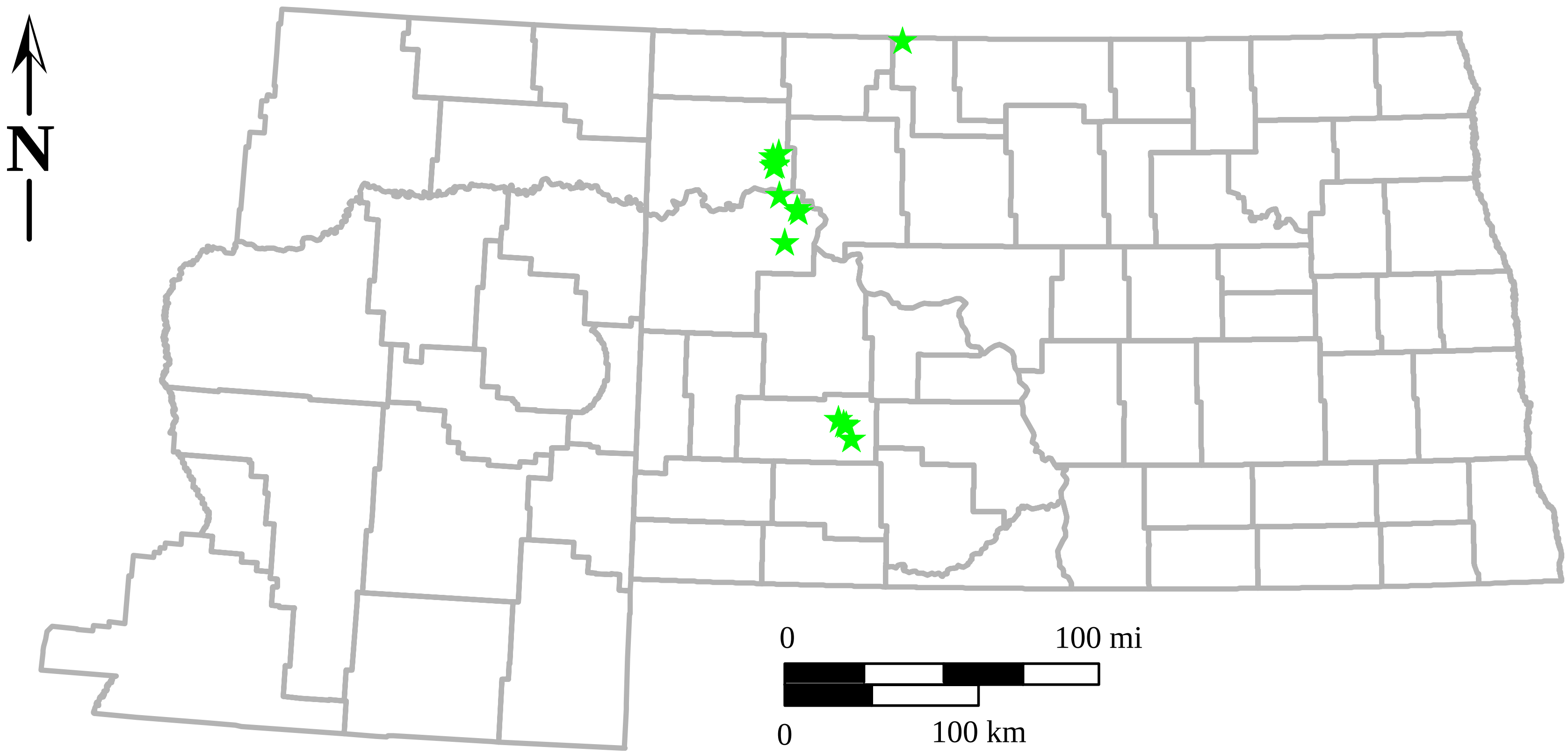

Figure 30. Locations of wells which have produced from the Winnipeg Group.

TABLE 2. WINNIPEG GROUP PRODUCING WELLS.

