U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Subsurface Stratigraphic Analysis of Upper Cretaceous Rocks, Southeastern Flank of the Williston Basin, North and South Dakota

by

J. K. Baird[1]

and

T. S. Dyman[1]

Open-File Report 93-335

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards (or with the North American Stratigraphic Code). Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

[1]Lakewood, Colorado

1993

Contents

Tables

Figures

Introduction

Cretaceous strata of the northern Rocky Mountains and Great Plains regions of the United States were deposited in and adjacent to a broad north-trending epicontinental sea (Western Interior seaway) that was bordered on the west by the Cordilleran thrust belt and was underlain and bordered on the east by the cratonic platform. Variable rates of subsidence related to tectonic and sediment loading produced an asymmetric sedimentary basin with Cretaceous strata ranging in thickness from nearly 20,000 ft in southwestern Montana to less than 1,000 ft in eastern South Dakota and western Minnesota. During Early to middle Cretaceous time, this sedimentary package formed a foreland wedge that thinned to the east, away from the thrust belt. Later, during middle to Late Cretaceous time, the foreland was broken by Laramide uplifts (younger to the east) that sequentially deformed the wedge. Active uplifts affected the distribution and configuration of contemporaneous and later Cretaceous,sediments, creating complex stratigraphic and sedimentologic relationships.

In many parts of the northern Great Plains region Cretaceous rocks have been studied in great detail because of the economic incentives associated with exploration for energy resources. In other areas these rocks have been studied primarily in a a reconnaissance manner. Recent work in biostratigraphy, geochronology, and sequence stratigraphy provides data that aid significantly in resolving problems in correlation and facies analysis of these rocks. Palynostratigraphic studies have provided time markers for precise correlation of nonmarine rocks at the western margin of the seaway to marine rocks in the east. Similarly, nannofossils in marginal marine rocks along the eastern margin have been correlated with those to the west. See Dyman and others (in press) for more detailed discussions of Cretaceous rocks in the entire region.

The purpose of this report is to present new subsurface correlations and structure and isopach contour maps of Cretaceous rocks in the southeastern part of the Williston basin in northern South Dakota and southern North Dakota (fig.1). These correlations will be integrated into the regional stratigraphic framework of the Western Interior Cretaceous Project (WIK). The goal of the WIK Project is to create a publicly available data base from which to construct and interpret the depositional history within the Western Interior Cretaceous basin. Ongoing WIK objectives include publishing regional stratigraphic transects (see Dyman and others, in press) and a compendium of Laramide basins within the Rocky Mountain and Great Plains regions. WIK is a subproject of the Global Sedimentary Geology Program (GSGP). The International Union of the Geological Sciences established the GSGP as a new commission to extend the understanding of the history of the earth including sedimentary rocks and their contained organisms.

Many thanks to C. M. Molenaar and J. E. Fox of the U.S. Geological Survey for their careful and helpful reviews of the manuscript.

Methods

The 11 stratigraphic cross sections along the southeastern flank of the Williston basin described in this report use 82 electric well logs to illustrate stratigraphic relationships of an interval of Upper Cretaceous rocks (Greenhorn Formation to Niobrara Formation). Table 1 lists the wells shown on the sections plus 22 additional wells used for greater mapping control. On the cross sections the average well spacing is 14 mi, and the total area studied is approximately 19,000 sq mi.

The datum for all sections is the thick Ardmore Bentonite Bed, or series of beds, near the base of the Sharon Springs Member of the Pierre Shale. This unit is believed to have been deposited on a nearly flat or very gently dipping basin floor.

The original borehole logs used for these cross sections, at a scale of one in. = 100 ft, were digitized by tracing the spontaneous potential (SP) curves and the resistivity or conductivity curves. Conductivities were converted to resistivities, and the SP and resistivity curves were computer-plotted at one in. = 200 ft (see fig. 2). On many of the logs the SP curve was very weak; a condition probably caused by the drilling mud having a resistivity similar to that of the formation water. These weak amplitudes were computer- enhanced in an attempt to provide better correlations. The final cross sections were reduced to the present size (vertical scale one in. = 520 ft) for convenience in handling and reproduction (figs. 3-7).

The structure and thickness maps were computer-contoured and smoothed by hand. Formation tops were picked from both digitized and undigitized logs to the nearest five feet.

Definition and Location

The study area is located on the southeast margin of the Williston basin along the eastern shelf of the Western Interior basin. From the Black Hills eastward, Cretaceous rocks overstep progressively older rocks. Southeast of the study area, Cretaceous sedimentary rocks overlie Precambrian rocks of the

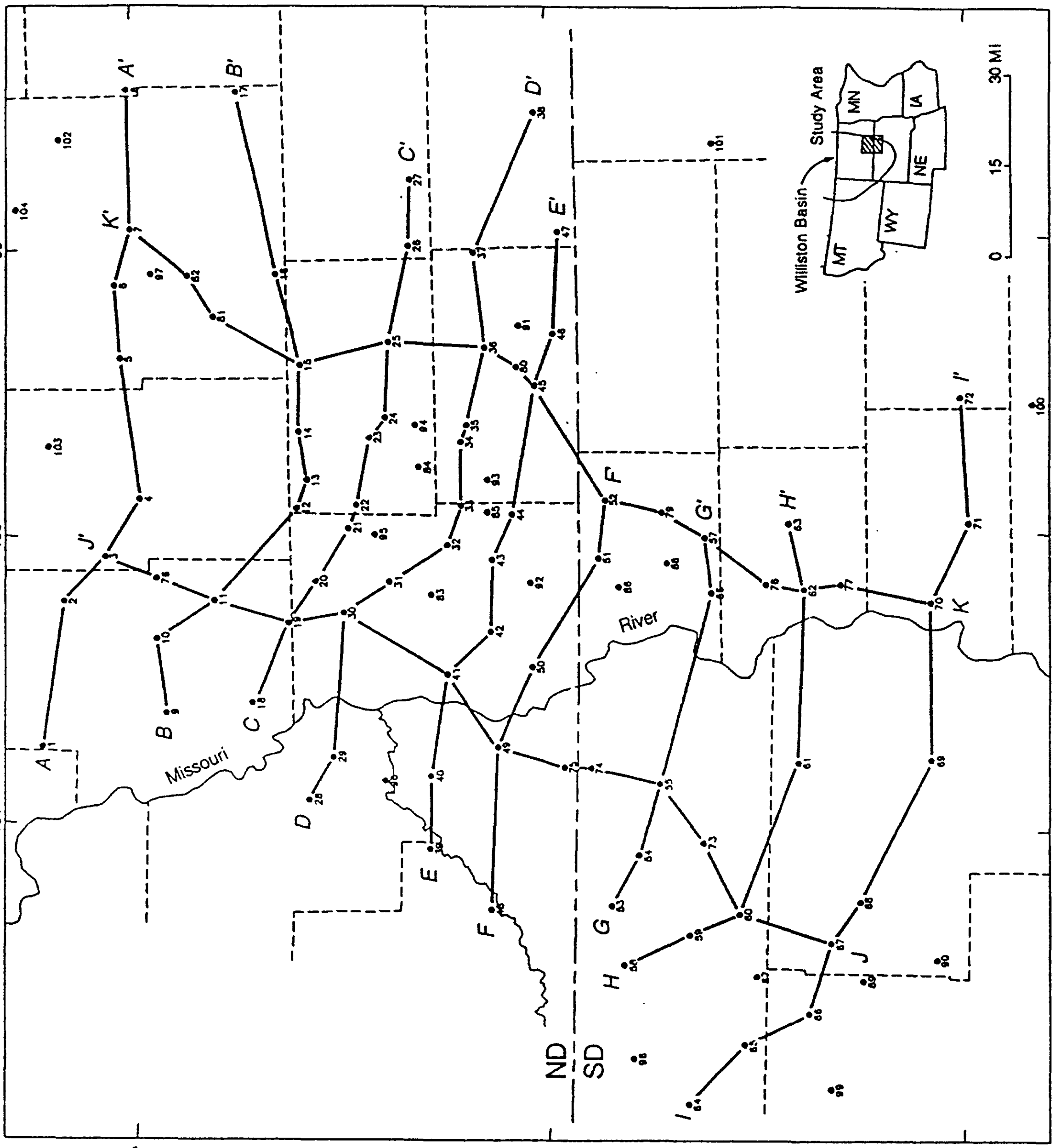

Figure 1. Index map showing location of cross sections and all wells used in study area along southeastern flank of Williston basin, North and South Dakota. Fine dashed lines are county boundaries.

Table 1. Names and locations of wells used to construct cross sections and maps in the study area along the southeastern flank of the Williston basin, North and South Dakota.

No.	Sec. Tps. Rgs.	State	Well name	KB elev. (ft.)
1	6-143N-79W	ND	Brown-Love Aune No. 1	1977
2	30-143N-75W	ND	Continental & Pure J.F. Miller No. 1	2051
3	32-142N-74W	ND	Caroline Hunt Trust E.B. Sauter Estate No. 1	1848
4	36-141N-73W	ND	Magnolia State A No.1	1968
5	14-141N-69W	ND	Mobil Gross No. 1	1893
6	11-141N-67W	ND	Barnett Drilling Gaier Bros. No. 1	1873
7	28-141N-65W	ND	Chambers & Kennedy Perleberg et al No. 1	1570
8	30-141N-61W	ND	Johnston Drilling Clarence Johnson No. 1	1472
9	23-140N-79W	ND	Caroline Hunt Trust Paul Ryberg No. 1	2007
10	11-140N-77W	ND	Calvert Drilling & Leach Oil Patterson LC No. 1	2019
11	36-139N-76W	ND	Caroline Hunt Trust Schlaback No. 1	1880
12	6-136N-73W	ND	Caroline Hunt Trust F.M. Fuller No. 1	2011
13	13-136N-73W	ND	Chambers & Kennedy Louis Wald et at No. 1	2048
14	8-136N-71W	ND	Calvert-Leach Inter.-Western C.A. Zimmerman No. 1	2022
15	7-136N-69W	ND	Chambers & Kennedy Graf Estate No. 1	1881
16	25-137N-67W	ND	Calvert Exploration Margret Meyers No. 1	1907
17	24-138N-62W	ND	Jack M. Johnston Drilling Leo Nicholls No. 1	1437
18	31-138N-78W	ND	Asamera Oil (US) Welch No. 1	1752
19	32-137N-76W	ND	Continental Oil McCay No. 1	1869
20	19-136N-75W	ND	Texas Pacific Wolbaum No. 1	1849
21	22-135N-74W	ND	Arkla Exploration A.E.C.-Ellefson No. 1-22	1968
22	29-135N-73W	ND	Wise Oil Weigel No. 1	2117
23	6-134N-71W	ND	Calvert-Leach Inter.-Western Knute Jensen No. 1	2111
24	22-134N-71W	ND	Calvert-Leach Inter.-Western Leroy Burnstad No. 1	2013
25	26-134N-69W	ND	Calvert-Leach Inter.-Western Albert Roesler No. 1	1954
26	9-133N-66W	ND	Don D. Bills Bjur No. 1	1970
27	18-133N-64W	ND	Vaughn Petroleum Smith No. 1	1653
28	18-136N-81W	ND	Houston Oil & Minerals Haider et al No. 1	1907
29	5-135N-80W	ND	Lamar Hunt John Schaff No. 1	2254
30	17-135N-76W	ND	Southwestern Energy R.K. Weiser No. 1	2004
31	30-134N-75W	ND	Mobil Kruse F22-30P	2044
32	12-132N-75W	ND	Forest Oil Hulm No. 1	1990
33	25-132N-74W	ND	Forest Oil Meier No. 1	1960
34	26-132N-72W	ND	Galaxy Oil Rudolph No. 1	2155
35	31-132N-71W	ND	Galaxy Oil Niess No. 1	2157
36	17-131N-69W	ND	Calvert Exploration Karl Schock No. 1	2143
37	1-131N-67W	ND	Chambers & Kennedy Isaak No. 1	2009
38	34-130N-63W	ND	Snowden & Sheehan Gibson No. 1	1465?
39	26-133N-83W	ND	Youngblood & Youngblood Kelstrom No. 1	1997
40	35-133N-81W	ND	Gruy Management Services Kary No. 1	1849
41	8-132N-78W	ND	Peak Drilling Ohlhauser No. 1	1820
42	21-131N-77W	ND	Placid Jacobs No. 1	1930
43	21-131N-75W	ND	Westcoast-Kelsch & Donlin Wald No. 1	1949
44	3-130N-74W	ND	Forest Oil Werlinger No. 1	2004
45	29-130N-70W	ND	Home Petroleum Baumann No. 1	2025
46	10-129N-69W	ND	Chamers & Kennedy Roeszlar No. 1	2038
47	22-129N-66W	ND	Calvert-Leach Inter.-Western Marvin Kamm No. 1	2196
48	23-131N-85W	ND	Union NPRR No. 1	2014
49	29-131N-80W	ND	Ohio Standing Rock Sioux Tribal No. 1	1732
50	28-130N-78W	ND	Placid Jakobsen No. 1	1815
51	18-128N-76W	SD	Wilhite-Simcox-Star Drilling Stephen Weisbeck No. 1	1707
52	26-128N-75W	SD	Wilhite-Simcox-Star Drilling Edward Beck No. 1	1866
53	16-22N-23E	SD	Murphy & Cayman State "C-2" No. 1	2147

54	12-21N-24E	SD	Murphy & Cayman State "B" No. 1	1983
55	35-21N-26E	SD	Koch Exploration Schott-Knudson No. 1	2100
56	30-125N-77W	SD	Wilhite-Simcox-Star Drilling Thompson No. 1	1854
57	22-125N-76W	SD	Wilhite-Simcox-Star Drilling Brockel No. 1	1783
58	36-22N-21E	SD	Wilhite State No. 1	2226
59	25-20N-22E	SD	Koch Exploration American Lutheran Church No. 1	2096
60	4-18N-23E	SD	Koch Exploration Bickel No. 1	2137
61	27-17N-27E	SD	Herndon Drilling Louis Merkle No. 1	1909
62	7-122N-77W	SD	Wilhite-Simcox-Star Drilling Hodeste E. Marin No. 1	1927
63	36-123N-76W	SD	Peppers Refining So. Dak. State No. 1	2064
64	32-20N-18E	SD	Consolidated Tribal No. 1	2383
65	12-18N-19E	SD	Shell Evridge No. 22-12	2231
66	1-16N-20E	SD	Herndon Drilling Jack Young No. 1	2334
67	25-16N-22E	SD	Youngblood & Youngblood Galvin No. 1	2289
68	13-15N-23E	SD	Herndon Drilling James O'Leary No. 1-A	2236
69	13-13N-27E	SD	Gulf Wallace Jewett No. 1	2319
70	27-119N-78W	SD	Dakota-Texas Williams Thompson No. 1	1899
71	25-118N-76W	SD	Gettysburg Town Well	2090
72	20-118N-72W	SD	H.B. Hunt Leona & Leo T. Gutenkauf No. 1	1940
73	4-19N-25E	SD	Koch Exploration Richter No. 1	2050
74	32-23N-27E	SD	Koch Exploration State No. 1	2149
75	26-129N-81W	ND	Gruy Management Services Sandland No. 1	2215
76	9-140N-75W	ND	Continental Dronen No. 1	1912
77	8-121N-77W	SD	Wilhite-Simcox-Star Drilling Beckman No. 1	1780
78	8-123N-77W	SD	Wilhite-Simcox-Star Drilling Mandernach No. 1	1935?
79	8-126N-75W	SD	Wilhite-Simcox-Star Drilling Edward Quenzer No. 1	1792
80	11-130N-70W	ND	Home Petroleum Home Wishek No. 1	2042?
81	35-139N-68W	ND	Calvert Exploration Christ Rau No. 1	1880
82	12-139N-67W	ND	Calvert Exploration Vincet Wanzek No. 1	1867
83	35-133N-76W	ND	Roeser-Pendleton J.J. Weber No. 1	2012
84	20-133N-72W	ND	Herman Hansen Welder No. 1	2004
85	14-131N-74W	ND	Forest Weber No. 1	2013
86	5-127N-77W	SD	Wilhite-Simcox-Star Drilling Walter Mittleider No. 1	1660
87	26-18N-21E	SD	Kilroy & Swindler Scholl No. 1	2323
88	13-126N-77W	SD	Wilhite-Simcox-Star Drilling Ralph Ritter No. 1	1820
89	25-15N-21E	SD	Norris Oil Cheyenne No. 1	2298
90	21-13N-22E	SD	Pendak R.H. Cowan, Jr. No. 1	2300
91	13-130N-69W	ND	Calvert Exploration G.C. Nitschke No. 1	2042
92	26-130N-76W	ND	Sunmark Slagh No. 1	1839
93	15-131N-73W	ND	General Atlas Carbon Ketterling No. 1	2176?
94	16-133N-71W	ND	Galaxy State No. 1	2068
95	9-134N-74W	ND	Nelson & Donlin Grunfelder No. 1	1948
96	22-134N-81W	ND	Gruy Management Service Hatzenbuhler No. 1	1721
97	12-140N-67W	ND	Calvert Exploration Ganser No. 1	1900
98	8-21N-19E	SD	Youngblood & Youngblood Macheel No. 1	2371
99	26-16N-18E	SD	Amerada Roy Trent No. 1	2445?
100	24-116N-73W	SD	N.B. Hunt So. Dak. Com. School & Indemnity No. 2	1889?
101	33-125N-65W	SD	Oil Hunters Raetzman No. 1	1385?
102	35-143N-63W	ND	Chambers & Kennedy Ray Nutt No. 1	1543
103	16-143N-71W	ND	Carter State No. 1	1889
104	24-144N-65W	ND	Chambers & Kennedy Roger Nieland No. 1	1535

Canadian Shield. Cretaceous rocks in this region are relatively flat lying. Their deposition onlapped a smoothed, peneplaned land surface, and the area was subjected only to minor tectonic adjustments during and since Cretaceous time. Cretaceous rocks were deposited in nonmarine, shoreline, and marine shelf environments.

Stratigraphy and Structure

Following is a brief description of the selected subsurface rock units, in ascending order, for this part of the Williston basin with comments on geophysical log interpretation. The Greenhorn Formation, the oldest unit studied, consists mainly of interbedded gray, calcareous marine shale and fragmented, argillaceous limestone. It is concordant with the underlying Graneros Shale (also called Belle Fourche Shale) which is composed of dark-gray, noncalcareous, pyritic, poorly fossiliferous shale, and is mid-Cenomanian in age (Dyman and others, in press). The Greenhorn ranges in thickness from 125 to 200 ft (see figs. 6 & 8), and is latest Cenomanian to early Turonian in age. The amount of limestone appears to increase basinward (to the northwest). The upper contact is sharply defined on the resistivity curves, and the lower contact is a prominent bentonite bed represented by a lack of resistivity and a positive SP deflection.

Conformably overlying the Greenhorn Formation is the Turonian Carlile Shale, which in the study area is mainly a single unit consisting of gray to black marine noncalcareous shale containing thin, limy siltstone beds in the upper part. To the southwest and southeast of the area the Carlile is sometimes divided into three alternating sand and shale members that were not recognized in this study (Fairport, Blue Hill, and Codell Members; unpublished data, South Dakota Geological Survey; see Dyman and others, in press; and Rice, 1977). A few thin bentonite beds within the formation serve as time marker horizons. The formation ranges in thickness from about 250 ft in the southeast to about 550 ft in the northwest (see figs. 4 & 9).