NDIC File No.	Location	Well	Field/Pool	Initial Completion	Cum. Oil (bbls) (Dec. 2004)	Cum. Gas (MCF) (Dec. 2004)
13405	LT7 1-152-95	Amerada Hess Corp. Brenna-Lacey 1-32	Antelope Winnipeg/Deadwood	1992	10,636	15,068,978
13647	NESE 32-153-94	Amerada Hess Corp. Oscar Moe 32-43	Antelope Winnipeg/Deadwood	1994	8,597	8,830,617
1231	SENE 2-155-96	Amerada Hess Corp. Beaver Lodge Ordovician Unit 1	Beaver Lodge Ordovician	1963	7,121	12,651,738
4716	C NW 11-155-96	Amerada Hess Corp. Beaver Lodge Ordovician Unit 4	Beaver Lodge Ordovician	1969	445,571	17,719,883
12432	SESE 2-155-96	Amerada Hess Corp. Beaver Lodge Ordovician Unit 9	Beaver Lodge Ordovician	1992	4,870	8,465,561
12305*	NENE 13-156-96	Amerada Hess Corp. Nels Anderson 1	Beaver Lodge Ordovician	1988	211,755	4,845,743
12831*	SESE 22-156-96	Amerada Hess Corp. Nelson 22-4	Beaver Lodge Ordovician	1990	866	883,220
14399	SWNE 6-150-95	Amerada Hess Corp. Lovaas 6-32	Blue Buttes Winnipeg/Deadwood	1996	138	8,450,074
14724	SWNE 6-153-95	Amerada Hess Corp. Thompson 6-32	Charlson Winnipeg/Deadwood	1996	0	347,186
6466	SWNE 3-163-87	Georesources Mott 32X-3	Newporte Cambro/Ordovician	1978	214,866	69,023
8169*	NENW 21-138-92	Zinke & Trumbo Schilla 1-21	Richardton Winnipeg/Deadwood	1981	3,288	1,111,332
9056	SENW 24-139-93	Georesources Ogre 1-24	Taylor Winnipeg	1982	137,942	6,168,764
9257*	NESW 19-139-92	Ventex Hamann 1-19-4B	Taylor Winnipeg	1983	74	56
9341*	NESW 10-139-93	Gulf Moore 1-10-4B	Taylor Winnipeg	1982	486	0

**Abandoned*

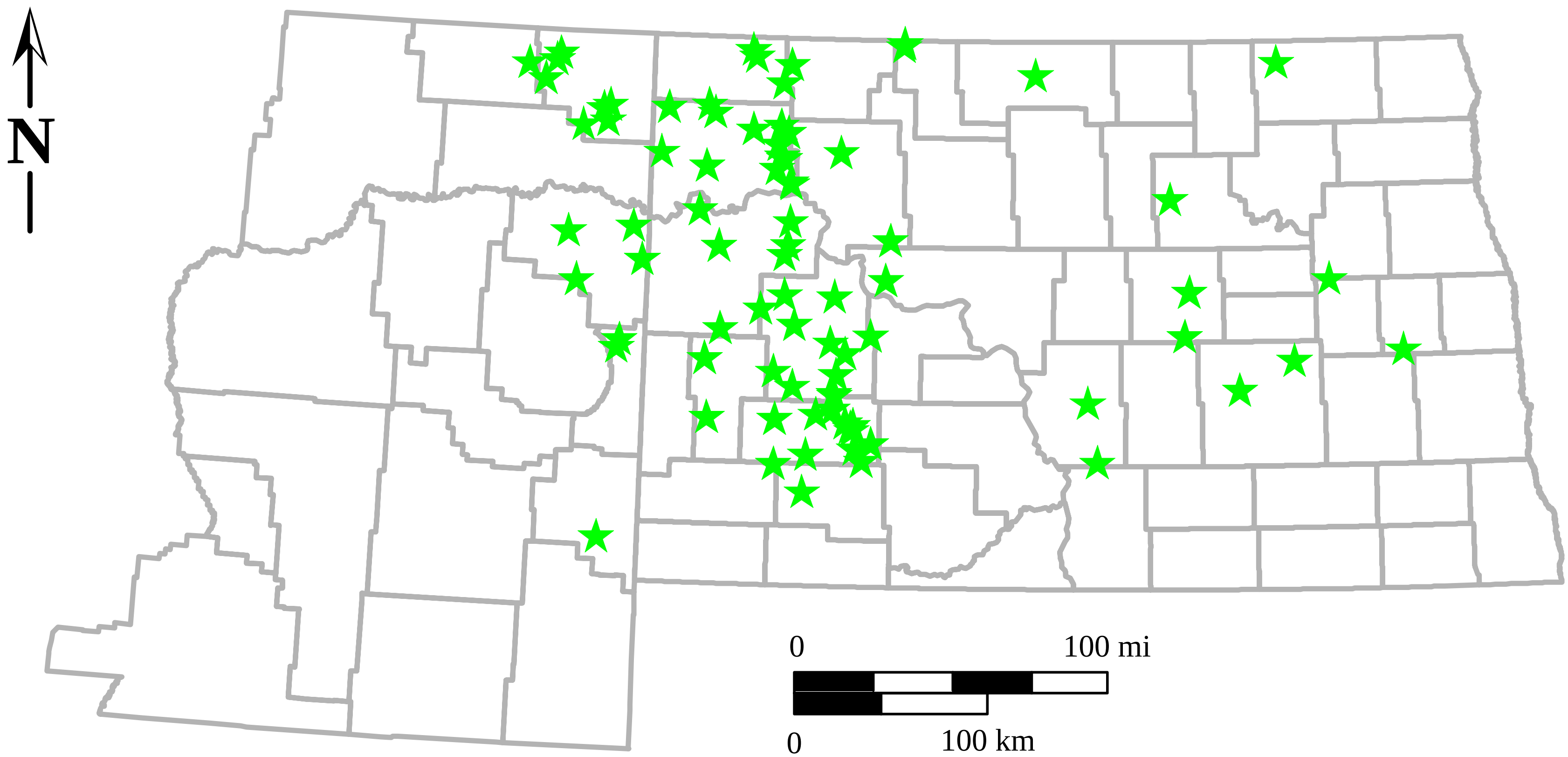

Figure 31. Locations of wells in which the Winnipeg Group was tested.