The Niobrara Formation rests unconformably on the Carlile Shale, and has approximate thicknesses in the study area of 80 ft in the east to 225 ft in the west (see figs. 4, 6, & 10). This variation is probably the result of lateral facies changes and erosion (Shurr and Sieverding, 1980). It is mainly composed of calcareous shale and marl or chalk containing some bentonite, and is early Santonian to early Campanian in age. As shown on the sections (figs. 3-7) the Niobrara typically has a lower chalk unit (large negative SP deflections) and an upper calcareous shale unit, shown by Rice (1977) as the Fort Hays Limestone Member and Smoky Hill Shale Member, respectively. However, Shurr and Rice (1987) refer to the chalk unit as chalk tongue "B". On the west side of the area the chalk thins, and finally grades into chalky or calcareous shale and intertongues with the overlying Gammon Member (not shown on cross sections) of the Pierre Shale (figs. 3-7). On the east side the logs indicate less shale and more chalk, possibly chalk tongues "A" and "B" of Shurr and Rice (1987). The top of the Niobrara was difficult to pick on many logs owing to local unconformities and gradation with the Gammon.

The Pierre Shale, which overlies the Niobrara, was not intended to be a major part of this study. Only two members of the Pierre are included in the cross sections. They are identified by their relationship with the Ardmore Bentonite Bed (Rice, 1977); the early to mid-Campanian Gammon Member (Gammon Ferruginous Member) a marine, noncalcareous, gray shale lies below the bentonite bed, and the mid-Campanian Sharon Springs Member, of similar lithology, lies generally above the bentonite.

The depositional environment for this interval of rocks on the edge of the cratonic basin was probably one of changing Cretaceous sea levels in relatively shallow water on a gently sloping shelf. The Graneros Shale and Greenhorn Formation record the transgression of the Greenhorn depositional cycle, and the Carlile Shale represents the regressive phase of the same cycle (Dyman and others, in press). The Niobrara Formation in this region is bounded above and below by major unconformities, both of which are postulated to be sequence boundaries bracketing the Niobrara depositional cycle (unpublished data, South Dakota Geological Survey; Dyman and others, in press).

Post-depositional features on the cross sections are generally subtle. Formation contacts and time marker beds are essentially parallel with maximum dips into the basin of about eight feet per mile. Areas of somewhat higher structural relief, especially at the Greenhorn level, on sections A-A', C-C', J-J', and K-K' may be paleostructures related to the Paleozoic Bottineau-Burleigh trend shown by Peterson and MacCary (1987). Another feature shown by a dashed line on the sections was interpreted as a bentonite bed within the Graneros Shale that converges with the base of the Greenhorn in a generally westerly direction. This indicates greater deposition to the southeast during that time interval.

Present-day structure in the area displays gentle basinward (northwest) dips of approximately 10 feet per mile for the Ardmore Bentonite Bed and Niobrara and Greenhorn Formations (see figs. 11-13). These rocks and others probably conform to the structural framework controlled by the Precambrian

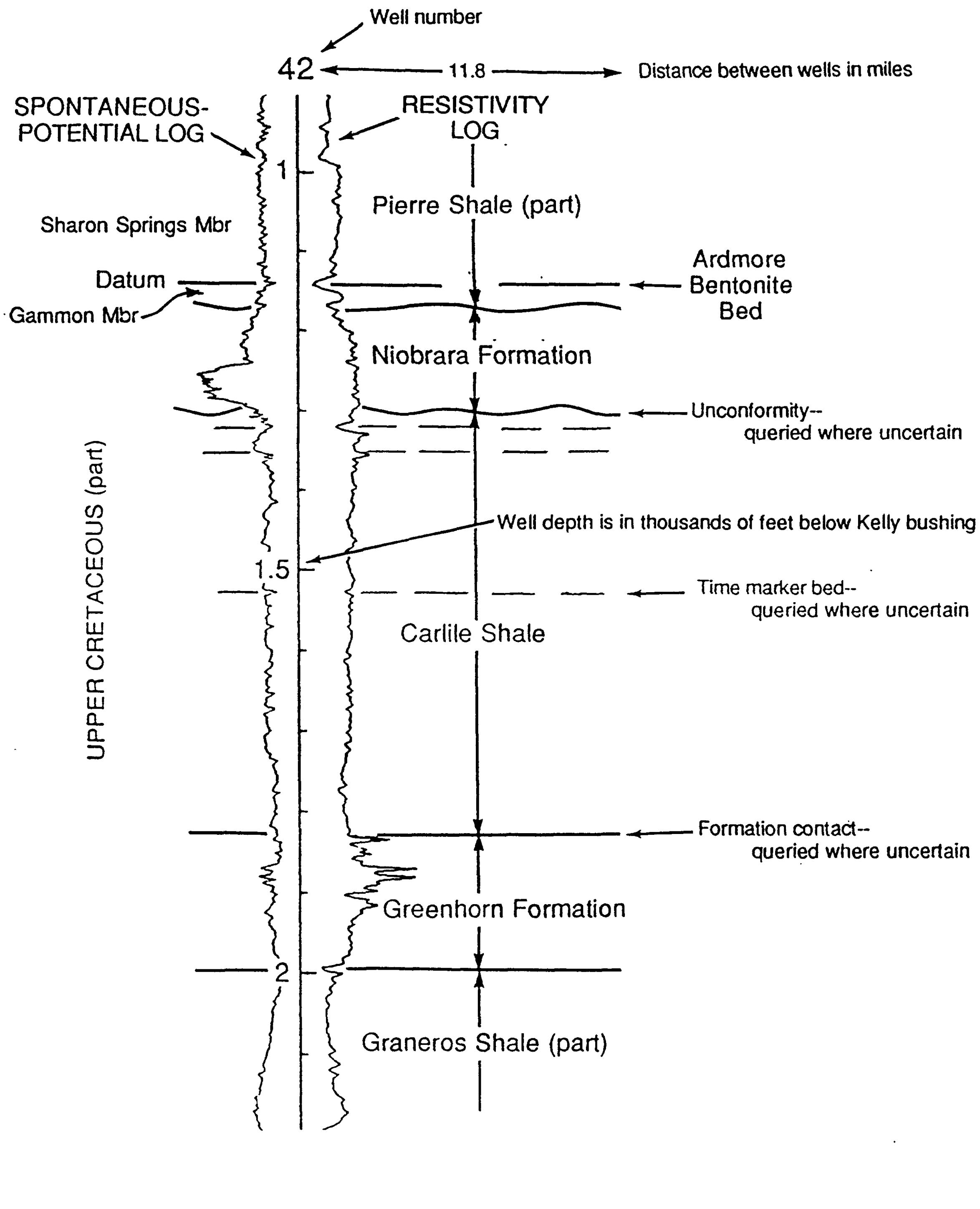

Figure 2. Explanation and typical log (well no. 42, Table 1) showing characteristics used in correlating wells in study area in southeastern Williston basin, North and South Dakota. Scale 1 in. = 200 ft.

basement. Faulting and depositional patterns were no doubt influenced by lineament-block tectonics (Shurr and Rice, 1986).

Isopach maps (figs. 8-10) demonstrate a general westward thickening for all three formations, but the Niobrara and Greenhorn maps also reveal a north-south thinning through the middle of the study area. Figure 14 is an isopach map of the interval from the Ardmore Bentonite Bed to the bentonite at the base of the Greenhorn Formation. These two bentonites are assumed to be good time markers. The Ardmore is dated at 80.54 ± 0.55 Ma by Obradovich (in press), and the base of the Greenhorn interpolated at approximately 92.5 Ma (Obradovich, in press). The average rate of deposition of this interval, excluding the hiatus at the top and bottom of the Niobrara and compaction, is estimated to have been about one inch per 1000 years.

Natural Gas Prospects

Cretaceous rocks in the region may yield future petroleum accumulations. Of the three main rock units discussed here, the Niobrara Formation is most often mentioned as a possible source of natural gas; in fact gas is produced from the Niobrara in eastern Colorado and north western Kansas (Lockridge and Scholle, 1978). Several workers (including Rice and Shurr, 1980, and Steece, 1989) have described it as a "tight" formation, but having high porosity at burial depths found within the study area. Steece (1989) also describes numerous dry holes with Niobrara gas shows in South Dakota. Areas of natural fracturing and the use of new horizontal drilling techniques might improve the outlook for gas production in this and other parts of the northern Great Plains.

References Cited

Dyman, T.S., Cobban, W.A., Fox, J.E., Hammond, R.H., Nichols, D.J.,Perry, W.J., Jr., Porter, K.W., Rice, D.D., Setterholm, D.R., Shurr, G.W., Tysdal, R.G., Haley, J.C., and Campen, E.B., in press a, Cretaceous rocks from southwestern Montana to southwestern Minnesota, northern Rocky Mountains and Great Plains regions, *in* Shurr, G.W., Ludvigson, G.A., and Hammond, R.H., eds., Cretaceous rocks along the eastern margin of the Western Interior seaway: Geological Society of America Special Paper 287.

Lockridge, J.P., and Scholle, P.A., 1978, Niobrara gas in eastern Colorado and northwestern Kansas, *in* Pruit, John D., and Coffin, Peter E., eds., Energy resources of the Denver basin: Rocky Mountain Association of Geologists Symposium, p. 35-49.

Obradovich, John D., in press, A Cretaceous time scale: Geological Association of Canada, Special Paper, 51 manuscript pages, with figures.

Peterson, J.A., and MacCary, L.M., 1987, Regional stratigraphy and general petroleum geology of the U.S. portion of the Williston basin and adjacent areas, *in* Longman, M.W., ed., Williston basin: anatomy of a cratonic oil province: Rocky Mountain Association of Geologists, p. 9-43.

Rice, D.D., 1977, Stratigraphic sections from well logs and outcrops of Cretaceous and Paleocene rocks, northern Great Plains, North and South Dakota: U.S. Geological Survey Oil and Gas Investigations Chart OC-72.

Rice, D.D., and Shurr, G.W., 1980, Shallow, low-permeability reservoirs of northern Great Plains--assessment of their natural gas resources: American Association of Petroleum Geologists Bulletin, v. 64, n. 7, p. 969-987.

Shurr, G.W., and Rice, D.D., 1986, Paleotectonic controls on deposition of the Niobrara Formation, Eagle Sandstone, and equivalent rocks (Upper Cretaceous), Montana and South Dakota, *in* Peterson, J.A., ed., Paleotectonics and sedimentation in the Rocky Mountain region, United States: American Association of Petroleum Geologists Memoir 41, p.193-211.