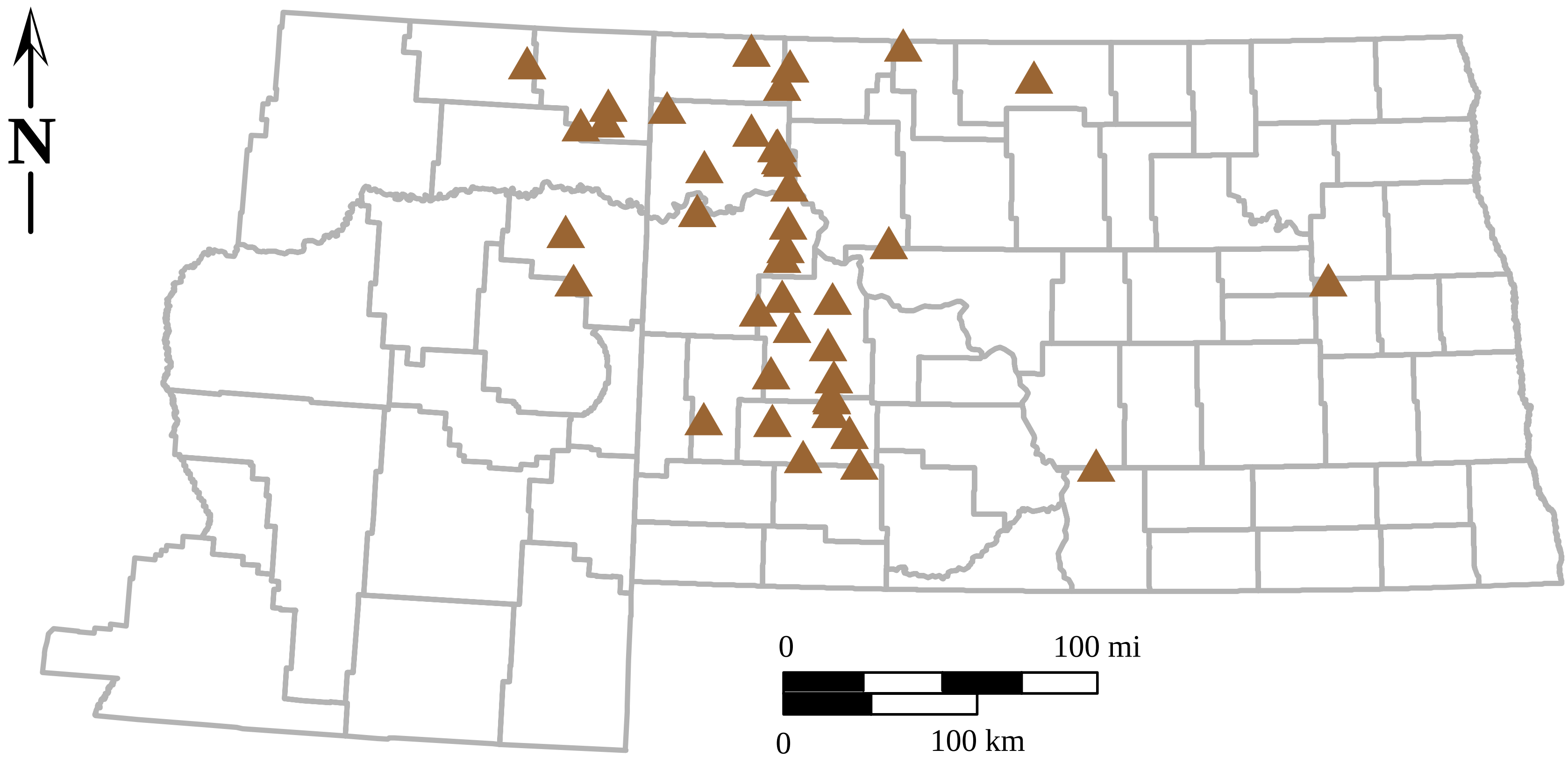

Figure 32. Locations of wells reporting gas in Winnipeg.