Shurr, G.W., and Rice, D.D., 1987, Geologic setting and potential for natural gas in the Niobrara Formation (Upper Cretaceous) of the Williston basin, *in* Longman, M.W., ed., Williston basin: anatomy of a cratonic oil province: Rocky Mountain Association of Geologists, p. 245-257.

Shurr, G.W., and Sieverding, J.L., 1980, Preliminary synthesis of subsurface stratigraphy of the Niobrara Formation (Upper Cretaceous) in the northern Great Plains: U.S. Geological Survey Open-File Report 80-1266, 18 p.

Steece, F.V., 1989, Natural gas prospects in the Niobrara Formation in South Dakota, *in* Eisert, J.L., ed., Gas resources of Wyoming: Wyoming Geological Association, 40th Field Conference Guidebook, p. 73-81.

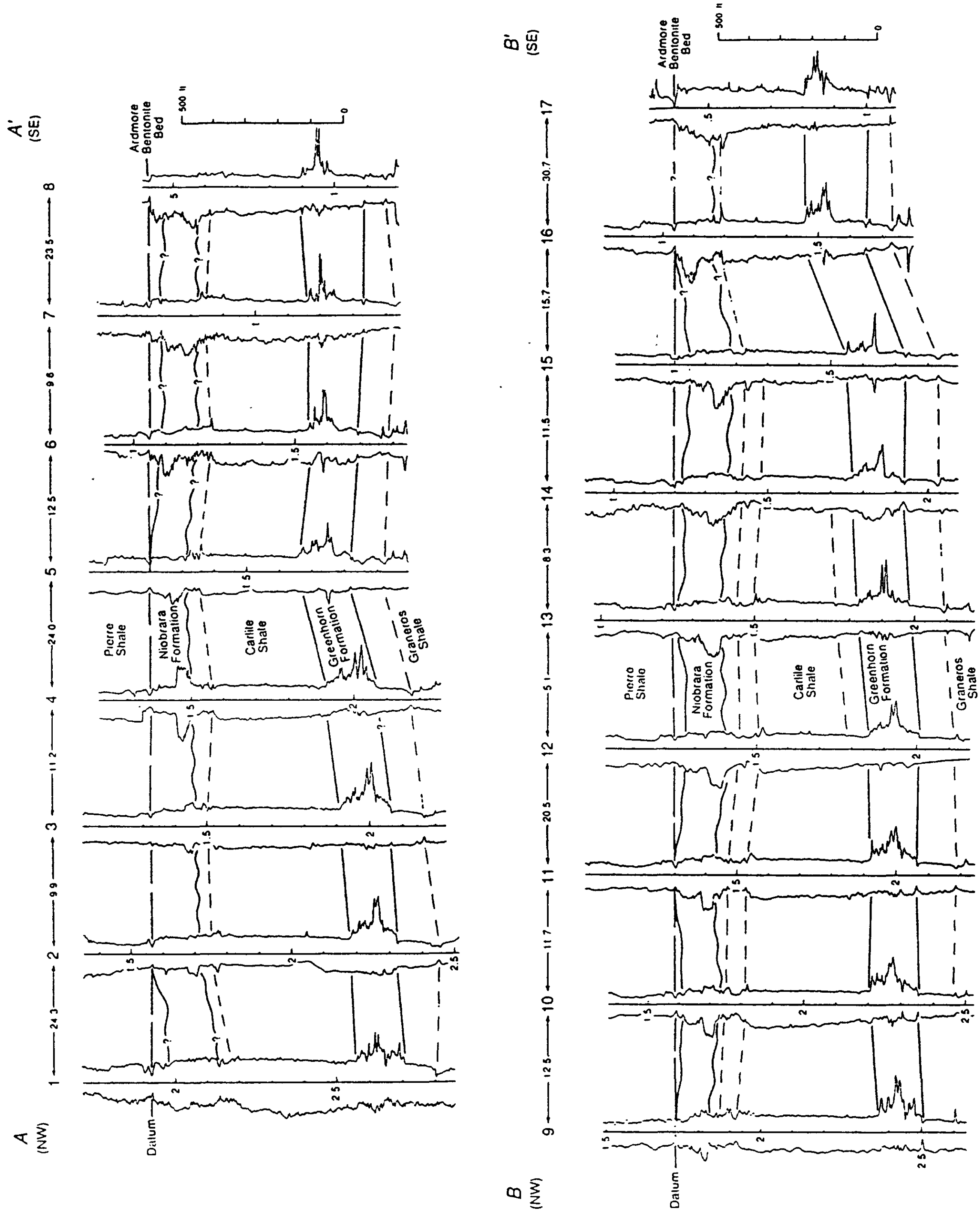

Figure 3. Stratigraphic cross sections A-A' and B-B' showing digitized traces of electric logs of some Upper Cretaceous rocks, southeastern flank of Williston basin, North and South Dakota. Location of cross sections shown on Figure 1. Datum is Ardmore Bentonite Bed. Numbers above logs identify wells (see Table 1). Vertical scale 1 in. = 520 ft. Distance between wells is given at top of section.

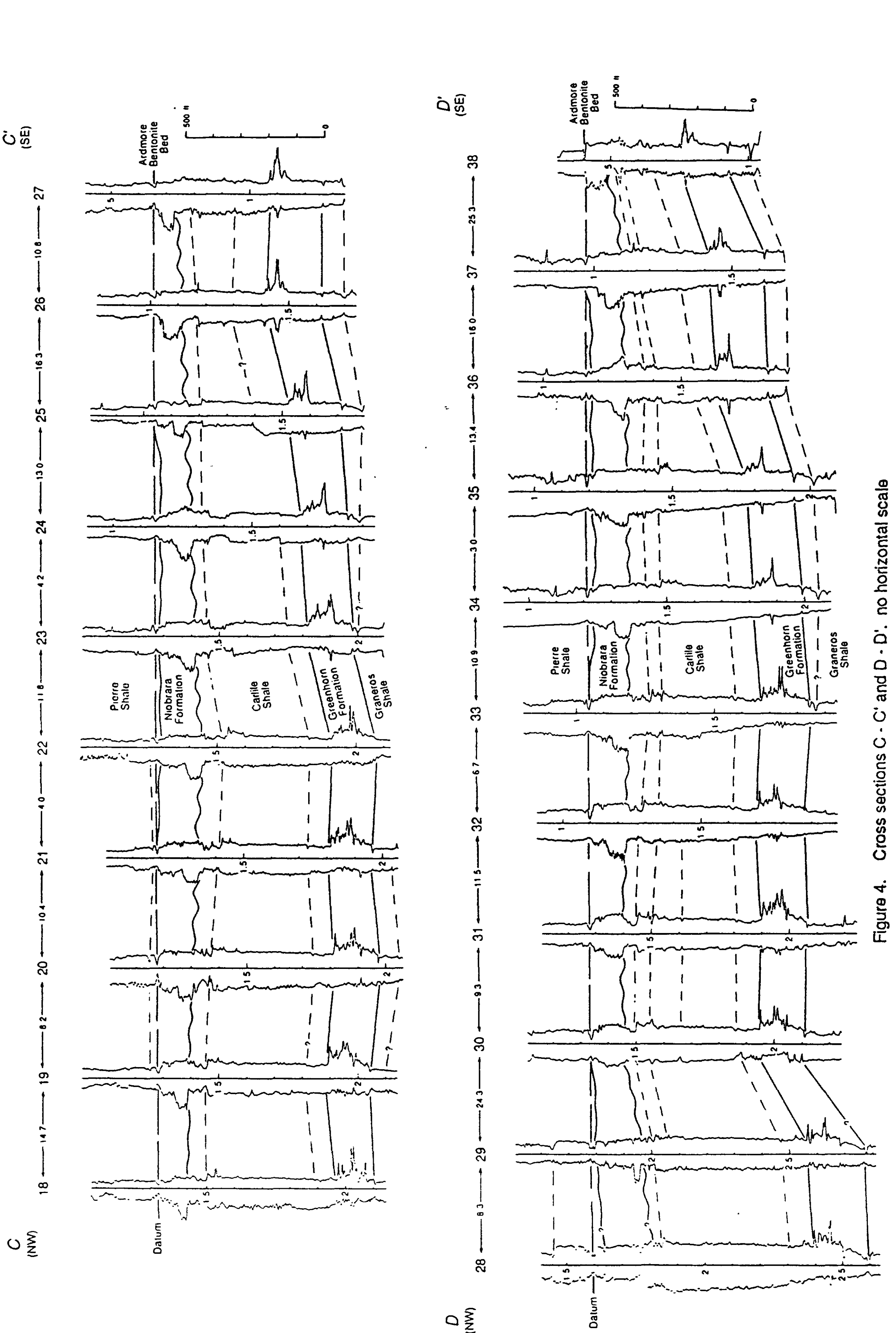

Figure 4. Stratigraphic cross sections C-C' and D-D' showing digitized traces of electric logs of some Upper Cretaceous rocks, southeastern flank of Williston basin, North and South Dakota. Location of cross sections shown on Figure 1. Datum is Ardmore Bentonite Bed. Numbers above logs identify wells (see Table 1). Vertical scale 1 in. = 520 ft. Distance between wells is given at top of section.