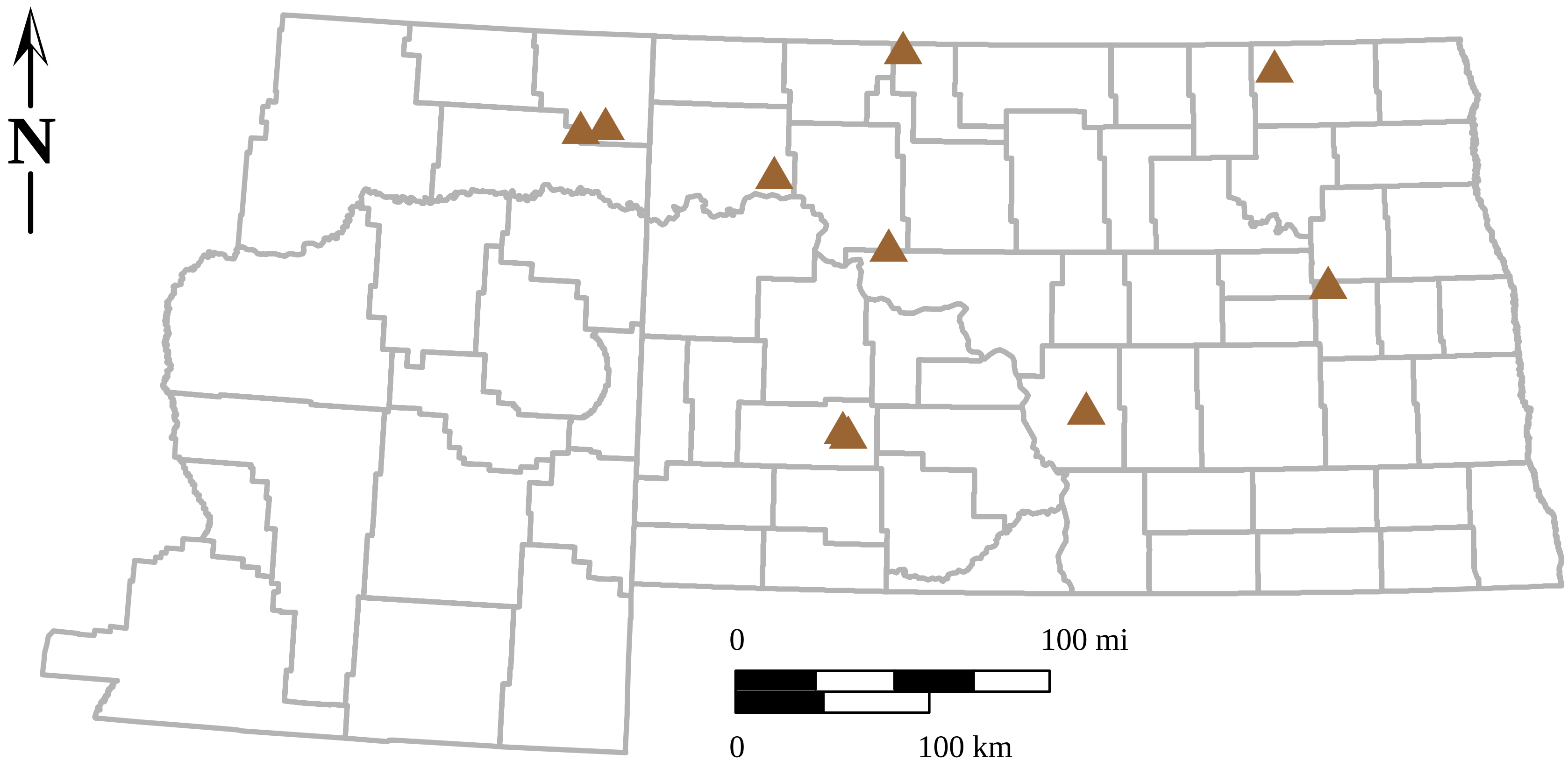

Figure 33. Locations of wells reporting oil in Winnipeg tests.

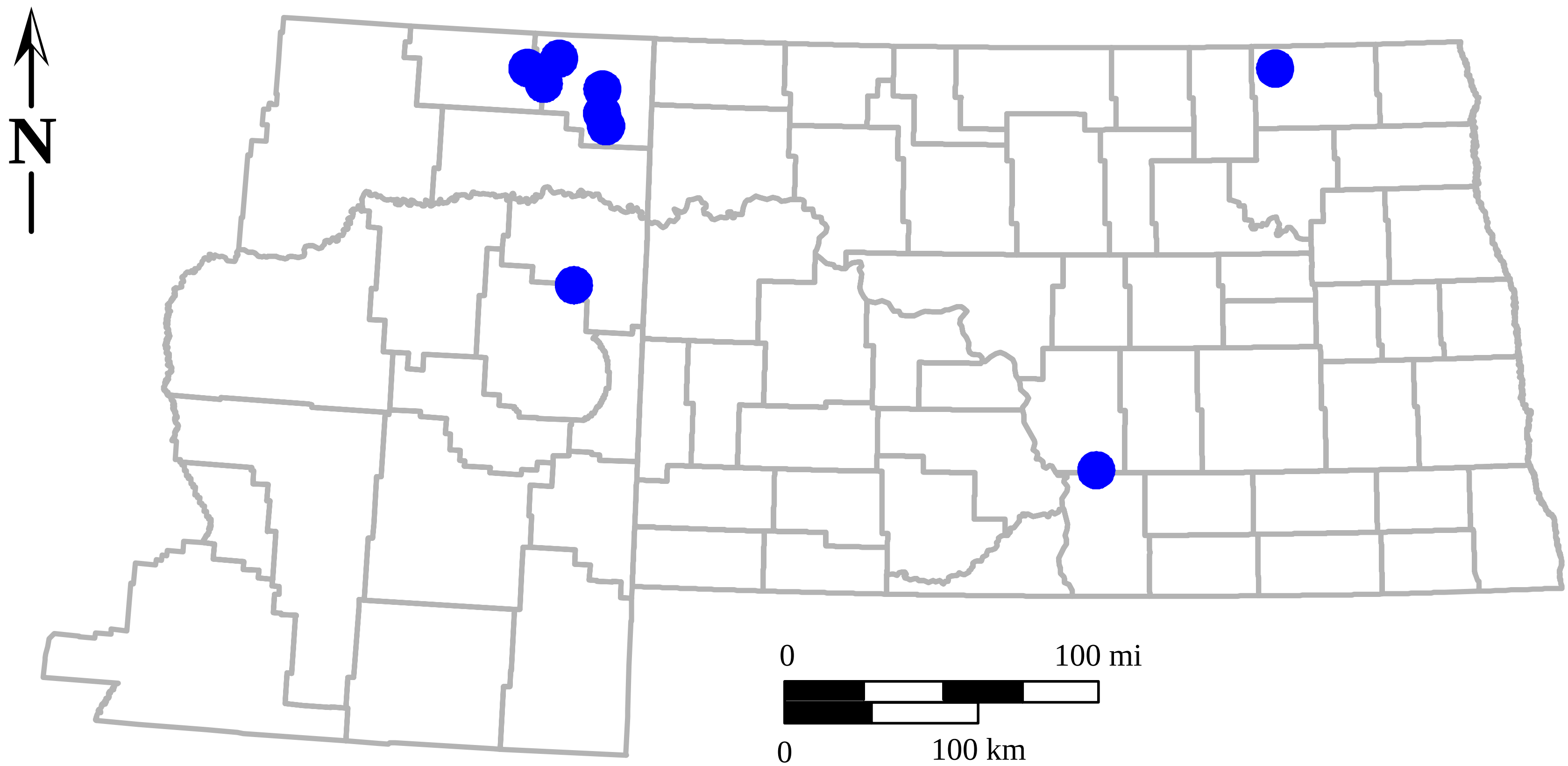

Figure 34. Locations of wells in which the Icebox Formation was tested.