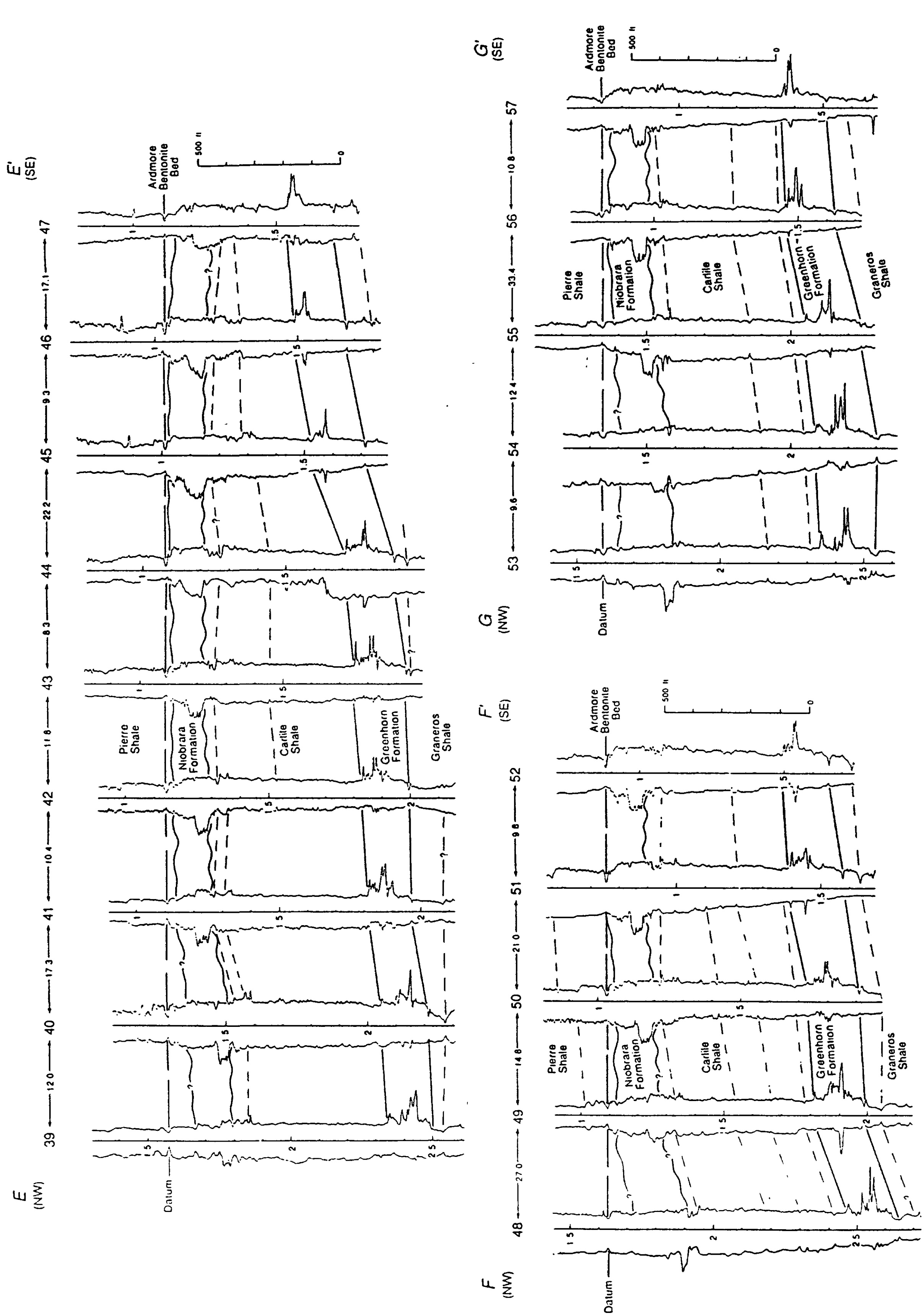

Figure 5. Stratigraphic cross sections E-E', F-F' and G-G' showing digitized traces of electric logs of some Upper Cretaceous rocks, southeastern flank of Williston basin, North and South Dakota. Location of cross sections shown on Figure 1. Datum is Ardmore Bentonite Bed. Numbers above logs identify wells (see Table 1). Vertical scale 1 in. = 520 ft. Distance between wells is given at top of section.

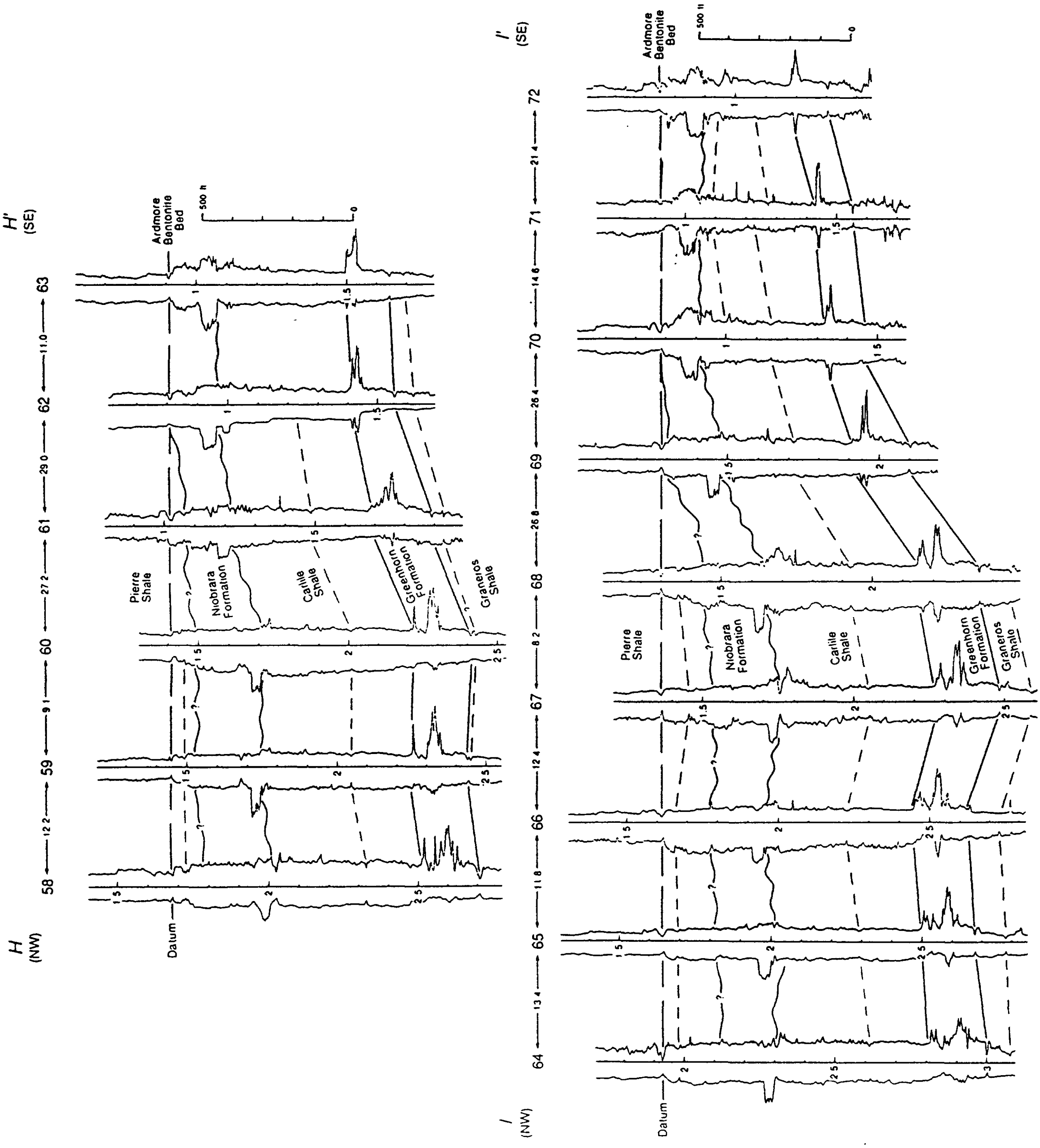

Figure 6. Stratigraphic cross sections H-H' and I-I' showing digitized traces of electric logs of some Upper Cretaceous rocks, southeastern flank of Williston basin, North and South Dakota. Location of cross sections shown on Figure 1. Datum is Ardmore Bentonite Bed. Numbers above logs identify wells (see Table 1). Vertical scale 1 in. = 520 ft. Distance between wells is given at top of section.