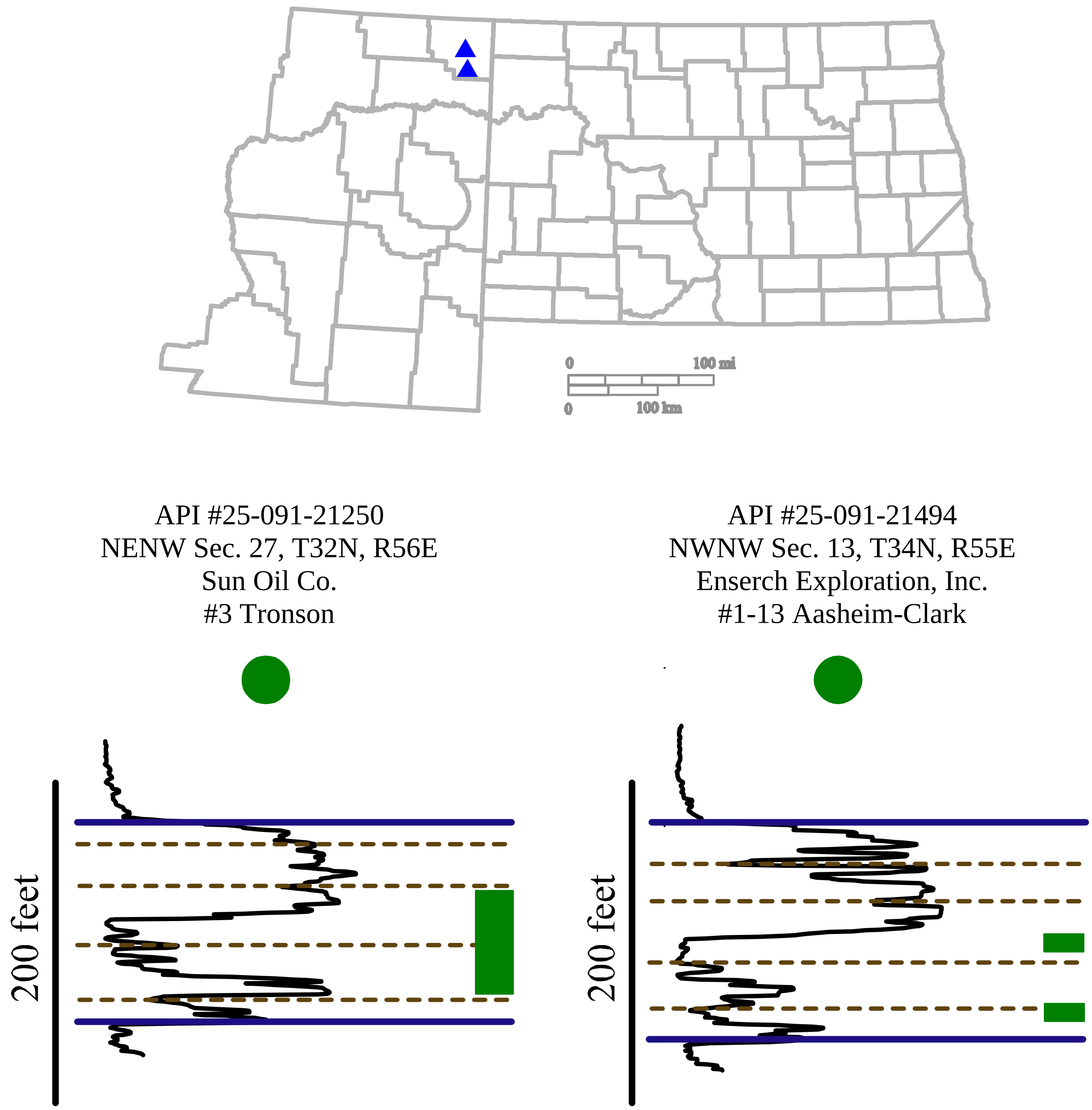

Figure 35. Locations and gamma-ray curves for the Sun Tronson and the Enserch Aasheim-Clark wells, Sheridan County, Montana. Dashed lines represent the centers of the sand bodies. Heavy bars are the tested intervals.

TABLE 3. PRODUCTION TESTS ON THE ICEBOX FORMATION.

Date	Well	Location	DST	Production test
1979	Sun Oil Co. #1 Tronson	NENW Sec. 27, T32N R56E	SC: 12 cf gas, 400 cc oil	2 bbl oil 150 MCF gas
1983	Enserch Exploration, Inc. #1-13 Aasheim-Clark	NWNW Sec. 13, T34N R55E	None	2400 gal oil