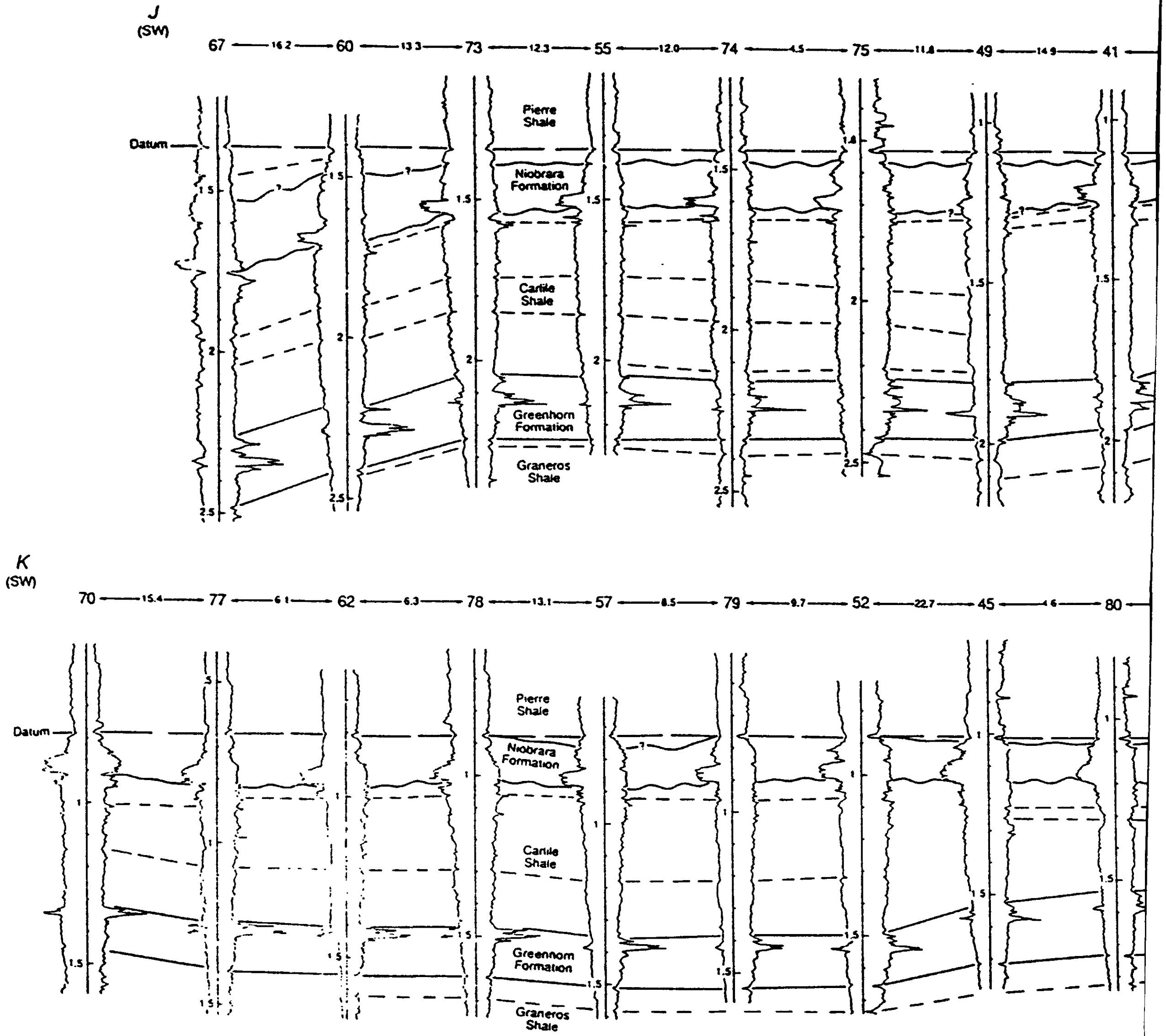

Figure 7. Stratigraphic cross sections J-J' and K-K' sho
Cretaceous rocks, southeastern flank of Williston ba
sections shown on Figure 1. Datum is Ardmore Be
(see Table 1). Vertical scale 1 in. = 520 ft. Distance

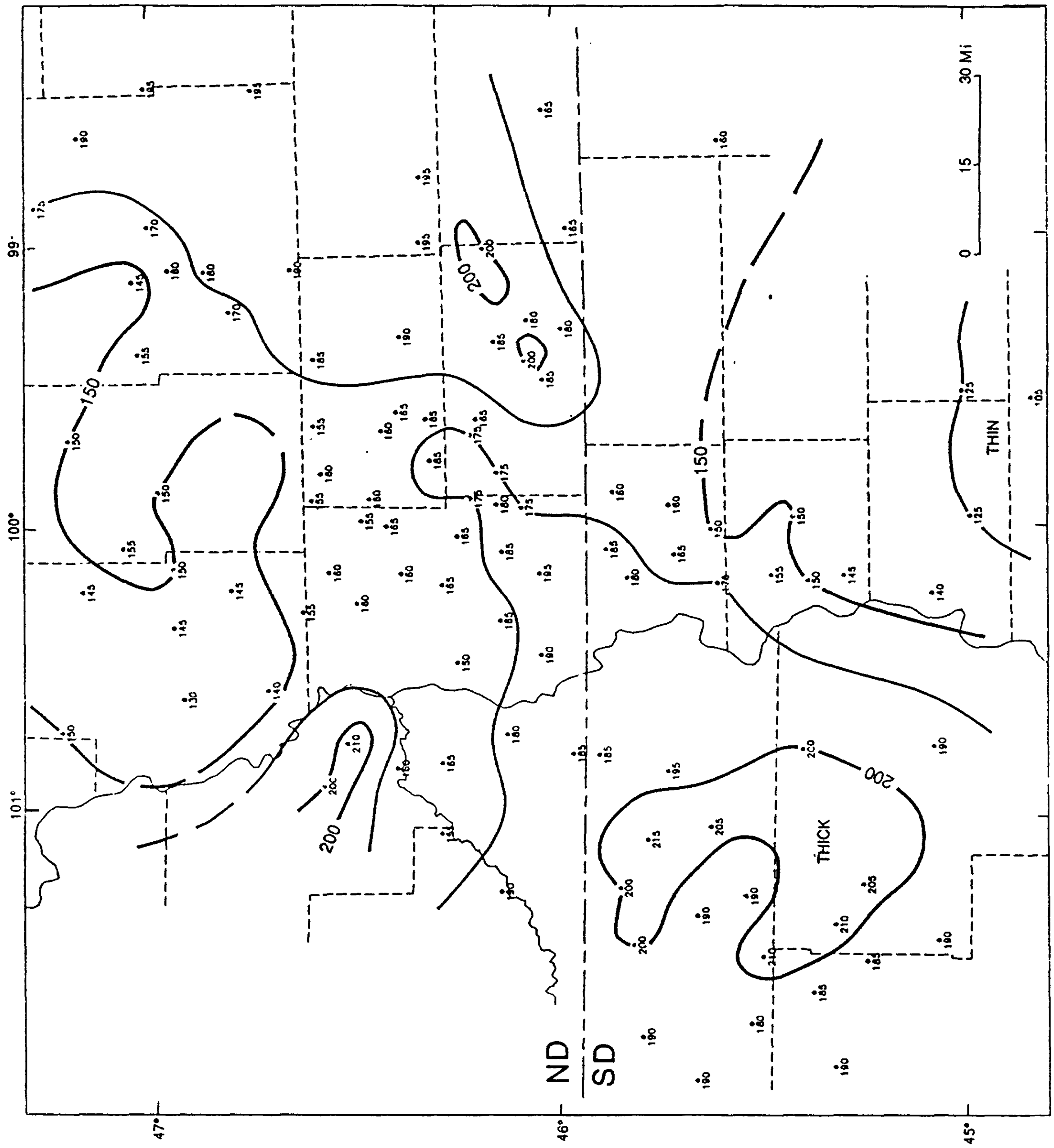

Figure 8. Isopach map of Greenhorn Formation, southeastern flank of Williston basin, North and South Dakota. Contour interval equals 25 ft.

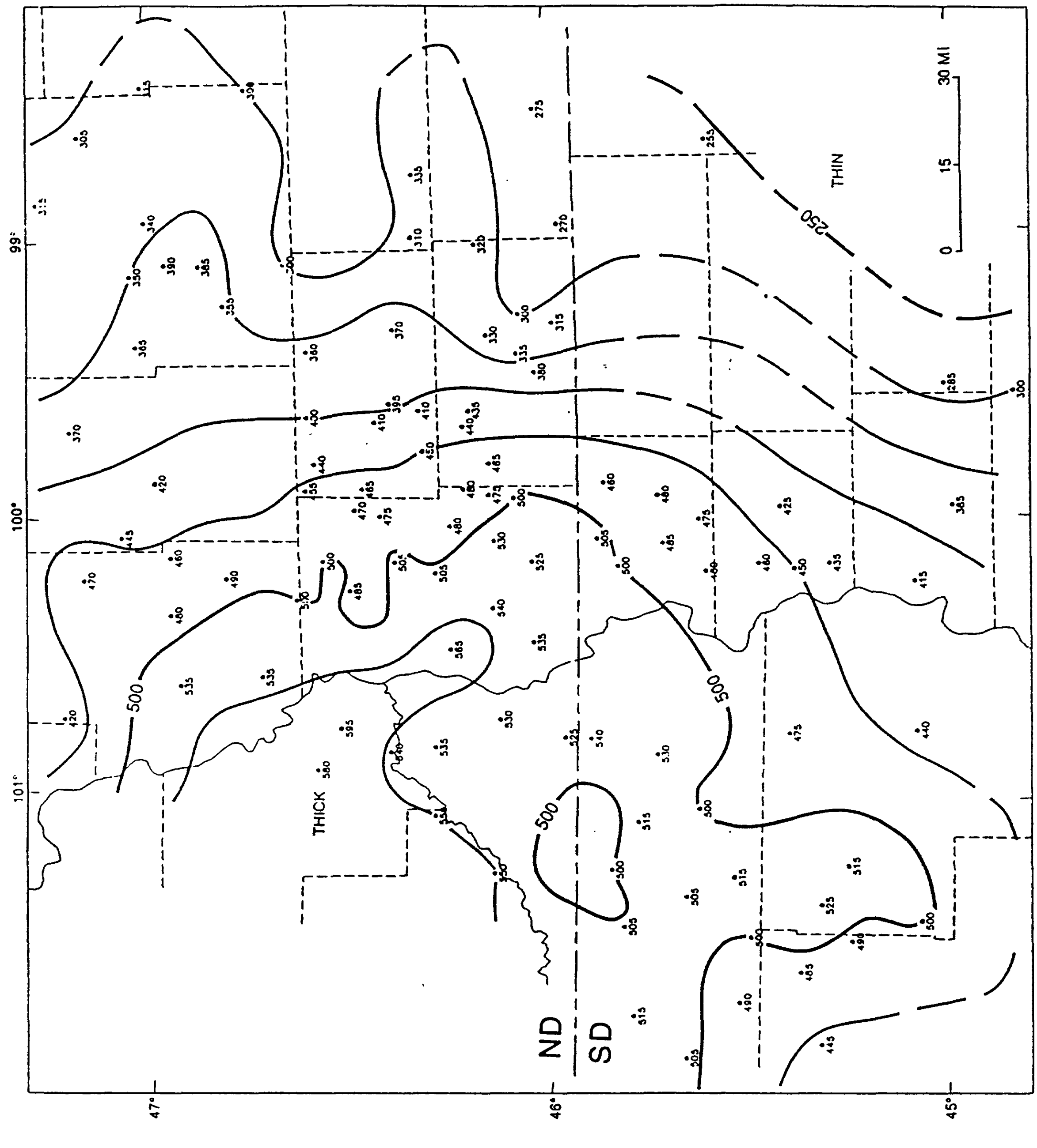

Figure 9. Isopach map of Carlile Shale, southeastern flank of Williston basin, North and South Dakota. Contour interval equals 50 ft.

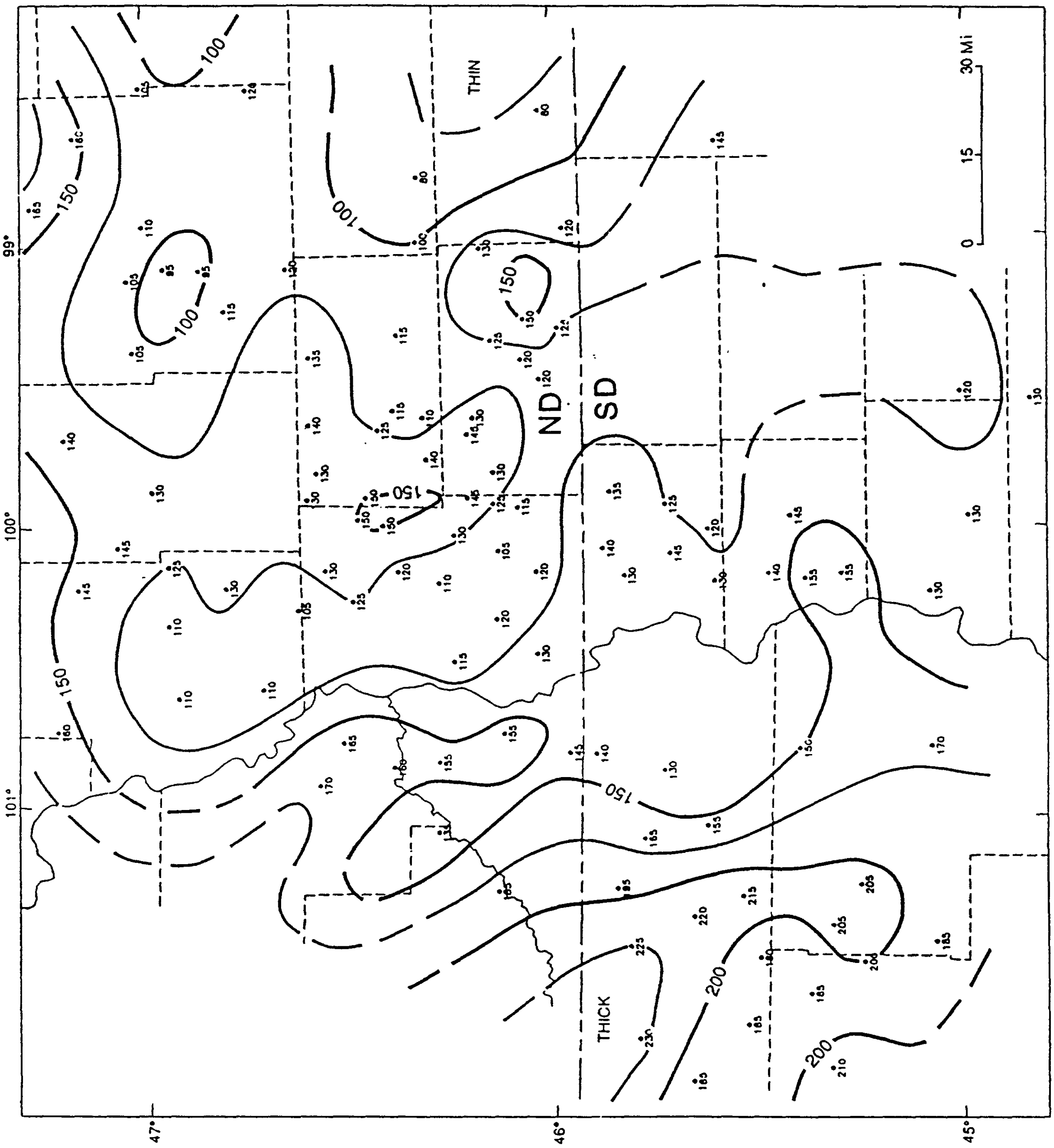

Figure 10. Isopach map of Niobrara Formation, southeastern flank of Williston basin, North and South Dakota. Contour interval equals 25 ft.

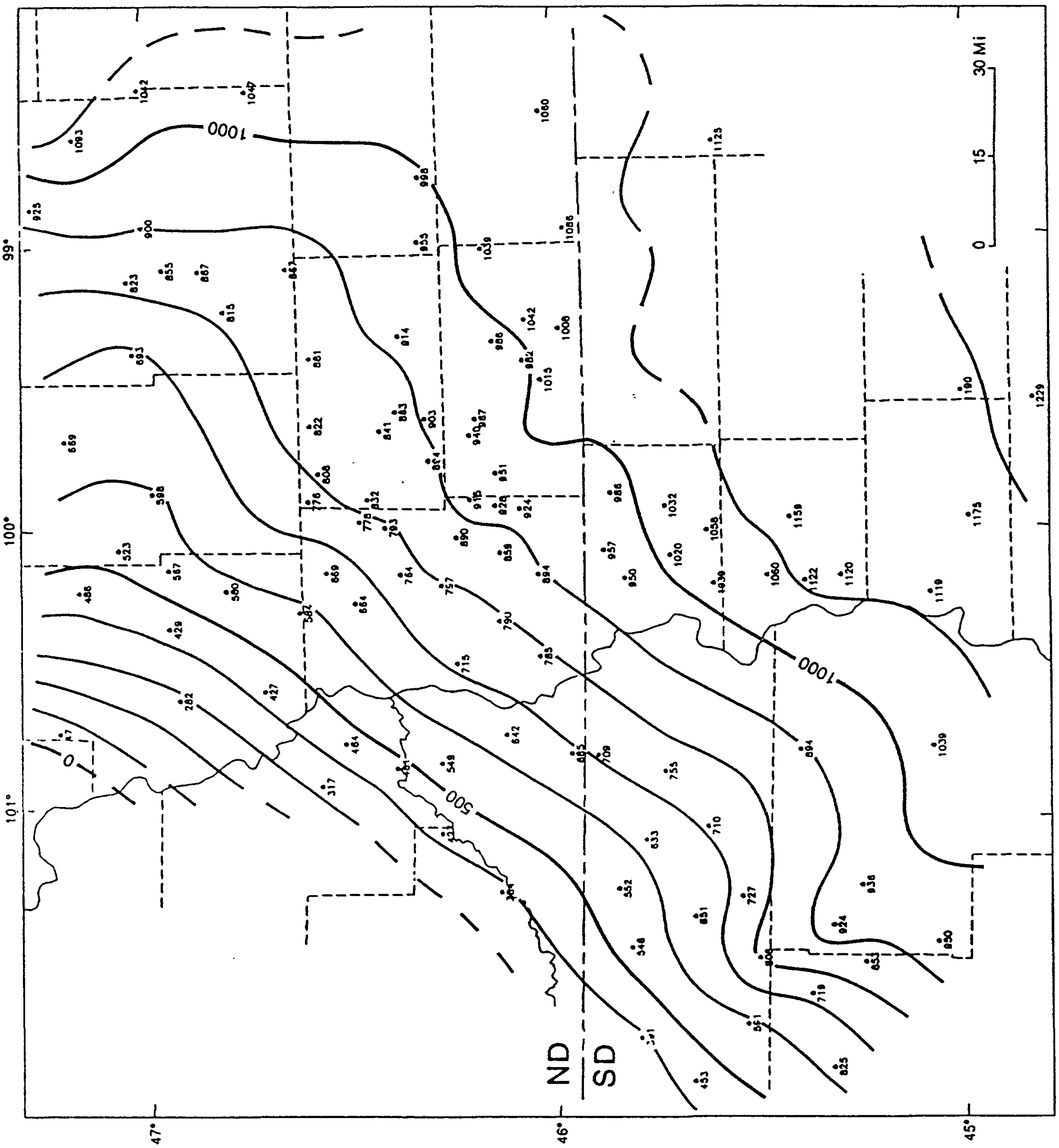

Figure 11. Structure contour map showing configuration of Ardmore Bentonite Bed relative to mean sea level, southeastern flank of Williston basin, North and South Dakota. Well locations and depth to Ardmore Bentonite Bed are also shown. Contour interval equals 100 ft.