API #25-091-21597
SESE Sec. 36, T32N, R54E
Amerada-Hess Corp.
#36-44 Federal

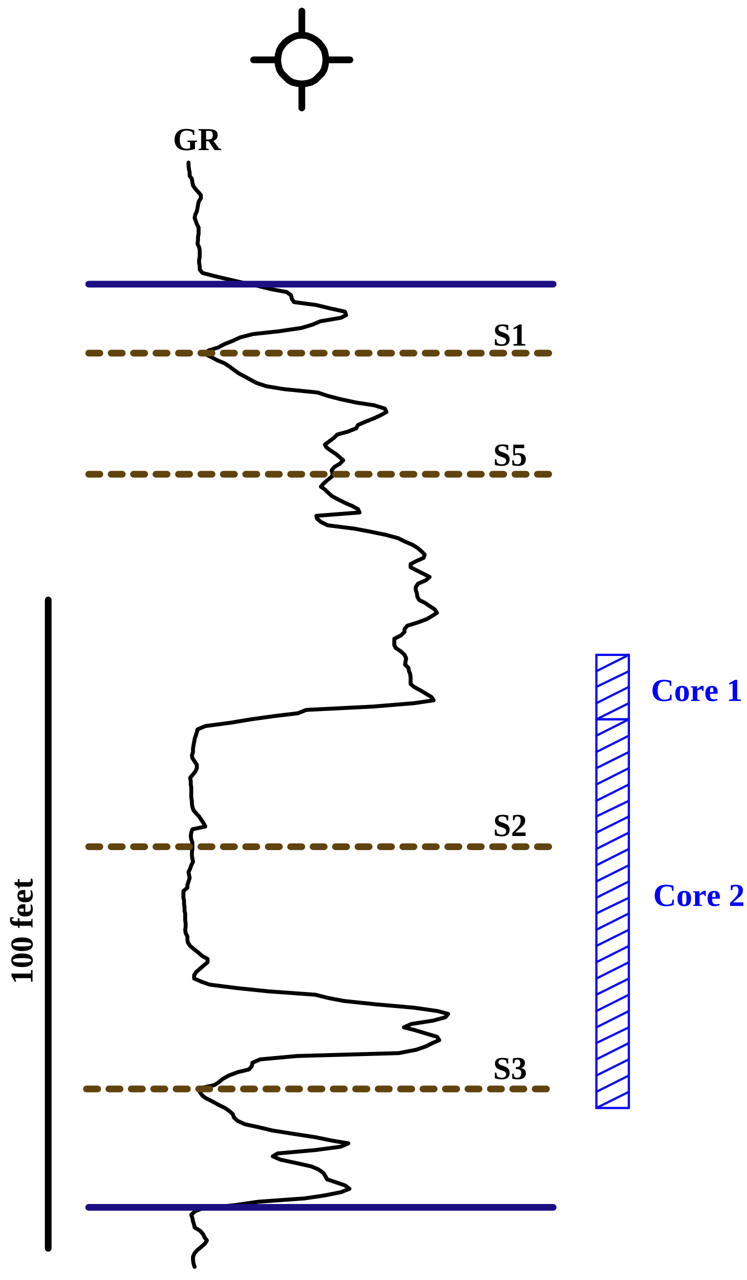

Figure 36. Gamma-ray curve and cored interval for the Amerada-Hess #36-44 Federal well Sheridan County, Montana.

shaly, with some pyrite. Reported permeabilities averaged about 21 md (.01 - 90 md), and porosity averaged 7.3% (2.5 - 12.1%). Oil saturation ranged from 0 to 28.7% (average 7.3%), and water saturation from 4.7% to 43.7% (average 20.4%).

Potential

The only previous work on the production history and potential of the Winnipeg over the Williston Basin in North Dakota and Montana is Anderson's (1982) thorough summary. His study was concerned entirely with the history and potential of the Winnipeg Sand (Black Island Formation), and did not address the Icebox Formation at all.

The oil and gas potential of the Icebox Formation within the area studied is difficult to assess for two reasons. First, there are comparatively few wells which encounter it in the area; only about 400 out of the more than 22,000 wells in North Dakota and eastern Montana are deep enough to penetrate the Icebox. Second, tests reported on the Winnipeg Group include only 85 wells, only about 20% of the wells drilled to that level. Of the 85, only nine appear to have tested the Icebox Formation.

Despite the relative lack of data on the Icebox Formation within the area, there are some grounds to consider it to have potential as a hydrocarbon producer. First, although only five wells have tested the sand bodies in the Icebox, three of the five reported hydrocarbons, two in significant quantities.

Second, based on the tests run and on the log characteristics, the sand bodies are good candidates for reservoir rock, and their interbedding with an extensive source rock would have made it comparatively easy for hydrocarbons generated in the source rock to have accumulated in the sand bodies. The Icebox is considered to be a source rock for the Lower Paleozoic in the Williston Basin (Dow, 1974; Osadetz *et al.*, 1994; Burrus *et al.*, 1995). Dow (1974) considered that the maximum extent of effective Winnipeg source rocks in the Williston Basin, as determined from studies of thermal alteration of organic matter, is defined by the -5,000 ft contour on the top of the Icebox shales on the east, and on the west by the depositional limit of the shale. Using those criteria, a large fraction of the study area would be considered thermally mature enough to generate hydrocarbons from the Icebox (Fig. 37).

On balance, it seems likely that the Icebox Formation, particularly the sand bodies, has some oil and gas potential. The sand bodies have only been tested in five locations in eastern Montana. Large areas of sand body occurrence are entirely untested. The major sand bodies cover very large areas, and reach thicknesses of tens of feet in the counties along the North Dakota-Montana border. Several of the bodies classified above as extensive or minor reach thicknesses of more than 10 feet, and, collectively, cover a large portion of the area.

Based on the Icebox tests and the Winnipeg production from the fields in North Dakota, it seems likely that any production from the Icebox will be predominantly gas, although some oil seems to be present.

Summary

The Icebox Formation (Ordovician) is a regionally extensive shale, the middle of three formations within the Winnipeg Group. Wireline gamma-ray logs were used to study the Icebox Formation in North Dakota and eastern Montana. The gamma-ray traces were converted to digital format to allow us to recognize and trace coarser lithofacies within the shale.