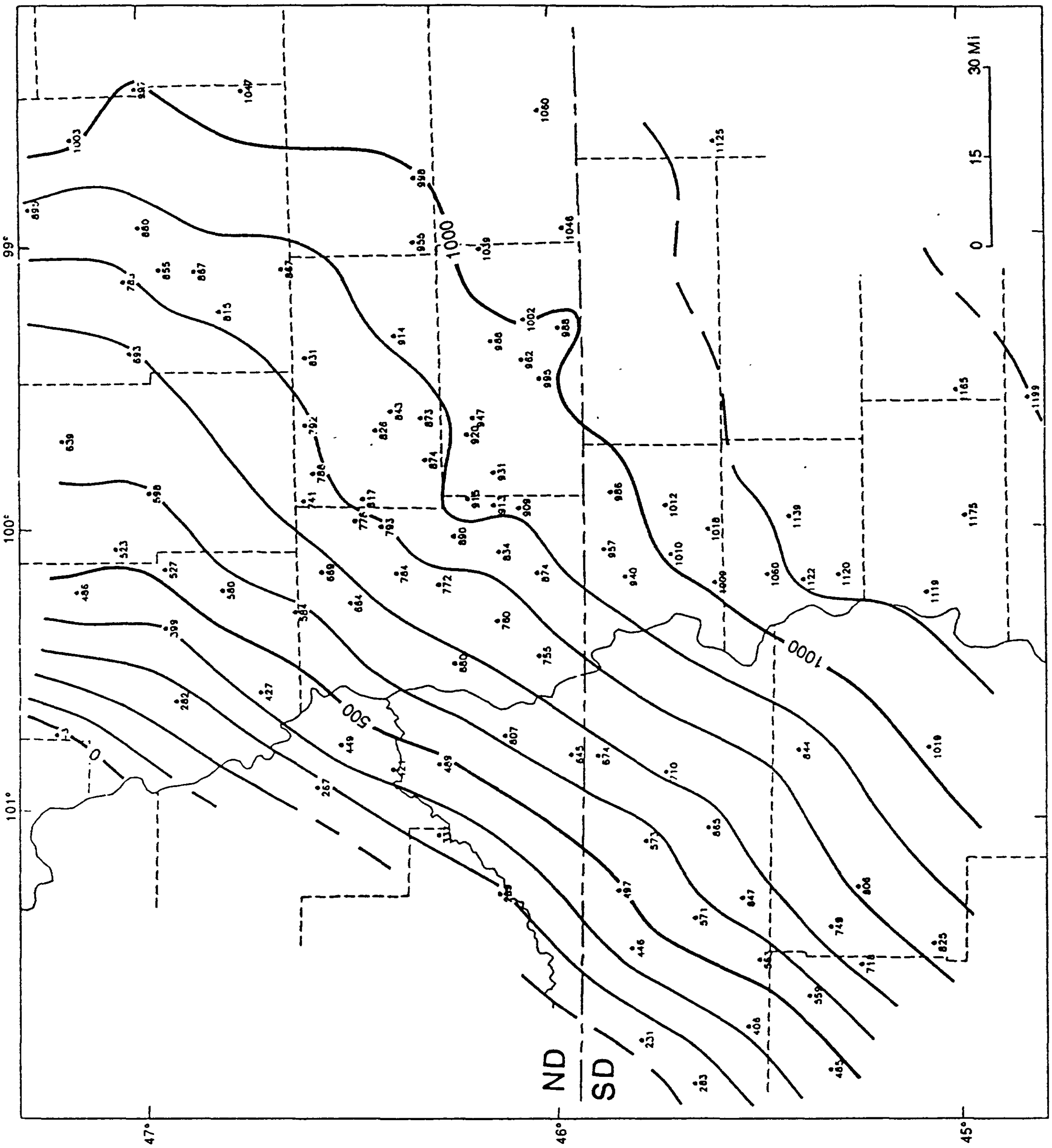

Figure 12. Structure contour map on top of Niobrara Formation relative to mean sea level, southeastern flank of Williston basin, North and South Dakota. Well locations and depth to Ardmore Bentonite Bed are also shown. Contour interval equals 100 ft.

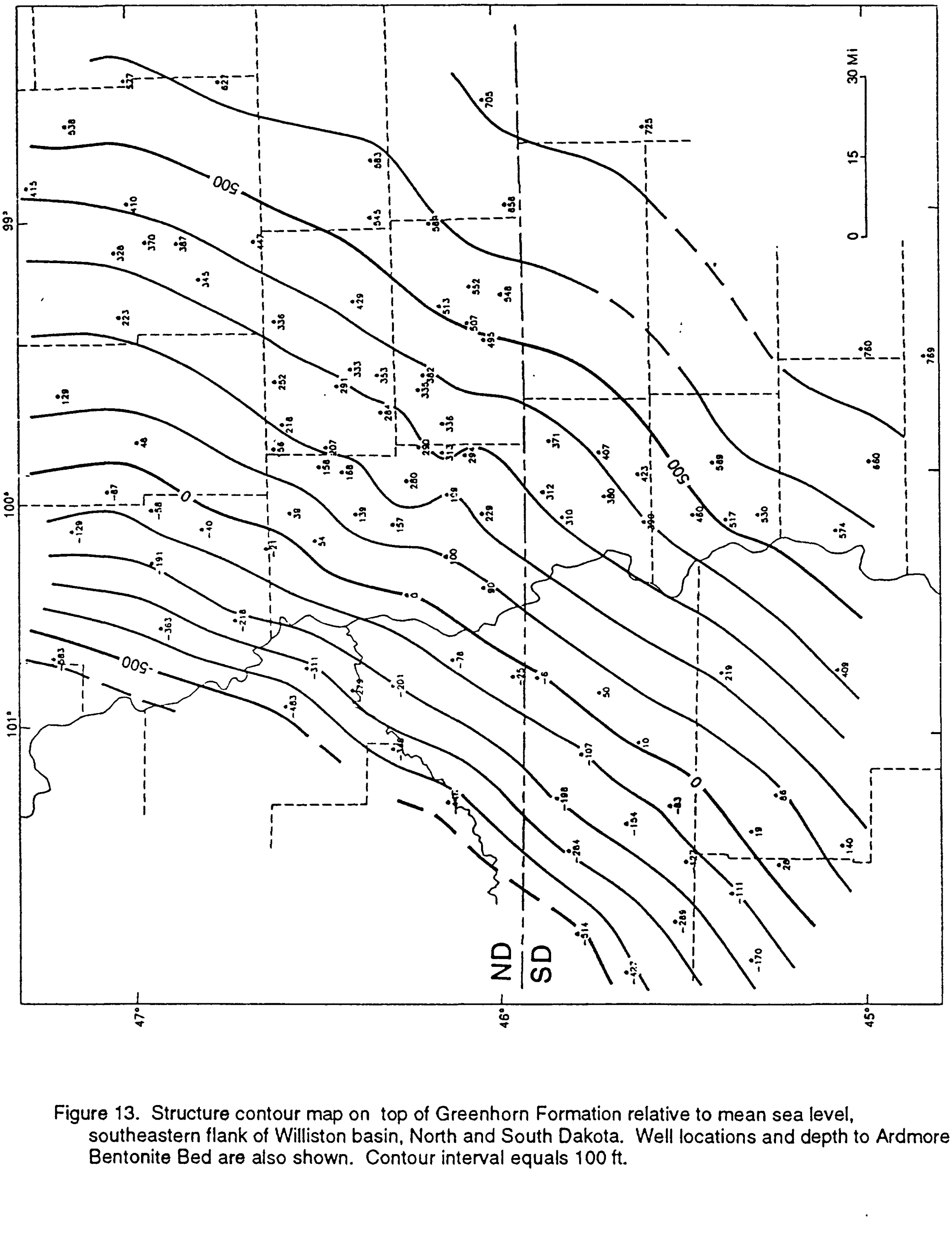

Figure 13. Structure contour map on top of Greenhorn Formation relative to mean sea level, southeastern flank of Williston basin, North and South Dakota. Well locations and depth to Ardmore Bentonite Bed are also shown. Contour interval equals 100 ft.

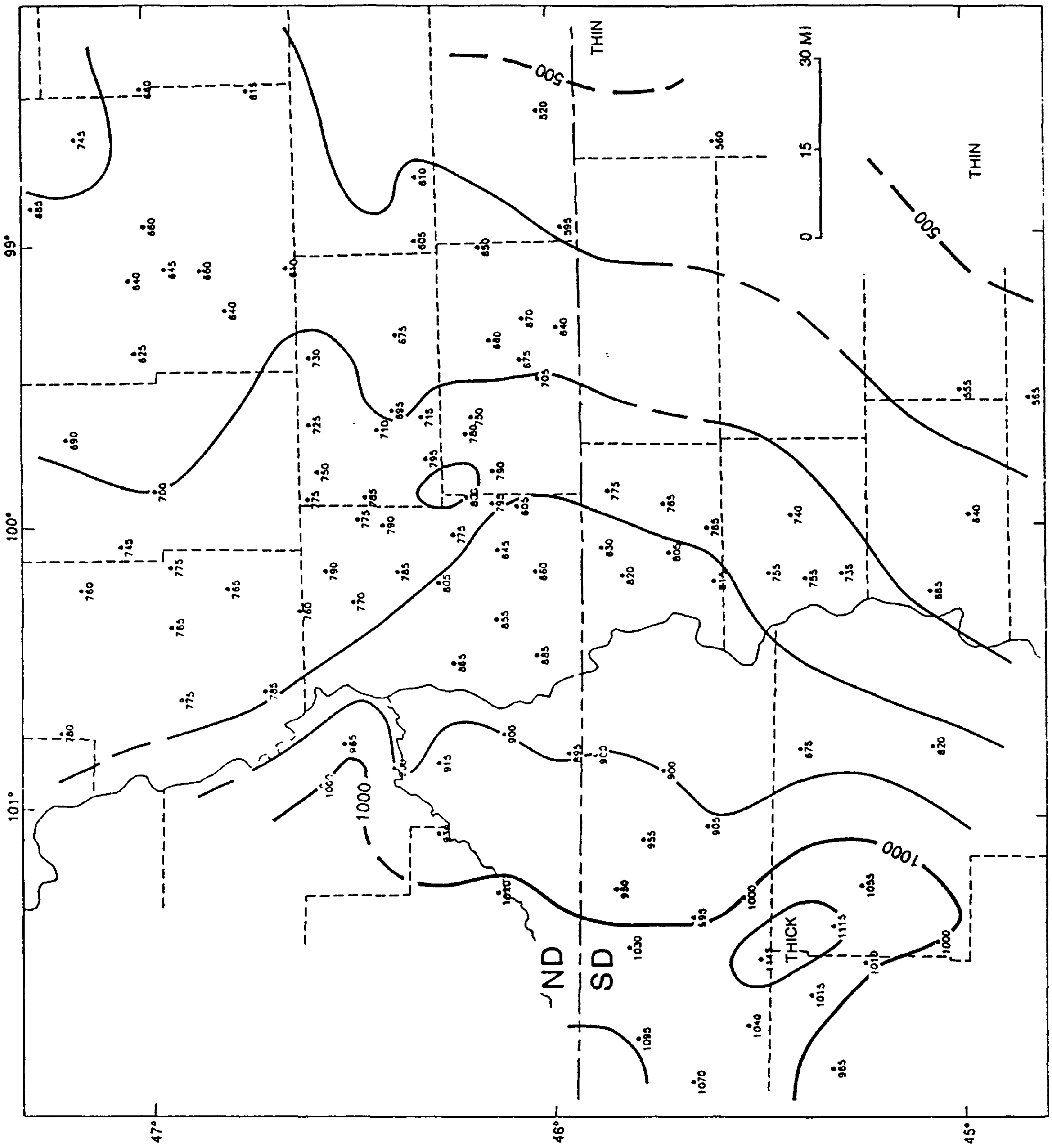

Figure 14. Isopach map of interval between Ardmore Bentonite Bed and bentonite bed at base of Greenhorn Formation, southeastern flank of Williston basin, North and South Dakota. Well locations and depth to Ardmore Bentonite Bed are also shown. Contour interval equals 100 ft.