Forty sandy lithofacies were identified in the study area. Five have regional extent, and cover most of the study area. These major bodies tend to thicken westward, and their maximum thicknesses occur near their westward limits. Five additional sand bodies each extend across

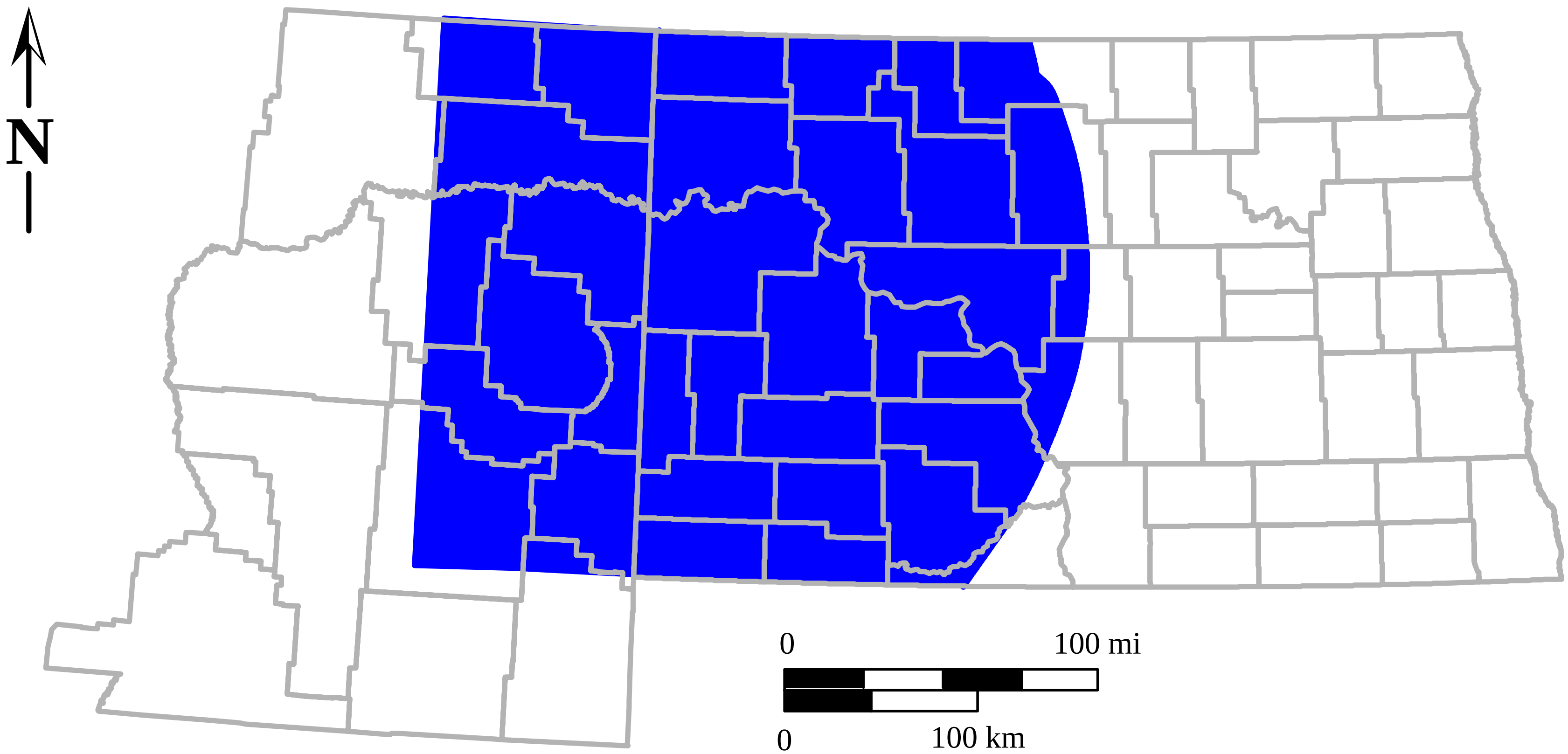

Figure 37. Portion of the study area below the -5,000 ft structure contour on the top of the Icebox Formation.

distance from shore rather than water depth.

The bioturbated sandy intervals were probably deposited in a lower shoreface or shallow offshore environment. Areas of greater sand body thickness to the west probably represent deposition in shoreline settings. There were several shallowing episodes in the region during Icebox time.

The less extensive sand bodies do not appear to have resulted from significant basinwide sea level fluctuations. It seems likely that many were deposited on top of smaller topographic highs, perhaps associated with local structural features.

The Winnipeg Group has produced from 14 wells in seven fields in North Dakota. All of the production is from the Black Island Formation, below the Icebox. The wells are primarily gas producers.

Formation tests on the Winnipeg Group, including both drill stem tests and production tests, have been reported on 85 wells in North Dakota and eastern Montana. Nine tests were done on the Icebox Formation. Of the nine, four reported gas and three reported oil. Five of the nine, all in eastern Montana, appear to have tested the sand bodies in the Icebox; one test reported oil, one gas, and one both.

On balance, it seems likely that the Icebox Formation, particularly the sand bodies, has some oil and gas potential. The sand bodies have only been tested in five locations in eastern Montana. Large areas of sand body occurrence are entirely untested. The sand bodies are good candidates for reservoir rock, and interbedding with an extensive source rock would have allowed generated hydrocarbons to accumulate in the sand bodies. Any production from the Icebox will probably be predominantly gas.

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